

Design Science and Innovation

Chitrarekha Kabre

Sustainable Building Design

Applications Using Climatic Data in India

 Springer

Design Science and Innovation

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Applications Using Climatic Data in India

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Preface

The sustainable building design lays a new emphasis on passive design strategies. Over the last decade, much progress has been made in our understanding of the climate and thermal behaviour of buildings with the more sophisticated analytical techniques available and relying on the assistance offered by computers, many factors can be quantified which were previously handled in qualitative terms only. However, as research is becoming more and more sophisticated, its results are becoming more and more remote from the everyday practice of architecture as these enhancements are not available in any book for ready reference.

The aim of this publication is to bridge the gap with the objectives:

- to define parameters of passive design: climate, comfort and sun
- to present state-of-the-art design strategies; and
- to illustrate design case studies for each of the five climatic zones of India
- to present climatic data and sun path diagrams in a readily usable format for application in passive design;

The manuscript is organized into five distinct chapters as follows:

- Chapter 1 Introduction
- Chapter 2 Climate, Comfort and Sun
- Chapter 3 Design Strategies
- Chapter 4 Design Case Studies
- Chapter 5 Climatic Data and Sun-Path Diagrams

Chapter 1 presents a brief literature review of sustainable development, climate responsive design and its significance in the present day practice. Chapter 2 presents classification of climate, elements of climate, parameters of thermal comfort and solar geometry. The heart of the book is Chap. 3 that discusses passive design strategies and application of climatic data at different design stages: briefing, pre-conceptual, conceptual, preliminary and detailed. The qualitative assessment of climate, the pre-conceptual analysis, the bioclimatic analysis (climate and comfort zone) and passive design concepts are presented for early design stages. The steady-state analysis of cooling and heating load of a given design using the

monthly average data of the hottest and coldest months and solar control design are discussed for design development and energy conservation. Chapter 4 presents design case studies for each of the climatic zones of India. Each exemplar study includes an overview of the design intentions, climate and site responses, thermal strategies, energy systems, lessons for the future generation of sustainable design thinking and practice, and a profile summarizing design strategies. These exemplar studies may be useful in inspiring a broader understanding of the potential of the climate responsive design to shape the future generation of sustainable architecture. The pioneering architects and projects featured in the exemplar studies reveal the promise of a new climate responsive architecture that responds deeply to the environmental challenges of our day, while recognizing that when our buildings delight our senses, architecture can help inspire us to dwell more lightly on our beautiful earth. Chapter 5 is a compilation of climatic data for 62 cities in India. Temperature, humidity, sunshine hours, solar radiation, wind and rainfall data are given both numerically and in graphic form; the latter for quick, visual appreciation and the former for more detailed climate analysis. Some single-figure indices are included, such as an indication of temperature variability; outdoor design conditions recommended as a basis for calculating the required heating or cooling capacity; and rainfall intensity, which would be the basis for drainage and rain harvesting system design. Wind roses show the direction and frequency of winds, while average speeds are given in numerical form. The latter must be the basis of structural design. Sun-path diagrams are provided for solar control design.

The book is a first of its kind and the state-of-the-art book to be used as a practical tool or manual for senior undergraduate and postgraduate students of architecture and related disciplines, as well as for researchers and practicing architects and other designers. This book will provide them an understanding of the physical phenomena to be dealt with and means for appropriate implementation and application of climate responsive design principles for sustainable future in India.

Sonepat, India

Chitrarekha Kabre

Acknowledgements

This book evolved over a long period from my research in architectural science carried out while teaching at the Indian Institute of Technology, Kharagpur, and while pursuing Ph.D. at the University of Queensland, Australia, under supervision of Dr. Richard Hyde and Dr. Steven S. Szokolay. This research formed the basis of my teaching Environmental Science courses at the University of Queensland, Australia, along with Mr. Peter Skinner and at the North Dakota State University, Fargo, USA, as Fulbright Visiting Professor along with Mr. David Crutchfield. I am teaching Sustainable Architecture course at the DCR University of Science and Technology, Murthal, a State University of Haryana, India.

I am grateful to all the esteemed organizations and individuals who helped to compile the information for climate, case studies and other topics.

My father, late Mr. Ram Gopal Kabre, was a great mentor and inspirer. I am highly indebted to Mr. Tapan K. Ghoshal, an engineer, for reading the text and for wonderful photographs.

This book is dedicated to my students from India, Australia and USA; who motivated me for this venture.

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Abbreviations

AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BEE	Bureau of Energy Efficiency
BEEP	Building Energy Efficiency Project
BIS	Bureau of Indian Standards
CoP	Coefficient of performance
DX	Direct expansion
ECBC	Energy conservation building code
ECBD	Energy conservation building directives
EPI	Energy performance Index
FDFA	Federal Department of Foreign Affairs
ft ²	Square feet
GHG	Green house gas
GRIHA	Green Rating for Integrated Habitat Assessment
HVAC	Heating, ventilation and air conditioning
IIA	Indian Institute of Architects
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
ISHRAE	Indian Society of Heating, Refrigerating and Air-conditioning Engineers
kWh	Kilo watt hour
LEED	Leadership in Energy and Environmental Design
LPD	Litres per day
m ²	Square meter
NBC	National Building Code
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PDEC	Passive Downdraft Evaporative Cooling
PMTU	Project Management and Technical Unit

RIBA	Royal Institute of British Architects
RSRDC	Rajasthan State Road Development and Construction Corporation Ltd.
SDC	Swiss Agency for Development and Cooperation
SHGC	Solar heat gain coefficient
SPV	Solar photovoltaic
SWH	Solar water heater
TRNSYS	The Transient Energy System Simulation Tool
UNCED	UN Conference on Environment and Development
UNEP	UN Environment Program
VLT	Visual light transmission
VRF	Variable refrigerant flow
VRV	Variable refrigerant volume
WMO	World Meteorological Organization

Chapter 1

Introduction

Susan Maxman, FAIA, in 1993: “We have the knowledge, we have the riches, we have the power. What is called for is a profound shift in the way we regard this planet and everything on it. Exploitation must be replaced by stewardship. And for stewardship to extend its healing hand, we must act responsibly.”

(AIA 2007).

1.1 Introduction

In 2010, buildings accounted for 32% of total global final energy use, 19% of energy-related green house gas (GHG) emissions (including electricity-related), approximately one-third of black carbon emissions, as proved by IPCC reports (Lucon et al. 2014). The three main problem areas are as follows:

Population explosion,
Resource depletion,
Environmental degradation.

The world population has increased at an immense rate—about threefold in the last century—and continues to do so. Urbanization has taken over in all parts of the inhabited world, now more than 50% of the inhabitants live in cities. The human race has depleted the earth’s natural resources at a catastrophic rate causing environmental degradation. Integrating sustainable design practices in built environment, which often leave the largest carbon footprints, is key to extending the earth’s longevity. This chapter first discusses the paradigm shift from climate-responsive architecture of yesteryears to sustainable architecture of the present day. Further, the chapter gives an overview of developments in sustainable building design in India. Finally, the chapter concludes delineating the scope of the book.

1.2 Climate-Responsive Architecture

The evolution of the built environment, with responses to multiple and complex requirements, started by providing the ‘shelter’ needed for protection from attack by human enemies and wild animals as well as protection from hostile to unfavourable aspects of the physical environment. At later stages, durability, status, fashion and improved environmental quality were the motors of development (Rapoport 1969). According to this sequence, the protection from climate was one of the initial factors that have remained a constant preoccupation and priority in the long process of the development of the built environment and the history of architecture (Oliver 1987). From the early huddle of buildings at Catalhöyük in Anatolia, 7000 BC, indigenous building design demonstrated ingenuity for climate amelioration through a basic understanding of thermal and structural behaviour of natural materials. From Aristotle to Montesquieu, many scholars believed that climate had pronounced effects on human physiology and temperament. However, the first written documents to explain the functioning of the house in relation to climate impacts are those of the Greeks and Romans. In the first century BC, Vitruvius (Morgan 1960) wrote:

If our designs for private houses are to be correct, we must at the outset take note of the countries and climates in which they are built. One style of house seems appropriate to build in Egypt, another in Spain, a different kind in Pontus, one still different in Rome, and so on with lands and countries of other characteristics. This is because one part the earth is directly under the sun’s course, another is far away from it, while another lies midway between these two...it is obvious that designs for houses ought similarly to conform to the nature of the country and to diversities of climate.

All over the world, indigenous and traditional architecture are replete with appropriate built responses to climate, which is also true in India. Indigenous and traditional architecture exemplify how basic passive cooling strategies evolved through ages of adaptation in tropical climate of India (Faris 1981, Koita 1981 and Gupta 1984). As renowned architect Charles M. Correa (1987) says:

Environmental and cultural conditions in India vary a great deal—from the dry heat of Punjab (with its Indo-Islamic cultural roots) to the lush tropical vegetation of Tamil Nadu and Kerala (the gateway to South–East Asia). The architecture of each of these regions, reflecting these varying conditions, is often wonderfully inventive.

In the extreme arid heat of the north Indian summer, formal gardens created comfortable microclimate through simple cooling techniques at the time of the Mughal Empire (1526–1707), Bowen (1981). In the hot dry climate of Jaisalmer, compact clustering of houses and narrow streets not only ensured minimum exposure of individual buildings to the scorching summer sun but it also kept out hot wind while allowed movement of cool air through buildings and open area (Jain 1977 and Gupta 1985); while as in warm humid tropics, the traditional built forms provided for ventilation and protection from the direct sun, as in Fig. 1.1. Charles M. Correa (1984) said:



Fig. 1.1 Traditional pavilion at Napier Museum in Trivandrum (India) © Mr. T. K. Ghoshal

In a warm climate, people have a very different relationship to built form. One needs but minimal protection, such as a Chhatra (an overhead canopy), during the day.

The relatively recent industrial revolution—a mere 165 years—has seriously eroded this 8000 years old priceless tradition, and proliferation of modern technology brought radical changes in the morphology of built environment. The globalization in the modern and contemporary architecture—similar designs, similar materials and similar construction methods—resulted in ubiquitous built form irrespective of climate of the place and caused growing energy demands.

Climate-responsive design of buildings became a concern when, in the post-war years, European and North American modern architects started working in unfamiliar climates of tropics. In the 1950s, architects began to promote the idea that traditional architecture existed in harmony with nature and could educate modern architects on climate responsiveness and resource maximization. Later in 1964, Bernard Rudofsky's exhibition at the Museum of Modern Art, New York, and his book *Architecture without architects* brought the traditional architecture into the eye of the public and of mainstream architecture.

Le Corbusier's mature modern architecture evolved through three distinct periods: a purist or 'high-tech' phase of the 1920s; a transitional or reassessment phase of the 1930s; and a primitive or 'low-tech' phase from 1945 to 1965 inspired by traditional climate-responsive architecture (Sobin 2007).

Walter Gropius (1955) considering regional expression writes:

...true regional character cannot be found through a sentimental or imitative approach by incorporating either old emblems or the newest local fashions which disappear as fast as they appear. But if you take...the basic difference imposed on architectural design by the climatic condition...diversity of expression can result...if the architect will use the utterly contrasting indoor–outdoor relations...as focus for design conception.

The term ‘bioclimatic design’ has been coined by Victor Olgyay in 1953 in his research paper: *Bioclimatic approach to architecture*. In the same year (1953), Aronin wrote his book: *Climate and architecture*. The book *Solar control and shading devices* written by Victor Olgyay and Aldar Olgyay was published in 1957. The book *Le confort dans l’habitat en pays tropicale* by Dreyfus was published in 1960.

Victor Olgyay’s most influential book *Design with climate* with the subtitle *Bioclimatic approach to architectural regionalism* was published in 1962. The term is defined as the architecture that responds to its climatic environment and achieves comfort for the occupants through appropriate design decisions. In many ways, he can be considered as an important progenitor of what is now called ‘sustainable architecture’. He synthesized elements of climatology, human physiology and building physics, with a strong advocacy of architectural regionalism in terms of designing in sympathy with the environment:

the process of building a climate-balanced house can be divided into four steps, of which the last is architectural expression. Architectural expression must be preceded by study of the variables in climate, biology, and technology. The first step towards environmental adjustment is a survey of climatic elements at a given location. However, each element has a different impact and presents a different problem. Since man is the fundamental measure in architecture and the shelter is designed to fulfil his biological needs, the second step is to evaluate each climate impact in physiological terms, the second step is to evaluate each climate impact in physiological terms. As a third step the technological solutions must be applied to each climate-comfort problem. At the final stage these solutions should be combined, according to their importance, in architectural unity. The sequence of this interplay of variables is Climate → Biology → Technology → Architecture. (Olgyay 1963, p. 11).

Lippsmeier wrote his book *Tropenbau* in 1969. Givoni’s (1969) book *Man, climate and architecture* was based on the extensive research carried out in Israel. Ian McHarg’s (1969) book *Design with nature* is a comprehensive landmark study of integrating buildings in the natural context by using natural systems; this book pioneered the concept of ecological planning.

The term ‘sustainability’ was not formally defined then in the context of environment, but it echoed in various forums. Sir Alexander John Gordon (1917–1999), the then President of the Royal Institute of British Architects, espoused his ideas at the RIBA conference in 1972 ‘good architecture’ as buildings that exhibit “long life, loose fit and low energy”, nicknamed as 3L Principle and are measurable (Gordon 1972). The philosophical basis of this was that it would be ecologically beneficial to erect buildings which last, which are designed in a way to remain adaptable for changed uses and which use little energy in their operation.

The émigré architect Otto Koenigsberger (1909–1999) immigrated to India in 1939. In India, Koenigsberger served as the Chief Architect for the Maharaja of Princely Mysore from 1939 to 1948 and as Federal Director of Housing for Nehru

Government from 1948 to 1951. Koenigsberger's most important contribution is a historically significant study of climate-responsive design methods and passive design principles in his book *Manual of Tropical Housing and Building: Part I*, which was first published in 1973. This classical publication illustrates the energy conscious traditional methods of building design and construction. It was important contribution then, and it had a seminal influence.

Edward Mazria wrote his book *Passive solar energy* in 1979. In the 1950s and 1960s, modern architects Le Corbusier and Louis I. Kahn designed a number of buildings in the Indian subcontinent. These buildings were driven by sound response to the climate (Ali and Yannas 1999). One of the physical hallmarks of modern architecture of the tropics was the sunscreen, usually called the *brise-soleil*, located on the facades that faced the sun to prevent its rays penetrating the building's interior in the summer, as in Fig. 1.2.

Jane Drew (1911–1996) and Maxwell Fry (1899–1987) were a husband-and-wife team of architects who had worked on designing houses in Chandigarh, India, with Le Corbusier. They later produced their book *Tropical architecture* in 1964. These modern architects and the Indian architects trained overseas had a significant influence on architectural development in India.

The Tropical Architecture book by Kukreja (1978) assimilates the traditional architectural and constructional techniques within the matrix of the technological



Fig. 1.2 Assembly building, Chandigarh (India)

developments like new methods of construction, new materials of construction, new methods of ventilation and air conditioning, taking into consideration the varying physical, social, and economic factors in the tropics.

1.3 Sustainable Architecture

The modern environmental movement is believed to have begun in the USA in 1962 inspired by the Rachel Carson's book *Silent Spring*, the publication of which caused a paradigm shift in understanding of the environmental impact of pesticide use (IISD 2012). Barbara Ward and Rene Dubos (1972) present the state of affairs in their book: *Only one earth*.

The environmental degradation was the main concern at the Stockholm UNEP conference in 1972:

Our purpose here is to reconcile man's legitimate, immediate ambitions with the rights of others, with respect for all life supporting systems, and with the rights of generations yet unborn. Our purpose is the enrichment of mankind in every sense, of that phrase. We wish to advance – not recklessly, ignorantly, selfishly and perilously, as we have done in the past – but with greater understanding, wisdom and vision. We are anxious and rightly so, to eliminate poverty, hunger, disease, racial prejudice and the glaring economic inequalities between human beings.

Opening Statement, United Nations Conference on the Human Environment, 4 June 1972 by Maurice F. Strong (Dodds et al. 2012)

In the following year, the OPEC's oil embargo brought the realization of the finite nature of our fossil fuel supplies and energy conservation emerged as environmental concern in architectural discourse. In response to OPEC's oil crisis, the American Institute of Architects (AIA) established an energy task force in 1973 and a committee on energy conservation in 1975. The OECD established the International Energy Agency (IEA) in 1974 to help countries coordinate a collective response to major disruptions in the supply of oil. The United Nations established the World Commission on Environment and Development (WCED) in 1987, which is known as the Brundtland Commission after its Chair Gro Harlem Brundtland, the Norwegian prime minister. The commission's report, known as the Brundtland Report (WCED 1987) weaves together social, economic, cultural and environmental issues and global solutions and introduced the term 'sustainable development':

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The latter point has been labelled as 'intergenerational equity'.

The Montreal protocol on Substances that Deplete the Ozone Layer, an international treaty, was signed in 1987 to phase out of organofluorides, which are affecting the ozone layer and admitting more ultraviolet irradiation causing the greenhouse effect.

The Intergovernmental Panel on Climate Change (IPCC) in its first assessment report in 1990, firmly established that the climate is changing due to anthropogenic influences, caused by the emission of greenhouse gases by human activities (Houghton et al. 1990). The Brundtland report, the Montreal protocol and the IPCC first assessment report had a direct and significant impact on the definition of sustainable architecture.

The next milestone in the history of sustainable architecture was the formulation of Agenda 21 at the ‘Earth Summit’ 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. The key points prescribed in Agenda 21 for a sustainable construction industry are the utilization of indigenous and local materials and technologies; labour-intensive construction and maintenance technologies; energy-efficient designs and technologies and sustainable utilization of natural resources (i.e. recycling of materials, waste prevention); development of knowledge on the environmental impacts of buildings; and self-help housing for the urban and rural poor (UNSD 1992).

The architectural profession faces a formidable set of challenges folded within the inclusive concept of sustainability. Sustainable buildings are an integral part of the overarching aim to achieve sustainable development. Susan Maxman, then president of American Institute of Architects (AIA), presided over National convention 1993 themed “Sustainability—architecture at the crossroads”. At that Chicago congress, more than 3000 AIA members joined Maxman and the Union Internationale des Architects, in signing the Declaration of Interdependence for a Sustainable Future, a document placing ‘environmental and social sustainability at the core of our practices and professional responsibilities’ (AIA 2007). Its scope and breadth were suggested as: “... sustainable design integrates considerations of resource and energy efficiency, healthy buildings and materials, ecologically and socially sensitive land-use, and an aesthetic sensitivity that inspires, affirms, and ennobles...”. Many national bodies and institutions of architecture adopted this declaration and developed energy and environmental policies for sustainable future.

The United Nations Framework Convention on Climate Change (UNFCCC) convened a meeting in Kyoto, which reached a very landmark treaty in 1997: the reduction of 1990 level of CO₂ emissions by 5% by 2012. The 191 countries ratified the agreement by March 2007 (UNFCC 2016), with the notable absence of the greatest emitters the USA.

The United Nations Conference on Sustainable Development (also known as Rio +20 or Earth Summit 2012) launched a process to develop a set of Sustainable Development Goals (SDGs), and one of the goals is to make cities and human settlements inclusive, safe, resilient and sustainable.

The historic United Nations Summit held in September 2015 in Paris adopted the 2030 Agenda for Sustainable Development—the 17 Sustainable Development Goals (SDGs) will universally apply to all, over the next 15 years. One of the goals is to make sustainable cities and communities.

In December 2015, in Paris, the world leaders reached a monumental agreement to limit global average temperature increase to “well below 2 °C and to drive efforts to limit the temperature increase even further to 1.5 °C above pre-industrial levels”.

To realize this goal, the scientific community (Hare et al. 2014) estimates that the world must peak CO₂ emissions by 2020, reach zero fossil fuel emissions by about 2050 and zero total global greenhouse gas (GHG) emissions by 2060–2080. It is projected that cities would need about 80 billion m² of residential and commercial floor space by 2025 (MGI 2012).

Sustainable Architecture is a much larger and comprehensive concept compared to climate-responsive architecture of yesteryears. Sustainable architecture is inspired by the environmental concerns. There are many good books that deal with the need for sustainable design. Vale and Vale (1991) in their classical book: *Green architecture, design for a sustainable future*, provides a balanced overview of the way forward for architecture, showing how the choice of materials and construction processes response to the landscape and climate, and the involvement of users can solve environmental problems.

John Tillman Lyle (1994), in his book *Regenerative Design for Sustainability*, discusses dichotomy of design as degenerative and regenerative. The term regenerative design added a new dimension—a new intention to sustainable design, as in Fig. 1.3. A regenerative system provides for continuous replacement, through its own functional processes, of the energy and materials used in its operation. There have other publications on the sustainable design in qualitative terms, e.g. Farmer (1999), Roaf (2001), Smith (2001), Beggs (2002), McDonough and Braungart (2002).

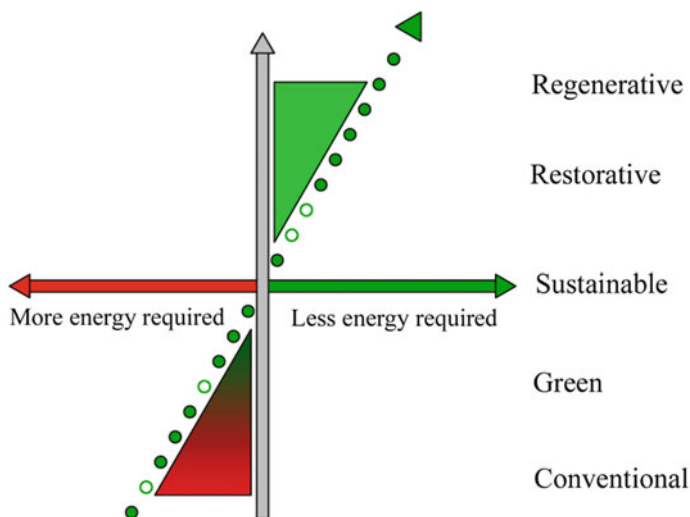


Fig. 1.3 Environmentally responsive trajectory (after Reed 2006)

Szokolay (2008) explains the scientific approach and basics to energy-efficient architecture by giving an introduction to architectural science.

1.3.1 Sustainability Rating Systems

According to ISO 15392 (2008), construction sustainability includes “considering sustainable development in terms of its three primary aspects (economic, environmental and social), while meeting the requirements for technical and functional performance”.

As many as 600 building sustainability rating systems are available worldwide (BRE 2008) and new ones are being added, but no consensus emerged. This situation led to release of the standards Sustainability in Building Construction—Framework for Methods of Assessment of the Environmental Performance of Construction Works—Part I: Building (ISO 21931-I 2010) and Sustainability of Construction Works—Sustainability Assessment of Buildings—General Framework (ISO 15643-I 2010).

Rating systems range from building energy ratings to multidimensional sustainability ratings. Table 1.1 gives an overview of sustainability rating systems in different countries. According to Hastings and Wall (2007), the rating systems can be grouped into the following:

- Cumulative energy demand (CED) systems are mono-dimensional and focus on energy consumption
- Life cycle analysis (LCA) systems measure the impact of the building on environment by assessing the emission of one or more chemical substances related to the building construction and operation. LCA can have one or more evaluation parameters.
- Total quality assessment (TQA) systems are multidimensional and evaluate environmental issues such as GHG emission and energy consumption; economic aspects such as investment; and social aspects such as accessibility and quality of spaces.

The above typology may not be exhaustive as many rating systems do not fit perfectly into one category. The first two categories of systems have a quantitative approach to the assessment, whereas a TQA system generally has a qualitative or quantitative approach for different criteria. The building energy performance is considered the most important criterion in sustainability rating systems and the least achieved one in sustainability assessments (Berardi 2011). The energy use in buildings during their operation is the domain of the building designer (the architect, engineer or planner). Depending on the level of energy services, the operational energy consumption can be up to 80% of the total energy demand of a building, with the balance being the energy consumed in construction, demolition and the embodied energy in the materials (WBCSD 2009, p. 6). About 80% of

Table 1.1 An overview of sustainability rating systems around the world

Continent	Labelling	Country	Web page	No.
	World Green Building Council		http://www.worldgbc.org/	
UNEP	Sustainable Buildings Climate Index		http://www.unep.org/sbci/	
America	LEED	USA	http://www.usgbc.org/	1
	Green Globes	USA	http://www.greenglobes.com/	2
	LEED Canada	Canada	http://www.cagbc.org/	3
	Green Globes	Canada	http://www.greenglobes.com/	4
	LEED Brasil	Brazil	http://www.gbcbrazil.org.br/	5
	LEED	Argentina	http://www.argentinagbc.org.ar/	6
Europe	CRISP	Europe	http://cic.vtt.fi/eco/crisp/	7
	DGNB	Germany	http://www.dgnb.de/en	8
	BREEAM	UK	http://www.breeam.org	9
	HQE	France	http://www.assohqe.org/	10
	ESCALE	France	http://www.cstb.fr/	11
	Certivéa	France	http://www.certivea.fr/	12
	PromisE	Finland	http://www.vtt.fi/	13
	LiderA	Portugal	http://www.lidera.info/	14
	BREEAM Netherlands	Netherlands	http://www.dgbc.nl/	15
	Protocol Itaca	Italy	http://www.itaca.org/	16
	LEED	Italy	http://www.gbcaitalia.org/	17
	Minergie	Swiss	http://www.minergie.ch/	18
	LEED	Poland	http://www.plgbc.org	19
	LEED	Romania	http://www.rogbc.org/r	20
	Verde	Spain	http://www.gbce.es/	21
	SBTool PT	Portugal	http://www.iisbeportugal.org/	22
SBTool CZ	Czech Republic	http://www.sbtool.cz/	23	
Asia	LEED Emirates	UAE	http://emiratesgbc.org/	24
	LEED India	India	http://www.gbci.org/	25
	GRIHA	India	http://www.grihaindia.org/	26
	Green Mark	Singapore	http://www.bca.gov.sg/GreenMark/	27
	EEWH	Taiwan	http://www.abri.gov.tw/en	28
	ESTIDAMA-Pearl	UAE	http://estidama.upc.gov.ae/	29
	GBEL (three star)	China	http://www.gbgi.org/	30
	HK-BEAM	Hong Kong	http://www.beamsociety.org.hk/	31
	CASBEE	Japan	http://www.ibec.or.jp/CASBEE/	32
Africa	Green Star SA	South Africa	http://www.gbca.org.za/	33
Australia	Green Star	Australia	http://new.gbca.org.au/green-star/	34
	Nabers	Australia	https://www.nabers.gov.au/	35
	Green Star NZ	New Zealand	http://www.nzgbc.org.nz/main/	36

GHG emissions take place during the operational phase of buildings, when energy is used for heating, cooling, ventilation, lighting, appliances and other appliances. The buildings sector represents great potential to reduce energy consumption in both new and existing buildings by an estimated 30–50% (UNEP 2009).

1.4 Sustainable Building Design in India

India is witnessing tremendous growth in infrastructure and construction development. The construction industry in India is one of the largest economic activities and is contributing around 8.87% to the nation's gross value added at basic price (at current prices), RBI (2016). As the sector is growing rapidly, preserving the environment poses a host of challenges.

India's urban population grew from the 286 million reported in the 2001 Census to 377 million reported in the 2011 Census (Census of India 2011). The country doubled its floor space between 2001 and 2005 and is expected to add 35 billion m² of new buildings by 2050 (Shnapp and Laustsen 2013). Buildings account for 33% of total final energy consumption in India today, and building energy use is growing at 8% annually (Rawal et al. 2012).

The environmental policy of India is embedded in the Constitution (forty-second amendment) Act (GOI 1976):

48A. Protection and improvement of environment and safeguarding of forests and wild life.-The State shall endeavour to protect and improve the environment and to safeguard the forests and wild life of the country.

51A. Fundamental duties.-It shall be the duty of every citizen of India: (g) to protect and improve the natural environment including forests, lakes, rivers and wild life, and to have compassion for living creatures.

In January 2000, the Energy Conservation and Commercialization (ECO) programme was signed between the Government of India and United States Agency for International Development (USAID) with the objective to enhance commercial viability and performance of Indian energy sector and to promote utilization of clean and energy-efficient technologies in the sector. Ministry of Environment, Forest and Climate Change (MoEFCC 2006) issued the Environmental Impact Assessment Notification, 2006, which makes environmental clearance mandatory for the development activities listed in its schedule. Builders and developers, therefore, need to obtain an Environmental Impact Assessment (EIA) clearance before construction. The Planning Commission (presently known as Niti Aayog) issued the Integrated Energy Policy in 2006 (GOI 2006). This document identifies major areas with large potential for energy savings. Five of the thirteen areas are related to the building sector, including building design, construction, heating, ventilation and air conditioning (HVAC), lighting and household appliances.

The National Urban Housing and Habitat Policy (GOI 2007, p. 17) aims to use technological advances for modernizing the housing sector for enhancing energy

and cost efficiency and implement the concept of “green” and “intelligent” buildings.

India released its National Action Plan on Climate Change (NAPCC) to mitigate and adapt to climate change on 30 June 2008. The Action Plan focuses on eight missions: National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, Green India Mission, National Mission for Sustainable Agriculture, National Mission on Strategic Knowledge for Climate Change (GOI 2008).

India submitted its Intended Nationally Determined Contribution (INDC): working towards climate justice, to UNFCCC (GOI 2015).

Recently, Partnership to Advance Clean Energy-Deployment (PACE-D), a bilateral programme, is launched in 2016 on clean energy between the USA and India to jointly work on a range of issues related to energy security, clean energy and climate change (USAID 2016). Programme for Net Zero Energy Buildings in India is initiated as a long-term strategy to gradually reduce consumption of energy derived from fossil fuels by enhancing utilization of energy generated through renewable energy sources.

1.4.1 Building Energy Efficiency Standards in India

During the past three decades, the Government of India has initiated policies to reduce energy consumption in buildings. Most of these policies can be grouped into one of the following three categories: economic incentives (e.g. taxes, energy pricing), informational programmes (e.g. energy awareness campaigns, energy audits) or regulatory requirements (e.g. codes or standards). Building energy efficiency standards are an important tool to improve energy efficiency in new and existing buildings. Building energy efficiency standards set requirements for how energy-efficient a building will be. Standards vary between countries in several respects including the extent of their coverage, the specific requirements, means of attaining compliance and enforcement.

The Bureau of Indian Standards (BIS) published three cogent documents; which have a bearing, either direct or indirect, on sustainable building design in India:

- (i) The Handbook on Functional Requirements of Industrial Buildings (lighting and ventilation), SP 36 (S & T), BIS (1986).
- (ii) The Handbook on Functional Requirements of Building (other than industrial building), SP 41 (S & T). BIS (1987) Part I deals with Climatology; defines four climatic zones hot and arid, hot and humid, warm and humid and cold and summer design dry bulb (DB) wet bulb (WB) and solar radiation for towns representing various hot/warm climate: Jodhpur, Mumbai, New Delhi and Hyderabad.

- (iii) The National Building Code of India, SP 7 (S & T), BIS (2016). The NBC proposes ‘integrated approach’ for utilizing appropriate knowledge and experience of qualified professionals right from the conceptualization through construction and completion stages of a building project and during entire life cycle. The NBC covers a range of structural, safety and other design issues. The NBC incorporated *Part 11: Approach to Sustainability* in September 2015.

The above codes include among other the research conducted by two national research institutes, namely the Central Building Research Institute (CBRI) at Roorkee and the Structural Engineering Research Centre (SERC) at Chennai.

The Indian Parliament enacted the Energy Conservation Act (ECA 2001), which promotes energy efficiency and conservation in India. ECA 2001 mandated the creation of the Bureau of Energy Efficiency (BEE), which was constituted under the Ministry of Power in 2002. ECA 2001 also authorized BEE to launch the Energy Conservation Building Code (ECBC). The Ministry of Power and BEE (2007 and 2017) issued ECBC—the first stand-alone national building energy code in India. While it is currently voluntary, ECBC intends to be mandatory for commercial buildings or building complexes that have a connected load of 100 kW or greater or a contract demand of 120 kVA or greater. The code is also applicable to all buildings with a conditioned floor area of 500 m² or greater. The code is recommended for all other buildings.

The ECBC establishes minimum energy efficiency requirements for building envelopes, lighting, mechanical systems and equipment, including heating, ventilating and air conditioning, service hot water heating, interior and exterior and electrical power and motors. There would be three ways of being compliant with the ECBC: first, through a prescriptive approach, i.e. all minimum standards for separate components must be met based on the climate zone in which building is located; second, the envelope and lighting system would be assessed through a system of performance criteria, while other components would have to meet the minimum requirements; and third, setting the whole building target energy use and trading off between systems (energy cost budget method).

1.4.2 Sustainability Rating Systems in India

There are three sustainability rating systems in India: GRIHA, IGBC Green Building and LEED. The Green Rating for Integrated Habitat Assessment (GRIHA) is the national rating system of India conceived by The Energy and Resources Institute (TERI) and endorsed by the Ministry of New and Renewable Energy, Government of India on 1 November 2007; which is updated time to time (GRIHA Council and TERI 2015). GRIHA integrates relevant provisions of NBC, ECBC,

and Indian codes and standards for buildings. The rating evaluates the energy and environmental performance of a building holistically over its entire life cycle and strikes a balance between the established practices and emerging concepts, both national and international. It will benefit the community at large with the improvement in the environment by reducing GHG emissions, improving energy security and reducing the stress on natural resources. GRIHA emphasises on passive solar techniques for optimizing indoor visual and thermal comfort. In order to address energy efficiency, GRIHA encourages optimization of building design to reduce conventional energy demand and further optimize energy performance of the building within specified comfort limits.

GRIHA is a five star rating system for green buildings in four climatic zones of the country, and the cold climate is not included in this rating. GRIHA is an indigenous green building rating system and applicable for commercial, institutional and residential buildings in all operation modes: non-air-conditioned, partially air-conditioned and fully air-conditioned.

The IGBC green building rating systems have been launched by the Indian Green Building Council (IGBC 2015), which includes the following:

1. IGBC Green New Buildings,
2. IGBC Green Existing Buildings,
3. IGBC Green Homes,
4. IGBC Green Schools,
5. IGBC Green Factory Buildings,
6. IGBC Green Townships,
7. IGBC Green SEZs,
8. IGBC Green Landscapes,
9. IGBC Green Mass Rapid Transit System.

All the IGBC rating systems are voluntary, consensus-based, market-driven building programmes. The rating systems are applicable to all five climatic zones of the country, and the different levels of certification are as follows: certified, silver, gold, platinum and superplatinum. With a modest beginning of 1858 m² (20,000 ft²) green built-up area in the country in the year 2003, presently (as on 3 August 2017) more than 4205 Green Buildings projects coming up with a footprint of over 430.14 million m² (4630 million ft²) are registered with the Indian Green Building Council (IGBC), out of which 1098 Green Building projects are certified and fully functional in India.

LEED, or Leadership in Energy and Environmental Design, is a green building certification programme administered by the Green Business Certification Inc. (GBCI 2016) within the framework of the UG Green Building Council. To receive LEED certification, building projects satisfy prerequisites and earn points to achieve different levels of certification: Certified, Silver, Gold and Platinum. LEED is available for both new construction and existing buildings and for all building types

ranging from commercial office spaces, retail, warehouses, data centres, health facilities, interior fit-outs, core and shell development, as well as homes, communities and entire neighbourhoods.

1.5 Conclusion

It is well established that buildings consume significant amount of energy and are responsible for GHG emissions through burning of fossil fuels and thus contribute to climate change. Sustainable architecture can control environmental climate change while still fulfils its primitive function as ‘shelter’ that protects the body from the climate. There are two basic paradigms of environmentally sustainable building design. The first is based on the principles of ‘passive’ design where building responds to its climatic context to limit the effects of external conditions on the internal environment and saves energy consumption. The second paradigm is based on the principles of ‘active’ design that uses state-of-the-art energy-efficient technologies and building management systems to reduce the energy load of buildings.

The greatest opportunities to achieve a higher environmental performance for buildings can be found in the early stages of their design. It should be the designer’s aim to ensure the required indoor conditions with little or no use of energy, other than from ambient or renewable sources. Therefore, the designer’s task is as follows:

1. To analyse the given climate conditions;
2. To establish the limits of desirable or acceptable thermal comfort;
3. To consider appropriate passive design strategies to control heat and sun;
4. To consider energy-efficient active design strategies for cooling and heating.

The primary purpose of this book is to introduce the parameters of climate, comfort and sun for building design, to present principles of passive design and quantitative climatic data for application. An implicit aim is also to create an authoritative reference work, which would provide a concise but comprehensive overview of the state-of-the-art of the subject of sustainable design of buildings.

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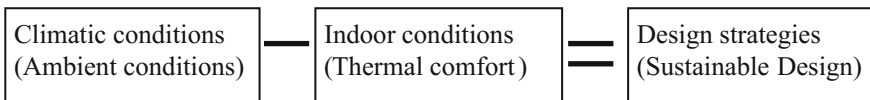
Chapter 2

Climate, Comfort and Sun

A well know American writer said once that, while everybody talks about the weather, nobody seems to do anything about it.
(Warner 1897).

2.1 Introduction

Sustainable design of building entails an understanding of climate of the given place and desirable comfort conditions:



This chapter intends to present classification of climate, elements of climate, parameters of thermal comfort and solar geometry. Globally prevalent Köppen classification of climate and five climatic zones in India are discussed. The section on elements of climate presents sources and derivation of climatic data given in Chap. 5. The section on thermal comfort defines parameters of physiological thermal comfort and method to delineate comfort zone for a given city. The last section deals with solar geometry and method to draw sun-path diagrams.

2.2 Classification of Climate

Important characteristics of any planet are controlled by its climate. The word ‘climate’ comes from the Greek *klima*, which means the slope of the earth with respect to the sun. Climate is defined as ‘region with certain conditions of temperature, dryness, wind, light, etc. of a region,’ Oxford dictionary. Climate is also defined, ‘an integration in time of the weather conditions, characteristics of a certain

geographical location.’ As weather is the set of atmospheric conditions, including temperature, rainfall, wind, humidity and sky conditions prevailing at a given place and time. Climate on the other hand, is the general weather conditions over a long period of time. In totality, climate is the sum of all the statistical weather information that helps to describe a place or region.

Since Aristotle’s time, attempts at climate classification have been done chiefly by biologists who realised that the natural vegetation represents a very good indication of the climate of a place. The well known vegetation-based classification of climates by Wladimir Köppen, a German biologist trained in St. Petersburg, was first published in 1900 and is still prevalent. The Köppen system is based on monthly mean temperature, monthly mean precipitation, and mean annual temperature. The five vegetation groups of Köppen distinguish between plants of the equatorial zone (A), the arid zone (B), the warm temperate zone (C), the snow zone (D) and the polar zone (E). A second letter in the classification considers the precipitation (e.g. Df for snow and fully humid), a third letter indicates the air temperature (e.g. Dfc for snow, fully humid with cool summer). The annual mean near-surface (2 m) temperature is denoted by T_{ann} and the monthly mean temperatures of the warmest and coldest months by T_{max} and T_{min} . P_{ann} is the accumulated annual precipitation and P_{min} is the precipitation of the driest month. Additionally P_{smin} , P_{smax} , P_{wmin} and P_{wmax} are defined as the lowest and highest monthly precipitation values for the summer and winter half-years on the hemisphere considered. All temperatures are given in °C, monthly precipitations in mm/month and P_{ann} in mm/year. In addition to these temperature and precipitation values a dryness threshold P_{th} in mm is introduced for the arid climates (B), which depends on $\{T_{ann}\}$ the absolute measure of the annual mean temperature in °C, and on the annual cycle of precipitation:

$P_{th} = \left\{ \begin{array}{l} \end{array} \right.$	$2\{T_{ann}\}$	If at least 2/3 of the annual precipitation occurs in winter
	$2\{T_{ann}\} + 28$	If at least 2/3 of the annual precipitation occurs in summer
	$2\{T_{ann}\} + 14$	Otherwise

Köppen classification enlist some 25 climate types, Fig. 2.1 and Table 2.1.

The Indian subcontinent is a big geographical unit, which has almost thirty degrees of latitudinal extent (between 6°N and 36°N) and the same amount of longitudinal extent (between 68°E and 98°E). With its vast size about 3.2 million square kilometers, India has sharp contrasts in its climatic conditions. The climatic map included in the National Building Code of India (BIS 2016) for the purpose of design of buildings distinguishes five climate zones (Fig. 2.2; Table 2.2):

1. Hot and dry
2. Warm and humid
3. Temperate
4. Cold
5. Composite

An extensive study in the book *Climatic zones and rural housing in India* by Bansal and Minke (1988) covered the climatic data of 32 stations along with 21

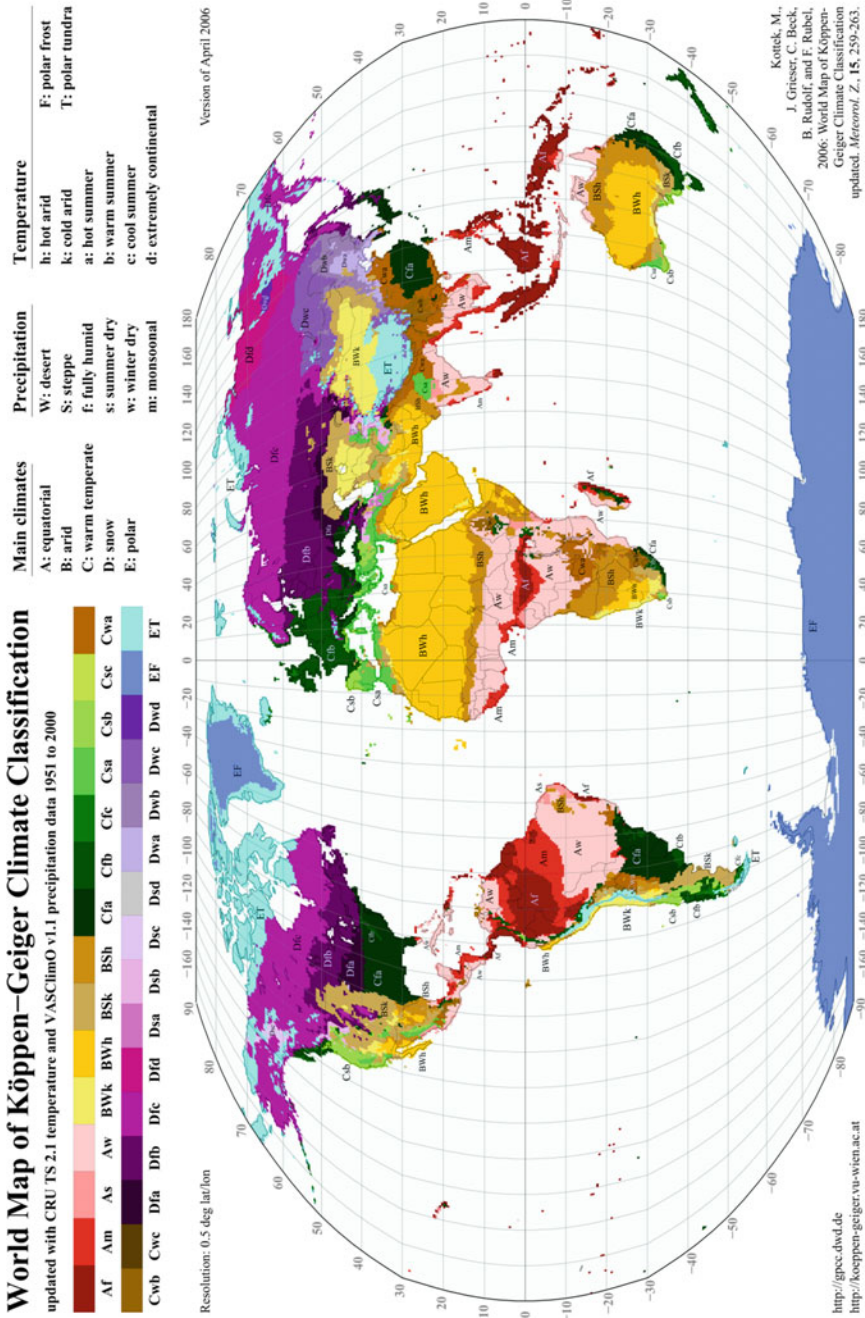


Fig. 2.1 World map of Köppen–Geiger climate classification. (Kottek et al. 2006)

Table 2.1 Köppen's major climates (Kottek et al. 2006)

Type	Main group-climates	Sub-group: precipitation	Second sub-group: temperature
A	Equatorial climates ($T_{\min} \geq +18\text{ °C}$)		
Af		Equatorial rainforest, fully humid ($P_{\min} \geq 60\text{ mm}$ Rainy all seasons)	
Am		Equatorial Monsoon [$P_{\text{ann}} \geq 25(100 - P_{\min})$]	
Aw		Equatorial savannah with dry winter ($P_{\min} < 60\text{ mm}$ in winter)	
As		Equatorial savannah with dry summer ($P_{\min} < 60\text{ mm}$ in summer)	
B	Arid climates ($P_{\text{ann}} < 10 P_{\text{th}}$)		
Bs		Semi-arid Steppe climate ($P_{\text{ann}} > 5 P_{\text{th}}$)	
Bsh			Hot steppe/desert ($T_{\text{ann}} \geq +18\text{ °C}$)
Bsk			Cold steppe/desert ($T_{\text{ann}} \leq +18\text{ °C}$)
Bw		Desert climate ($P_{\text{ann}} \leq 5 P_{\text{th}}$)	
Bwh			Hot steppe/desert ($T_{\text{ann}} \geq +18\text{ °C}$)
Bwk			Cold steppe/desert ($T_{\text{ann}} \leq +18\text{ °C}$)
C	Warm temperate climates ($-3\text{ °C} < T_{\min} < +18\text{ °C}$)		
Cw		Warm temperate climate with dry winter ($P_{\text{wmin}} < P_{\text{smin}}$ and $P_{\text{smax}} > 10 P_{\text{wmin}}$)	
Cwa			Hot summer ($T_{\text{max}} \geq +22\text{ °C}$)
Cwb			Warm summer (not 'a' and at least 4 $T_{\text{mon}} \geq +10\text{ °C}$)
Cs		Warm temperate climate with dry summer ($P_{\text{smin}} < P_{\text{wmin}}$, $P_{\text{wmax}} > 3 P_{\text{smin}}$ and $P_{\text{smin}} < 40\text{ mm}$)	
Csa			Hot summer ($T_{\text{max}} \geq +22\text{ °C}$)
Csb			Warm summer (not 'a' and at least 4 $T_{\text{mon}} \geq +10\text{ °C}$)
Cf		Neither Cs nor Cw (Moist all seasons)	
Cfa			Hot summer ($T_{\text{max}} \geq +22\text{ °C}$)
Cfb			Warm summer (not 'a' and at least 4 $T_{\text{mon}} \geq +10\text{ °C}$)

(continued)

Table 2.1 (continued)

Type	Main group-climates	Sub-group: precipitation	Second sub-group: temperature
Cfc			Cool summer and cold winter (not 'b' and $T_{min} > - 38 \text{ }^{\circ}\text{C}$)
D	Snow climates ($T_{min} \leq - 3 \text{ }^{\circ}\text{C}$)		
Ds		Snow climate with dry summer ($P_{smin} < P_{wmin}$, $P_{wmax} > 3 P_{smin}$ and $P_{smin} < 40 \text{ mm}$)	
Df		Snow climate, fully humid (neither Ds nor Dw)	
Dfa			Hot summer ($T_{max} \geq + 22 \text{ }^{\circ}\text{C}$)
Dfb			Warm summer (not 'a' and at least 4 $T_{mon} \geq + 10 \text{ }^{\circ}\text{C}$)
Dfc			Cool summer and cold winter (not 'b' and $T_{min} > - 38 \text{ }^{\circ}\text{C}$)
Dfd			Extremely continental (like 'c' but $T_{min} \leq - 38 \text{ }^{\circ}\text{C}$)
Dw		Snow climate with dry winter ($P_{wmin} < P_{smin}$ and $P_{smax} > 10 P_{wmin}$)	
Dwa			Hot summer ($T_{max} \geq + 22 \text{ }^{\circ}\text{C}$)
Dwb			Warm summer (not 'a' and at least 4 $T_{mon} \geq + 10 \text{ }^{\circ}\text{C}$)
Dwc			Cool summer and cold winter (not 'b' and $T_{min} > - 38 \text{ }^{\circ}\text{C}$)
Dwd			Extremely continental (like 'c' but $T_{min} \leq - 38 \text{ }^{\circ}\text{C}$)
E	Polar climate ($T_{max} < + 10 \text{ }^{\circ}\text{C}$)		
ET		Tundra Climate Short summer allows tundra vegetation ($0 \text{ }^{\circ}\text{C} \leq T_{max} < + 10 \text{ }^{\circ}\text{C}$)	
EF		Frost climate (perpetual ice and snow) ($T_{max} < 0 \text{ }^{\circ}\text{C}$)	

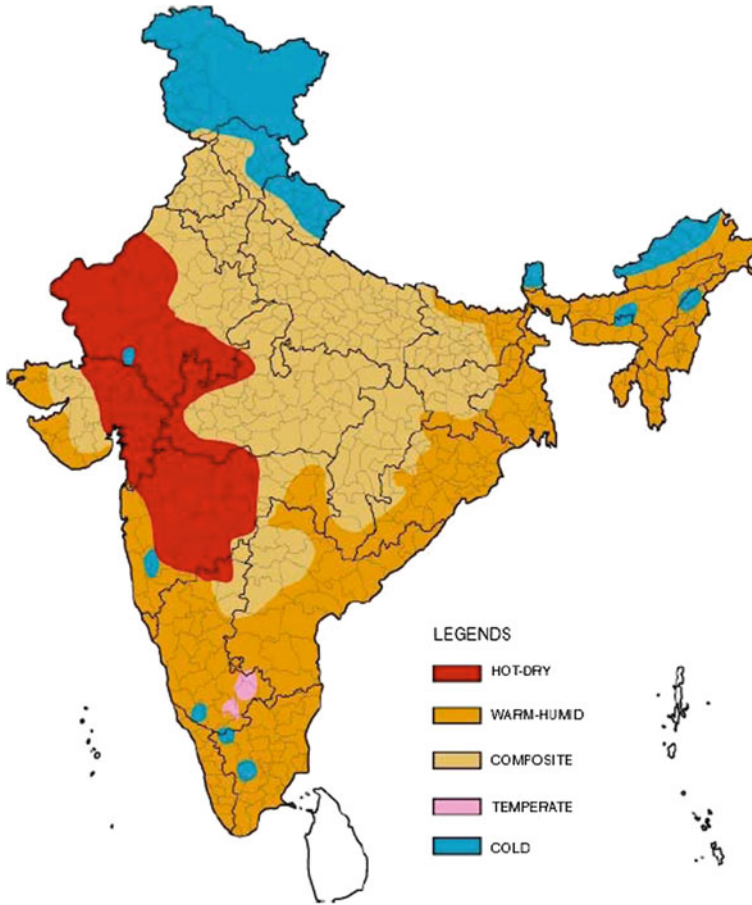


Fig. 2.2 Climatic zones of India, BEE (2017) and BIS (2016)

Table 2.2 Climatic zones of India

Climatic zone	Mean monthly maximum temperature (°C)	Mean monthly relative humidity (%)
Hot and dry	Above 30	Below 55
Warm and humid	Above 30	Above 55
	Above 25	Above 75
Temperate	Between 25 and 30	Below 75
Cold	Below 25	All values
Composite	Each climatic zone does not have same climate for the whole year; it has a particular season for more than six months and may experience other seasons for the remaining period. A climatic zone that does not have any season for more than six months may be called as composite zone.	

Source BIS (2016, Part 8 Building Services, Sect. 1: lighting and natural ventilation, clause 3.2 basic zones, Table 2)

examples of rural housing across six climatic zones in India. *A design handbook for energy efficient buildings* by Krishan et al. (2001) and *Handbook on Energy Conscious Buildings* by Nayak and Prajapati (2006) present climatic data of six stations representing each climate zones of the country and the methodology of design, design tools, developments in energy efficient architecture and case studies. Chapter 5 presents climatic data of 62 cities across five climatic zones of India.

2.3 Elements of Climates

The main climatic elements regularly measured by meteorological organization and published in summary form. Further, climatic data are also obtained from satellites. In absence of observed climatic data, it can be also estimated based on standard algorithms. The following sections discuss the elements of climate needed for building design.

2.3.1 Temperature and Humidity

Air temperature is expressed by the dry bulb temperature (DBT), measured with a standard thermometer in the shade, usually in a ventilated box, the Stevenson screen, 1.2–1.8 m above ground level. The bulb of thermometer should not wet—if it were wet, the evaporation of moisture from its surface would affect the reading and give something closer to the wet bulb temperature. Air temperature can also be measured by thermocouple, or resistance temperature devices. Air temperature is usually given in degrees Celsius ($^{\circ}\text{C}$) or Fahrenheit ($^{\circ}\text{F}$), however its true SI unit is Kelvin (K). On the Kelvin scale 0°K equals -273°C . In conformity with the accepted usage of the SI system, the symbol C is used to denote a specified point on the temperature scale, but K (degree Kelvin) is used for a range, a span or a difference of temperature, i.e., a length of the scale, without specifying its position.

Humidity, can be expressed by six psychrometric parameters: (i) Wet bulb temperature (WBT, $^{\circ}\text{C}/^{\circ}\text{F}$); (ii) dew-point temperature (DPT, $^{\circ}\text{C}/^{\circ}\text{F}$), (iii) absolute humidity (AH, g/kg or lb/lb), (iv) humidity ratio (HR) (v) vapour pressure (p , kPa/psi), (vi) relative humidity (RH, %).

It is usually measured by the wet-and-dry bulb (whirling) psychrometer or an aspirated psychrometer. These contain two thermometers; one has its bulb wrapped in gauze, which is kept moist from small water container. When whirled around (or the fan is operated) until their readings become steady to obtain maximum possible evaporation, this produces a cooling effect, showing the Wet bulb temperature (WBT). The other thermometer measures the air-or dry-bulb temperature (DBT). The difference $\text{DBT}-\text{WBT}$ is referred to as the wet bulb depression and it is indicative of the humidity. Evaporation is inversely proportional to humidity. In saturated air there is no evaporation, no cooling thus $\text{WBT} = \text{DBT}$. In the dry air

the moisture rapidly evaporates to produce a large depression which indicates of low humidity. In moisture-laden air evaporation is less and a small wet-bulb depression occurs; which indicates high humidity.

For any particular dry-bulb temperature there is only a certain amount of moisture vapour that can be absorbed in the air before it becomes saturated and precipitation occurs. The actual amount of moisture in the air is referred to as the absolute humidity (AH) and is measured in g/kg (or lb/lb). The dew-point temperature ($^{\circ}\text{C}/^{\circ}\text{F}$) refers to the maximum amount of moisture that the air can hold at a given temperature. The relative humidity (RH) is the ratio of the actual density of water vapour in air to the maximum density of water vapour that such air could contain, at the same temperature, if it were 100% saturated. Relative Humidity may be measured directly or derived from DBT and WBT. At 100% relative humidity, DBT and WBT are equal.

The main source of temperature and relative humidity data is the Indian Society for Heating Refrigerating Air Conditioning Engineers (ISHRAE 2014). The location's latitude, longitude and altitude above mean sea level are taken from these, as well as values of maximum and minimum temperature and relative humidity.

Both the graph and the table give the mean minimum and mean maximum temperatures. The monthly mean temperatures shown on the graph as well as in the table were calculated as

$$\bar{T} = \frac{T_{\text{mean max}} + T_{\text{mean min}}}{2} \quad (2.1)$$

Annual averages of all three temperatures values are given in the table, found as

$$\sum_1^{12} \frac{\bar{T}}{12} \quad (2.2)$$

Hourly values of temperature for a typical winter and summer day are given by the ISHRAE (2014).

The average diurnal range of temperatures is the difference between the monthly mean maximum and the monthly mean minimum. The annual mean range of temperature is the difference between the highest monthly mean maximum and the lowest monthly mean minimum.

The recommended outdoor “design conditions” (summer DBT and WBT and winter DBT) have been adopted from the BIS (2016, Part 8 Building Services—Sect. 3, Air Conditioning, Heating and Mechanical Ventilation, clauses 5 Table 2 Outside Design Conditions).

2.3.2 Cloud and Sunshine

Cloud cover, based on visual observation, expressed as a fraction of the sky hemisphere ('octas' eighths, or more recently tenths) covered by clouds. The cloud cover data for all the cities have been taken from the ISHRAE (2014).

Sunshine duration, i.e. the period of clear sunshine (when a sharp shadow is cast), measured by a sunshine recorder, in which a lens burns a trace on a paper strip; shown as hours per day or month. The sunshine data for 38 cities have been collated from the India Meteorological Department (IMD) and World Meteorological Organization (WMO). The sunshine duration was not available for 24 cities, so the values are estimated using standard algorithm (Muneer 2004, pp. 36–37):

$$n = \frac{N}{0.448} \left(\frac{\bar{G}}{\bar{E}} - 0.299 \right) \quad (2.3)$$

where \bar{G} and \bar{E} are the monthly-averaged daily terrestrial and extraterrestrial irradiation on a horizontal surface (W/m^2), 0.299 and 0.448 are empirical coefficients based on data of 18 Indian cities (Hawas and Muneer 1983), n is the average daily hours of bright sunshine duration (hours) and N is the day length (hours), obtained by:

$$\omega_s = \cos^{-1} (-\tan \text{LAT} \times \tan \text{DEC}) \quad (2.4)$$

$$N = (2\omega_s/15) \quad (2.5)$$

where ω_s = sunset hour angle degrees, LAT = latitude degrees (southern hemisphere -ve), DEC = solar declination degrees (varies from a maximum value of +23.45 on June 22 to a minimum value of -23.45 on Dec. 22. It is zero on the two equinox days of Mar. 21 and Sept. 22)

Cooper (1969) has given the following simple equation for calculating declination on any day of year:

$$\text{DEC} = 23.45 \times \sin \left[\frac{360}{365} (284 + DN) \right] \quad (2.6)$$

where DN = Julian date, counted Jan. 1st DN = 1 to Dec. 31st as DN = 365.

Another more accurate expression is given by (Aydinli 1981)

$$\text{DEC} = 23.45 + \sum_{i=1}^3 a_i \times \cos \left(i \frac{2\pi}{365} \text{DN} + b_i \right) \quad (2.7)$$

a_i and b_i are as follows:

i	a_i	b_i radians
1	-23.2559	0.1582
2	-0.3915	0.0934
3	-0.1764	0.4539

Another algorithm (Dogniaux 1975):

$$DEC = 0.33281 + \sum_{i=1}^3 a_i \times \cos\left(i \frac{2\pi}{366} DN\right) + b_i \times \sin\left(i \frac{2\pi}{366} DN\right) \quad (2.8)$$

where a_i and b_i are as follow:

i	a_i	b_i radians
1	-22.984	3.7872
2	-0.34990	0.03205
3	-0.13980	0.07187

The extraterrestrial irradiation, E may be calculated by:

$$E = \frac{0.024}{\pi} I_{sc} \left[1 + 0.033 \times \cos\left(360 \times \frac{DN}{365}\right) \right] \times \left[\cos LAT \times \cos DEC \times \sin \omega_s + \left(\frac{2\pi\omega_s}{360}\right) \times \sin LAT \times \sin DEC \right] \quad (2.9)$$

In the above equation I_{sc} is the solar constant (= 1367 W/m²).

Page et al. (1984) identified the particular day in each month for which the extra-terrestrial radiation is nearly equal to the monthly mean value, Table 2.3.

Table 2.3 Solar declination for representative dates, associated day number (DN) and recommended values of solar declination

Date	Day (DN)	Solar declination (DEC)	Date	Day (DN)	Solar declination (DEC)
Jan. 17	17	-20.71	Jul. 17	198	21.16
Feb. 15	46	-12.81	Aug. 16	228	13.65
Mar. 16	75	-1.80	Sep. 16	259	2.89
Apr. 15	105	9.77	Oct. 16	289	-8.72
May. 15	135	18.83	Nov. 15	319	-18.37
Jun. 11	162	23.07	Dec. 11	345	-22.99

Note: The values of monthly mean solar declination is the average of the individual daily values calculated using the algorithm given by Aydinli (1981). For use in the southern hemisphere the sign should be reversed (assuming that the latitude is given a positive value), Page et al. (1984)

These dates can be also taken for computing the monthly average values of instantaneous hourly radiation.

- Cloud over (table only) given in %, for some stations given in octas.
- Monthly mean sunshine hours (both table and graph).

2.3.3 Irradiation

Solar radiation, measured by a pyranometer (solarimeter), on an unobstructed horizontal surface and recorded either as the continuously varying irradiance in W/m^2 , or through an electronic integrator as irradiation over the hour or day in Wh/m^2 . If the hourly value of irradiation is given in Wh/m^2 , it will be numerically the same as the average irradiance (W/m^2) for that hour. As an energy unit, the Wh (Watt-hour) is used for solar radiation, although it is only a “tolerated” unit in the SI.

Monthly irradiation data, as well as the hourly values of direct and diffuse irradiation for a typical winter and summer day (in Wh/m^2) for all the cities have been adopted from the ISHRAE (2014). Hourly values of irradiation for a typical winter and summer day are given by the ISHRAE (2014).

2.3.4 Wind

Air movement, i.e. wind, normally measured at 10 m above ground in open country, but higher in built-up areas, to avoid obstructions; both velocity and direction are recorded. Wind velocity and direction is measured by a cup-type or propeller anemometer.

For all the cities wind data have been taken from the ISHRAE (2014). For building design wind data are best represented graphically in the form of wind rose.

Wind roses for 62 locations are drawn. These roses have eight sides, corresponding to the four cardinal and four semi-cardinal points of the compass, giving directions from which the wind comes. Each side has 12 lines, corresponding to the 12 months, from January to December in a clockwise direction, where the length of a line is proportionate to the frequency (% of observation) of wind from that direction in that month. Mean wind speed in m/s is shown in tables.

2.3.5 *Precipitation*

Precipitation, i.e. the total amount of rain, hail, snow or dew, measured in the tipping bucket rain gauges i.e. calibrated receptacles, and expressed in mm per unit time (day, month or year). Values indicating the total precipitation for each month of the year (and as many years' average) would show the pattern of dry and wet seasons. The mean monthly rain data have been obtained from the Indian Meteorological Department.

2.4 Thermal Comfort

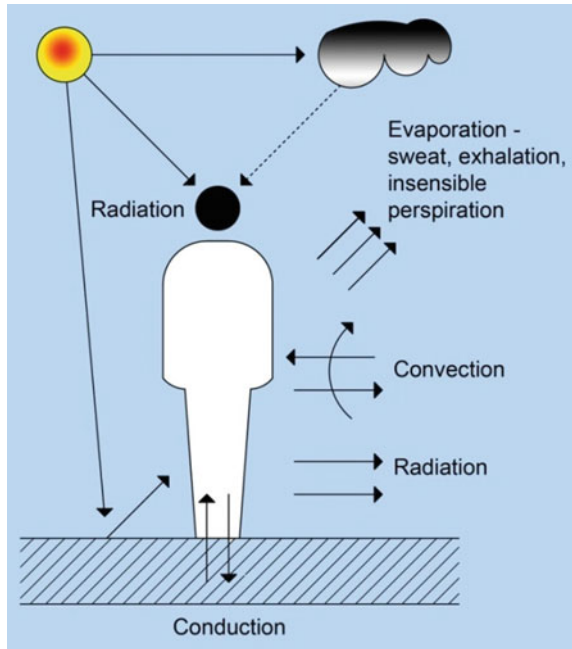
A principal purpose of sustainable building design is to provide conditions for human thermal comfort, 'condition of mind that expresses satisfaction with the thermal environment' ASHRAE standard 55 (ASHRAE 2010). This definition emphasizes that judgement of comfort is a cognitive process involving many parameters influenced by physical, physiological, psychological, and other processes (ASHRAE 2009).

2.4.1 *Heat Balance of Human Body*

The human body continuously produces heat through metabolic processes that must be dissipated and regulated to maintain normal body temperatures. The heat output of a resting adult is about 100 W, but it can range from about 70 W (in sleep) to about 700 W in heavy activity (playing tennis). The deep body temperature is about 36.8 °C at rest in comfort and rises with activity to about 37.4 °C when walking and 37.9 °C when jogging. While as the skin temperatures associated with comfort at sedentary activities are 33–34 °C and decrease with increasing activity (Fanger 1967). The metabolic heat production can be of two kinds: *basal* metabolism, due to biological processes (assimilation and utilization of food) which are continuous and non-conscious and *muscular* metabolism, whilst carrying out work, which is consciously controllable (except in shivering). The heat is dissipated to the environment by conduction, convection, radiation or evaporation, Fig. 2.3.

The human body interacts with its thermal environment through sensible heat loss or gain by conduction, convection, radiation and through latent heat loss by evaporation. Thermal comfort is achieved when there is a balance between metabolic heat production and heat dissipation. The heat balance of human body; i.e. thermal interaction with its environment can be expressed as Eq. 2.10.

Fig. 2.3 Heat balance of the human body; thermal interaction with its environment



$$M - W \pm R \pm C \pm K - E = S \tag{2.10}$$

where M = rate of metabolic heat production W/m^2 , W = rate of mechanical work accomplished W/m^2 , S = any surplus or deficit heat stored W/m^2 , C = sensible heat flow (loss or gain) by convection (including respiration) W/m^2 , R = sensible heat flow (loss or gain) by radiation W/m^2 , K = sensible heat flow (loss or gain) by conduction W/m^2 , E = latent heat loss by evaporation (including respiration) W/m^2 .

Thermal balance or comfort exists when external heat gains and heat produced by the body are fully dissipated to the environment and a condition of equilibrium prevails i.e. S is zero.

2.4.2 Parameters of Thermal Comfort

It is well established empirically that air temperature, relative humidity, radiant temperature and air speed all affect human thermal comfort. Several non-environmental factors like level of activity, clothing, acclimatisation etc. are also important for the determination of an optimum thermal environment. The parameters of thermal comfort are classified into three categories: personal, environmental and other, Table 2.4.

Table 2.4 Parameters of thermal comfort

Personal	Environmental	Other
Metabolic rate (level of activity)	Air temperature	Food and drink, living habits
Clothing insulation	Humidity	Body shape
State of health	Air speed	Subcutaneous fat
Acclimatisation	Radiant temperature	Age and gender

Metabolic activity is defined in terms of the rate of heat produced, expressed in W/m^2 of body surface. A unit used to express the metabolic rate per unit Du Bois area is the *met*, defined as the metabolic rate of a sedentary person (seated quite), 1 met = $58.2 W/m^2$ (ASHRAE 2009). This is based on the average male with a skin surface area of about $1.8 m^2$. Thus, the heat output of an average body is about $104.76 W$. Metabolic rate varies over a wide range, depending on activity, person, and conditions under which the activity is performed. With higher levels of met, cooler environment will be preferred, to accelerate the heat dissipation.

Du Bois and Du Bois (1916) proposed the body surface area can be given as:
 $BSA = 0.202 * weight^{0.425} * height^{0.725}$, where weight is in kg and height is in m.

Clothing is one of the dominant factors affecting heat dissipation. For the purpose of thermal comfort studies a unit has been advised, named the *clo*. A value of 1.0 *clo* corresponds to an insulating cover over the whole body of a transmittance (*U*-value) of $6.45 W/m^2K$ (i.e. a resistance of $0.155 m^2K/W$). The insulating value of a normal business suit, with cotton underwear is 1.0 *clo*. The clothing may range from 0 to more than 3.5 *clo*. Clothing is an important adjustment mechanism if chosen freely, but if it is restricted in a warm environment, cooler environment will be preferred.

Acclimatization and state of health have strong influence, both physiologically and psychologically.

The environmental factors vary independently of each other, but the sensation of comfort or discomfort depends on the simultaneous effect of all these. Thermal environmental parameters that must be measured or otherwise quantified to obtain accurate estimates of human thermal response are divided into two groups: those that can be measured directly, e.g. (a) air temperature, (b) humidity (c) air speed and those calculated from other measurements, e.g. Mean Radiant Temperature.

Air temperature is the most significant environmental parameter of thermal comfort; it determines convective heat dissipation, together with air movement. Humidity determines heat dissipation by evaporation. At high humidity, too much skin moisture tends to increase discomfort as evaporation is prevented from the skin and in respiration, thus curb the heat dissipation mechanism. Low humidity can dry the skin and mucous surfaces (mouth, throat), thus cause discomfort. Air movement across the skin accomplishes heat dissipation by convective heat transfer (removing warm air close to the skin) as well as increases evaporation from the skin, thus produces a physiological cooling effect. In the presence of air movement the surface resistance of the body (or clothing) is reduced.

Precise relationships between increased air speed and improved comfort have not been established. Under hot conditions 1 m/s is pleasant and indoor air velocities up to 1.5 m/s are acceptable. Above this, light objects may be blown about, thus indirect nuisance effects may be created. Under cold conditions, in a heated room 0.25 m/s velocity should not be exceeded, but even in a heated room stagnant air (velocities <0.1 m/s) would be judged as “stuffy”. A draft is an undesirable local cooling of the human body by air movement, and it is a serious comfort problem.

An additional effect is that with no air movement practically a saturated air layer is formed at the body surface, which prevents (reduces) further evaporation. Air movement would remove this saturated air envelope. The skin is surrounded by a thin, still air layer which is close to skin temperature and insulates the body from its surroundings. Air movement decreases the thickness of this insulating layer and thus gives a cooling effect provided that the vapour pressure of air is lower than the skin vapour pressure, even if the dry bulb temperature is higher than the skin temperature within a certain limit. Increased air movement reduces the amount moisture laden air close to the skin thereby increasing evaporation. The effect of air movement is, therefore, two-fold: the convection heat loss coefficient of the body (or clothing-) surface (h_c) is a function of air velocity and evaporation from the skin, thus the evaporation heat loss coefficient (h_e) is also increased by moving air.

Radiation exchange depends on the mean radiant temperature (T_{mrt}), the average temperature of the surroundings surfaces, each weighted by the solid angle it subtends at the measurement point. If the temperature of the surrounding surfaces is lower than skin temperature then the body will radiate heat. Surroundings which are hotter than skin temperature will radiate heat causing skin temperature to increase, (Vernon 1932). This effect is accentuated when lighter clothing is worn, (for example in summer). Radiation exchange with the surroundings can have a significant effect on human comfort. Measurements of globe temperature (T_g), air temperature (T_a) and air velocity (v) can be combined to estimate the mean radiant temperature. The globe thermometer is a mat black copper sphere, usually of 150 mm diameter, with a thermometer located at its centre. Positioned in a room, after equilibrium is reached (in 10–15 min) the globe will respond to the net radiation to or from the surrounding surfaces. If radiation is received, then $T_g > T_a$; $T_g < T_a$ indicates that the surrounding surfaces are cooler than the air, radiation is emitted. In still air $T_{mrt} = T_g$, but a correction for air movement of v velocity (in m/s) is possible:

$$T_{mrt} = T_g \times (1 + 2.35\sqrt{v}) - 2.35 \times T_a\sqrt{v} \quad (2.11)$$

In warm climates (with light clothing) the mean radiant temperature is twice as important as dry bulb temperature, which is accounted in environmental temperature (CIBSE 1999):

$$T_{\text{env}} = \frac{2}{3}T_{\text{mrt}} + \frac{1}{3}T_{\text{ai}} \quad (2.12)$$

However, in cooler climates (with heavier clothing) the mean radiant temperature has the same influence as the dry bulb temperature, which is expressed as the dry resultant temperature (T_{drt}) :

$$T_{\text{drt}} = 0.5 \times T_{\text{ai}} + 0.5T_{\text{mrt}} \quad (2.13)$$

In addition to independent personal and environmental parameters influencing thermal comfort, other factors may also have some effect. Food and drink consumed may have an influence on metabolism, thus have an effect on heat production and dissipation. Body shape is significant in that heat production is proportional to body mass, but heat dissipation depends on body surface area. Age and gender may have modicum influence in preferred temperature.

2.4.3 Thermo-Regulation

The human thermo-regulatory system attempts to maintain a constant deep body temperature of 36.8 °C. The *hypothalamus*, located in the brain, controls various physiological processes to regulate body temperature. Its control behavior is primarily proportional to deviations from deep-body temperatures with some integral and derivative response aspects. The most important and often-used physiological process is regulating blood flow to the skin: *vasodilation* (in extreme heat when internal temperatures rise above a set point), more blood is directed to the skin, to transport internal heat to elevate the skin temperature and increase heat dissipation to the environment. *Vasoconstriction* (in extreme cold when body temperatures fall below the deep-body temperature), skin blood flow is reduced to conserve heat. The effect of maximum vasoconstriction is equivalent to the insulating effect of a heavy sweater.

At temperatures less than the set point, muscle tension increases to generate additional heat; where muscle groups are opposed, this may increase to visible shivering, which can increase resting heat production to 4.5 met. At elevated internal temperatures, sweating occurs. This defence mechanism is a powerful way to cool the skin and increase heat loss from the core.

Insufficient heat loss leads to overheating (hyperthermia), and excessive heat loss results in body cooling (hypothermia).

2.4.4 Thermal Neutrality

Adaptive models predict the almost constant conditions under which people are likely to be comfortable in buildings. In general, people naturally adapt and may also make various adjustments to themselves and their surroundings to reduce discomfort and physiological strain. Auliciems (1981 and 1982) proposed psycho-physiological model of thermal perception, which is the basis of the adaptive models. It has been empirically established that, through adaptive actions, an acceptable degree of comfort in residences and offices is possible over a range of air temperatures from about 17 to 31 °C (Humphreys and Nicol 1998). An ASHRAE sponsored study (de Dear et al. 1997) compiled an extensive database from past field studies to study, develop, and test adaptive models (ASHRAE 2009).

Adaptive adjustments are typically conscious actions such as altering dress codes, posture, flexible activity schedules or levels, rate of working, diet, ventilation, air movement, and local temperature. They may also include unconscious long-term changes to physiological set points and gains for control of shivering, skin blood flow, and sweating, as well as adjustments to body fluid levels and salt loss after a few days of exposure up to about six months. In a hot climate this may consist of increased blood volume, which improves the effectiveness of vasodilation, enhanced performance of the sweat mechanism, as well as the readjustment of set point. In cold climate the vasoconstriction may become permanent, with reduced blood volume, whilst the body metabolic rate may increase (Szokolay 2008). The adjustment of seasonal preferences can be quite significant, even over a period of a month.

The term ‘thermal neutrality’ refers to a specific value of the indoor thermal environmental index (e.g. operative temperature) corresponding to a mean thermal sensation vote of zero on the seven-point scale (i.e. *neutral*). Values of thermal neutrality were calculated by using an empirical correlation function developed by de Dear and Brager (2002) as an improved version of the function earlier proposed by Auliciems (1981) and Humphreys (1978). Thermal neutrality (T_c) is expressed as a function of mean monthly temperature (\bar{T}_o):

$$T_c = 17.8 + 0.31 \times \bar{T}_o \quad (2.14)$$

with the limitation that $17 \text{ °C} < T_c < 31 \text{ °C}$ (Humphreys and Nicol 1998).

If mean monthly outdoor temperature is less than 10 °C or greater than 33.5 °C, this option may not be used (ASHRAE 2010).

2.5 Environmental Indices and Comfort Zone

The comfort zone is defined in terms of a range of thermally acceptable conditions within which the average person would feel comfortable. The environmental conditions required for comfort are not the same for everyone. However, extensive laboratory and field data have been collected that provide the necessary statistical data to define conditions that a specified percentage of occupants will find thermally comfortable. The comfort parameters are derived usually to satisfy about 80–90% people in a space.

As thermal comfort is influenced by four environmental parameters, attempts have been made to create a single index. An environmental index combines two or more parameters (e.g. air temperature, mean radiant temperature, humidity, air velocity) into a single variable to express the thermal response. Indices simplify description of the thermal environment and the stress it imposes. Since the early 1900s large number of thermal indices has been developed in various countries throughout the world. Environmental indices may be classified according to how they are developed. Empirical indices are based on field measurements with subject under defined environmental conditions or simplified relationships that do not necessarily follow theory. Rational or analytical indices are based on the theoretical concepts of the thermal exchanges with the environment i.e. heat flow paths from metabolic heat production to the environment and resistances to such flows.

The earliest empirical index, Effective Temperature, was developed at ASHVE Pittsburgh research laboratories (Houghten and Yaglaglou 1923a, b). It is defined as the temperature of a still, saturated atmosphere, which would, in the absence of radiation, produce the same effect as the atmosphere in question. It is represented by a set of equal *comfort lines* drawn on the psychrometric chart. There are about 30 different such indices developed over the years by various research workers, all based on different studies, all with different derivations and names (Auliciems and Szokolay 2007).

Effective Temperature (ET*) is an analytical index and it has the widest range of application in practice. It is defined as the temperature (DBT) of a uniform enclosure at 50% relative humidity, which would produce the same net heat exchange by radiation, convection and evaporation as the environment in question. It combines temperature and humidity into one single index, so two environments with the same ET* should evoke the same thermal response even though they have different temperatures and humidities, as long as they have the same air velocities. Because ET* depends on clothing and activity, it is not possible to generate a universal ET* chart.

A standard set of conditions representative of typical indoor applications is used to define a standard effective temperature SET*, defined as the equivalent air temperature of an isothermal environment at 50% relative humidity in which a subject, wearing clothing standardized for the activity concerned, has the same heat stress and thermoregulatory strain as in the actual environment. It is interpreted as a sub-set of ET* under standardized conditions: clothing standardised for given

activities. At sea level, under the above standard environmental conditions $SET = ET^*$. The SET thus defined combines the effect of temperature and humidity, the two most important determinants. The slope of the SET lines indicates that at higher humidities the temperature tolerance is reduced, whilst at lower humidities higher temperatures are acceptable.

ASHRAE used the psychrometric chart for the definition of the comfort zone since 1966. Current and past studies periodically reviewed to update ASHRAE Handbook of Fundamentals, which specifies conditions or comfort zones where 80% of sedentary or slightly active persons find the environment thermally acceptable. The 1966 version gave the temperature limits by DBT (vertical) lines and the humidity limits by two RH curves. In 1974 the side boundaries changed to ET^* lines and the humidity boundaries were defined in terms of vapour pressure (or the corresponding AH or RH (horizontal) lines).

The ASHRAE Handbook of Fundamentals (2009) specifies summer and winter comfort zones, Fig. 2.4, appropriate for clothing insulation levels of 0.5 [$0.078 \text{ m}^2 \text{ K/W}$] and 1 clo [$0.155 \text{ m}^2 \text{ K/W}$] respectively. It is assumed that a winter business suit has about 1 clo of insulation, and a short-sleeved shirt and trousers has about 0.5 clo. This is justified by needing an “objective” reason, rather than a nebulous notion of ‘acclimatisation’. The warmer and cooler temperature borders of the comfort zones are affected by humidity and coincide with the lines of constant ET^* . In the middle of a zone, typical person wearing the prescribed clothing would have a thermal sensation at or very near neutral. Near the boundary of the warmer zone, a person would feel about +0.5 warmer on the ASHRAE thermal sensation scale; near the boundary of the cooler zone, that person may have a thermal sensation of -0.5. In general, comfort temperature for other clothing levels can be approximated

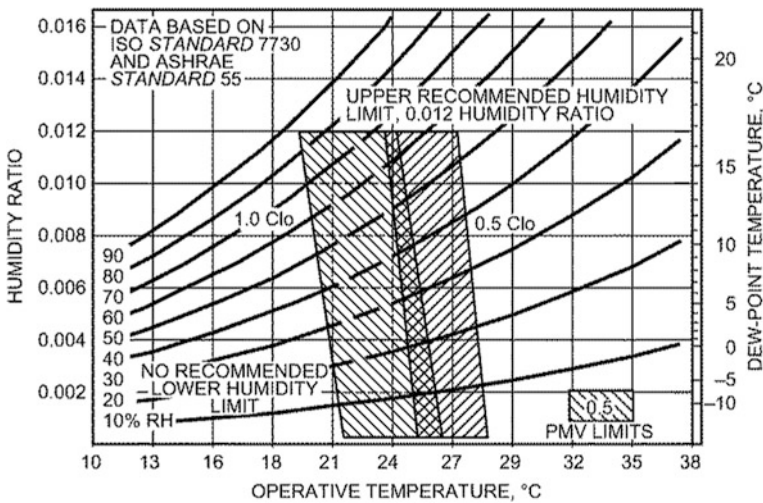


Fig. 2.4 ASHRAE summer and winter comfort zones. © ASHRAE, www.ashrae.org, (2009) ASHRAE Handbook of Fundamentals

by decreasing the temperature border of the zone by 0.6 K for each 0.1 clo increase in clothing insulation and vice versa. Similarly, a zone's temperatures can be decreased by 1.4 K per met increase in activity above 1.2 met.

ASHRAE (2009) specifies the upper humidity ratio limit of 0.012 kg_w/kg_{dry air} because it restricts the evaporation and thus the cooling effect. There is no lower limit specified, but the accepted lower humidity limit is 4 g/kg for non-thermal comfort factors such as skin drying, irritation of mucus membranes, dryness of the eyes, and static electricity generation (Liviana et al. 1988).

The comfort zone can be plotted on this chart that will vary with the climate and be different for each month. The procedure may be as follows:

The thermal neutrality temperature (T_c) as Eq. (2.14): $T_c = 17.8 + 0.31 \times T_o$ is used as a threshold to articulate comfort zone for both the summer and the winter month. The temperature limits of such a comfort zone is taken as $(T_c - 2.5)^\circ\text{C}$ to $(T_c + 2.5)^\circ\text{C}$ for 90% acceptability. The SET coincides with DBT at the 50% RH curve; these points are marked on the 50% RH curve. These will define the 'side' boundaries of the comfort zone as the corresponding SET lines. The humidity limits (top and bottom) will be 12 and 4 g/kg respectively (1.9 and 0.6 kPa vapour pressure).

Up to 14 °C the SET lines coincide with the DBT. Above that the slope of these isotherm lines is progressively increasing, with the slope coefficient taken as $\text{DBT}/\text{AH} \times 0.023 \times (\text{DBT} - 14)$ which gives the deviation from the corresponding vertical DBT line for each g/kg AH, positive below the 50% and negative above it (Szokolay 2008).

Figures 2.5 and 2.6 shows the summer and winter comfort zones for Mumbai and Jaipur respectively. It is noteworthy that Mumbai has very little seasonal variation (a warm-humid climate), while as in Jaipur (a composite climate) there is a large difference between winter and summer.

2.6 Cooling and Heating Degree-Days

Degree-days (DD or Kd, Kelvin-days) is relatively simple forms of climatic data, useful as an index of climatic severity as it affects energy use for space cooling or heating. Degree-days are calculated as the difference between the prevailing external, dry bulb temperature and a 'base temperature'. Traditionally used base temperatures to calculate HDD and CDD are 18.3 °C in the United States (ASHRAE 2009). This is the external temperature at which, in theory, no artificial cooling (or heating) is required to maintain an acceptable internal temperature. If the mean temperature of a day is \bar{T}_o , then for day we have $T_b - \bar{T}_o$ degree days. (When $\bar{T}_o = T_b$) the degree-day number is zero). This number can then be summed for any given period, e.g. a month or a year. The number multiplied by 24 gives the degree-hours number. Degree-days are used in energy estimating methods.

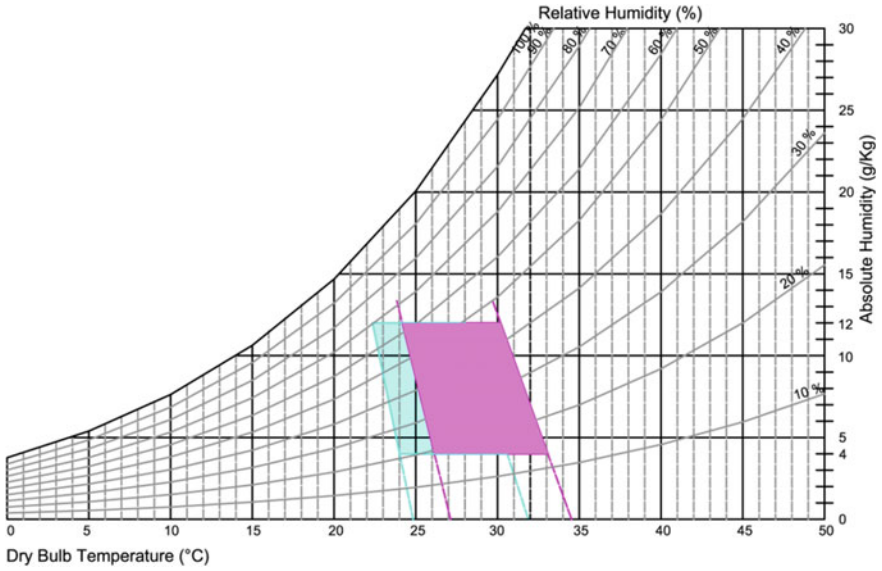


Fig. 2.5 Summer (*magenta, dark*) and winter (*cyan, light*) comfort zones for Mumbai

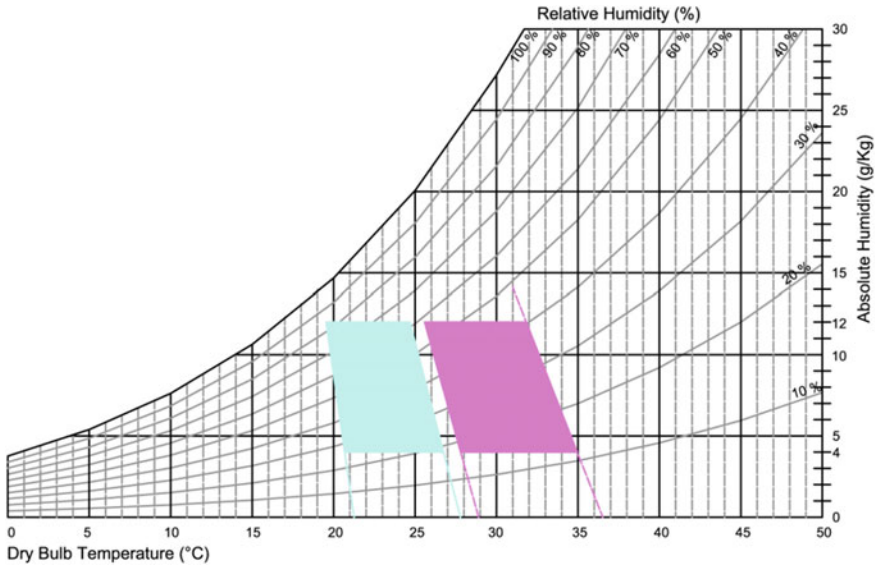


Fig. 2.6 Summer (*magenta, dark*) and winter (*cyan, light*) comfort zones for Jaipur

Two types of degree-days are used in building design. The cooling degree-days (K-day) or cooling degree-hours (K-h), indicate the warmth of the summer and hence cooling requirements. The heating degree-days (K day) indicate the severity of the winter season and therefore heating energy requirements.

Cooling and heating degree-days (base 18.0 °C) are calculated as the sum of the differences between daily average temperatures and the base temperature. The number of cooling degree-days (CDD) is defined as “cumulative temperature excess” above an agreed reference level or base temperature. For example the number of cooling degree-days (CDD) in the month is calculated as

$$\text{CDD} = \sum_{i=1}^N (\bar{T}_o - T_b)^+ \quad (2.15)$$

The concept of heating degree days is rather similar to the cooling degree-days, but here the definition would be: “cumulative temperature deficit” below an agreed reference level or base temperature (T_b).

The number of monthly heating degree-days (HDD) are calculated as:

$$\text{HDD} = \sum_{i=1}^N (T_b - \bar{T}_o)^+ \quad (2.16)$$

where N is the number of days in the month, T_b is the reference temperature to which the degree-days are calculated, and T_o is the mean daily temperature calculated by adding the maximum and minimum temperatures for the day, then dividing by 2. The + superscript indicates that only positive values of the bracketed quantity are taken into account in the sum.

The main source of cooling and heating degree-days (base 18.0 °C) data is the ISHRAE (2014).

2.7 Solar Geometry

The earth is almost spherical in shape, some 6371 km in radius and it revolves around the sun in a slightly elliptical (almost circular) orbit. The earth–sun distance is approximately 150×10^6 km, varying between:

152.10 $\times 10^6$ km (at *aphelion*, on July 1) and

147.09 $\times 10^6$ km (at *perihelion*, on January 1)

The full revolution takes 365.24 days (365 days 5 h 48' 46" to be precise) and as the calendar year is 365 days, an adjustment is necessary: one extra day every four years (the ‘leap year’). This would mean 0.25 days per year, which is too much. The excess 0.01 day a year is compensated by a one day adjustment per century.

The plane of the earth's revolution is referred to as the *ecliptic*. The earth's axis is not normal to the plane of its orbit, but tilted by 23.45° . Consequently the angle between the earth's equatorial plane and the earth–sun line (or the ecliptic, the plane of the earth's orbit) varies during the year (Fig. 2.7). This angle is known as the declination (DEC) and varies as

- $+23.45^\circ$ on June 22 (northern solstice)
- 0° on March 21 and September 22 (equinox dates)
- -23.45° on December 22 (southern solstice).

Geographic latitude (LAT) of a point on the earth's surface is the angle subtended between the plane of the equator and the line connecting the centre with the surface point considered. The latitude of the equator is $\text{LAT} = 0^\circ$, the north pole is $+90^\circ$ and the south pole -90° . The convention is to use negative sign for southern hemisphere latitudes. The extreme latitudes where the sun reaches the zenith at mid-summer are the 'tropics' (Fig. 2.8)

$\text{LAT} = +23.45$ is the tropic of Cancer and

$\text{LAT} = -23.45$ is the tropic of Capricorn.

The *heliocentric* view as given above is necessary for explaining the sun and earth relationship, but the *lococentric* view is essential to solve building design problems. In this view the observer's location is at the centre of the sky hemisphere, on which the sun's position can be determined by two angles (Fig. 2.9):

solar altitude (ALT): measured upwards from the horizon, 90° being the zenith

solar azimuth (AZM): measured in the horizontal plane from north (0°), through east (90°), south (180°) and west (270°) to north (360°)

Sun-path diagrams or solar charts are the simplest practical tools for depicting the sun's apparent movement. The sky hemisphere is represented by a circle (the horizon). Solar azimuth angles (i.e. the direction of the sun) are given along the perimeter and solar altitude angles (from the horizon up) are shown by a series of concentric circles, 90° (the zenith) being the centre. Several methods are in use for the construction of these charts: orthographic, equidistant, wall diagram, stereographic. The stereographic projection (developed by Phillips 1948) is widely used.

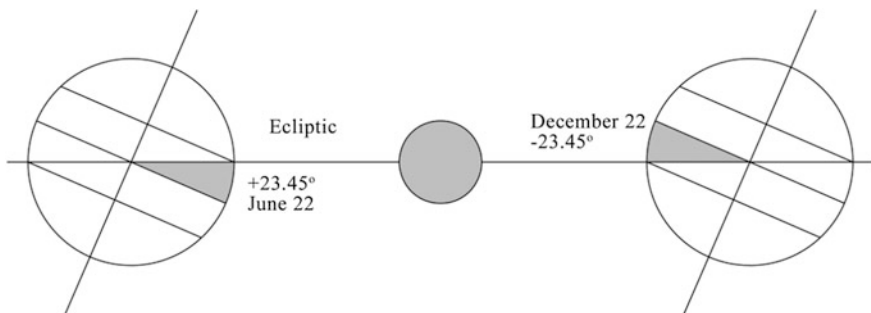


Fig. 2.7 Elevation section of the earth's orbit and solar declination (DEC)

Fig. 2.8 Definitions of tropics

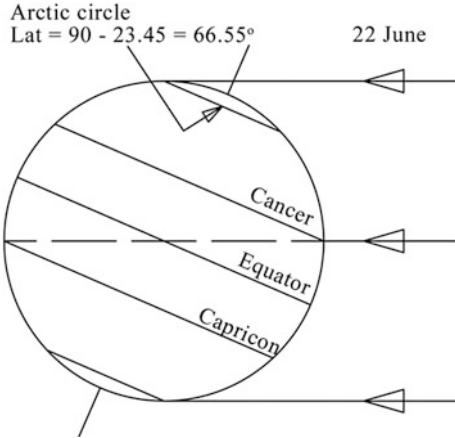
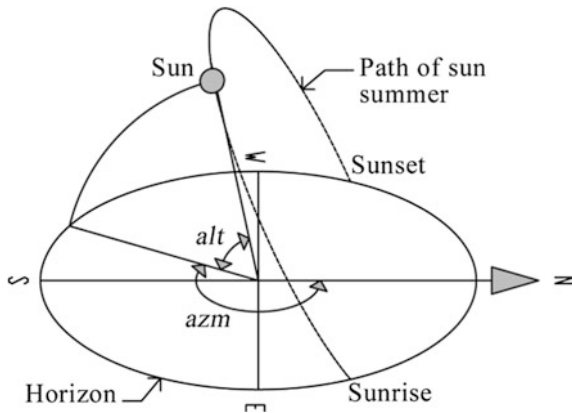


Fig. 2.9 Altitude and azimuth angles



These are constructed by a radial projection method (Fig. 2.10), in which the centre of projection is vertically below the observer's point, at a distance equal to the radius of the horizon circle (the nadir point). The sun-path lines are plotted on this chart for given latitude for the solstice days, for the equinoxes and for any intermediate dates. The date-lines (sun-path lines) are intersected by hour lines. The vertical line at the centre is noon. The solar time (local apparent time) is used on solar charts, which coincides with clock time only at the reference longitude of each time zone.

The local apparent time can be obtained from the standard time observed on a clock by applying two corrections. The first correction arises because of difference between the longitude of a location and the meridian on which the standard time is based. The correction has a magnitude of 4 min for every degree difference in longitude. The second correction called the equation of time correction is due to the

Fig. 2.10 Stereographic projection method for sun-path diagram

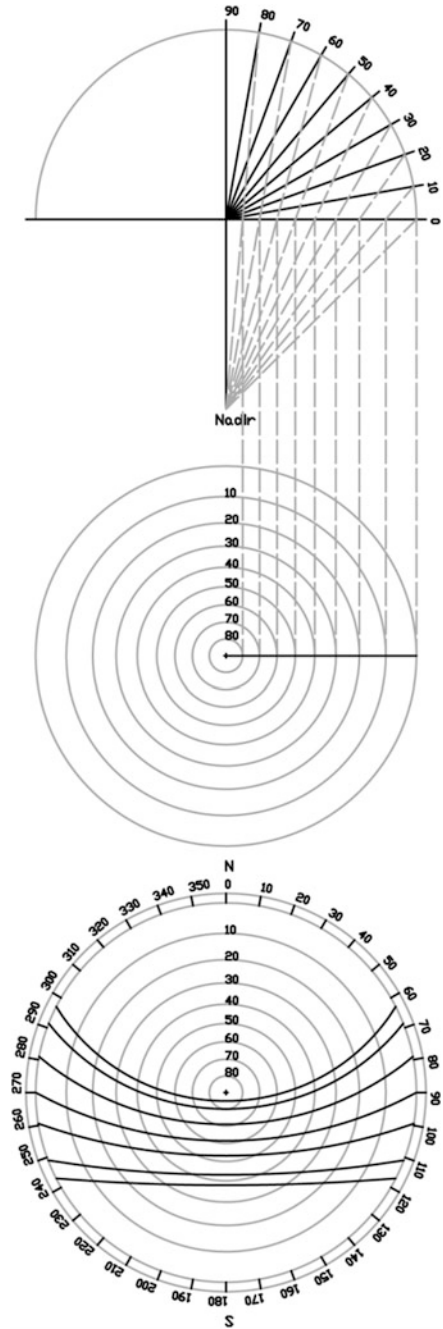


Table 2.5 Equation of time correction

Day	1–5	6–10	11–15	16–20	21–25	26–30	31
Jan	–3'14"	–5'33"	–7'41"	–9'34"	–11'10"	–12'28"	–13'26"
Feb	–13'35"	–14'09"	–14'22"	–14'16"	–13'51"	–13'11"	
Mar	–12'39"	–11'37"	–10'24"	–9'02"	–7'34"	–6'03"	–4'32"
Apr	–4'14"	–2'45"	–1'21"	–0'03"	+1'06"	+2'04"	
May	+2'50"	+3'22"	+3'41"	+3'46"	+3'37"	+3'14"	+2'38"
Jun	+2'29"	+1'41"	+0'45"	–0'17"	–1'21"	–2'26"	
Jul	–3'28"	–4'24"	+5'11"	–5'47"	–6'11"	–6'22"	–6'18"
Aug	–6'15"	–5'53"	–5'15"	–4'23"	–3'18"	–2'01"	–0'35"
Sep	–0'17"	+1'20"	+3'03"	+4'49"	+6'35"	+8'19"	
Oct	+9'59"	+11'33"	+12'58"	+14'11"	+15'10"	+15'52"	+16'16"
Nov	+16'19"	+16'20"	+16'01"	+15'21"	+14'19"	+12'56"	
Dec	+11'16"	+9'19"	+7'08"	+4'47"	+2'20"	–0'10"	–2'38"

Source Smithsonian meteorological tables (List 2000, pp. 445–446)

fact that the earth's orbit and rate of rotation are subject to small perturbations, Table 2.5. Thus,

$$\begin{aligned} \text{Local apparent time} = & \text{Standard time} \pm 4 (\text{standard time longitude} \\ & - \text{longitude of location}) + \text{Equation of time correction} \end{aligned} \quad (2.17)$$

The negative sign in the first correction is applicable for the eastern hemisphere, while the positive sign is applicable for the western hemisphere.

For example to find LAT for Jodhpur (Long. 73°01'E) at 1330 h IST on 11th June

The Indian standard time (IST) is the mean solar time for longitude 82.5°

Difference in longitude between Jodhpur and standard meridian (S.M.)
 $82^{\circ}30' - 73^{\circ}01' = 9^{\circ}29'$

Correction for obtaining LMT at Jodhpur = $9^{\circ}29' \times 4 \text{ min} = 37.9 \text{ min}$

Since Jodhpur is to the west of SM = $-37.9 \text{ min} = -37 \text{ min } 54 \text{ s}$

Local Mean Time (LMT) = $1330 - 37 \text{ min } 54 \text{ s} = 12 \text{ h } 52 \text{ min } 6 \text{ s}$

Equation of Time on 11th June as read from the table = $0 \text{ m } 45 \text{ s}$

LAT $12 \text{ h } 52 \text{ min } 6 \text{ s} + 0 \text{ min } 45 \text{ s} = 12 \text{ h } 52 \text{ min } 51 \text{ s} \sim 12.88 \text{ h}$

The path of the sun across the sky on any day is a circle on the stereographic projection whose radius (R_s) and position of its centre (D_s) depend on the latitude of the place for which the diagram is drawn and the declination of the day. These and the radius and the distance of hour circles (R_h and D_h^1, D_h^2) can be computed from the equations given below (Lim et al. 1979):

$$R_s = \frac{R \times \cos \text{DEC}}{\sin \text{LAT} + \sin \text{DEC}} \quad (2.18)$$

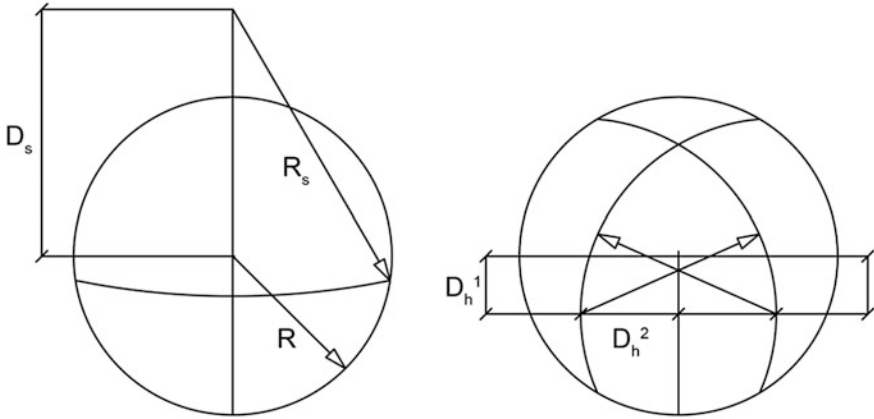


Fig. 2.11 Drawing of stereographic sun-path diagram

$$D_s = \frac{R \times \cos \text{LAT}}{\sin \text{LAT} + \sin \text{DEC}} \quad (2.19)$$

$$R_h = \frac{R}{\cos \text{LAT} \times \sin \omega} \quad (2.20)$$

$$D_h^1 = R \times \tan \text{LAT} \quad (2.21)$$

$$D_h^2 = \pm \frac{R}{\cos \text{LAT} \times \tan \omega} \quad (2.22)$$

where DEC = declination, LAT = latitude, ω = hour angle (noon = 0), R = Radius of the stereographic projection of the horizon circle. Fig. 2.11 illustrates drawing of stereographic sun-path diagram.

Chapter 5 presents sun-path diagrams of 62 cities in India drawn using the software Winshade (Kabre 1999).

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Chapter 3

Design Strategies

Victor Olgyay (1963) stated, “We do not expect to solve the problems of uncomfortable conditions by natural means only. The environmental elements aiding us have their limits. But it is expected that the architect should build the shelter in such a way as to bring out the best of the natural possibilities.”

3.1 Introduction

The process of sustainable design evolves through the different stages of design to bring out the best of climatic possibilities. The briefing stage entails the designer to look for general qualitative information of climate of a given location so that the climate can be perhaps be fitted into one of the climate types which would immediately conjure up certain typical solutions based on the well-known design recommendations. For this summary, climatic data is needed, preferably in a standardized graphic format which is easy to read at a glimpse and is easily comparable with others the designer already know.

The pre-conceptual stage analysis of climate using simple methods such as climate analysis tables given by Carl Mahoney. The designer could use this as one of the formative influences in the design.

The next step is to develop a design hypothesis. The given climate is related to human comfort requirements to diagnose the nature of the climatic problem and recommend the passive design strategies. It can be accomplished with the use of the bioclimatic chart or psychrometric chart as the base. The climatic data needed for this purpose is average data for twelve months.

When the designer has a preliminary design, the success of a design can be compared with a standard or with other design. A good measure is the cooling or heating energy requirements, calculated by a steady-state method using the average data one day in winter and one day in summer. If energy is excessive, the design can be modified and tested again, and the process is repeated till an energy efficient design is obtained.

At the detailed design stage, a consulting engineer is called to design the air conditioning or heating system using dynamic method and predict the load, probably using energy modelling software such as ESPr, DOE-2. The climatic data required for such programmes is often quite detailed, e.g. hourly values of temperature, humidity, radiation and wind for the whole year.

The solar control design is one of the important steps at the detailed design stage. The method of doing this is articulating the overheated period and finding the shadow angles for the openings according to orientation.

This chapter presents design strategies and application of climatic data and sun-path diagrams given in Chap. 5 for sustainable design.

3.2 Qualitative Assessment of Climate

An initial qualitative assessment of climate can be obtained from the climatic data tables and climate graphs in Chap. 5. The pattern of this graph should give an indication of the nature of the climate. This pattern of the graph can be compared with

- (a) graphs of the four basic climate types shown in Fig. 3.1;
- (b) a graph of a known location.

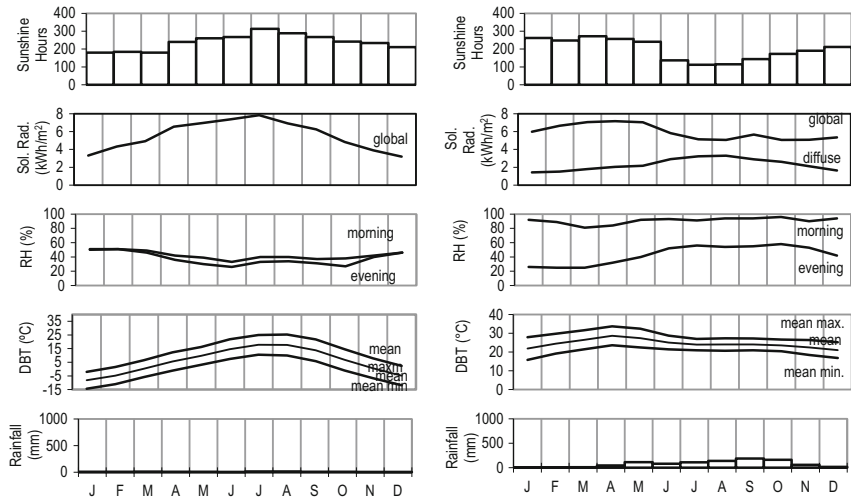
In each case, the similarities or dissimilarities can be noted.

If, according to (a) above, the graph is similar to one of the basic types, this may connote the type of design solution, along the lines of Fig. 3.2. If ventilation is important as a relief from overheating, the wind roses indicate prevalent wind direction given in Chap. 5. Conversely, winter wind exclusion can be designed based on the wind direction.

If the climate does not fit neatly into any of the four basic categories, some of the single figure indices (all near the right-hand side of the climate data tables in Chap. 5) may assist in an initial appreciation:

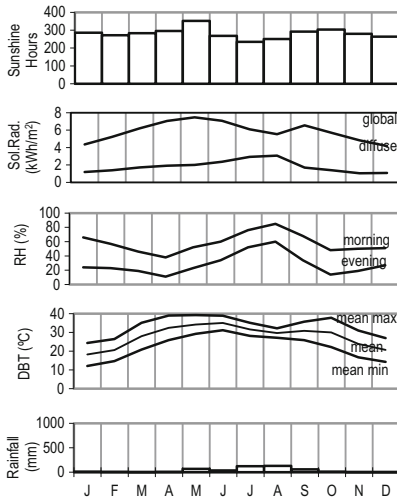
1. The annual mean temperature (AMT) gives a broad indication of the thermal problem;
2. the ‘annual mean range’ of temperatures indicates the seasonal variability;
3. the ‘average diurnal range’ indicates the extent of night-to-day variations. If this is less than about 8 K, mass will not be desirable, but the greater this value, the more beneficial a massive construction will be;
4. the annual averages of humidity show whether humidity is a problem;

In the next step, an examination of some the monthly values of the above variables will reveal the seasonal characteristics of the climate.

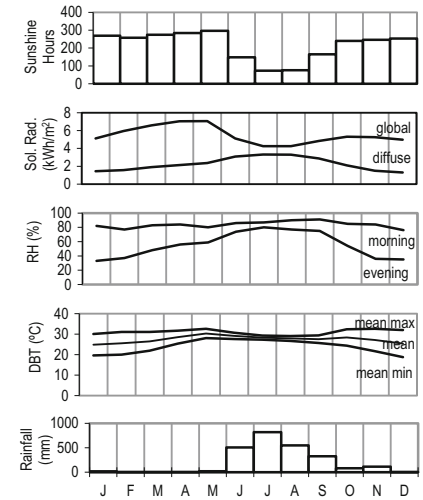


Cold: Leh N 34° 09' E 77° 40'

Temperate: Bengaluru N 12° 58' E 77° 34'



Hot and dry: Jodhpur N 26° 17' E 73° 1'



Warm and humid: Mumbai N 19° 7' E 72° 50'

Fig. 3.1 Four primary climate types

3.3 Pre-conceptual Analysis

The climate analysis tables devised by Carl Mahoney (Koenigsberger 1973) primarily for composite climate can be used for any climate.

1. Enter the monthly maximum (am) and minimum (pm) of relative humidity from data sheets in the first two lines in Table 3.1.

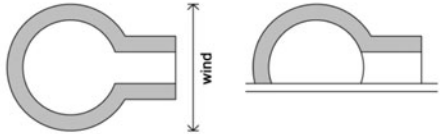
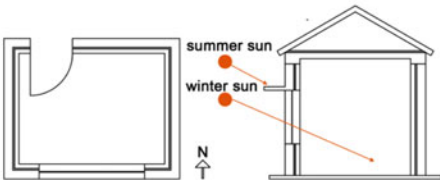
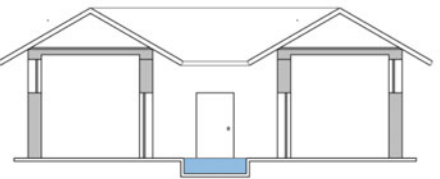
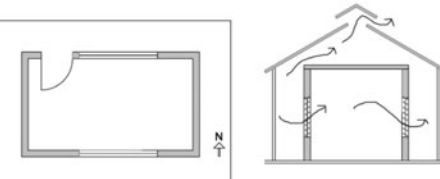
Climate type	Protection against	Control required	Typical characteristics
Cold	Wind, Cold Snow drift Snow load	Prevent heat loss	<p>Ideal shape the Eskimo igloo; minimum surface for largest volume, few openings at right angles to wind direction</p> 
Temperate	Rain, snow Cold winds Summer heat Winter cold	Prevent heat loss, winter insolation, summer shading and ventilation	<p>Good insulation, large windows facing winter sun, overhangs to exclude summer sun</p> 
Hot-dry	Insolation Sand, dust Wind Dryness	Utilise small amount of rain, level out large diurnal temperature variations	<p>Courtyard type, shaded verandah facing courtyard, often with pool or fountain, heavy walls with large time-lag, small openings</p> 
Warm-humid	Rain Heat Humidity Insolation	Ventilation Cooling Shading	<p>Shaded verandah type, length E-W, N and S walls: louvers for cross-vent, high rooms, ventilated roof space</p> 

Fig. 3.2 Design guidelines for the four primary climate types

Table 3.1 Climate analysis

Location	Latitude				Longitude					Altitude			
Months	J	F	M	A	M	J	J	A	S	O	N	D	
1 Relative humidity (%)													
am													
pm													
Average													
Humidity category													
2 Temperature (*C)													
Max													
Min													
Monthly mean range (K)													
Day comfort													
Upper													AMT
Lower													
Night comfort													
Upper													
Lower													
3 Thermal stress day													
Thermal stress night													
4 Rainfall >200 mm													
5 Diagnosis													Sum
I-1													
I-2													
I-3													
I-4													
I-5													
I-6													
If Avg. Relative humidity		<30%		30–50		50–70		>70%					
Humidity category		1		2		3		4					
Comfort limits	AMT >20				AMT 15–20				AMT <15				
	Day		Night		Day		Night		Day		Night		
Humidity category													
1	26–34		17–25		23–32		14–23		21–30		12–21		
2	25–31		17–24		22–30		14–22		20–27		12–20		
3	23–29		17–23		21–28		14–21		19–26		12–19		
4	22–27		17–21		20–25		14–20		18–24		12–18		
Indicators	Thermal stress			Rain		Humidity category			Mean range				
	Day		Night										
I-1	H						4						
I-1	H						2, 3						
I-2	O						4		<10 K				
I-3					>200								
I-4							1, 2, 3		>10 K				
I-5			H				1, 2						
I-5	H		O				1, 2		>10 K				
I-6	C												

Source Adapted from Koenigsberger et al. (1973) with permission from Mahoney (2016)

- Find the ‘average relative humidity’ for each month by adding above two values and dividing it by two. Enter these values in the third line;
- Establish ‘humidity category’ (1–4) for each month as specified.

Average relative humidity:

below 30% = category 1
 30–50% = category 2
 50–70% = category 3
 Above 70% = category 4

Enter these in the fourth line.

2. Enter the monthly maximum and minimum of temperature from data sheets in the fifth and sixth lines. All values should be rounded to the nearest 0.5 °C;
 - In the last box on the right side, enter the highest of the twelve maxima and the lowest of the twelve minima, respectively;
 - Find the annual mean temperature by adding these two values and dividing it by two and enter the value in the box marked AMT;
 - Find monthly mean range: the difference between the previously entered mean max. and mean min. and enter into Table 3.1 in seventh line;
 - Find the upper and lower comfort limits for day and night of each month, on the basis of key chart shown at the bottom of Table 3.1, as defined by the ‘annual mean temperature’ and the ‘humidity category’ for each month. Enter these values in the eighth, ninth, tenth and eleventh lines, respectively.
3. Compare the day comfort limits with the monthly mean maximum temperature and night comfort limits with the monthly mean minimum temperature to establish thermal stress for each month by entering the following notations in the twelfth and thirteenth lines:
 - O (comfort)—if mean max. or min. is within comfort limits;
 - H (hot)—if mean max. or min. is above upper comfort limit;
 - C (cold)—if mean max. or min. is below lower comfort limit.
4. Enter the monthly average rainfall values from data sheets and tick the month in which the rainfall exceeds 200 mm in the fourteenth line.
5. The tabulation is used to produce one or more indicators for each month (all conditions in any one line must be satisfied to qualify for the indicator specified by that line);
 - Tick the appropriate rubric in the table;
 - When completed, count the number of ticks in each line and enter number in the last column (sum).
6. Copy the numbers from this last column of Table 3.1 and enter into the heading of the Table 3.2

Table 3.2 Design recommendations

I-1	I-2	I-3	I-4	I-5	I-6			Indicator total
								Layout
			0-10					1
			11,12		5-12			
						0-4		
								Spacing
11,12								3
2-10								4
0,1								5
								Air movement
3-12								6
			0-5					
1,2			6-12					7
0	2-12							
	0,1							8
								Opening sizes
			0, 1		0			9
					1-12			10
			2-5					11
			6-10					12
			11,12		0-3			13
						4-12		
								Opening position
3-12								14
			0-5					
1-2			6-12					15
0	2-12							
								Protection of opening
					0-2			16
		2-12						17
								Walls and floors
			0-2					18
			3-12					19
								Roofs
10-12			0-2					20
			3-12					21
			0-5					
0-9			6-12					22
								External features
				2-12				23
		3-12						24

Source Adapted from Koenigsberger (1973) with permission from Mahoney (2016)

- Examine the table and when the number entered in the heading corresponds to the numbers shown in the same column, and place a tick against the recommendation item in that line;
- There can only be one item ticked in each of the sections, and it will be the first one arrived at when examining line by line and left to right;
- Where the first concurrence includes two lines of recommendation continue further to the right, the next concurrence will select the appropriate recommendation;
- The recommendations ticked comprise of broad design guidelines to be used wisely with other tools presented in this chapter.

3.4 Passive Design Strategies

The conceptual design stage involves the following design parameters that have the greatest influence on thermal performance of building:

- (i) Site and orientation: longer axis of the building should be in east–west direction with openings on north and south side; also position the building on site to facilitate breeze access. The term aspect ratio denotes the ratio of the longer side a rectangular plan to the shorter side. In most cases, the ratio may taken between 1.3 and 2.0 depending on the climate (Olgyay 1963).
- (ii) Building form: surface-to-volume ratio determines the heat loss or gain through the building envelope. It is advisable to design the built form with least surface area for a given volume; the hemisphere is most efficient form, but a compact plan is always better than a spread-out plan.
- (iii) Building envelope: thermophysical properties of the materials determine the heat gain or loss through the building components. Bureau of Indian Standards (BIS 1978 and 1987) prescribes thermophysical properties for roof and exposed walls in different climatic zones. The Energy Conservation Building Code (ECBC) has given prescriptive requirements for roofs and opaque walls in terms of maximum U -value of the overall assembly and minimum R -values of insulation alone for the five climate zones and two different building occupancy schedules (24-h use and daytime use only), BEE (2017). Size, position and orientation of windows affect solar heat gain and also affect ventilation. The ECBC provides the maximum limit of window-to-wall ratios (WWR) for vertical fenestration (such as windows and glass doors) and maximum area weighted U -factors and maximum area weighted shading heat gain coefficient (SHGC).

The subsequent subsections describe the process of design decision-making.

3.4.1 Bio-Climate Analysis

The next step in passive design is to delineate the summer and winter comfort zones and overlay the monthly temperatures and relative humidity ratios to diagnose the nature of the climatic problem. Comfort zones and climatic conditions can be represented graphically by either the ‘bioclimatic chart’ or the ‘psychrometric chart’.

Olgay (1963) devised his bioclimatic chart to show the effects of four environmental variables on human comfort, as in Fig. 3.3. Dry-bulb temperature (°F) is on the vertical axis and relative humidity (%) on the horizontal axis, and a comfort zone is delineated in terms of these two variables. Lines above this indicate an extension of the upper comfort limit by air movement and lines below it show a downward extension of the comfort zone by solar radiation. Arens et al. (1980) revised the bioclimatic chart on the basis of the J. B. Pierce laboratory human thermal model.

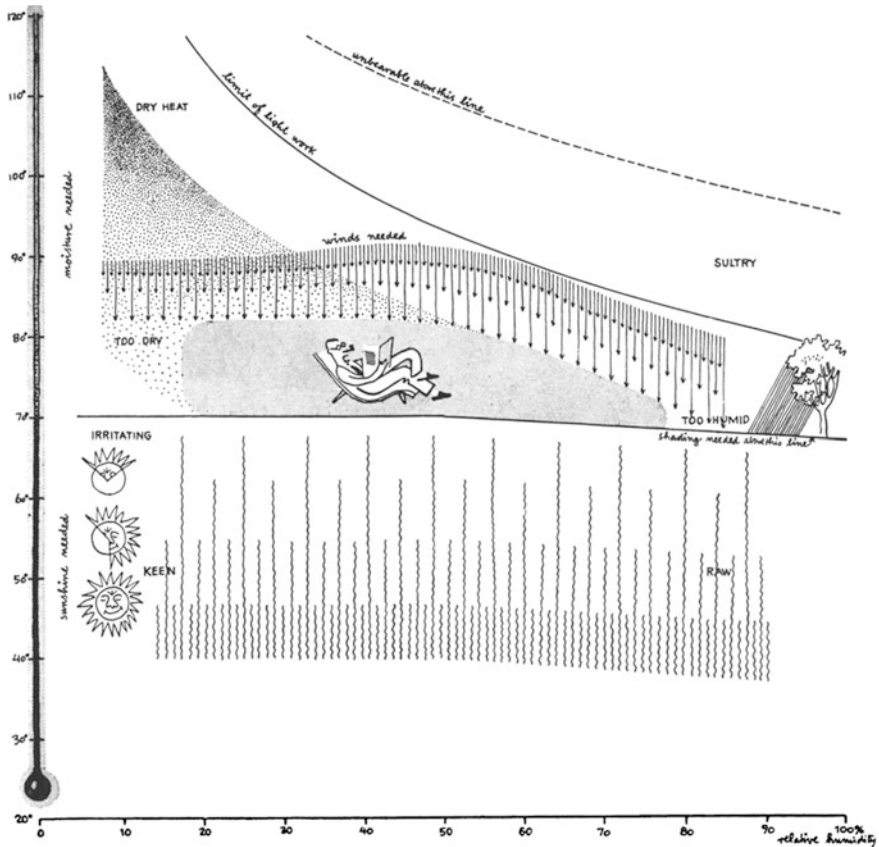


Fig. 3.3 Olgay’s bioclimatic chart (Olgay 1963)

Givoni (1969) used the psychrometric chart to delineate his bioclimatic chart. On this, he delineates the comfort zone and its extensions by various active and passive techniques. Milne and Givoni (1979) further developed this chart, and it is used in the Climate Consultant software developed by the Energy Design Tools Group, the University of California, as shown in Fig. 3.4. Watson and Labs (1983) further developed Givoni's system. Szokolay's (1986, 2008) control potential zone (CPZ) method defines the comfort zone on the psychrometric chart using the Auliciems (1982) expression for thermal neutrality. The zone is then taken as 5 K wide (± 2.5 °C to thermal neutrality) plotted on the 50% RH (relative humidity) line and the side boundaries taken as the corresponding sloping ET* (or standard effective temperature) lines.

The psychrometric chart is chosen as analytical tool, as it offers a more pedantic way and allows the representation of many other parameters, such as wet-bulb temperature, relative humidity, enthalpy and density. This analysis tool is recommended for 'envelope dominated buildings', e.g. residences and small office buildings. The method comprises of three steps:

1. Delineate the 'comfort zone' for summer and winter (as in Sect. 2.5, Figs. 2.5, 2.6). Note that the words 'summer' and 'winter' are used to refer to the overheated (warmest) and underheated (coldest) periods of the year and not necessarily to the calendar months.
2. Plot the ambient climatic conditions, mark on the chart two points for each of the 12 months: one taking mean maximum temperature with minimum RH and one taking mean minimum temperature with maximum RH. Connect two points by a line. The 12 lines would indicate the median zone of climatic conditions. A comparison of comfort zones with these lines would ascertain the nature of the climatic problem, as in Figs. 3.5, 3.6, 3.7, 3.8.

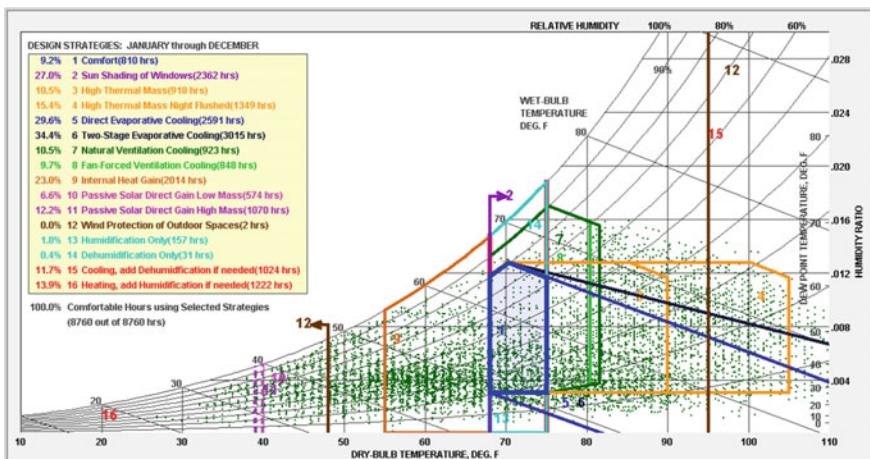


Fig. 3.4 Psychrometric chart showing design strategies © 2016 The Regents of the University of California

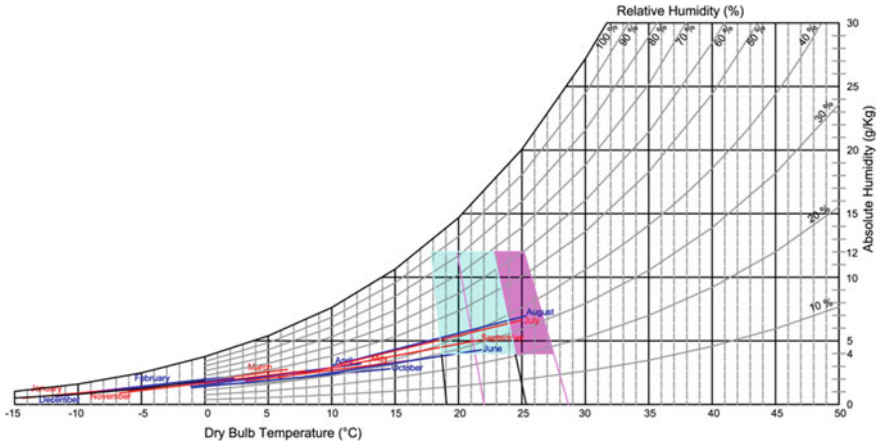


Fig. 3.5 Leh, Ladakh: cold with little seasonal difference in comfort zones rarely reaches comfort

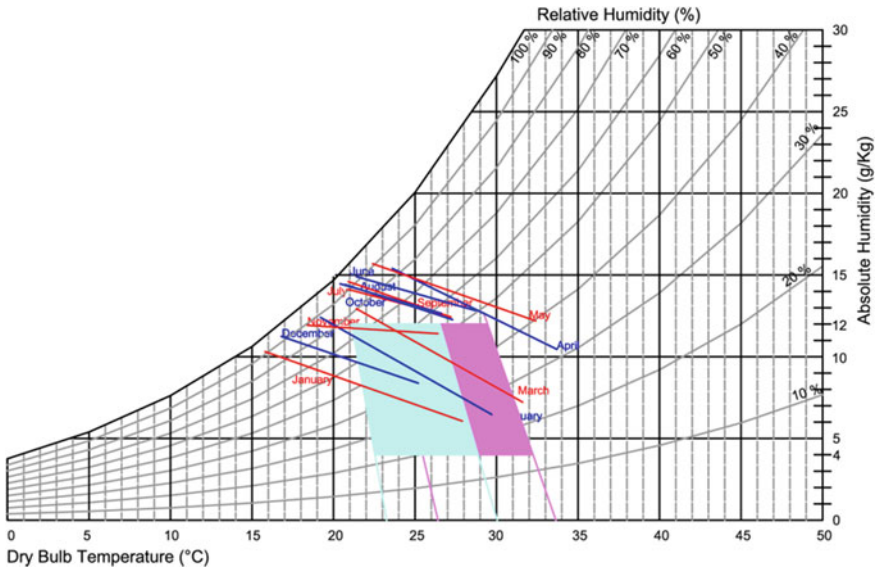


Fig. 3.6 Bengaluru: temperate climate comfortable summer, cool in winter but not severe

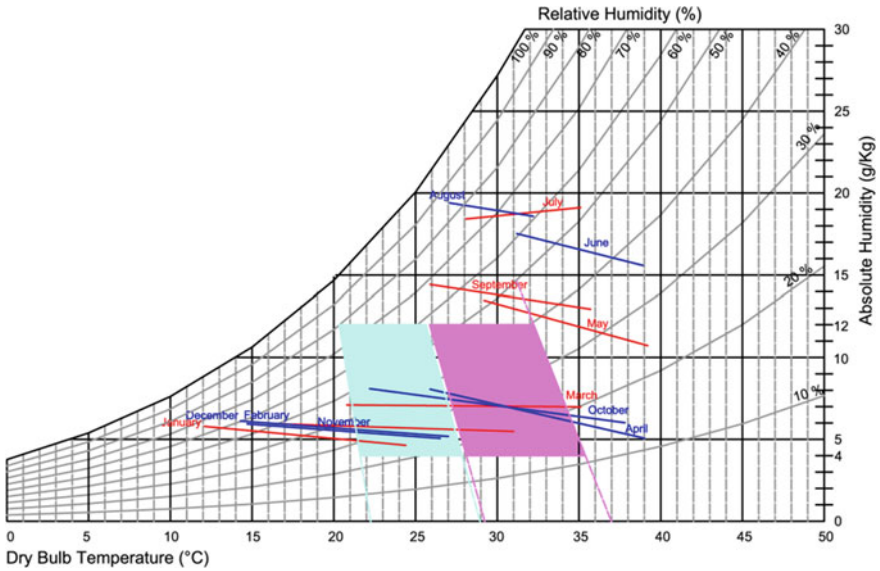


Fig. 3.7 Jodhpur: hot and dry with large seasonal difference in comfort zones, large diurnal ranges, hot summer and cold winter nights

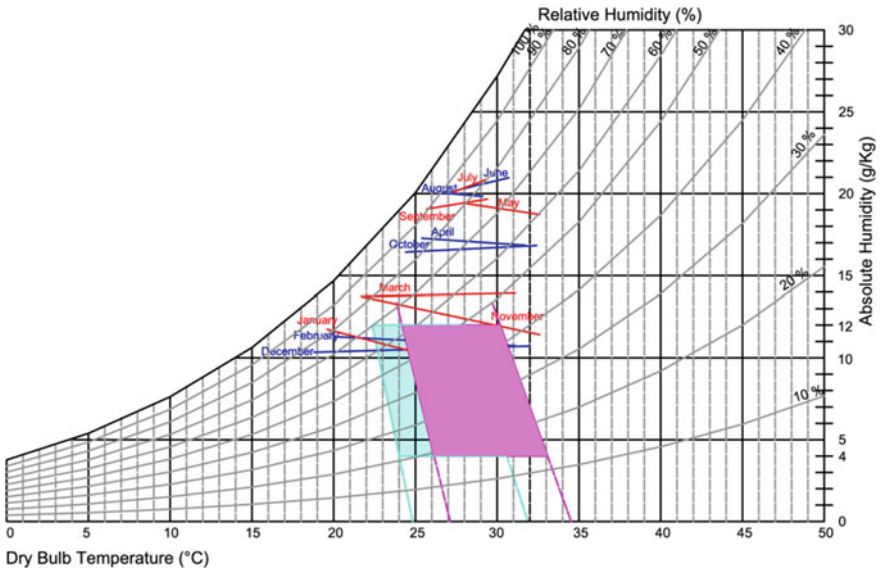


Fig. 3.8 Mumbai: warm and humid with little variation in summer and winter comfort zones, mostly humid, rarely reaches comfort

3. To identify the design strategies, i.e. the range of outdoor conditions within which indoor comfort can be achieved by passive design strategies, such as
 - for underheated conditions:
 - passive solar heating (direct gain, Trombe–Michel wall, green house);
 - for overheated conditions:
 - passive thermal mass (summer and winter, for summer with night-flush ventilation);
 - comfort ventilation (physiological cooling);
 - evaporative cooling (direct and indirect).

3.4.2 *Passive Solar Heating*

The passive solar heating strategy is applicable in cold climate. Every passive solar heating system has at least two elements: a collector consisting of equator-facing glazing and an energy storage element that consists of thermal mass. Three basic types of passive solar heating system are given below and shown in Fig. 3.9:

1. Direct solar gain,
2. Trombe–Michel wall,
3. Sunspaces (also known as solar greenhouses or conservatories).

A window facing the equator creates a direct solar gain system. Window glass transmits the short-wave infrared radiation emitted by the sun but obstructs the long-wave infrared radiation emitted by heated room surfaces from escaping and thus causing the greenhouse effect. The passive thermal mass (heavy walls and floors) inside the building then stores this heat, both to reduce daytime overheating and to release at night-time. A horizontal shading device may be provided to intercept the summer sun and to allow entry of the beneficial solar radiation in the winter. The Druk White Lotus School, Shey, uses direct gain system for classrooms meant for daytime use.

The Trombe–Michel wall was named after Professor Felix Trombe and architect Jacques Michel, who developed this system in France in 1966. In this passive system, a massive wall is placed behind the equator-facing glazing leaving an air gap of 100–150 mm. The wall is painted black for higher heat absorption. As the greenhouse effect traps the solar radiation, the wall surface behind the glass is heated, it will heat the air in the gap, and the wall incorporates vent openings near the floor and near the ceiling. As the heated air rises, it would enter the room through the top vent, drawing in cooler air from the room near the floor level, forming a thermosiphon circulation. In summer, the vents are closed and the vent in glass is opened to exhaust hot air. This system can be used when the sun's heat and not its light is desired. The Druk White Lotus School, Shey, uses Trombe–Michel wall system for the residences which are meant for night occupation.

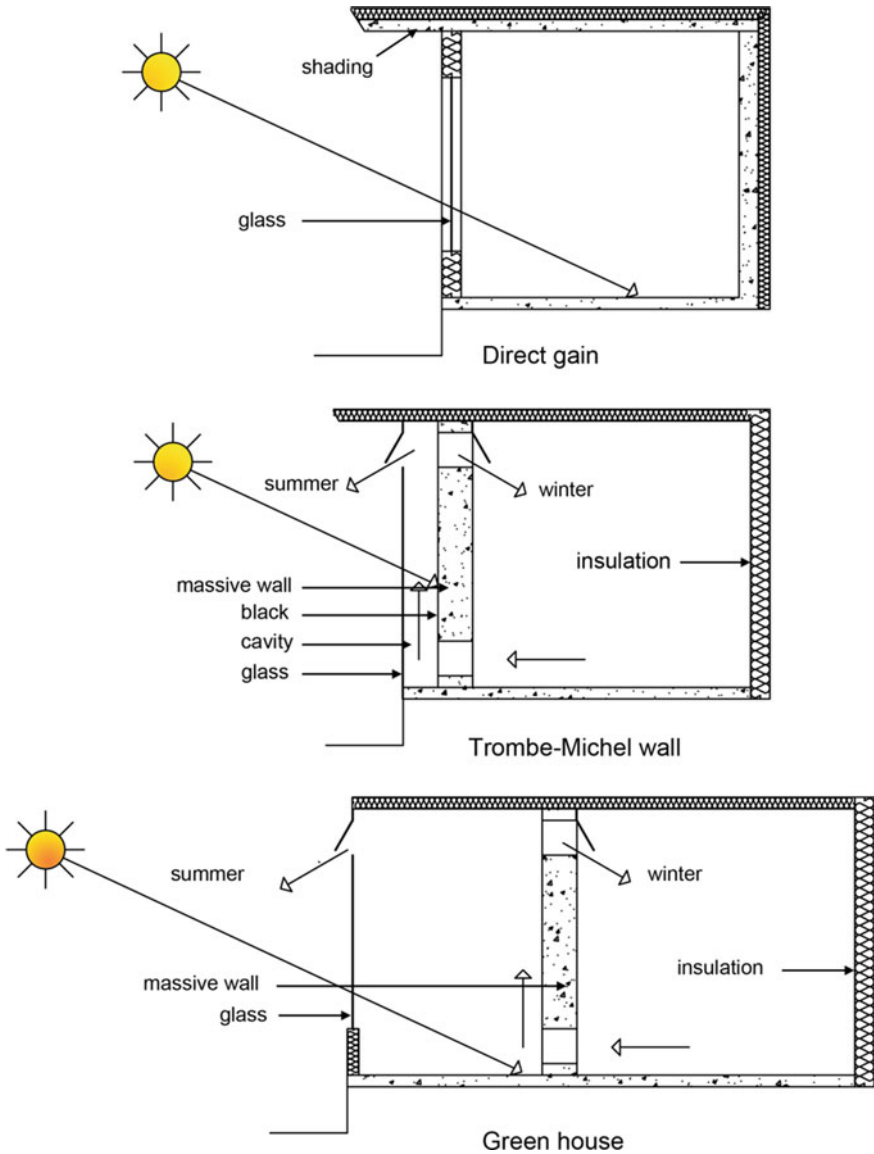


Fig. 3.9 Passive solar heating: direct gain, Trombe–Michel wall and green house

One of the fascinating passive solar heating systems is sunspace (greenhouse or conservatory), and it is an attached space of about 2 m or more. The thermal function is the similar to the Trombe–Michel wall; it serves dual purposes of heating the room behind it and providing a secondary living space for daytime use. At night-time, sunspace can lose heat, so it is essential to close off the room it serves.

The passive solar heating can be estimated as a function of the mean daily total irradiation on an equator-facing vertical plane (H_v in Wh/m²) for the coldest month. The climatic data tables in Chap. 5 include the daily total global irradiation (H_h) and diffuse irradiation on horizontal surface (H_d), the beam component (H_b) can be found ($H_b = H_h - H_d$), and then the value of H_v can be calculated by the below given equation:

$$H_v = R \times H_b + H_d/2 + r * H_h/2 \quad (3.1)$$

r = reflectance of the foreground, normally taken as 0.2

Mathematically, R is expressed as (Muneer 2004)

$$R = \frac{\cos(\text{LAT} - 90) * \cos \text{DEC} * \sin \omega_s' - \omega_s' * \sin(\text{LAT} - 90) * \sin \text{DEC}}{\text{COS LAT} * \cos \text{DEC} * \sin \omega_s + \omega_s * \sin \text{LAT} * \sin \text{DEC}} \quad (3.2)$$

where

sunset hour angle (ω_s):

$$\omega_s = \cos^{-1}(-\tan \text{LAT} \times \tan \text{DEC}) \quad (3.3)$$

And sunset hour angle (ω_s') on vertical plane:

$$\omega_s' = \min[\omega_s, \text{acos}(-\tan(\text{LAT} - 90) \times \tan \text{DEC})] \quad (3.4)$$

LAT = latitude degrees (southern hemisphere -ve)

DEC = solar declination degrees (varies from a maximum value of +23.45° on June 22 to a minimum value of -23.45° on December 22. It is zero on the two equinox days of March 21 and September 22)

The limiting condition will be the lowest temperature at which the solar gain can match the heat losses under steady-state conditions:

$$H_v \times A \times \eta = q \times (T_i - T_o) \times 24 \quad (3.5)$$

where

H_v = vertical irradiation (Wh/m² day);

A = area of solar aperture (m²);

η = efficiency (utilizability), taken as 0.5;

q = $q_c + q_v$, building conductance (W/K);

T_i = indoor temperature limit (°C), taken as $T_c - 2.5$;

T_o = the limiting temperature (°C) to be found.

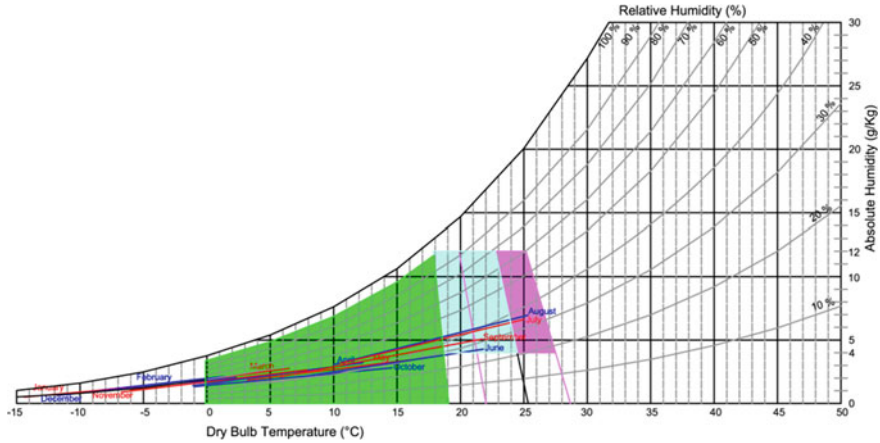


Fig. 3.10 Comfort zone for passive solar heating (green, middle grey)

Assume a simple office of 100 m² floor area and 20% (= 20 m²) solar window and a building conductance of 115 W/K. Substitute

$$H_v \times 20 \times 0.5 = 115 \times (T_i - T_o) \times 24$$

and rearrange for T_o

$$T_i - T_o = \frac{H_v \times 20 \times 0.5}{115 \times 24}$$

$$T_o = T_i - \frac{H_v \times 20 \times 0.5}{115 \times 24}$$

In Leh in January $H_v = 5140$ Wh/m² day on a south-facing vertical surface, $\bar{T}_o = -8.2$ °C, RH = 50.5% and taking $T_i = 18.4$ °C (for $T_c = 20.9$ °C $\sim T_o = 10$ °C the lowest limit of thermal neutrality) with $\eta = 0.5$, the lowest T_o that the passive solar heating can provide comfort for

$$T_o = 18.4 - 0.0036 \times 5140 = -0.104$$
 °C

Figure 3.10 delineates the comfort zone for passive solar heating.

3.4.3 Passive Thermal Mass

The passive thermal mass is the appropriate passive solar strategy for hot dry climate, characterized by a large diurnal temperature, and the mean outdoor temperature of the day is within the comfort zone. This technique involves the use of

high thermal mass materials, e.g. brick, stone, concrete, within the building, both in the external envelope and internally. This has a capacitive insulation effect which tends to attenuate and delay heat transmission through a wall or roof and even out both diurnal and seasonal internal temperature fluctuations. In other words, it would ensure that the indoor temperature is practically constant and at about the level of mean outdoor temperature of the 24-h period. Passive solar hostel at Jodhpur University exemplifies the principles of mass effect.

The passive thermal mass can be coupled with night-flush ventilation where the mean outdoor temperature of the day is higher than the comfort limit and night external air temperatures are relatively cool. The building is opened up, and high volume of air flow is facilitated to lower down the indoor temperature to near the outdoor minimum; consequently, the heat stored in building envelope will be dissipated, as in Fig. 3.11. The building is then closed up completely during the

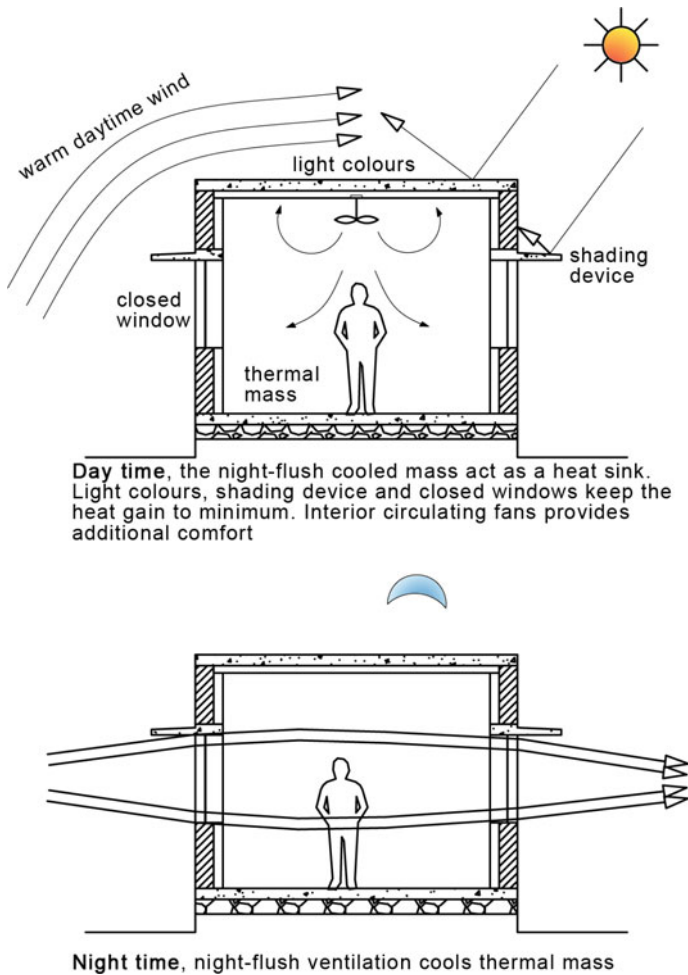


Fig. 3.11 Thermal mass with night ventilation

day. It may be achieved by natural means through windows and other openings or by mechanical means through an exhaust fan operated when $T_o < T_i$. If the building is occupied at night, like residences, the ventilation should not be so cold as to be uncomfortable for occupants.

An effectiveness of 0.5 may be assumed for this strategy; hence, the mean range of temperature for the hottest month is determined ($T_{max} - T_{min}$) and 0.5 times the mean range will be added to the upper comfort limit. The upper humidity is the 14 g/kg line, truncated by the relative humidity curve corresponding to the lower comfort temperature.

In a cold climate characterized by air temperatures below comfort, mass effect can be supplemented with passive solar heating to improve the indoor conditions. In Jodhpur, in the hottest month, June,

$$T_{o,max} = 38.9\text{ }^\circ\text{C}, T_{o,min} = 31.2\text{ }^\circ\text{C}, \bar{T}_o = 35.1\text{ }^\circ\text{C},$$

$$T_c = 28.7\text{ }^\circ\text{C}, \text{ hence upper comfort limit} = 31.2\text{ }^\circ\text{C}$$

$$\text{Amplitude} = (38.9 - 31.2) \times 0.5 = 3.85\text{ K}$$

$$\text{Limit of the extended comfort zone} = 31.2 + 3.85 = 35.05\text{ }^\circ\text{C}$$

Similarly, in the coldest month, January,

$$T_{o,max} = 24.2\text{ }^\circ\text{C}, T_{o,min} = 12.1\text{ }^\circ\text{C}, \bar{T}_o = 18.3\text{ }^\circ\text{C},$$

$$T_c = 23.5\text{ }^\circ\text{C}, \text{ hence lower comfort limit} = 26\text{ }^\circ\text{C}$$

$$\text{Amplitude} = (24.2 - 12.1) \times 0.5 = 6.15\text{ K}$$

$$\text{Limit of the extended comfort zone} = 21 - 6.15 = 14.85\text{ }^\circ\text{C}$$

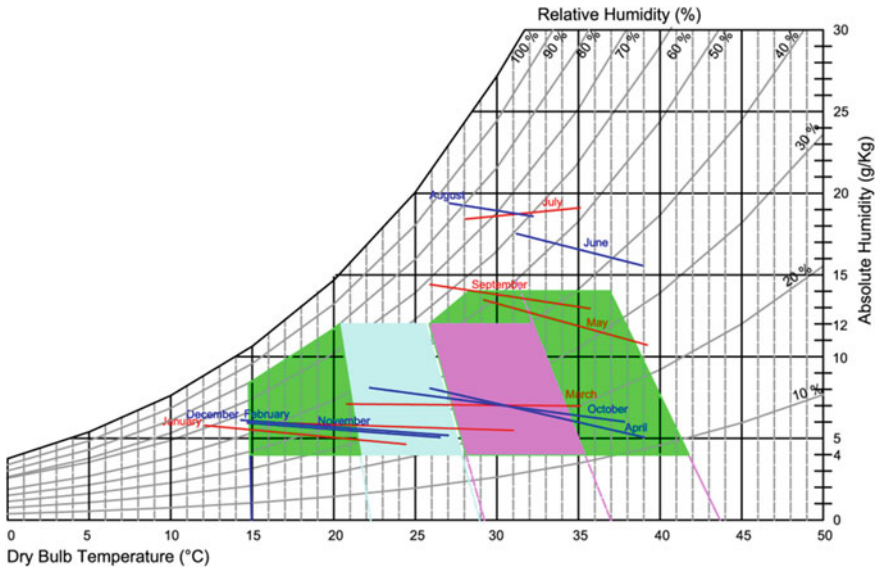


Fig. 3.12 Comfort zone for thermal mass (green, middle grey)

All these temperatures are taken at the 50% RH curve, and the corresponding SET lines are the boundaries of the comfort zone for mass effect, as in Fig. 3.12.

3.4.4 Comfort Ventilation

The term ‘ventilation’ serves three different functions in building: supply of fresh air (to fulfil oxygen requirement), convective cooling to remove heat from the inside of building ($T_o < T_i$ using stack effect) and physiological cooling by evaporating moisture from the surface of the skin to dissipate heat (using cross-ventilation). The comfort ventilation is physiological cooling; it is an important passive design strategy for the whole year in warm humid climate and for

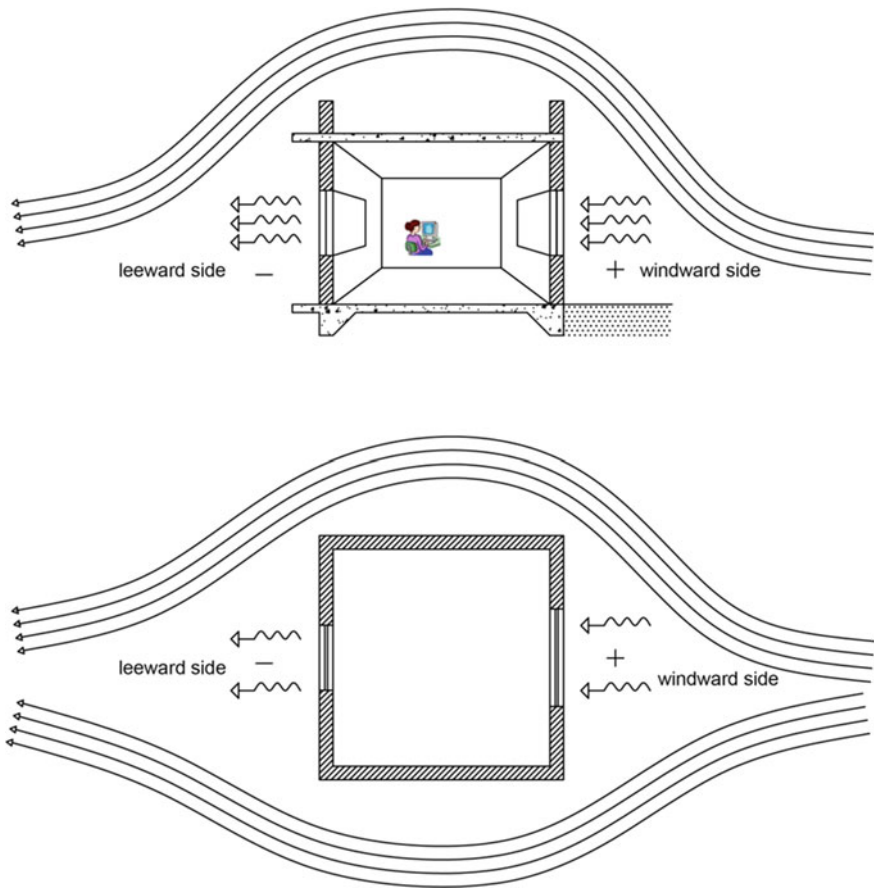


Fig. 3.13 Cross-ventilation for comfort

Table 3.3 Air velocities and subjective reactions and thermal comfort

Air velocity (m/s)	Equivalent temperature reduction (K)	Subjective reactions and effect on comfort
0.25	1.3	Design velocity for outlets that are near occupants
0.4	1.9	Noticeable and pleasant
0.8	2.8	Very noticeable but acceptable in certain high activity areas if air is warm
1	3.3	Awareness, upper limit for air-conditioned spaces, good air velocity for natural ventilation in hot and dry climates
2.0	3.9	Draughty, good air velocity for ventilation in hot and humid climates

Source Lechner (2009, Table 10.8, p. 281)

certain periods of the year in composite climate. This is achieved by ensuring air movement at the body level of the occupant through cross-ventilation (providing inlet on windward side and outlet on leeward side), as in Fig. 3.13. Climatic data tables provide wind rose diagrams to find the prevailing wind direction, and openings may be provided in this direction to ensure natural air movement. However, comfort ventilation can rarely be relied on passive means because in most climates winds are not sufficient to create the necessary indoor air velocities. Mechanical means electric fans are usually required to supplement the wind.

Air velocities and equivalent temperature reduction can be taken from Table 3.3 to define the comfort zone for comfort ventilation. Szokolay (2008) recommends that air velocity of 1 m/s and 1.5 m/s will offset increase in temperature by up to 3.8 and 5.1 K, respectively. However, ASHRAE (2009, p. 9.12) suggests the elevated air speed may be used to offset an increase in temperature by up to 3 K above the warm-temperature boundary.

The effect of comfort ventilation can be defined by adding the equivalent temperature reduction values to the upper comfort limit along the 50% RH curve. Above that, the boundary will be the corresponding SET line, but below 50%, there is a cooling effect even without air movement, as the air is dry, so the additional effect of the air movement is taken as only half of the above: the boundary line will be nearer to the vertical.

In Mumbai, the hottest month is May, with $\bar{T}_o = 30.4^\circ\text{C}$ hence $T_c = 27.2^\circ\text{C}$ and upper comfort limit = 29.7°C

Limit of the comfort ventilation will hence be = $29.7 + 3 = 32.7^\circ\text{C}$ as illustrated in Fig. 3.14. The boundary of comfort zone for ventilation will be the corresponding SET line above 50% RH curve, but below 50% it is taken as only half of the above; since below 50% there is a cooling effect even without air movement as air is dry (Szokolay 2008).

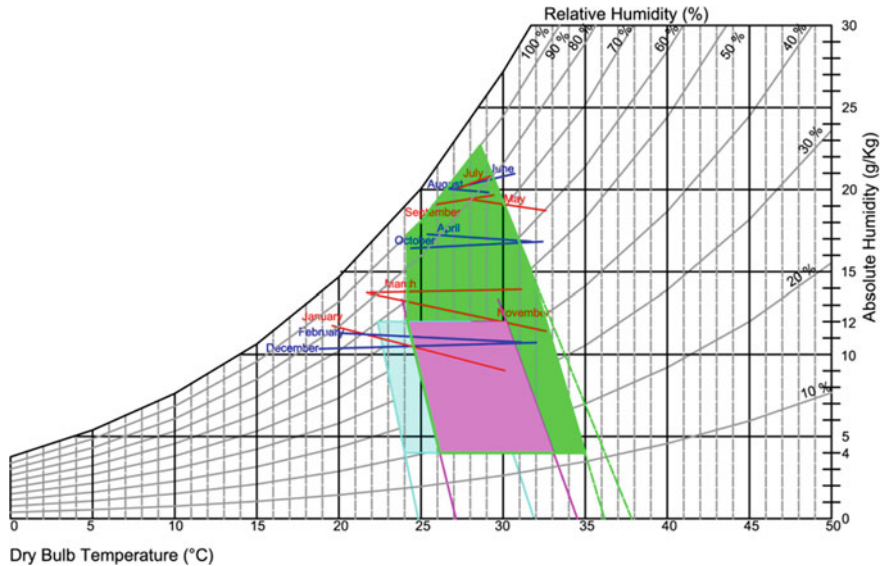


Fig. 3.14 Comfort zone for ventilation (green, middle grey)

3.4.5 Evaporative Cooling

The evaporative cooling is much less energy intensive than conventional cooling and therefore can be considered as part of a passive system in hot dry climate. When water evaporation occurs, it draws a large amount of sensible heat from its surrounding and converts this sensible heat into latent heat in the form of water vapour at a constant wet-bulb temperature. As a result, the dry-bulb temperature can be reduced by about 70–80% of the wet-bulb depression (Givoni 1991), which is defined as the difference between dry-bulb temperature (DBT) and the wet-bulb temperature (WBT). This principle is used for cooling buildings in two very different ways, as in Fig. 3.15:

1. Direct evaporative cooling
2. Indirect evaporative cooling

In direct evaporative cooling, the water evaporates within an enclosed space, and consequently, the dry-bulb temperature of air may decrease, but the humidity will increase. The total heat content of the system does not change, i.e. it is said to be adiabatic. Conventional desert cooler, misting, cooling towers and other systems work on this principle.

In indirect evaporative cooling, the building is cooled by evaporation without adding moisture or the moist air is removed by ventilation. In indirect evaporative cooling, secondary air removes heat from primary air using a heat exchanger. Indirect evaporative coolers are now commercially available as package units.

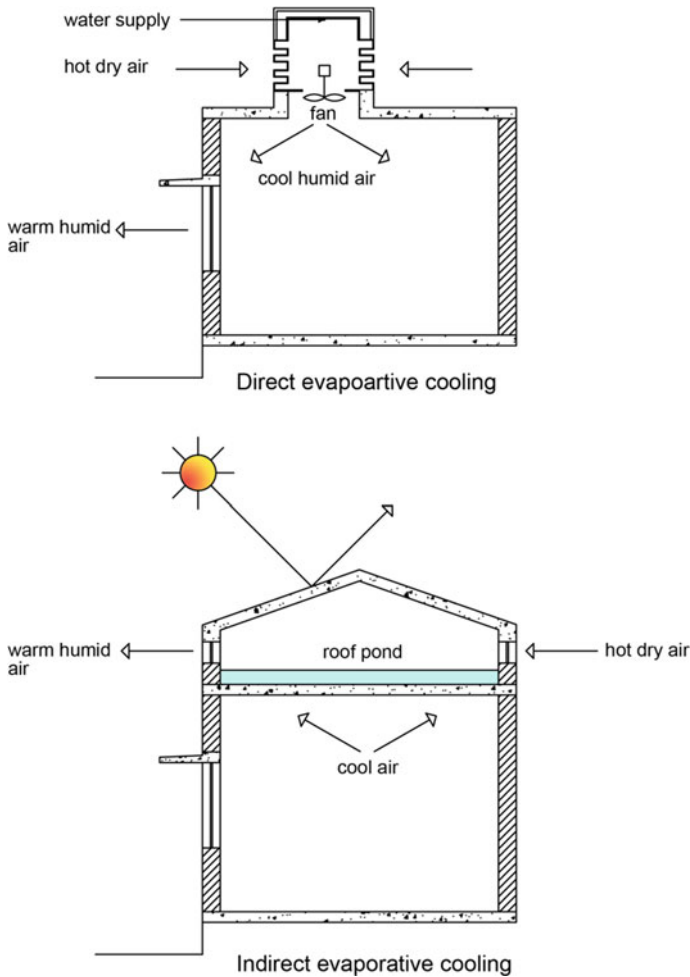


Fig. 3.15 Direct and indirect evaporative cooling

A simple example to explain principle of evaporative cooling can be a roof pool or a spray over the roof or some other building surface, which then becomes a heat sink to cool the interior. The passive solar hostel at Jodhpur University incorporates direct evaporative cooling.

The evaporative cooling can be defined by the wet-bulb temperature line tangential to the upper right and lower left corner of the comfort zone on the psychrometric chart and a vertical line at the $T_c + 0.8 \times (T_c - T_w)$, where T_w is the wet-bulb temperature. Indirect evaporative cooling, a slight increase in humidity tolerance (to 14 g/kg) can be accepted if the air is cooled; hence, the upper boundary of the comfort zone is a horizontal line at this level, but not beyond the RH curve corresponding to upper left corner of the comfort zone. The temperature

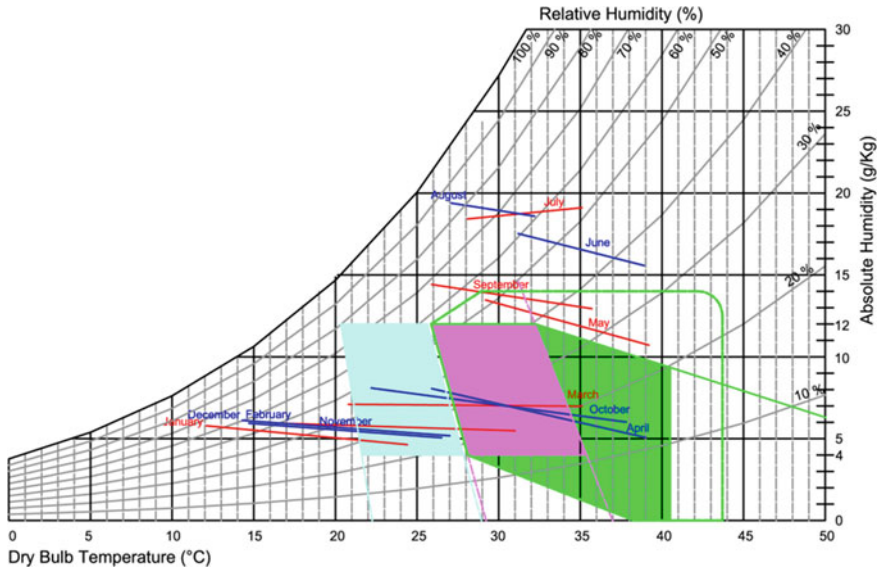


Fig. 3.16 Comfort zone of evaporative cooling (green, middle grey)

limit would be at $T_c + 15$ and the high humidity, high-temperature corner should be rounded off (Wooldridge et al. 1976 and Pescod 1976). The evaporation potential of the humid air primarily determines effectiveness of this strategy.

In Jodhpur in the hottest month, June, the wet-bulb temperature at the lower left corner is 13.7 °C and upper right corner is 21.0 °C and the vertical line is drawn at dry-bulb temperature 40.5 °C, as in Fig. 3.16.

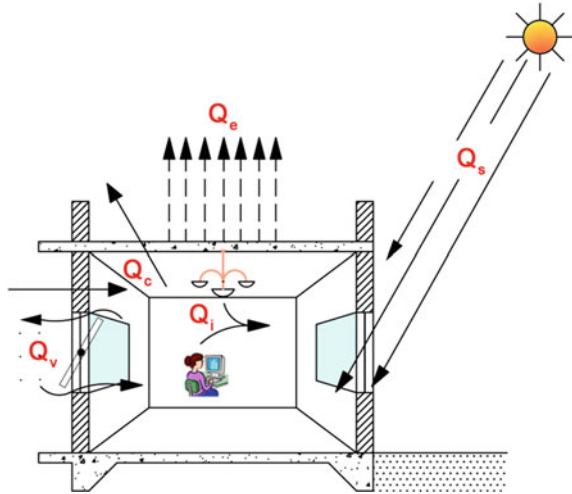
3.5 Energy Efficient Design Strategies

After considering passive design, the next step is to consider energy efficient active design strategies. Design of an energy efficient building system primarily depends on the following:

1. climatic conditions outside,
2. comfort conditions required inside,
3. thermal behaviour of the building,
4. occupancy pattern.

Thermal behaviour of a building is governed by a series of heat inputs and outputs, as in Fig. 3.17. Thermal performance of a building is determined by heat transfer mechanisms: radiation, conduction and convection, which can be expressed by the following equation:

Fig. 3.17 Heat inputs and outputs of a building



$$\pm Q_c + Q_s \pm Q_v + Q_i - Q_e = \Delta Q \quad (3.6)$$

where

- Q_c conduction heat gain or loss,
- Q_s solar heat gain,
- Q_v convection heat gain or loss,
- Q_i internal heat gain,
- Q_e evaporation heat loss.

ΔQ indicates any surplus or deficit heat stored in the building. If ΔQ is zero, thermal balance is achieved, and no cooling or heating is required. If ΔQ is negative, there is heat loss, the inside temperature is falling below the comfort level, and the building requires heating. If ΔQ is positive, there is heat gain, the inside temperature is rising above the comfort level, and the building requires cooling.

Thermal performance of a building can be mathematically analysed by the following two approaches:

1. steady-state heat flow—the inside and the outside conditions are assumed to be steady, non-changing.
2. dynamic heat flow—the inside and the outside conditions are assumed to be unsteady and changing.

The above methods provide useful quantitative information which helps the designers to understand the relationship between design decisions and thermal performance of a building. The sun is the primary source of energy, and the solar radiation is the most significant energy input into a building. The first section discusses thermophysical properties, U value and SHGC of building elements. The next section presents the concept of sol-air temperature to account for solar energy

input in a building. This will be followed by analysis of the cooling and heating requirements of a building adopting steady-state method. Finally, dynamic methods are discussed for energy performance modelling of a building.

3.5.1 Thermophysical Properties

Conduction heat flow depends on thermophysical properties of materials. Conductivity (k) is measured as the heat flow density (W/m^2) in a 1-m-thick material with one degree temperature difference ($^{\circ}K$), in unit of $W/m\ K$. Bureau of Indian standard (BIS 1987, Sect. 4, Table 3.2) published thermophysical properties of building and insulating materials at mean temperature of $50\ ^{\circ}C$; which is very high temperature. Typical thermal properties of common building and insulating materials design values for mean temperature of $24\ ^{\circ}C$ are published in the Handbook of Fundamentals by ASHRAE (2009, Chap. 26, Table 3.4).

The total thermal resistance to one-dimensional heat flow through building construction, e.g. roof or wall, is the numerical sum of the resistance (R_T) of all parts of the construction in series, as in Eq. 3.7. In buildings, the air film and cavity resistances must be added.

$$R_T = R_{si} + R_m + R_c + R_{so} \tag{3.7}$$

where

- R_{si} = is the inside film or surface resistance (m^2K/W), as in Table 3.4
- R_{so} = outside film or surface resistance (m^2K/W), as in Table 3.4
- R_c = airspace resistance (m^2K/W), as in Table 3.5
- R_T = total thermal resistance (m^2K/W)

Table 3.4 Surface resistance ($m^2\ K/W$)

Structure	Direction of heat flow	High emittance $\epsilon = 0.90$ R (m^2K/W)	Low emittance $\epsilon = 0.05$ R (m^2K/W)
<i>Inside</i>			
Walls (vertical)	Horizontal	0.12	0.30
Ceilings or floors (horizontal)	Upward	0.11	0.23
	Downward	0.16	0.80
Ceilings or floors (pitched 45°)	Upward	0.11	0.24
	Downward	0.13	0.39
<i>Outside</i>			
Walls or roofs (severe exposure)	Any	0.03	–
Walls or roofs (normal exposure)	Any	0.04	–

Source Based on average values ASHRAE (2009, Chap. 26, p. 26.1)

Table 3.5 Airspace resistance ($\text{m}^2 \text{K/W}$)

	Direction of heat flow	High emittance $\varepsilon = 0.90$ R ($\text{m}^2\text{K/W}$)	Low emittance $\varepsilon = 0.05$ R ($\text{m}^2\text{K/W}$)
<i>Unventilated</i>			
5 mm airspace	Any	0.11	0.18
≥ 25 mm airspace (wall)	Horizontal	0.18	0.44
≥ 15 mm airspace (roof)	Upward	0.16	0.34
	Downward	0.22	1.06
> 25 mm airspace (pitched 45°)	Upward	0.19	0.40
	Downward	0.20	0.98
Roof (attic)	Downward	0.33	1.14
<i>Ventilated</i>			
Walls	Any	0.13	0.29
Roofs (Attic)	Any	0.46	1.36

Source Based on ASHRAE (2009, Chap. 26 p. 26.1), ASHRAE (1997), ISO 6946 (2007)

Mathematically, R_m the total material resistance is expressed as

$$R_m = \frac{l_1}{k_1} + \frac{l_2}{k_2} + \frac{l_3}{k_3} \dots \quad (3.8)$$

where

l_1 = thickness of layer (m)

k_1 = conductivity of the material (W/m K)

The U -value (air-to-air thermal transmittance, $\text{W/m}^2\text{K}$) is the reciprocal of R_T ,

$$U = \frac{1}{R_T} \quad (3.9)$$

Surface resistance to heat flow is a function of the combined radiant and convective components of heat transfer, as in Eq. 3.10. The convection heat transfer coefficient is dependent on air speed and direction of heat flow. The radiation heat transfer coefficient is dependent on the view factor and the emittance of the radiation and absorbing surfaces. In the analysis of heat transfer from air into a body such as a wall, roof, or vice versa, it is convenient to use the published standard values, as in Table 3.4.

$$R_{so} \text{ or } R_{si} = \frac{1}{f_r} + \frac{1}{f_c} \quad (3.10)$$

where

- f_r = radiation coefficient (W/m²K)
- f_c = convection coefficient (W/m²K)

For pitched roofs containing a horizontal ceiling, the R -value is measured with respect to the plane of the ceiling and has to be corrected for the roof pitch as follows:

$$R_T = R_{si} + R_{m1} + R_c \cos \beta R_{m2} + \cos \beta R_{so} \tag{3.12}$$

where

- β = angle of pitch of roof
- R_{m2} = resistance of materials in the plane of pitched part of the roof (W/m²K).

An external wall consisting of 115 mm brickwork, 50 mm of unventilated cavity, 100 mm lightweight concrete block inner leaf finished with 13 mm of lightweight plaster, the U -value calculation is given Table 3.6.

In many constructions, components are arranged so that heat flows in parallel paths of different conductances. If no heat flows between lateral paths, heat flow in each part may be calculated using Eqs. (3.7) and (3.8). The average transmittance is then

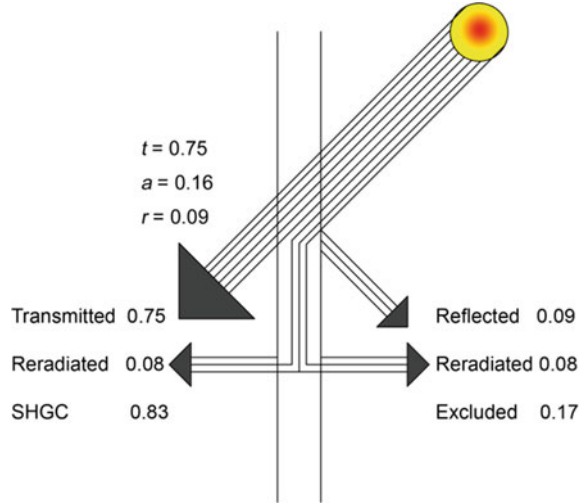
$$U_{av} = aU_a + bU_b + \dots + nU_n \tag{3.11}$$

where $a, b \dots$ are respective fractions of a typical basic area composed of several different paths with transmittance U_a, U_b, \dots, U_n .

Table 3.6 Example calculation of U -value of simple construction

	Element	Thickness (m)	Thermal conductivity (w/m K)	Thermal resistance (m ² K/W)
	Outside surface resistance R_{so}	–	–	0.06
	1 external brickwork	0.115	0.84	0.1369
	2 Cavity resistance (R_c)	–	–	0.18
	3 Lightweight concrete block	0.100	0.19	0.526
	4 Lightweight plaster	0.013	0.16	0.08125
	Inside surface resistance (R_{si})	–	–	0.12
	Resistance (R)	m ² K/W		
U -value (1/ R)	W/m ² K			0.90567

Fig. 3.18 Solar heat gain coefficient (SHGC) of glass



If heat flow is two-dimensional, three methods, the parallel path method, isothermal-planes method and zone or modified zone methods, are available to compute thermal transmittance through building components, ASHRAE (2009, Chap. 27, pp. 27.3–8).

The incident solar radiation falling on a glazed surface is partly transmitted (t) and partly reflected (r), and the remainder is absorbed (a) within the body of the glass. The solar heat gain coefficient (SHGC) is given by Eq. 3.13, Fig. 3.18:

$$\text{SHGC} = \frac{\text{Solar heat transmitted}}{\text{Solar irradiance on the window surface}} \quad (3.13)$$

3.5.2 Sol-Air Temperature (T_{sa})

Sol-air temperature, first introduced by Mackey and Wright (1943) and later modified by several researchers, combines the effect of solar radiation, ambient air temperature and long-wave radiant heat exchange with the environment. A precise definition of sol-air temperature is ‘the equivalent outdoor temperature that will cause the same rate of heat flow at the surface and the same temperature distribution through the material, as results from the outdoor air temperature and the net radiation exchange between the surface and its environment’ (Rao and Ballantyne 1970).

Consider the situation of external surfaces of a building exposed to air temperature and solar and other radiation exchanges. The outdoor air temperature is T_o , the global radiation per unit area at short wavelength (solar) is H_h , and the net

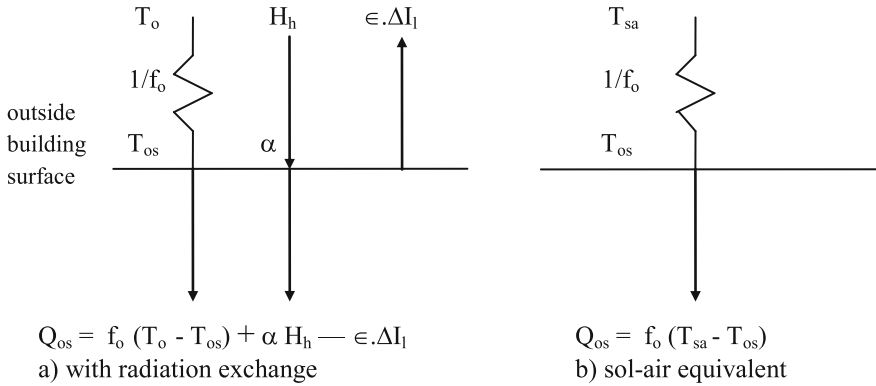


Fig. 3.19 Energy balance at the exterior surface of outside building surface

radiation per unit area at long wavelength is $\epsilon \cdot \Delta I_l$. Heat from outdoors flows into the surface by means of radiation, convection and conduction through the still air adhering to the surface, which can be represented by air film conductance f_o (reciprocal of resistance R_{os}). The heat flow per unit area into the building element can be represented as Q_{os} , Fig. 3.19.

A sol-air equivalent temperature is that that will lead to the same surface temperature and heat flow; these latter are connected by the conditions within the surface, and matching surface temperature on a continuous basis will lead to the same heat flow in the two systems. The heat flow in Fig. 3.19a is given as follows:

$$Q_{os} = \alpha H_h + f_o (T_o - T_{os}) - \epsilon \Delta I_l \tag{3.14}$$

and in Fig. 3.19b is

$$Q_{os} = f_o (T_{sa} - T_{os}) \tag{3.15}$$

The resulting sol-air temperature is

$$T_{sa} = T_o + \frac{1}{f_o} (H_h \alpha - \epsilon \Delta I_l) \tag{3.16}$$

where

- T_{os} = outside surface temperature °C
- T_o = outdoor air temperature °C
- H_h = total solar radiation (direct + diffuse) incident on the surface (W/m^2)
- α = absorptance of the material for short wave or solar radiation (Table 3.7)
- f_o = Outside film or surface conductance ($W/m^2 K$)

Table 3.7 Absorbance (α) and emittance (ϵ) of surfaces (average value)

Surfaces	α	ϵ
Clean surfaces	0.25	0.95
Brick	0.40	0.90
White glazed	0.80	0.90
Light colours		
Dark colours		
Roofs	0.90	0.96
Asphalt	0.65	0.85
Red tiles	0.40	0.50
White tiles	0.20	0.11
Aluminium (oxidized)		
Paint	0.30	0.95
White	0.96	0.96
Matt black		
Dirty Building Surfaces:	0.50	0.60
Light	0.80	0.85
Medium	0.90	0.95
Dark		

ϵ = emittance of surface, for low temperature radiation usually taken as 0.9 for most building surfaces, but only 0.05–0.2 for low emittance surfaces such as polished metals (e.g. 0.2 for dull aluminium and 0.05 for polished aluminium).

ΔI_1 = net long-wave radiation exchange between a black body at outside air temperature and the outside environment (W/m^2)

The term $(T_{\text{sa}} - T_o)$ is often referred to as ‘sol-air excess’ temperature, especially in British literature. For vertical walls, the long-wave exchange can be neglected and the sol-air computation can be simplified as follows:

$$T_{\text{sa}} = T_o + \frac{1}{f_o} H_h \alpha$$

Although there is an abundant literature on precise computation of the term ΔI_1 , the degree of accuracy depends on the availability of data on sky cover and other atmospheric factors. Further, the associated computational efforts and complexity make the more sophisticated methods of limited use for practical purposes. However, a reasonable approximation was proposed by Loudon (1968) at BRS. For a horizontal surface, ΔI_1 may be taken as 95 W/m^2 for a cloudless sky, 15 for an overcast sky, and intermediate values proportional to the cloud amount for partially clouded skies. Therefore,

$$\epsilon \cdot \Delta I_1 = 0.9 \times (95 - 15) * m/8 \quad (3.17)$$

Using this equation, the long-wave component of sol-air temperature ranged from -1.65 to -4.24 $^{\circ}\text{C}$ for Trivandrum, as in Table 3.8. This is comparable to the

Table 3.8 Long-wave radiation component of sol-air temperature for Trivandrum (India)

	Cloud cover (oktas)	Net long-wave radiation	The long-wave radiation correction, $f_o = 17.0$
Jan	2.6	69	-4.06
Feb	2.3	72	-4.24
Mar	2.4	71	-4.18
Apr	4.0	55	-3.24
May	5.4	41	-2.41
June	6.6	29	-1.71
July	6.7	28	-1.65
Aug	6.1	34	-2.00
Sept	5.1	44	-2.59
Oct	5.4	41	-2.41
Nov	4.7	48	-2.82
Dec	3.4	61	-3.59

recommended value of $-3.9\text{ }^\circ\text{C}$ by ASHRAE (2009, Chap. 18, p 18.23), if seasonal variation in cloud cover is accounted.

In the climate data tables, hourly values of solar irradiation on a horizontal plane are given for a typical summer and winter day (Wh/m^2 for a period of 1 h beginning and ending at the hours indicated. The irradiance in W/m^2 , at mid of the hours indicated, will be numerically the same. The direct (beam) and diffuse components are shown separately. The winter day data may be used for solar (especially passive) heating design and the summer day data for the assessment of solar gain as a load for a cooling system.

Select the ‘design time’. Irradiance is at its maximum (on the horizontal surface) at noon, but the temperature maximum usually occurs 2–3 h later. Note the worst condition hour, say between 14:00 and 15:00 h, and the values of H_b (direct or beam component) and H_d (diffuse component) at this time from the climate tables.

Find the total irradiance at the selected time for all building surfaces.

$$H_h = H_b + H_d$$

For any vertical surface,

$$H_v = H_b \frac{\cos \text{INC}}{\sin \text{ALT}} + 0.5H_d + 0.5\rho[H_b + H_d] \quad (3.18)$$

INC = angle of incidence of beam radiation

ALT = solar altitude angle above the horizontal

ρ = reflectance of foreground, normally taken as 0.2

The solar position angles, solar altitude (ALT) and solar azimuth (AZI 0–360°) can be read from sun-path diagrams as given in Chap. 5, or can be calculated as follows:

find solar hour-angle: $HRA = 15 \times [HR-12]$ where HR = hour (0–24) then

$$ALT = \arcsin [\sin LAT \times \sin DEC + \cos LAT \times \cos DEC \times \cos HRA] \quad (3.19)$$

$$AZI = \arccos \left[\frac{\cos LAT \times \sin DEC - \sin LAT \times \cos DEC \times \cos HRA}{\cos ALT} \right] \quad (3.20)$$

$T\sigma$ of AZI in the range 0–180°, i.e. for forenoon only, for afternoon $AZI = 360^\circ - AZI$ (as computed from the above equation).

The horizontal shadow angle is the azimuth difference between the sun and the building orientation (of the wall considered):

$$HSA = AZI - ORI \text{ (maximum } 90^\circ \text{, beyond this the sun is behind)} \quad (3.21)$$

if $90^\circ < |HSA| < 270^\circ$, then sun is behind the vertical face of the building

$$\text{if } HSA > 270^\circ \text{ then } HSA = HSA - 360^\circ$$

$$\text{if } HSA < -270^\circ \text{ then } HSA = HSA + 360^\circ$$

And the angle of incidence for vertical surface will be:

$$INC = \arccos [\cos HSA \times \cos ALT] \quad (3.22)$$

The climate tables give standard clock time, and the time used for calculation the hour angle in Eqs. 3.19 and 3.20 is local apparent time. This can be obtained from the standard time observed on a clock by applying two corrections using Eq. 2.17.

3.5.3 Cooling Requirements

In early design stage, cooling requirements at the ‘design time’ can be calculated using steady-state method (CIBSE 1999) based on maximum use and worst-case climate, by following the steps:

1. Read the climatic data tables for the recommended outdoor design condition, summer DBT (T_o).
2. Establish indoor design temperature (T_i) the ‘thermal neutrality’ given in the climatic data table is valid for summer and can serve as a guide.
3. Calculate conduction heat gains (Q_c in Watt) due to transmission through the building envelope by summing the mean gains through the external opaque and glazed surfaces

$$Q_c = \sum A_n U_n (T_{sa} - T_i)_n \quad (3.23)$$

where

- A = surface area for each n element, in m^2
- U = transmittance value for each n element, in W/m^2K
- T_i = indoor air temperature ($^{\circ}C$), taken as the summer thermal neutrality
- T_{sa} = sol-air temperature ($^{\circ}C$), outdoor air temperature (T_o) taken as the summer design temperature given in the climate data and solar radiation different for each orientation as element is facing

Note that, for glazing, T_o is used in Eq. 3.22 rather than T_{sa} , because the effect of solar radiation is included in the solar heat gain, see below.

4. Calculate solar heat gains (Q_s in Watt) through glazed elements consisting of solar radiation incident on the glazing and transmitted to the inside.

$$Q_s = \sum A_g H_n SHGC \quad (3.24)$$

where

- A_g = area for each n glazing, in m^2
- H_n = the global solar irradiance for each n elevation, in W/m^2
- SHGC = solar heat gain coefficient for each n glass

For the case of external shading, effective SHGC should be taken based on the procedure given in ECBC (BEE 2017).

5. Calculate the ventilation heat gain (Q_v in Watt) consists of the rate of heat flow between the interior of a building and the outdoor air, which depends on the rate of ventilation, i.e. air changes. Ventilation rates must include air infiltration, natural ventilation due to open windows and mechanical ventilation where applicable. The rate of ventilation can be given in m^3/s . Recommended outdoor air supply rate for sedentary occupant is 8 L/s/person (CIBSE 1999).

$$Q_v = \frac{c_p \rho N_v V}{3600} (T_o - T_i) \quad (3.25)$$

- c_p = specific heat capacity of air ($J/kg K$)
- ρ = density of air (kg/m^3)
- N = Number of air changes per hour, Table 3.9
- V = volume of space (m^3)

Table 3.9 Recommended values for air changes

S. No.	Space	Air changes per hour
1.	Banks, offices	4–8
2.	Bathrooms	6–10
3.	Bedrooms	2–4
4.	Cafes/restaurants	10–12
5.	Cinemas/theatres	10–15
6.	Classrooms	6–9
7.	Conference rooms	8–12
8.	Factories and workshops	8–10
9.	Hospital wards	6–8
10.	Kitchens	6–9
11.	Laboratories	6–15
12.	Lecture theatres	5–8
13.	Libraries	3–5
14.	Living rooms	3–6
15.	Refectory	8–12

For practical purposes $(c_p \rho / 3600) = 1/3$, therefore

$$Q_v = 0.33NV(T_o - T_i) \quad (3.26)$$

6. Calculate the internal heat gain (Q_i in Watt) from internal sources such as the heat output of occupants (Table 3.10), lighting, computers, appliances, which is calculated by multiplying each individual load by its duration, summing over all sources and averaging the total over 24 h. Hence,

$$Q_i = \frac{\sum q_{in} \theta_{in}}{24} \quad (3.27)$$

where

q_{in} = the instantaneous heat gain from internal heat source n (W)

θ_{in} = duration of internal heat source n (h)

7. Calculate evaporation heat loss (Q_e , in Watt) if it takes place on the surface of the building from, say, a roof pond, fountain or within the building from, say, human sweat, water in an aquarium, washing and the vapours are removed, this can be computed as

$$Q_e = E_r L \quad (3.28)$$

Table 3.10 Heat emission (W) per person for a mixture of men, women and children typical of the stated application

S. No.	Activity	Typical application	Total heat emission (W)
1.	Seated, inactive	Cinema	100
2.	Seated, light work	Restaurant	126
3.	Seated, moderate work	Office	136
4.	Standing, light work	Bank	142
5.	Light bench work	Factory	209
6.	Medium bench work	Factory	249
7.	Heavy work	Factory	440
8.	Moderate dancing	Dance hall	249

Source CIBSE (1999), figures are based on assumption that heat gain for women is 85% and children is 75% of that an adult male

where

- E_r = the rate of evaporation (kg/h)
- L = the latent heat of evaporation (J/kg)

The rate of evaporation depends on many parameters, such as available moisture, humidity of the air, temperature of the moisture itself and of the air, and velocity of the air movement. It can be estimated from the number of people in the room, their activity and thus their likely sweat rate (BS 5250 suggest a typical daily moisture production rate of 7 kg for a five person family but clothes washing use of moisture producing room heaters can increase this to 20 kg). Usually, evaporation heat loss is either ignored for the purposes of calculations (except in mechanical installations), or it is handled qualitatively only: evaporative cooling will be utilized to reduce air temperature “as far as possible”.

8. The required cooling capacity (Q), in Watt, will be

$$Q = Q_c + Q_s + Q_v + Q_i - Q_e$$

Example for calculation of steady-state design heat gain using the simple model: Figure 3.20 shows a simple office (ignoring internal walls), 5 × 4 m on plan and 3 m high, with windows/doors. It is situated in Jodhpur, Rajasthan, latitude 26° 17'N and longitude 73°1'E. Constructional and occupancy details along with surface areas and thermal transmittances are given in Table 3.11. The calculation is based on the following assumptions:

- the window will be open during the day and closed at night.
- the thermal transmittance of the window frame is equal to that of the glass.
- there are no internal blinds, therefore the solar gain.

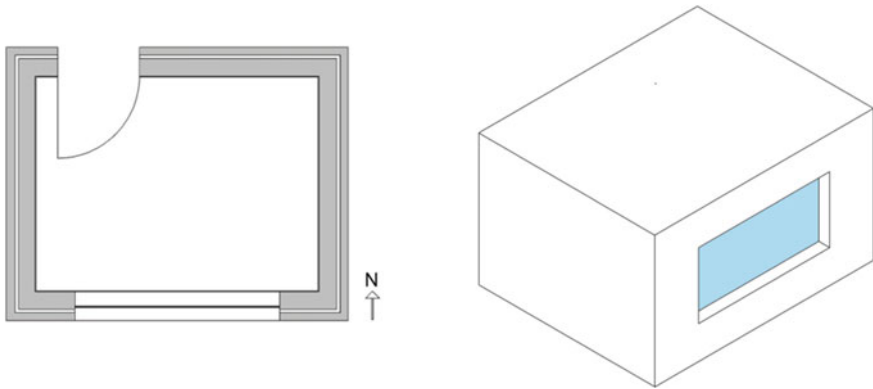


Fig. 3.20 Plan and view of example office

In Jodhpur, the hottest month is June.

$T_i = 28.7\text{ }^\circ\text{C}$, as in Table 5.59 (thermal neutrality)

Design temperature is $T_o = 40.8\text{ }^\circ\text{C}$, as in Table 5.60

Direct solar irradiance $H_b = 706\text{ W/m}^2$, diffuse solar irradiance $H_d = 219\text{ W/m}^2$ at 13:30 h, Table 5.60

Equation of time correction = $-37\text{ m } 9\text{ s}$

The local apparent time is 12.88 h for standard time of 1330 h.

These results would be approximately valid for a building of negligible mass. For heavy buildings, it would give an overestimate. To predict the long-term effects of thermal mass, a detailed thermal model, e.g. dynamic model, will be required using admittance procedure (CIBSE 1999).

3.5.4 Heating Requirements

In early design stage, heating requirements at the ‘design time’ can be calculated using steady-state method based on the simple model (CIBSE 1999) by following the steps:

1. Read the climatic data tables for the recommended outdoor design condition, winter DBT (T_o).
2. Establish indoor design temperature (T_i)—the lower limit of ‘thermal neutrality’ given in the climatic data table for winter can serve as a guide.
3. Calculate the ‘specific heat loss rate’ of the building (q) in W/K

conduction:

$q_c = \sum(A \times U)$, i.e. the sum of the products of area and U value of all enclosing elements ($\text{m}^2\text{ W/m}^2\text{K} = \text{W/K}$)

Table 3.11 Construction, occupancy details and heat gain calculation of example office

Item	Details					
External wall (opaque)	230 mm inner brickwork; 50 mm airspace; 115 mm outer brickwork; 13 mm cement plaster, U value 1.3009 W/m ² K					
Roof	13 mm outer cement plaster, 100 mm RC, 25 mm air gap; 16 mm plasterboard ceiling, U value 1.6447 W/m ² K					
Window	Single glazed, south facing, 3 m × 1.2 m SHGC 0.86, U value 5.3 W/m ² K					
Door	25 mm plywood, north-facing 1.5 m × 2.0 m; U value 2.7688 W/m ² K					
Ventilation	2 air changes per hour					
Lighting	10 W/m ² floor area; in use 0700–0900 h and 1700–1900 h					
Occupancy	Occupied 0900–1700 h by 2 persons; 80 W sensible heat output per person					
Electrical equipment	IT equipment generating 10 W/m ² ; in use 0900–1700 h					
S. No.	Surfaces	Direct H_b (W/m ²)	Diffuse H_d (W/m ²)	Reflected (W/m ²)	Solar irradiance (W/m ²)	Sol-air temperature (°C)
1.	Roof	706	219	–	925	67.15
2.	North wall	–	$219 \times 0.5 = 109.5$	$925 \times 0.5 \times 0.2 = 92.5$	202	47.26
3.	East wall	–	$219 \times 0.5 = 109.5$	$925 \times 0.5 \times 0.2 = 92.5$	202	47.26
4.	South wall	$0.04631 \times 706 = 32.705$	$219 \times 0.5 = 109.5$	$925 \times 0.5 \times 0.2 = 92.5$	234.705	48.31
5.	West wall	$0.2151 \times 706 = 151.875$	$219 \times 0.5 = 109.5$	$925 \times 0.5 \times 0.2 = 92.5$	353.875	52.12
S. No.	Building element	Area (m ²)	U value (W/m ² K)	$\Delta T = T_{sa} - T_i$ (K) or $\Delta T = T_o - T_i$ (K)	Heat gain $-A \times U \times \Delta T$ (W)	
1.	Roof	20	1.6447	$67.15 - 28.7 = 38.45$	1264.77	
2.	North wall	$15 - 2.4 = 12.6$	1.3009	$47.26 - 28.7 = 18.56$	304.22	
3.	North door	2.4	2.7688	$47.26 - 28.7 = 18.56$	123.33	
4.	East wall	12	1.3009	$47.26 - 28.7 = 18.56$	289.74	
5.	South wall	$15 - 3.6 = 11.4$	1.3009	$48.31 - 28.7 = 19.61$	290.82	
6.	South window	3.6	5.3	$40.8 - 28.7 = 12.1$	230.87	

(continued)

Table 3.11 (continued)

S. No.	Building element	Area (m ²)	U value (W/m ² K)	$\Delta T = T_{sa} - T_i$ (K) or $\Delta T = T_o - T_i$ (K)	Heat gain $-A \times U \times \Delta T$ (W)
7.	West wall	12	1.3009	$52.12 - 28.7 = 23.42$	365.60
	Q_c (W)				2869.35
8.	Q_s (W) South window	3.6	SHGC = 0.86	$H_{hi} \times A \times SHGC =$ $234.705 * 3.6 * 0.86$	726.65
9.	Q_v (W)	$V = 60 \text{ m}^3$	$N = 2 \text{ air changes/h}$	$40.8 - 28.7 = 12.1$	$0.33NV\Delta T = 479.16$
10.	Lighting	20	10 W/m ²	4 h	$20 \times 10 \times 4 = 800/24$
11.	Occupancy	2 persons	80 W/per	8 h	$80 \times 2 \times 8 = 1280/24$
12.	IT equipment	20	10 W/m ²	8 h	$20 \times 10 \times 8 = 1600/24$
	Q_i (W)				153.33
	Q (W)				4228.49

ventilation:

$q_v = 0.33 \times V \times N$, i.e. the volume of building times number of air changes per hour, times the volumetric specific heat of air

$$(Wh/m^3K. m^3/h = W/K)$$

$$q = q_c + q_v$$

4. Find the difference between outdoor and indoor design temperatures

$$\Delta T = T_i - T_o (\text{°C} - \text{°C} = K)$$

and the required heating capacity will be

$$Q = q \cdot \Delta T (W/K \cdot K = W)$$

Take example of a simple house (ignoring internal walls), Table 3.12; 12 × 6 m on plan and 3 m high, with 30% windows/doors, vertical surfaces: 2 (12 + 6) × 3 = 108 m²

In Srinagar, the coldest month is January $T_i = 16.5 \text{ °C}$ (lower limit of thermal neutrality)

$$T_o = -2.4 \text{ °C}$$

$$\Delta T = 18.9 \text{ K}$$

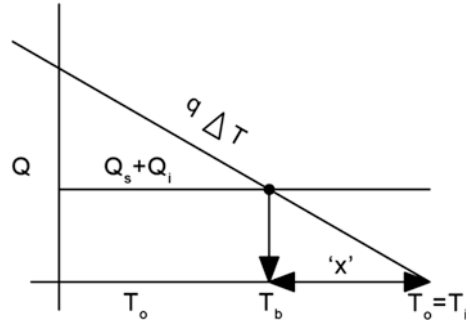
$$Q = 669.96 \times 18.9 = 12662.24W = 12.66 \text{ kW}$$

which is the required heat output rate for the heating system.

Table 3.12 Construction, occupancy details and heat gain calculation of example house

S. No.	Building element	Area (A) m ²	U value W/m ² K	Heat loss (A × U) W/K
1.	Walls, cavity brick	108 × 0.7	1.7	75.6 × 1.7 = 128.52
2.	Windows, single glazed	108 × 0.3	5.4	32.4 × 5.4 = 174.96
3.	Floor, concrete on ground	12 × 6	0.62	72 × 0.62 = 44.64
4.	Roof, tiled, plaster ceiling	12 × 6	1.5	72 × 1.5 = 108
	q_c			456.12
	Ventilation: 3 air changes/h	volume 72 × 3 = 216 m ³		$Q_v = 0.33 \times 216 \times 3 = 213.84$
	Q			669.96

Fig. 3.21 Balance-point temperature



Solar and internal gains need to be adjusted by the ‘balance-point temperature’, at which the heat loss rate (q) equals the internal (Q_i) plus solar (Q_s) heat gains. The term $Q (= q.\Delta T)$ is plotted against outdoor temperature, as in the graph below, as in Fig. 3.21.

Q_i is the heat output rate of human bodies, total wattage of lighting (if used) plus any other heat producing equipment

Q_s can be evaluated as in 3.5.3.

The value of $Q_i + Q_s$ is plotted as a constant (a horizontal line) and where it intersects the $q.\Delta T$ line, the balance-point temperature is determined.

This should then be used as the base temperature (T_b) for degree hours.

3.5.5 Dynamic Models

There are several methods available for assessing thermal performance of a building using non-steady-state or dynamic (heat flow) methods. When estimates are to be made of cooling or heating load for human occupation, it is neither possible nor desirable to attempt high accuracy: uncertain assumptions have to be made for some of the physical parameters needed, the weather is variable, patterns of usage differ widely, individuals differ in their choice of conditions, and some space and time variation in indoor temperature is generally welcomed (Davies 2004, preface, p. xv).

There are essentially two approaches to calculate the periodic thermal response of buildings (Milbank and Harrington-Lynn 1974), which has proponents in different parts of the world. In their more sophisticated forms, the two solutions give similar results to given design problems.

A number of numerical methods available for solving the transient conduction equations, the response factor method and finite difference method are the most widely used in energy calculations. For use in design, it is common to feed this type of programme with the same sequence of weather data for several days until the model reaches a stable condition. In other words, the hourly temperature and energy requirements are the same from day to day. The ‘response factor’ method is adopted by the ASHRAE (1972).

Finite difference method treats storage effects by dividing the building structure into a number of layers and calculating the temperature or energy distributions at selected time intervals. The exterior and interior temperature variations are modelled with piecewise linear functions.

In analytical or harmonic approach, the transient conduction equations are solved analytically in building thermal energy calculation with a periodic temperature boundary condition on one side of the slab and a constant temperature boundary condition on other side. Therefore, this approach is called the ‘harmonic’ solution. This approach gives the temperature or energy pattern for a building assuming it has reached the stable, or equilibrium, state for some given cycle of weather and usage. The ‘admittance’ procedure, developed by Danter (1960) and adopted by the IHVE (1970), is typical of this type of solution. It is a comprehensive procedure and as described there (without the complications of harmonics other than that of period 24 h and with only reference to time lag). The admittance procedure has the advantage that it is very simple to carry out suitable for early design stages. This procedure requires the calculation of three parameters in addition to the thermal transmittance: admittance, surface factor and decrement factor. These parameters depend upon the thickness, thermal conductivity, density and specific heat capacity of the materials used within the structure and the relative positions of the various elements that make up the construction. Each of these parameters is expressed as amplitude and associated time lead/lag.

There are a number of computer programmes for modelling thermal response of buildings which compute heat flow hour-by-hour through all components of the building using an annual hourly climatic data (8760 h). These can predict hourly indoor temperatures or the heating/cooling load if set indoor conditions are to be maintained. The most sophisticated of these are ESPr (European reference programme) and DOE-2/EnergyPlus (US reference programme). The programmes with graphical user interface include eQuest (DOE-2 engine), Design Builder, TRANSYS and IES. Nevertheless, describing the building in energy modelling software is quite time-consuming and this is not an exercise one would want to do many times over to test out different possible design solutions in the formative stages of design.

3.6 Solar Control Design

Windows are multivalent and essential feature of nearly every type of building. The environmental attributes of windows determine the luminous, thermal, acoustical and psychological environment inside of a building (Fig. 3.22), Le Corbusier

...one could say that the history of windows is the same as that of architecture or, at least this is the trait which is the most characteristic in the history of architecture.

The thermal performance of a window system depends on the meteorological conditions, the thermal behaviour of the window components and the comfort

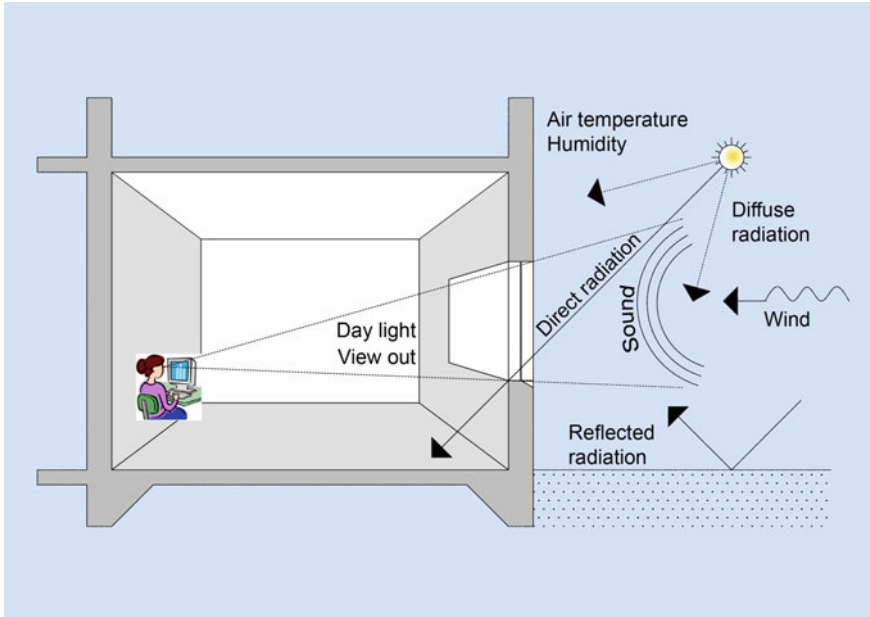


Fig. 3.22 Environmental attributes of a window

conditions required inside. The example in Sect. 3.5.3 shows that the solar radiation entering through a window is one of the greatest sources of heat gain. Window glasses have high transmittance for short-wave infrared radiation emitted by the sun, but almost no transmittance for long-wave radiation emitted by objects at terrestrial temperature in the room. Consequently, the radiant heat once it has entered through a window is trapped inside the building and increases the indoor temperature far above the outdoor air temperature; this phenomenon is known as greenhouse effect. Protection against the solar penetration through the openings is one of the most important means to prevent undesirable increase of indoor temperature.

The well-established principle of thermal solar control is to allow the solar energy into the building when the weather is cool, conversely to intercept it when it is hot. Given the wide spectrum of buildings and the different climate zones, the solar control has to be exclusively designed. There are four methods available to the designers for the solar control:

1. Orientation and window size,
2. Internal shading devices,
3. High-performance glasses,
4. External shading devices.

3.6.1 Orientation and Wall Window Ratio (WWR)

The best orientation from solar control point of view is that the building receives the maximum solar radiation in winter and the minimum in summer. For practical application, it is useful to compare the total solar radiation (direct plus diffused) incident on a horizontal and on vertical surfaces of different orientations for summer (22 June) and winter (22 December) in graph form as shown for six latitudes: 9 °N, 13 °N, 17 °N, 21 °N, 25 °N and 29 °N for summer and winter (Figs. 3.23, 3.24).

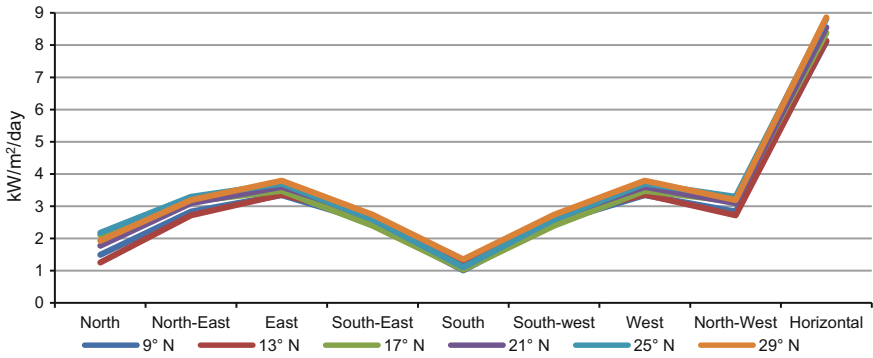


Fig. 3.23 Total solar radiation (direct plus diffused) incident on various surfaces of buildings for summer season based on data given in BIS (2016 part 8: Building services, Sect. 1 Lighting and natural ventilation, clause 3.4 Table 3)

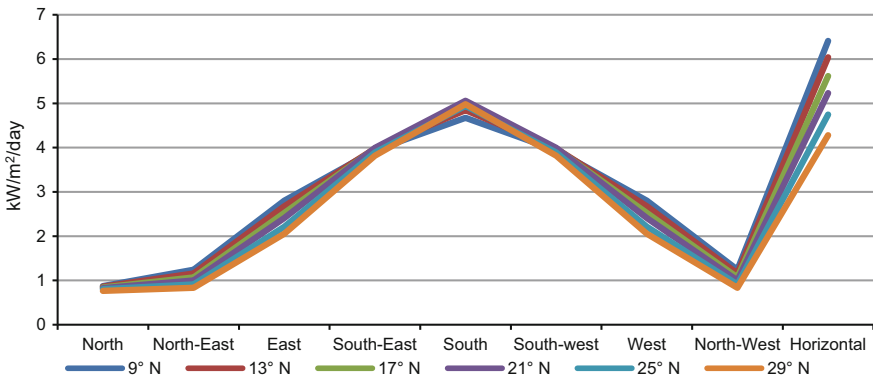


Fig. 3.24 Total solar radiation (direct plus diffused) incident on various surfaces of buildings for winter season based on data given in BIS (2016 part 8: Building services, Sect. 1 Lighting and natural ventilation, clause 3.4 Table 3)

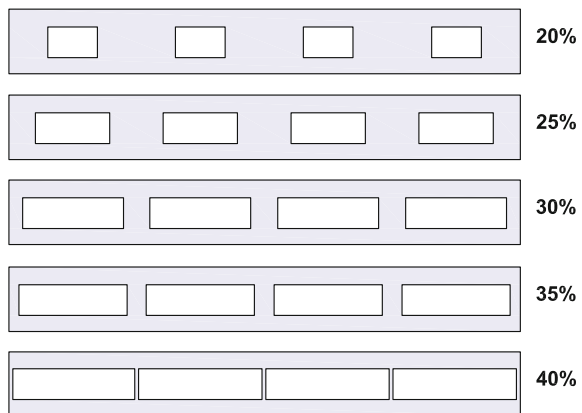
The following inferences can be drawn from the graphs:

- The horizontal surfaces receive the highest solar radiation in summer as well as in winter. It is, therefore, essential to restrict skylights, and the SRR (skylight roof ratio) should not exceed 5% as prescribed by ECBC (BEE 2017). Also, consider shading the roof even if there are no skylights since the roof is a major source of transmitted solar heat gain into the building.
- The east- and west-facing surfaces receive the second highest intensities of solar radiation for the given six latitudes. Hence, limit the amount of east and west glass. Direct solar radiation on the west side coincides with the highest temperature in the afternoon. Generally, the west side should accommodate services spaces not meant for occupants.
- The south wall (facing equator) receives the next highest intensities in the winter (when the altitude of sun is less), but it receives comparatively less solar radiation in summer. The windows may be provided on the south wall for allowing winter sun but with solar control devices to intercept the direct sun in summer.
- The north side of a building will receive solar radiation in summer. The windows may be provided on the north wall but with solar control devices to intercept the direct sun in summer.
- The wall window ratio (WWR) should not exceed 40% as prescribed by ECBC (BEE 2017), as in Fig. 3.25.

3.6.2 Internal Shading Devices

The interior shading devices such as Venetian blinds or vertical louvers do not considerably reduce cooling loads since the solar heat gain has already been admitted into the space. However, these interior devices do offer glare control and can contribute to visual comfort in the workplace. These devices absorb the solar

Fig. 3.25 Wall window ratio



heat and can increase temperature. The absorbed heat will be partly convected to the indoor air and partly reradiated. Half of this reradiation is outwards, but as it is of a long wavelength, it is stopped by the window glass. The usual narrow space between the window and the blind will thus be quite substantially overheated. The hot surface of the blind causes the indoor Mean Radiant Temperature to rise far above the air temperature.

3.6.3 High-Performance Glasses

Transmission of heat through glass depends on indoor and outdoor temperatures, area of glass and shading heat gain coefficient of glass. An ordinary glass transmits a large proportion of all radiation between 300 and 3000 nm, i.e. both visible light and short-wave infrared, but very little around and outside the 300 and 3000 nm range. Its transmittance is selective. This selective transmittance can be modified by varying the composition of the glass to reduce substantially the infrared transmission, while only slightly affecting the light transmission. The primary function of high-performance glass is to act as an efficient heat filter with little effect on the other functions of the window such as view and contact, provision of daylight. These high-performance glass elevations have great current popularity. This is probably due to the fact that a relatively simple solution to the problem of sun control can be integrated with purely abstract design without necessitating the reduction of glass area.

A wide spectrum of high-performance glasses for solar control application of fenestration has been developed by glass industry. The types of high-performance glasses are usually classified under the following broad categories:

With fixed performance:

- Heat absorbing glass,
- Solar reflecting glass,
- Solar control reflective polyester coated film glass,
- Low emittance coating glass.

With variable performance (smart glasses):

- Electrochromic glass,
- Thermochromic glass,
- Photochromic glass.

Figure 3.26 compares solar heat gain coefficient of plate glass, heat absorbing glass and heat reflecting glass.

While selecting glass for external doors and windows, the designer should ensure that the shading heat gain coefficient (SHGC) and U -value are as prescribed by the ECBC (BEE 2017). There are certain minimum requirements for visible transmittance (VT) of vertical fenestration as a function of the WWR.

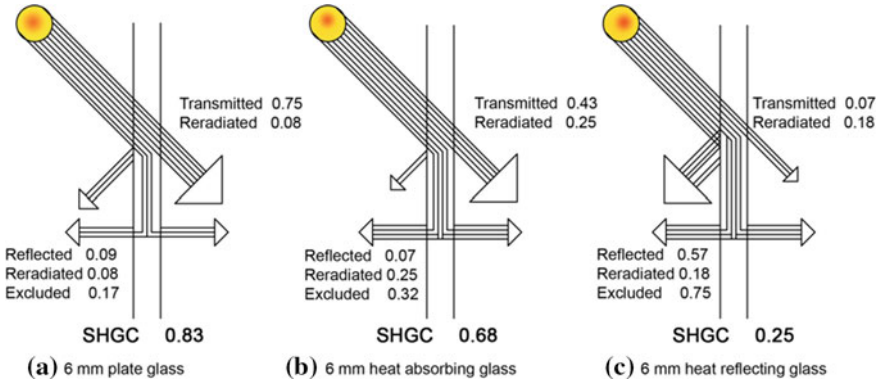


Fig. 3.26 Comparison of solar heat gain coefficient of three types of glass

3.6.4 External Shading Devices

The solar control devices have to satisfy the diametrically opposite functions to let the sun’s energy into the buildings at all times when the weather is cool and to intercept it at all times when it is hot. A solution suitable for one season may not be satisfactory for the other. A solution that is effective for a given site (latitude) may be ineffective at different latitudes.

The external shading devices are characterized by horizontal and vertical shadow angles, as in Fig. 3.27. These two angles are measured from a line perpendicular to the elevation and indicate the limit beyond which the sun would be excluded, but within which the sun would reach the point considered.

1. The horizontal shadow angle (HSA) characterizes a vertical shading device, and it is the difference between the solar azimuth and wall azimuth, same as the horizontal component of the angle of incidence.

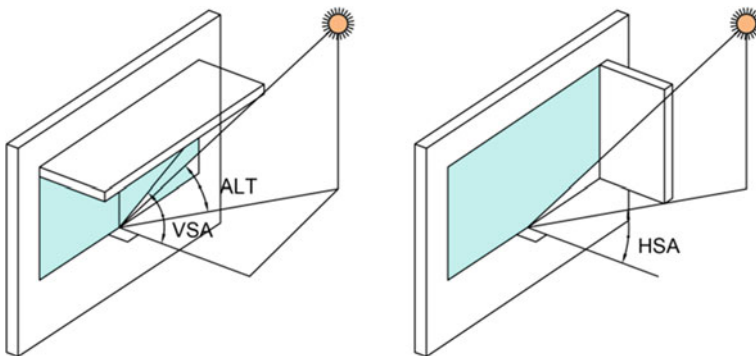


Fig. 3.27 Vertical shadow angle (VSA) and horizontal shadow angle (HAS)

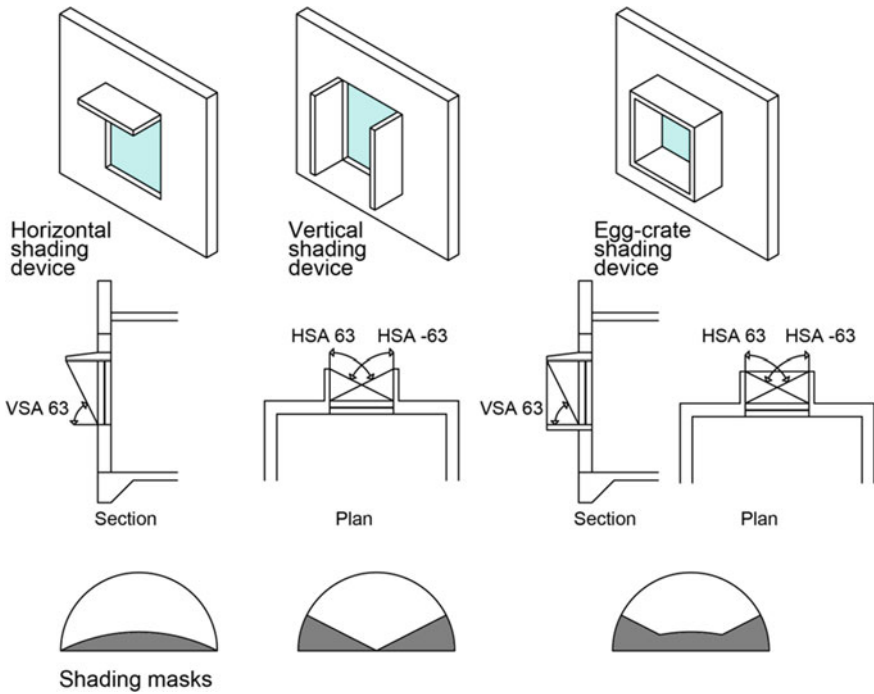


Fig. 3.28 Three basic types of shading devices and corresponding shading masks

2. The vertical shadow angle (VSA) characterizes a horizontal shading device, e.g. a long horizontal projection from the wall, and it is measured on a vertical plane normal to the elevation considered.

There are three basic types of external shading devices, as in Fig. 3.28:

1. horizontal shading device,
2. vertical shading device, and
3. egg-crate shading device.

Horizontal shading devices are very effective on south-facing windows during the summer since the sun is opposite to the building face and at a high angle in the sky. Although less effective, the horizontal overhang may also work well on the east, southeast, southwest and west orientations. Their performance will be measured by a vertical shadow angle (VSA).

Vertical shading devices are required on north-facing windows in equatorial and low-latitude climates because, during the summer, the sun rises north of east and sets north of west. Since the sun is low in the sky at these times, the horizontal overhangs are not effective and small vertical fins work well on the north façade. The horizontal shadow angle (HSA) measures their performance.

Egg-crate shading devices are combinations of horizontal and vertical elements. This type of device is most effective when the sun is to one side of the elevation, such as a north–east or south–west elevation. These can be also effective for south orientation. East- and west-facing windows receive the low-altitude angle of the sun in the morning and evening. A combination of horizontal and vertical shading devices is found effective in some cases depending on the latitude.

There is a wide spectrum of design variations for shading devices, as can be seen in the work of modern architects Le Corbusier, Oscar Niemeyer, Richard Neutra, Marcel Breuer, Paul Rudolph and others (Olgyay and Olgyay 1957).

The process of design of external shading devices essentially involves three steps:

- i. to delineate overheated and underheated periods,
- ii. to plot the overheated period on the sun-path diagram,
- iii. to find optimum shadow angles for given window orientation.

Delineate overheated and underheated periods

For any given location, the bioclimatic analysis based on the temperature data and thermal neutrality delineates the ‘underheated’ (cold discomfort) and ‘overheated’ (hot discomfort) periods. The overheated period is the one when $T_o > T_c$ (mean outdoor temperature is greater than thermal neutrality for the hottest month); the solar radiation is to be intercepted. The underheated period is the one when the mean outdoor temperature is below lower limit of thermal neutrality of the coldest month ($T_o < T_c - 2.5$ °C); the solar radiation is desirable in the building.

Table 3.13 illustrates the bioclimatic analysis of New Delhi with the use of hourly temperature for an average day of each month, the thermal neutrality for the hottest month May is 28.2 °C, and the lower limit of thermal neutrality for the coldest month January is 19.5 °C. The dark colour designates the overheated period, the mid-shade designates comfortable period, and the light area shows underheated period. Three periods are delineated for 62 cities in Chap. 5.

Plot the overheated period on the sun-path diagram

A sun-path diagram can be used as a chart to plot the overheated period, where the long east–west arcs represent the month and the cross-curves are the hour lines. The diagram can be used to find the specific position of the sun during the overheated period. Sun-path diagrams for 62 cities are given in Chap. 5. The overheated periods will differ according to climate, and the sun position will differ according to the latitude of city or place.

Except the summer and winter solstice date, each sun-path arc is representing two dates; therefore, two sun-path diagrams must be used, one from 22 December to 22 June and the other from 22 June to 22 December. The overheated period (when outdoor temperature greater than 28.2 °C) is plotted on the sun-path diagram, as in Fig. 3.29. It is relevant to mention that the overheated period is asymmetrical on both the sun-path diagrams; 22 December–22 June half-year has

Table 3.13 New Delhi N 28° 34' E 77° 11'

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours												
0:01- 1:00	9.8	13.9	18.8	25.6	29.8	30.2	28.7	28.7	27.6	22.5	15.7	11.7
1:01- 2:00	9.5	13.5	18.3	25.1	29.5	29.7	28.5	28.5	27.4	22.2	15.3	11.3
2:01- 3:00	9.2	13.2	17.8	24.6	29.0	29.5	28.4	28.3	27.2	21.9	14.9	10.9
3:01- 4:00	9.0	13.0	17.3	24.2	28.7	29.3	28.2	28.1	26.9	21.6	14.7	10.7
4:01- 5:00	8.9	12.8	16.8	23.7	28.3	29.0	28.1	28.0	26.8	21.4	14.5	10.5
5:01- 6:00	8.7	12.6	16.3	23.3	27.9	28.8	27.9	27.8	26.7	21.1	14.2	10.2
6:01- 7:00	8.5	12.5	16.0	23.1	28.3	29.0	27.9	27.8	26.5	20.9	14.0	10.2
7:01- 8:00	8.5	12.5	16.9	24.8	29.9	29.8	28.6	28.3	26.6	21.7	14.5	10.2
8:01- 9:00	9.7	14.0	19.7	28.8	32.3	31.1	29.4	29.7	28.1	25.1	18.4	11.9
9:01-10:00	11.9	16.3	22.8	31.4	34.3	32.3	30.2	30.7	29.5	28.0	22.1	14.9
10:01-11:00	14.1	18.7	25.1	33.4	36.1	33.4	31.1	31.8	30.5	30.1	25.0	17.6
11:01-12:00	16.0	20.4	26.6	34.8	37.5	34.7	31.8	32.6	31.4	31.7	26.8	19.5
12:01-13:00	17.6	21.5	27.9	35.8	38.1	35.6	32.4	33.1	32.1	32.6	27.6	20.6
13:01-14:00	18.4	22.2	28.5	36.6	38.8	36.1	32.6	32.9	32.3	33.2	28.1	21.3
14:01-15:00	18.8	22.5	28.8	37.0	39.1	36.3	32.6	32.9	32.6	33.3	28.1	21.5
15:01-16:00	18.7	22.5	28.7	36.9	38.8	36.2	32.5	32.4	32.6	33.1	27.7	21.4
16:01-17:00	18.1	22.3	28.3	36.3	37.8	35.7	32.2	31.9	32.5	31.7	25.7	20.3
17:01-18:00	16.5	21.3	26.8	35.1	37.3	34.9	32.0	31.6	31.9	29.0	22.2	18.0
18:01-19:00	14.3	19.4	24.8	32.9	35.4	34.0	31.3	30.9	30.9	26.7	20.0	15.5
19:01-20:00	12.9	17.5	23.5	30.8	33.3	32.8	30.5	30.3	29.9	25.3	18.7	14.6
20:01-21:00	12.0	16.5	22.2	29.2	31.9	31.8	29.9	29.8	29.1	24.4	17.8	13.7
21:01-22:00	11.4	15.8	21.2	28.0	31.0	31.2	29.5	29.5	28.6	23.7	17.1	12.9
22:01-23:00	10.7	15.1	20.3	27.0	30.6	30.8	29.1	29.1	28.0	23.3	16.5	12.3
23:01-24:00	10.1	14.4	19.7	26.5	30.2	30.4	28.8	28.9	27.6	22.8	16.0	11.8
Legend	Underheated		<19.5°C		Overheated		>28.2°C		Comfortable			

less overheated period than 22 June–22 December half (temperatures are lagging behind solar heating by couple of months due to heat retaining capacity of the earth). Hence, the shading device design will have to be optimized between the two limits.

Determine geometrical parameters of shading devices

To determine the geometrical parameters of shading devices, draw a line across the centre of the sun-path diagram, representing the plan of the window wall such that

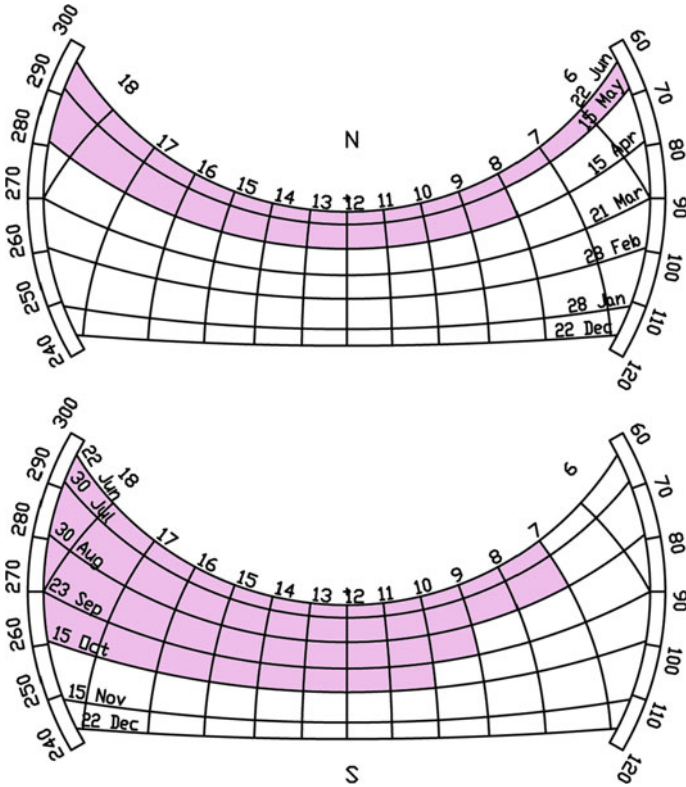


Fig. 3.29 Overheated period on sun-path diagram, New Delhi

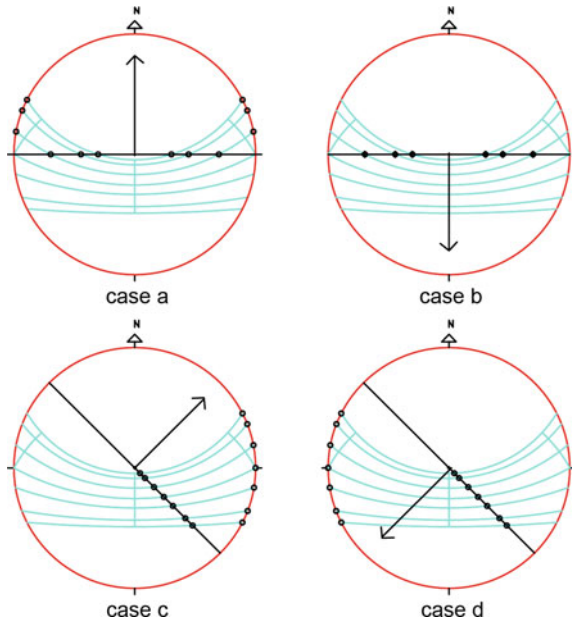
the normal to the wall is the orientation; Fig. 3.30 shows four orientations, case ‘a’ is north, case ‘b’ is south, case ‘c’ is north east, and case ‘d’ is south west and the sun rise and sun set for each wall is marked with small circles. The sun shines for maximum period on south and south west wall.

Plot on the sun-path diagram the overheated period when shading is desirable. Overlay the shadow protractor to find the horizontal shadow angle and (or) vertical shadow angle for the given window orientation, as in Fig. 3.31.

Select the horizontal shadow angle and (or) vertical shadow angles which would cover as much as possible of the given overheated period while taking care not to cover too much of the underheated period, when solar radiation is needed. Efficiency of a shading device depends on the proportionate success with which it covers the overheated area without covering the underheated area.

A north–east-facing window is illustrated for New Delhi in Fig. 3.31, below given combinations of vertical and horizontal shadow angles may give satisfactory results:

Fig. 3.30 Four orientations of window wall



- a combination of VSA 40° and HSA 37° would provide complete shading of the overheated period, but still exclude the mid-winter sun after 11:00 h.
- a combination of VSA 43° and HSA 16° would also give the required shading, but would also exclude the winter sun from about 10:00 h, which is undesirable.
- a combination of VSA 50° and HSA 30° may be an acceptable compromise: on February 28, the sun would enter from 09:20 to 11:00 h (a little longer in early March).
- a combination of VSA 60° and HSA 20° may be an acceptable compromise: on February 28, the sun would enter from 09:20 to 11:00 h (a little longer in early March).

Figure 3.32 A window facing the equator (south in the Northern Hemisphere and due north in the Southern Hemisphere) is the easiest to handle, and it can give an automatic seasonal adjustment: full shading in summer but allowing solar heat gain in winter. For complete summer 6-month sun exclusion (for an equinox cut-off) the VSA will have to be $VSA = 90^\circ - LAT$; e.g. for $LAT = 36^\circ$, it will be $VSA = 90 - 36^\circ = 54^\circ$.

This shading mask exactly matches the equinox sun-path line. For other dates, the match is not so exact, but still quite similar to the sun-path line. For orientations other than due north, the situation is not so simple. A combination of vertical and horizontal devices may be the most appropriate answer.

During any period when the sun is behind this line, its radiation would not reach that wall, thus it is of no interest. The illustration shows a north-east orientation ($LAT 36^\circ$, $ORI 45^\circ$).

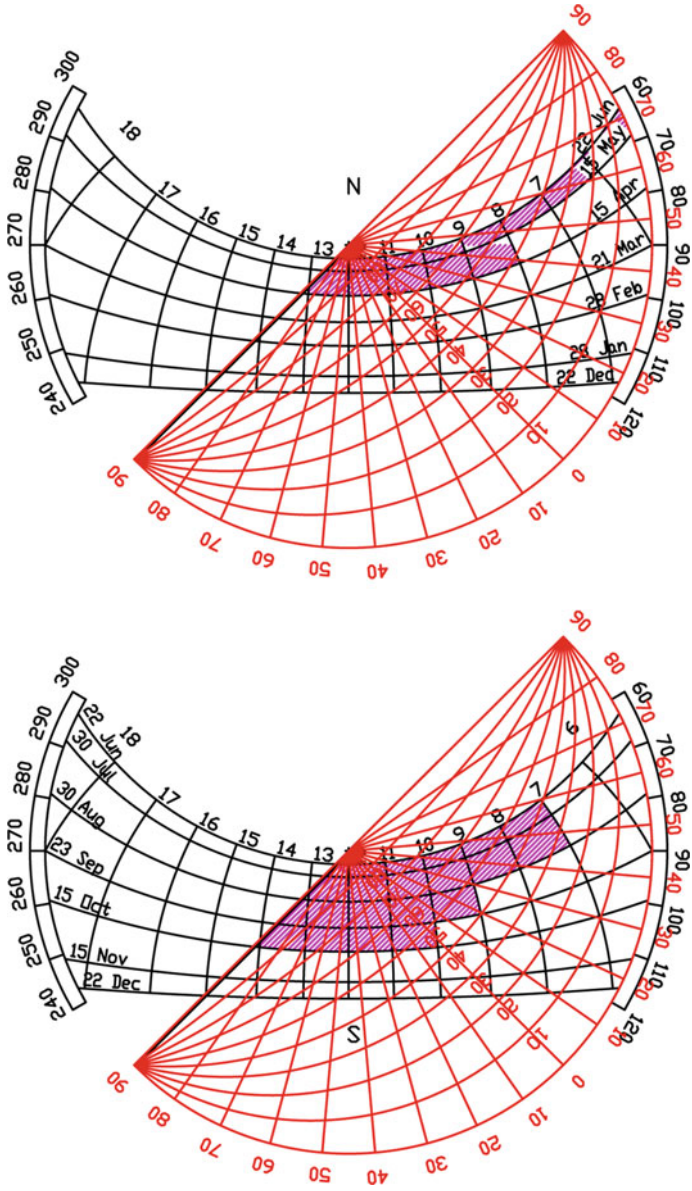


Fig. 3.31 Shadow protractor overlaid on the sun-path diagram, New Delhi

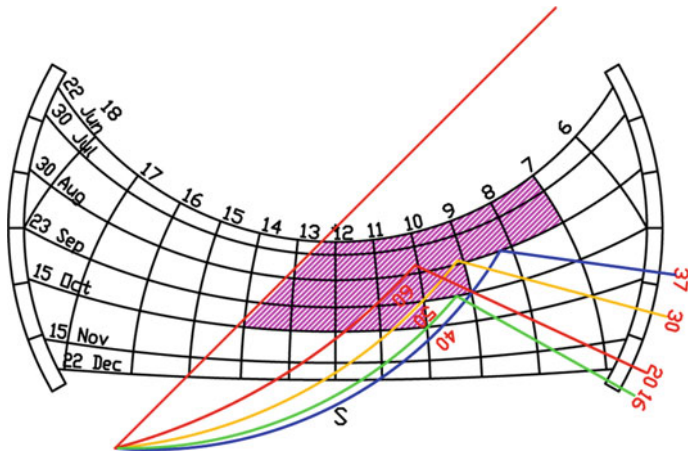


Fig. 3.32 Optimum shadow angles for N-E window, New Delhi

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Chapter 4

Design Case Studies

A human being is part of the whole called by us the universe, a part limited in time and space. We experience ourselves, our thoughts and feelings, as something separate from the rest, a kind of optical illusion of consciousness... Our task must be to free ourselves from the prison by widening our circle of compassion to embrace all living creatures and the whole of nature in its beauty... We shall require a substantially new manner of thinking if humanity is to survive.

Albert Einstein (1879–1955).

4.1 Introduction

This chapter presents five design case studies to illustrate principles and practices of sustainable building design. The selection of the design case studies is done on three criteria:

- (i) Paradigms of sustainable building design
- (ii) Representative design for each of five climatic zones in India
- (iii) Accessibility of data

Regions that fall in the cold climate zone are situated at high altitudes. The temperatures range between 20 and 30 °C in summers, while in winters, it can range from –3 to 8 °C. Cold climate needs buildings to have thermal insulation and controlled infiltration to resist heat loss and promote heat gain by directly allowing solar radiation within the living space. Druk White Lotus School, Shey, is an environmentally sustainable building designed in response to cold climate and in harmony with cultural tradition combining local construction technology with twenty-first century engineering design by UK-based firm Arup Associates and Ove Arup and partners.

Regions in hot and dry climate are usually flat with sandy or rocky ground conditions. The mean monthly maximum temperature is above 30 °C in summers, while in winters temperatures vary between 20 and 30 °C. In this climate, it is essential to control solar radiation and movement of hot winds. The building design should provide shading, reduce exposed area, and increase thermal capacity.

A number of buildings at the Jodhpur University are examples of passive solar architecture and also cost-effective design solutions for hot dry climate by veteran architect Uttam C Jain. The passive solar hostel at the Jodhpur University designed by Dr Vinod Gupta is an experimental project of the Government of India.

Temperate climate is characterized by temperatures which are within comfort zone. The annual rainfall usually exceeds 1000 mm. Relative humidity is low in winter. This climate requires a building design which would reduce heat gain by providing shading and promote heat loss by ventilation. The Energy and Resources Institute, Bengaluru, is an innovative passive solar design by the architect Sanjay Mohe, three times IIA Gold medal award winner.

Regions in warm and humid climate are along the coastal areas. In this climate, the temperatures usually vary between 25 and 35 °C in summers, while in winters, temperatures vary between 20 and 30 °C. This climate is characterized by high relative humidity, around 70–90%, and high precipitation levels, about 1200 mm per year. The building design in this climate should reduce heat gain by providing shading and promote heat loss by maximizing cross-ventilation. Dehumidification is also required to reduce discomfort in this climate. The Tata Consultancy Services (TCS) Banyan Park, Mumbai, in warm and humid climate, is designed by American architects Tod Williams, Billie Tsien and Partners. This building is LEED Certified Gold by the IGBC LEED India NC.

Most characteristics of the composite climate are similar to those of the hot and dry climate zone, except that higher humidity levels are experienced during monsoons. The building design criteria are more or less the same as for hot and dry climate (appropriate shading, reduced exposed area, and increased thermal capacity), except that maximizing cross-ventilation is desirable in the monsoon period. Aranya Bhawan, Jaipur, is a collaborative design project of Swiss engineers, and Indian building professionals to demonstrate compliance with the Energy Conservation Building Code of India would yield energy efficiency in composite climate.

More case studies can be found in the book *Energy-efficient buildings in India* by Majumdar (2002).

4.2 Druk White Lotus School, Shey, Ladakh

4.2.1 Design Intentions

If you know your foundation, then of course you can do whatever you want. Some people say modernization is very bad, Coca Cola is very bad... Nothing is bad, if you know your foundation... Everything has beauty of its own nature.

His Holiness the 12th Gyalwang Drukpa on the modernization of Tibetan Buddhist society

Druk White Lotus School, situated in the village of Shey about 15 km from the district town of Leh, emerged from the local community's desire to create a modern school that "enable(s) the students to have the confidence and competence needed to succeed in the modern world, together with a sound grounding in the Ladakhi



Fig. 4.1 Druk White Lotus School set amidst the rocky terrain (© Christian Richters)

language, culture and traditions” (DWLS 2012). The design of the school combines the best of local building materials and construction techniques of traditional monasteries of Ladakh with twenty-first century leading edge environmental design to make sustainable building in the cold climatic zone of India, Fig. 4.1 shows views of the school. It is known locally as “Druk Padma Karpo School” (*Druk* means dragon, and *Padma Karpo* can be translated as *White Lotus* in English). The school is named after Kunkhyen Padma Karpo, a great scholar of the Drupka lineage of Tibetan Buddhism, who lived in the years 1527–1592.

The school is a unique initiative of the Drukpa Kargyud Trust (UK charity no. 1014948) under the directorship of His Holiness Gyalwang Drukchen Rinpoche, the head of the Drupka Kargyund School of Tibetan Buddhism. The trust is under the patronage of His Holiness the 14th Dalai Lama, the spiritual and exiled political leader of Tibet. The school is managed by the Druk Padma Karpo Education Society (a local non-profit society) with support from Live to Love, Drupka Kargyud Trust, the Drukpa Charitable Foundation (a US 501(C)(3) organization) and Drukpa Humanitaire (France).

The plan for the school building was inspired by His Holiness Gyalwang Drupka and is laid out in the form of a traditional nine-square grid of the *mandala*, a symbolic figure of particular significance in Buddhist philosophy, surrounded by a series of concentric circles formed by low walls, stupas and willow trees. At the heart of the *mandala*, the circular library building offers an open-air temple and assembly space.

The master plan and school buildings are designed by international architects and engineers from Arup Associates and Ove Arup & Partners. The application of Arup’s engineering skills and Arup Associates’ architectural expertise in sustainability has been intentionally directed to both innovative and low-tech design approach. The innovative and sustainable architecture of the school has won several international design awards, including the 2002 World Architecture Awards for Best Educational Building, Best Asian Building and Best Green Building (joint winner).

The Druk White Lotus School is entirely sustainable project; this includes the architectural and engineering design, as well as construction, operation and educational mission of the school—all of which aspire to a modern education in harmony with local traditions, culture and religion. The school is designed for 740 pupils, including about 300 residential pupils from the surrounding villages and from nomadic families. The school will cater for girls and boys from nursery through high school, aged four to sixteen years.

The design team prioritized simplicity, robustness, adaptability and appropriateness. The team was inspired by the superbly rendered mud-brick and stone construction of the ancient monasteries. The buildings, designed to recall the region's monasteries, open onto tree-lined avenues, gardens and small stone-paved streets or squares. The courtyards in the schools are planned as outdoor teaching areas to be used during summer months.

The design strategies include the following:

- Using locally available indigenous materials, which have the least impact on the environment
- Exploiting natural ventilation and passive solar heating
- Minimizing energy use and emissions
- Minimizing water use
- Refining and adapting traditional techniques to provide modern solutions

Adapting to local conditions, Arup developed and used powerful software tools that allowed accurate analysis of the passive solar heating systems (thermosyphon and Trombe-Mechel walls), the feasibility of using wool as an insulating layer, the use of double glazing and daylighting studies. In addition, the design team had access to the firm's broader experience in seismic engineering, as many members have been involved in examining the aftermath of earthquakes, often in developing countries. Lessons learnt elsewhere were applied on this project. The project team is diverse, including the British engineers and architects, local construction manager, carpenters from Punjab and Nepalese labourers, many of whom are women. The construction manager on site is Mr. Sonam Angdus, a local Ladakhi raised in Shey.

The school is a multiphase project, and the construction started in 1998. The Nursery and Infant Courtyard opened in September 2001 and the Junior school in November 2004. Middle and Secondary school facilities were built year by year as funds permitted, with the last two secondary school classrooms completed in 2014. The school has class rooms, workshops, computer facilities, science laboratories and studios, a library, sports facilities, residential accommodation, dining hall and support facilities. The school now has over 700 students with 40% living on campus in purpose to built accommodation. The school is likely to complete by 2017.

In 2012, staff and students from the School of Architecture, Design and Construction at the University of Greenwich (London) began pioneering work on a sustainable landscape and garden environment relating to Tibetan Buddhist culture, which students, local people and visitors can enjoy and learn from. The landscape

design will transform the school's environment from a barren desert into a lush and sustainable garden that will be used for learning, playing, sports and food production.

4.2.2 *Climate and Site*

Ladakh, the “land of high passes”, is part of the state of Jammu and Kashmir, located in the northern India on the border with the Tibet Autonomous region. The only road that connects it to the plains to the south is frequently cut off for seven to eight months each year by snow. The region is situated between the Karakoram Mountain and the Great Himalayan Range. Because of its location in the rain shadow of the Himalayas, it receives minimum amount of precipitation, i.e. 100 mm only in a year; Ladakh is classified as cold climate and also a ‘high-altitude desert’ climate, warm in summer and extremely cold in winter. Ladakh is prone to seismic activity and comes under seismic zone V of National Building Code of India (BIS 2016).

January is the coldest month when mean minimum temperature is about $-14.4\text{ }^{\circ}\text{C}$ and mean maximum temperature is about $-2\text{ }^{\circ}\text{C}$ in areas of height at 3500 m. The day and night temperatures both begin to rise from March and reach its highest in July/August, which are the hottest months with average maximum temperature of about $25\text{ }^{\circ}\text{C}$ and mean minimum temperature of about $10.3\text{ }^{\circ}\text{C}$. The atmosphere over Leh district is generally dry throughout the year. The period from April to November is the driest part of year, when relative humidity is about 25–40%. Winter months January and February are slightly high humid, when humidity is around 50%.

The skies are moderately clouded to overcast on some days in the period from December to April. In the winter season, the skies are sometimes obscured in the morning due to lifted fog which clears with the advancement of day. Cloudiness decreases slightly thereafter, and skies are lightly clouded in the remaining year. The region has yearly average of 300 days of sunshine. The global solar radiation is as high as $6\text{--}7\text{ kWh/m}^2$ (which is among the highest in the world) due to high altitude and low humidity. Climatic data of Leh is given in Table 4.1 and Fig. 4.2 shows the sun-path diagram of Leh.

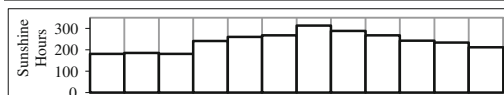
The campus is built on the edge of an outwash fan. The area is strewn with granite boulders. It has minimal soil development, with low chemical weathering, and a relative absence of humus and sparse vegetation.

Culturally, Ladakh is one of the few remaining mountain societies where a traditional Tibetan Buddhist way of life is practised, and it is often described as “Little Tibet”. Buddhism plays an important role in Ladakhi society, with the local monasteries acting as the spiritual and political centres for most villages.

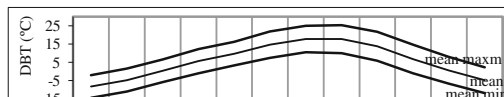
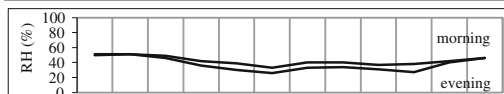
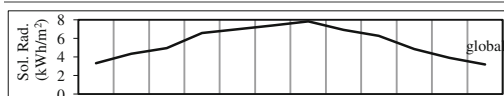
The school is close to the river Indus and its irrigated fields. It is the site of the historic Shey monastery of Ladakh. Encircled by peaks rising to over 6000 m and overlooked by two important monasteries, the site possesses a unique sense of place. The site slopes gently to the south, providing the opportunity for a south-facing settlement.

Table 4.1 Climatic data, Leh, Ladakh

Latitude	N 34° 09'					Longitude	E 77° 40'					Altitude	3700 m
Climate	Cold					Köppen	Bwk						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	179.8	184.8	179.8	240.0	260.4	267.0	313.1	288.3	267.0	241.8	234.0	210.8	238.9
Cloud (octa)													
0830 h	4.6	4.5	4.2	3.5	3.4	2.6	3.5	3.7	2.6	1.7	2.6	3.8	3.4
1730 h	4.4	4.9	5.0	4.7	4.7	3.3	3.6	3.9	3.0	2.6	3.0	3.8	3.9
Solar irradiation daily average (Wh/m²)													
Global ^a	3310	4330	4930	6550	6960	7380	7830	6920	6250	4840	3900	3190	5533
Relative Humidity (%)													
0830 h	50	51	49	42	39	33	40	40	37	38	42	46	42.3
1730 h	51	51	46	36	30	26	33	34	31	27	40	46	37.6
Dry Bulb Temperature (°C)													
max	-2	1.5	6.5	12.3	16.2	21.8	25.0	25.3	21.7	14.6	7.9	2.3	12.8
min	-14.4	-11	-5.9	-1.1	3.2	7.4	10.5	10.0	5.8	-1.0	-6.7	-11.8	-1.3
mean	-8.2	-4.8	0.3	5.6	9.7	14.6	17.8	17.7	13.8	6.8	0.6	-4.8	5.8
Neutrality	20.9	20.9	20.9	20.9	20.9	22.3	23.3	23.3	22.1	20.9	20.9	20.9	20.9
Upper limit	23.4	23.4	23.4	23.4	23.4	24.8	25.8	25.8	24.6	23.4	23.4	23.4	23.4
Lower limit	18.4	18.4	18.4	18.4	18.4	19.8	20.8	20.8	19.6	18.4	18.4	18.4	18.4
Rain (mm)	8.3	7.6	9.2	8.1	7.5	4.1	13.7	14.3	7.5	7	4.1	4.1	95.5
Wind (m/s)	1.1	1.3	1.7	2.0	2.1	1.9	1.6	1.6	1.5	1.5	1.6	1.3	1.6
Direction	C/NE/ SW/S	C/NE/ SW	C/S/ SW	C/SW/ S	C/S/ SW	C/SW/ S	C/SW/ S	C/SW/ W	C/S/ SW	C/S/ SW	C/S/ SW	C/S/ SW	
Morning						W/ SW/ NW	SW/W	SW/W	SW/W	SW	SW	C/SW	
Evening	C/SW	SW	SW	SW/W	SW/W	NW	SW/W	SW/W	SW/W	SW	SW	C/SW	



Average diurnal range (°K)	14.0
Annual mean range (°K)	39.7



Source Jacobson (2000) and IMD (2014)

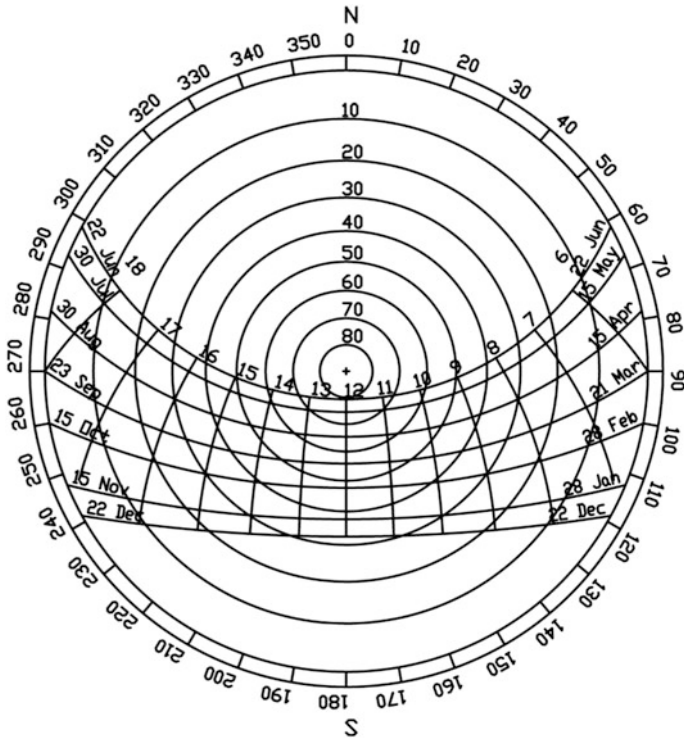
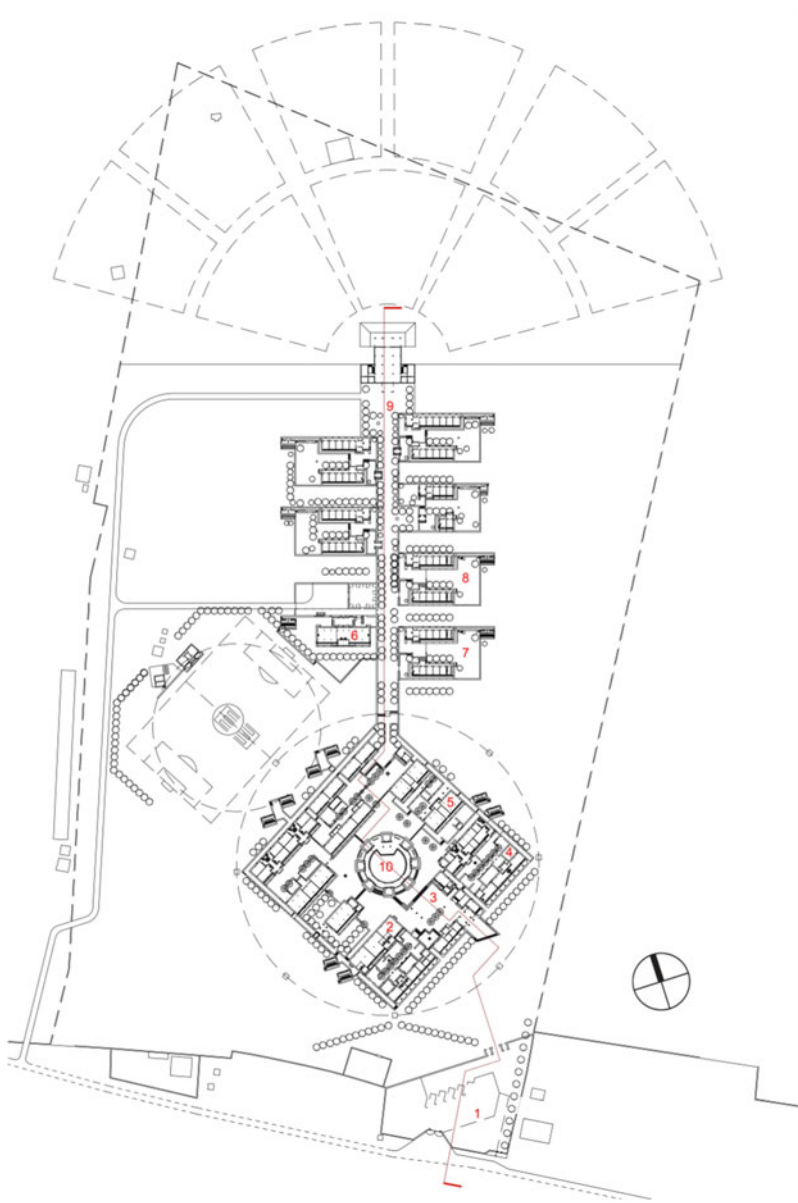


Fig. 4.2 A stereographic sun-path diagram for Leh, latitude N 34° 09'

Considering global warming and fragile ecosystem of the context, the site strategy aims to ensure a nearly zero-impact system for water, energy and waste management. The environmental design developed for the Druk White Lotus School is in direct response to the changing climate of the site, and it is environmentally selective, taking advantage of the beneficial effects of climate while moderating the adverse effects of the weather.

The master plan can be divided into four main areas: the first, the site entrance, caretaker house, visitor centre and bus drop off from the road to the south, gives pedestrian access to the second, the daytime teaching areas and the third, the residential spine rising to the north. The fourth area, comprising the water and energy infrastructure and the sports facilities, is located separately alongside a service track to the west (Galeazzi 2009). Figure 4.3 shows the master plan of the school campus.

School buildings consist of a series of classrooms and staff offices grouped in two parallel buildings planned around an open courtyard, which provides play areas and additional secure outdoor teaching spaces. Classrooms are interconnected with corridors as shown in Fig. 4.4.



Key

1. Site entrance	4. Junior school courtyard	8. Residential courtyard 2
2. Nursery & Infant's courtyard	5. Middle school courtyard	9. Naropa Temple/Palace
3. Entrance courtyard	6. Dining hall	10. Future library
	7. Residential courtyard 1	

Fig. 4.3 Master plan (© Arup Associates)



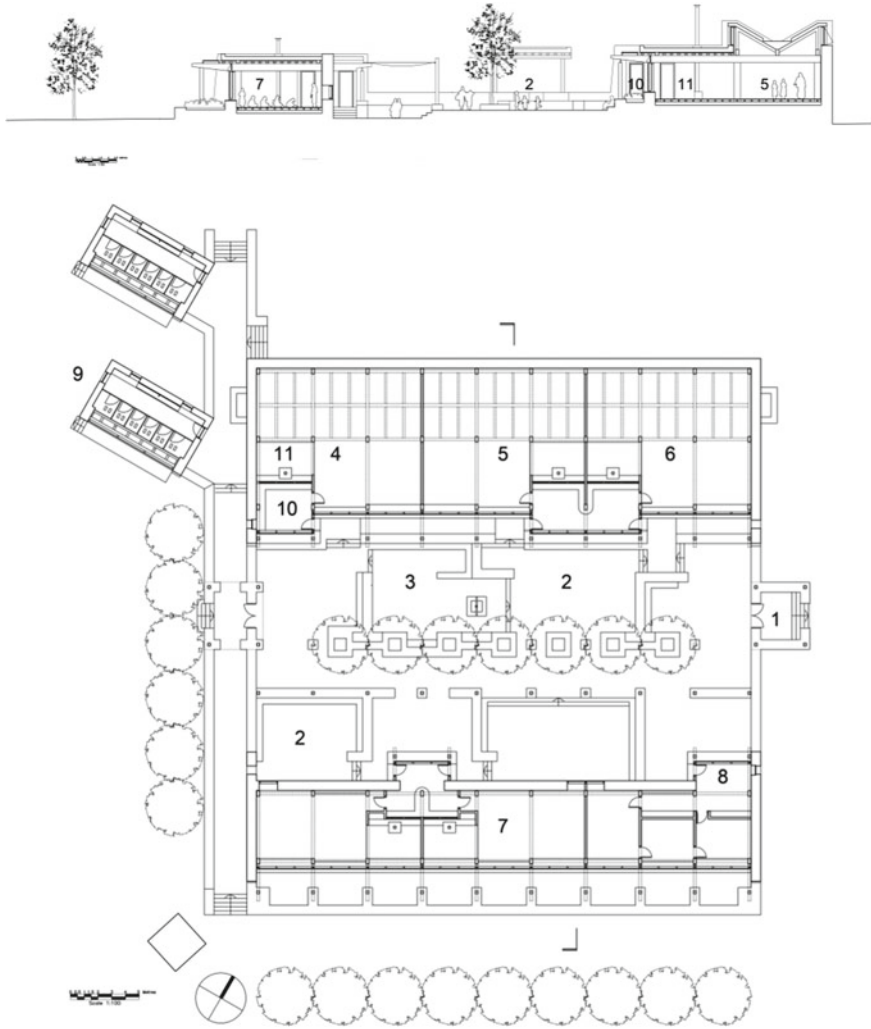
Fig. 4.4 Classrooms connected by corridor (© Christian Richters)

Residential accommodation is contained in pairs of parallel buildings that flank the main pedestrian path, stepping down the slightly sloping site. Each of the residence blocks has five rooms, each accommodating eight children, together with staff facilities, a large day living/activity room and a shower room. Similar to the school buildings, the arrangement of the residential blocks is planned around a landscaped courtyard, which offers play areas and the possibility to grow their own food and vegetables to the little residents as part of their education programme.

A dining hall located between the school and the residences provides a focus for the complex, hosting communal events. Sited as so to step towards south, the zoning of rooms within each of the blocks has been organized to provide good views out and passive solar heating and cross-ventilation for each room, while at the same time maintaining privacy.

The Druk Padma Karpo School uses timber frames to resist seismic loads and ensures life safety in the event of an earthquake. The timber frames are independent of the walls, and steel connections and cross-bracing provide earthquake stability.

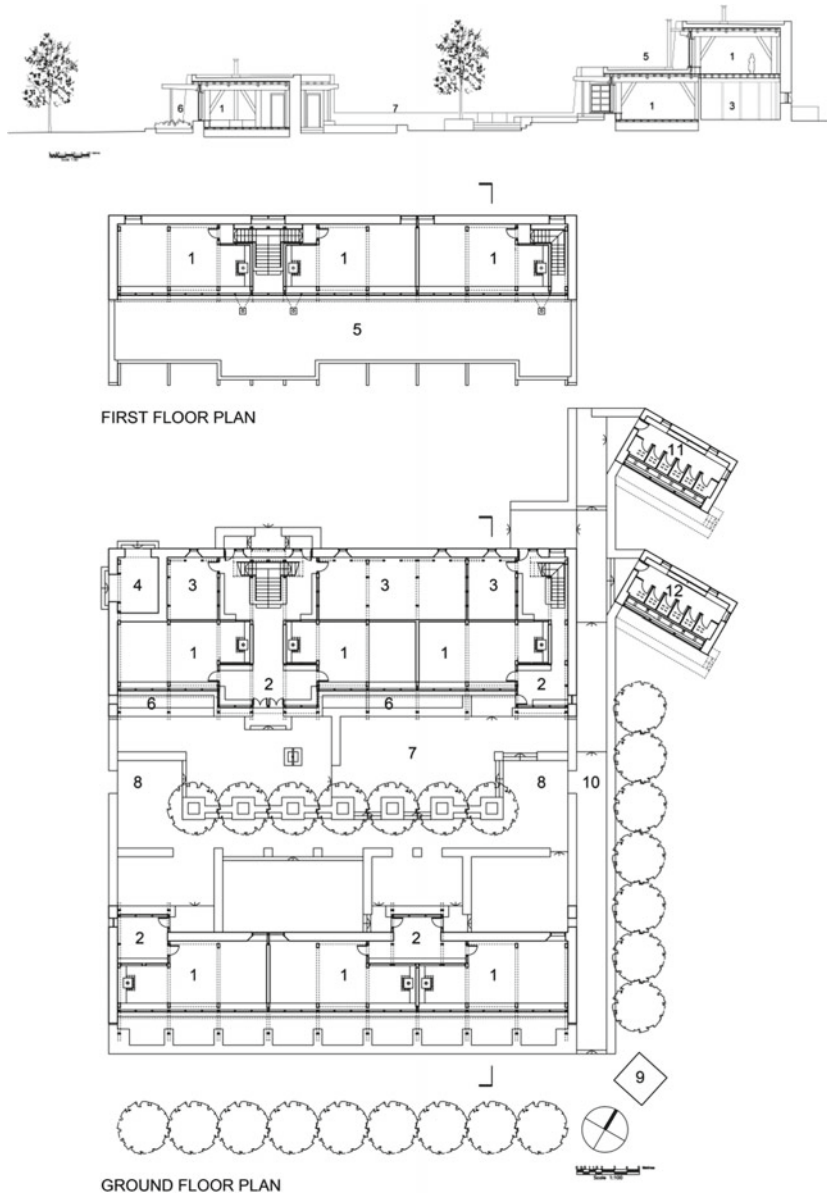
In the Nursery and Infant school, timber frames help create distinct spaces for teaching areas, Balamir (2007). While the side aisle remains at the height of the frame, the middle part is raised higher by means of a V-shaped ceiling. The structural configuration here is an M-shaped frame resting on the primary frame below. The resulting ceiling shape allows for wide clerestory window on two sides and is expressed on the outside as a distinctive ‘butterfly roof’ as shown in Fig. 4.5.



Key					
1.	Entrance to courtyard	5.	Lower kindergarten	9.	Solar assisted VIP latrines
2.	External teaching spaces	6.	Upper kindergarten	10.	Air lock and lockers
3.	Water point and play	7.	Year 1	11.	Warm/quiet corner
4.	Nursery	8.	Teachers/admin spaces		

Fig. 4.5 Plan and section, Nursery and Infants School (© Arup Associates)

In the Junior school classrooms, a ‘knee-brace’ detail has been introduced in the design of the timber frames, Balamir (2007). This makes it possible to reduce the sizes of timber sections while still maintaining seismic stability. In the two-storey building, a timber-to-timber column splice detail was derived from traditional Japanese construction as shown in Fig. 4.6.

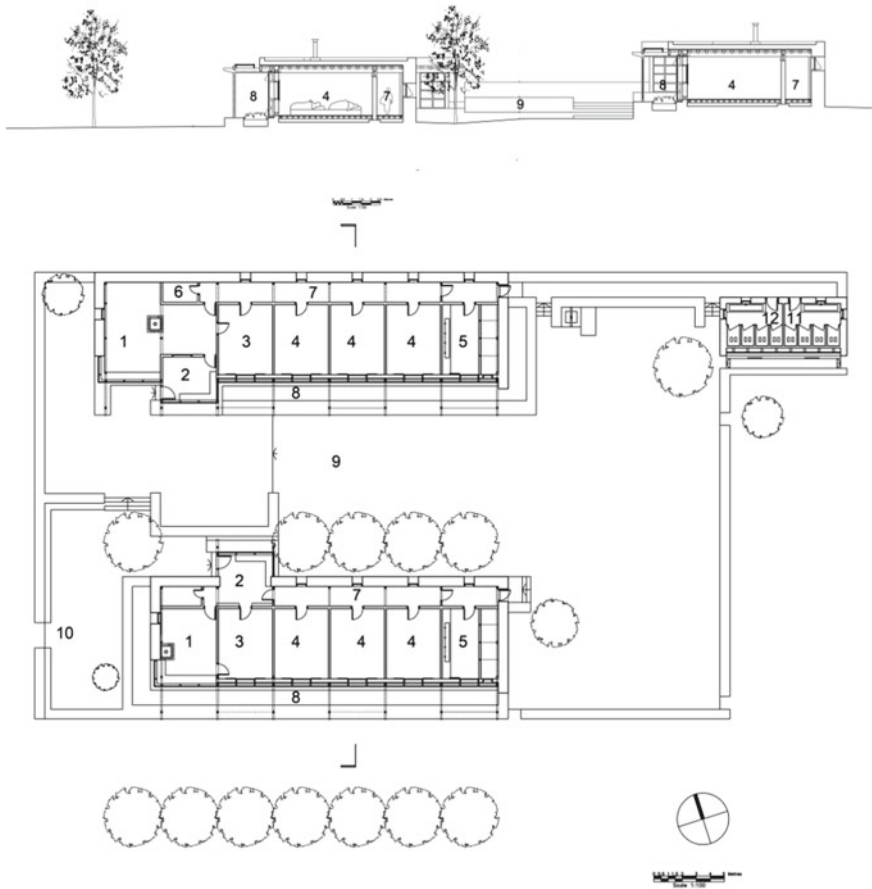


FIRST FLOOR PLAN

GROUND FLOOR PLAN

Key		
1. Classroom	5. Roof terrace	9. Stupa
2. Lobby	6. Flower bed	10. Service route
3. Store	7. Courtyard	11. VIP Dry Latrine male
4. Loggia	8. Entrance gate	12. VIP Dry Latrine female

Fig. 4.6 Plan and section, Junior school (© Arup Associates)

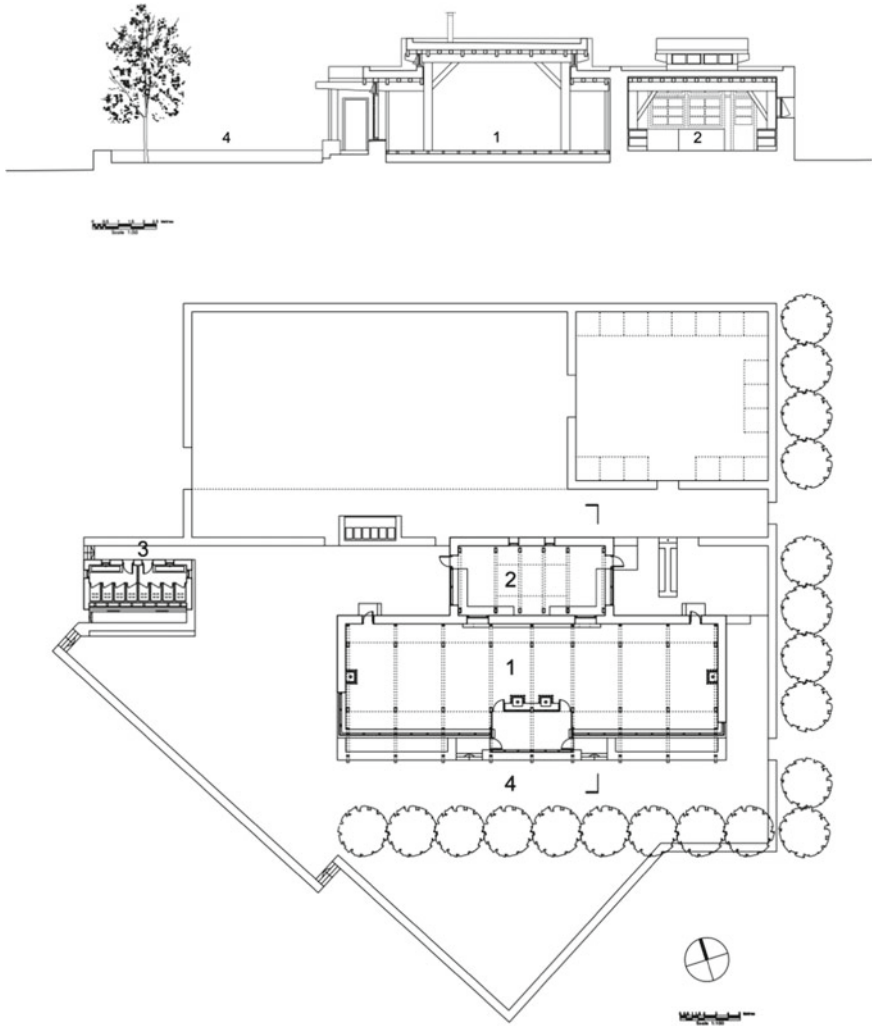


Key		
1. Living room	5. Wash room	9. Court yard
2. Lobby	6. Store	10. Entrance gate
3. Teachers' bedroom	7. Corridor	11. VIP Dry Latrine female
4. Children's bedroom	8. Flower	12. VIP Dry Latrine male

Fig. 4.7 Plan and section, Residences (© Arup Associates)

As the residences are made of a series of enclosed rooms, the structural system has been designed to take advantage of internal walls, Balamir (2007). These walls were formed from braced timber frames that provide lateral stability and carry vertical loads. Rather than panels, mud-brick walls are used in the newer residential building for acoustic reasons. As there are relatively small spans in these buildings, it was possible to use smaller section timbers as shown in Fig. 4.7.

In the dining hall, the wooden structure has been developed from the one used in the Junior school to create taller spaces and longer spans, Balamir (2007). Here, the two side aisles are lower than the middle part, providing clerestory windows on



Key	
1. Dining	3. Washrooms
2. Kitchen	4. Courtyard

Fig. 4.8 Dining hall (© Christian Richters)

both sides as shown in Fig. 4.8. One aisle provides a seating area along the double-glazed façade as shown in Fig. 4.9; the other defines the service area along with a linked building that houses the kitchen. Both the kitchen and the dining area have direct access to the outside.



Fig. 4.9 Plan and section, Dining hall

4.2.3 Daylight and Thermal Design

The whole scheme is designed to optimize use of natural resources such as solar radiation, shade, daylight and ventilation. All the classrooms are designed for optimum daylight, Fig. 4.10 shows how daylight is optimized in a classroom. In the wider Nursery and Infant building, the daylight from the window with direct solar gain is balanced by top-lighting from north- and south-facing clerestories and a splayed ceiling. No electric lighting is normally needed in the classrooms.

The master plan takes maximum advantage of the site with primarily one-storey buildings oriented differently according to their function. The *mandala* is oriented 30° east of true south to gather early morning solar radiation to warm up classrooms



Fig. 4.10 Daylight in a classroom (© Christian Richters)

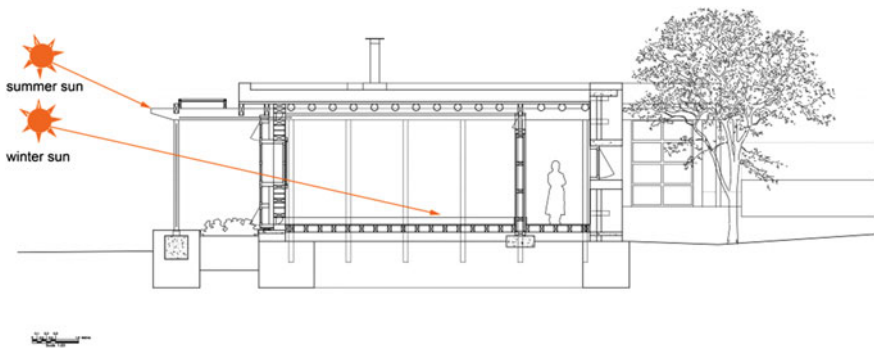


Fig. 4.11 Typical Trombe-Michel wall detail (© Arup Associates)

in winter by means of fully glazed solar caption facades using thermosyphon and store heat in high thermal mass walls and rock store under the floor (McCarthy 2010).

The residential buildings are oriented on a true north–south axis, to maximum solar gain throughout the day by means of a thermal storage and delivery system called a Trombe–Michel wall, named after French inventor Felix Trombe and architect Jacques Michel, Fig. 4.11 shows detail of a typical Trombe-Michel wall. The thick masonry that forms the Trombe–Michel wall system is coated externally with a dark heat-absorbing material and is faced with a double layer of glass creating, separated by a small airspace of 150 mm. Heat from sunlight passing through the glass is absorbed by the dark surface, stored in the wall and conducted

slowly inward through the masonry to the dormitories at night-time. Adjustable openings on the top and bottom of the thermal storage wall allow heat transfer from the heated air cavity to the room inside. This increases the efficiency of the system and ensures constant comfort levels for the young occupants. Thick stonewalls on the three sides of the block act as thermal storage for the heat gained through the Trombe–Michel wall, keeping the internal conditions almost stable, even when outdoor temperatures drop to below zero. All classrooms are entered from the courtyard via a lobby, which provides an airlock that acts as thermal buffer between the winter cold exterior and warm interior, as well as minimizing dust to the interior. The buildings, appositely separated to avoid overshadowing, take maximum advantage of the unique solar potential of the high-altitude location by using glazed south-east and south-facing facades to gather the sun’s energy, and high thermal inertia walls to store the gained heat.

Each classroom has a quiet warm corner, with a small stove on a concrete floor that is only used on days of extreme cold weather. In all buildings, occupants can control glare with internal light curtains and can use heavy internal curtains to reduce unwanted heat losses from windows during night-time.

The Trombe–Michel walls are shaded and ventilated to prevent overheating in summer. The rooms have well-shaded operable windows and roof vents that allow natural cross-ventilation and provide a cool, glare-free, high-quality teaching environment.

Throughout the school, an emphasis is placed on using local materials wherever possible. Soil from the site is used in roof construction, and the mud bricks for the inner walls are handmade in Shey. The granite blocks of the exterior walls are formed and finished from stone found on the site or gathered from the surrounding boulder field. Nearby monastery and village plantations grow the willow used in roof construction. The clay and poplar used in construction are also sourced locally.

All buildings have cavity walls on three sides. Granite blocks set in mud mortar are used for the outer leaf, while traditional mud-brick masonry is used for the inner leaf. This gives increased thermal performance and durability in comparison with the local rendered mud-brick walls.

The Ladakhi-style heavy mud and straw roof is used and is supported by a timber structure that is independent of the walls. The roofs need good insulation to minimize heat transfer in both winter and summer. The roof is constructed of local poplar rafters, willow sheathing topped with mud and rock wool and felt insulation. On top of this, corrugated aluminium sheets and sand are added to cover the felt to prevent it from melting under the constant sunshine. Timber floors provide good insulation.

4.2.4 Energy Systems

The mains electricity supply is sporadic and unreliable, with voltage frequently out of range. The school, therefore, aims to manage the electricity demand within the constraints of solar energy that take maximum advantage of Ladakh’s high and

consistent exposure to direct sunlight. Passive solar heating and effective day-lighting design help to minimize the energy demand on site. The school's electricity demands are met by solar photovoltaic (SPV) panels, and solar water heaters (SWHs) are attached to the residential buildings. The school also has a diesel generator for emergencies and periods of high demand.

The strategic decision was made by the school to construct a solar farm accommodating 300 PV panels to supply the energy for the whole campus. The gained electricity may be used directly or stored in batteries for later use, after sunlight hours (Sohie 2006). The PV panels will be mounted externally on structures south facing and tilted at 30°–40° to the horizontal. The DC circuit boards, batteries and power conditioning units shall be mounted within a protected electrical housing.

In October 2008, the first stage of a state-of-the-art 42 kWp photovoltaic microgrid solar power system was installed on the campus. The photovoltaic system generates energy with 54 south-orientated polycrystalline photovoltaic panels (9 kWp) mounted on timber frames. The panels are connected via inverters to the existing site low-voltage distribution infrastructure. An energy centre is constructed to house valve-regulated lead–acid batteries, which allow on-site energy storage. The system makes use of an AC coupling technique between the PV cells and battery system, where the frequency of the site grid is modulated in order to control the supply of electricity and prevent the batteries being overcharged. The system is fully modular, allowing for additional solar panels and battery capacity to be installed as the school building programme progresses (Cornwell and Angdus 2010). Additional panels and inverters have been purchased, and in late 2012, an additional installation of panels and inverters was completed to increase capacity to meet the demands of the expanding school.

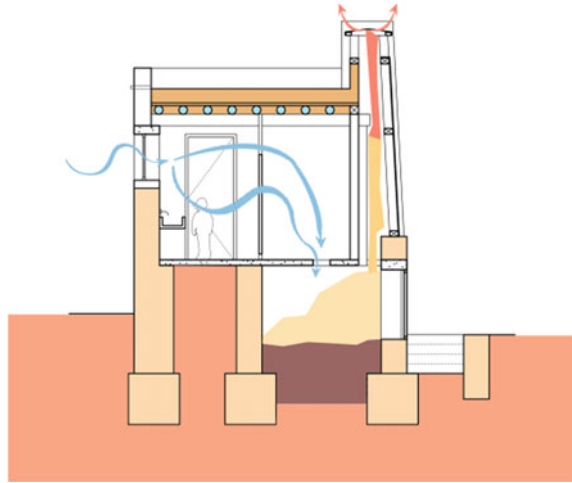
The solar scheme was independently audited and approved by TICOS, the Tourism Industry Carbon Offsetting Service, now called Beyond Carbon, and travellers may offset their carbon travel footprint via their travel agent and Beyond Carbon. Around half of the initial investments in solar energy was cofinanced by carbon-offset funds.

Arup Associates have funded 60% of the £50,000 PV installation costs as part of a voluntary agreement with Drukpa Trust (World Architecture News 2009).

4.2.5 Sustainable Thinking

Traditional dry latrines have been enhanced to Ventilation Improved Pit (VIP) latrines. These eliminate fly and odour problems and most importantly in a desert environment do not require water. A double-chamber system with an

Fig. 4.12 Ventilation
Improved Pit (VIP) latrine
(© Arup Associates)



integrated solar flue allows their operation as composting toilets and produces odourless compost (humus) that can be used as an excellent fertilizer as illustrated in Fig. 4.12.

Water is a limited resource in a region with very little rainfall. The main source of water is snowmelt from the surrounding Himalayas. The volume of water potentially available at any time depends on the amount of accumulated ice stored in glaciers and permafrost and on snowfall each winter. Through spring and summer, the snow and ice gradually melt, and the water runs down numerous channels and eventually joins the Indus River that runs through Ladakh and into Pakistan.

Two solar pumps raise water from an aquifer located about 32 m below ground (Cronwell and Angdus 2010). One pump sends water to 60,500 l reservoir located on higher ground behind Naropa Photang, from where it distributes under gravity throughout the campus, while the other provides irrigation water for the numerous trees and plants. When not needed for pumping, the PVs charge batteries that run the school's computers.

The Ventilated Improved Pit (VIP) latrines help to limit water demands because their unique design allows them to function without water. Currently, wastewater is redirected and used for irrigation of landscaping, including for willow saplings.

Solid waste is sorted for recycling into paper, plastic and other, while compostable material is utilized to create soil. Table 4.2 summarizes design profile of Druk White Lotus School, Shey, Ladhak.

Table 4.2 Design profile Druk White Lotus School, Shey

Building profile	Building name	Druk White Lotus School
	Client	Drukpa trust
	Architect	Arup Associates/Jonathan Rose
	Location	Shey, Ladakh, Jammu and Kashmir, India
	Building type	School
	Site area	130,000 m ² (13 ha)
	Built-up area	1240 m ² (ground floor 1200 m ² + 40 m ² first floor)
Solar design profile	Latitude	34° 09' N
	Longitude	77° 40' E
	Altitude	3,700 m
	Heating degree days	4000
	Cooling degree days	0
	Conservation strategies	Orientation, optimize building form and massing; luminous and thermal zoning
	Passive solar strategies	Direct gain, Mass effect, shading
	Active solar strategies	Photovoltaic system
	Other renewable energy strategies	None
	High-performance strategies	Trombe-Michel wall
Performance profile	Total annual building energy consumption	Not available
	Total annual on-site energy produced	Not available
	Size of photovoltaic system	42 kWp (first stage)
	Size of solar thermal system	300 l (79 gallons)

4.3 University of Jodhpur Campus Extension, Jodhpur

4.3.1 Design Intentions

Concord-hopping man is universal, with a fundamental sameness of urge to move faster, but he has to modify his clothing at every landing. There is a specific response to a place and climate whether one's destination is Alaska or Dhaka. Similarly, man-made shelter has fundamentally global roots in the need for protection against the elements, and yet the realization of its form and content are in response to a given place, climate and time Jain (1985).

The University of Jodhpur, now Jai Narayan Vyas University, was established in 1962. In his inaugural address, the Hon'ble President revered Prof. Radha Krishnan desired and defined the goals and objective of the university "That the young people, who will be educated in this university, will go forward not as prisoners of the past, but as pilgrims of the future; will develop in them a spirit of dedication, a spirit of renunciation, a spirit of whole-hearted, single-minded concentration on the advancement of the knowledge, whether in science or humanities" (<https://www.jnvu.edu.in/>).

This was the only residential university in the State of Rajasthan, catering mainly the needs of students of western-most Rajasthan (the Marwar). The university imparts education not only to citizens of the desert/border districts but also to the wards of defence/paramilitary forces and other organizations which are working in strategically important sectors of the country. Jai Narain Vyas University is now a divisional university for western part of the Rajasthan state.

Built in the hot and dry climatic zone, the architecture of Jodhpur University is modernism rooted in tradition Scherr (1987). The university campus extension designed by the veteran architect Uttam C. Jain exemplifies a consciousness of the local context in terms of climate, technology, economy, culture and architectural traditions. The buildings are determined by the essential characteristics and needs of its locale, but at the same time remain aligned to a predominantly modern building. Uttam C Jain espouses creating "labour intensive buildings" which "maximize the employment of unskilled (local) labour". He used the local materials, the yellow sandstone of Jodhpur, for all the campus buildings. Thus, the design and construction of the university exemplify environmental, social and economic objectives of sustainability.

The passive solar hostel designed by eminent architect Dr. Vinod Gupta is an experimental project of the Department of Non-Conventional Energy Sources, Government of India. Although energy conservation was stated as the objective, the design demonstrates application of passive solar concepts such as orientation, shading devices, passive thermal mass, earth berm, wind tower and evaporative cooling to effectively keep the room temperature conditions close to comfort limits in the hot and dry climate of Jodhpur.

4.3.2 Climate and Site

The hot and dry climate of Jodhpur is characterized by extreme dryness, wide range and extremes of temperature and the fitful and uncertain rainfall. The winter season is from November to March and is followed by the summer from April to June. The period from July to mid-September forms the south-west monsoon season and mid-September to October is the post-monsoon season (IMD 2010).

May is the hottest month with the mean daily maximum temperature at 41.5 °C, and mean daily minimum temperature is 26.6 °C at Jodhpur. January is the coldest month when the mean daily maximum temperature is 25.4 °C, and mean daily

minimum temperature is 8.9 °C at Jodhpur. Except during the short south-west monsoon season, humidity is very low. In the monsoon season, skies are heavily clouded to overcast on many days. In the rest of the year, clear or lightly clouded skies are common.

Except for moderate to strong winds during the period May to August, winds are generally light during the rest of the year. During the winter season, winds blow from north-easterly direction. By April, south-westerly winds begin and these become predominant in the summer and monsoon months. In October, winds are south-westerly and north-easterly winds begin to appear. The average annual rainfall in Jodhpur is 377.4 mm. The rainfall generally increases from the north-west to the south-east. The climatic data of Jodhpur is given in the Table 5.59, and the sun-path diagram is shown in Fig. 5.31.

The sprawling campus of the university is spread over 600 acres of land. The site is usually flat with sandy or rocky ground conditions. This project, initially commissioned in 1968 and built during the 1970s, is comprised of 12 separate academic and service buildings, as well as faculty and staff housing. The construction of passive solar hostel was completed in 1987. The project was completed in 1999.

The university buildings are widely dispersed on the campus, but their sculptural expressiveness and their sun-etched stone textures make a strong imprint on the environment (Bhatt and Scriver 1990). Eight buildings—the faculty of arts and social sciences, the central library, the central lecture theatre cluster, canteen, health centre, printing press, seminar hall and passive solar hostel—standout among them.

4.3.3 Daylight and Thermal Design

The critical problem of the Jodhpur campus was to design an appropriate structure to meet exceptionally difficult climatic demands, as well as the material, technical and budgetary limitations.

In a hot and dry climate, when the body is able to dissipate to the immediate surroundings all the undesirable heat it receives, it experiences comfort. In a modified environment, gain or loss of heat beyond comfort level to the immediate surroundings will depend on the environmental factors, air temperature of the interior and exterior, the mean radiant temperature, humidity and air movements.

In this climate, it is imperative to control solar radiation and movement of hot winds. The building design criteria should, thus, provide appropriate shading, reduce exposed area and increase thermal capacity. In this climate, the air being very dry, evaporative cooling in summer can prove to be extremely effective, but Jodhpur city faces water scarcity in summer, and any water-based cooling system should function with minimum water.

The University of Jodhpur is patterned to pick up the threads from the region's traditional roots and respond to the climatic imperatives in working out the built form. The design, therefore, uses other established passive design principles, favourable orientation, compact built forms, massive structure, reflective external

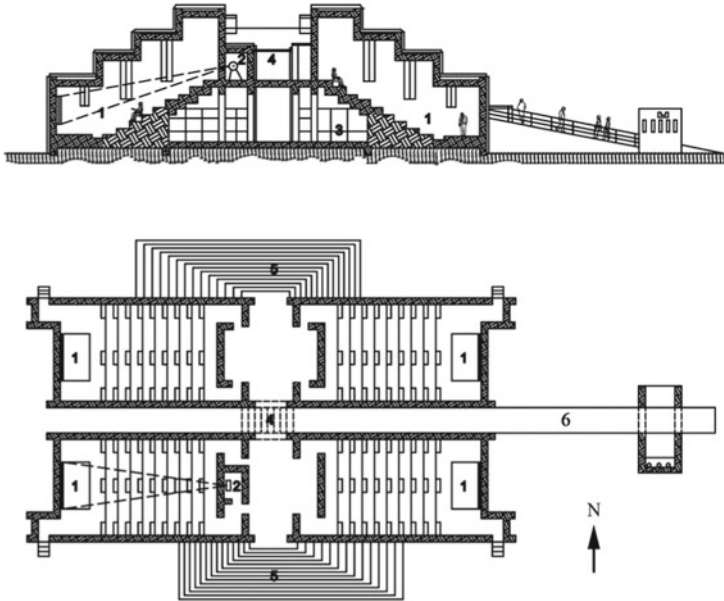
finishes, deep-set openings for diffuse daylight, twin wall screen, to combat the heat and moderate internal diurnal temperature variation. Since the university is normally on vacation during the worst summer months, winter comfort is as important as summer comfort. Deep recessed and shaded windows are provided on the north and south face in most of the buildings to allow winter sun and to shade summer sun. There are no windows on the east and west walls to avoid overheating due to sun.

Stone masonry has been used for walls because it is a local material and can provide good thermal mass to balance out diurnal temperature variation. Walls of dressed masonry laid in lime mortar are 300–450 mm thick, and floor and roof spanned by standard 3.5-m-long stone slabs determine the basic planning module. Steel and cement are used only minimally in this cost-effective design and sustainable building.

The four lecture theatres demonstrate design decisions that are rooted in traditions, craft and culture of the locality (Jain 1985). The lecture theatres are oriented true north–south to allow diffuse light through small slit openings on longer walls while as east–west walls do not have openings, Fig. 4.13 shows a view of the lecture theatres. Each lecture theatre is a simple rectangle in plan with inclined seating, supported by two parallel walls along its longer axis, Fig. 4.14 shows plan and section of lecture theatre cluster. These support the stone slab roof with intermediate structural beams resulting in cascading roof form. A stone pergola screens the central node at which the four theatres emerge. An approach ramp on the east is framed between two of the theatres reminiscent the streets of desert towns of Rajasthan. The pyramidal sit-out steps on the north and the south for summer and winter use. The robust forms intend to reinterpret the city’s architectural heritage without aiming at revivalism of architectonic forms or shapes. Philosophically spatial configuration in this design is an attempt to invoke a spirit that will establish



Fig. 4.13 Lecture theatre cluster (courtesy architect Uttam C. Jain)



Key	
1.	Lecture hall
2.	Projection room
3.	Store
4.	Court
5.	Outdoor sitting area
6.	Ramp

Fig. 4.14 Plan and section, lecture theatre cluster (courtesy architect Uttam C. Jain)

a symbiotic bond between the present and the past, between the new city and the old (Jain 1985).

The central library building is a simple rectangular Greek cross. In this building, the architect has achieved minimum distance between readers and the books. The stacks are placed in the central area on the mezzanine floor along with circulation core. And the reading areas are placed in all the four I-shaped halls, which receive ambient light. The core is interspersed with voids to allow filtered diffuse light through roof. Figure 4.15 shows a view of the library building. Figure 4.16 shows ground floor plan and typical section of the library building.

The three wings of the faculty of arts and social sciences complex form a U-shaped plan around a central open space. The ground floor houses all the faculty offices, and some of the lecture rooms. The first floor houses mainly the lecture rooms. Internally, the classrooms, seminar rooms, laboratories and offices are organized along double-loaded corridors. A double-height courtyard with a surrounding colonnade, cross-lighting at intervals and the provision of wider areas in front of office clusters animate what otherwise could have been a banal circulation scheme. The building is constructed with a double wall to counter the hot dry desert



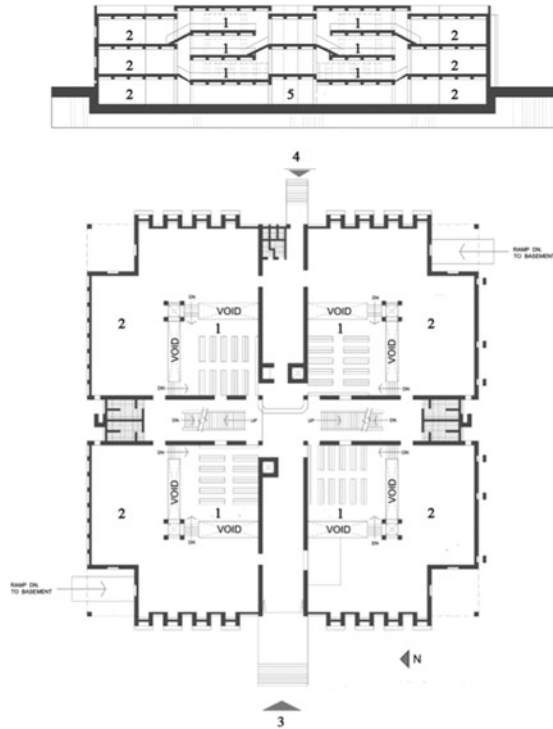
Fig. 4.15 Central library (courtesy architect Uttam C. Jain)

climate. The inner wall is structural with conventional glazed openings. The outer wall screens out direct sunlight. Its rhythmic openings follow the pattern of load-bearing stone piers behind. The sculptural gesture of the raised water tank and stair towers sandwiched between stonewalls and the ordered treatment of the façade gives the building a bold presence (Bhatt and Scriver 1990). Figure 4.17 shows a view of the faculty of arts and social sciences building. Department of Botany and Zoology is similar in plan, simple with colonnaded corridors.

Similar to the lecture theatre, the printing press has stepped profile, Fig. 4.18 shows a view of the building. This allows the light to enter in the central space. It also has steeped entrance which is clearly visible. Like other buildings of the campus, it is also made of locally available sandstone. The east–west façade is made of dead wall to cut off the heat of sun.

The canteen comprises shared kitchen and service areas with separate dining facilities for staff and students. The staff area is a small mezzanine that overlooks the larger student dining hall below. It is reached by an open staircase rising from the entrance court. With its strong sculptural disposition, offset by a backdrop of rustic masonry, this staircase transforms the diminutive structure into a set piece for some larger, still unfolding drama.

The passive solar hostel uses north–south orientation, passive thermal mass effect and airspace in the roof for insulation, reflective external finishes, deep shading device and a wind tower for ventilation and evaporative cooling (Gupta 1992). Figure 4.19 shows a view of the passive solar hostel.



Key

- | | |
|------------|----------------|
| 1. Stacks | 4. Staff entry |
| 2. Reading | 5. Basement |
| 3. Entry | |

Fig. 4.16 Ground floor plan and typical section, central library (courtesy architect Uttam C. Jain)

The hostel consists of ten two-roomed flats, each 50 m² area arranged in two blocks of five flats, three on the ground floor and two on the first floor, Fig. 4.20 shows floor plans of the hostel. The building is provided all around a 750-mm earth berm to insulate the lower part of the building, Fig. 4.21 shows section of the hostel. The walls are 380 mm thick of locally available light coloured stone. Large slabs of stone have been used for roofing, staircases, partitions and lintels over windows. The roof has been insulated by providing small inverted terracotta pots over the stone slabs and filling up the intervening spaces with lime concrete, Fig. 4.22 shows comparison of the innovative roof of the passive solar hostel with the traditional roof. Since very few manufactured materials have used, this is a low embodied energy building.

Large windows are provided on the north and south sides for lighting and ventilation. The south windows also allow the solar radiation during winter for passive solar heating, and shading devices are provided to cut off the direct solar

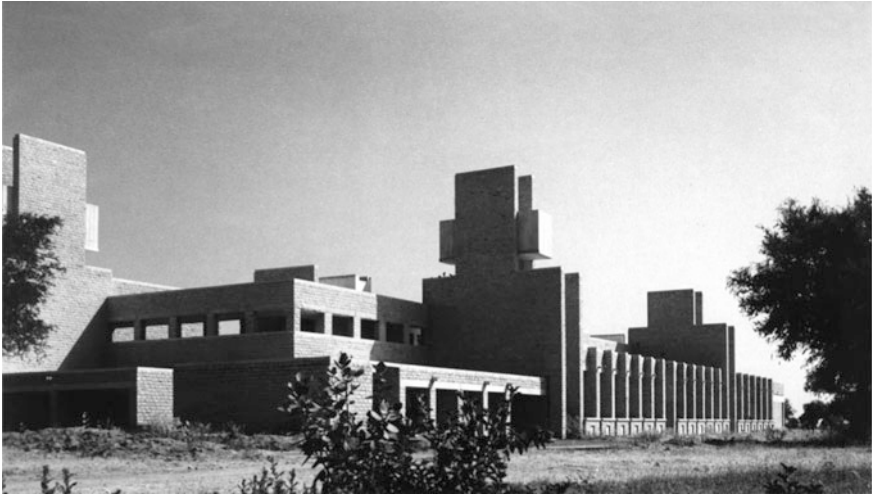


Fig. 4.17 View of the faculty of arts and social sciences (courtesy architect Uttam C. Jain)



Fig. 4.18 Printing press (courtesy architect Uttam C. Jain)

radiation during summer. One small recessed window is provided on the east and the west sides to restrict the solar heat gain. To prevent heat loss during night, solid timber shutters have been provided in addition to glass.

The prevailing direction for cool winds in Jodhpur is the south-west, but windows cannot be provided in this orientation as this is the least favourable from the point of view of solar radiation. The wind towers located over the staircase in each block overcome this problem. The wind tower rises 14.2 m high above the ground level and 7.5 m high from the rooftop. It serves as evaporative cooler during

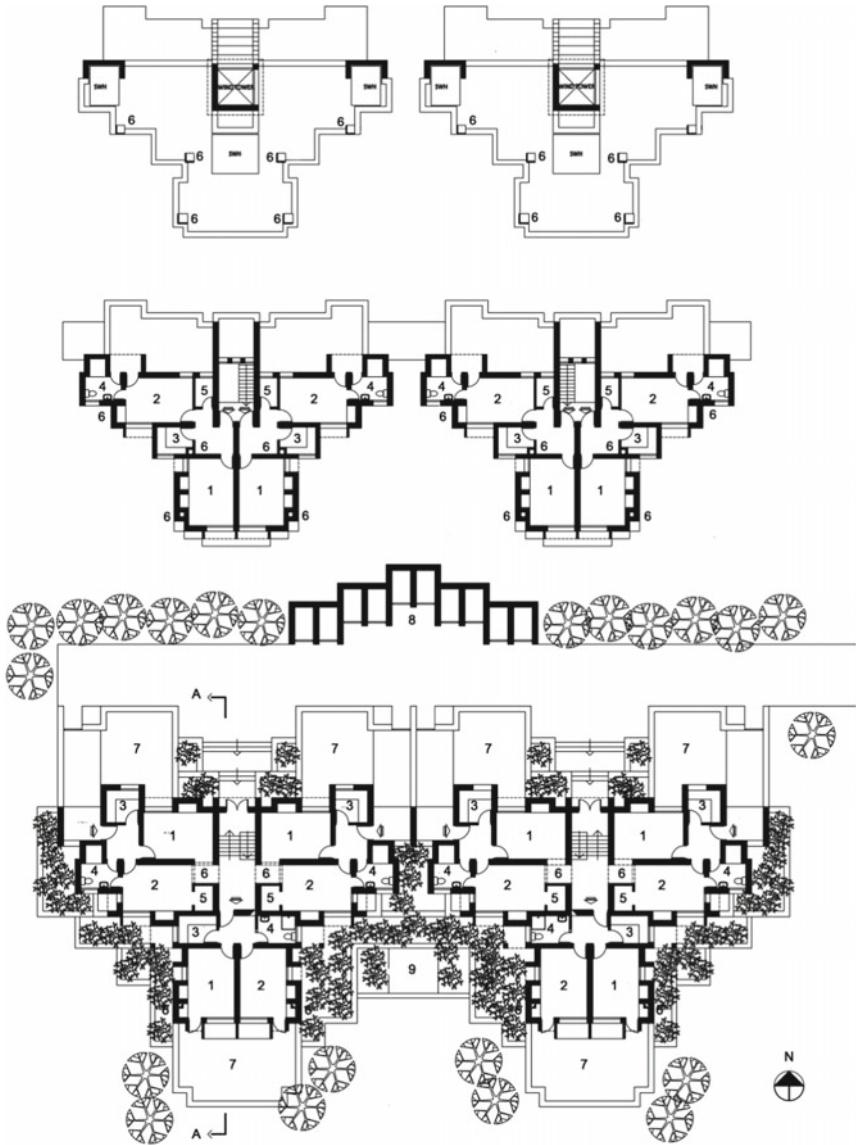


Fig. 4.19 Passive solar hostel, Jodhpur University (courtesy architect Uttam C. Jain)

summer and as ventilation device during rainy season (monsoon). It is closed during winter. Each tower is provided with two large openings of $2.5 \times 2.5 \text{ m}^2$ on windward (south-west) sides. These openings are fitted with built-in evaporative cooling systems; one tower is fitted with pad-type system as in desert coolers and the other with spray nozzles as in air washers. Water is supplied to the coolers by an overhead tank in a closed circuit by an electric pump of 0.37 kW. Cool air is drawn into the building through the wind tower and is brought into each room through the shutters located near the floor, and hot air is exhausted through small vents. One wind tower serves seven vents (smaller shafts) to assist distribution of the cool air throughout the building, with doors and windows closed; the vents are provided with exhaust openings above the roof oriented away from the prevailing winds, i.e. leeward (north-east) side to cause suction.

4.3.3.1 Energy Systems

The passive solar hostel functions in naturally ventilated mode, and there is no air conditioning. The average room temperature recorded was $20 \text{ }^\circ\text{C}$ with variation of 2 K, Mathur et al. (1993a). The average room temperature even on the coldest days ($7.5 \text{ }^\circ\text{C}$ on 5 January and $8.5 \text{ }^\circ\text{C}$ on 16 February 1992) was $18 \text{ }^\circ\text{C}$ which is about 3 K below thermal neutrality. Thus, the heating energy is substantially minimized during winter.



Key

1. Living room	4. Toilet	7. Courtyard
2. Bedroom	5. Store	8. Garages
3. Kitchen	6. Vent	9. Water tank

Fig. 4.20 Floor plans of ground floor, first floor and terrace of passive solar hostel, Jodhpur (courtesy architect Dr. Vinod Gupta)

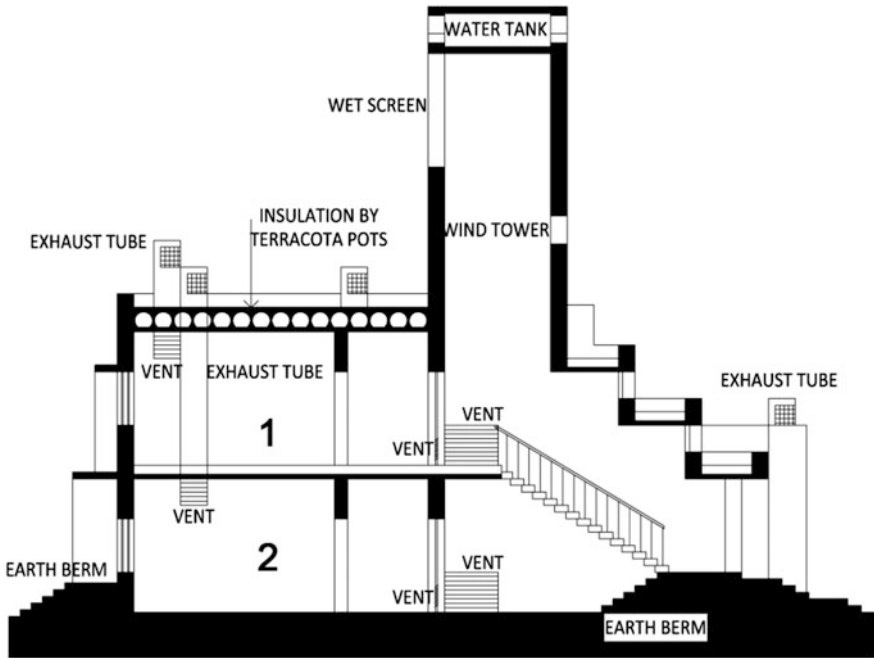
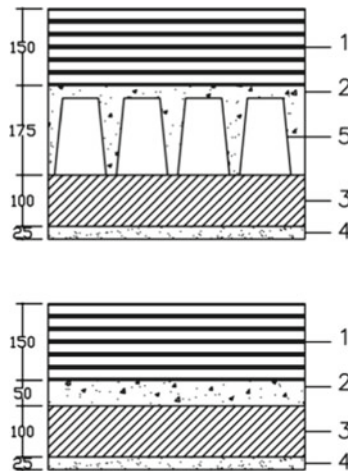


Fig. 4.21 Section 'AA' of the passive solar hostel, Jodhpur (courtesy architect Dr. Vinod Gupta)



Key

1. Lime terracing	3. Stone slab	5. Earthen pots
2. Lime concrete	4. Plaster	All dimensions in mm

Fig. 4.22 Comparison of innovative roof of passive solar hostel with the traditional roof

During summer season (May and June 1992), the airflow caused by the wind tower was measured under two conditions: (a) when the evaporative cooler was not in operation and (b) when the evaporative cooler was in operation. The average air velocity through the vent in the afternoon during May and June was about 0.95 m/s giving airflow of about 1260 m³/h through the rooms (having vents); which is about 30 air changes per hour. There was less or no ventilation in the utility areas such as kitchen and washrooms which do not have direct vent. The evaporative cooler was put into operation for 8 h during some of the days in May and June. The average air velocity increased to about 1.75 m/s increasing airflow to 2300 m³/h in the rooms (having vents), which resulted in 55 air changes per hour. Due to evaporative cooling, the temperature of the room was decreased by about 3 K, from 36 to 33 °C and the relative humidity increased from 30 to 45% (Mathur et al. 1993b). However, when the extreme ambient temperature was 45 °C and above, the room temperature achieved was 33 °C which is about 2 K above upper limit of thermal neutrality. Thus, the cooling energy is substantially saved during summer.

A common bank of solar water heater has also been installed to meet hot water requirements for ablution. Table 4.3 summarizes design profile of the University of Jodhpur.

Table 4.3 Design profile University of Jodhpur, Jodhpur

Building profile	Building name	University of Jodhpur
	Client	Jai Narayan Vyas University
	Architect	Uttam C. Jain (lecture theatre, central library, faculty of arts and social science, printing press, canteen, seminar hall, health centre) Vinod Gupta (passive solar hostel)
	Location	Jodhpur, Rajasthan
	Building type	Educational
	Site area	242.8 ha (600 acres)
	Built-up area	Lecture hall 680 m ² , canteen—330 m ² , Arts and Social science block—6970 m ² Passive solar hostel—420 m ²
Solar design profile	Latitude	26° 17' N
	Longitude	73° 1' E
	Altitude	224 m
	Heating degree days	55
	Cooling degree days	3583
	Conservation strategies	Orientation, optimized building form, luminous and thermal zoning
	Passive solar strategies	Mass effect, shading devices, earth berming, insulation
	Active solar strategies	Evaporative cooling and vents
	Other renewable energy strategies	None
	High-performance strategies	None

(continued)

Table 4.3 (continued)

Building profile	Building name	University of Jodhpur
Performance profile	Total annual building energy consumption	Not available
	Total annual on-site energy produced	Not available
	Size of photovoltaic system	Not available
	Size of solar thermal system	Not available

4.4 The Energy and Resources Institute-SRC, Bengaluru

4.4.1 Design Intentions

The Energy and Resource Institute (TERI), Southern Regional Centre (SRC) was set up in Bengaluru in 1990 with the primary objective to promote concepts and practices for improving industrial energy efficiency through a concerted programme of research, consultancy, training and information dissemination (TERI).

The project is designed to house an office block with approximately 75 workstations (spread across in two floors), interaction spaces, meeting rooms, conference rooms, laboratory, etc. The office building is attached with a small guest house with three suites, six twin sharing rooms, dining facility, business centre and library. The dining hall and recreation area are shared by the office.

Designed by the eminent architects Sanjay Mohe and V. Tushar, the building marks a novel paradigm in the creation of an energy-efficient, eco-friendly and sustainable space, successfully facilitating all thermal, visual and aural comforts for users. The design conveys a dexterous integration of five basic natural elements—sun, air, earth, water and sky—with the built form, to meet all requirements of thermal, visual and aural comfort. The five elements interplay with building design in the following manner (Majumdar 2002):

- Sun for solar water heating, electricity generation, creating stack effect by use of solar chimneys, etc.;
- Sky for daylight and also as heat sink;
- Air to create convection currents within the building through wind-induced vents, use of the Venturi effect for comfort ventilation;
- Earth for roof gardens and earth berms for insulation; and
- Water for rainwater harvesting, roof ponds and fountains for humidification.

This building is an example of sustainable architecture in the temperate climate zone of India.

4.4.2 *Climate and Site*

Bengaluru being in a moderate climate zone of India has comfortable temperature round the year. The year may be divided into four seasons. The dry season with clear bright weather is from December to February. The summer season from March to May is followed by the south-west monsoon season from June to September. October and November constitute the post-monsoon or retreating monsoon seasons (IMD 1984).

The average annual rainfall in the district is 888.9 mm. About 51% of the annual rainfall is received during the monsoon months—June to September, September being the rainiest month. The city gets almost as much as 26% of the annual rainfall during the post-monsoon or the retreating monsoon period, the rainfall during October being about as much as during September. There is also some good amount of rainfall during the summer months April and May, and it is mostly in the form of thunder showers. Except for occasional drizzle due to the incursion of the north-east monsoon current, the period from December to January is generally dry.

April is usually the hottest month with the mean daily maximum temperature at 33.4 °C and the mean daily minimum at 21.2 °C. With the onset of the monsoon early in June, there is appreciable drop in the day temperatures but that in night temperature is only slight. In October, the temperatures are same as in the south-west monsoon season, but thereafter, the temperatures are decreasing. December is generally the coolest month with the mean daily maximum temperature at 25.7 °C, and the mean daily minimum temperature at 15.3 °C. Nights during January are however slightly colder than during December. Relative humidity is high during the period June to October, being between 80 and 85% on the average. Humidity decreases thereafter, and in the period February to April, the air is comparatively drier, the afternoon relative humidity being some 25–35%. Skies are heavily clouded to overcast in the south-west monsoon season and to a lesser extent in the post-monsoon season. In the rest of the year, skies are mostly clear or lightly clouded.

Winds are generally light with some strengthening in force during the south-west monsoon season. During October, winds are either south-westerly to westerly or from the north-east to east. In November and December, winds mainly blow from the north-east and east. In the next two months, winds are mainly from directions between north-east and south-east. By March, south westerlies and westerlies begin to appear, and in May and the south-west monsoon season, winds are mostly from the directions between south-west and north-west. The climatic data of Bengaluru is given in the Table 5.15, and the sun-path diagram is shown in Fig. 5.9.

The site is located in Domlur Stage II about 3 km from Bengaluru airport, it is a long and narrow site with roads on eastern and northern sides, the western sides have an open ground, and the southern side has an open drain about 9 m wide.

Ideal long-term solution would be to improve the condition of the drain and make it a pleasant landscaped element similar to Nallah Park next to the Osho Ashram in Pune. This can be done by basic filtration and aeration as well as using plants that absorb impurities. This would be a major civic project and would

involve undertaking a longer stretch of the drain. Nevertheless, the architects had a major design challenge to prevent the foul unhygienic air blowing from the existing drain on the south side to enter the building.

The entry to the building is from the road on the northern side, which has less traffic, as compared to the one on the east. The office block is kept towards the east, close to the main road for high visibility, and the guest house is located towards the quieter western side. The open space between the office and the guest house can be used for future expansion of either the office block or the guest house.

4.4.3 Daylight and Thermal Design

The building is oriented on east–west axis with long façades facing north–south to maximize daylight and ventilation and minimize the solar heat gain. The strip windows with shading devices in the north façade help to bring glare-free daylight and cool breeze inside the building, Fig. 4.23 shows the northern façade. The double glazing with coating allows daylight inside while as prevents heat gain.

The whole section of the office building is interspersed with two main light wells with north-facing sky lights so that uniform and glare-free daylight filters into the heart of the building, Figs. 4.24 and 4.25 show the effects of daylighting strategies



Fig. 4.23 North façade, TERI-SERC (© Tapan Kumar Ghoshal)



Fig. 4.24 Daylighting, TERI-SERC (© Tapan Kumar Ghoshal)

inside the building. The interior spaces house within them subsidiary skylights that further the light into the lower floors. So as one moves through the building, one perceives alternate shade of well lit and shaded spaces. This brings about a sense of the continuation of light through and through. Even the basement parking receives natural light through the light well.

The south façade (drain side) was designed as double-wall system with a cavity to function like a solar chimney. The outer blank wall is finished with black Cudappa stone since the black colour has high heat absorptivity. The inner south wall of building has no openings at the lower level, and only ventilators are provided at the top of the wall for hot air from building to rise and escape. The sun's rays heat the black south wall increasing the temperature and causing air in the cavity to rise upwards and blow away from the building by the natural winds flowing from south to north. This creates a vacuum or negative pressure in the cavity, which in turn draws up air from inside the building by convectional currents. Thus, desired reverse wind circulation is established by bringing in the fresh air from the north open façade of the building and drawing it through the entire building and exhausting it by convectional currents through solar chimney on the south façade, Fig. 4.26 shows the southern façade the building.

The filler slabs are designed with alternate panel of concrete and hollow blocks for insulation. The hollow blocks help in reducing the transmission of heat from the outside to the inside of the building.

Fig. 4.25 Interior lighting, TERI-SERC (© Tapan Kumar Ghoshal)



The ground cover, which is disturbed due to the building of this structure, is relocated on the rooftop in the form of terrace gardens, giving insulation to the building and reducing solar radiation.

The building maintains comfortable conditions throughout the year in the natural ventilation mode without air conditioning, and this is achieved as there are no floor-to-ceiling partitions in the whole building.

4.4.4 Energy Systems

Thermally optimum building envelope, daylighting, energy-efficient lamps, luminaries and control strategies have been employed to reduce dependence on artificial means of lighting and to create comfortable conditions.

The annual average energy consumption is only about 30 kWh/m² (Majumdar 2002), with daily average demand of 12 kW (peak at 18 kW), which is almost one-tenth of that in case of a conventional building with air conditioning.

A 2-kW peak solar photovoltaic system meets a part of the power requirement. These photovoltaic cells have been arranged in line with the primary orbit of the sun

Fig. 4.26 South façade
TERI-SERC (© Tapan Kumar
Ghoshal)



(about 22–22.5° from the west ccw). The panels are integrated with the dynamic truss to optimize the generation of energy.

The solar energy is further harnessed in the form of solar water heaters (SWHs), which meets the hot water requirement of the guest house.

4.4.5 Sustainable Thinking

The other features planned in the building are an effective waste and water management system, a centralized uninterrupted power supply and a cooler kitchen that seeks to reduce internal heat. The materials come together to form a building with low embodied energy.

The central court which connects the office complex and the guest house section plays an important role as a space generator. The spaces around it follow the age-old concept of the verandah that are outside but are shaded, hence giving a feel of “withinness” to it. The central court houses an amphitheatre that acts as an informal gathering but more importantly it holds within it the rain harvesting sump



Fig. 4.27 Amphitheatre (*and sump*), TERI-SERC (© Tapan Kumar Ghoshal)

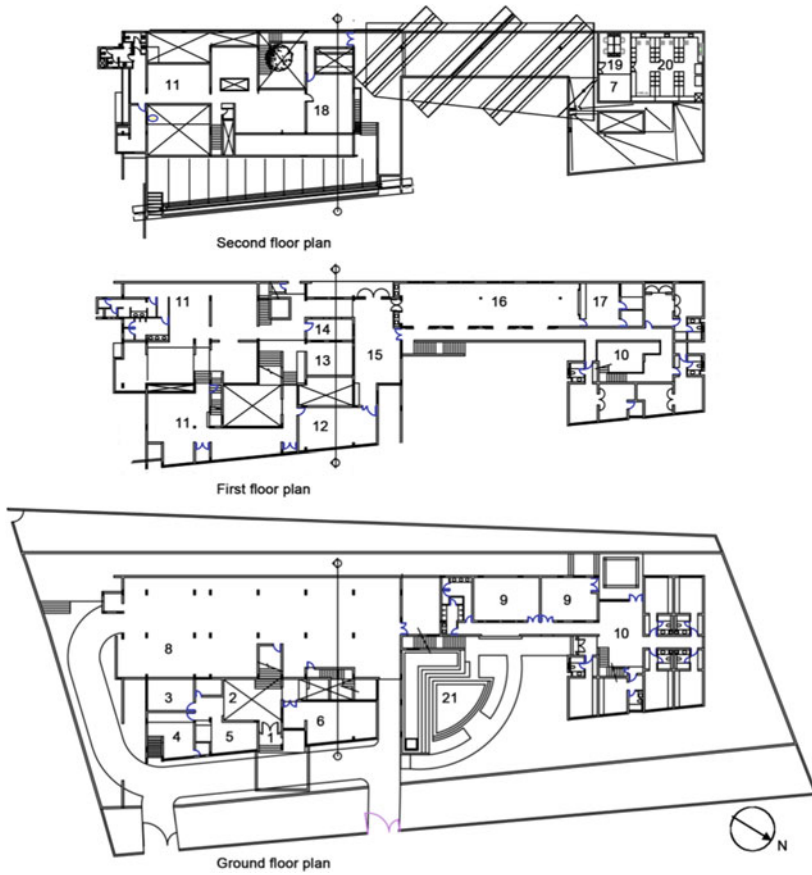
for the whole complex, Fig. 4.27 shows the exterior of the building and the amphitheatre. The rainwater is collected through down take pipes at the various levels of terraces.

The water is then pumped up to the overhead tank and is used for flushing and other maintenance activities like landscaping, etc. The water collected is directly proportional to the seasonal changes in the monsoons. This rainwater harvesting plays an effective role in water management. Figure 4.28 shows ground floor, first floor and terrace plans of TERI-SERC building. Figure 4.29 presents two elevations and a section of TERI-SERC building.

The building has been designed with landscaped courts at various levels. These courts help to enliven the working environment as well as enhance the microclimate within the structure.

The various levels of terraces also have been landscaped which reduces the heat exchanges and heat flow between the structure and the outside environment and hence acts as good insulation devices. Having this ground cover on the roof further reduces the impact on the environment through photosynthesis.

An integrated approach to building and system design has been adopted. Table 4.4 summarizes the design profile of TERI-SERC, Bengaluru.



Key

1. Entry	8. Car park	15. Discussion
2. Reception	9. Recreation	16. Kitchen
3. Conference	10. Double room	17. Dining
4. Director's office	11. Office space	18. Staff common room
5. Administrative staff	12. Auditorium	19. Work station
6. Library	13. Computer room	20. Laboratory
7. Store	14. Server room	21. Sump
		22. UPS

Fig. 4.28 Ground floor, first floor and terrace plans, TERI-SERC (Courtesy architect Sanjay Mohe)

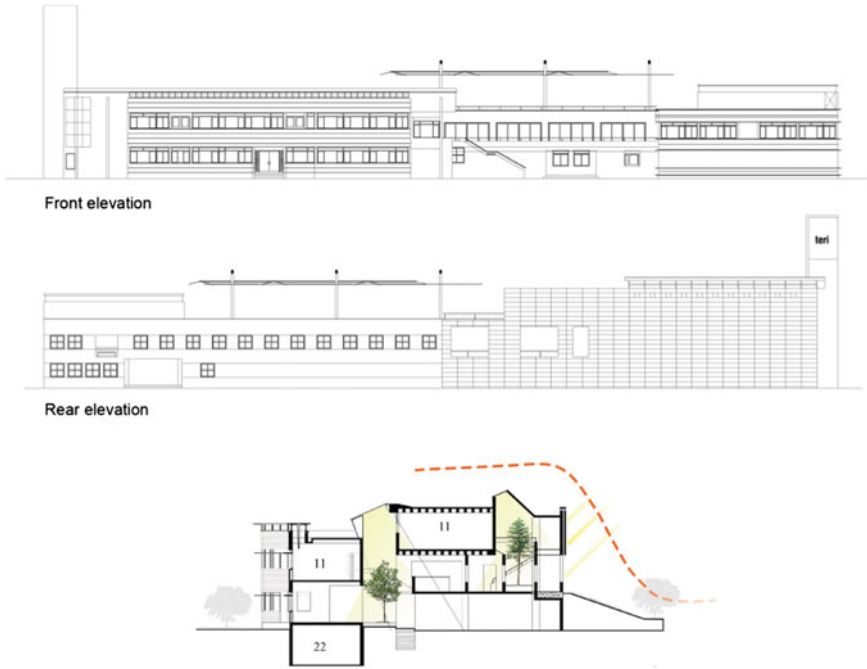


Fig. 4.29 Elevations and detailed section AA, TERI-SERC (Courtesy architect Sanjay Mohe)

Table 4.4 Design profile TERI-SERC, Bengaluru

Building profile	Building name	TERI-SERC
	Client	The Energy and Resource Institute
	Architect	Sanjay Mohe and V. Tushar
	Location	Bengaluru, Karnataka
	Building type	Office
	Site area	2506 m ²
Solar design profile	Built-up area	2465 m ² basement 82 m ² , ground floor 1147 m ² , first floor 985 m ² , second floor 251 m ²
	Latitude	N 12° 58'
	Longitude	E 77° 34'
	Altitude	921 m
	Heating degree days	0
	Cooling degree days	2143
	Conservation strategies	Orientation, optimize building form and massing, luminous and thermal zoning
	Passive solar strategies	Daylighting, shading devices
	Active solar strategies	Solar photovoltaic
	Other renewable energy strategies	Not available
High-performance strategies	Solar chimney	

(continued)

Table 4.4 (continued)

Building profile	Building name	TERI-SERC
Performance profile	Total annual building energy consumption	74143 kWh (2012) 75502 kWh (2013)
	Total annual on-site energy produced (2012)	1113 kWh
	Size of photovoltaic system	2-kW peak
	Size of solar thermal system	Not available

4.5 Tata Consultancy Services, Banyan Park, Phase 1, Mumbai

4.5.1 Design Intention

In a warm climate, people have a very different relationship to built form. One needs but minimal protection, such as a chhatri (an overhead canopy), during the day Charles M. Correa (1984).

The Tata Consultancy Services, Banyan Park, 23-acre campus, is located on a wooded site near the international airport of Mumbai. Thoughtful design decisions, both low and high-tech, emphasize the commitment to creating this environmentally sensitive building. The first 42085 m² (453000 ft²) of its development was completed in 2014, with second and third phases are scheduled for 2016 and 2018.

Ratan Tata, the chairman emeritus of Tata Sons—the parent company for the client, IT support company Tata Consultancy Services—and a current member of the Pritzker Prize jury, studied architecture in the USA, and he asked Tod Williams Billie Tsien Architects and Partners for a complex in harmony with its verdant setting. The project was done in collaboration with Somaya & Kalappa Consultants of Mumbai (Dixon 2015).

Serving as the company's headquarters, the campus houses offices for 2000 software engineers, training and conference centres, cafeteria, library, auditorium and a recreation centre with a covered swimming pool. Its buildings are connected by covered walkways that offer refuge from Mumbai's heat and monsoons, and to ensure employee comfort, the interiors are air-conditioned.

The campus is intended to be experienced on foot. Rather than grouping the entire programme into one structure, the project is divided into 12 separate buildings. They are low to the ground to emphasize the natural beauty of the site, in particular the 1800 trees, which provide a habitat for many exotic birds, butterflies and endangered fruit bats.

Banyan Park was conceived of as a landscape with buildings that are subservient to the gardens and courtyards. The project included over 1800 trees at the start, out of which it has now 1400 trees. The arrangement and shape of the buildings

conformed to the open areas and vastly reduced the number of trees that were removed for construction. The owner and architects together decided to underdevelop the site by 50% based on the available buildable area in order to preserve the unique existing landscape. The project preserves the majority of the open areas for gardens which means that most of the rainwater is managed on site.

This LEED Certified Gold building has created the latest standard for sustainable construction at the Tata Consultancy Services.

The campus also showcases the historic and the modern, for this rare property has old bungalows dating from British times that have been carefully restored out of their dilapidation into the aesthetic vocabulary of contemporary villas (Somaya and Kalappa Cons. Pvt. Ltd.). TCS, Banyan Park, won the Urban Heritage Award of the Indian Heritage Society in 2007.

4.5.2 *Climate and Site*

The warm and humid climate of Mumbai is characterized by an oppressive summer, dampness in the atmosphere nearly throughout the year and heavy south-west monsoon rainfall. The cold season from December to February is followed by the summer season from March to beginning of June. The period from June to about the end of September constitutes the south-west monsoon season. October and November form the post-monsoon season (IMD 2005).

The average annual rainfall is 2387.9 mm in the Santaruz observatory. About 96% of annual rainfall in Mumbai is received during the south-west monsoon months June to September. July is the rainiest month when about one-third of the annual rainfall is received.

May is generally the hottest month when the mean daily maximum temperature is 33.3 °C and the mean daily minimum temperature is 26.2 °C at Santacruz. January is generally the coldest month when the mean daily maximum temperature is 30.4 °C and the mean daily minimum temperature is 16.6 °C at Santacruz. Usually, mornings are more humid than afternoons over Mumbai. In the period June to October, the relative humidity is above 80%. The driest part of the year is the afternoons during the period November to February with relative humidity between 47 and 65%.

During the south-west monsoon months, the skies are generally heavily clouded or overcast. During the period December to March, clear or lightly clouded skies prevail generally. Winds are generally moderate with appreciable increase in speed during the monsoon months. Winds during the south-west monsoon season are mainly from directions between south-west and west. From post-monsoon season till May, wind is calm or from east–north-east direction in mornings and from north-west in afternoons. The climatic data of Mumbai is given in the Table 5.75, and the sun-path diagram is shown in Fig. 5.39.

TCS, Banyan Park, Mumbai, site originally housed a chemical factory and was bought by TCS in 2002. The site is located in the centre of Mumbai, close to the

international airport. The total site area is 54,496 m² of which 40% or 27,243 m² is designated as open space. This greatly exceeds the local open space requirement.

This location is central to the office buildings downtown and the outskirts of the city where the majority of the employees live. It is adjacent to the main north–south road of Mumbai and is located steps from the western express highway metrostation, a major transportation hub. This hub connects the two main branches of the Mumbai rail system. Shopping, restaurants and shops are all within steps of the project. For its very walkable location, it was given a 96/100 walk score rating. The building provides 289 parking spots for cars and 211 spots for two wheelers including bicycles for a total of 500 parking spaces for the 2000 occupants. This results in 0.25 parking spaces per occupant. The project has provided electric charging points for 3% of the car parking capacity and 3% of two wheeler parking capacity.

Every tree in the campus has been mapped, divided into five zones and subdivided into endemic (these cannot be disturbed) and exotic (these can be transplanted) types. Wooden signposts provide information on Banyan Park's biodiversity. Shortly after purchasing the property, TCS commissioned Anish Andheria from Sanctuary magazine to prepare a report on the estate's flora and fauna. Based on his findings, TCS has mapped a 'nature trail' that highlights the wildlife found in Banyan Park. This includes 51 species of butterflies, around 2500 bats and 44 kinds of birds, which amount to about 14% of the bird species found in Mumbai (TCS 2007, 2008).

For Banyan Park, the impact on account of construction of a new facility has been considered and accordingly various measures have been undertaken to protect the natural environment. Some of these measures are as follows:

- Only 45% of ground area is being used for construction, and 55% of the area is protected.
- The total capacity has been reduced from 6000 to 2000 employees, thereby avoiding cutting of a large number of trees.
- The snakes that have been spotted on campus are being relocated to the National Park in Mumbai.
- The bat colony inside Banyan Park has been declared as a "No development" zone.

To retain the biodiversity value of the property, the protected area is being maintained and monitored on a continual basis. TCS has sought the help and advice of local environmentalists and specialists in the preservation of trees, birds, bats and butterflies in our property. The company also has a partnership with the Sanctuary magazine and an in-house organization named Maitree in providing assistance in this regard.

In the first phase, Gandavali and Sarosh villas, built in the style of colonial bungalows, were restored and converted into state-of-the-art Executive Briefing Centres. While the exteriors retraced its traditionalism with similar materials, the interiors were interpreted in direct contrast through an infusion of high technology.

The two guesthouses Lotus and Orchid, one being an art deco building and the other a colonial type bungalow, were also restored and upgraded. These structures, with their landscaping and water bodies, form a unique centre in the middle of this campus. Figures 4.30 and 4.31 show the site plan and section respectively of the TCS, Banyan Park. Figures 4.32 and 4.33 show the floor plans of workstation and corporate buildings respectively.



Key

1. Corporate building	9. Utility building	18. Library
2. Executive briefing centre	10. Lotus villa	19. Jali bridge
3. Workstation building (phase2)	11. Orchid villa	20. Landscape berms
4. Recreation building	12. Entry canopy	21. Western express highway
5. Cafeteria and conference centre (Phase 3)	13. Entry courtyard	22. Security building
6. Gandavali villa	14. Garden courtyard	
7. Sarosh villa	15. Central courtyard	
8. Oculus courtyard	16. Amphitheatre	
	17. Main entry	

Fig. 4.30 Site plan, TCS, Banyan Park (Courtesy Tod Williams Billie Tsien Architects and Partners)

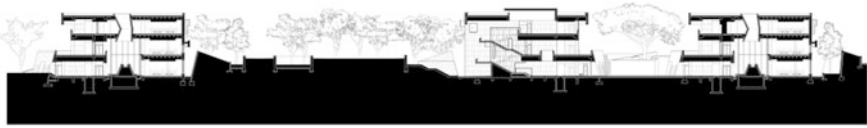


Fig. 4.31 Site section, TCS, Banyan Park (Courtesy Tod Williams Billie Tsien Architects and Partners)



Key

1. Oculus courtyard	4. Exterior walkway	7. Central courtyard
2. Workstations	5. Amphitheater	8. Garden courtyard
3. Exterior stair	6. Landscape berms	

Fig. 4.32 Workstation building level 1 plan, TCS, Banyan Park (Courtesy Tod Williams Billie Tsien Architects and Partners)

4.5.3 Daylight and Thermal Design

The office space areas are configured around a series of open to sheltered courtyards that allow filtered light. This approach allows natural daylight throughout the day, but avoids glare that often results in the use of blinds. Sunscreen elements on the facade also assist in this daylighting approach.

Elliptical openings in the roofs, known as oculi, filter light and air into courtyards below. They also impart diffused daylight to the surrounding workspaces, which have been designed to encourage views to the outside while being shielded from direct sunlight. The roofs and oculi are clad in traditional China tile mosaics. Figure 4.34 shows section of the recreation building which incorporates opening to sky for daylighting.



Key

1. Entry	4. Exterior stair	7. Presentation room
2. Entry courtyard	5. Jali bridge	8. Conference room
3. Water feature	6. Corridor	9. Office
		10. Stair

Fig. 4.33 Corporate building plan, TCS, Banyan Park (Courtesy Tod Williams Billie Tsien Architects and Partners)



Key

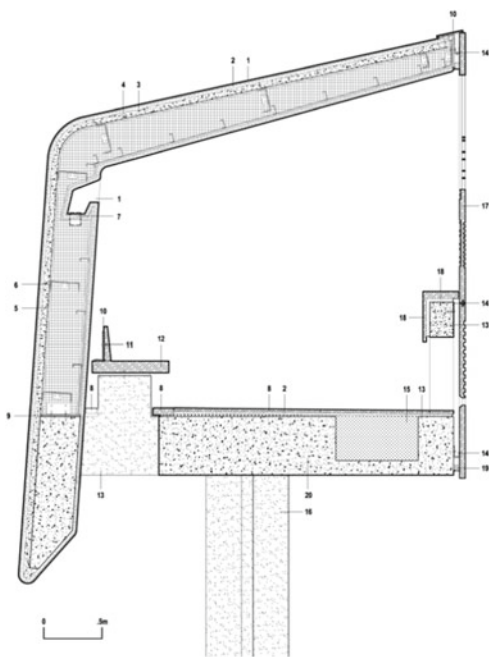
1. Pool	3. Landscape berm	5. Opening to sky
2. Gymnasium	4. Ramp	6. Stone fins

Fig. 4.34 Recreation building section, TCS, Banyan Park (Courtesy Tod Williams Billie Tsien Architects and Partners)

The buildings are connected by a network of raised, shaded passageways, providing refuge from Mumbai’s intense heat and seasonal monsoons. Walking from building to building is under cover and in the open air. Areas of grass and trees, as well as quiet, contemplative courtyards, further enrich the exterior experience. Water features, found throughout the campus, help to provide soothing relief from the intense heat.

Modern reinterpretations of jali (filigree) screens, traditional hand-carved stone panels, clad a pedestrian bridge at the entrance to the campus. They filter light, allow air to circulate, frame views of the campus and take advantage of local construction methods. Figure 4.35 shows bridge detail incorporating stone jali (filigree).

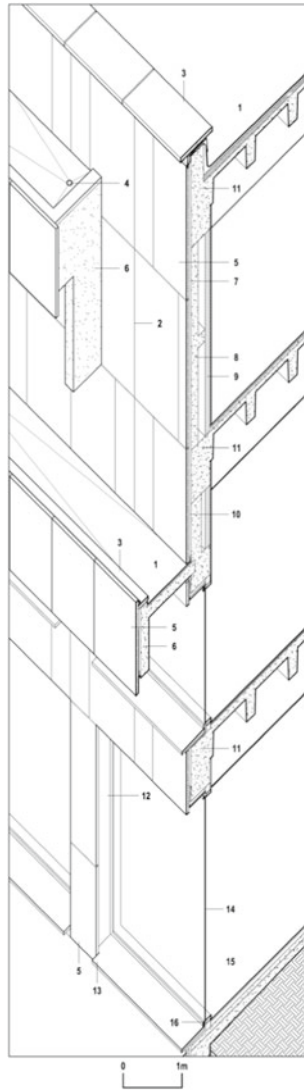
Even when walking within one building, hallways remain outdoor spaces. They are connected by generous exterior stairways, encouraging people to move from floor to floor on foot. “Breakout” spaces are incorporated into the hallways, allowing people to interact with views of the verdant landscape. This planning approach greatly reduces the building’s cooling demands and energy usage by limiting the conditioned space to the areas where it is required. Concrete and local stone are used extensively to give a sense of permanence and mass. Figure 4.36 shows axonometric view of the façade.



Key

1. China tile	8. Exterior stone paving	15. Lightweight fill
2. Mortar	9. Steel base plate	16. Concrete column
3. Waterproofing	10. Stainless steel plate	17. Stone jali
4. Gunnite	11. Stainless steel dowel	18. Stone panel
5. Steel mesh	12. Stone bench	19. Stone reveal
6. Steel	13. Concrete	20. Concrete beam
7. Light fixture	14. Stainless steel anchor	

Fig. 4.35 Bridge detail, TCS, Banyan Park (Courtesy Tod Williams Billie Tsien Architects and Partners)



Key

1. China tile roof	6. Exposed architectural concrete	11. Structural concrete
2. Open joints	7. Waterproofing	12. Stone jamb
3. Stone coping	8. Concrete wall	13. Stone sill
4. Stainless steel drain	9. Brick	14. Glass
5. Stone cladding (rain screen)	10. Air gap/insulation	15. Stone floor
		16. Aluminium window frame

Fig. 4.36 Façade axonometric, TCS, Banyan Park (Courtesy Tod Williams Billie Tsien Architects and Partners)

4.5.4 Energy Systems

The entire project is conceived of as a campus that only conditions the work areas. All circulation and break out spaces are unconditioned covered walkways that are cooled by natural breezes and ceiling fans. This approach significantly reduces energy demand and connects the campus to the surrounding landscape. Of the 31387 m² (337852 ft²) of non-parking and utility area, the net conditioned area is only 15066 m² (162169 ft²). This reduces energy consumption in combination with other major strategies incorporated in the project design including high-performance envelope, efficient HVAC system & efficient lighting system (30% better than baseline) and solar-powered exterior lighting. The result is that the project has a 19% energy cost reduction in proposed design over ASHRAE 90.12004 requirements. The project has submitted comparative details between the base case and proposed case. This results in a predicted energy use of 3,540,483 kWh/year or 10.47939 kBtus/ft²/year.

There was a careful consideration of every material chosen for the project. The design is focused on the use of Indian materials fabricated by Indian craftspeople. Almost all materials are sourced from India within 800 km of the project which both reduces transportation requirements and also roots in the place it is built. For example, 94% of the project's roof surface is coated with high albedo roofing material—china mosaic tiles. This traditional Indian roofing technique provides work craftspeople while vastly reducing the heat island effect of the building. All wood for the building was sourced from certified reclaimed wood suppliers.

Due to the conservation and efficiency improvements listed below, TCS has achieved an efficiency improvement of 5% in its energy usage:

- Auto power off of PC monitors/computers after some idle time
- Maintaining constantly the air conditioning temperature at 24 °C
- Encouraging employees to physically switch off the monitor and PC before leaving
- Energy-saving lighting techniques such as “alternate lighting”—in a succession of lights, keeping every alternate light off, and maximizing usage of daylight
- Reducing elevator usage by operating only a percentage of lifts available.

4.5.5 Sustainable Thinking

Materials and finishes for the Banyan Park project were specified with sustainability in mind. An emphasis on the use of local materials sourced in India and on the use of hand-crafted materials was central to the design process. 5.94% of salvaged, refurbished or reused materials were used on-site. Salvaged timber which was a structural roof of a demolished factory building located in Mumbai was procured to be used in furniture and millwork for the project. The project has achieved a

combined recycled content value of 7.12% of the total materials, by cost. Some of the recycled materials used in the project include steel, glass, gypsum, MDF (Medium density fibre) board & tiles. 50.56% of the total project's materials by cost are manufactured within 800 km of the project site. Locally extracted and manufactured materials used in the project include RMC (Ready-mix concrete), bricks, stainless steel railings, timber, china mosaic and stone. 46.12% of the total project's materials by cost are also extracted within 800 km of the project site. VOC (Volatile organic compound) levels in all adhesives, sealants, paints and coatings do not exceed stipulated limits. The carpet systems and cushions used in the project meet or exceed the requirements of CRI's Green Label Indoor Air Quality Test programme, and the carpet adhesive meets the VOC requirements.

The project has diverted more than 77.82% of construction waste from landfills. The construction waste management plan was to separate, store, reuse and recycle the construction waste generated on the project site. The list of materials that the project has diverted includes concrete, bricks, steel, stone, metal and packaging material.

Materials which demonstrate India's great capacity for handiwork and craft are used throughout the campus. Door handles are detailed with a blackened metal and silver engraving technique, known as bidri. Vivid handmade tiles and wood screens bring colour, texture and warmth to the interiors. The foundation Women Weave is collaborating on the project to create 140 custom Ikat tapestries, which will be woven in rural India and then hung throughout the campus. Modern reinterpretations of these traditional and local techniques add character and beauty to the campus and emphasize a sense of place that is particular to India.

Water reuse and wastewater treatment were also carefully managed on the project. The project includes an on-site sewage treatment plant (STP) that assures that 100% of wastewater is treated to tertiary standards, recycles 90% of the water that is used on site for irrigation, and makes up water for the AC system. The project uses recycled site water to reduce potable water consumption for air conditioning makeup by at least 50; 61% of total air conditioning cooling tower makeup is supplied by treated grey water. The predicted annual potable water use is a total of 4,986,360 resulting in 14.75 gallons/sf/year. The water use has been reduced by 49.38% from baseline through the use of low flow urinals and faucets and showers. Native and adaptive plant species are selected for landscape to reduce water consumption, and 100% of irrigation water requirement is met with from STP-treated water.

The design of storm water system will ensure removal of 80% of the average annual post-development total suspended solids from the storm water run-off. The project has provided a screen of smaller mesh to filter finer suspended solids from entering into the rainwater harvesting system. Similarly, the project has provided additional screens at the overflow outlet of the rainwater harvesting so that any further additional suspended solids are removed before the water overflows into the Municipal storm water system.

TCS introduced vermiculture at its Banyan Park site in September 2005 as a way of recycling its canteen and garden waste of approximately 150 kg a day. The beds

Table 4.5 Design profile, TCS, Banyan park, Mumbai

Building Profile	Building name	TCS
	Client	TCS
	Architect	Tod Williams Billie Tsien Architects and Partners, USA
	Location	Mumbai, Maharashtra
	Building type	Office
	Site area	93,077.7 m ² (23 acres)
	Built-up area	42,085 m ² (Phase I)
Solar design profile	Latitude	N 19° 7'
	Longitude	E 72° 50'
	Altitude	14 m
	Heating degree days	0
	Cooling degree days	3355
	Conservation strategies	Orientation, building form, luminous and thermal zoning
	Passive solar strategies	Daylighting
	Active solar strategies	Not available
	Other renewable energy strategies	Not available
High-performance strategies	High-performance glazing	
Performance profile	Total annual building energy consumption: (estimated)	3,540,483 kWh/year (10.47939 kBtus/ft ² /year)
	Total annual on-site energy produced	Not available
	Size of photovoltaic system	Not available
	Size of solar thermal system	Not available

were laid by Clean Air Island, a society for urban rejuvenation, with the deep burrowing earthworm technology. TCS staff were trained in the simple, daily routine of laying waste. Monitoring was carried out by Clean Air Island technical staff for two months, and the process is now streamlined. Vermiculture pits have now been introduced at other TCS sites. Table 4.5 summarizes the design profile of TCS, Banyan Park, Mumbai.

4.6 Aranya Bhavan, Jaipur

4.6.1 Design Intentions

Aranya bhawan, the new office building of the Rajasthan Forest Department in Jaipur, captures the eye and the imagination through the heritage gestures of its jali (filigree), jharukha (oriel or bay window) and chattri (umbrella or canopy) on roof,



Fig. 4.37 Front view of Aranya Bhawan (© Tapan Kumar Ghoshal)

Fig. 4.37 shows front view of the building. The project was selected for the Indo-Swiss Building Energy Efficiency Project (BEEP) Integrated Design process Charrette (BEEP 2012). BEEP is a bilateral cooperation project (five years 2012–2016) between the Swiss Agency for Development and Cooperation (SDC) under the Federal Department of Foreign Affairs (FDFA) and the Ministry of Power, Government of India. The overall objective of the BEEP is to reduce energy consumption in new buildings in India consistent with the objectives of the National Mission on Sustainable Habitat and the Energy Conservation Programme of the Government of India.

An integrated design process charrette is an interactive workshop, which brings together the building team and senior Swiss experts to develop the energy concept of the building together during the early phase of design of a building. The expert team carry out dynamic energy modelling, using advanced energy modelling tools such as TRNSYS and Energy Plus to estimate the energy-saving potentials of the strategies proposed. The design charrette for Aranya Bhawan was held on 14 and 15 December 2012 at the Development Alternatives World Headquarters in New Delhi and on 20 December 2012 at Van Bhawan in Jaipur.

Rajasthan is one of the first states to notify the Energy Conservation Building Code (ECBC) as Energy Conservation Building Directives (EDB). Aranya bhawan being a public project aims for high-performance building as given below:

- ECBC compliance
- BEE 5-star rating, i.e. EPI less than 90 kWh/m²/annum

Table 4.6 Building details, Aranya Bhawan

1.	Basement	Car & two wheelers parking (70 nos. cars, 150 two wheelers), electrical room, A.C. plant room (3265.00 m ²)
2.	Ground floor	Auditorium for 225 persons capacity, library, museum, canteen, & reception area (2536.91 m ²)
3.	First floor	PCCF (HoFF) chamber with small meeting hall (24 person), 5 nos. PCCF chamber with attached toilets, additional PCCF chambers and large conference hall (72 persons) (2121.86 m ²)
4.	Second floor	Additional PCCF & CCF Chambers (2121.86 m ²)
5.	Third floor	Offices for DCF & staff, accounts section & record room (2121.86 m ²)
6.	Fourth floor	Offices for ACF & Staff, guest room (4 nos.) (2121.86 m ²)
7.	External	Visitor car parking & land escape
8.	Lifts and staircase	3 nos. passenger lift with 2 nos. staircase well and 2 nos. fire escape staircase
9.	Firefighting	Wet riser and sprinklers in basement

In terms of energy efficiency strategies, the focus is on:

- (i) reducing unwanted solar gains,
- (ii) minimizing internal gains through promotion of daylight,
- (iii) promotion of natural ventilation,
- (iv) implementation of mechanical ventilation with heat recovery for indoor air quality,
- (v) highly efficient active systems, as well as
- (vi) on-site renewable energy production.

The 9519 m² multistory building houses offices (250 uses), auditorium (225 capacity), conference hall, meeting rooms, library, museum, refectory, four guest rooms and other utilities, Table 4.6 enumerates building details. It is a high-performance building project with 6172 m² (65%) air-conditioned and 3347 m² (35%) unconditioned area. The building is designed to be earthquake-resistant reinforced concrete-framed structure with provision for future expansion of two more floors. The construction of building was completed in two years, commencing from January 2013 and ending in January 2015.

4.6.2 Climate and Site

Jaipur falls in the composite climatic zone, warm and humid during the south-west monsoon season and cold season from December to February after which the hot season commences and continues till about the third week of June when the south-west monsoon sets in and lasts only till mid-September. The period from the

second half of September to the end of November is the post-monsoon season or retreating monsoon season (IMD 2010).

The annual rainfall in Jaipur is 671.7 mm. The rainfall during the period June to September constitutes nearly 90% of the annual rainfall.

May and the first half of June are being the hottest part of the year. The mean daily maximum temperature in May is 40.1 °C, and the mean daily minimum temperature is 25.3 °C. The setting in of the south-west monsoon after the middle of June lowers the temperature somewhat, but the relief from the heat is not marked because of the added discomfort from the increase in humidity, brought in by the south-west monsoon air. After the withdrawal of the monsoon by mid-September, days become hotter, and in October, a secondary maximum in day temperature is reached. The nights become progressively cooler. After mid-November, both day and night temperatures drop rapidly till January, which is the coldest month with the mean daily maximum temperature at 22.6 °C and the mean daily minimum temperature at 7.9 °C.

During the brief south-west monsoon season, the relative humidity is generally over 60%. In the rest of the year, the air is dry. In the summer season, afternoon relative humidity may be as low as 15–20%.

During the south-west monsoon season, skies are moderately to heavily clouded generally and overcast on some days. In the rest of the year, clear or lightly clouded skies prevail. But on a few days in the winter season, the skies become cloudy, when the city is affected by passing western disturbances.

Winds are generally light to moderate, but in summer and early south-west monsoon season, winds may strengthen slightly on some days. Westerly to north-westerly winds prevail in the south-west monsoon season. In the period from October to March, winds are mostly from direction east in the morning, while in the afternoon, they are mainly from north-west. North-westerly winds prevail during summer season. The climatic data of Jaipur is given in the Table 5.53, and the sun-path diagram is shown in Fig. 5.28.

The site is located in the Jhalana Doongri Institutional Area, right next to Setu Bhawan which houses the office of Rajasthan State Road Development and Construction Corporation (RSRDC). The total site area is 18620 m² with a building footprint of 2400 m², i.e. a ground coverage of 13.62% which is less than the permissible 33%, Fig. 4.38 shows the site plan. This has been done to keep most of the site 'green' or vegetated at the suggestion of the client, the Rajasthan Forest Department.

There are three distinct blocks in the building which are connected by corridors and two staircase blocks, Fig. 4.39 shows the view of three blocks. The longer sides of these blocks face north-east and south-west. The south-east and the north-west facades have 2-m-wide verandahs for shading as well as for aesthetical purposes Fig. 4.40 shows two elevations and one section. Figures 4.41, 4.42, and 4.43 present floor plans of the building.

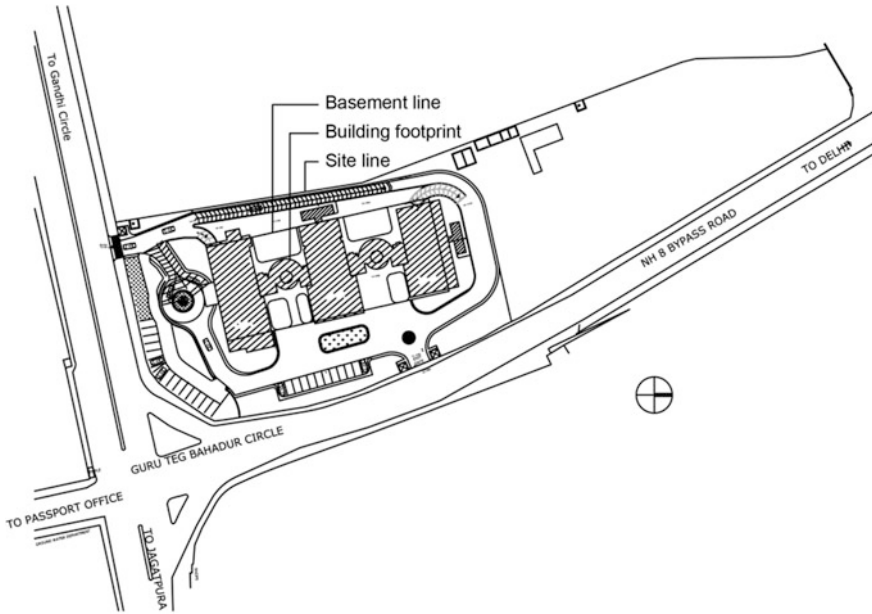


Fig. 4.38 Site plan, Aranya Bhawan (© Mathur Ugam & Associates)



Fig. 4.39 Three blocks connected by stair wells, Aranya Bhawan (© Tapan Kumar Ghoshal)

4.6.3 Daylight and Thermal Design

All the offices are located along the periphery of the building for maximum daylight and wall window ratio (WWR) is less than 60% in compliance with the ECBC. Early daylighting analysis was done to ensure that even the interior room receives the requisite daylight. Figure 4.44 shows the effect of daylighting strategies inside an

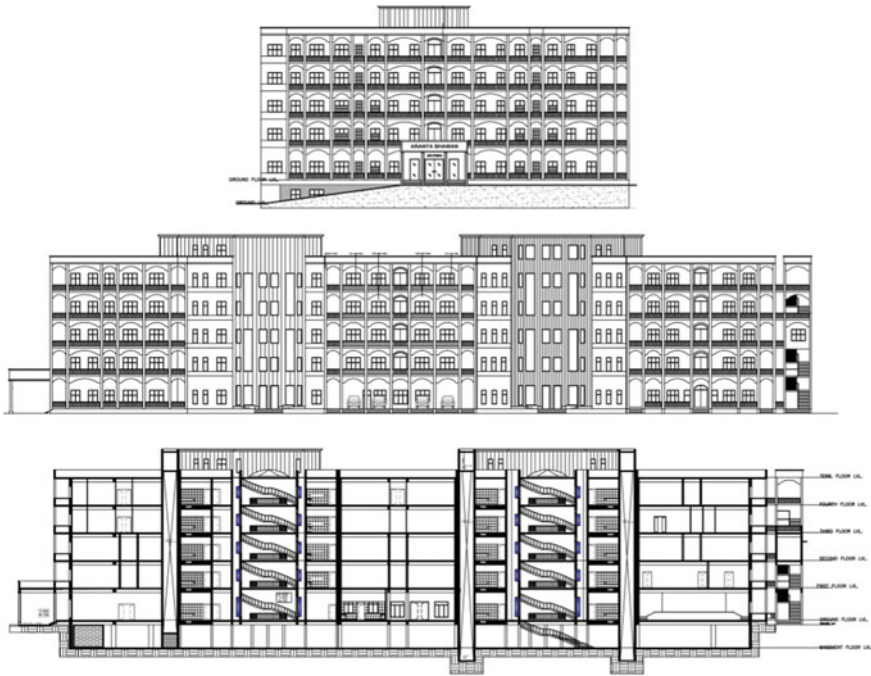


Fig. 4.40 Section, side and front elevations, Aranya Bhavan (© Mathur Ugam & Associates)

office. The two staircase blocks are covered with skylight for daylighting the internal circulation corridors, Fig. 4.45 shows daylighting through the staircase block.

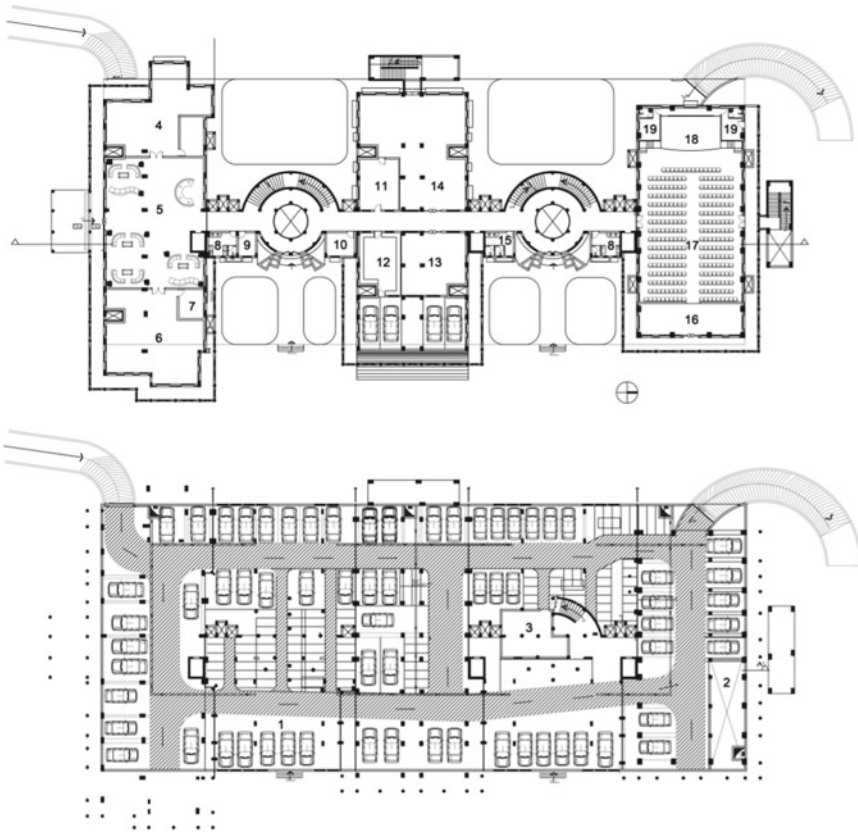
The building envelope is ECBC (BEE 2005) compliant to optimize energy efficiency over the conventional design; Fig. 4.46 shows the comparison of traditional and ECBC-compliant wall, roof and glazing.

4.6.4 Energy Systems

The building is air-conditioned except for the corridors, staircases and toilets. Passive Downdraft Evaporative Cooling (PDEC) is proposed in the two staircase blocks for the dry months of the year, which would keep the non-air-conditioned corridors at a comfortable temperature and would also be conducive for plants.

Initial computer modelling of energy-efficient strategies by the project team was taken up for comparative analysis as given below:

- (i) Baseline
- (ii) ECBC-compliant envelope with VRV (variable refrigerant volume) system
- (iii) ECBC-compliant envelope with water chiller system
- (iv) ECBC-compliant envelope with air-cooled chiller



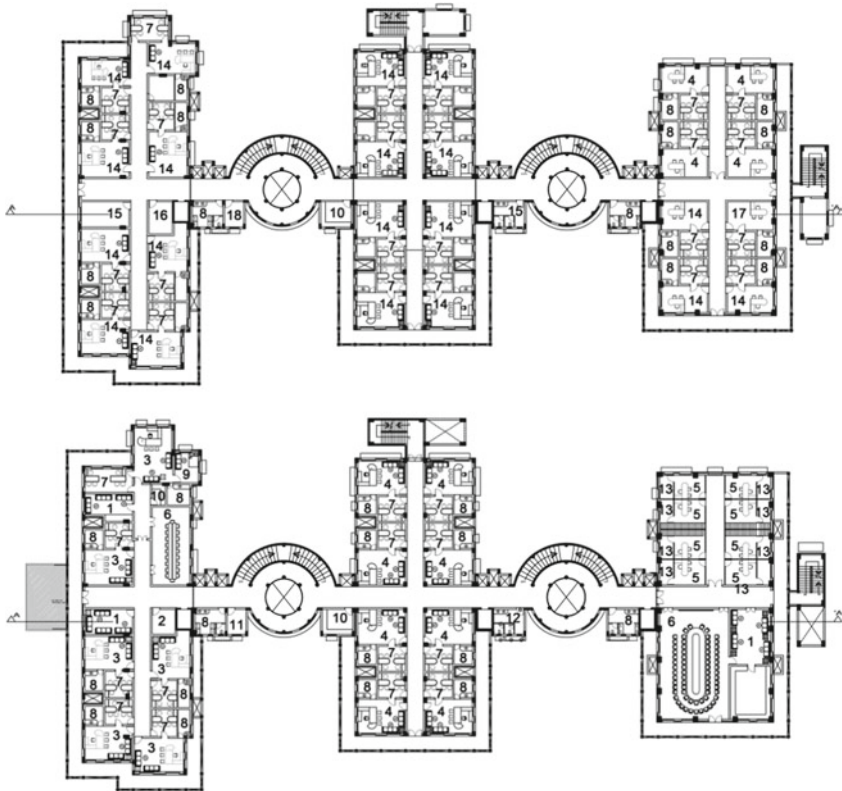
Key

1. Parking	7. Driver rest rooms	13. Dining
2. A/C plant room	8. Kitchen	14. Cafeteria
3. Electrical room	9. Office	15. Female toilets
4. Library	10. Male toilets	16. Waiting lobby
5. Reception and waiting	11. Care taker	17. Multipurpose hall
6. Museum	12. Record/despach	18. Stage
		19. Green room

Fig. 4.41 Basement plan and ground floor plan, Aranya Bhawan (© Mathur Ugam & Associates)

The considerations of each of these cases with the resultant Energy Performance Index (EPI) values are given in the Table 4.7. Further, Table 4.8 enumerates daily energy supply monitoring from 6 May to 19 May in the peak summer month.

Energy-efficient LED lighting is used in the building, Fig. 4.47 shows lighting in the auditorium.



Key

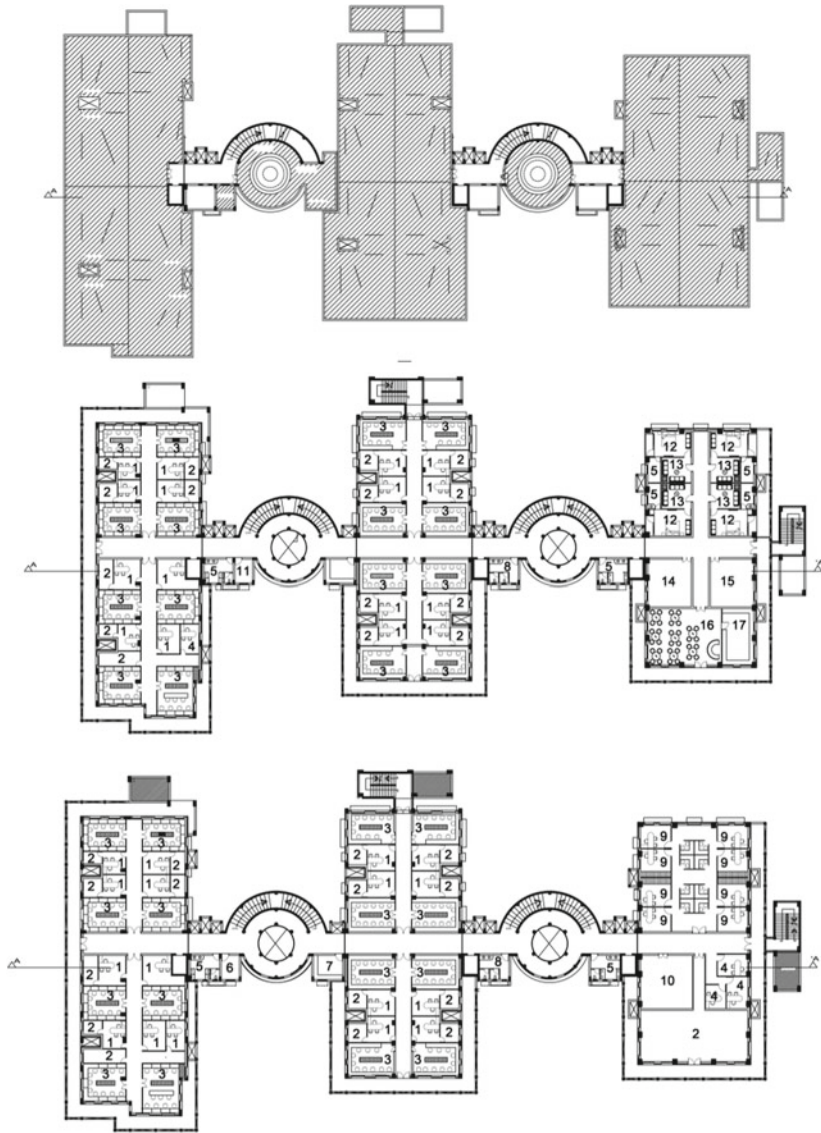
1. Waiting	7. Personal Assistant	12. Female toilet
2. Attendants' space	8. Toilet	13. Record room
3. Principal Chief Conservator of Forest	9. Rest room	14. Chief conservator of forest
4. Assistant Chief Conservator of Forest	10. Pantry	15. Drawing
5. Office	11. Main	16. Female common room
6. Conference room		17. Photostat room

Fig. 4.42 First floor plan and second floor plan, Aranya Bhawan (© Mathur, Ugam & Associate)

4.6.5 Sustainable Thinking

The rooftop solar photovoltaic system of 45 kWp produces electricity with help of solar cells made up of silicon wafers. Figure 4.48 shows roof-mounted solar photovoltaic (SPV). Typically, SPV system consists of:

- Solar PV module which generates DC electricity directly from the solar radiation
- Charge controller which regulate the output from SPV module.



Key

1. Deputy Conservator of Forest/ Assistant Conservator of Forest	6. Cashier room	12. Guest room
2. Record room	7. Pantry	13. Drawing room
3. Workstation	8. Female toilet	14. Entertainment room
4. Office	9. AAO	15. Knowledge centre & yoga
5. Toilet	10. HRD	16. Cafeteria
	11. Utility room	17. Kitchen

Fig. 4.43 Third, fourth floors and terrace plans, Aranya Bhawan (© Mathur, Ugam & Associate)



Fig. 4.44 Daylighting in offices, Aranya Bhawan (© Tapan Kumar Ghoshal)



Fig. 4.45 Daylighting through the staircase block covered with skylight, Aranya Bhawan (© Tapan Kumar Ghoshal)

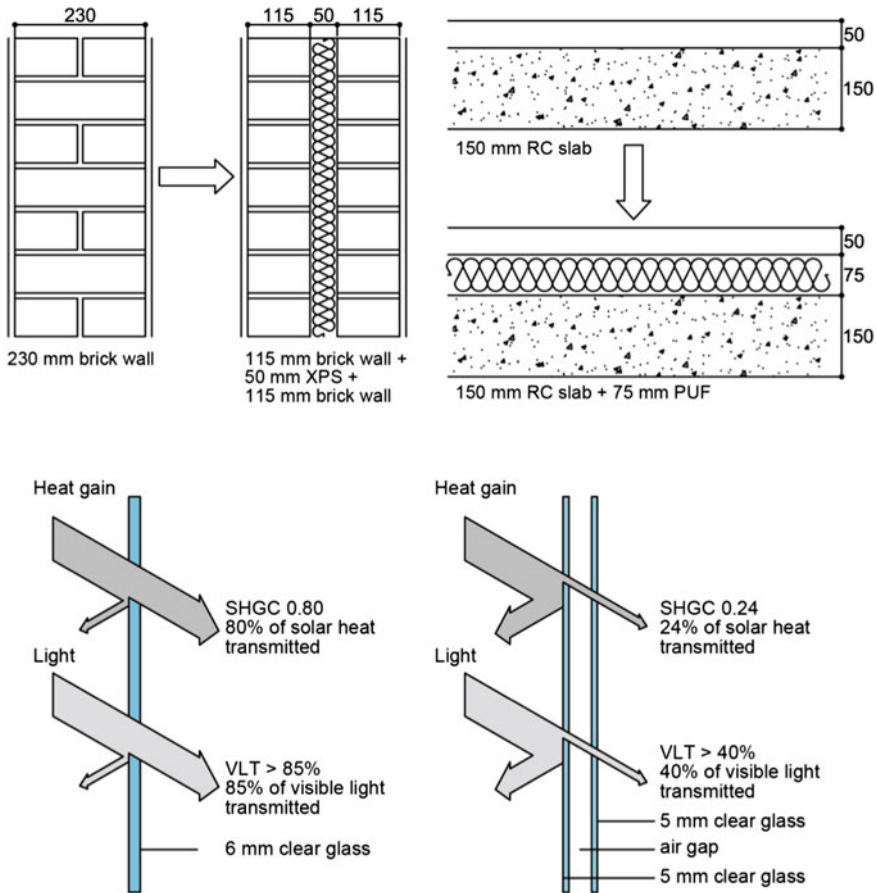


Fig. 4.46 Comparison of traditional and ECBC-compliant building envelope

- Battery bank which stores the generated energy coming from charge controller. From batteries, energy can be directly supplied to DC appliances.
- Inverter which converts DC electricity stored in batteries to AC electricity so that the energy can be utilized by AC appliances.

It is further envisaged that installing (SPV) system on half the roof area (1200 m^2 of the total roof area 2400 m^2) would result in 120 kWp system. The annual electricity generation from this system would be around 1,95,000 kWh. Considering the office schedule of 6 days/week, around 167,000 kWh can be utilized. The other important thing is the energy generated by SPV system would be utilized in the same time as the energy generation, and demand occurs simultaneously. The average hourly energy requirement for 'ECBC-compliant envelope with

Table 4.7 Comparison of base case with three energy-efficient strategies

	Base case	ECBC envelope with VRV	ECBC envelope with water chiller	ECBC envelope with air-cooled chiller
Wall	230 mm brick wall U: 2.05 W/m ² K	230 mm + 115 mm brick cavity wall with 65-mm rock wool insulation U: 0.44 W/m ² K	230 mm + 115 mm brick cavity wall with 65-mm rock wool insulation U: 0.44 W/m ² K	230 mm + 115 mm brick cavity wall with 65-mm rock wool insulation U: 0.44 W/m ² K
Glazing	Single glazing 5-mm clear glass U: 5.8 W/m ² K SHGC: 0.8 VLT: > 85%	Double glass unit 6/13/6 mm U: 1.6 W/m ² K SHGC: 0.24 VLT: 40%	Double glass unit 6/13/6 mm U: 1.6 W/m ² K SHGC: 0.24 VLT: 40%	Double glass unit 6/13/6 mm U: 1.6 W/m ² K SHGC: 0.24 VLT: 40%
Roof	150-mm RC slab U: 3.2 W/m ² K	150-mm RC slab with 50 mm of PUF insulation U: 0.409 W/m ² K	150-mm RC slab with 50 mm of PUF insulation U: 0.409 W/m ² K	150-mm RC slab with 50 mm of PUF insulation U: 0.409 W/m ² K
HVAC system	VRV system CoP = 2.75	VRV system CoP = 2.75	High-efficiency water-cooled chiller CoP = 7.6	Air-cooled chiller CoP = 3.1
Annual electricity consumption	734,048 kWh	587,545 kWh	430,749 kWh	552,140 kWh
Overall built-up area	9519 m ²			
Overall energy performance index (EPI)	77 kWh/m ² /annum	62 kWh/m ² /annum	45 kWh/m ² /annum	58 kWh/m ² /annum

Table 4.8 Energy supply monitoring results (kWh)

	6 May	7 May	8 May	9 May	10 May	11 May	12 May	13 May	14 May	15 May	16 May	17 May	18 May	19 May
DG	3.5	3.4	3.2	20.9	3.6	3.5	21.5	5.8	3.4	3.5	3.3	3.4	3.5	3.3
Solar	204.0	68.9	83.0	224.0	204.0	228.0	192.0	192.0	86.1	65.4	220.0	228.0	216.0	128.0
Grid	1485	112.5	101.8	1419.3	1661.0	1806.5	1384.4	1624.3	119.1	112.9	1759.0	1815.2	1775.5	1514.0
Energy export	0	-147.1	-149.0	0.0	0.0	0.0	0.0	0.0	-121.9	-142.6	0.0	0.0	0.0	0.0

Source BEEP (2016)



Fig. 4.47 Auditorium, Aranya Bhawan (© Tapan Kumar Ghoshal)



Fig. 4.48 Roof-mounted SPV panels, Aranya Bhawan (© Tapan Kumar Ghoshal)

Table 4.9 Design profile Aranya Bhawan, Jaipur

Building profile	Building name	Van Bhawan (Aranya Bhawan) at Jhalana Doongri, Jaipur
	Client	Rajasthan Forest Department
	Architect	M/s Mathur Ugam & Associates, New Delhi
	Contractor	Rajasthan State Road Development and Construction Corporation
	Project team	Implemented recommendations of Building Energy Efficiency Project (BEEP), Ministry of Energy, GoI
	Location	Jaipur, Rajasthan
	Building type	Office
	Built-up area	Plinth area 2536.91 m ² all floors 14289.35 m ² i.e. 1,53,753.40 ft ²
Solar design profile	Latitude	N 26° 49'
	Longitude	E 75° 48'
	Altitude	390 m
	Heating degree days	141
	Cooling degree days:	2952
	Conservation strategies:	Orientation, optimize building form and massing, luminous and thermal zoning
	Passive solar strategies:	Daylighting, exterior shading
	Active solar strategies:	Photovoltaic system
	Other renewable energy strategies:	None
	High-performance strategies:	High-performance glazing and envelope compliant with ECBC, centralized high-efficiency water-cooled chiller for air conditioning, high-performance electrical lighting
Performance profile	Total annual building energy consumption	Connected load 600 kWh, EPI 70 kWh/m ² /annum
	Total annual on-site energy produced	Not available
	Size of photovoltaic system	45 kWp rooftop solar photovoltaic system
	Size of solar thermal system	1000 l per day

water chiller system' case is around 141 units. Hence, no storage/minimal storage would be required.

Financial analysis for the system is done after taking into consideration the subsidy and accelerated depreciation benefits. The cost of electricity is taken from the tariff order for Jaipur as Rs. 6.25/kWh, and an annual escalation of 10% is considered in the electricity price.

Solar water heater (SWH) uses simple principles and components to capture incoming solar radiation (sunlight) and transform its heat energy—providing the hot water needed for domestic, commercial, industrial and other uses. Typically, SWH system consists of:

- Solar panel which captures the solar radiation and transfers it to water
- Storage tank where the heated water is stored
- Cold water tank from which the cold water is supplied to solar panel
- Distribution and piping to connect the components and supply heated water from storage tank to the end use point.
- Back-up heater (inside the hot water storage tank) to provide hot water in case the solar radiation is low or the demand is high.

Sewerage Treatment Plant of 15 kl per day is installed for recycling 100% wastewater, and treated water is used in A.C. chiller plant and gardening. Softening and filtration plant are installed for treatment of groundwater. Rainwater harvesting two structures are provided. Table 4.9 summarizes design profile of Aranya Bhawan, Jaipur.

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Chapter 5

Climatic Data

5.1 Introduction

The map of India, as shown in Fig. 5.1, shows the sixty-two locations for which climatic data is presented in this chapter. The selection of locations was based on two criteria:

1. the intention to obtain a fairly even distribution of points over the country and
2. the availability of data.

The basic climatic data are taken from the following sources:

1. the Indian Society of Heating Refrigerating Air Conditioning Engineers (ISHRAE 2014) weather data created with the help of White Box Technologies (USA) and utilizes weather data from various sources, including the India Meteorological Department (IMD), the US National Center for Environmental Data (NCEI) and satellite-derived solar radiation data developed by the US National Renewable Energy Laboratory (NREL) in collaboration with Ministry of New and Renewable Energy Sources, Government of India;
2. the India Meteorological Department;
3. the World Meteorological Organization;
4. the Bureau of Indian Standards.

The sunshine duration was not available for twenty-four locations, so the values given are based on estimates using standard algorithm. The climatic data of sixty-two cities is presented in Tables 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19, 5.20, 5.21, 5.22, 5.23, 5.24, 5.25, 5.26, 5.27, 5.28, 5.29, 5.30, 5.31, 5.32, 5.33, 5.34, 5.35, 5.36, 5.37, 5.38, 5.39, 5.40, 5.41, 5.42, 5.43, 5.44, 5.45, 5.46, 5.47, 5.48, 5.49, 5.50, 5.51, 5.52,

5.53, 5.54, 5.55, 5.56, 5.57, 5.58, 5.59, 5.60, 5.61, 5.62, 5.63, 5.64, 5.65, 5.66, 5.67, 5.68, 5.69, 5.70, 5.71, 5.72, 5.73, 5.74, 5.75, 5.76, 5.77, 5.78, 5.79, 5.80, 5.81, 5.82, 5.83, 5.84, 5.85, 5.86, 5.87, 5.88, 5.89, 5.90, 5.91, 5.92, 5.93, 5.94, 5.95, 5.96, 5.97, 5.98, 5.99, 5.100, 5.101, 5.102, 5.103, 5.104, 5.105, 5.106, 5.107, 5.108, 5.109, 5.110, 5.111, 5.112, 5.113, 5.114, 5.115, 5.116, 5.117, 5.118, 5.119, 5.120, 5.121, 5.122, 5.123 and 5.124—two tables for each city. The first table gives summary of the basic climatic data for twelve months: mean sunshine hours, cloud cover (%), daily average solar irradiation global and diffuse on horizontal surface (W/m^2), maximum and minimum relative humidity (%), maximum and minimum dry-bulb temperature ($^{\circ}\text{C}$), rainfall (mm) and wind speed (m/s). The average diurnal range and annual mean range are computed from the temperature data. Thermal neutrality (T_c) is calculated from the monthly mean temperature using the Eq. 2.14 with the limitation that $17^{\circ}\text{C} < T_c < 31^{\circ}\text{C}$ (Humphreys and Nicol 1998). The upper and lower limits of thermal neutrality are taken as $\pm 2.5^{\circ}\text{C}$ for 90% acceptability. The heating degree days (HDD) and cooling degree days (CDD) are for the base temperature of 18°C . The wind direction is graphically represented in wind rose diagram. The sunshine hours, solar irradiations, relative humidities, dry-bulb temperatures and rainfall are also shown graphically. The second table gives the design conditions, the hourly dry-bulb temperature for all twelve months with overheated, comfortable and underheated period delineated in different shades. The second table also gives the hourly direct and diffuse solar irradiation on horizontal surface for the hottest and coldest month. Chapter 2 discusses origin and derivation of the climatic data presented in this chapter. Chapter 3 explains application of the climatic data. The sources of data in each case are indicated below the second table. Stereographic sun-path diagrams of 62 locations in Fig. 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19, 5.20, 5.21, 5.22, 5.23, 5.24, 5.25, 5.26, 5.27, 5.28, 5.29, 5.30, 5.31, 5.32, 5.33, 5.34, 5.35, 5.36, 5.37, 5.38, 5.39, 5.40, 5.41, 5.42, 5.43, 5.44, 5.45, 5.46, 5.47, 5.48, 5.49, 5.50, 5.51, 5.52, 5.53, 5.54, 5.55, 5.56, 5.57, 5.58, 5.59, 5.60, 5.61, 5.62 and 5.63 are drawn using the software Winshade (Kabre 1999). Shadow protractor is shown in Fig. 5.64.

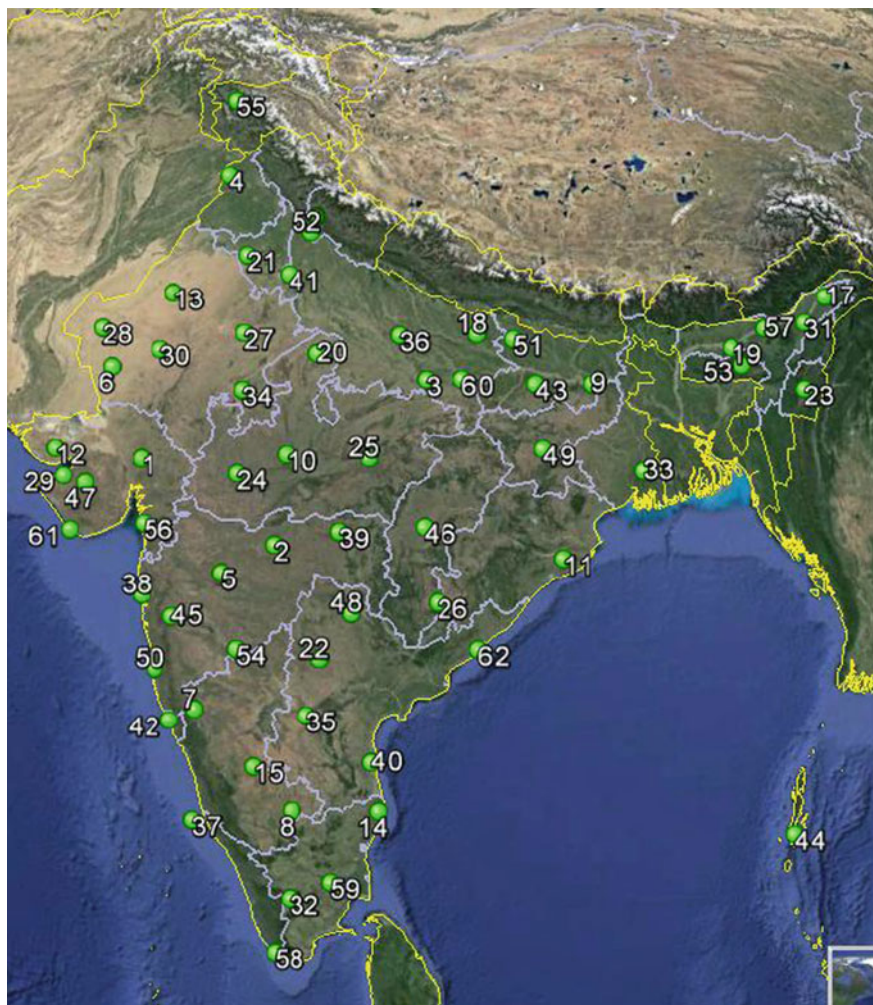
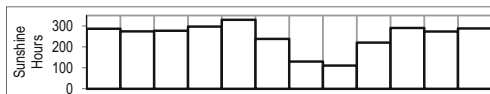


Fig. 5.1 Map of India showing 62 locations

Table 5.1 Climatic data Ahmedabad, Gujarat

Latitude	N 23° 4'				Longitude	E 72° 37'				Altitude	55 m		
Climate	Hot and dry				Köppen	Bwh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	287.3	274.3	277.5	297.2	329.6	238.3	130.1	111.4	220.6	290.7	274.1	288.6	251.6
Cloud (%)	10.9	4.8	20.9	8.4	14.0	49.9	75.6	75.3	40.4	28.0	15.6	16.7	30.03
Solar irradiation daily average (Wh/m²)													
Global	4852	5801	6516	7323	7622	6667	4861	4622	5813	5526	5006	4479	5757
Diffuse	1233	1338	1656	1838	1988	2592	3409	3306	2328	1754	1321	1232	2000
Relative Humidity (%)													
morning	72	69	56	64	74	79	86	91	88	76	66	68	74.1
evening	29	27	20	20	20	42	69	72	56	33	29	33	37.5
Dry Bulb Temperature (°C)													
max	25.7	29.2	34.2	38.3	41.1	38.2	31.8	30.6	32.8	35.9	32.5	29.2	33.3
min	13.4	15.8	19.8	25.5	27.4	29.0	26.6	25.9	25.6	23.8	19.2	16.2	22.4
mean	19.6	22.5	27.0	31.9	34.3	33.6	29.2	28.3	29.2	29.9	25.9	22.7	27.8
Neutrality	23.9	24.8	26.2	27.7	28.4	28.2	26.9	26.6	26.9	27.1	25.8	24.8	24.7
Upper limit	26.4	27.3	28.7	30.2	30.9	30.7	29.4	29.1	29.4	29.6	28.3	27.3	27.2
Lower limit	21.4	22.3	23.7	25.2	25.9	25.7	24.4	24.1	24.4	24.6	23.3	22.3	22.2
Rain (mm)^b	2.1	1.2	1.1	1.9	9.1	97.4	309.8	213.8	126.6	13.5	6.1	1.7	784.3
Wind (m/s)	1.7	1.8	1.8	2.5	3.3	3.2	2.7	2.5	1.9	1.2	1	1.7	2.1
HDD	8	0	0	0	0	0	0	0	0	0	0	0	8
CDD	38	116	284	421	489	451	339	311	328	344	216	116	3453



Average diurnal range (°K)	10.9
Annual mean range (°K)	27.7

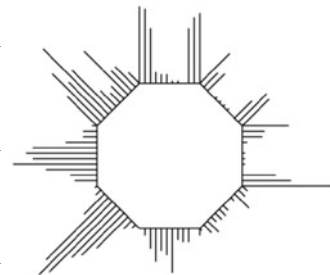
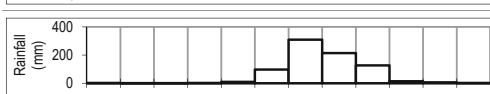
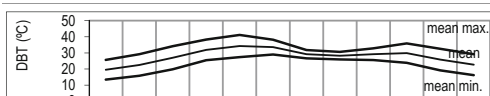
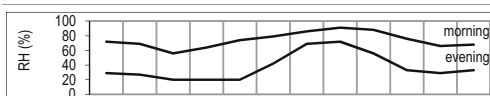
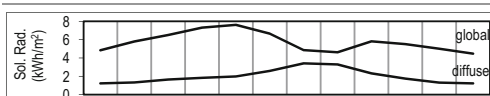


Table 5.2 Design conditions and overheat–underheated periods, Ahmedabad

Recommended “Design” conditions		
Summer	DBT (°C)	41.2
	MCWB (°C)	23.5
	WBT (°C)	28.2
	MCDB (°C)	33.6
Winter	DBT (°C)	12.9

Hourly temperature (°C) in all 12 months

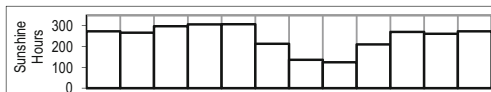
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	15.2	18.6	23.4	29.4	30.8	30.8	27.7	27.0	27.2	25.6	21.4	17.5	0	0	0	0
1:01- 2:00	14.9	17.7	22.7	28.8	30.0	30.4	27.5	26.8	26.8	25.2	21.0	17.1	0	0	0	0
2:01- 3:00	14.6	17.1	22.1	28.0	29.4	30.0	27.2	26.4	26.5	24.8	20.4	16.8	0	0	0	0
3:01- 4:00	14.1	16.8	21.7	27.3	28.8	29.7	26.9	26.3	26.1	24.6	20.0	16.7	0	0	0	0
4:01- 5:00	13.7	16.3	21.1	26.5	28.2	29.4	26.8	26.2	25.9	24.3	19.7	16.4	0	0	0	0
5:01- 6:00	13.5	16.0	20.4	25.8	27.5	29.0	26.6	26.0	25.7	24.0	19.4	16.3	0	0	0	0
6:01- 7:00	13.4	15.8	19.8	25.5	27.4	29.1	26.6	25.9	25.6	23.8	19.2	16.2	8	34	0	0
7:01- 8:00	13.4	15.9	21.1	26.4	28.4	29.7	26.8	26.1	26.3	24.7	19.9	16.3	101	119	7	16
8:01- 9:00	16.4	19.5	24.8	28.7	30.7	31.1	28.5	27.3	27.7	27.9	23.7	19.7	266	176	90	78
9:01-10:00	19.5	22.6	27.5	31.0	32.6	32.0	28.9	27.6	28.9	30.3	26.4	22.7	428	213	253	121
10:01-11:00	21.9	24.9	29.7	32.9	34.7	33.3	29.8	28.2	30.0	32.2	28.9	25.3	587	223	422	139
11:01-12:00	23.5	26.5	31.4	34.9	36.7	35.0	30.6	29.2	31.1	34.0	31.0	26.9	713	217	558	140
12:01-13:00	24.7	27.5	32.7	36.4	38.4	36.1	31.2	29.8	31.9	34.9	32.0	28.1	824	184	609	146
13:01-14:00	25.4	28.7	33.6	37.5	39.7	37.1	31.7	30.3	32.5	35.3	32.3	28.9	833	166	583	151
14:01-15:00	25.7	29.1	34.1	38.0	40.5	37.9	31.8	30.6	32.8	35.8	32.5	29.2	747	160	497	148
15:01-16:00	25.6	29.2	34.2	38.3	41.1	38.0	31.6	30.6	32.8	35.9	32.3	28.9	585	160	356	136
16:01-17:00	25.1	29.0	34.1	38.3	41.0	38.2	31.3	30.2	32.7	35.4	31.7	28.3	373	154	196	105
17:01-18:00	23.8	28.0	33.7	37.9	40.1	37.7	30.7	29.8	32.1	33.7	29.8	26.2	150	129	48	53
18:01-19:00	21.6	25.8	31.9	36.8	37.9	36.1	30.0	29.4	30.4	30.6	26.7	23.7	17	53	1	1
19:01-20:00	20.0	23.9	29.1	34.9	35.7	34.3	29.3	28.7	29.3	28.8	24.9	22.0	0	1	0	0
20:01-21:00	18.7	22.3	27.2	32.9	34.2	32.9	28.8	28.0	28.6	27.7	23.9	20.9	0	0	0	0
21:01-22:00	17.7	21.0	26.0	31.8	33.1	32.1	28.4	27.8	28.2	26.9	23.2	20.3	0	0	0	0
22:01-23:00	16.8	19.9	25.1	31.0	32.3	31.6	28.1	27.6	27.7	26.3	22.5	19.2	0	0	0	0
23:01-24:00	15.9	19.1	24.1	30.1	31.5	31.0	27.8	27.2	27.6	25.8	21.8	18.4	0	0	0	0
Legend	Underheated	<21.4°C				Comfortable					Overheated	>28.4°C				

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.3 Climatic data Akola, Maharashtra

Latitude	N 20° 42'				Longitude	E 77° 4'				Altitude	309 m		
Climate	Hot and dry				Köppen	Bwh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine(h) ^a	272.8	266	297.6	306	306.9	213	136.4	124	210	269.7	261	272.8	244.7
Cloud (%)	43.5	43.5	43.7	45.3	45.0	46.6	44.3	45.2	44.8	44.9	44.1	44.8	44.64
Solar irradiation daily average (Wh/m²)													
Global	4751	5701	6545	7055	7065	5805	4609	4320	5307	5617	4982	4669	5536
Diffuse	1534	1612	1827	2096	2367	3239	3540	3452	2892	1933	1579	1350	2285
Relative Humidity (%)													
morning	79	45	60	40	50	77	83	86	79	81	85	69	69.5
evening	41	18	41	22	20	45	61	65	46	42	39	41	40.1
Dry Bulb Temperature (°C)													
max	28.9	33.3	36.1	40.8	41.5	35.8	30.4	29.4	33.3	32.8	30.9	28.8	33.5
min	16.2	16.7	21.6	25.7	28.7	26.2	24.7	23.8	24	21.3	17.5	14.5	21.7
mean	22.6	25.0	28.9	33.3	35.1	31.0	27.6	26.6	28.7	27.1	24.2	21.7	27.6
Neutrality	24.8	25.6	26.7	28.1	28.7	27.4	26.3	26.0	26.7	26.2	25.3	24.5	26.4
Upper limit	27.3	28.1	29.2	30.6	31.2	29.9	28.8	28.5	29.2	28.7	27.8	27.0	28.9
Lower limit	22.3	23.1	24.2	25.6	26.2	24.9	23.8	23.5	24.2	23.7	22.8	22.0	23.9
Rain (mm) ^a	10.4	8.1	10	4.1	9.8	144.9	217.2	196.6	122.7	47.7	18.7	12.1	802.3
Wind (m/s)	0.98	1.28	1.53	1.83	2.44	2.13	3.21	2.89	1.50	1.10	0.96	1.07	1.7
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	133	187	340	458	527	370	292	261	312	274	177	111	3442



Avg diurnal range (°K)	11.8
Annual mean range (°K)	27.0

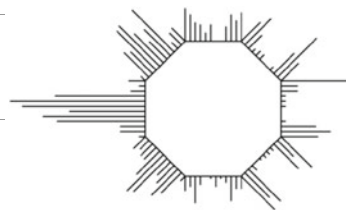
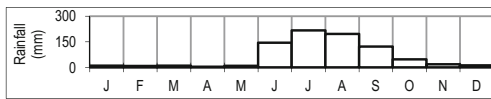
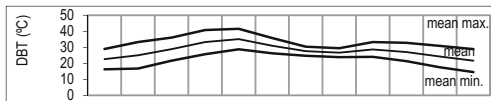
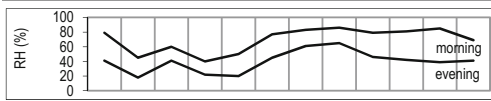
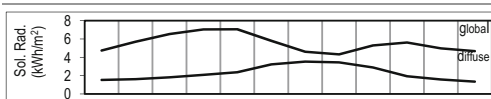


Table 5.4 Design conditions and overheat–underheated periods, Akola

Recommended “Design” conditions													
Summer	DBT (°C)			42.2									
	MCWB (°C)			23.3									
	WBT (°C)			26.7									
	MCDB (°C)			34.4									
Winter	DBT (°C)			13.9									

Hourly temperature (°C) in all 12 months

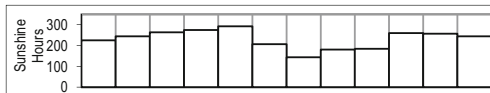
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	19.4	20.3	25.0	29.0	32.0	27.7	26.0	24.8	25.8	23.7	19.6	18.2	0	0	0	0
1:01- 2:00	18.4	19.1	23.7	27.6	30.9	27.4	25.6	24.4	25.2	23.0	18.9	17.2	0	0	0	0
2:01- 3:00	17.8	18.5	22.7	26.6	29.9	26.9	25.3	24.1	24.6	22.2	17.9	16.4	0	0	0	0
3:01- 4:00	16.9	17.4	21.6	25.7	29.0	26.5	24.9	23.8	24.1	21.5	17.5	15.3	0	0	0	0
4:01- 5:00	16.6	17.0	21.7	25.9	28.7	26.2	24.7	23.8	24.0	21.3	17.5	14.7	0	0	0	0
5:01- 6:00	16.2	16.7	21.9	26.4	29.0	26.6	24.8	23.9	24.4	21.9	18.9	14.5	5	13	0	0
6:01- 7:00	16.8	17.8	23.3	28.0	30.1	27.4	25.3	24.5	25.3	23.2	20.7	15.5	68	98	8	14
7:01- 8:00	17.8	19.5	25.3	30.0	31.7	28.6	26.1	25.2	26.6	25.1	23.3	17.3	214	163	90	78
8:01- 9:00	20.1	22.8	28.1	32.7	33.9	30.1	27.2	26.2	28.3	27.2	25.4	20.2	368	217	244	124
9:01-10:00	22.3	25.8	30.6	35.0	36.0	31.5	28.2	27.1	29.9	29.2	27.5	22.9	520	238	392	151
10:01-11:00	24.8	28.9	32.9	37.3	38.0	32.9	29.1	28.0	31.4	30.9	29.0	25.7	631	247	496	171
11:01-12:00	26.4	30.7	34.2	38.6	39.4	34.1	29.7	28.7	32.5	32.0	30.3	27.3	681	252	551	172
12:01-13:00	27.8	32.2	35.2	39.7	40.6	35.0	30.1	29.2	33.2	32.6	30.8	28.4	667	253	536	172
13:01-14:00	28.4	32.7	35.6	40.2	41.2	35.6	30.2	29.4	33.3	32.8	30.9	28.7	593	245	457	164
14:01-15:00	28.9	33.3	36.1	40.8	41.5	35.8	30.4	29.4	33.0	32.6	30.0	28.8	464	232	331	142
15:01-16:00	28.5	32.9	35.8	40.6	41.2	35.3	30.3	29.1	32.3	32.0	28.9	28.2	308	199	175	108
16:01-17:00	27.9	32.3	35.3	39.9	40.4	34.3	30.0	28.7	31.4	30.9	27.2	27.5	149	144	37	53
17:01-18:00	26.5	30.3	33.9	38.2	39.0	32.8	29.2	28.0	30.4	29.4	25.9	25.8	31	63	1	0
18:01-19:00	25.1	28.3	32.2	36.4	37.4	31.2	28.4	27.2	29.3	27.9	24.5	24.2	1	3	0	0
19:01-20:00	23.4	25.7	30.2	34.3	35.8	29.7	27.4	26.5	28.4	26.4	23.5	22.3	0	0	0	0
20:01-21:00	22.4	24.2	28.9	33.0	34.6	28.6	26.8	26.0	27.7	25.4	22.4	21.1	0	0	0	0
21:01-22:00	21.4	22.7	27.7	31.8	33.8	28.0	26.3	25.6	27.2	24.7	21.7	19.9	0	0	0	0
22:01-23:00	21.0	22.1	27.1	31.1	33.3	27.9	26.2	25.3	26.8	24.3	20.9	19.4	0	0	0	0
23:01-24:00	20.1	21.0	26.1	30.1	32.7	27.7	26.0	25.1	26.4	23.9	20.5	18.6	0	0	0	0
Legend	Underheated			<22.0°C	Comfortable								Overheated		>28.7°C	

Sources of data: ISHRAE (2014), ^aIMD (2005)

Table 5.5 Climatic data, Allahabad, Uttar Pradesh

Latitude	N 25° 27'				Longitude	E 81° 43'				Altitude	98 m		
Climate	Composite				Köppen	BSH							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	224.9	244.2	263.2	274.1	292.3	206.4	143.3	180.6	184.3	259.7	256.7	244.0	231.1
Cloud (%)	25.9	5.2	20.3	20.7	20.3	49.0	81.6	80.9	62.2	29.7	11.0	4.0	34.23
Solar irradiation daily average (Wh/m²)													
Global	3842	5346	6596	6926	7384	6308	4995	5043	5342	5217	4432	3761	5433
Diffuse	1594	1431	1502	2081	2119	2804	3461	3235	2564	1714	1447	1489	2120
Relative Humidity (%)													
morning	75	74	53	55	53	67	79	89	80	78	67	77	70.6
evening	59	43	32	21	20	50	71	79	77	61	51	67	52.6
Dry Bulb Temperature (°C)													
max	20.7	25.8	33.4	39.1	40.9	37.4	33.2	31.0	32.0	32.0	27.2	21.8	31.2
min	11.1	14.6	19.8	25.5	28.0	28.7	28.7	27.3	27.2	23.6	17.2	12.3	22.0
mean	15.9	20.2	26.6	32.3	34.5	33.1	31.0	29.2	29.6	27.8	22.2	17.1	26.6
Neutrality	22.7	24.1	26.0	27.8	28.5	28.0	27.4	26.8	27.0	26.4	24.7	23.1	26.0
Upper limit	25.2	26.6	28.5	30.3	31.0	30.5	29.9	29.3	29.5	28.9	27.2	25.6	28.5
Lower limit	20.2	21.6	23.5	25.3	26.0	25.5	24.9	24.3	24.5	23.9	22.2	20.6	23.5
Rain (mm) ^b	17.9	17.3	9.6	5.5	8.8	88.8	280.9	296.1	185.0	36.6	9.3	7.0	962.8
Wind (m/s)	0.60	0.67	0.89	0.82	1.12	1.20	1.23	1.10	1.04	0.44	0.38	0.42	0.8
HDD	88	20	0	0	0	0	0	0	0	0	0	59	167
CDD	1	63	254	422	503	440	389	342	337	287	114	9	3161



Avg diurnal range (°K)	9.2
Annual mean range (°K)	29.8

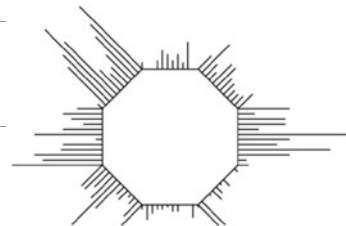
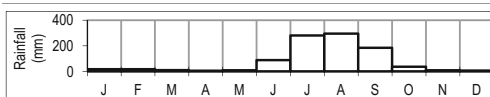
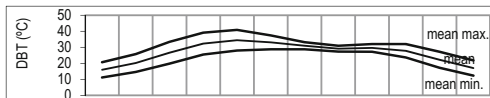
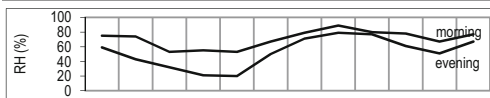
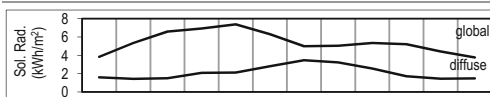


Table 5.6 Design conditions and overheat–underheated periods, Allahabad

Recommended “Design” conditions													
Summer	DBT (°C)		42.2										
	MCWB (°C)		23.5										
	WBT (°C)		28.4										
	MCDB (°C)		32.8										
Winter	DBT (°C)		9.1										

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m^2) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H_b	H_d	H_b	H_d
0:01- 1:00	12.6	16.2	22.4	28.3	30.2	30.3	29.1	27.8	27.8	24.8	19.0	13.6	0	0	0	0
1:01- 2:00	12.2	15.8	21.9	27.6	29.5	29.7	29.0	27.7	27.7	24.5	18.6	13.3	0	0	0	0
2:01- 3:00	12.1	15.5	21.4	26.9	29.1	29.4	28.9	27.6	27.5	24.3	18.3	13.1	0	0	0	0
3:01- 4:00	11.7	15.1	20.9	26.3	28.6	29.1	28.8	27.5	27.3	24.0	18.0	12.9	0	0	0	0
4:01- 5:00	11.5	14.8	20.4	25.8	28.3	28.8	28.7	27.5	27.3	23.8	17.7	12.7	0	0	0	0
5:01- 6:00	11.3	14.6	20.1	25.5	28.0	28.7	28.7	27.3	27.2	23.6	17.4	12.5	4	36	0	0
6:01- 7:00	11.1	14.6	19.8	25.8	28.9	29.1	29.0	27.4	27.3	23.6	17.2	12.3	99	135	3	7
7:01- 8:00	11.4	15.3	21.4	27.7	31.6	30.3	29.6	27.7	27.9	24.7	18.2	12.6	276	183	47	86
8:01- 9:00	13.4	17.5	25.0	31.0	34.1	32.5	30.4	28.6	29.2	26.8	20.7	14.5	442	212	151	152
9:01-10:00	15.4	20.1	27.9	33.8	36.1	33.5	31.0	29.1	30.0	28.6	23.3	16.6	582	230	253	194
10:01-11:00	17.2	22.6	30.1	35.9	37.9	34.9	31.8	29.7	30.8	30.1	25.6	18.5	722	214	332	217
11:01-12:00	18.8	24.4	31.8	37.6	39.4	36.2	32.4	30.5	31.5	31.3	27.2	20.6	779	203	396	217
12:01-13:00	19.8	24.9	32.5	38.4	40.2	36.8	32.9	30.7	31.9	31.8	27.2	21.6	777	187	404	208
13:01-14:00	20.4	25.3	33.2	38.8	40.8	37.4	33.2	30.9	32.0	31.9	27.1	21.6	683	183	338	193
14:01-15:00	20.7	25.5	33.4	39.1	40.9	37.3	33.1	31.0	31.7	32.0	27.1	21.8	509	185	222	167
15:01-16:00	20.6	25.8	33.1	38.8	40.6	36.6	32.9	30.9	31.5	31.8	27.1	21.8	294	177	93	118
16:01-17:00	19.7	24.9	32.0	38.1	39.7	36.1	32.2	30.6	30.9	30.5	25.9	20.6	96	137	9	37
17:01-18:00	17.8	23.1	30.1	36.3	38.4	35.2	31.5	30.2	30.0	28.9	23.8	18.8	3	36	0	0
18:01-19:00	16.2	21.2	28.0	34.6	36.3	33.6	30.8	29.8	29.5	27.7	22.5	17.7	0	0	0	0
19:01-20:00	15.5	20.1	26.5	32.7	34.6	32.6	30.4	29.4	29.2	26.9	21.5	16.6	0	0	0	0
20:01-21:00	14.6	19.0	25.4	31.5	33.4	31.9	30.1	29.1	28.9	26.4	20.8	15.9	0	0	0	0
21:01-22:00	13.9	18.2	24.5	30.5	32.3	31.6	29.7	29.0	28.5	25.8	20.2	15.3	0	0	0	0
22:01-23:00	13.6	17.4	23.7	29.8	31.5	31.3	29.4	28.8	28.3	25.4	19.7	14.7	0	0	0	0
23:01-24:00	13.0	16.8	23.0	28.9	30.7	30.9	29.2	27.9	27.9	24.9	19.1	13.9	0	0	0	0
Legend	Underheated		<20.2°C		Comfortable				Overheated				> 28.5°C			

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.7 Climatic data, Amritsar, Punjab

Latitude	N 31° 37'				Longitude				E 74°52'				Altitude	234 m
Climate	Composite				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	181.7	192.7	219.4	265	294.7	269.0	215.5	227.7	240.8	253.2	220.1	182.2	230.2	
Cloud (%)	45.7	44.5	43.4	31.0	30.6	35.8	52.8	47.1	23.8	7.5	19.5	33.0	34.54	
Solar irradiation daily average (Wh/m²)														
Global	3320	4103	5598	6845	7050	7087	5877	5904	5728	4817	3690	3221	5270	
Diffuse	1163	1435	1634	1886	2258	2321	2698	2463	1960	1547	1314	1057	1811	
Relative Humidity (%)														
morning	84	85	82	78	70	70	85	85	89	80	88	83	81.6	
evening	58	51	44	25	25	35	63	69	55	48	42	51	47.2	
Dry Bulb Temperature (°C)														
max	18.9	20.3	27.4	34.0	37.2	39.2	33.5	33.2	33.5	30.9	24.3	20.6	29.4	
min	7.1	8.6	12.5	17.3	21.7	25.6	26.6	26.3	23.3	18.3	12.5	8.6	17.4	
mean	13.0	14.5	20.0	25.7	29.5	32.4	30.1	29.8	28.4	24.6	18.4	14.6	23.4	
Neutrality	21.8	22.3	24.0	25.8	26.9	27.8	27.1	27.0	26.6	25.4	23.5	22.3	23.9	
Upper limit	24.3	24.8	26.5	28.3	29.4	30.3	29.6	29.5	29.1	27.9	26.0	24.8	26.4	
Lower limit	19.3	19.8	21.5	23.3	24.4	25.3	24.6	24.5	24.1	22.9	21.0	19.8	21.4	
Rain (mm)^b	28.3	29.2	34.8	19.3	19.6	51.7	224.7	174.5	94.6	21.3	5.7	14.6	718.3	
Wind (m/s)	0.7	1.1	1.3	1.2	1	0.8	0.7	0.3	0.4	0.5	0.5	0.5	0.8	
HDD	180	114	12	0	0	0	0	0	0	0	36	138	480	
CDD	0	0	50	219	359	421	372	355	295	185	30	0	2286	

Avg diurnal range (°K)	12.1
Annual mean range (°K)	32.1

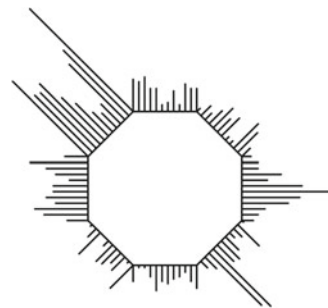
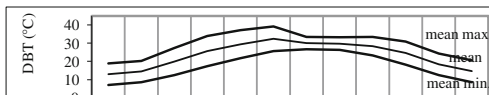
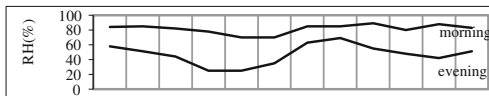
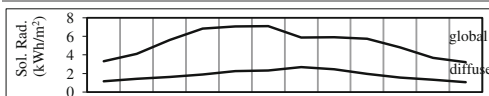
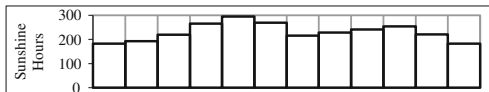


Table 5.8 Design conditions and overheat–underheated periods, Amritsar

Recommended “Design” conditions														
Summer	DBT (°C)		40.3											
	MCWB (°C)		24.6											
	WBT (°C)		28.8											
	MCDB (°C)		34.8											
Winter	DBT (°C)		4.0											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	9.3	10.7	14.5	19.8	24.2	27.4	28.0	27.4	24.8	20.1	14.8	10.6	0	0	0	0
1:01- 2:00	8.9	10.3	14.0	19.2	23.7	26.9	27.6	27.3	24.4	19.7	14.2	10.0	0	0	0	0
2:01- 3:00	8.4	9.8	13.6	18.6	23.0	26.6	27.5	27.1	24.2	19.5	13.8	9.6	0	0	0	0
3:01- 4:00	8.1	9.4	13.3	18.0	22.4	26.3	27.1	26.7	24.0	19.2	13.3	9.3	0	0	0	0
4:01- 5:00	7.9	9.2	12.9	17.6	22.0	25.9	27.0	26.5	23.7	18.8	13.0	8.9	0	0	0	0
5:01- 6:00	7.6	8.9	13.0	17.3	21.7	25.6	26.6	26.3	23.4	18.6	12.7	8.8	1	1	0	0
6:01- 7:00	7.3	8.6	12.5	17.8	24.0	27.1	26.7	26.3	23.3	18.3	12.5	8.6	7	55	0	0
7:01- 8:00	7.1	8.8	14.4	21.1	27.8	29.6	27.4	26.7	24.9	19.6	12.5	8.6	59	146	4	7
8:01- 9:00	8.9	11.1	17.5	25.8	30.0	31.5	29.0	28.4	26.8	22.7	14.7	10.5	213	197	64	59
9:01-10:00	12.1	14.1	21.0	28.6	32.1	33.6	30.1	29.7	29.0	25.7	17.4	13.5	370	223	174	104
10:01-11:00	14.7	16.8	23.4	30.7	34.2	35.4	31.3	30.7	30.8	28.0	20.2	16.2	637	186	302	129
11:01-12:00	16.5	18.7	25.0	32.3	35.6	37.0	32.3	31.8	31.9	29.3	22.2	18.1	686	219	377	149
12:01-13:00	17.8	19.7	26.5	33.5	36.6	38.0	32.5	32.5	32.7	30.1	23.4	19.3	726	217	393	165
13:01-14:00	18.7	20.3	27.1	34.0	37.2	38.7	33.0	33.2	33.3	30.7	24.0	20.0	662	231	344	172
14:01-15:00	18.9	20.2	27.4	34.0	37.2	39.2	33.4	33.0	33.5	30.9	24.3	20.6	567	231	261	160
15:01-16:00	18.7	20.0	27.0	33.5	37.0	38.9	33.5	32.9	33.3	30.7	24.2	20.5	414	226	163	126
16:01-17:00	18.1	19.5	26.3	32.7	36.5	38.5	33.3	32.5	32.8	30.0	23.9	19.2	309	180	67	76
17:01-18:00	16.1	18.2	24.9	31.1	35.4	37.3	33.3	32.0	31.6	27.6	22.0	16.7	108	148	9	15
18:01-19:00	13.8	16.1	21.7	28.7	33.1	35.2	32.4	31.3	29.3	25.3	20.2	14.9	8	58	0	0
19:01-20:00	12.3	14.6	19.6	25.7	30.3	32.6	31.1	30.1	27.5	23.8	18.5	13.7	0	2	0	0
20:01-21:00	11.3	13.5	18.0	23.5	28.3	31.0	30.0	29.4	26.6	22.7	17.5	12.8	0	0	0	0
21:01-22:00	10.5	12.5	16.8	22.2	26.8	29.9	29.6	28.8	25.9	21.9	16.7	12.1	0	0	0	0
22:01-23:00	9.9	11.9	16.0	21.3	25.7	28.8	29.0	28.4	25.3	21.3	16.0	11.5	0	0	0	0
23:01-24:00	9.4	11.3	15.2	20.4	24.9	27.7	28.4	27.7	24.8	20.5	15.2	11.1	0	0	0	0
Legend	Underheated		< 19.3°C		Comfortable				Overheated		> 27.8°C					

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.9 Climatic data, Aurangabad, Maharashtra

Latitude	N 19° 51'				Longitude	E 75° 24'				Altitude	579 m		
Climate	Hot and dry				Köppen	BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	310.0	293.2	328.3	308.5	322.7	195.2	90.4	105.5	175.8	251.1	290.6	314.5	248.8
Cloud (%)	6.7	6.6	5.7	14.5	17.6	56.5	80.1	78.8	64.0	34.8	17.2	7.3	32.47
Solar irradiation daily average (Wh/m²)													
Global	5339	6151	6940	7344	7597	6080	4638	4719	5368	5613	5443	5173	5867
Diffuse	1210	1341	1582	1873	1942	2865	3407	3276	2763	1911	1270	1083	2044
Relative Humidity (%)													
morning	76	73	48	46	67	83	91	92	93	87	81	82	76.6
evening	40	32	23	25	30	53	72	69	60	44	43	37	44.0
Dry Bulb Temperature (°C)													
max	29.0	29.7	35.7	37.4	38.5	33.5	28.2	27.8	29.1	30.7	30.3	28	31.5
min	13.5	14.7	20.3	24.2	25.8	24.9	23.3	22.1	22.2	20.3	15.4	11.8	19.9
mean	21.3	22.2	28.0	30.8	32.2	29.2	25.8	25.0	25.7	25.5	22.9	19.9	25.7
Neutrality	24.4	24.7	26.5	27.3	27.8	26.9	25.8	25.5	25.8	25.7	24.9	24.0	24.3
Upper limit	26.9	27.2	29.0	29.8	30.3	29.4	28.3	28.0	28.3	28.2	27.4	26.5	26.8
Lower limit	21.9	22.2	24.0	24.8	25.3	24.4	23.3	23.0	23.3	23.2	22.4	21.5	21.8
Rain (mm) ^b	11.3	2.7	5.6	3.9	26.2	132.2	157.9	152.7	146.0	62.1	26.8	12.0	739.4
Wind (m/s)	1.1	1.8	1.9	2.1	4.2	4	5.1	3.5	2.4	1.4	0.7	0.9	2.4
HDD	2	0	0	0	0	0	0	0	0	0	0	0	2
CDD	87	117	322	403	438	324	231	202	218	227	144	49	2762

Avg diurnal range (°K)	11.6
Annual mean range (°K)	26.7

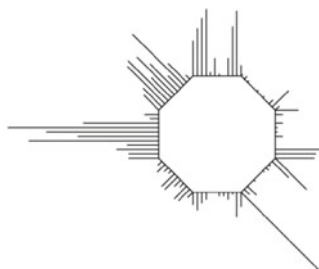
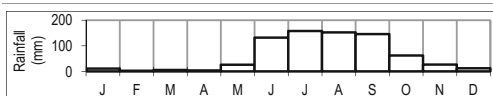
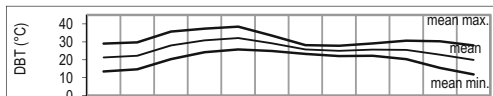
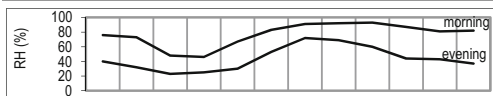
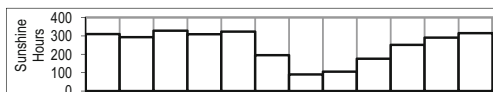


Table 5.10 Design conditions and overheated–underheated periods, Aurangabad

Recommended “Design” conditions														
Summer	DBT (°C)		39.3											
	MCWB (°C)		22.9											
	WBT (°C)		25.3											
	MCDB (°C)		33.1											
Winter	DBT (°C)		12.0											

Hourly temperature (°C) in all 12 months

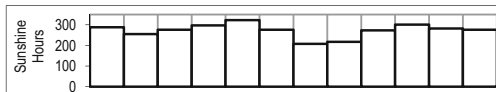
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	16.8	18.4	25.2	28.7	28.9	26.5	24.0	22.8	23.3	22.5	18.4	14.7	0	0	0	0
1:01- 2:00	16.1	17.6	24.4	28.0	28.1	26.2	23.7	22.6	23.1	21.9	17.9	14.2	0	0	0	0
2:01- 3:00	15.3	16.9	23.2	26.9	27.3	25.4	23.5	22.4	22.8	21.4	17.3	13.5	0	0	0	0
3:01- 4:00	14.6	16.3	22.5	25.9	26.7	25.4	23.4	22.3	22.6	21.0	16.8	12.9	0	0	0	0
4:01- 5:00	14.2	15.9	21.6	25.2	26.1	25.2	23.4	22.2	22.4	20.9	16.2	12.5	0	0	0	0
5:01- 6:00	13.5	15.3	21.1	24.7	25.8	24.9	23.3	22.1	22.2	20.5	15.6	12.2	0	0	0	0
6:01- 7:00	13.9	14.7	20.3	24.2	26.0	25.1	23.3	22.1	22.2	20.3	15.4	11.8	19	46	0	0
7:01- 8:00	14.9	15.8	22.3	26.6	27.4	26.1	24.0	22.7	23.0	22.9	18.0	14.2	149	120	35	40
8:01- 9:00	16.4	21.4	27.6	30.5	30.3	28.3	25.3	24.2	25.0	26.2	23.5	20.3	337	162	179	94
9:01-10:00	18.9	24.1	30.0	32.4	32.4	29.2	25.9	24.8	26.1	27.8	26.0	23.0	519	186	358	121
10:01-11:00	21.6	25.9	31.9	34.0	34.5	30.7	26.8	26.0	27.4	29.1	27.6	24.9	687	188	519	131
11:01-12:00	24.3	27.3	33.5	35.3	36.1	31.9	27.6	26.9	28.2	29.8	28.7	26.2	816	175	639	126
12:01-13:00	26.2	28.2	34.5	36.1	37.2	32.6	28.0	27.4	28.7	30.5	29.6	27.1	859	169	688	118
13:01-14:00	27.6	29.1	35.3	36.9	37.9	33.2	28.2	27.8	29.1	30.6	30.1	27.8	790	182	639	119
14:01-15:00	28.4	29.6	35.7	37.3	38.4	33.5	28.1	27.7	29.1	30.7	30.3	28.0	660	190	521	117
15:01-16:00	29.0	29.7	35.7	37.4	38.5	33.5	28.0	27.3	28.6	30.3	30.3	28.0	461	198	344	109
16:01-17:00	28.8	29.4	35.3	37.2	38.2	32.9	27.6	26.7	27.9	29.7	29.5	27.3	261	176	148	85
17:01-18:00	28.2	28.2	34.3	36.6	37.3	31.5	27.1	26.2	26.9	27.9	26.9	24.9	91	119	23	22
18:01-19:00	26.4	24.9	31.8	34.7	35.6	30.3	26.2	25.3	26.0	26.2	24.4	21.4	9	30	0	0
19:01-20:00	24.3	22.6	28.9	32.8	33.9	28.9	25.6	24.6	25.4	25.1	23.0	19.2	0	0	0	0
20:01-21:00	21.8	21.3	27.6	31.5	32.7	28.3	25.0	24.0	24.7	24.0	21.9	17.7	0	0	0	0
21:01-22:00	20.0	20.6	26.7	30.8	31.6	27.9	24.7	23.7	24.3	23.2	21.1	16.7	0	0	0	0
22:01-23:00	18.9	19.7	26.2	30.6	30.6	27.3	24.4	23.3	24.0	22.8	19.7	15.9	0	0	0	0
23:01-24:00	17.7	19.1	25.6	29.9	29.8	26.8	24.0	23.0	23.6	22.4	18.8	15.4	0	0	0	0
Legend	Underheated			<21.5°C	Comfortable								Overheated		>27.8°C	

Sources of data: ISHRAE (2014), ^aEstimated based on the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.11 Climatic data, Barmer, Rajasthan

Latitude	N 25° 45'				Longitude				E 71° 22'				Altitude	194 m
Climate	Hot and dry				Köppen				'BWh'					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	288.3	254.8	275.9	297	322.4	276	207.7	217	273	300.7	282	275.9	272.6	
Cloud (%)	46.2	43.7	44.8	44.9	45.3	45.6	44.5	44.3	44.9	44.2	43.3	44.8	44.71	
Solar irradiation daily average (Wh/m²)														
Global	4299	5126	6171	6755	7186	7084	6574	6329	6096	5346	4551	4053	5798	
Diffuse	1336	1584	1810	2186	2304	2474	2740	2582	2101	1693	1351	1241	1950	
Relative Humidity (%)														
morning	66	65	52	49	58	70	81	84	79	49	61	53	63.9	
evening	38	39	22	21	24	29	50	59	39	24	37	29	34.3	
Dry Bulb Temperature (°C)														
max	24.5	26.4	33.7	37.2	41.3	40.1	35.8	33.1	36.0	35.4	29.8	26.1	33.3	
min	11.8	13.9	19.9	26.1	28.5	28.7	27.6	27.1	25.9	25.0	18.6	13.6	22.2	
mean	18.2	20.2	26.8	31.7	34.9	34.4	31.7	30.1	31.0	30.2	24.2	19.9	27.8	
Neutrality	23.4	24.0	26.1	27.6	28.6	28.5	27.6	27.1	27.4	27.2	25.3	24.0	26.4	
Upper limit	25.9	26.5	28.6	30.1	31.1	31.0	30.1	29.6	29.9	29.7	27.8	26.5	28.9	
Lower limit	20.9	21.5	23.6	25.1	26.1	26.0	25.1	24.6	24.9	24.7	22.8	21.5	23.9	
Rain (mm)^a	1.2	1.9	3.3	5.3	8.6	30.6	82.9	89.3	38.7	5.8	2.9	0.5	271	
Wind (m/s)	1.45	1.40	1.41	2.33	3.52	3.83	2.85	2.26	1.95	0.99	1.42	0.80	2.0	
HDD	31	12	0	0	0	0	0	0	0	0	0	16	59	
CDD	18	68	274	408	519	490	411	367	388	369	178	58	3548	



Average diurnal range (°K)	11.1
Annual mean range (°K)	29.5

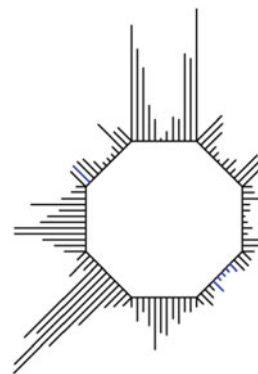
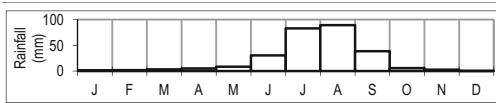
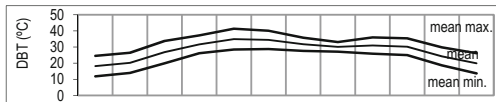
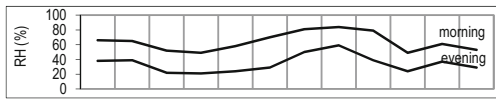
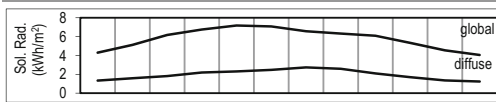


Table 5.12 Design conditions and overheated–underheated periods, Barmer

Recommended “Design” conditions														
Summer	DBT (°C)		42.0											
	MCWB (°C)		23.6											
	WBT (°C)		27.8											
	MCDB (°C)		35.3											
Winter	DBT (°C)		10.7											

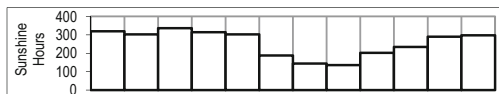
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	14.8	17.0	24.1	28.9	31.7	31.9	29.0	28.1	28.6	27.4	21.4	16.8	0	0	0	0
1:01- 2:00	14.1	16.0	23.1	27.8	30.6	30.9	28.5	27.7	27.9	26.8	20.6	16.2	0	0	0	0
2:01- 3:00	13.8	15.6	22.5	27.2	29.8	30.0	28.2	27.4	27.0	26.4	20.3	15.9	0	0	0	0
3:01- 4:00	13.0	14.7	21.3	26.5	29.0	29.3	27.8	27.2	26.3	25.8	19.6	15.1	0	0	0	0
4:01- 5:00	12.5	14.6	20.6	26.2	28.6	28.8	27.6	27.1	25.9	25.3	19.1	14.3	0	0	0	0
5:01- 6:00	11.8	13.9	19.9	26.1	28.5	28.7	27.6	27.2	26.0	25.0	18.6	13.6	1	2	0	0
6:01- 7:00	12.0	14.2	20.3	26.8	29.1	29.2	28.0	27.5	26.5	25.6	19.1	13.8	24	71	0	0
7:01- 8:00	12.6	15.0	21.5	27.9	30.2	30.2	28.7	28.1	27.6	26.8	20.0	14.7	146	154	20	34
8:01- 9:00	14.6	17.3	24.2	29.8	32.1	31.8	30.0	29.0	28.9	28.8	22.2	17.0	316	202	131	92
9:01-10:00	16.9	19.6	26.9	31.7	34.1	33.6	31.3	30.1	30.6	30.9	24.5	19.5	488	222	271	135
10:01-11:00	19.6	22.4	29.9	33.8	36.4	35.5	32.7	31.1	32.3	33.0	27.0	22.3	623	231	389	164
11:01-12:00	21.5	24.0	31.7	35.3	38.2	37.2	33.8	32.0	33.9	34.3	28.5	24.2	705	231	473	172
12:01-13:00	23.2	25.5	33.0	36.4	39.8	38.6	34.8	32.7	35.1	35.2	29.6	25.6	722	227	493	179
13:01-14:00	24.0	25.9	33.4	36.9	40.7	39.5	35.4	33.0	35.9	35.4	29.7	26.0	661	231	459	173
14:01-15:00	24.5	26.4	33.7	37.2	41.3	40.1	35.8	33.1	36.0	35.3	29.8	26.1	545	225	368	159
15:01-16:00	24.1	26.1	33.3	36.9	41.2	40.1	35.7	32.9	35.7	34.7	29.1	25.3	386	208	242	128
16:01-17:00	23.4	25.8	32.7	36.4	40.7	39.7	35.3	32.4	35.0	33.9	28.4	24.4	205	177	103	81
17:01-18:00	21.9	24.3	31.2	35.3	39.6	38.8	34.4	31.8	34.2	32.6	26.9	22.7	58	107	12	20
18:01-19:00	20.4	23.1	29.9	34.2	38.4	37.7	33.2	31.1	33.3	31.4	25.7	21.2	1	15	0	0
19:01-20:00	18.6	21.3	28.0	33.0	37.0	36.5	32.0	30.4	32.6	30.0	24.2	19.5	0	0	0	0
20:01-21:00	17.5	20.5	27.0	32.2	35.9	35.4	31.0	29.9	31.8	29.1	23.5	18.5	0	0	0	0
21:01-22:00	16.3	19.4	25.8	31.3	34.8	34.4	30.2	29.3	31.1	28.3	22.7	17.6	0	0	0	0
22:01-23:00	15.8	19.0	25.4	30.7	33.8	33.5	29.8	28.9	30.3	28.0	22.4	17.3	0	0	0	0
23:01-24:00	15.1	17.9	24.5	29.7	32.7	32.6	29.3	28.4	29.6	27.5	21.7	16.8	0	0	0	0
Legend	Underheated	<20.9°C			Comfortable				Overheated	>28.6°C						

Sources of data: ISHRAE (2014), ^aIMD (2010)

Table 5.13 Climatic data, Belgaum, Karnataka

Latitude	N 15° 51'				Longitude	E 74° 37'				Altitude	747 m		
Climate	Warm and humid				Köppen	BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	319.1	302.8	336.2	314.6	302.5	187.8	143.7	135.7	202.1	233.9	290.2	297.0	255.5
Cloud (%)	14.3	9.9	6.9	22.5	41.4	72.7	80.4	83.1	71.8	59.6	33.4	29.0	43.75
Solar irradiation daily average (Wh/m²)													
Global	5779	6557	7217	7476	7289	5894	5253	5098	5806	5628	5758	5362	6093
Diffuse	1276	1367	1543	1775	1980	2943	3292	3314	2661	2174	1465	1382	2098
Relative Humidity (%)													
morning	86	82	74	79	85	91	95	93	89	96	85	82	86.4
evening	32	23	21	20	36	62	80	73	64	60	37	30	44.8
Dry Bulb Temperature (°C)													
max	27.4	31	34.5	35.7	32.8	27.6	24.6	24.8	27.6	27.7	28.5	28.3	29.2
min	15.1	16.2	19.8	21.1	21.4	22.1	21.2	21.1	20.6	20.7	17.5	16.5	19.4
mean	21.3	23.6	27.2	28.4	27.1	24.9	22.9	23.0	24.1	24.2	23.0	22.4	24.3
Neutrality	24.4	25.1	26.2	26.6	26.2	25.5	24.9	24.9	25.3	25.3	24.9	24.7	23.8
Upper limit	26.9	27.6	28.7	29.1	28.7	28.0	27.4	27.4	27.8	27.8	27.4	27.2	26.3
Lower limit	21.9	22.6	23.7	24.1	23.7	23.0	22.4	22.4	22.8	22.8	22.4	22.2	21.3
Rain (mm)^b	1.1	2.1	10.6	45.1	89.8	166.1	268.9	157.4	109.3	124.9	34.2	5.6	1015
Wind (m/s)	1.8	2.2	2.5	2.7	3.6	4.6	4	3.4	2	1.7	2	2.4	2.7
HDD	1	0	0	0	0	0	0	0	0	0	0	0	1
CDD	88	140	260	281	256	182	138	141	167	173	142	125	2093



Average diurnal range (°K)	9.8
Annual mean range (°K)	20.6

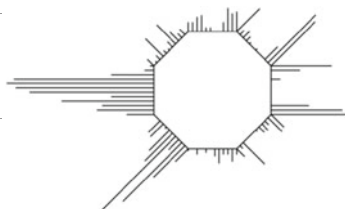
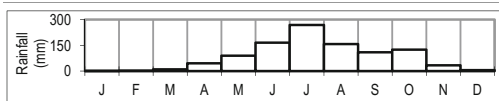
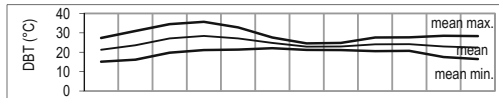
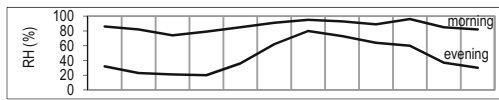
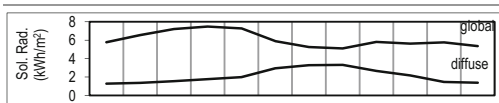


Table 5.14 Design conditions and overheated–underheated periods, Belgium

Recommended “Design” conditions														
Summer	DBT (°C)		35.7											
	MCWB (°C)		19.6											
	WBT (°C)		23.8											
	MCDB (°C)		29.5											
Winter	DBT (°C)		14.3											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Jan	
Hours													H _b	H _d	H _b	H _d
0:01- 1:00	16.9	18.5	21.6	23.0	22.7	22.4	21.4	21.2	21.3	21.5	19.3	18.6	0	0	0	0
1:01- 2:00	16.4	17.8	21.1	22.7	22.4	22.3	21.3	21.2	21.2	21.4	18.9	18.3	0	0	0	0
2:01- 3:00	16.0	17.3	20.5	22.4	22.2	22.2	21.2	21.1	21.0	21.3	18.4	17.8	0	0	0	0
3:01- 4:00	15.7	17.0	20.3	21.8	21.9	22.2	21.2	21.1	20.9	21.1	18.1	17.2	0	0	0	0
4:01- 5:00	15.5	16.7	20.2	21.4	21.7	22.2	21.2	21.1	20.8	20.9	17.8	16.8	0	0	0	0
5:01- 6:00	15.4	16.4	19.9	21.1	21.4	22.1	21.2	21.1	20.7	20.7	17.7	16.6	0	0	0	0
6:01- 7:00	15.1	16.2	19.8	21.2	21.5	22.3	21.3	21.1	20.6	20.8	17.5	16.5	9	12	0	0
7:01- 8:00	16.0	17.6	21.6	23.2	22.9	23.0	21.8	21.5	21.2	22.0	19.8	18.4	99	100	29	33
8:01- 9:00	20.3	22.0	25.6	26.6	25.6	24.2	22.7	22.3	22.8	23.7	23.3	21.7	296	151	173	93
9:01-10:00	22.8	25.1	28.6	29.7	27.7	25.3	23.5	23.0	24.1	25.1	25.2	23.7	493	180	366	126
10:01-11:00	24.5	27.3	31.0	32.0	29.8	26.3	24.2	23.7	25.3	26.3	26.5	25.3	680	182	547	138
11:01-12:00	25.7	28.9	32.5	33.8	31.2	26.9	24.3	24.4	26.4	27.0	27.4	26.7	812	176	667	144
12:01-13:00	26.5	30.0	33.5	34.9	32.3	27.4	24.6	24.7	26.9	27.7	28.0	27.4	862	172	716	147
13:01-14:00	27.1	30.9	34.2	35.5	32.6	27.6	24.5	24.8	27.2	27.7	28.5	28.0	826	172	689	147
14:01-15:00	27.4	31.0	34.5	35.7	32.8	27.2	23.9	24.8	27.6	27.3	28.5	28.3	705	175	589	145
15:01-16:00	27.4	30.7	34.0	34.9	31.8	25.7	23.7	24.6	27.2	26.9	28.4	28.2	512	177	427	134
16:01-17:00	27.1	29.8	33.1	33.6	31.0	25.3	23.3	24.0	26.8	25.7	27.8	27.7	292	159	236	109
17:01-18:00	25.3	28.3	31.1	31.3	29.1	24.3	22.8	23.3	25.5	24.5	25.9	26.2	104	105	60	60
18:01-19:00	22.8	25.3	28.5	28.3	27.2	23.8	22.2	22.8	24.5	23.3	23.8	23.7	12	14	3	1
19:01-20:00	21.1	23.3	26.7	26.2	25.9	23.3	22.0	22.5	23.8	22.8	22.5	22.0	0	0	0	0
20:01-21:00	20.1	21.9	25.2	25.4	25.0	23.1	21.8	22.0	22.8	22.3	21.5	20.8	0	0	0	0
21:01-22:00	19.0	20.8	24.2	24.6	24.4	22.9	21.6	21.9	22.6	22.1	20.9	20.2	0	0	0	0
22:01-23:00	18.4	19.8	23.4	23.9	23.7	22.7	21.5	21.8	22.4	21.9	20.4	19.8	0	0	0	0
23:01-24:00	17.6	19.0	22.3	23.2	23.1	22.5	21.4	21.3	21.4	21.6	19.9	19.0	0	0	0	0
Legend	Underheated			<21.9°C				Comfortable				Overheated		>26.6°C		

Sources of data: ISHRAE (2014), ^aEstimated based on the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.15 Climatic data, Bengaluru, Karnataka

Latitude	N 12° 58'				Longitude	E 77° 34'				Altitude	921 m		
Climate	Temperate				Köppen	BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	262.3	247.6	271.4	257.0	241.1	136.8	111.8	114.3	143.6	173.1	190.2	211.7	196.7
Cloud (%)	25.92	18.46	23.42	38.79	49.79	69.13	81.96	80.67	72.71	69.13	57.17	41.54	52.39

Solar irradiation daily average (Wh/m²)

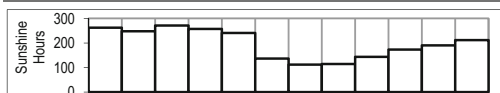
Global	5984	6654	7056	7159	7040	5823	5135	5073	5667	5067	5086	5346	5924
Diffuse	1436	1517	1793	2040	2166	2913	3223	3307	2898	2607	2123	1646	2306

Relative Humidity (%)

morning	92	89	81	84	92	93	91	94	94	96	90	94	90.8
evening	26	25	25	32	40	52	56	54	55	58	53	42	43.2

Dry Bulb Temperature (°C)

max	27.9	29.7	31.6	33.7	32.4	28.7	27.0	27.3	27.2	26.6	26.4	25.2	28.6
min	15.8	19.2	21.4	23.6	22.4	21.4	20.9	20.7	20.9	20.4	18.4	16.8	20.2
mean	21.9	24.5	26.5	28.7	27.4	25.1	24.0	24.0	24.1	23.5	22.4	21.0	24.4
Neutrality	24.6	25.4	26.0	26.7	26.3	25.6	25.2	25.2	25.3	25.1	24.7	24.3	23.7
Upper limit	27.1	27.9	28.5	29.2	28.8	28.1	27.7	27.7	27.8	27.6	27.2	26.8	26.2
Lower limit	22.1	22.9	23.5	24.2	23.8	23.1	22.7	22.7	22.8	22.6	22.2	21.8	21.2
Rain (mm)^b	4.9	7.9	10	43.9	111.9	79.7	109.7	138.8	185.9	161.7	59.2	17.4	931
Wind (m/s)	1	0.7	0.7	0.8	0.9	1.1	1.2	1.4	0.7	0.6	0.9	1.3	0.9
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	103	170	255	304	271	194	167	162	170	154	119	74	2143



Average diurnal range (°K)	8.5
Annual mean range (°K)	17.9

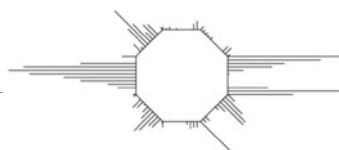
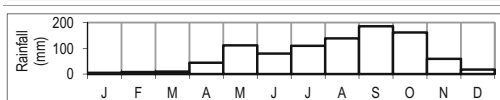
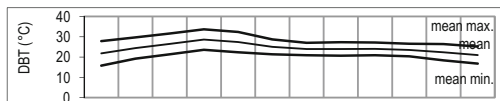
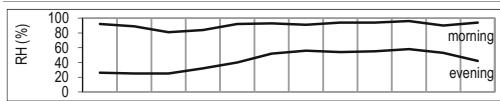
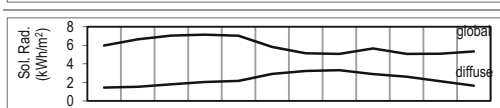


Table 5.16 Design conditions and overheated–underheated periods, Bengaluru

Recommended “Design” conditions		
Summer	DBT (°C)	34.0
	MCWB (°C)	19.6
	WBT (°C)	22.9
	MCDB (°C)	28.2
Winter	DBT (°C)	15.7

Hourly temperature (°C) in all 12 months

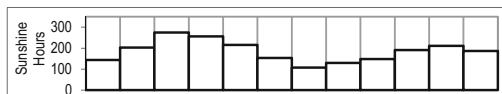
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Dec		
													H _b	H _d	H _b	H _d	
0:01- 1:00	18.2	21.5	23.7	25.4	24.1	22.3	21.7	21.4	22.1	21.0	19.8	18.0	0	0	0	0	
1:01- 2:00	17.7	21.0	23.2	25.0	23.7	22.0	21.4	21.2	21.8	20.8	19.5	17.7	0	0	0	0	
2:01- 3:00	17.1	20.4	22.7	24.5	23.2	21.8	21.3	21.0	21.5	20.6	19.2	17.5	0	0	0	0	
3:01- 4:00	16.8	20.1	22.3	24.2	22.9	21.7	21.1	20.9	21.3	20.5	18.9	17.3	0	0	0	0	
4:01- 5:00	16.4	19.9	21.9	23.9	22.6	21.5	21.0	20.8	21.1	20.5	18.7	17.3	0	0	0	0	
5:01- 6:00	16.0	19.4	21.6	23.7	22.4	21.4	20.9	20.7	21.0	20.4	18.4	17.0	0	0	0	0	
6:01- 7:00	15.8	19.2	21.4	23.6	22.4	21.4	20.9	20.7	20.9	20.4	18.4	16.8	30	23	6	3	
7:01- 8:00	16.5	19.5	22.3	24.6	23.3	21.9	21.5	21.0	21.2	21.2	19.7	17.4	151	104	81	64	
8:01- 9:00	19.8	21.9	24.4	26.5	25.3	23.6	22.4	22.0	22.6	22.3	21.5	19.3	350	151	197	133	
9:01-10:00	22.3	23.8	26.4	28.3	26.9	24.8	23.6	23.3	23.9	23.5	23.2	20.8	515	191	333	182	
10:01-11:00	24.4	25.8	28.2	30.0	28.4	26.1	24.8	24.6	25.0	24.7	24.5	22.5	641	217	455	210	
11:01-12:00	26.1	26.8	29.6	31.7	30.1	27.3	26.0	25.7	26.1	25.9	25.4	23.9	742	219	548	216	
12:01-13:00	27.0	28.2	30.5	32.8	31.2	28.0	26.7	26.5	26.7	26.4	25.9	24.7	771	218	586	208	
13:01-14:00	27.7	29.0	31.2	33.5	32.0	28.3	26.9	27.2	27.1	26.6	26.3	25.1	693	230	552	195	
14:01-15:00	27.9	29.7	31.6	33.7	32.4	28.7	27.0	27.3	27.2	26.5	26.4	25.2	566	227	458	173	
15:01-16:00	27.3	29.6	31.5	33.5	31.7	28.3	26.5	27.0	26.5	26.1	25.7	24.6	396	205	311	141	
16:01-17:00	25.9	28.9	30.8	32.5	30.6	27.8	25.7	26.2	25.9	25.4	24.8	23.7	203	163	141	96	
17:01-18:00	24.5	27.9	29.8	31.3	29.6	26.8	24.6	24.9	25.4	24.5	23.6	22.5	58	82	31	26	
18:01-19:00	23.0	26.4	28.4	29.9	28.6	25.8	23.9	23.8	24.6	23.6	22.6	21.2	4	10	0	0	
19:01-20:00	21.8	25.4	27.3	28.6	27.6	24.7	23.5	22.9	24.1	22.8	21.9	20.4	0	0	0	0	
20:01-21:00	20.9	24.4	26.2	27.9	26.6	23.8	22.9	22.5	23.6	22.3	21.4	19.7	0	0	0	0	
21:01-22:00	20.2	23.7	25.6	27.3	25.9	23.4	22.6	22.1	23.2	22.1	21.0	19.3	0	0	0	0	
22:01-23:00	19.5	23.0	24.9	26.6	25.3	22.9	22.3	21.9	23.0	21.7	20.5	18.9	0	0	0	0	
23:01-24:00	18.7	22.0	24.0	25.9	24.6	22.5	22.0	21.6	22.4	21.3	20.1	18.4	0	0	0	0	
Legend	Underheated			<21.8°C				Comfortable			Overheated			>26.7°C			

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.17 Climatic data, Bhagalpur, Bihar

Latitude	N 25° 13'				Longitude				E 86° 56'				Altitude	49 m
Climate	Warm and humid				Köppen		BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	143.7	202.8	274.2	255.7	215.5	153.4	107.1	129.4	147.7	191.2	211.1	186.7	184.9	
Cloud (%)	45.8	44.0	45.4	43.4	43.5	46.1	45.3	46.5	46.8	45.9	44.4	45.2	45.19	
Solar irradiation daily average (Wh/m²)														
Global	3320	4693	6020	6537	6242	5606	4912	4995	4852	4633	4192	3530	4961	
Diffuse	1942	1875	1960	2310	2846	3187	3489	3267	2828	2160	1613	1608	2424	
Relative Humidity (%)														
morning	90	80	66	76	87	90	94	93	92	88	80	82	84.8	
evening	56	44	34	45	56	70	72	71	67	59	41	46	55.1	
Dry Bulb Temperature (°C)														
max	25.8	27	34.4	36.3	36.6	33.4	32.6	33.2	33.3	32.9	31.8	26.5	32.0	
min	12.8	15.5	20.1	24.9	25.9	27.0	27.1	27.3	26.9	24.2	18.2	14.3	22.0	
mean	19.3	21.3	27.3	30.6	31.3	30.2	29.9	30.3	30.1	28.6	25.0	20.4	27.0	
Neutrality	23.8	24.4	26.2	27.3	27.5	27.2	27.1	27.2	27.1	26.7	25.6	24.1	26.2	
Upper limit	26.3	26.9	28.7	29.8	30.0	29.7	29.6	29.7	29.6	29.2	28.1	26.6	28.7	
Lower limit	21.3	21.9	23.7	24.8	25.0	24.7	24.6	24.7	24.6	24.2	23.1	21.6	23.7	
Rain (mm)^b	18.2	11.4	10.3	21.5	63	187.4	264.5	240.7	211.6	83.2	5.4	3.3	1121	
Wind (m/s)	0.65	1.04	0.94	1.80	1.43	1.09	1.11	0.98	0.98	0.61	0.73	0.71	1.0	
HDD	13	2	0	0	0	0	0	0	0	0	0	3	18	
CDD	19	72	260	374	403	359	363	371	342	302	177	42	3084	



Average diurnal range (°K)	10.0
Annual mean range (°K)	23.8

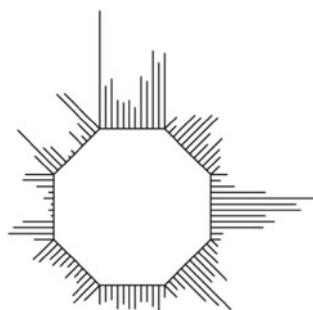
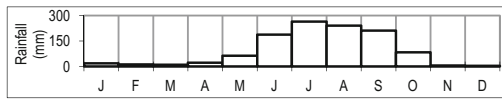
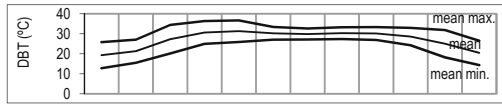
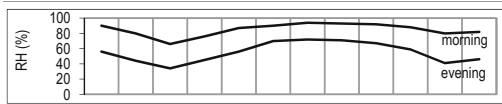
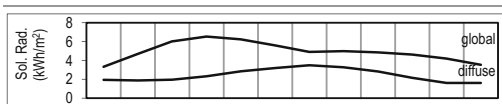


Table 5.18 Design conditions and overheated–underheated periods, Bhagalpur

Recommended “Design” conditions														
Summer	DBT (°C)		40.7											
	MCWB (°C)		27.4											
	WBT (°C)		29.6											
	MCDB (°C)		36.4											
Winter	DBT (°C)		12.6											

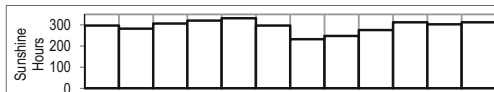
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	14.7	17.2	22.5	27.1	27.9	28.0	28.0	28.2	27.5	25.4	20.3	15.9	0	0	0	0
1:01- 2:00	14.1	16.6	21.7	26.3	27.1	27.6	27.7	27.8	27.3	25.1	19.6	15.4	0	0	0	0
2:01- 3:00	13.7	16.3	21.1	25.4	26.5	27.3	27.4	27.5	27.1	24.8	18.9	15.0	0	0	0	0
3:01- 4:00	13.2	15.8	20.4	24.9	25.9	27.1	27.1	27.3	26.9	24.5	18.5	14.6	0	0	0	0
4:01- 5:00	12.9	15.7	20.1	25.0	26.1	27.0	27.2	27.4	26.9	24.2	18.2	14.3	0	3	0	0
5:01- 6:00	12.8	15.5	20.1	25.9	26.5	27.3	27.6	27.8	27.1	24.5	18.8	14.6	16	66	0	0
6:01- 7:00	13.5	16.2	21.1	27.5	27.6	28.0	28.4	28.5	27.9	25.3	20.1	15.4	101	162	6	34
7:01- 8:00	15.0	17.4	22.9	29.4	29.3	29.1	29.3	29.5	28.9	26.6	22.1	17.1	218	237	55	117
8:01- 9:00	17.6	19.7	25.8	31.2	31.3	30.4	30.4	30.6	30.3	28.3	24.6	19.3	332	292	123	194
9:01-10:00	20.4	22.1	28.8	32.9	33.2	31.6	31.2	31.7	31.7	30.1	27.2	21.9	440	310	192	243
10:01-11:00	23.2	24.6	31.7	34.2	34.9	32.6	32.0	32.5	32.8	31.6	29.5	24.2	511	310	236	271
11:01-12:00	25.0	26.1	33.5	35.2	36.0	33.1	32.4	33.1	33.3	32.7	31.2	25.9	526	304	238	289
12:01-13:00	25.8	27.0	34.4	35.9	36.6	33.4	32.6	33.2	33.3	32.9	31.8	26.5	471	306	220	272
13:01-14:00	25.4	26.8	34.1	36.3	36.5	33.3	32.6	33.0	32.8	32.5	31.4	26.2	368	298	164	241
14:01-15:00	24.4	26.4	33.4	36.2	36.1	33.1	32.5	32.5	32.1	31.5	30.0	24.9	251	257	102	175
15:01-16:00	22.8	25.2	32.0	35.6	35.2	32.6	32.0	31.9	31.2	30.3	28.2	23.4	127	193	37	93
16:01-17:00	21.3	24.2	30.6	34.5	34.2	32.0	31.4	31.2	30.4	29.1	26.3	21.7	33	97	4	14
17:01-18:00	19.7	22.7	28.9	33.0	32.9	31.2	30.6	30.5	29.6	28.2	24.7	20.3	1	10	0	0
18:01-19:00	18.6	21.5	27.5	31.4	31.8	30.4	29.8	30.0	29.0	27.4	23.5	19.3	0	0	0	0
19:01-20:00	17.6	20.3	26.0	30.1	30.7	29.5	29.1	29.5	28.4	26.9	22.7	18.5	0	0	0	0
20:01-21:00	17.0	19.6	25.2	29.0	30.0	29.0	28.7	29.2	28.1	26.5	22.2	17.8	0	0	0	0
21:01-22:00	16.4	18.8	24.4	28.5	29.5	28.6	28.5	29.0	27.8	26.1	21.8	17.3	0	0	0	0
22:01-23:00	15.9	18.5	23.9	28.1	29.1	28.4	28.4	28.8	27.7	25.8	21.3	16.8	0	0	0	0
23:01-24:00	15.2	17.8	23.2	27.7	28.6	28.2	28.3	28.5	27.6	25.5	20.7	16.3	0	0	0	0
Legend	Underheated		<21.3°C			Comfortable				Overheated			>27.5°C			

Sources of data: ISHRAE (2014), ^aEstimated based on the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.19 Climatic data, Bhopal, Madhya Pradesh

Latitude	N 23° 16'				Longitude	E 77° 20'				Altitude	523 m		
Climate	Composite				Köppen	BWh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	297.6	282.8	306.9	321.0	331.7	297.0	232.5	248.0	276.0	313.1	303.0	313.1	293.6
Cloud (%)	31.83	10.13	22.25	24.21	25.5	60.42	82.13	87.5	66.67	27.42	15.0	22.17	39.6
Solar irradiation daily average (Wh/m²)													
Global	4591	5716	6552	7134	7470	6223	4703	4286	5555	5651	5006	4514	5617
Diffuse	1383	1399	1672	1964	2133	2954	3438	3395	2549	1728	1304	1159	2090
Relative Humidity (%)													
morning	71	61	44	43	43	70	91	90	90	77	83	81	70.3
evening	37	26	17	18	24	38	68	74	63	36	31	37	39.1
Dry Bulb Temperature (°C)													
max	23.2	28.2	33.3	36.2	39.8	35.8	29.4	28.2	29.3	30.7	27.8	25.4	30.6
min	12.3	15.0	19.7	23.9	28.0	27.5	24.6	24.1	23.1	19.6	16.4	13.2	20.6
mean	17.8	21.6	26.5	30.1	33.9	31.7	27.0	26.2	26.2	25.2	22.1	19.3	25.6
Neutrality	23.3	24.5	26.0	27.1	28.3	27.6	26.2	25.9	25.9	25.6	24.7	23.8	24.1
Upper limit	25.8	27.0	28.5	29.6	30.8	30.1	28.7	28.4	28.4	28.1	27.2	26.3	26.6
Lower limit	20.8	22.0	23.5	24.6	25.8	25.1	23.7	23.4	23.4	23.1	22.2	21.3	21.6
Rain (mm)^b	13.2	8.7	8.4	4.3	11.7	120.2	354.1	363.3	185.1	31.0	12.1	11	1123
Wind (m/s)	2.1	2.4	2.4	3.6	4.1	4.1	4.2	3.9	3.2	1.6	1.6	1.9	2.9
HDD	38	11	0	0	0	0	0	0	0	0	2	13	64
CDD	17	102	262	369	498	402	274	242	239	223	111	35	2774



Average diurnal range (°K)	10.0
Annual mean range (°K)	27.5

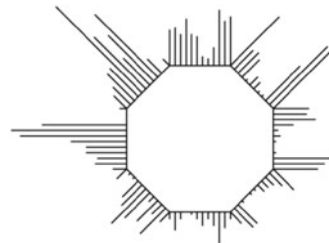
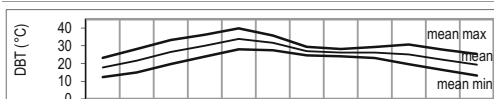
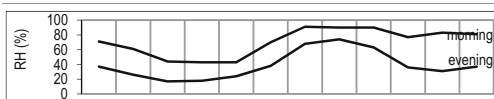
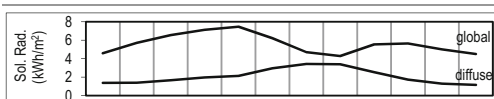


Table 5.20 Design conditions and overheated–underheated periods, Bhopal

Recommended “Design” conditions														
Summer	DBT (°C)		40.5											
	MCWB (°C)		21.7											
	WBT (°C)		25.6											
	MCDB (°C)		30.3											
Winter	DBT (°C)		11.0											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	14.5	17.2	22.5	26.7	30.6	29.0	25.6	24.5	24.2	21.8	18.2	15.5	0	0	0	0
1:01- 2:00	14.1	16.5	21.9	26.2	30.0	28.8	25.3	24.4	24.0	21.3	17.8	14.9	0	0	0	0
2:01- 3:00	13.6	15.9	21.2	25.7	29.4	28.3	25.1	24.2	23.8	20.8	17.2	14.4	0	0	0	0
3:01- 4:00	13.1	15.4	20.4	25.2	28.7	28.0	24.9	24.2	23.6	20.2	16.9	14.0	0	0	0	0
4:01- 5:00	12.6	15.0	19.7	24.6	28.0	27.7	24.7	24.1	23.4	19.6	16.5	13.7	0	0	0	0
5:01- 6:00	12.3	15.0	20.2	23.9	28.4	27.5	24.6	24.1	23.2	20.0	16.4	13.5	1	2	0	0
6:01- 7:00	12.5	15.6	21.5	23.9	29.6	27.7	24.7	24.1	23.1	21.2	16.8	13.2	28	63	0	0
7:01- 8:00	13.5	17.0	23.5	26.0	31.4	28.8	25.2	24.3	23.5	23.0	18.8	13.3	126	146	20	30
8:01- 9:00	15.2	19.1	25.7	29.5	33.4	30.7	26.3	25.3	25.4	25.1	21.6	17.4	278	203	119	98
9:01-10:00	17.4	21.6	27.7	31.6	35.4	31.6	27.1	25.9	26.6	27.1	23.6	20.1	449	229	275	138
10:01-11:00	19.5	23.9	29.5	33.0	37.0	33.3	27.8	26.8	27.8	28.6	25.3	22.1	557	254	417	159
11:01-12:00	21.2	25.8	30.9	34.5	38.1	34.2	28.6	27.4	28.8	29.7	26.5	23.6	570	294	521	167
12:01-13:00	22.3	27.0	32.0	35.4	39.0	34.9	29.0	27.7	29.3	30.4	27.2	24.7	588	296	556	170
13:01-14:00	23.0	27.8	32.8	35.9	39.5	35.5	29.4	28.0	29.3	30.7	27.5	25.2	658	238	508	174
14:01-15:00	23.2	28.2	33.3	36.1	39.8	35.8	29.3	28.1	29.2	30.6	27.8	25.4	758	136	403	169
15:01-16:00	23.0	28.1	33.2	36.2	39.7	35.1	29.2	28.2	29.2	30.3	27.4	25.2	714	76	260	147
16:01-17:00	22.3	27.5	32.5	36.1	39.2	35.1	28.9	27.9	28.7	29.6	26.6	24.4	466	77	110	103
17:01-18:00	21.1	26.3	31.2	35.7	38.1	34.7	28.4	27.4	27.8	28.5	24.4	22.1	140	95	19	29
18:01-19:00	19.7	24.7	29.3	33.7	36.7	33.7	27.6	26.7	26.7	27.2	22.8	20.2	4	23	0	0
19:01-20:00	18.2	23.0	27.4	31.8	35.1	32.2	27.1	25.9	26.0	25.7	21.5	18.9	0	0	0	0
20:01-21:00	17.0	21.5	25.9	30.5	33.9	31.2	26.8	25.3	25.5	24.6	20.6	17.9	0	0	0	0
21:01-22:00	16.2	20.3	25.0	29.3	33.0	30.5	26.5	25.1	25.2	23.7	19.9	17.2	0	0	0	0
22:01-23:00	15.4	19.2	24.0	28.2	32.0	29.9	26.1	24.9	24.8	22.9	19.3	16.6	0	0	0	0
23:01-24:00	14.7	18.3	23.2	27.5	31.3	29.3	25.8	24.6	24.3	22.2	18.7	16.0	0	0	0	0
Legend	Underheated		<20.8°C			Comfortable						Overheated		>28.3°C		

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.21 Climatic data, Bhubaneswar, Orissa

Latitude	N 20° 15'				Longitude				E 85° 49'				Altitude		46 m		
Climate	Warm and humid				Köppen				BSh								
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year				
Sunshine h ^a	253.4	234.0	237.8	238.8	242.9	140.7	107.2	128.6	150.8	221.8	217.5	255.0	202.4				
Cloud (%)	14.17	20.63	26.17	46.04	52.5	75.04	79.38	80.42	72.33	58.58	38.08	30.71	49.5				

Solar irradiation daily average (Wh/m²)

Global	4994	5545	6342	6581	6745	5326	4758	4592	4942	4701	4665	4505	5308
Diffuse	1428	1769	2021	2369	2548	3132	3405	3284	2875	2354	1690	1453	2361

Relative Humidity (%)

morning	89	92	88	87	88	87	95	94	95	95	92	88	90.8
evening	37	35	44	50	54	62	77	78	75	73	46	44	56.3

Dry Bulb Temperature (°C)

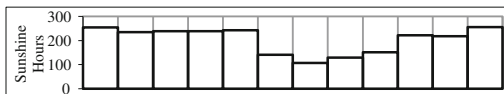
max	28.4	32.6	34.3	35.5	36.1	35.2	30.7	30	31.1	29.2	29	26.9	31.6
min	17.0	20.2	24.2	25.8	26.5	28.1	26.4	26.7	26.3	24.3	19.2	16.0	23.4
mean	22.7	26.4	29.3	30.7	31.3	31.7	28.6	28.4	28.7	26.8	24.1	21.5	27.5
Neutrality	24.8	26.0	26.9	27.3	27.5	27.6	26.7	26.6	26.7	26.1	25.3	24.4	24.3
Upper limit	27.3	28.5	29.4	29.8	30.0	30.1	29.2	29.1	29.2	28.6	27.8	26.9	26.8
Lower limit	22.3	23.5	24.4	24.8	25.0	25.1	24.2	24.1	24.2	23.6	22.8	21.9	21.8

Rain (mm)^b	13.1	25.5	25.2	30.8	68.2	204.9	326.2	366.8	256.3	190.7	41.7	4.9	155.4
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Wind (m/s)	1.7	2.7	3.2	5.2	4.9	4.3	3.7	2.7	2.6	2.1	1.2	1.3	3.0
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HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
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CDD	127	208	321	346	388	375	317	310	303	254	163	84	3196
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Average diurnal range (°K) 8.2

Annual mean range (°K) 20.1

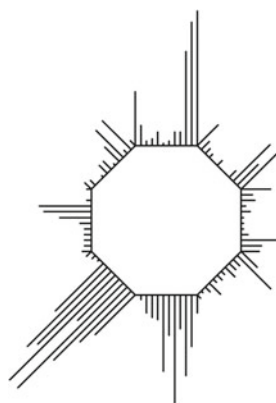
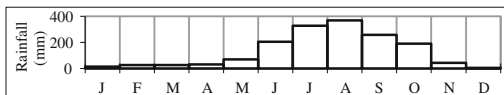
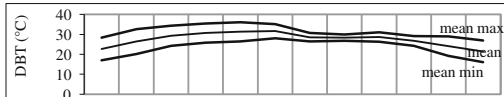
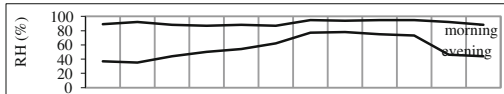
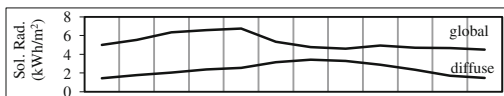


Table 5.22 Design conditions and overheated–underheated periods, Bhubaneswar

Recommended “Design” conditions														
Summer	DBT (°C)		37.6											
	MCWB (°C)		26.6											
	WBT (°C)		28.9											
	MCDB (°C)		33.3											
Winter	DBT (°C)		15.4											

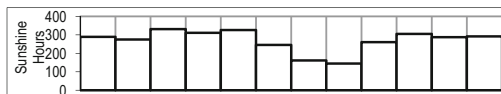
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	18.9	22.3	25.4	26.8	27.4	28.3	26.8	26.9	26.7	24.6	20.6	17.4	0	0	0	0
1:01- 2:00	18.6	21.9	25.1	26.4	27.2	28.2	26.8	26.8	26.5	24.5	20.2	17.0	0	0	0	0
2:01- 3:00	18.3	21.5	24.8	26.2	27.0	28.2	26.7	26.8	26.5	24.5	19.9	16.7	0	0	0	0
3:01- 4:00	17.9	21.1	24.6	26.1	26.8	28.2	26.6	26.7	26.4	24.4	19.7	16.5	0	0	0	0
4:01- 5:00	17.4	20.7	24.4	26.0	26.7	28.1	26.5	26.7	26.4	24.4	19.4	16.2	0	0	0	0
5:01- 6:00	17.0	20.2	24.2	25.8	26.5	28.2	26.4	26.7	26.3	24.3	19.2	16.0	2	15	0	0
6:01- 7:00	17.2	20.5	24.5	26.3	27.6	28.6	26.6	27.1	26.7	24.8	19.6	16.1	27	102	10	19
7:01- 8:00	18.0	21.3	26.2	28.0	29.4	29.6	27.4	27.9	27.7	26.0	21.7	18.3	86	202	83	90
8:01- 9:00	19.4	22.7	28.7	30.3	32.2	31.4	29.0	28.3	28.9	27.5	24.6	21.6	164	279	227	141
9:01-10:00	21.4	24.7	30.7	32.3	33.8	32.5	29.3	28.9	29.8	28.4	26.5	23.1	234	338	373	169
10:01-11:00	23.7	27.1	32.5	33.8	35.0	33.8	30.1	29.6	30.6	28.9	28.0	25.1	289	372	483	180
11:01-12:00	25.8	29.4	33.7	34.8	35.9	34.7	30.6	30.0	31.1	29.2	28.8	26.1	318	384	531	183
12:01-13:00	27.2	31.1	34.3	35.5	36.1	35.2	30.6	30.0	31.0	29.1	29.0	26.8	316	375	511	179
13:01-14:00	28.1	32.2	34.3	35.3	35.8	35.2	30.7	29.9	30.6	28.9	28.9	26.9	286	343	411	177
14:01-15:00	28.4	32.6	33.9	34.3	35.3	34.3	30.4	29.7	30.1	28.0	28.4	26.5	228	293	274	158
15:01-16:00	28.1	32.0	32.7	32.9	33.9	33.3	29.7	29.3	29.7	27.5	27.4	25.5	152	227	128	113
16:01-17:00	27.4	30.8	31.0	31.3	32.4	31.8	29.2	28.8	29.1	27.0	25.8	24.1	74	145	21	44
17:01-18:00	26.3	29.3	29.2	29.9	30.9	30.2	28.7	28.1	28.1	26.1	24.1	22.1	17	55	0	0
18:01-19:00	24.9	27.7	28.0	29.0	29.9	29.4	28.2	27.8	27.6	25.7	23.3	20.6	0	2	0	0
19:01-20:00	23.6	26.4	27.3	28.2	29.3	29.0	27.9	27.7	27.2	25.5	22.6	20.1	0	0	0	0
20:01-21:00	22.0	24.8	26.8	27.7	28.8	28.6	27.7	27.4	27.0	25.1	22.0	19.3	0	0	0	0
21:01-22:00	20.9	23.9	26.5	27.4	28.5	28.5	27.5	27.3	27.0	25.0	21.5	18.8	0	0	0	0
22:01-23:00	20.2	23.4	26.1	27.1	28.2	28.5	27.4	27.0	26.9	24.8	21.0	18.1	0	0	0	0
23:01-24:00	19.5	22.9	25.7	26.9	27.8	28.4	27.0	27.0	26.7	24.6	20.6	17.7	0	0	0	0
Legend	Underheated		<21.9°C			Comfortable						Overheated		>27.6°C		

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.23 Climatic data, Bhuji, Rajasthan

Latitude	N 23° 15'				Longitude				E 69° 40'				Altitude	80 m
Climate	Hot and dry				Köppen				Bwh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	289.5	275.1	331.4	311.4	326.0	245.4	161.4	145.1	260.5	305.5	288.0	291.6	269.2	
Cloud (%)	3.9	16.6	8.3	9.5	9.1	40.1	60.6	59.7	33.7	3.0	8.0	13.2	22.1	
Solar irradiation daily average (Wh/m²)														
Global	4833	5674	6798	7307	7654	6802	5590	5208	6331	6009	5123	4639	5997	
Diffuse	1237	1382	1473	1857	1921	2565	3144	3125	2019	1447	1224	1093	1874	
Relative Humidity (%)														
morning	70	80	79	88	84	88	88	92	86	75	65	90	82.1	
evening	34	35	37	29	37	53	61	69	43	39	34	39	42.5	
Dry Bulb Temperature (°C)														
max	25.7	29.6	35.0	37.5	38.2	34.8	34.0	30.9	33.8	36.6	31.5	29.1	33.1	
min	12.7	14.9	18.3	25.1	26.4	28.1	27.7	26.4	26.1	24.6	20.0	12.7	21.9	
mean	19.2	22.3	26.7	31.3	32.3	31.5	30.9	28.7	30.0	30.6	25.8	20.9	27.5	
Neutrality	23.8	24.7	26.1	27.5	27.8	27.5	27.4	26.7	27.1	27.3	25.8	24.3	24.6	
Upper limit	26.3	27.2	28.6	30.0	30.3	30.0	29.9	29.2	29.6	29.8	28.3	26.8	27.1	
Lower limit	21.3	22.2	23.6	25.0	25.3	25.0	24.9	24.2	24.6	24.8	23.3	21.8	22.1	
Rain (mm)^b	2	1.5	2.1	1.1	7.5	38	125.7	103.5	63.1	19.7	8.5	1	373.7	
Wind (m/s)	0.7	1.3	2	3	4.1	3.5	3.9	3.1	1.9	1.2	1.1	1	2.2	
HDD	16	3	0	0	0	0	0	0	0	0	0	0	19	
CDD	41	114	267	369	422	385	379	314	332	371	210	54	3258	



Average diurnal range (°K)	11.1
Annual mean range (°K)	25.5

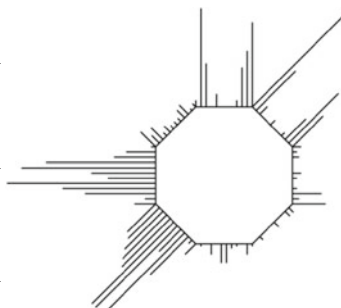
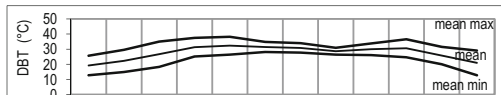
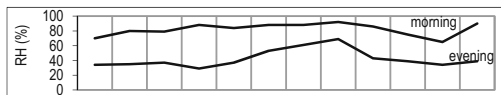
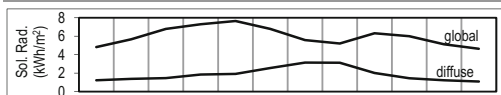


Table 5.24 Design conditions and overheated–underheated periods, Bhuj

Recommended “Design” conditions ^c														
Summer	DBT (°C)		39.7											
	MCWB (°C)		23.8											
	WBT (°C)		28.3											
	MCDB (°C)		33.8											
Winter	DBT (°C)		9.8											

Hourly temperature (°C) in all 12 months

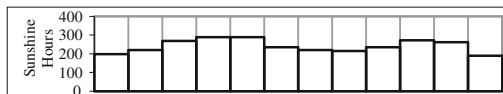
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	15.4	18.3	22.3	26.4	27.9	28.5	28.1	26.7	26.8	26.8	22.2	15.0	0	0	0	0
1:01- 2:00	14.8	17.5	21.6	26.1	27.7	28.4	28.0	26.6	26.6	26.2	21.8	14.5	0	0	0	0
2:01- 3:00	14.4	17.0	21.1	25.8	27.1	28.4	28.0	26.6	26.5	25.9	21.2	13.9	0	0	0	0
3:01- 4:00	14.0	16.5	20.4	25.5	26.8	28.3	27.8	26.5	26.3	25.5	20.9	13.5	0	0	0	0
4:01- 5:00	13.6	15.8	19.5	25.3	26.7	28.2	27.8	26.4	26.2	25.2	20.5	13.3	0	0	0	0
5:01- 6:00	13.2	15.3	18.8	25.2	26.4	28.1	27.7	26.4	26.1	24.8	20.2	13.0	0	0	0	0
6:01- 7:00	13.0	14.9	18.3	25.1	26.5	28.1	27.8	26.4	26.1	24.6	20.0	12.7	3	15	0	0
7:01- 8:00	12.7	15.2	19.6	26.0	28.5	28.7	28.5	26.7	26.3	25.3	20.2	13.0	72	107	4	3
8:01- 9:00	14.9	19.4	24.4	28.2	30.9	30.3	30.1	27.8	27.8	27.8	22.3	17.2	234	166	72	64
9:01-10:00	18.8	22.1	27.7	31.1	32.8	31.2	30.9	28.5	28.9	30.3	24.8	21.2	429	193	229	110
10:01-11:00	21.5	24.7	30.2	33.5	34.6	32.4	31.8	29.3	30.3	32.7	27.5	24.7	618	194	389	137
11:01-12:00	23.2	26.8	32.2	35.3	36.3	33.6	32.5	29.9	31.8	34.6	29.2	26.5	779	176	519	147
12:01-13:00	24.4	28.5	33.6	36.6	37.3	34.1	33.2	30.4	32.6	35.6	30.3	27.9	848	170	583	154
13:01-14:00	25.3	29.1	34.5	37.3	38.2	34.5	33.7	30.7	33.3	36.5	30.9	28.9	847	164	585	153
14:01-15:00	25.7	29.6	35.0	37.5	38.2	34.8	34.0	30.9	33.8	36.6	31.5	29.1	760	165	515	150
15:01-16:00	25.7	29.5	34.9	37.2	37.9	34.6	33.8	30.5	33.6	36.2	31.1	28.8	587	176	393	136
16:01-17:00	25.5	29.0	34.4	36.2	36.8	34.1	33.2	30.2	32.9	35.4	30.4	28.0	367	178	231	111
17:01-18:00	24.6	28.3	33.4	34.7	35.4	33.2	32.4	29.7	31.9	33.8	28.5	26.0	162	144	73	65
18:01-19:00	22.6	26.3	31.0	32.6	33.5	31.8	31.1	28.8	30.0	31.8	26.7	22.0	26	71	4	6
19:01-20:00	20.5	23.3	28.5	30.5	31.8	30.8	30.1	27.9	29.1	30.5	25.6	19.0	1	2	0	0
20:01-21:00	18.7	21.2	26.2	29.0	30.5	30.1	29.2	27.4	28.4	29.3	24.6	17.4	0	0	0	0
21:01-22:00	17.5	19.9	24.6	28.0	29.5	29.6	28.9	27.2	27.9	28.5	23.8	16.6	0	0	0	0
22:01-23:00	16.4	19.4	23.8	27.3	28.9	29.2	28.7	26.9	27.4	27.7	23.2	16.2	0	0	0	0
23:01-24:00	15.7	19.1	22.9	26.7	28.2	28.6	28.3	26.7	27.0	27.1	22.5	15.7	0	0	0	0
Legend	Underheated			<21.3°C	Comfortable								Overheated		>27.8°C	

Sources of data: ISHRAE (2014), ^aEstimated from the equation given by Muneer (2004), ^bIndia Meteorological Department (nd), ^chttp://climate.onebuilding.org/WMO_Region_2_Asia/IND_India/index.html

Table 5.25 Climatic data, Bikaner, Rajasthan

Latitude	N 28° 0'				Longitude	E 73° 18'				Altitude	224 m		
Climate	Hot and dry				Köppen	BWh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	198.2	220.3	267.7	288.4	288.7	235.3	220.3	215.0	235.1	272.2	260.8	190.0	241.0
Cloud (%)	44.58	43.63	46.46	45.21	44.58	44.29	46.04	43.46	44.42	45.25	44.13	46.13	44.8
Solar irradiation daily average (Wh/m²)													
Global	3597	4685	5790	6870	7157	6708	6364	6027	5813	5309	4435	3332	5507
Diffuse	1569	1685	1934	2033	2313	2800	2907	2800	2191	1539	1197	1465	2036
Relative Humidity (%)													
morning	77	69	68	49	34	65	80	79	67	65	67	78	66.5
evening	33	26	26	18	13	27	53	49	32	24	28	39	30.7
Dry Bulb Temperature (°C)													
max	22.3	25.2	32.3	38.2	41.7	41.0	36.4	35.8	36.6	35.3	31.4	22.8	33.3
min	7.1	9.7	19.1	23.3	26.7	29.6	29.5	28.1	26	21	12.1	8.4	20.1
mean	14.7	17.5	25.7	30.8	34.2	35.3	33.0	32.0	31.3	28.2	21.8	15.6	26.7
Neutrality	22.4	23.2	25.8	27.3	28.4	28.7	28.0	27.7	27.5	26.5	24.5	22.6	26.1
Upper limit	24.9	25.7	28.3	29.8	30.9	31.2	30.5	30.2	30.0	29.0	27.0	25.1	28.6
Lower limit	19.9	20.7	23.3	24.8	25.9	26.2	25.5	25.2	25.0	24.0	22.0	20.1	23.6
Rain (mm) ^b	5.7	7.8	6.3	11.9	15.9	33	91.1	82.6	40.8	10.1	1.9	3.0	310.1
Wind (m/s)	0.6	0.8	0.8	1.4	1.2	3.4	1.9	2.0	1.0	0.6	0.1	0.4	1.2
HDD	113	44	0	0	0	0	0	0	0	0	2	93	252
CDD	1	23	214	383	517	516	452	422	394	298	91	2	3313



Average diurnal range (°K)	13.2
Annual mean range (°K)	34.6

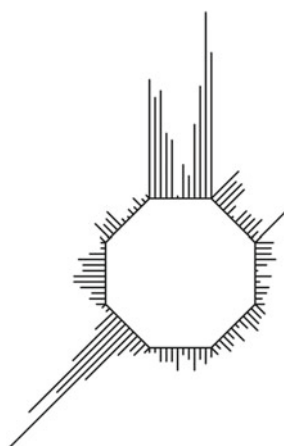
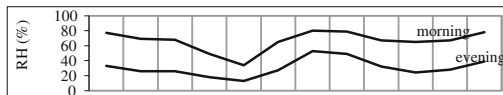
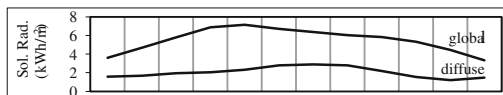


Table 5.26 Design conditions and overheated–underheated periods, Bikaner

Recommended “Design” conditions		
Summer	DBT (°C)	43.4
	MCWB (°C)	22.4
	WBT (°C)	27.9
	MCDB (°C)	33.1
Winter	DBT (°C)	5.3

Hourly temperature (°C) in all 12 months

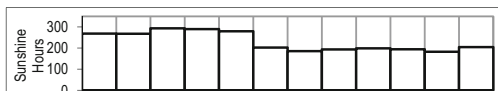
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	10.5	13.6	22.9	26.6	30.6	33.3	30.6	29.7	28.4	23.6	15.5	11.4	0	0	0	0
1:01- 2:00	9.4	12.5	23.8	25.6	29.5	32.3	30.2	29.2	27.6	22.7	14.3	10.7	0	0	0	0
2:01- 3:00	9.1	12.0	23.9	24.7	28.2	31.3	29.9	28.8	27.0	22.2	13.5	10.4	0	0	0	0
3:01- 4:00	8.3	10.8	22.7	23.8	27.1	30.4	29.5	28.3	26.3	21.4	12.4	9.6	0	0	0	0
4:01- 5:00	8.0	10.3	21.6	23.3	26.7	29.9	29.5	28.1	26.1	21.0	12.1	9.0	0	0	0	0
5:01- 6:00	7.1	9.7	20.0	23.4	27.2	29.6	29.5	28.1	26.0	21.1	12.4	8.4	1	6	0	0
6:01- 7:00	7.7	10.6	19.9	24.7	28.7	29.9	30.0	28.5	26.8	22.5	14.5	9.0	35	84	0	0
7:01- 8:00	9.0	12.2	20.8	26.8	31.2	30.7	30.7	29.3	27.9	24.4	17.4	10.4	168	161	14	38
8:01- 9:00	12.1	15.3	23.2	29.7	34.0	32.1	31.8	30.6	29.8	27.5	21.6	13.3	348	195	98	103
9:01-10:00	15.2	18.3	25.7	32.4	36.7	33.7	33.0	32.0	31.6	30.3	25.3	16.4	502	225	195	162
10:01-11:00	18.5	21.5	28.3	35.0	38.7	35.7	34.2	33.5	33.6	32.9	28.7	19.7	629	233	284	196
11:01-12:00	20.3	23.2	29.8	36.6	40.1	37.4	35.3	34.6	34.9	34.2	30.4	21.6	702	232	329	224
12:01-13:00	21.6	24.6	31.1	37.7	41.0	39.0	36.0	35.4	35.9	35.2	31.4	22.8	707	231	339	230
13:01-14:00	21.8	24.8	31.6	38.0	41.4	40.1	36.4	35.8	36.3	35.2	31.3	22.7	642	232	311	215
14:01-15:00	22.3	25.2	32.3	38.2	41.7	40.9	36.4	35.8	36.6	35.3	31.2	22.4	523	223	246	183
15:01-16:00	21.7	24.6	32.0	37.8	41.6	41.0	36.0	35.4	36.3	34.5	30.0	21.3	355	212	153	134
16:01-17:00	21.1	24.0	31.2	37.1	41.1	40.7	35.4	34.8	35.8	33.6	28.5	20.3	186	169	53	73
17:01-18:00	19.2	22.1	28.7	35.7	40.0	39.7	34.5	33.9	34.6	31.4	25.5	18.5	45	97	4	11
18:01-19:00	17.4	20.3	25.7	34.0	38.4	38.6	33.7	33.0	33.4	29.3	22.5	17.1	1	12	0	0
19:01-20:00	15.0	17.9	22.2	32.1	36.5	37.4	32.8	32.0	32.1	26.9	19.3	15.3	0	0	0	0
20:01-21:00	13.9	16.6	20.1	30.5	34.7	36.4	32.2	31.3	31.2	25.5	17.5	14.2	0	0	0	0
21:01-22:00	12.6	15.3	19.1	29.2	33.3	35.6	31.8	30.7	30.3	24.4	16.2	13.0	0	0	0	0
22:01-23:00	12.2	14.9	20.0	28.3	32.2	34.9	31.4	30.3	29.8	24.2	16.1	12.5	0	0	0	0
23:01-24:00	15.7	19.1	22.9	26.7	28.2	28.6	28.3	26.7	27.0	27.1	22.5	15.7	0	0	0	0
Legend	Underheated	<19.9°C			Comfortable							Overheated	>28.7°C			

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.27 Climatic data, Chennai, Tamil Nadu

Latitude	N 13° 0'				Longitude				E 80° 10'				Altitude	16 m
Climate	Warm and humid				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	268.3	268.1	293.6	290.2	279.9	202.6	185.2	193.6	198.6	194.6	182.7	204.3	168.5	
Cloud (%)	41.9	35.8	30.7	36.1	49.4	67.3	66.3	73.4	58.3	62.2	59.6	49.0	52.5	
Solar irradiation daily average (Wh/m²)														
Global	5278	6160	6754	6883	6733	5860	5675	5510	6052	4852	4609	4701	5756	
Diffuse	1986	1924	2070	2287	2296	2753	2869	3037	2506	2645	2330	2028	2394	
Relative Humidity (%)														
morning	96	91	93	84	82	76	78	82	87	93	94	89	87.1	
evening	53	47	46	53	45	41	51	50	54	69	60	62	52.6	
Dry Bulb Temperature (°C)														
max	28.8	32.1	32.8	34.6	36.9	35.8	33.3	32.9	33.1	30.2	29.7	28.0	32.4	
min	21.8	22.7	23.9	27.2	29.1	28.5	26.6	26.3	26.2	25.0	24.6	22.2	25.3	
mean	25.3	27.4	28.4	30.9	33.0	32.2	30.0	29.6	29.7	27.6	27.2	25.1	28.8	
Neutrality	25.6	26.3	26.6	27.4	28.0	27.8	27.1	27.0	27.0	26.4	26.2	25.6	24.5	
Upper limit	28.1	28.8	29.1	29.9	30.5	30.3	29.6	29.5	29.5	28.9	28.7	28.1	27.0	
Lower limit	23.1	23.8	24.1	24.9	25.5	25.3	24.6	24.5	24.5	23.9	23.7	23.1	22.0	
Rain (mm) ^b	35.3	13.0	14.5	15.9	42.4	53.9	99.6	129.9	123.5	284.6	353	146.3	1312	
Wind (m/s)	0.7	0.6	0.7	0.5	0.8	1.2	1.1	0.9	0.5	0.6	0.4	0.6	0.7	
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	
CDD	217	242	305	374	443	401	357	348	333	292	261	212	3785	



Average diurnal range (°K)	7.0
Annual mean range (°K)	15.1

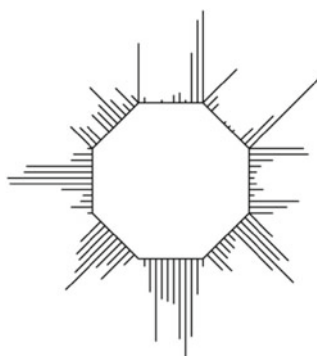
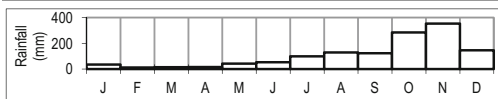
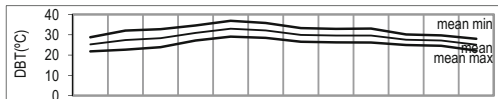
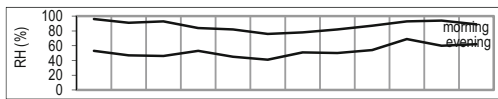
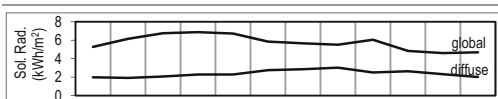


Table 5.28 Design conditions and overheated–underheated periods, Chennai

Recommended “Design” conditions		
Summer	DBT (°C)	37.3
	MCWB (°C)	26.7
	WBT (°C)	28.6
	MCDB (°C)	33.2
Winter	DBT (°C)	18.7

Hourly temperature (°C) in all 12 months

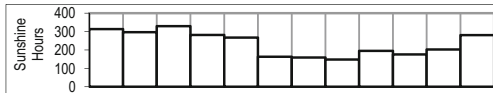
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	22.9	23.8	25.2	28.6	29.9	29.4	27.7	27.4	27.4	26.0	25.1	23.0	0	0	0	0
1:01- 2:00	22.6	23.5	24.9	28.3	29.8	29.3	27.5	27.2	27.1	25.8	25.0	22.8	0	0	0	0
2:01- 3:00	22.3	23.3	24.6	28.0	29.6	29.1	27.2	27.0	26.8	25.5	24.9	22.6	0	0	0	0
3:01- 4:00	22.1	23.2	24.3	27.6	29.4	29.0	27.0	26.7	26.6	25.4	24.7	22.5	0	0	0	0
4:01- 5:00	22.0	23.0	24.1	27.4	29.2	28.8	26.7	26.5	26.4	25.2	24.6	22.3	0	0	0	0
5:01- 6:00	21.8	22.7	23.9	27.2	29.1	28.5	26.6	26.3	26.2	25.0	24.6	22.2	0	1	0	0
6:01- 7:00	21.8	22.7	24.1	27.8	29.7	28.9	26.9	26.4	26.5	25.3	24.6	22.2	26	56	4	13
7:01- 8:00	23.2	23.9	25.9	29.5	31.5	30.1	28.1	27.2	27.7	26.6	25.7	23.3	140	141	57	87
8:01- 9:00	24.9	26.0	27.9	31.2	32.9	31.3	29.3	29.1	29.0	27.9	27.1	25.0	298	199	163	165
9:01-10:00	26.8	28.2	29.8	32.7	34.4	32.5	30.4	30.1	30.4	28.9	28.3	26.4	446	240	279	217
10:01-11:00	27.8	30.0	31.4	33.8	35.5	33.5	31.4	31.0	31.5	29.8	29.1	27.1	568	258	369	252
11:01-12:00	28.3	31.3	32.4	34.5	36.5	34.4	32.5	31.9	32.5	30.0	29.6	27.8	638	265	422	268
12:01-13:00	28.8	32.0	32.7	34.6	36.9	35.0	33.2	32.6	33.0	30.0	29.7	28.0	665	245	428	267
13:01-14:00	28.8	32.1	32.8	34.2	36.8	35.6	33.2	32.9	33.1	30.2	29.5	28.0	605	241	383	253
14:01-15:00	28.5	31.7	32.3	33.7	36.0	35.8	33.3	32.9	32.8	30.0	29.3	27.9	495	223	299	220
15:01-16:00	27.9	30.9	31.6	33.0	35.2	35.1	32.4	32.4	32.0	29.5	28.9	27.5	337	200	183	173
16:01-17:00	27.2	29.6	30.6	31.9	34.2	33.9	31.7	31.8	31.0	28.6	28.0	26.8	173	151	75	97
17:01-18:00	26.0	28.0	29.1	30.8	32.8	32.4	30.8	30.7	29.8	27.7	27.1	25.7	43	73	10	16
18:01-19:00	25.3	27.0	28.0	30.2	31.8	31.1	29.8	29.7	28.9	27.3	26.6	25.3	3	4	0	0
19:01-20:00	25.0	26.4	27.5	29.8	31.3	30.3	29.4	29.2	28.5	27.0	26.3	24.8	0	0	0	0
20:01-21:00	24.6	25.8	26.9	29.5	30.9	30.0	28.9	28.7	28.1	26.8	25.9	24.3	0	0	0	0
21:01-22:00	24.2	25.3	26.5	29.4	30.8	29.9	28.7	28.2	27.9	26.7	25.6	23.9	0	0	0	0
22:01-23:00	23.8	24.7	26.1	29.2	30.6	29.6	28.2	27.9	27.8	26.4	25.4	23.7	0	0	0	0
23:01-24:00	23.3	24.2	25.6	28.8	30.3	29.4	27.8	27.6	27.6	26.0	25.2	23.2	0	0	0	0
Legend	Underheated	<23.1°C			Comfortable				Overheated			>28.0°C				

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.29 Climatic data, Chitradurga, Karnataka

Latitude	N 14° 13'				Longitude				E 76° 25'				Altitude	733 m
Climate	Warm and humid				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	312.9	296.6	328.9	281.6	266.7	162.8	158.9	148.4	195.0	175.5	202.1	280.2	234.1	
Cloud (%)	19.6	13.4	17.3	39.4	57.3	78.0	82.0	81.3	72.5	64.9	59.2	31.0	51.3	
Solar irradiation daily average (Wh/m²)														
Global	5849	6590	7190	7049	6800	5519	5409	5254	5746	5004	4879	5325	5885	
Diffuse	1402	1470	1654	2118	2344	3109	3157	3198	2806	2378	2089	1563	2274	
Relative Humidity (%)														
morning	75	68	62	76	84	87	91	91	90	88	86	79	81.4	
evening	35	29	26	31	34	64	64	70	56	62	51	38	46.7	
Dry Bulb Temperature (°C)														
max	29.5	30.6	34.1	35.0	33.5	28.3	27.0	26.1	28.5	27.2	26.7	26.6	29.4	
min	18.8	19.8	22.2	23.8	23.6	22.3	21.6	21.4	21.4	21.2	20.2	18.0	21.2	
mean	24.2	25.2	28.2	29.4	28.6	25.3	24.3	23.8	25.0	24.2	23.5	22.3	25.3	
Neutrality	25.3	25.6	26.5	26.9	26.7	25.6	25.3	25.2	25.5	25.3	25.1	24.7	25.6	
Upper limit	27.8	28.1	29.0	29.4	29.2	28.1	27.8	27.7	28.0	27.8	27.6	27.2	28.1	
Lower limit	22.8	23.1	24.0	24.4	24.2	23.1	22.8	22.7	23.0	22.8	22.6	22.2	23.1	
Rain (mm) ^b	3.9	5.0	3.7	23.9	72.8	52.2	65.0	74.8	102.4	114.0	50.6	11.0	579.3	
Wind (m/s)	1.8	1.8	1.9	2.4	3.2	3.7	4	3.9	2.8	1.7	1.7	2.3	2.6	
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	
CDD	165	195	311	331	307	206	178	162	199	183	160	118	2515	



Average diurnal range (°K)	8.2
Annual mean range (°K)	17.0

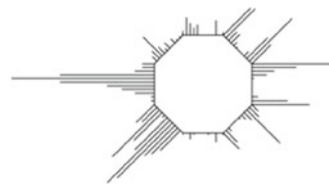
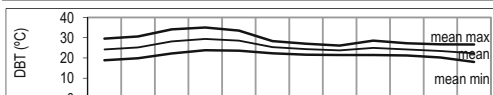
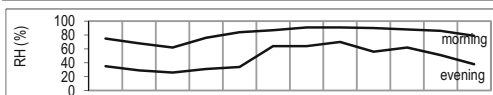
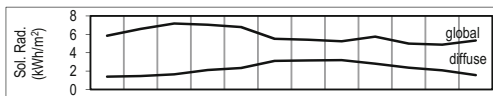


Table 5.30 Design conditions and overheated–underheated periods, Chitradurga

Recommended “Design” conditions														
Summer	DBT (°C)		35.8											
	MCWB (°C)		19.0											
	WBT (°C)		23.5											
	MCDB (°C)		28.2											
Winter	DBT (°C)		16.4											

Hourly temperature (°C) in all 12 months

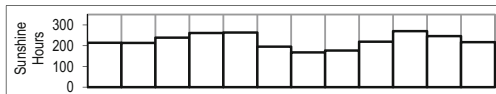
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Dec			
													H _b	H _d	H _b	H _d		
Hours															H _b	H _d	H _b	H _d
0:01- 1:00	20.2	22.6	25.4	26.1	25.2	23.2	22.1	21.8	22.7	22.0	21.6	19.4	0	0	0	0		
1:01- 2:00	19.8	22.1	24.7	25.5	24.8	23.0	22.0	21.7	22.6	21.8	21.6	19.1	0	0	0	0		
2:01- 3:00	19.3	21.5	24.2	25.0	24.2	22.5	21.9	21.6	22.0	21.5	21.1	18.8	0	0	0	0		
3:01- 4:00	19.0	21.0	23.4	24.6	24.1	22.5	21.8	21.5	22.0	21.4	21.0	18.7	0	0	0	0		
4:01- 5:00	18.9	20.4	23.1	24.3	23.9	22.5	21.8	21.5	22.0	21.4	21.0	18.5	0	0	0	0		
5:01- 6:00	18.8	19.8	22.6	24.0	23.6	22.3	21.6	21.5	21.4	21.2	20.2	18.1	0	0	0	0		
6:01- 7:00	18.9	20.0	22.2	23.8	23.7	22.4	21.6	21.4	21.4	21.2	20.2	18.0	11	20	2	1		
7:01- 8:00	19.4	20.8	23.3	24.3	24.1	22.8	21.8	21.5	21.6	21.8	20.7	18.4	125	104	64	56		
8:01- 9:00	20.4	22.0	26.3	26.4	25.8	24.1	22.9	22.9	23.1	23.4	22.4	20.2	287	168	213	112		
9:01-10:00	22.0	23.6	28.2	28.2	27.2	24.8	23.8	23.6	23.8	24.2	23.1	21.6	421	224	372	153		
10:01-11:00	23.8	25.4	30.1	30.3	28.7	25.5	24.8	24.5	24.9	25.2	24.0	23.0	553	249	497	180		
11:01-12:00	25.7	27.1	31.7	32.0	30.8	26.9	25.9	25.2	26.6	26.4	25.4	24.6	692	237	599	184		
12:01-13:00	27.1	28.4	33.0	33.2	31.9	27.5	26.3	25.9	27.2	26.7	25.7	25.5	781	212	587	201		
13:01-14:00	28.2	29.4	33.9	34.2	32.6	27.6	27.0	25.9	27.5	27.0	26.1	26.1	756	202	534	201		
14:01-15:00	29.0	30.1	34.1	34.8	33.5	28.3	27.0	26.1	28.5	27.2	26.7	26.6	624	205	427	188		
15:01-16:00	29.5	30.6	33.9	35.0	33.2	28.1	26.6	25.7	28.3	27.2	26.7	26.6	402	214	297	152		
16:01-17:00	29.4	30.6	33.5	34.7	33.0	27.8	26.3	25.1	28.1	26.8	26.5	26.2	209	176	143	102		
17:01-18:00	28.8	30.2	32.3	34.1	32.1	26.8	25.3	24.2	27.5	26.0	25.5	25.0	62	97	27	33		
18:01-19:00	27.3	28.9	30.4	32.7	30.4	26.3	24.4	23.5	27.2	25.0	25.2	23.6	5	12	0	0		
19:01-20:00	25.7	27.4	29.0	31.0	29.6	25.7	23.8	23.1	26.5	24.2	24.8	22.5	0	0	0	0		
20:01-21:00	23.7	25.7	27.8	29.7	28.0	24.8	23.3	22.8	24.9	23.6	23.1	21.5	0	0	0	0		
21:01-22:00	22.3	24.5	27.0	28.6	27.3	24.4	22.9	22.5	24.5	23.2	23.0	21.2	0	0	0	0		
22:01-23:00	21.6	23.9	26.4	27.7	26.6	23.9	22.7	22.3	24.2	22.9	22.9	20.7	0	0	0	0		
23:01-24:00	20.9	23.4	25.8	26.7	25.4	23.2	22.3	21.9	22.8	22.2	21.6	19.7	0	0	0	0		
Legend	Underheated			<22.2°C			Comfortable						Overheated		>26.9°C			

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (1984)

Table 5.31 Climatic data, Dehradun, Uttarakhand

Latitude	N 30° 19'				Longitude	E 78° 1'				Altitude	682 m		
Climate	Composite				Köppen	Cfa							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	213.9	212.8	238.7	261.0	263.5	195.0	167.4	176.7	219.0	269.7	246.0	217.0	2681
Cloud (%)	26.5	35.7	32.2	23.1	34.5	48.8	74.8	75.0	51.6	17.5	13.5	16.2	37.45
Solar irradiation daily average (Wh/m²)													
Global	3596	4405	5565	6755	7627	6517	5160	4917	5256	5385	4338	3837	5280
Diffuse	1067	1373	1803	1985	1892	2343	2848	2628	1881	1248	1000	789	1738
Relative Humidity (%)													
morning	87	85	77	68	55	72	87	90	87	98	80	85	80.9
evening	48	46	42	31	29	53	75	78	66	43	46	45	50.2
Dry Bulb Temperature (°C)													
max	18.8	21.1	25.2	31.8	34.0	31.9	29.3	28.9	29.7	27.4	24.8	21.4	27.0
min	7.6	9.8	14.1	18.8	22.1	23.7	24.4	23.8	22.5	16.7	12.2	8.6	17.0
mean	13.2	15.5	19.7	25.3	28.1	27.8	26.9	26.4	26.1	22.1	18.5	15.0	22.0
Neutrality	21.9	22.6	23.9	25.6	26.5	26.4	26.1	26.0	25.9	24.6	23.5	22.5	24.6
Upper limit	24.4	25.1	26.4	28.1	29.0	28.9	28.6	28.5	28.4	27.1	26.0	25.0	27.1
Lower limit	19.4	20.1	21.4	23.1	24.0	23.9	23.6	23.5	23.4	22.1	21.0	20.0	22.1
Rain (mm)^b	55.0	58.8	49.0	22.5	41.7	201.8	672.6	728.2	296.5	49.8	8.6	24.4	2209
Wind (m/s)	0.5	0.6	0.9	0.8	0.9	0.8	0.6	0.6	0.7	0.7	0.6	0.5	0.7
HDD	185	91	26	0	0	0	0	0	0	0	24	138	464
CDD	0	0	59	204	306	288	270	246	227	102	6	0	1708



Average diurnal range (°K)	10.0
Annual mean range (°K)	26.4

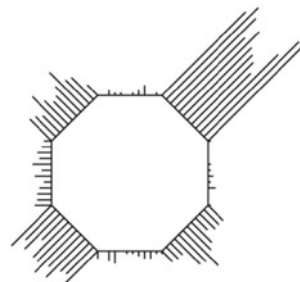
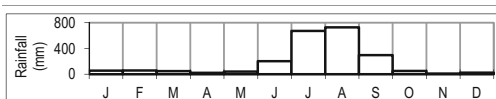
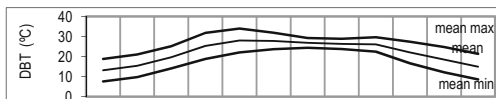
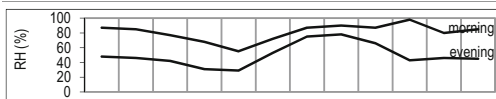
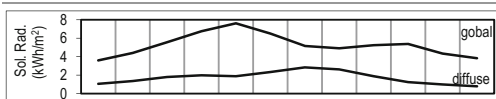


Table 5.32 Design conditions and overheated–underheated periods, Dehradun

Recommended “Design” conditions														
Summer	DBT (°C)		36.3											
	MCWB (°C)		23.9											
	WBT (°C)		26.5											
	MCDB (°C)		30.1											
Winter	DBT (°C)		6.8											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	9.1	11.6	15.7	20.8	24.0	24.8	25.2	24.5	23.4	18.5	14.3	10.4	0	0	0	0
1:01- 2:00	8.8	11.3	15.4	20.5	23.6	24.4	25.0	24.3	23.2	18.1	13.9	10.2	0	0	0	0
2:01- 3:00	8.5	11.1	15.2	19.9	23.1	24.3	24.8	24.1	23.0	17.8	13.6	9.9	0	0	0	0
3:01- 4:00	8.3	10.9	14.9	19.5	22.7	24.1	24.6	24.0	22.8	17.5	13.2	9.5	0	0	0	0
4:01- 5:00	8.1	10.6	14.7	19.4	22.2	23.9	24.5	23.9	22.7	17.2	12.9	9.2	0	0	0	0
5:01- 6:00	7.8	10.2	14.4	18.8	22.1	23.7	24.4	23.8	22.5	17.0	12.6	8.9	4	5	0	0
6:01- 7:00	7.6	9.8	14.1	19.1	22.4	23.9	24.6	23.8	22.5	16.7	12.2	8.6	52	75	0	0
7:01- 8:00	7.6	10.1	15.2	21.3	25.2	25.6	25.5	24.4	23.1	17.5	12.6	8.8	203	131	13	17
8:01- 9:00	9.6	12.9	17.9	24.3	28.1	27.7	27.1	25.6	25.2	20.8	16.7	11.1	406	154	107	70
9:01-10:00	12.3	15.7	20.0	26.1	29.6	28.8	27.9	26.6	26.7	22.9	19.5	14.0	634	148	227	108
10:01-11:00	15.0	17.6	21.8	27.9	31.4	29.9	28.5	27.4	27.7	23.8	21.4	17.3	775	153	329	131
11:01-12:00	16.9	19.3	23.3	29.8	32.8	31.2	29.2	28.2	28.9	25.0	23.0	19.6	845	157	399	144
12:01-13:00	18.0	20.2	24.3	30.7	33.6	31.8	29.3	28.7	29.4	26.1	24.2	20.3	765	198	435	140
13:01-14:00	18.5	20.9	24.9	31.5	33.9	31.9	29.3	28.9	29.7	27.3	24.8	21.3	719	194	400	140
14:01-15:00	18.8	21.1	25.2	31.8	34.0	31.6	28.7	28.9	29.6	27.4	24.8	21.4	596	190	321	129
15:01-16:00	18.1	20.4	24.9	31.4	33.2	31.4	28.6	28.6	29.0	26.8	23.3	20.2	405	191	205	107
16:01-17:00	16.6	19.3	24.1	30.8	32.7	31.2	28.1	27.8	28.2	25.8	21.6	18.1	237	160	82	67
17:01-18:00	14.4	17.7	22.7	29.3	31.7	30.7	27.8	27.1	27.2	23.8	18.8	15.3	85	105	10	13
18:01-19:00	12.5	16.0	20.8	27.0	30.3	29.3	27.3	26.3	26.2	22.2	17.4	13.5	9	32	0	0
19:01-20:00	11.5	14.7	19.3	25.1	28.2	28.0	26.8	25.8	25.4	21.1	16.5	12.5	0	0	0	0
20:01-21:00	10.7	13.8	18.3	23.8	27.0	27.0	26.4	25.4	24.9	20.3	15.8	11.9	0	0	0	0
21:01-22:00	10.4	13.4	17.4	22.7	26.4	26.4	26.1	25.2	24.5	19.8	15.4	11.4	0	0	0	0
22:01-23:00	10.0	12.9	16.7	22.2	25.6	25.8	25.8	25.0	24.1	19.1	14.9	11.0	0	0	0	0
23:01-24:00	9.6	12.3	16.2	21.3	24.9	25.1	25.4	24.6	23.6	18.6	14.5	10.5	0	0	0	0
Legend	Underheated			<19.4°C	Comfortable								Overheated		>26.5°C	

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.33 Climatic data, Dibrugarh, Assam

Latitude	N 27° 28'				Longitude				E 95° 1'				Altitude	111 m
Climate	Warm and humid				Köppen				Cfa					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	173.6	158.6	137.9	98.0	119.8	93.9	81.0	108.3	140.0	192.6	219.2	232.9	146.3	
Cloud (%)	46.1	45.0	45.0	44.3	44.6	43.6	43.7	44.0	44.4	45.3	44.8	45.7	44.71	

Solar irradiation daily average (Wh/m²)

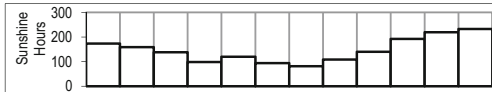
Global	3422	4042	4348	4469	5023	4845	4593	4704	4679	4511	4089	3737	4372
Diffuse	1685	2092	2745	3255	3561	3623	3497	3278	2853	2125	1509	1258	2623

Relative Humidity (%)

morning	96	94	92	91	94	94	96	95	97	96	96	96	94.8
evening	55	56	59	65	68	74	81	74	80	67	49	52	65.0

Dry Bulb Temperature (°C)

max	21.3	21.6	24.7	26.3	28.8	30.6	29.4	30.7	29.1	28.1	26.5	22.9	26.7
min	10.1	13.0	16.7	19.3	22.2	25.2	25.1	25.1	24.5	20.9	14.7	10.4	18.9
mean	15.7	17.3	20.7	22.8	25.5	27.9	27.3	27.9	26.8	24.5	20.6	16.7	22.8
Neutrality	22.7	23.2	24.2	24.9	25.7	26.4	26.2	26.4	26.1	25.4	24.2	23.0	24.9
Upper limit	25.2	25.7	26.7	27.4	28.2	28.9	28.7	28.9	28.6	27.9	26.7	25.5	27.4
Lower limit	20.2	20.7	21.7	22.4	23.2	23.9	23.7	23.9	23.6	22.9	21.7	20.5	22.4
Rain (mm)^b	32.0	78.5	109.7	218.7	316.0	419.5	520.9	443.8	333.1	143.4	24.7	18.0	2658
Wind (m/s)	0.75	1.24	1.76	2.17	1.69	1.42	1.17	1.29	1.32	0.68	0.90	0.68	1.30
HDD	99	40	1	0	0	0	0	0	0	0	4	72	216
CDD	0	5	75	137	230	289	278	302	256	189	55	0	1816



Average diurnal range (°K)	7.7
Annual mean range (°K)	20.6

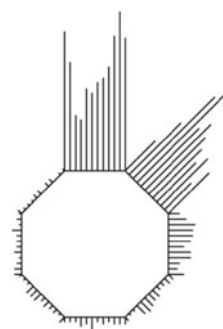
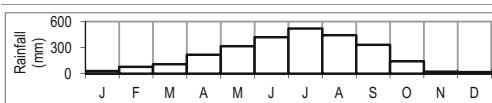
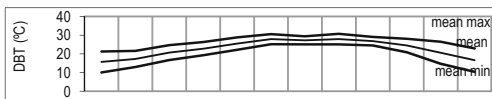
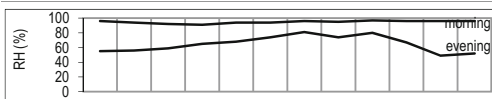
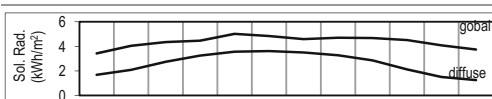


Table 5.34 Design conditions and overheated–underheated periods, Dibrugarh

Recommended “Design” conditions		
Summer	DBT (°C)	33.2
	MCWB (°C)	26.8
	WBT (°C)	27.8
	MCDB (°C)	31.8
Winter	DBT (°C)	8.7

Hourly temperature (°C) in all 12 months

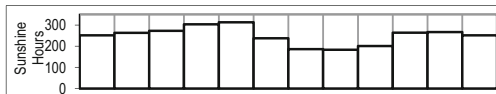
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	11.4	14.1	18.0	20.5	23.2	25.8	25.6	25.9	25.2	22.0	15.9	11.9	0	0	0	0
1:01- 2:00	11.1	13.7	17.5	20.2	22.9	25.5	25.4	25.6	25.1	21.7	15.6	11.6	0	0	0	0
2:01- 3:00	10.3	13.2	16.9	19.5	22.3	25.2	25.2	25.1	24.7	21.1	14.7	10.6	0	0	0	0
3:01- 4:00	10.1	13.0	16.7	19.3	22.2	25.2	25.1	25.1	24.6	20.9	14.7	10.4	0	1	0	0
4:01- 5:00	10.3	13.2	16.9	19.3	22.5	25.5	25.1	25.3	24.5	21.0	14.8	10.5	8	42	0	0
5:01- 6:00	11.3	14.0	17.6	20.3	23.5	26.3	25.4	26.0	25.1	22.0	16.6	12.2	35	130	3	7
6:01- 7:00	12.7	15.1	18.7	21.4	24.6	27.1	25.9	26.8	25.7	23.1	18.5	14.1	77	218	48	67
7:01- 8:00	14.7	16.7	20.2	22.8	25.8	28.0	26.5	27.7	26.5	24.6	21.0	16.7	108	307	128	138
8:01- 9:00	16.4	18.1	21.5	23.7	26.6	28.6	27.2	28.4	27.0	25.7	22.6	18.5	130	382	200	196
9:01-10:00	18.3	19.5	22.8	24.6	27.3	29.1	27.8	29.1	27.6	26.8	24.3	20.5	152	425	260	228
10:01-11:00	19.7	20.5	23.7	25.0	27.6	29.5	28.3	29.5	27.9	27.4	25.1	21.5	149	455	288	243
11:01-12:00	20.9	21.4	24.4	25.6	28.1	30.0	28.8	30.0	28.5	28.0	26.3	22.8	162	429	276	246
12:01-13:00	21.3	21.6	24.7	25.9	28.4	30.4	29.2	30.4	28.8	28.1	26.5	22.9	137	402	238	223
13:01-14:00	21.1	21.5	24.6	26.3	28.8	30.6	29.4	30.7	29.1	28.0	26.5	22.6	113	339	179	175
14:01-15:00	19.8	20.7	24.0	26.0	28.7	30.4	29.4	30.6	28.8	27.1	24.9	20.9	84	255	97	116
15:01-16:00	18.3	19.6	23.2	25.5	28.4	29.9	29.2	30.3	28.5	26.2	23.2	19.0	49	161	19	47
16:01-17:00	16.4	18.3	22.1	24.5	27.5	29.0	28.7	29.5	27.7	24.9	20.9	16.6	17	69	0	0
17:01-18:00	15.1	17.2	21.1	23.6	26.6	28.1	28.0	28.7	27.1	24.1	19.5	15.1	1	9	0	0
18:01-19:00	13.8	16.1	20.1	22.5	25.5	27.3	27.3	27.9	26.5	23.3	18.0	13.8	0	0	0	0
19:01-20:00	13.3	15.5	19.5	21.8	24.7	26.8	26.6	27.2	26.1	23.0	17.5	13.4	0	0	0	0
20:01-21:00	12.6	15.0	19.0	21.1	24.0	26.4	26.1	26.8	25.7	22.6	16.8	12.8	0	0	0	0
21:01-22:00	12.4	14.9	18.8	21.0	23.7	26.3	25.9	26.6	25.6	22.5	16.7	12.8	0	0	0	0
22:01-23:00	12.0	14.6	18.6	20.7	23.5	26.1	25.7	26.4	25.4	22.3	16.2	12.4	0	0	0	0
23:01-24:00	11.9	14.5	18.5	20.8	23.5	26.1	25.7	26.3	25.4	22.3	16.3	12.5	0	0	0	0
Legend	Underheated	<20.2°C			Comfortable				Overheated	>26.4°C						

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.35 Climatic data, Gorakhpur, Uttar Pradesh

Latitude	N 26° 45'				Longitude				E 83° 22'				Altitude	77 m	
Climate	Composite				Köppen				BSh						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year		
Sunshine h^a	251.1	263.2	272.8	303.0	313.1	237.0	186.0	182.9	201.0	263.5	267.0	251.1	249.3		
Cloud (%)	22.9	17.3	13.5	13.7	17.0	45.7	70.2	67.8	50.8	35.1	3.3	8.9	30.5		
Solar irradiation daily average (Wh/m²)															
Global	3165	4736	6053	6742	7135	5899	4747	4773	4872	4678	4226	3316	5029		
Diffuse	1709	1628	1820	2200	2216	2488	3067	2852	2264	1564	1460	1541	2067		
Relative Humidity (%)															
morning	86	83	72	61	68	82	87	88	80	84	82	84	79.8		
evening	56	43	39	34	36	62	75	80	79	62	50	47	55.3		
Dry Bulb Temperature (°C)															
max	17.5	24.6	31.4	36.0	37.0	33.6	31.9	31.9	30.3	30.3	29.0	22.6	29.7		
min	11.7	14.6	19.6	23.6	26.0	27.8	27.9	27.5	26.8	22.4	17.2	14.0	21.6		
mean	14.6	19.6	25.5	29.8	31.5	30.7	29.9	29.7	28.6	26.4	23.1	18.3	25.6		
Neutrality	22.3	23.9	25.7	27.0	27.6	27.3	27.1	27.0	26.7	26.0	25.0	23.5	25.7		
Upper limit	24.8	26.4	28.2	29.5	30.1	29.8	29.6	29.5	29.2	28.5	27.5	26.0	28.2		
Lower limit	19.8	21.4	23.2	24.5	25.1	24.8	24.6	24.5	24.2	23.5	22.5	21.0	23.2		
Rain (mm)^b	14.2	15.2	9.4	11.7	36.1	166.7	342.7	339.1	232.3	60.4	4.9	6.2	1239		
Wind (m/s)	0.65	0.63	1.32	1.04	1.36	1.00	1.20	0.62	0.40	0.28	0.16	0.13	0.7		
HDD	106	9	0	0	0	0	0	0	0	0	0	41	156		
CDD	8	36	229	352	415	379	364	351	315	238	119	31	2837		



Average diurnal range (°K)	8.1
Annual mean range (°K)	25.3

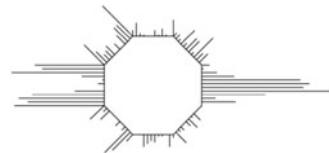
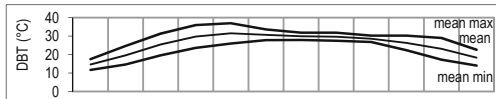
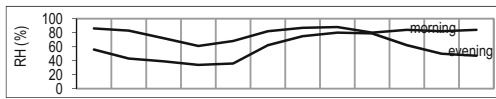


Table 5.36 Design conditions and overheated–underheated periods, Gorakhpur

Recommended “Design” conditions														
Summer	DBT (°C)		40.3											
	MCWB (°C)		26.0											
	WBT (°C)		29.7											
	MCDB (°C)		35.5											
Winter	DBT (°C)		9.0											

Hourly temperature (°C) in all 12 months

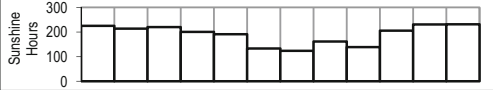
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

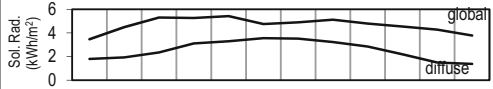
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	13.8	16.2	22.2	26.2	28.1	29.0	28.7	28.0	27.7	23.7	18.9	15.5	0	0	0	0
1:01- 2:00	13.7	15.8	21.6	25.7	27.6	28.7	28.6	27.9	27.6	23.3	18.5	15.3	0	0	0	0
2:01- 3:00	13.5	15.5	21.1	25.1	27.1	28.5	28.5	27.8	27.4	23.0	18.2	15.1	0	0	0	0
3:01- 4:00	13.3	15.3	20.7	24.6	26.7	28.2	28.5	27.7	27.2	22.8	17.9	14.9	0	0	0	0
4:01- 5:00	13.1	15.0	20.2	24.1	26.3	27.9	28.2	27.6	27.0	22.6	17.7	14.8	0	0	0	0
5:01- 6:00	13.0	14.8	19.8	23.6	26.0	27.8	28.1	27.5	26.8	22.5	17.4	14.6	8	50	0	0
6:01- 7:00	13.0	14.6	19.6	23.6	26.6	27.9	27.9	27.5	26.8	22.4	17.2	14.5	110	144	3	9
7:01- 8:00	12.9	14.6	20.4	25.5	28.4	28.9	28.2	28.0	26.9	22.9	17.5	14.3	285	192	34	88
8:01- 9:00	11.7	16.6	23.8	29.4	30.3	30.4	29.0	29.0	27.8	25.1	19.7	14.0	450	215	118	161
9:01-10:00	12.1	19.4	27.0	32.0	32.4	31.6	29.4	29.9	28.5	27.3	23.7	16.5	621	208	196	214
10:01-11:00	13.6	21.8	29.0	33.6	33.6	32.5	30.2	30.6	29.3	28.7	26.3	19.5	719	206	243	242
11:01-12:00	15.9	23.4	30.3	34.8	35.2	33.1	30.7	31.4	29.9	29.7	27.9	21.3	740	207	250	244
12:01-13:00	16.7	24.0	31.0	35.6	36.3	33.4	31.2	31.7	30.3	30.2	28.7	22.0	674	224	237	238
13:01-14:00	17.1	24.4	31.3	36.0	36.9	33.5	31.6	31.9	30.3	30.3	29.0	22.4	578	219	201	218
14:01-15:00	17.5	24.6	31.4	35.9	37.0	33.6	31.8	31.8	30.3	30.1	29.0	22.6	421	211	124	173
15:01-16:00	17.5	24.5	31.4	35.9	37.0	33.5	31.9	31.4	30.2	29.5	27.7	22.6	239	186	46	102
16:01-17:00	17.4	23.8	30.8	35.3	36.7	33.1	31.7	30.7	30.0	28.1	25.5	21.7	72	128	4	21
17:01-18:00	17.1	21.9	29.3	33.7	35.5	32.5	31.4	30.2	29.6	26.6	23.5	19.8	2	27	0	0
18:01-19:00	16.7	20.2	27.3	31.5	33.5	31.5	31.0	29.6	29.1	25.8	22.7	18.8	0	0	0	0
19:01-20:00	16.1	19.0	25.9	29.9	32.1	30.7	30.3	29.2	28.8	25.2	21.2	18.2	0	0	0	0
20:01-21:00	15.6	18.2	24.9	28.8	31.0	30.2	29.7	28.9	28.5	24.7	20.4	17.3	0	0	0	0
21:01-22:00	15.3	17.6	24.2	28.1	30.5	29.9	29.4	28.8	28.3	24.3	19.8	16.9	0	0	0	0
22:01-23:00	15.0	17.1	23.5	27.6	29.6	29.5	29.3	28.4	28.2	23.9	19.3	16.5	0	0	0	0
23:01-24:00	14.0	16.8	22.8	26.9	28.8	29.1	28.7	28.2	27.9	23.5	18.9	15.5	0	0	0	0
Legend	Underheated		<19.8°C Comfortable							Overheated			>27.6°C			

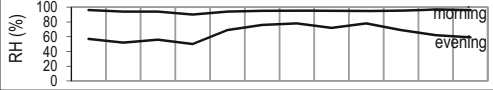
Sources of data: ISHRAE (2014), ^aIMD (1989), ^bIndia Meteorological Department (nd)

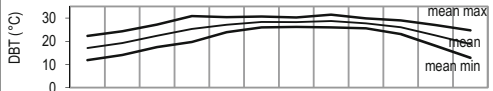
Table 5.37 Climatic data, Guwahati, Assam


Latitude	N 26° 6'				Longitude				E 91° 34'				Altitude	54 m
Climate	Warm and humid				Köppen				Cfa					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	225.5	213.8	220.1	200.6	191.1	133.1	123.7	161.6	139	205.8	230.9	231.7	189.7	
Cloud (%)	45.0	45.9	43.8	44.6	44.5	45.2	44.2	44.2	44.5	44.7	45.5	45.2	44.78	
Solar irradiation daily average (Wh/m²)														
Global	3465	4491	5309	5260	5419	4745	4896	5125	4790	4536	4283	3784	4675	
Diffuse	1800	1930	2342	3109	3292	3556	3519	3233	2843	2186	1492	1377	2557	
Relative Humidity (%)														
morning	96	94	94	90	94	95	95	95	95	95	97	96	94.7	
evening	57	52	56	50	69	76	78	72	78	69	62	59	64.8	
Dry Bulb Temperature (°C)														
max	22.3	24.3	27.2	30.9	30.4	30.7	30.3	31.5	29.9	29.0	27.0	24.7	28.2	
min	11.9	14.1	17.5	19.7	23.9	26.0	26.2	26.0	25.6	23.1	18.0	12.9	20.4	
mean	17.1	19.2	22.4	25.3	27.2	28.4	28.3	28.8	27.8	26.1	22.5	18.8	24.3	
Neutrality	23.1	23.8	24.7	25.6	26.2	26.6	26.6	26.7	26.4	25.9	24.8	23.6	25.3	
Upper limit	25.6	26.3	27.2	28.1	28.7	29.1	29.1	29.2	28.9	28.4	27.3	26.1	27.8	
Lower limit	20.6	21.3	22.2	23.1	23.7	24.1	24.1	24.2	23.9	23.4	22.3	21.1	22.8	
Rain (mm) ^b	11.8	17.2	55.1	147.0	248.9	316.8	351.2	269.4	187.0	90.9	18.5	7.3	1721	
Wind (m/s)	0.46	0.75	2.18	1.77	1.53	1.19	0.65	1.09	1.01	0.83	1.51	0.42	1.10	
HDD	58	5	0	0	0	0	0	0	0	0	0	8	71	
CDD	8	23	124	215	285	308	312	326	290	237	117	7	2252	

	Average diurnal range (°K)	7.8
	Annual mean range (°K)	11.7

	global
	diffuse

	morning
	evening

	mean max
	mean
	mean min

	J	F	M	A	M	J	J	A	S	O	N	D
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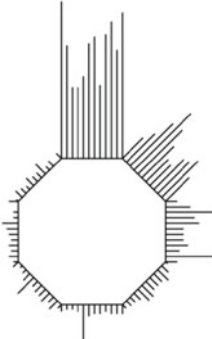


Table 5.38 Design conditions and overheated–underheated periods, Guwahati

Recommended “Design” conditions														
Summer	DBT (°C)		33.4											
	MCWB (°C)		27.3											
	WBT (°C)		28.3											
	MCDB (°C)		31.8											
Winter	DBT (°C)		11.3											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	13.5	15.7	18.9	21.7	24.7	26.5	26.8	26.7	26.1	23.7	19.1	14.6	0	0	0	0
1:01- 2:00	13.1	15.1	18.4	21.0	24.4	26.2	26.6	26.4	25.9	23.5	18.8	14.2	0	0	0	0
2:01- 3:00	12.4	14.5	17.8	20.1	24.0	26.0	26.4	26.1	25.6	23.2	18.2	13.5	0	0	0	0
3:01- 4:00	12.0	14.1	17.5	19.7	23.9	26.0	26.2	26.0	25.6	23.1	18.0	13.2	0	0	0	0
4:01- 5:00	11.9	14.1	17.7	20.0	24.3	26.2	26.2	26.2	25.8	23.2	18.0	12.9	1	18	0	0
5:01- 6:00	12.4	14.8	18.5	21.2	25.0	26.8	26.5	26.8	26.3	23.8	18.8	13.9	18	99	1	1
6:01- 7:00	13.4	16.0	19.6	22.8	26.1	27.5	27.0	27.6	27.0	24.6	20.0	15.3	54	196	25	55
7:01- 8:00	15.1	17.6	21.1	24.8	27.3	28.4	27.8	28.5	27.8	25.6	21.6	17.3	89	291	93	137
8:01- 9:00	16.8	19.3	22.7	26.5	28.4	29.2	28.5	29.2	28.4	26.3	23.1	19.2	124	367	177	196
9:01-10:00	18.8	20.9	24.2	28.0	29.3	29.9	29.2	30.0	29.0	27.2	24.7	21.3	151	418	250	231
10:01-11:00	20.3	22.3	25.4	29.0	29.8	30.3	29.7	30.6	29.4	27.8	25.8	22.9	166	441	279	260
11:01-12:00	21.7	23.4	26.5	30.0	30.2	30.6	30.1	31.3	29.7	28.5	26.7	24.3	157	446	280	262
12:01-13:00	22.2	24.1	27.0	30.6	30.4	30.7	30.3	31.5	29.9	28.9	27.0	24.7	154	402	246	243
13:01-14:00	22.3	24.3	27.2	30.9	30.4	30.6	30.3	31.5	29.9	29.0	26.9	24.6	133	338	177	208
14:01-15:00	21.5	23.8	26.8	30.6	30.2	30.4	30.0	31.0	29.6	28.6	26.1	23.3	83	273	106	139
15:01-16:00	20.4	23.0	26.1	29.9	29.8	30.0	29.7	30.4	29.2	28.1	25.1	21.8	45	178	30	63
16:01-17:00	18.9	21.6	24.9	28.5	29.1	29.5	29.2	29.5	28.7	27.1	23.7	19.9	14	79	2	5
17:01-18:00	17.6	20.2	23.6	27.1	28.4	28.9	28.7	28.9	28.2	26.3	22.6	18.6	0	9	0	0
18:01-19:00	16.4	18.9	22.3	25.6	27.5	28.3	28.2	28.3	27.7	25.5	21.5	17.3	0	0	0	0
19:01-20:00	15.6	17.8	21.4	24.5	26.8	27.8	27.8	28.0	27.4	25.0	20.8	16.7	0	0	0	0
20:01-21:00	14.8	17.0	20.6	23.5	26.2	27.4	27.4	27.7	27.0	24.5	20.1	16.0	0	0	0	0
21:01-22:00	14.4	16.6	20.2	23.1	25.8	27.2	27.2	27.6	26.8	24.3	19.8	15.7	0	0	0	0
22:01-23:00	14.1	16.3	19.9	22.6	25.4	27.0	27.0	27.3	26.5	24.1	19.4	15.1	0	0	0	0
23:01-24:00	14.0	16.1	19.6	22.4	25.2	26.8	27.0	27.1	26.3	23.9	19.3	15.0	0	0	0	0
Legend	Underheated			<20.6°C Comfortable					Overheated				>26.6°C			

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.39 Climatic data, Gwalior, Madhya Pradesh

Latitude	N 26° 13'				Longitude	E 78° 15'				Altitude	207 m		
Climate	Composite				Köppen	Bwh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	263.5	266.0	291.4	303.0	300.7	249.0	151.9	145.7	219.0	282.1	288.0	266.6	252.2
Cloud (%)	44.5	44.4	45.1	45.0	45.7	44.9	44.8	44.3	46.3	45.0	45.0	45.4	45.02

Solar irradiation daily average (Wh/m²)

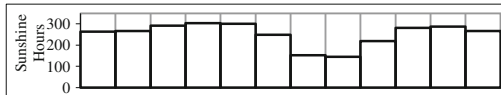
Global	3619	4873	6179	6908	6899	6175	5234	5120	5349	5222	4173	3653	5284
Diffuse	1747	1732	1811	2124	2573	3189	3544	3368	2663	1694	1547	1473	2289

Relative Humidity (%)

morning	89	82	76	59	57	60	78	84	80	75	79	85	75.3
evening	43	38	29	19	29	35	56	58	46	46	29	38	38.8

Dry Bulb Temperature (°C)

max	22.3	26.1	32.3	38.4	39.9	38.8	34.0	33.1	34.1	29.5	29.0	22.6	31.7
min	8.7	12.5	16.5	21.7	29.1	29.8	28.3	26.4	25.4	22.4	14.0	7.7	20.2
mean	15.5	19.3	24.4	30.1	34.5	34.3	31.2	29.8	29.8	26.0	21.5	15.2	25.9
Neutrality	22.6	23.8	25.4	27.1	28.5	28.4	27.5	27.0	27.0	25.8	24.5	22.5	25.8
Upper limit	25.1	26.3	27.9	29.6	31.0	30.9	30.0	29.5	29.5	28.3	27.0	25.0	28.3
Lower limit	20.1	21.3	22.9	24.6	26.0	25.9	25.0	24.5	24.5	23.3	22.0	20.0	23.3
Rain (mm) ^b	14.4	10.0	6.5	4.5	11.2	67.5	248.8	274.4	151.2	40.7	5.8	7.0	842
Wind (m/s)	0.49	0.79	0.79	0.87	1.56	1.19	1.48	1.58	1.07	0.55	0.19	0.31	0.91
HDD	101	16	0	0	0	0	0	0	0	0	2	114	233
CDD	0	36	191	364	499	472	397	355	339	230	79	2	2964



Average diurnal range (°K)	11.5
Annual mean range (°K)	19.4

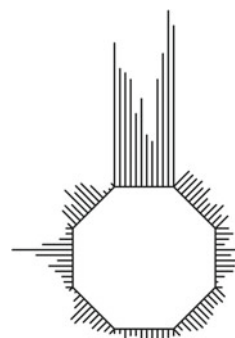
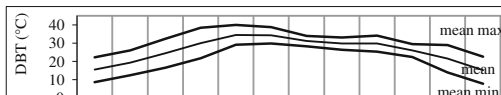
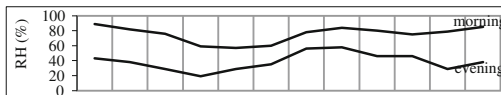
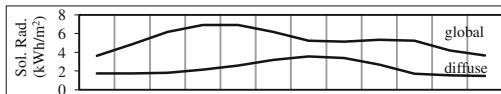


Table 5.40 Design conditions and overheated–underheated periods, Gwalior

Recommended “Design” conditions														
Summer	DBT (°C)		42.5											
	MCWB (°C)		22.9											
	WBT (°C)		27.6											
	MCDB (°C)		32.4											
Winter	DBT (°C)		6.4											

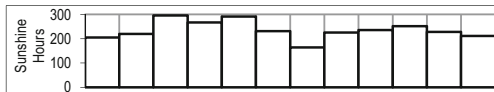
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	10.5	14.5	19.2	24.8	31.0	31.4	29.1	27.3	26.8	22.9	14.0	10.1	0	0	0	0
1:01- 2:00	9.6	13.6	18.2	23.6	30.4	31.1	28.9	26.9	26.4	22.8	14.3	9.5	0	0	0	0
2:01- 3:00	9.4	13.1	17.3	22.4	29.7	30.6	28.6	26.5	25.9	22.6	15.0	9.0	0	0	0	0
3:01- 4:00	8.7	12.5	16.5	21.7	29.2	30.1	28.4	26.4	25.5	22.4	15.9	8.2	0	0	0	0
4:01- 5:00	9.0	12.8	16.9	22.3	29.1	29.8	28.3	26.6	25.4	22.5	17.5	7.7	0	0	0	0
5:01- 6:00	8.9	13.1	17.8	24.0	29.8	30.1	28.5	27.0	26.0	22.9	19.5	7.9	6	26	0	0
6:01- 7:00	10.1	14.4	19.7	26.6	31.1	31.1	29.0	27.7	27.0	23.8	21.8	9.3	77	110	4	8
7:01- 8:00	11.5	16.0	22.0	29.5	32.7	32.3	29.9	28.5	28.5	24.9	24.1	11.4	203	187	47	73
8:01- 9:00	14.3	18.4	24.7	32.2	34.3	33.8	30.9	29.5	30.0	25.7	26.3	14.5	357	229	154	135
9:01-10:00	16.8	20.6	26.9	34.1	35.8	35.0	32.0	30.4	31.3	26.7	27.9	17.4	488	258	265	176
10:01-11:00	19.5	22.8	28.9	35.4	37.0	36.1	32.9	31.3	32.5	27.5	28.8	20.2	585	270	350	197
11:01-12:00	20.9	24.1	30.2	36.3	38.0	37.0	33.6	32.1	33.3	28.5	29.0	21.7	628	275	388	204
12:01-13:00	22.1	25.3	31.2	37.1	38.9	37.7	33.9	32.7	33.9	29.1	28.5	22.6	613	272	370	203
13:01-14:00	22.1	25.7	31.9	37.9	39.6	38.4	34.0	33.1	34.1	29.4	27.2	22.5	533	269	304	187
14:01-15:00	22.3	26.1	32.3	38.4	39.9	38.8	33.7	33.1	34.0	29.5	25.5	22.2	415	249	200	156
15:01-16:00	21.5	25.5	31.9	38.1	39.6	38.7	33.3	32.8	33.5	29.1	23.5	21.2	270	211	85	104
16:01-17:00	20.5	24.4	30.8	36.9	38.6	37.9	32.7	32.1	32.5	28.4	21.6	19.9	129	148	11	30
17:01-18:00	18.3	22.4	28.7	34.6	37.2	36.5	31.9	31.1	31.1	27.2	19.6	17.7	22	67	0	0
18:01-19:00	16.3	20.4	26.3	31.9	35.4	34.7	31.2	30.1	29.7	25.9	18.0	15.6	0	2	0	0
19:01-20:00	14.0	18.4	23.9	29.3	33.8	33.0	30.5	29.3	28.3	24.7	16.6	13.4	0	0	0	0
20:01-21:00	13.0	17.2	22.3	27.4	32.6	31.8	30.0	28.7	27.5	23.8	15.7	12.0	0	0	0	0
21:01-22:00	11.9	16.2	21.2	26.4	31.9	31.1	29.6	28.3	27.0	23.2	14.9	10.9	0	0	0	0
22:01-23:00	11.8	15.8	20.7	26.0	31.5	31.1	29.4	28.0	26.8	23.0	14.4	10.6	0	0	0	0
23:01-24:00	11.0	15.2	20.2	25.6	31.4	31.1	29.2	27.7	26.7	22.9	14.0	10.1	0	0	0	0
Legend	Underheated			<20.0°C	Comfortable								Overheated		>28.5°C	

Sources of data: ISHRAE (2014), ^aIMD (1981), ^bIndia Meteorological Department (nd)

Table 5.41 Climatic data, Hissar, Haryana

Latitude	N 29° 10'				Longitude				E 75°43'				Altitude	221 m	
Climate	Composite				Köppen				BWh						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year		
Sunshine h^a	205.1	219.4	295.6	266.7	291.2	231.1	164.1	225.3	235.4	251.8	228.1	211.2	235.4		
Cloud (%)	19.1	26.3	18.9	26.0	13.0	34.8	51.5	37.5	21.9	8.8	10.5	19.2	23.97		
Solar irradiation daily average (Wh/m²)															
Global	3557	4581	6030	6556	7175	6657	5651	6133	5765	5013	4028	3407	5379		
Diffuse	1378	1584	1682	2261	2261	2725	3191	2448	2156	1628	1351	1302	1997		
Relative Humidity (%)															
morning	91	90	79	77	62	66	78	89	88	82	86	79	80.6		
evening	57	39	23	19	23	29	54	62	45	23	24	31	35.8		
Dry Bulb Temperature (°C)															
max	17.9	22.7	30.7	36.7	39.9	40.0	36.4	34.5	33.8	33.5	28.7	22.8	31.5		
min	10.0	12.9	17.4	22.7	28.8	29.7	29.4	28.3	25.6	21.9	15.3	11.4	21.1		
mean	14.0	17.8	24.1	29.7	34.4	34.9	32.9	31.4	29.7	27.7	22.0	17.1	26.3		
Neutrality	22.1	23.3	25.3	27.0	28.4	28.6	28.0	27.5	27.0	26.4	24.6	23.1	26.0		
Upper limit	24.6	25.8	27.8	29.5	30.9	31.1	30.5	30.0	29.5	28.9	27.1	25.6	28.5		
Lower limit	19.6	20.8	22.8	24.5	25.9	26.1	25.5	25.0	24.5	23.9	22.1	20.6	23.5		
Rain (mm)^b	14.8	15.2	14	8.9	17.3	39.7	133.1	130.6	74.5	29.2	3.2	10.2	490.7		
Wind (m/s)	0.7	0.6	0.8	0.9	0.9	0.9	0.9	0.8	0.6	0.4	0.4	0.4	0.7		
HDD	147	36	0	0	0	0	0	0	0	0	0	75	258		
CDD	0	16	168	341	494	498	452	409	332	276	89	13	3088		



Average diurnal range (°K)	10.4
Annual mean range (°K)	30.0

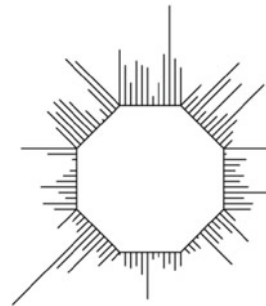
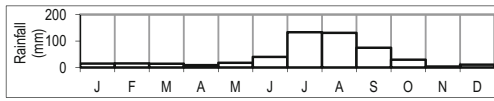
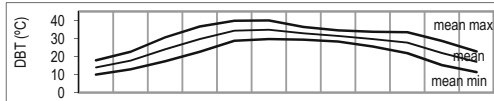
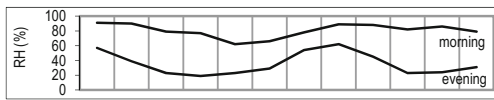
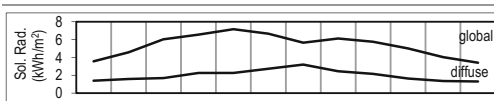


Table 5.42 Design conditions and overheated–underheated periods, Hissar

Recommended “Design” conditions														
Summer	DBT (°C)		43.3											
	MCWB (°C)		25.8											
	WBT (°C)		29.9											
	MCDB (°C)		39.0											
Winter	DBT (°C)		6.1											

Hourly temperature (°C) in all 12 months

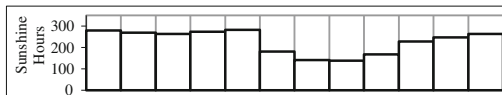
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	11.3	14.8	20.0	25.4	30.7	31.9	30.2	29.5	27.0	24.0	17.8	13.5	0	0	0	0
1:01- 2:00	11.1	14.5	19.4	24.8	30.2	31.3	30.0	29.2	26.7	23.6	17.3	13.1	0	0	0	0
2:01- 3:00	10.7	14.2	18.8	24.2	29.8	30.9	29.9	28.9	26.5	23.2	16.9	12.7	0	0	0	0
3:01- 4:00	10.6	13.9	18.3	23.7	29.5	30.5	29.7	28.8	26.3	22.9	16.5	12.5	0	0	0	0
4:01- 5:00	10.6	13.6	18.0	23.3	29.2	30.1	29.6	28.6	26.0	22.6	16.1	12.2	0	0	0	0
5:01- 6:00	10.4	13.3	17.5	22.8	28.8	29.7	29.4	28.3	25.7	22.2	15.7	11.8	0	2	0	0
6:01- 7:00	10.2	13.0	17.4	22.7	28.8	29.8	29.4	28.3	25.6	21.9	15.4	11.6	8	57	0	0
7:01- 8:00	10.0	12.9	17.4	24.1	29.3	30.9	30.2	28.6	25.8	21.9	15.3	11.4	84	154	5	10
8:01- 9:00	10.0	13.7	20.0	27.6	31.8	33.1	32.1	30.2	27.6	24.1	16.9	11.9	221	211	55	79
9:01-10:00	11.5	16.3	23.5	30.5	34.0	35.0	33.4	31.3	29.3	26.7	19.3	13.8	366	243	173	131
10:01-11:00	13.5	18.5	26.5	33.0	36.0	36.5	34.5	32.4	30.9	29.6	23.2	16.6	488	260	294	159
11:01-12:00	15.4	20.9	28.7	34.9	37.5	37.9	35.2	33.3	32.1	31.7	26.4	19.9	557	278	371	176
12:01-13:00	16.1	22.0	29.9	36.0	38.6	38.8	35.8	33.8	32.7	32.9	28.0	21.8	575	288	392	189
13:01-14:00	16.7	22.5	30.7	36.6	39.5	39.6	36.3	34.5	33.2	33.2	28.6	22.4	543	287	357	193
14:01-15:00	17.4	22.7	30.6	36.7	39.9	40.0	36.4	34.5	33.8	33.5	28.7	22.8	460	279	278	180
15:01-16:00	17.9	22.4	30.1	36.4	39.7	40.0	36.2	34.3	33.3	33.2	27.9	22.2	342	255	174	147
16:01-17:00	17.5	21.9	29.1	35.4	39.3	39.6	35.8	33.9	32.6	31.9	26.8	21.2	203	215	69	93
17:01-18:00	16.6	20.8	27.6	34.0	38.2	38.9	35.3	33.6	31.3	30.3	24.8	19.4	76	147	12	20
18:01-19:00	15.4	19.4	26.0	32.3	37.0	37.5	34.4	32.6	30.2	28.6	22.9	17.8	6	51	0	0
19:01-20:00	14.4	18.3	24.5	30.6	35.4	35.7	33.1	31.8	29.3	27.3	21.5	16.7	0	1	0	0
20:01-21:00	13.6	17.3	23.4	29.1	34.2	34.5	32.2	31.2	28.6	26.2	20.5	15.7	0	0	0	0
21:01-22:00	13.1	16.5	22.4	27.9	33.4	33.6	31.6	30.8	28.1	25.4	19.6	15.0	0	0	0	0
22:01-23:00	12.5	15.8	21.6	27.0	32.5	32.7	31.1	30.3	27.7	24.8	18.9	14.3	0	0	0	0
23:01-24:00	11.8	15.2	20.7	26.0	31.4	31.9	30.5	29.8	27.1	24.0	18.2	13.6	0	0	0	0
Legend	Underheated		<19.6°C		Comfortable								Overheated		>28.6°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.43 Climatic data, Hyderabad, Telangana

Latitude	N 17° 27'					Longitude	E 78° 28'					Altitude	545 m
Climate	Composite					Köppen	Bwh						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	278.6	269.3	263.4	273.7	281.5	179.8	141.1	137.3	167.2	227.3	247.1	263.2	227.5
Cloud (%)	26.8	21.1	23.9	32.0	55.2	70.6	82.3	72.2	64.6	61.7	39.5	23.0	47.76
Solar irradiation daily average (Wh/m²)													
Global	5173	6173	6770	7094	6554	5956	5120	5033	5745	5114	5026	5088	5737
Diffuse	1588	1521	1812	2088	2560	2965	3365	3209	2634	2295	1832	1403	2273
Relative Humidity (%)													
morning	81	83	63	65	63	70	82	87	87	85	87	83	78.0
evening	43	27	24	25	30	46	60	69	64	58	47	38	44.3
Dry Bulb Temperature (°C)													
max	28.1	31.4	34.4	37.1	36.2	34.3	30.3	28.4	29.5	28.6	28.5	27.4	31.2
min	17.6	19.4	22.4	25.8	26	25.6	23.9	23.4	23.5	21.4	19.6	15.7	22.0
mean	22.9	25.4	28.4	31.5	31.1	30.0	27.1	25.9	26.5	25.0	24.1	21.6	26.6
Neutrality	24.9	25.7	26.6	27.5	27.4	27.1	26.2	25.8	26.0	25.6	25.3	24.5	26.0
Upper limit	27.4	28.2	29.1	30.0	29.9	29.6	28.7	28.3	28.5	28.1	27.8	27.0	28.5
Lower limit	22.4	23.2	24.1	25.0	24.9	24.6	23.7	23.3	23.5	23.1	22.8	22.0	23.5
Rain (mm) ^b	13.2	7.9	15.3	20.2	35.7	103.8	169.9	178.7	158.3	97.2	22.4	5.9	828.5
Wind (m/s)	1.7	2.3	2.4	2.3	2.9	3.9	3.9	3.4	2.1	2.2	2	1.8	2.6
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	149	206	322	400	397	347	269	237	243	211	173	107	3061



Average diurnal range (°K)	9.2
Annual mean range (°K)	21.4

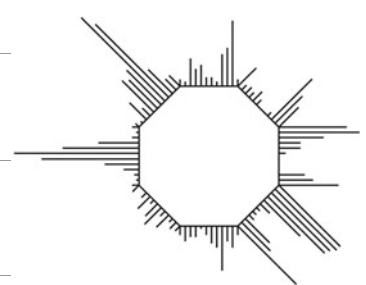
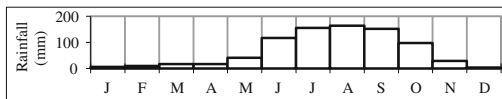
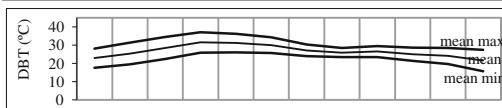
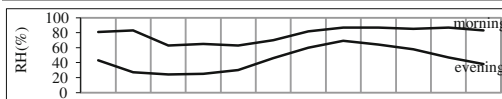
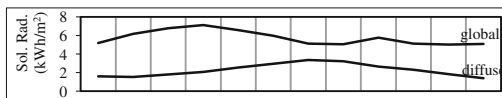


Table 5.44 Design conditions and overheated–underheated periods, Hyderabad

Recommended “Design” conditions		
Summer	DBT (°C)	39.2
	MCWB (°C)	22.5
	WBT (°C)	25.2
	MCDB (°C)	32.4
Winter	DBT (°C)	15.5

Hourly temperature (°C) in all 12 months

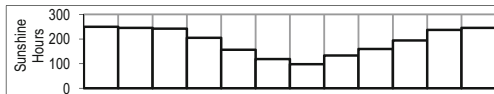
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	20.2	22.4	25.6	28.4	28.1	27.6	25.5	24.4	24.5	22.6	21.1	18.4	0	0	0	0
1:01- 2:00	19.5	21.8	24.8	27.9	27.7	27.2	25.2	24.2	24.4	22.2	20.7	17.7	0	0	0	0
2:01- 3:00	19.0	21.1	24.1	27.0	27.3	26.7	24.7	24.0	24.1	21.9	20.3	17.2	0	0	0	0
3:01- 4:00	18.6	20.5	23.5	26.6	26.9	26.3	24.5	23.7	23.9	21.8	20.1	16.7	0	0	0	0
4:01- 5:00	18.2	20.1	23.0	26.2	26.3	25.9	24.2	23.6	23.7	21.6	19.9	16.3	0	0	0	0
5:01- 6:00	17.8	19.7	22.6	25.8	26.0	25.6	24.0	23.4	23.5	21.5	19.6	15.9	0	0	0	0
6:01- 7:00	17.6	19.4	22.4	25.8	26.2	25.7	23.9	23.4	23.5	21.4	19.6	15.7	12	36	3	2
7:01- 8:00	18.0	20.3	23.6	27.2	27.1	26.4	24.3	23.9	24.1	22.3	20.9	17.1	113	127	64	60
8:01- 9:00	20.9	23.3	26.2	29.9	29.2	27.8	25.3	24.6	25.4	24.6	23.7	20.7	296	183	221	111
9:01-10:00	23.0	25.5	28.3	32.1	30.7	29.2	26.2	25.5	26.4	25.9	25.4	22.9	499	203	376	146
10:01-11:00	24.7	27.9	30.5	34.0	32.4	30.7	27.5	26.4	27.6	26.8	26.6	24.7	658	210	509	163
11:01-12:00	26.1	29.5	32.0	35.7	33.9	32.1	28.5	27.3	28.5	27.8	27.6	25.8	767	205	589	170
12:01-13:00	26.9	30.5	33.1	36.8	35.1	33.0	29.5	27.7	28.8	28.3	28.1	26.7	785	206	600	173
13:01-14:00	27.6	31.2	33.9	37.0	35.8	33.5	29.9	28.3	29.2	28.6	28.4	27.3	715	213	532	174
14:01-15:00	28.1	31.4	34.4	37.1	36.2	33.9	30.2	28.4	29.5	28.6	28.5	27.4	557	225	409	164
15:01-16:00	28.1	31.4	34.4	36.7	36.2	34.3	30.3	28.1	28.8	28.3	28.1	27.1	373	213	262	135
16:01-17:00	27.8	30.9	33.9	35.6	35.9	33.4	29.2	27.7	28.4	27.9	27.4	26.2	184	171	105	87
17:01-18:00	26.5	29.6	32.9	34.9	34.6	32.8	28.2	27.2	27.7	27.0	25.9	24.7	46	88	13	20
18:01-19:00	25.4	28.1	31.4	33.6	32.9	31.5	27.5	26.6	27.0	26.0	24.8	23.4	3	7	0	0
19:01-20:00	24.5	26.8	30.0	32.6	31.7	30.7	27.1	26.2	26.6	25.2	24.0	22.2	0	0	0	0
20:01-21:00	23.8	25.8	29.1	31.8	30.7	29.8	26.7	25.5	25.7	24.6	23.2	21.3	0	0	0	0
21:01-22:00	22.7	24.6	28.0	31.1	30.1	29.1	26.2	25.2	25.2	24.0	22.6	20.4	0	0	0	0
22:01-23:00	21.7	23.7	27.0	29.6	29.4	28.6	25.9	24.9	24.9	23.5	22.1	19.7	0	0	0	0
23:01-24:00	20.8	22.9	26.3	28.9	28.6	28.0	25.5	24.6	24.6	23.0	21.5	19.0	0	0	0	0
Legend	Underheated			<22.0°C			Comfortable						Overheated		>27.5°C	

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.45 Climatic data, Imphal, Manipur

Latitude	N 24° 40'				Longitude				E 93° 54'				Altitude	774 m
Climate	Warm and humid				Köppen				Cfa					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	249.6	245.3	242.4	205.2	156.6	118.9	98.0	133.3	159.4	194.0	237.2	245.1	190.4	
Cloud (%)	42.8	45.9	45.9	44.7	45.3	45.2	45.2	44.4	44.8	45.3	44.8	44.2	44.86	
Solar irradiation daily average (Wh/m²)														
Global	4337	5219	5681	5900	5489	5148	4789	5049	5016	4693	4495	4093	4992	
Diffuse	1387	1561	2209	2750	3256	3421	3538	3309	2825	2245	1479	1321	2442	
Relative Humidity (%)														
morning	94	94	89	93	93	95	94	94	95	94	96	95	93.8	
evening	38	38	38	61	59	76	70	70	69	56	55	44	56.2	
Dry Bulb Temperature (°C)														
max	21.1	23.0	25.6	25.0	27.9	27.5	28.0	28.4	27.8	28.0	23.2	21.6	25.6	
min	5.3	7.6	11.8	17.3	19.1	22.4	22.8	22.8	21.7	17.7	12.3	6.4	15.6	
mean	13.2	15.3	18.7	21.2	23.5	25.0	25.4	25.6	24.8	22.9	17.8	14.0	20.6	
Neutrality	21.9	22.5	23.6	24.4	25.1	25.5	25.7	25.7	25.5	24.9	23.3	22.1	24.2	
Upper limit	24.4	25.0	26.1	26.9	27.6	28.0	28.2	28.2	28.0	27.4	25.8	24.6	26.7	
Lower limit	19.4	20.0	21.1	21.9	22.6	23.0	23.2	23.2	23.0	22.4	20.8	19.6	21.7	
Rain (mm)^b	12.2	37.5	84.5	120.1	154.2	262.1	407.3	198.7	131.5	112.1	48.1	14.0	1582	
Wind (m/s)	0.83	0.93	1.53	1.28	1.38	1.0	1.11	1.11	0.85	0.68	0.37	0.48	0.96	
HDD	169	87	10	0	0	0	0	0	0	0	38	151	455	
CDD	0	1	33	89	169	205	221	225	185	131	10	0	1269	



Average diurnal range (°K)	10.0
Annual mean range (°K)	12.4

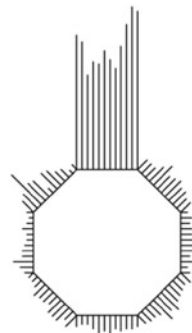
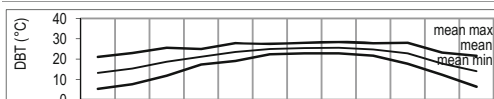
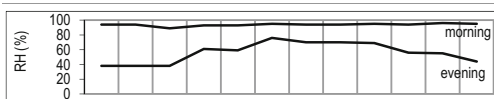
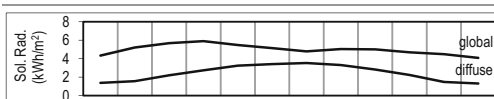


Table 5.46 Design conditions and overheated–underheated periods, Imphal

Recommended “Design” conditions														
Summer	DBT (°C)		30.2											
	MCWB (°C)		23.5											
	WBT (°C)		24.6											
	MCDB (°C)		28.6											
Winter	DBT (°C)		5.0											

Hourly temperature (°C) in all 12 months

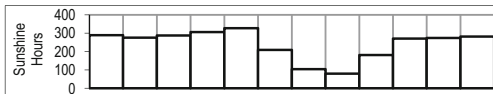
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aug		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	7.4	9.8	14.4	18.6	20.4	23.1	23.6	23.6	22.4	19.2	14.1	8.2	0	0	0	0
1:01- 2:00	6.7	9.2	13.5	18.2	19.9	22.8	23.3	23.3	22.2	18.8	13.7	7.8	0	0	0	0
2:01- 3:00	5.7	8.0	12.3	17.5	19.2	22.4	22.9	22.9	21.8	17.9	12.9	6.7	0	0	0	0
3:01- 4:00	5.3	7.6	11.8	17.3	19.1	22.4	22.8	22.8	21.7	17.8	12.6	6.5	0	0	0	0
4:01- 5:00	5.7	7.7	12.2	17.4	19.6	22.6	22.9	22.9	21.7	17.7	12.3	6.4	2	11	0	0
5:01- 6:00	7.0	9.2	13.8	18.1	20.7	23.3	23.5	23.6	22.3	19.1	13.4	7.9	27	89	4	7
6:01- 7:00	8.9	11.1	15.8	19.1	22.2	24.1	24.2	24.4	23.1	20.6	14.7	9.8	77	191	64	66
7:01- 8:00	11.6	13.9	18.6	20.4	23.9	25.1	25.1	25.4	24.2	22.7	16.8	12.6	139	278	200	118
8:01- 9:00	14.1	16.2	20.8	21.6	25.2	25.8	25.8	26.2	25.1	24.1	18.4	14.9	191	351	332	158
9:01-10:00	16.8	18.7	22.9	22.8	26.4	26.5	26.5	27.1	26.2	25.6	20.3	17.5	220	409	435	179
10:01-11:00	18.8	20.4	24.2	23.6	27.1	26.9	27.1	27.6	26.9	26.6	21.6	19.2	252	417	495	181
11:01-12:00	20.5	22.2	25.3	24.4	27.6	27.3	27.6	28.2	27.6	27.7	22.9	21.1	256	404	486	183
12:01-13:00	21.1	22.8	25.6	24.8	27.8	27.4	27.9	28.4	27.8	28.0	23.2	21.6	218	382	419	174
13:01-14:00	20.9	23.0	25.6	25.0	27.9	27.5	28.0	28.3	27.7	28.0	23.1	21.6	173	325	308	149
14:01-15:00	19.6	21.8	24.7	24.5	27.4	27.1	27.8	27.7	27.0	26.7	21.7	19.9	114	247	163	116
15:01-16:00	18.0	20.5	23.6	23.9	26.7	26.6	27.2	26.9	26.1	25.3	20.3	18.1	54	153	39	56
16:01-17:00	15.9	18.6	21.9	22.9	25.6	25.8	26.4	25.9	24.9	23.4	18.4	15.7	14	51	1	2
17:01-18:00	14.3	17.4	20.6	22.2	24.6	25.2	25.6	25.3	24.1	22.2	17.4	14.4	1	2	0	0
18:01-19:00	12.8	16.0	19.1	21.4	23.4	24.6	24.9	24.7	23.4	21.1	16.4	12.9	0	0	0	0
19:01-20:00	11.8	15.1	18.2	20.9	22.6	24.3	24.4	24.5	23.1	20.8	16.1	12.2	0	0	0	0
20:01-21:00	10.7	13.7	17.1	20.3	22.0	24.0	24.0	24.2	22.8	20.3	15.4	11.0	0	0	0	0
21:01-22:00	10.0	12.8	16.6	20.0	21.6	23.9	23.9	24.2	22.7	20.2	15.2	10.4	0	0	0	0
22:01-23:00	9.1	11.5	15.9	19.4	21.3	23.6	23.8	24.0	22.5	19.8	14.5	9.3	0	0	0	0
23:01-24:00	8.5	10.9	15.5	19.2	21.0	23.5	23.8	23.9	22.6	19.7	14.4	9.0	0	0	0	0
Legend	Underheated			<19.4°C	Comfortable								Overheated		>25.7°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.47 Climatic data, Indore, Madhya Pradesh

Latitude	N 22° 43'				Longitude				E 75° 48'				Altitude	567 m
Climate	Composite				Köppen				BWh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	289.0	275.6	287.6	305.9	326.9	208.6	104.1	79.9	180.6	270.8	274.0	281.3	240.4	
Cloud (%)	44.3	43.8	43.8	47.2	44.6	43.6	44.9	44.6	44.4	46.9	46.2	45.4	44.98	
Solar irradiation daily average (Wh/m²)														
Global	4593	5623	6579	7112	7172	5985	4430	4200	5214	5656	4827	4475	5489	
Diffuse	1430	1494	1704	2024	2332	3237	3548	3423	2857	1775	1488	1284	2216	
Relative Humidity (%)														
morning	71	71	48	41	53	78	93	95	88	69	76	68	70.9	
evening	32	30	16	15	19	40	66	77	52	31	35	26	36.6	
Dry Bulb Temperature (°C)														
max	26.0	28.0	34.2	37.6	39.1	34.6	29.6	27.2	30.8	31.5	29.2	26.9	31.2	
min	11.3	13.9	17.2	22.6	25.4	25.1	23.3	22.7	21.1	19.0	15.2	11.0	19.0	
mean	18.7	21.0	25.7	30.1	32.3	29.9	26.5	25.0	26.0	25.3	22.2	19.0	25.1	
Neutrality	23.6	24.3	25.8	27.1	27.8	27.1	26.0	25.5	25.8	25.6	24.7	23.7	25.6	
Upper limit	26.1	26.8	28.3	29.6	30.3	29.6	28.5	28.0	28.3	28.1	27.2	26.2	28.1	
Lower limit	21.1	21.8	23.3	24.6	25.3	24.6	23.5	23.0	23.3	23.1	22.2	21.2	23.1	
Rain (mm)^b	7.7	2.5	2.4	2.4	10.6	131.9	283.7	276.9	183.1	40.1	13.3	6.3	960.9	
Wind (m/s)	2.24	4.00	4.25	4.58	7.19	5.02	6.81	7.78	5.13	1.76	3.25	2.50	4.54	
HDD	14	0	0	0	0	0	0	0	0	0	0	13	27	
CDD	21	67	236	360	436	342	248	203	224	219	110	24	2490	



Average diurnal range (°K)	12.2
Annual mean range (°K)	28.1

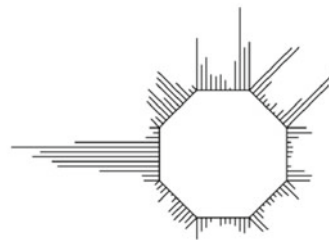
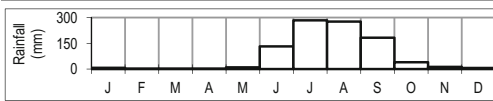
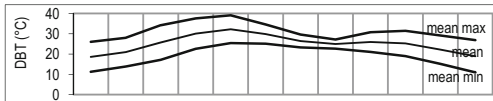
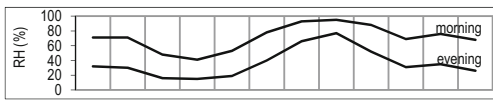
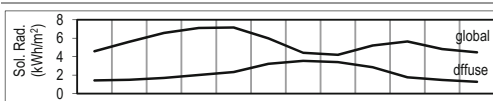


Table 5.48 Design conditions and overheated–underheated periods, Indore

Recommended “Design” conditions														
Summer	DBT (°C)	40.4												
	MCWB (°C)	20.6												
	WBT (°C)	25.2												
	MCDB (°C)	30.0												
Winter	DBT (°C)	9.7												

Hourly temperature (°C) in all 12 months

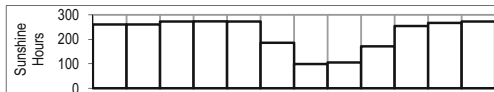
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	14.2	16.6	20.4	25.5	27.8	27.0	24.0	23.3	22.4	21.5	17.2	13.4	0	0	0	0
1:01- 2:00	13.4	15.7	19.2	24.6	27.0	26.5	23.7	23.0	21.9	20.8	16.4	12.4	0	0	0	0
2:01- 3:00	13.0	15.0	18.0	23.7	26.1	25.8	23.5	22.9	21.5	20.0	15.7	11.8	0	0	0	0
3:01- 4:00	12.2	14.0	17.2	22.8	25.4	25.3	23.3	22.7	21.1	19.3	15.2	11.0	0	0	0	0
4:01- 5:00	11.8	13.9	17.3	22.6	25.4	25.1	23.4	22.7	21.1	19.0	15.2	11.3	0	0	0	0
5:01- 6:00	11.3	13.9	18.3	23.4	26.0	25.4	23.6	22.7	21.6	19.8	16.0	11.8	5	11	0	0
6:01- 7:00	12.1	15.0	20.5	25.2	27.4	26.1	24.1	23.0	22.7	21.5	17.8	13.6	61	97	2	1
7:01- 8:00	13.5	16.8	23.2	27.6	29.4	27.3	24.8	23.5	24.1	23.7	20.1	15.9	205	163	51	59
8:01- 9:00	16.5	19.5	26.1	30.4	31.8	28.7	25.8	24.3	25.8	26.1	22.9	19.3	370	207	185	117
9:01-10:00	19.4	22.0	28.5	32.8	34.0	30.3	26.7	25.1	27.3	28.1	25.3	22.2	526	227	335	150
10:01-11:00	22.5	24.5	30.5	34.7	36.0	31.8	27.7	25.9	28.7	29.6	27.3	24.8	636	241	442	180
11:01-12:00	24.2	26.0	31.8	36.0	37.3	33.2	28.5	26.4	29.6	30.6	28.5	26.1	694	244	514	185
12:01-13:00	25.6	27.2	33.0	36.9	38.4	34.1	29.2	26.9	30.3	31.2	29.2	26.9	686	244	519	187
13:01-14:00	25.7	27.6	33.7	37.5	38.9	34.6	29.5	27.0	30.6	31.5	29.2	26.8	615	240	464	179
14:01-15:00	26.0	28.0	34.2	37.6	39.1	34.5	29.6	27.2	30.8	31.4	28.9	26.6	490	229	355	162
15:01-16:00	25.4	27.4	33.8	37.2	38.8	33.9	29.3	27.0	30.5	30.9	27.9	25.5	335	199	217	125
16:01-17:00	24.7	26.6	32.8	36.2	37.9	32.8	28.6	26.6	29.6	29.8	26.5	24.2	174	148	73	74
17:01-18:00	22.8	24.6	30.8	34.4	36.5	31.7	27.7	25.8	28.1	28.1	24.5	21.8	42	76	5	11
18:01-19:00	21.0	22.7	28.3	32.3	34.7	30.4	26.7	25.0	26.5	26.2	22.5	19.6	2	6	0	0
19:01-20:00	18.7	20.4	25.9	30.1	32.8	29.4	25.7	24.2	24.8	24.3	20.5	17.2	0	0	0	0
20:01-21:00	17.4	19.1	24.2	28.4	31.3	28.6	25.1	23.7	23.8	22.9	19.2	15.8	0	0	0	0
21:01-22:00	16.0	18.0	22.9	27.2	30.1	28.1	24.6	23.4	23.1	22.1	18.3	14.8	0	0	0	0
22:01-23:00	15.4	17.7	22.3	26.6	29.3	27.7	24.5	23.4	22.9	21.8	18.0	14.5	0	0	0	0
23:01-24:00	14.5	17.2	21.5	26.1	28.5	27.4	24.2	23.3	22.6	21.6	17.5	13.9	0	0	0	0
Legend	Underheated	<21.1°C			Comfortable						Overheated	>27.8°C				

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.49 Climatic data, Jabalpur, Madhya Pradesh

Latitude	N 23° 12'				Longitude				E 79° 56'				Altitude	393 m
Climate	Composite				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	260.4	260.4	272.8	273.0	272.8	186.0	99.2	105.4	171.0	254.2	267.0	272.8	224.6	
Cloud (%)	44.7	43.3	46.3	44.8	43.3	45.6	44.9	44.9	44.2	43.7	45.8	44.4	44.65	
Solar irradiation daily average (Wh/m²)														
Global	4462	5519	6589	7144	7057	5753	4561	4341	5127	5592	4807	4378	5444	
Diffuse	1526	1553	1680	1992	2442	3400	3617	3500	2954	1804	1486	1296	2271	
Relative Humidity (%)														
morning	89	69	69	55	49	75	93	93	90	89	91	85	78.9	
evening	45	42	28	27	22	46	76	75	61	50	50	49	47.6	
Dry Bulb Temperature (°C)														
max	24.8	28.6	32.4	37.0	39.2	35.7	29.2	28.6	30.9	30.0	27.5	22.9	30.6	
min	11.2	13.2	18.1	22.7	25.8	27.5	25.0	23.8	23.7	21.4	15.3	12.2	20.0	
mean	18.0	20.9	25.3	29.9	32.5	31.6	27.1	26.2	27.3	25.7	21.4	17.6	25.3	
Neutrality	23.4	24.3	25.6	27.1	27.9	27.6	26.2	25.9	26.3	25.8	24.4	23.2	25.6	
Upper limit	25.9	26.8	28.1	29.6	30.4	30.1	28.7	28.4	28.8	28.3	26.9	25.7	28.1	
Lower limit	20.9	21.8	23.1	24.6	25.4	25.1	23.7	23.4	23.8	23.3	21.9	20.7	23.1	
Rain (mm)^b	22.2	23.4	15.5	7.7	12.9	167.3	421.9	422.9	200.1	39.9	15	9.9	1359	
Wind (m/s)	0.93	0.91	1.14	0.98	1.56	1.79	1.52	1.25	1.15	0.71	0.82	1.05	1.15	
HDD	30	4	0	0	0	0	0	0	0	0	0	44	78	
CDD	13	72	219	355	443	388	275	251	269	231	85	16	2617	



Average diurnal range (°K)	10.6
Annual mean range (°K)	28.0

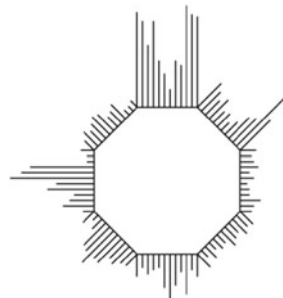
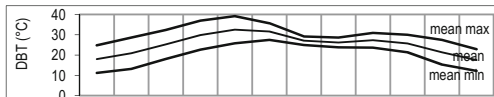
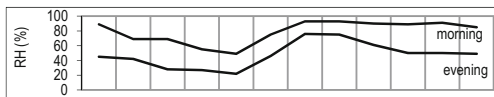
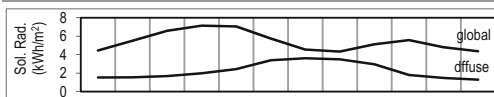


Table 5.50 Design conditions and overheated–underheated periods, Jabalpur

Recommended “Design” conditions														
Summer	DBT (°C)		41.2											
	MCWB (°C)		23.2											
	WBT (°C)		26.4											
	MCDB (°C)		32.0											
Winter	DBT (°C)		9.3											

Hourly temperature (°C) in all 12 months

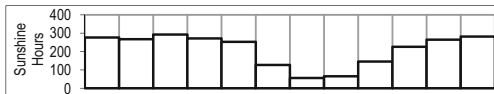
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	13.7	16.5	21.3	26.0	28.3	28.8	25.6	24.7	25.0	23.0	17.4	14.1	0	0	0	0
1:01- 2:00	12.9	15.2	20.2	24.8	27.4	28.3	25.3	24.4	24.6	22.6	16.9	13.4	0	0	0	0
2:01- 3:00	12.3	14.3	19.2	23.6	26.4	27.8	25.1	24.1	24.2	22.1	16.2	13.0	0	0	0	0
3:01- 4:00	11.5	13.2	18.2	22.7	25.8	27.5	25.0	23.9	23.8	21.7	15.6	12.4	0	0	0	0
4:01- 5:00	11.3	13.3	18.1	22.9	25.9	27.5	25.1	23.8	23.7	21.4	15.3	12.2	0	0	0	0
5:01- 6:00	11.2	13.2	18.7	23.8	27.0	27.9	25.3	24.0	24.0	21.9	15.9	12.4	11	33	0	0
6:01- 7:00	12.3	14.5	20.3	25.7	28.7	28.6	25.8	24.6	24.7	23.0	17.3	13.6	96	117	14	18
7:01- 8:00	14.0	16.4	22.5	27.9	30.9	29.6	26.4	25.3	25.7	24.5	19.4	15.1	239	184	105	83
8:01- 9:00	16.9	19.3	25.3	30.3	33.0	30.8	27.1	26.2	27.0	26.1	21.8	17.3	396	224	252	126
9:01-10:00	19.5	22.0	27.6	32.3	34.9	32.1	27.8	27.0	28.1	27.6	24.0	19.4	533	246	390	149
10:01-11:00	22.2	24.8	29.7	34.0	36.5	33.4	28.3	27.7	29.2	28.8	25.9	21.3	630	254	480	166
11:01-12:00	23.7	26.3	30.9	35.1	37.8	34.5	28.8	28.1	30.0	29.6	27.0	22.2	662	263	517	170
12:01-13:00	24.7	27.7	31.9	36.1	38.7	35.3	29.0	28.5	30.6	30.0	27.5	22.9	642	257	491	167
13:01-14:00	24.8	28.1	32.2	36.7	39.2	35.7	29.2	28.6	30.8	30.0	27.4	22.8	555	253	406	157
14:01-15:00	24.8	28.6	32.4	37.0	39.0	35.5	29.1	28.6	30.9	29.6	26.7	22.6	427	233	277	134
15:01-16:00	24.0	28.1	31.8	36.5	38.2	34.8	28.9	28.4	30.5	28.9	25.7	21.9	275	194	129	94
16:01-17:00	23.0	27.2	30.6	35.4	36.9	33.7	28.4	28.0	29.8	28.0	24.2	21.0	129	131	21	32
17:01-18:00	21.0	25.1	28.7	33.4	35.3	32.5	27.8	27.3	28.7	27.0	22.7	19.4	21	52	0	0
18:01-19:00	19.1	22.9	26.6	31.5	33.5	31.2	27.1	26.7	27.6	25.9	21.1	18.0	1	0	0	0
19:01-20:00	17.0	20.6	24.6	29.6	32.1	30.3	26.5	26.0	26.6	25.0	19.8	16.4	0	0	0	0
20:01-21:00	15.8	19.3	23.4	28.5	30.8	29.6	26.1	25.5	25.9	24.2	18.7	15.5	0	0	0	0
21:01-22:00	14.9	18.3	22.6	27.9	30.1	29.3	25.8	25.2	25.5	23.7	18.1	14.8	0	0	0	0
22:01-23:00	14.6	18.1	22.5	27.6	29.5	29.0	25.7	25.1	25.3	23.4	17.8	14.6	0	0	0	0
23:01-24:00	14.1	17.4	22.1	27.0	29.1	28.9	25.7	24.9	25.1	23.2	17.6	14.2	0	0	0	0
Legend	Underheated		<20.7°C				Comfortable						Overheated		>27.9°C	

Sources of data: ISHRAE (2014), ^aIMD (1981), ^bIndia Meteorological Department (nd)

Table 5.51 Climatic data, Jagdalpur, Chhattisgarh

Latitude	N 19° 4'				Longitude				E 82° 1'				Altitude	553 m
Climate	Warm and humid				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	276.3	267.4	292.7	271.6	252.7	127.2	55.9	65.5	145.2	225.7	264.7	281.4	210.5	
Cloud (%)	44.4	45.0	45.4	44.8	43.8	43.7	45.1	43.4	44.9	44.9	46.0	45.4	44.74	
Solar irradiation daily average (Wh/m²)														
Global	5068	5893	6546	6869	6690	5167	4181	4202	4997	5367	5230	4926	5428	
Diffuse	1485	1622	1935	2269	2635	3462	3473	3429	3060	2234	1566	1380	2379	
Relative Humidity (%)														
morning	90	77	73	78	82	88	94	95	96	95	90	91	87.4	
evening	38	29	25	30	35	63	75	76	71	58	46	35	48.4	
Dry Bulb Temperature (°C)														
max	27.5	31.1	33.3	36.4	36.1	30.8	27.4	27.5	28.5	29.5	27.9	27.4	30.3	
min	12.4	15.6	18.1	22.1	23.4	23.8	22.9	23.1	22.5	19.9	15.9	12.1	19.3	
mean	20.0	23.4	25.7	29.3	29.8	27.3	25.2	25.3	25.5	24.7	21.9	19.8	24.8	
Neutrality	24.0	25.0	25.8	26.9	27.0	26.3	25.6	25.6	25.7	25.5	24.6	23.9	25.5	
Upper limit	26.5	27.5	28.3	29.4	29.5	28.8	28.1	28.1	28.2	28.0	27.1	26.4	28.0	
Lower limit	21.5	22.5	23.3	24.4	24.5	23.8	23.1	23.1	23.2	23.0	22.1	21.4	23.0	
Rain (mm)^b	9.1	15.6	16.0	51.1	73.2	239.6	369.4	377.5	236.9	101.1	24.3	7.7	1522	
Wind (m/s)	0.48	0.63	0.67	1.17	0.86	1.64	0.89	0.82	1.11	0.43	0.54	0.31	0.80	
HDD	15	0	0	0	0	0	0	0	0	0	0	7	22	
CDD	66	124	238	345	348	274	216	216	220	192	100	41	2380	



Average diurnal range (°K)	11.0
Annual mean range (°K)	24.3

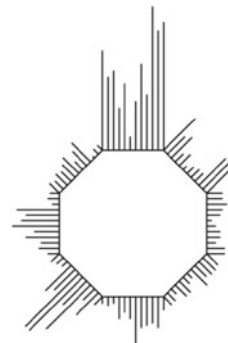
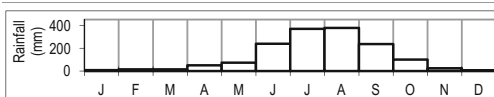
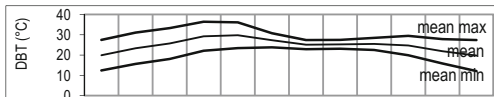
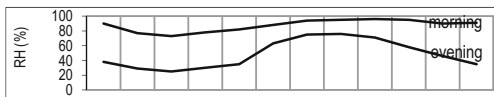
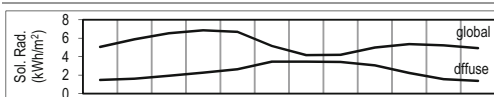


Table 5.52 Design conditions and overheated–underheated periods, Jagdalpur

Recommended “Design” conditions														
Summer	DBT (°C)		38.6											
	MCWB (°C)		22.5											
	WBT (°C)		25.9											
	MCDB (°C)		31.8											
Winter	DBT (°C)		10.1											

Hourly temperature (°C) in all 12 months

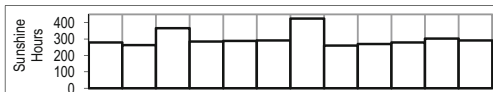
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	15.1	18.1	20.8	25.1	25.1	25.1	23.6	23.6	23.4	21.3	17.5	14.4	0	0	0	0
1:01- 2:00	14.2	17.8	19.8	23.9	24.6	24.6	23.4	23.5	23.2	20.9	17.0	13.6	0	0	0	0
2:01- 3:00	13.4	17.1	18.8	22.8	23.6	24.1	23.0	23.2	22.7	20.3	16.4	12.8	0	0	0	0
3:01- 4:00	12.6	16.1	18.1	22.1	23.4	23.8	22.9	23.1	22.5	20.0	16.0	12.1	0	0	0	0
4:01- 5:00	12.4	15.6	18.2	22.5	23.7	23.9	22.9	23.1	22.7	19.9	15.9	12.1	0	0	0	0
5:01- 6:00	12.9	16.0	19.1	23.9	25.1	24.5	23.3	23.5	23.4	20.8	16.9	12.7	14	39	0	0
6:01- 7:00	14.5	17.8	21.1	26.2	26.8	25.4	24.1	24.0	24.3	22.2	18.4	14.4	101	123	27	44
7:01- 8:00	16.8	20.3	23.6	28.8	29.0	26.6	24.9	24.8	25.6	24.1	20.6	16.7	231	195	168	93
8:01- 9:00	19.8	23.6	26.4	31.3	30.8	27.6	25.8	25.4	26.5	25.9	22.9	19.6	364	248	321	136
9:01-10:00	22.6	26.3	29.0	33.2	32.6	28.7	26.4	26.1	27.4	27.5	25.0	22.5	480	278	452	163
10:01-11:00	25.1	28.6	31.0	34.6	33.9	29.4	26.9	26.7	27.9	28.6	26.5	24.9	557	294	540	175
11:01-12:00	26.5	29.8	32.3	35.5	35.2	30.1	27.2	27.2	28.4	29.4	27.6	26.6	582	299	571	177
12:01-13:00	27.4	30.6	33.0	36.1	35.8	30.6	27.3	27.5	28.5	29.5	27.9	27.4	554	294	536	173
13:01-14:00	27.5	30.9	33.3	36.4	36.1	30.8	27.4	27.5	28.5	29.3	27.7	27.4	472	280	443	161
14:01-15:00	27.2	31.1	33.1	36.3	35.3	30.6	27.3	27.1	28.1	28.6	26.9	26.8	358	246	312	130
15:01-16:00	26.3	30.5	32.4	35.7	34.2	30.2	27.0	26.6	27.5	27.6	25.8	25.6	231	187	155	89
16:01-17:00	25.2	29.1	31.3	34.4	32.4	29.3	26.4	25.9	26.7	26.3	24.4	24.0	100	116	22	38
17:01-18:00	23.4	26.4	29.5	32.5	30.8	28.5	25.7	25.3	25.9	25.0	23.0	22.1	13	35	0	0
18:01-19:00	21.5	23.3	27.6	30.5	29.1	27.5	24.9	24.8	25.0	23.7	21.6	20.2	0	0	0	0
19:01-20:00	19.5	20.0	25.7	28.8	28.1	26.8	24.2	24.5	24.5	22.8	20.3	18.4	0	0	0	0
20:01-21:00	18.1	17.9	24.2	27.6	27.1	26.1	23.7	24.1	24.0	22.0	19.2	17.1	0	0	0	0
21:01-22:00	17.0	16.8	23.2	26.9	26.7	25.8	23.6	24.0	23.8	21.7	18.5	16.1	0	0	0	0
22:01-23:00	16.4	17.0	22.5	26.5	26.1	25.5	23.6	23.8	23.6	21.4	18.0	15.6	0	0	0	0
23:01-24:00	15.8	17.4	21.7	26.0	25.9	25.3	23.6	23.7	23.7	21.4	17.7	15.0	0	0	0	0
Legend	Underheated			<21.4°C			Comfortable						Overheated		>27.0°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.53 Climatic data, Jaipur, Rajasthan

Latitude	N 26° 49'				Longitude	E 75° 48'				Altitude	390 m		
Climate	Composite				Köppen	BWh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	279	263.2	365.8	285.0	288.3	291.0	424.7	260.4	270.0	279.0	303.0	291.4	300.1
Cloud (%)	19.5	23.9	24.8	20.0	22.0	38.3	66.1	63.4	31.9	17.3	17.0	15.5	29.98
Solar irradiation daily average (Wh/m²)													
Global	4399	5125	6183	7001	7493	6824	5417	5342	6145	5509	4508	4143	5674
Diffuse	1119	1471	1753	1985	2025	2557	3202	2940	1956	1487	1261	1043	1900
Relative Humidity (%)													
morning	74	70	49	47	44	61	83	88	85	52	58	66	64.8
evening	34	32	22	15	21	31	63	74	50	28	27	30	35.6
Dry Bulb Temperature (°C)													
max	21.6	24.9	31.3	35.3	39.1	38.9	32.3	30.1	33.9	33.8	29.7	25.3	31.4
min	9.9	12.8	18.3	22.9	28.6	30.1	26.3	25.8	24.6	21.8	15.5	10.2	20.6
mean	15.8	18.9	24.8	29.1	33.9	34.5	29.3	28.0	29.3	27.8	22.6	17.8	26.0
Neutrality	22.7	23.6	25.5	26.8	28.3	28.5	26.9	26.5	26.9	26.4	24.8	23.3	25.8
Upper limit	25.2	26.1	28.0	29.3	30.8	31.0	29.4	29.0	29.4	28.9	27.3	25.8	28.3
Lower limit	20.2	21.1	23.0	24.3	25.8	26.0	24.4	24.0	24.4	23.9	22.3	20.8	23.3
Rain (mm) ^b	20.4	11.1	11.4	9.0	35.6	141	319.2	279.3	212.6	72.3	8.2	7.4	1128
Wind (m/s)	1.1	1.3	1.7	1.7	2.4	2.5	2	1.4	1.7	1.0	0.5	0.7	1.5
HDD	87	13	0	0	0	0	0	0	0	0	0	41	141
CDD	0	27	210	336	492	487	342	304	330	293	121	10	2952



Average diurnal range (°K)	10.8
Annual mean range (°K)	29.2

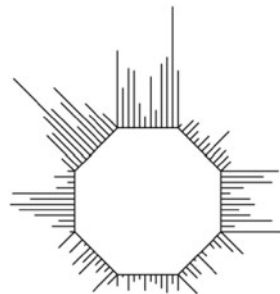
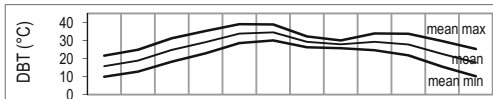
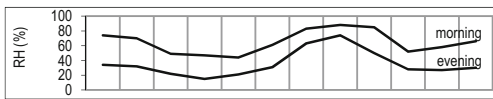
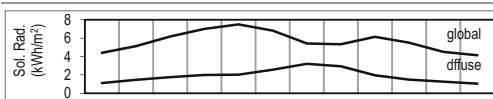


Table 5.54 Design conditions and overheated–underheated periods, Jaipur

Recommended “Design” conditions														
Summer	DBT (°C)		41.4											
	MCWB (°C)		22.6											
	WBT (°C)		27.0											
	MCDB (°C)		32.1											
Winter	DBT (°C)		8.0											

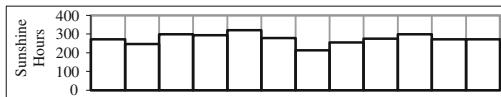
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	12.2	15.1	21.6	25.5	31.1	31.9	27.4	26.5	26.2	24.2	17.5	12.8	0	0	0	0
1:01- 2:00	11.9	14.7	20.9	25.2	30.5	31.4	27.2	26.4	25.8	23.8	17.0	12.3	0	0	0	0
2:01- 3:00	11.5	14.3	20.3	24.3	30.1	31.1	26.9	26.2	25.4	23.3	16.8	11.8	0	0	0	0
3:01- 4:00	11.2	13.9	19.8	23.9	29.5	30.7	26.6	26.1	25.2	22.9	16.6	11.4	0	0	0	0
4:01- 5:00	10.7	13.4	19.4	23.4	28.9	30.4	26.4	26.0	24.9	22.4	16.1	11.0	0	0	0	0
5:01- 6:00	10.2	13.1	18.7	22.9	28.6	30.1	26.3	25.8	24.6	22.0	15.8	10.5	0	0	0	0
6:01- 7:00	9.9	12.8	18.3	23.1	28.9	30.4	26.5	25.8	24.6	21.8	15.5	10.2	9	53	0	0
7:01- 8:00	10.0	13.4	19.6	25.3	30.3	31.5	27.3	26.2	26.5	24.1	17.5	11.1	96	148	12	14
8:01- 9:00	13.3	17.1	22.7	28.0	32.5	32.8	28.1	27.3	28.4	27.4	22.5	15.8	243	206	91	81
9:01-10:00	15.8	19.5	24.9	30.0	34.2	34.3	28.8	27.8	29.8	29.3	25.5	19.7	417	232	239	123
10:01-11:00	18.0	21.3	26.8	31.9	35.9	35.8	29.9	28.6	31.3	31.0	27.0	21.8	563	241	396	139
11:01-12:00	19.4	22.8	28.5	33.5	37.3	37.3	30.8	29.8	32.5	32.3	28.2	23.5	664	240	526	135
12:01-13:00	20.5	23.7	29.8	34.4	38.4	38.3	31.6	30.0	33.3	33.1	29.0	24.6	668	253	592	126
13:01-14:00	21.3	24.6	30.7	34.9	39.1	38.5	32.1	29.8	33.9	33.7	29.5	25.1	570	274	553	130
14:01-15:00	21.5	24.9	31.2	35.2	38.8	38.9	32.3	30.0	33.9	33.8	29.7	25.3	468	270	442	132
15:01-16:00	21.6	24.9	31.3	35.3	38.9	38.9	32.2	30.1	33.9	33.6	29.3	25.0	327	253	288	122
16:01-17:00	20.8	24.3	31.1	35.2	38.7	38.0	32.0	29.6	33.2	32.6	28.1	23.7	177	215	123	91
17:01-18:00	18.9	23.1	30.2	34.4	38.4	37.1	31.4	29.1	32.0	30.4	25.1	20.3	59	131	18	26
18:01-19:00	16.9	20.7	28.2	32.7	37.1	36.2	30.4	28.6	30.5	28.5	23.0	18.1	4	40	0	0
19:01-20:00	15.5	19.1	26.5	30.6	35.5	35.1	29.4	28.2	29.5	27.3	21.7	16.4	0	1	0	0
20:01-21:00	14.4	17.8	25.0	29.4	33.9	34.4	28.8	27.8	28.6	26.3	20.7	15.5	0	0	0	0
21:01-22:00	13.7	17.0	23.8	28.1	32.7	33.4	28.3	27.5	27.8	25.7	19.9	14.6	0	0	0	0
22:01-23:00	13.2	16.4	23.0	27.3	32.0	32.8	28.0	27.2	27.0	25.1	18.9	14.0	0	0	0	0
23:01-24:00	12.6	16.0	22.3	26.6	31.5	32.2	27.7	26.8	26.7	24.4	18.2	13.4	0	0	0	0
Legend	Underheated	<20.2°C		Comfortable								Overheated	>28.5°C			

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.55 Climatic data, Jaisalmer, Rajasthan

Latitude	N 26° 53'				Longitude				E 70° 55'				Altitude	231 m
Climate	Hot and Dry				Köppen				BWh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	271.5	246.4	299.4	293.4	319.6	277.8	213.3	254.1	275.8	298.7	272.1	271.0	274.4	
Cloud (%)	11.13	18.21	14.08	13.08	7.792	18.67	44.13	28.79	7.875	5.542	1.333	10.71	15.11	
Solar irradiation daily average (Wh/m²)														
Global	4335	5061	6217	6973	7559	7264	6275	6540	6361	5672	4642	4113	5918	
Diffuse	1183	1477	1732	2004	2044	2399	2834	2377	1851	1376	1170	1075	1794	
Relative Humidity (%)														
morning	60	65	44	47	58	70	67	82	82	58	53	54	61.7	
evening	39	29	21	21	25	35	53	51	41	25	26	30	33.0	
Dry Bulb Temperature (°C)														
max	22.8	25.9	32.7	37.8	41.5	39.9	36.9	34.8	36.0	37.4	30.3	25.6	32.8	
min	11.5	15.3	19.9	25.6	27.5	28.9	27.9	28.6	27.3	24.0	18.6	13.9	20.3	
mean	17.2	20.6	26.3	31.7	34.5	34.4	32.4	31.7	31.7	30.7	24.5	19.8	27.9	
Neutrality	23.1	24.2	26.0	27.6	28.5	28.5	27.8	27.6	27.6	27.3	25.4	23.9	26.5	
Upper limit	25.6	26.7	28.5	30.1	31.0	31.0	30.3	30.1	30.1	29.8	27.9	26.4	29.0	
Lower limit	20.6	21.7	23.5	25.1	26.0	26.0	25.3	25.1	25.1	24.8	22.9	21.4	24.0	
Rain (mm)^b	1.5	3.0	2.7	21.0	8.9	15.1	60.1	75.8	17.6	2.4	1.5	2.4	212	
Wind (m/s)	2.1	2.1	2.1	2.8	5.2	6.1	5.1	5	3.9	1.5	1.4	1.5	3.2	
HDD	53	15	0	0	0	0	0	0	0	0	2	11	81	
CDD	17	81	265	419	522	489	437	420	401	390	186	51	3678	



Average diurnal range (°K)	11.1
Annual mean range (°K)	30.0

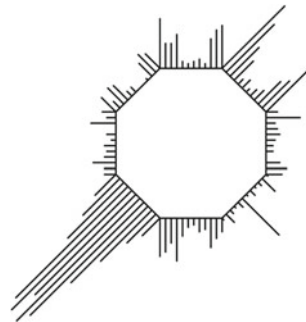
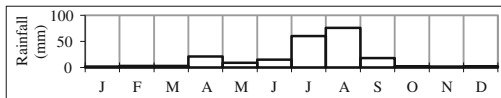
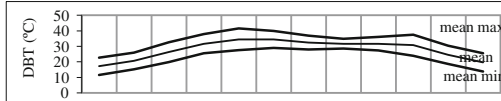
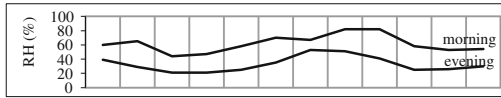
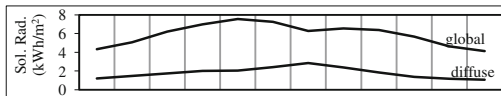


Table 5.56 Design conditions and overheated–underheated periods, Jaisalmer

Recommended “Design” conditions														
Summer	DBT (°C)		42.5											
	MCWB (°C)		23.1											
	WBT (°C)		27.3											
	MCDB (°C)		34.5											
Winter	DBT (°C)		6.5											

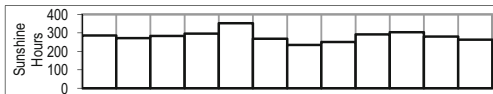
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	14.4	17.9	23.6	29.0	31.8	31.6	29.7	30.0	29.4	27.4	21.4	16.6	0	0	0	0
1:01- 2:00	14.2	17.3	22.9	28.2	30.7	30.6	29.5	29.7	29.0	26.5	20.9	16.1	0	0	0	0
2:01- 3:00	13.6	16.8	22.2	27.5	29.8	30.0	29.0	29.3	28.6	25.9	20.4	15.6	0	0	0	0
3:01- 4:00	13.2	16.4	21.6	26.9	29.0	29.6	28.6	29.0	28.2	25.5	19.9	15.2	0	0	0	0
4:01- 5:00	12.6	16.0	21.0	26.5	28.2	29.3	28.3	28.9	27.9	25.0	19.5	14.7	0	0	0	0
5:01- 6:00	12.1	15.5	20.4	25.9	27.6	29.1	28.0	28.7	27.4	24.5	19.1	14.4	0	0	0	0
6:01- 7:00	11.8	15.3	19.9	25.6	27.5	28.9	27.9	28.6	27.3	24.0	18.7	14.0	2	24	0	0
7:01- 8:00	11.6	15.3	20.0	26.8	28.4	29.4	28.3	28.7	27.3	24.7	18.6	13.9	81	120	3	2
8:01- 9:00	11.5	16.1	22.3	29.0	30.7	30.8	29.3	28.7	27.4	28.0	21.0	14.7	256	170	60	60
9:01-10:00	14.4	18.9	25.9	31.9	33.5	32.7	30.8	29.9	29.2	31.3	24.8	18.5	450	192	200	108
10:01-11:00	17.3	21.7	28.7	34.2	36.1	34.8	32.3	31.3	31.2	33.7	27.5	21.3	627	194	352	134
11:01-12:00	19.8	23.6	30.5	35.9	38.2	36.7	33.9	32.8	33.3	35.3	29.0	23.4	755	188	463	149
12:01-13:00	21.0	24.7	31.5	36.9	39.6	38.1	35.1	33.7	34.4	36.4	29.8	24.4	817	181	528	152
13:01-14:00	22.0	25.3	32.2	37.5	40.6	39.0	36.3	34.5	35.3	36.9	30.2	25.0	795	183	520	153
14:01-15:00	22.6	25.9	32.7	37.7	41.2	39.7	36.6	34.7	35.9	37.4	30.3	25.5	681	196	458	144
15:01-16:00	22.8	25.9	32.7	37.8	41.5	39.9	36.9	34.8	36.0	37.3	30.2	25.6	531	195	336	129
16:01-17:00	22.8	25.8	32.6	37.4	41.2	39.6	36.6	34.5	36.0	36.9	29.6	25.3	346	182	184	101
17:01-18:00	21.9	25.1	32.2	37.0	41.0	39.6	36.1	34.8	35.7	35.6	27.7	23.9	153	148	46	51
18:01-19:00	20.1	23.7	30.7	36.0	40.1	38.8	35.1	34.4	34.5	33.3	25.7	21.6	20	70	1	1
19:01-20:00	18.7	22.0	28.9	34.4	38.5	37.6	34.3	33.5	33.4	31.7	24.5	20.3	0	1	0	0
20:01-21:00	17.6	21.0	27.6	33.0	37.1	36.3	33.4	32.8	32.4	30.5	23.6	19.3	0	0	0	0
21:01-22:00	16.9	20.1	26.4	31.7	35.9	35.2	32.4	32.1	31.8	29.6	22.8	18.6	0	0	0	0
22:01-23:00	16.1	19.4	25.5	30.7	34.5	33.7	31.6	31.3	31.1	28.7	22.2	17.9	0	0	0	0
23:01-24:00	14.9	18.8	24.7	29.8	33.1	32.4	30.5	30.3	30.0	27.9	21.6	16.9	0	0	0	0
Legend	Underheated		<20.6°C		Comfortable							Overheated		>28.5°C		

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.57 Climatic data, Jamnagar, Gujarat

Latitude	N 22° 27'				Longitude	E 70° 4'				Altitude	20 m		
Climate	Warm and humid				Köppen	BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	270.8	269.1	315.9	299.7	292.5	198.2	74.6	78.4	205.9	279.8	261.0	272.4	234.9
Cloud (%)	44.5	45.2	45.2	43.8	45.5	43.2	45.3	44.7	46.5	45.3	45.0	42.7	44.74
Solar irradiation daily average (Wh/m²)													
Global	4726	5668	6658	7175	7221	6165	4468	4362	5671	5777	4917	4539	5612
Diffuse	1407	1490	1663	1950	2256	3084	3515	3423	2572	1669	1448	1273	2146
Relative Humidity (%)													
morning	80	84	86	90	92	86	88	94	95	90	79	81	87.1
evening	40	31	36	46	47	56	67	76	62	51	32	37	48.4
Dry Bulb Temperature (°C)													
max	25.6	28.7	30.7	32.5	35.4	34.2	31.2	29.6	31.8	32.7	31.0	27.9	30.9
min	11.8	13.0	17.8	22.5	25.0	27.1	26.4	25.1	23.8	23.0	17.0	13.6	20.5
mean	18.7	20.9	24.3	27.5	30.2	30.7	28.8	27.4	27.8	27.9	24.0	20.8	25.7
Neutrality	23.6	24.3	25.3	26.3	27.2	27.3	26.7	26.3	26.4	26.4	25.2	24.2	25.8
Upper limit	26.1	26.8	27.8	28.8	29.7	29.8	29.2	28.8	28.9	28.9	27.7	26.7	28.3
Lower limit	21.1	21.8	22.8	23.8	24.7	24.8	24.2	23.8	23.9	23.9	22.7	21.7	23.3
Rain (mm)^b	1.2	1.6	1.7	0.3	4.9	63.8	225.9	122.7	60.7	10	2.9	1.5	497.2
Wind (m/s)	3.2	2.9	4.0	5.5	6.9	8.4	6.7	5.3	4.4	2.7	2.5	3.5	4.7
HDD	6	0	0	0	0	0	0	0	0	0	0	2	8
CDD	28	81	181	280	362	374	329	283	287	294	182	86	2767



Average diurnal range (°K) 10.4
Annual mean range (°K) 23.6

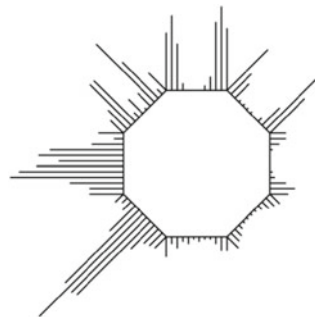
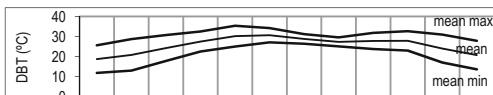
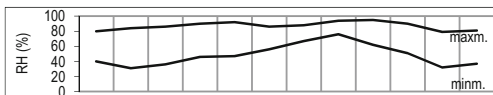
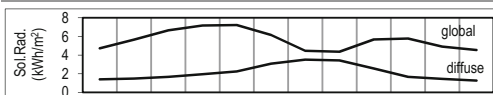


Table 5.58 Design conditions and overheated–underheated periods, Jamnagar

Recommended “Design” conditions														
Summer	DBT (°C)		36.1											
	MCWB (°C)		25.6											
	WBT (°C)		28.4											
	MCDB (°C)		32.5											
Winter	DBT (°C)		11.7											

Hourly temperature (°C) in all 12 months

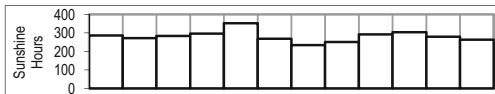
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	15.7	17.0	21.1	24.6	26.4	28.2	27.1	25.8	25.3	24.6	20.5	17.8	0	0	0	0
1:01- 2:00	14.8	16.0	20.1	23.9	25.8	27.8	26.8	25.6	24.9	24.2	19.3	16.7	0	0	0	0
2:01- 3:00	14.8	15.6	19.3	23.2	25.3	27.3	26.6	25.4	24.5	23.7	18.4	16.1	0	0	0	0
3:01- 4:00	13.7	14.4	18.3	22.6	25.0	27.1	26.4	25.2	24.0	23.3	17.4	15.0	0	0	0	0
4:01- 5:00	13.2	13.9	17.9	22.5	25.1	27.1	26.4	25.1	23.8	23.0	17.0	14.4	0	0	0	0
5:01- 6:00	11.8	13.0	17.8	23.1	25.6	27.8	26.7	25.3	24.0	23.3	17.0	13.6	1	1	0	0
6:01- 7:00	11.9	13.6	18.7	24.4	26.8	28.8	27.3	25.7	24.9	24.2	18.4	14.2	15	57	0	0
7:01- 8:00	12.7	15.0	20.1	26.2	28.5	30.1	28.1	26.4	26.2	25.6	20.3	15.4	83	154	24	35
8:01- 9:00	15.8	18.3	22.5	28.1	30.5	31.4	29.0	27.3	27.3	23.4	18.4	185	235	143	96	
9:01-10:00	18.8	21.7	24.8	29.7	32.4	32.5	29.8	28.1	29.4	29.1	26.1	21.2	285	299	294	139
10:01-11:00	22.4	25.3	27.1	31.0	34.0	33.4	30.5	28.8	30.7	30.7	28.8	24.4	380	330	426	165
11:01-12:00	24.1	27.2	28.7	31.8	35.0	34.0	31.0	29.3	31.5	31.8	30.1	26.1	436	351	513	179
12:01-13:00	25.4	28.6	30.0	32.3	35.4	34.2	31.2	29.6	31.8	32.5	31.0	27.5	461	346	540	185
13:01-14:00	25.3	28.5	30.5	32.5	35.2	34.2	31.2	29.6	31.7	32.7	31.0	27.6	421	347	509	180
14:01-15:00	25.6	28.7	30.7	32.4	34.6	33.8	31.1	29.4	31.2	32.5	31.0	27.9	353	321	420	166
15:01-16:00	25.0	28.1	30.1	31.8	33.7	33.3	30.7	29.1	30.7	32.0	30.3	27.2	255	278	289	138
16:01-17:00	24.8	27.6	29.1	30.9	32.6	32.5	30.2	28.6	29.9	31.1	29.6	26.7	149	211	139	93
17:01-18:00	23.1	25.9	27.3	29.5	31.3	31.7	29.6	28.0	29.1	29.9	27.9	24.9	54	124	23	31
18:01-19:00	21.8	24.4	25.6	28.0	30.1	30.8	28.9	27.4	28.3	28.7	26.3	23.4	4	30	0	0
19:01-20:00	19.6	22.2	23.9	26.7	29.0	30.0	28.3	26.9	27.4	27.4	24.5	21.5	0	0	0	0
20:01-21:00	18.6	20.9	22.9	25.8	28.2	29.4	27.9	26.4	26.7	26.4	23.5	20.5	0	0	0	0
21:01-22:00	17.2	19.3	22.3	25.3	27.6	29.0	27.6	26.2	26.1	25.6	22.4	19.4	0	0	0	0
22:01-23:00	16.9	18.7	22.1	25.2	27.2	28.7	27.4	26.0	25.7	25.2	22.0	19.1	0	0	0	0
23:01-24:00	15.9	17.5	21.6	25.0	26.9	28.6	27.2	25.9	25.5	24.9	21.1	18.2	0	0	0	0
Legend	Underheated			<21.1°C	Comfortable								Overheated		>27.3°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (1995)

Table 5.59 Climatic data, Jodhpur, Rajasthan

Latitude	N 26° 17'				Longitude				E 73° 1'				Altitude	224 m
Climate	Hot and dry				Köppen				BWh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	286.0	272.0	283.4	296.0	352.3	268.2	234.3	251.0	291.8	303.5	279.7	263.6	281.8	
Cloud (%)	31.0	27.0	31.2	24.5	25.0	45.1	73.8	75.7	35.2	20.0	11.7	26.5	35.57	
Solar irradiation daily average (Wh/m²)														
Global	4358	5221	6207	7049	7467	7075	6103	5530	6540	5679	4827	4171	5852	
Diffuse	1187	1387	1713	1909	2007	2361	2936	3081	1705	1388	1048	1078	1817	
Relative Humidity (%)														
morning	66	57	46	38	52	60	76	85	68	48	50	51	58.1	
evening	24	23	19	11	23	34	52	60	34	14	19	27	28.3	
Dry Bulb Temperature (°C)														
max	24.4	26.5	35.1	39.0	39.2	38.9	35.1	32.2	35.7	37.8	31.0	27.0	33.5	
min	12.1	14.7	20.8	25.9	29.2	31.2	28.1	27.1	25.9	22.2	16.7	14.3	22.4	
mean	18.3	20.6	28.0	32.5	34.2	35.1	31.6	29.7	30.8	30.0	23.9	20.7	27.9	
Neutrality	23.5	24.2	26.5	27.9	28.4	28.7	27.6	27.0	27.3	27.1	25.2	24.2	26.5	
Upper limit	26.0	26.7	29.0	30.4	30.9	31.2	30.1	29.5	29.8	29.6	27.7	26.7	29.0	
Lower limit	21.0	21.7	24.0	25.4	25.9	26.2	25.1	24.5	24.8	24.6	22.7	21.7	24.0	
Rain (mm)^b	10.2	4.8	3.9	5.1	66.1	35.1	120.8	128.9	57.6	8.1	2.6	1.6	444.8	
Wind (m/s)	0.9	1.1	1.1	1.2	2.8	2.2	1.8	1.6	1.2	0.4	0.5	0.7	1.3	
HDD	25	15	0	0	0	0	0	0	0	0	0	15	55	
CDD	13	80	301	449	501	506	413	355	376	355	159	75	3583	



Average diurnal range (°K)	11.1
Annual mean range (°K)	27.1

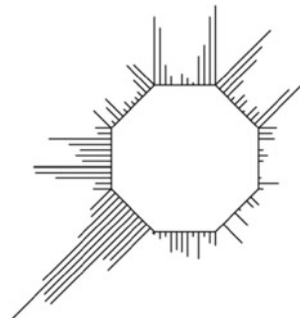
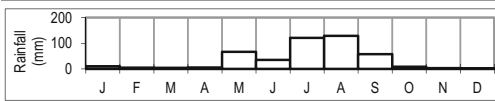
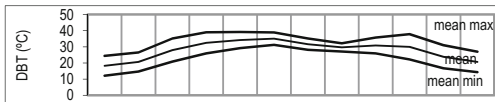
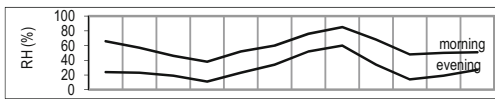
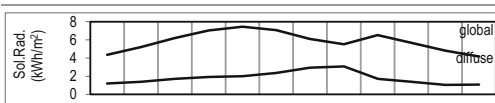


Table 5.60 Design conditions and overheated–underheated periods, Jodhpur

Recommended “Design” conditions														
Summer	DBT (°C)		40.8											
	MCWB (°C)		23.0											
	WBT (°C)		27.4											
	MCDB (°C)		33.7											
Winter	DBT (°C)		8.7											

Hourly temperature (°C) in all 12 months

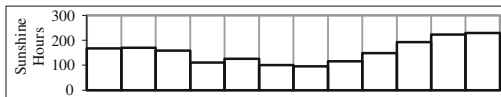
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	14.7	17.6	25.1	30.3	32.8	33.9	29.9	28.3	28.1	25.5	19.8	17.3	0	0	0	0
1:01- 2:00	14.3	17.2	24.4	29.9	32.0	33.2	29.6	28.1	27.7	24.9	19.4	16.8	0	0	0	0
2:01- 3:00	13.9	16.8	23.8	29.3	31.1	32.6	29.1	27.9	27.2	24.5	18.9	16.2	0	0	0	0
3:01- 4:00	13.4	16.2	23.0	28.5	30.4	32.1	28.7	27.6	26.9	24.0	18.3	15.9	0	0	0	0
4:01- 5:00	12.9	15.7	22.0	27.6	29.9	31.7	28.4	27.5	26.5	23.3	17.6	15.4	0	0	0	0
5:01- 6:00	12.5	15.1	21.1	26.6	29.2	31.3	28.2	27.2	26.0	22.7	17.1	14.8	0	0	0	0
6:01- 7:00	12.2	14.7	20.8	25.9	29.4	31.2	28.1	27.1	25.9	22.2	16.7	14.5	1	29	0	0
7:01- 8:00	12.1	14.7	21.3	26.8	29.9	31.3	28.3	27.3	26.6	23.5	17.4	14.3	66	131	5	10
8:01- 9:00	13.4	16.6	22.6	30.2	30.5	31.6	29.4	28.3	28.4	27.7	21.3	16.2	209	196	76	67
9:01-10:00	16.1	19.0	24.8	32.7	31.6	32.5	30.2	28.9	30.1	30.9	24.4	19.1	365	235	214	115
10:01-11:00	19.5	21.7	27.3	34.9	33.1	33.8	31.4	29.9	31.9	33.9	27.3	21.8	515	249	348	146
11:01-12:00	21.8	23.8	29.7	36.9	34.7	35.2	32.4	30.9	33.4	35.7	29.3	24.4	652	239	450	162
12:01-13:00	23.2	25.2	31.5	38.1	36.1	36.4	33.4	31.4	34.5	36.9	30.3	26.0	727	227	534	155
13:01-14:00	24.0	26.0	33.0	38.6	37.3	37.5	34.4	32.0	35.3	37.6	30.9	26.5	706	227	550	141
14:01-15:00	24.4	26.4	34.2	38.9	38.3	38.4	35.0	32.2	35.7	37.8	31.0	27.0	628	219	483	129
15:01-16:00	24.2	26.5	34.9	39.0	39.0	38.8	35.1	31.9	35.7	37.5	30.7	27.0	462	218	326	124
16:01-17:00	24.1	26.2	35.1	38.7	39.2	38.9	35.0	31.6	35.4	37.0	30.0	26.5	273	197	155	98
17:01-18:00	22.5	25.5	34.8	38.3	39.2	38.8	34.6	31.4	34.3	34.3	26.9	23.9	102	142	28	40
18:01-19:00	19.8	23.4	33.5	36.9	38.6	38.3	34.0	30.9	32.7	30.8	24.3	21.5	8	51	0	0
19:01-20:00	18.2	21.6	31.9	34.7	37.5	37.5	32.8	29.9	31.4	28.8	22.9	20.2	1	1	0	0
20:01-21:00	17.2	20.5	29.6	33.2	36.4	36.7	31.8	29.5	30.7	27.7	22.2	19.1	0	0	0	0
21:01-22:00	16.6	19.9	27.8	32.3	35.4	35.8	31.1	29.2	30.0	27.0	21.5	18.3	0	0	0	0
22:01-23:00	16.0	19.3	26.9	31.8	34.5	35.1	30.5	28.8	29.4	26.4	20.9	18.0	0	0	0	0
23:01-24:00	15.5	18.6	26.0	31.0	33.5	34.4	30.2	28.5	28.7	26.0	20.1	17.5	0	0	0	0
Legend	Underheated		<21.0°C		Comfortable								Overheated		>28.7°C	

Sources of data: ISHRAE (2014), ^aTyagi (2009 p. 304, 3929–3937), ^bIndia Meteorological Department (nd)

Table 5.61 Climatic data, Jorhat, Assam

Latitude	N 26° 53'				Longitude	E 94° 11'				Altitude	87 m		
Climate	Warm and humid				Köppen	Cfa							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	167.6	169.6	157.9	110.1	125.9	100.6	95.68	115.7	147.7	192.3	222.2	228.6	152.8
Cloud (%)	43.7	44.1	45.3	46.2	46.0	45.3	43.8	45.1	45.0	44.0	43.2	45.3	44.75
Solar irradiation daily average (Wh/m²)													
Global	3414	4204	4603	4637	5099	4929	4777	4803	4794	4546	4166	3753	4477
Diffuse	1737	2042	2663	3249	3438	3574	3536	3348	2861	2157	1506	1300	2618
Relative Humidity (%)													
morning	96	95	90	95	95	93	94	95	95	96	96	93	94.4
evening	62	55	44	63	75	72	74	73	75	65	62	58	64.8
Dry Bulb Temperature (°C)													
max	21.5	23.2	27.8	27.4	28.6	30.7	31.1	31.8	30.4	29.8	26.0	22.7	27.6
min	11.2	12.7	15.6	19.5	22.5	25.3	25.8	26.0	25.0	22.3	16.1	11.1	19.4
mean	16.4	18.0	21.7	23.5	25.6	28.0	28.5	28.9	27.7	26.1	21.1	16.9	23.5
Neutrality	22.9	23.4	24.5	25.1	25.7	26.5	26.6	26.8	26.4	25.9	24.3	23.0	25.1
Upper limit	25.4	25.9	27.0	27.6	28.2	29.0	29.1	29.3	28.9	28.4	26.8	25.5	27.6
Lower limit	20.4	20.9	22.0	22.6	23.2	24.0	24.1	24.3	23.9	23.4	21.8	20.5	22.6
Rain (mm) ^b	22.2	34.7	85.1	186.8	266.3	275.1	380.0	327.2	273.2	117.8	21.8	17.7	2008
Wind (m/s)	0.9	2.1	3.1	2.8	2.3	2.2	2.8	2.4	2.4	1.2	0.7	0.7	2.0
HDD	88	27	0	0	0	0	0	0	0	0	2	58	175
CDD	0	9	104	156	237	301	321	330	284	241	83	3	2069



Average diurnal range (°K)	8.2
Annual mean range (°K)	20.7

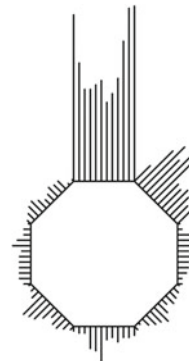
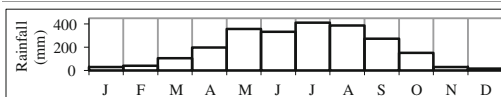
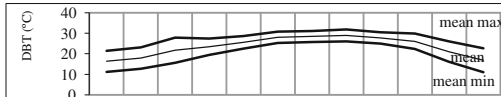
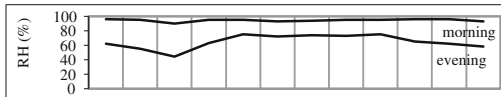
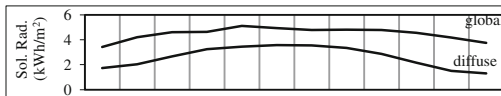


Table 5.62 Design conditions and overheated–underheated periods, Jorhat

Recommended “Design” conditions													
Summer	DBT (°C)		33.6										
	MCWB (°C)		27.7										
	WBT (°C)		28.3										
	MCDB (°C)		32.1										
Winter	DBT (°C)		10.6										

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aug		Jan	
Hours													H _b	H _d	H _b	H _d
0:01- 1:00	11.9	13.9	17.4	20.7	23.5	26.2	26.5	27.0	26.1	24.0	18.4	13.0	0	0	0	0
1:01- 2:00	11.8	13.5	16.7	20.3	23.1	25.9	26.3	26.6	25.8	23.7	17.9	12.6	0	0	0	0
2:01- 3:00	11.4	12.9	15.9	19.6	22.6	25.4	25.9	26.2	25.3	22.9	16.9	11.7	0	0	0	0
3:01- 4:00	11.3	12.7	15.6	19.5	22.5	25.3	25.8	26.0	25.1	22.6	16.4	11.4	0	0	0	0
4:01- 5:00	11.2	13.1	16.1	19.8	22.9	25.4	26.0	26.1	25.0	22.3	16.1	11.1	2	12	0	0
5:01- 6:00	11.9	14.1	17.4	20.7	23.6	26.2	26.6	26.6	25.7	23.1	17.1	12.0	23	92	2	6
6:01- 7:00	12.8	15.3	19.1	21.9	24.5	27.1	27.4	27.3	26.4	24.2	18.4	13.3	67	192	36	64
7:01- 8:00	14.3	17.1	21.3	23.4	25.6	28.2	28.4	28.3	27.5	25.8	20.5	15.4	114	286	112	139
8:01- 9:00	15.9	18.7	23.2	24.5	26.4	28.9	29.2	29.1	28.2	27.0	22.1	17.2	163	354	191	198
9:01-10:00	17.8	20.4	25.0	25.6	27.1	29.5	30.0	30.0	29.1	28.3	23.9	19.4	201	397	255	234
10:01-11:00	19.4	21.6	26.2	26.3	27.6	29.9	30.5	30.7	29.6	29.0	24.9	20.9	218	418	289	249
11:01-12:00	20.9	22.8	27.3	27.1	28.1	30.3	30.9	31.3	30.3	29.8	25.9	22.3	193	432	276	255
12:01-13:00	21.5	23.2	27.8	27.3	28.4	30.5	31.1	31.6	30.4	29.8	26.0	22.7	167	402	241	228
13:01-14:00	21.4	23.1	27.8	27.4	28.6	30.7	31.1	31.8	30.4	29.7	25.7	22.5	159	312	169	189
14:01-15:00	20.2	22.0	27.0	26.8	28.4	30.5	30.8	31.5	29.7	28.6	24.4	21.1	90	251	89	124
15:01-16:00	18.8	20.8	25.8	26.0	28.0	30.2	30.4	31.0	28.9	27.6	23.1	19.7	49	146	19	48
16:01-17:00	16.9	19.2	24.1	24.7	27.4	29.5	29.7	30.2	27.9	26.3	21.6	18.0	9	52	0	1
17:01-18:00	15.7	18.1	22.7	23.8	26.8	29.0	29.1	29.4	27.4	25.7	20.7	17.0	1	2	0	0
18:01-19:00	14.5	17.1	21.2	22.8	26.1	28.3	28.4	28.7	26.9	25.2	20.0	16.0	0	0	0	0
19:01-20:00	13.9	16.5	20.2	22.3	25.6	27.9	27.9	28.2	26.9	25.2	19.9	15.6	0	0	0	0
20:01-21:00	13.2	15.9	19.3	21.8	25.2	27.4	27.4	27.8	26.7	24.8	19.5	14.9	0	0	0	0
21:01-22:00	12.8	15.5	18.9	21.7	24.9	27.1	27.2	27.6	26.8	24.8	19.4	14.5	0	0	0	0
22:01-23:00	12.3	15.0	18.4	21.4	24.5	26.8	27.0	27.4	26.5	24.3	19.0	13.8	0	0	0	0
23:01-24:00	12.1	14.7	18.1	21.3	24.3	26.6	26.9	27.2	26.5	24.3	18.9	13.5	0	0	0	0
Legend	Underheated			<20.4°C	Comfortable					Overheated			>26.8°C			

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (2013)

Table 5.63 Climatic data, Kodaikanal, Tamil Nadu

Latitude	N 10° 13'				Longitude				E 77° 28'				Altitude	2343 m
Climate	Cold				Köppen				Csb					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	223.2	221.2	241.8	207.0	186.0	117.0	86.8	108.5	126.0	120.9	138.0	195.3	164.3	
Cloud (oct)^a	5.1	4.9	4.3	6.1	6.7	7.1	7.5	7.4	7.2	7.2	6.8	5.7	6.3	
Solar irradiation daily average (Wh/m²)														
Global	4922	5769	6271	6063	5655	4859	4829	5009	5223	4130	3576	4593	5075	
Diffuse	2038	2157	2365	2861	2406	2667	2819	2836	2680	2644	2213	1944	2469	
Relative Humidity (%)														
morning	82	87	85	92	90	90	89	90	89	92	93	73	87.7	
evening	52	48	41	57	72	83	79	78	78	84	84	52	67.3	
Dry Bulb Temperature (°C)														
max	18.0	19.6	20.7	20.5	19.5	18.0	16.8	16.8	17.8	16.5	15.3	17.4	18.1	
min	9.8	10.4	11.4	12.5	13.2	12.7	12.4	12.1	11.7	11.9	11.7	9.7	11.6	
mean	13.9	15.0	16.1	16.5	16.4	15.4	14.6	14.5	14.8	14.2	13.5	13.6	14.9	
Neutrality	22.1	22.5	22.8	22.9	22.9	22.6	22.3	22.3	22.4	22.2	22.0	22.0	22.4	
Upper limit	24.6	25.0	25.3	25.4	25.4	25.1	24.8	24.8	24.9	24.7	24.5	24.5	24.9	
Lower limit	19.6	20.0	20.3	20.4	20.4	20.1	19.8	19.8	19.9	19.7	19.5	19.5	19.9	
Rain (mm)^b	59.1	34.6	52.6	136.0	146.1	97.7	122.1	153.1	185.6	253.9	235.0	141.4	1617	
Wind (m/s)	0.8	0.6	0.8	0.7	0.6	0.7	0.9	1.0	0.5	0.6	1.2	0.9	0.8	
HDD	154	115	89	66	73	92	123	126	110	126	146	161	1381	
CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	

	Average diurnal range (°K)	6.5
	Annual mean range (°K)	11.0

	global
	diffuse

	morning
	evening

	mean max
	mean
	mean min

	J
	F
M	
A	
M	
J	
J	
A	
S	
O	
N	
D	

Table 5.64 Design conditions and overheated–underheated periods, Kodaikanal

Recommended “Design” conditions													
Summer	DBT (°C)	22.1											
	MCWB (°C)												
	WBT (°C)												
	MCDB (°C)												
Winter	DBT (°C)	6.8											

Hourly temperature (°C) in all 12 months

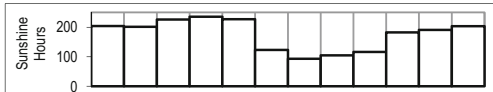
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	10.2	11.0	12.3	13.6	13.7	13.3	12.9	12.5	12.5	12.6	11.8	10.4	0	0	0	0
1:01- 2:00	10.1	10.8	12.1	13.3	13.5	13.2	12.8	12.4	12.3	12.4	11.8	10.0	0	0	0	0
2:01- 3:00	10.0	10.6	11.8	13.0	13.3	13.0	12.7	12.3	12.0	12.3	11.7	9.9	0	0	0	0
3:01- 4:00	10.0	10.5	11.7	12.8	13.2	12.8	12.6	12.3	11.9	12.2	11.7	9.8	0	0	0	0
4:01- 5:00	10.0	10.4	11.5	12.6	13.2	12.7	12.5	12.2	11.8	12.0	11.8	9.8	0	0	0	0
5:01- 6:00	9.9	10.4	11.4	12.5	13.2	12.7	12.4	12.1	11.7	11.9	11.7	9.7	0	8	0	0
6:01- 7:00	9.8	10.4	11.6	12.7	13.4	12.9	12.5	12.1	11.8	12.0	11.8	10.0	20	163	8	108
7:01- 8:00	11.6	12.2	13.5	14.2	14.7	13.9	13.2	12.5	13.3	13.0	12.7	11.9	144	265	111	215
8:01- 9:00	14.5	15.2	16.6	16.8	17.1	16.0	14.8	14.1	15.7	14.6	14.1	14.3	328	318	244	246
9:01-10:00	16.5	17.5	18.8	19.0	18.5	17.4	15.9	15.4	17.0	15.7	14.9	15.9	427	352	356	254
10:01-11:00	17.7	18.8	19.9	20.0	19.4	18.0	16.5	16.5	17.7	16.1	15.2	17.0	414	371	413	253
11:01-12:00	18.0	19.6	20.7	20.5	19.5	17.9	16.8	16.8	17.8	16.4	15.3	17.3	487	362	404	237
12:01-13:00	17.9	18.6	20.6	20.4	19.3	17.9	16.8	16.5	17.1	16.5	15.2	17.4	486	326	400	208
13:01-14:00	17.7	18.2	19.7	19.7	18.8	17.5	16.2	16.4	16.8	16.4	15.0	17.0	352	288	305	187
14:01-15:00	17.0	17.7	18.9	19.1	18.1	17.2	15.8	16.2	16.6	16.0	14.8	16.5	310	209	227	134
15:01-16:00	16.3	16.8	18.1	18.4	17.2	16.6	15.1	15.7	16.3	15.5	14.4	15.8	177	138	142	80
16:01-17:00	15.1	15.8	17.1	17.3	16.8	16.1	14.6	15.2	15.9	15.0	13.9	14.5	58	61	41	22
17:01-18:00	13.5	14.8	15.9	16.5	16.1	15.6	14.1	14.6	15.2	14.3	13.2	13.0	0	0	0	0
18:01-19:00	12.2	13.6	14.8	15.6	15.3	14.8	13.5	13.8	14.4	13.9	12.8	12.0	0	0	0	0
19:01-20:00	11.6	12.9	14.0	15.0	14.8	14.2	13.2	13.2	13.9	13.6	12.5	11.5	0	0	0	0
20:01-21:00	11.1	12.5	13.4	14.6	14.5	13.9	13.1	13.0	13.5	13.4	12.4	11.2	0	0	0	0
21:01-22:00	10.8	12.0	13.1	14.3	14.2	13.8	13.1	12.9	13.1	13.2	12.2	11.0	0	0	0	0
22:01-23:00	10.6	11.5	12.8	14.0	14.1	13.7	13.0	12.8	12.8	13.0	12.1	10.8	0	0	0	0
23:01-24:00	10.5	11.2	12.7	13.7	14.0	13.5	13.0	12.7	12.7	12.9	12.0	10.6	0	0	0	0
Legend	Underheated	<19.5°C		Comfortable					Overheated	>25.4°C						

Sources of data: ^aIMD (1999), ^bIndia Meteorological Department (nd), ISHRAE (2014), http://climate.onebuilding.org/WMO_Region_2_Asia/IND_India/index.html

Table 5.65 Climatic data, Kolkata, West Bengal

Latitude	N 22° 38'				Longitude				E 88° 26'				Altitude	6 m
Climate	Warm and humid				Köppen				Aw					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	203.9	201.2	225.8	235.4	227.1	123.1	93.1	104.9	116.2	182.6	190.8	203.4	175.6	
Cloud (%)	14.2	20.0	26.5	46.3	61.9	76.3	83.6	84.3	74.3	54.0	24.4	20.0	48.81	
Solar irradiation daily average (Wh/m²)														
Global	4242	4856	5810	6273	5728	4895	4129	4011	4558	4466	4650	4117	4811	
Diffuse	1601	1922	2211	2483	3105	3351	3489	3366	2945	2323	1558	1522	2490	
Relative Humidity (%)														
morning	84	88	77	84	81	90	87	91	91	89	84	84	85.8	
evening	51	50	48	51	64	71	76	77	76	70	54	51	61.6	
Dry Bulb Temperature (°C)														
max	25.2	28.5	33	35.3	34.9	32.3	31.8	31.7	31.2	30.8	29.1	26.0	30.8	
min	14.0	16.4	23.3	25.2	27	27.1	27.2	27.2	26.1	24.7	19.6	15.1	22.7	
mean	19.6	22.5	28.2	30.3	31.0	29.7	29.5	29.5	28.7	27.8	24.4	20.6	26.8	
Neutrality	23.9	24.8	26.5	27.2	27.4	27.0	26.9	26.9	26.7	26.4	25.3	24.2	26.1	
Upper limit	26.4	27.3	29.0	29.7	29.9	29.5	29.4	29.4	29.2	28.9	27.8	26.7	28.6	
Lower limit	21.4	22.3	24.0	24.7	24.9	24.5	24.4	24.4	24.2	23.9	22.8	21.7	23.6	
Rain (mm)^b	13.3	25.6	33.3	51.2	126.2	282.4	339.8	333.2	277.2	138.9	23.9	6.4	1651	
Wind (m/s)	0.61	0.64	0.95	1.74	1.96	1.86	1.55	1.25	1.03	0.57	0.48	0.45	1.1	
HDD	7	0	0	0	0	0	0	0	0	0	0	0	7	
CDD	39	106	298	341	389	341	347	342	306	291	175	57	3032	



Average diurnal range (°K)	8.1
Annual mean range (°K)	21.3

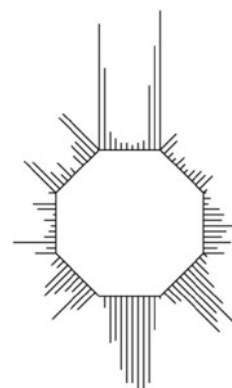
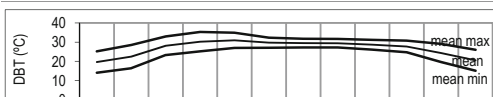
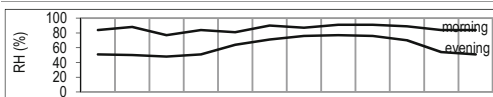
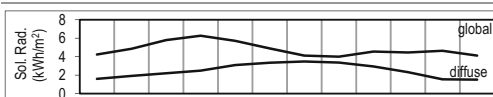


Table 5.66 Design conditions and overheated–underheated periods, Kolkata

Recommended “Design” conditions														
Summer	DBT (°C)		36.2											
	MCWB (°C)		26.1											
	WBT (°C)		29.0											
	MCDB (°C)		33.4											
Winter	DBT (°C)		13.1											

Hourly temperature (°C) in all 12 months

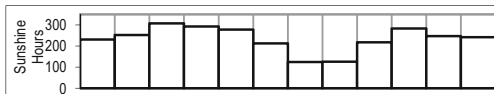
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	15.3	17.6	24.3	26.1	27.8	27.7	27.7	27.6	26.8	25.3	20.8	16.2	0	0	0	0
1:01- 2:00	15.1	17.1	24.1	25.9	27.6	27.7	27.6	27.5	26.6	25.1	20.6	15.9	0	0	0	0
2:01- 3:00	14.8	16.9	23.7	25.7	27.4	27.5	27.5	27.4	26.5	25.0	20.2	15.8	0	0	0	0
3:01- 4:00	14.5	16.8	23.5	25.5	27.2	27.3	27.4	27.3	26.3	24.8	20.0	15.5	0	0	0	0
4:01- 5:00	14.4	16.7	23.4	25.3	27.1	27.3	27.2	27.2	26.2	24.7	19.8	15.3	0	0	0	0
5:01- 6:00	14.1	16.6	23.3	25.2	27.0	27.1	27.2	27.2	26.1	24.7	19.6	15.1	3	27	0	0
6:01- 7:00	14.0	16.4	23.5	26.0	28.0	27.7	27.5	27.7	26.4	25.3	19.7	15.1	46	122	0	7
7:01- 8:00	15.4	18.3	25.3	27.6	29.5	28.6	28.3	28.6	27.4	27.0	21.9	17.0	128	219	45	94
8:01- 9:00	19.5	21.9	27.8	29.8	31.6	29.8	29.9	30.2	29.5	28.6	25.0	20.6	222	293	180	157
9:01-10:00	21.9	24.2	29.5	31.1	32.7	30.7	30.5	30.7	30.0	29.5	26.6	22.9	313	336	327	184
10:01-11:00	23.5	26.1	30.7	32.4	33.6	31.3	31.3	31.1	30.6	30.2	27.8	24.6	372	364	431	199
11:01-12:00	24.5	27.2	31.7	33.8	34.5	32.0	31.8	31.7	30.9	30.7	28.6	25.5	394	374	476	205
12:01-13:00	25.0	28.0	32.4	34.5	34.9	32.2	31.5	31.6	31.2	30.8	29.0	26.0	380	361	452	207
13:01-14:00	25.2	28.5	33.0	34.9	34.8	32.3	31.5	31.3	30.7	30.8	29.1	26.0	323	336	374	198
14:01-15:00	25.2	28.5	33.0	35.3	34.4	32.2	31.4	30.9	30.3	30.6	28.8	25.9	237	291	246	176
15:01-16:00	24.8	27.8	32.8	34.5	33.8	31.9	31.1	30.5	29.8	30.0	28.3	25.3	143	220	100	130
16:01-17:00	23.7	26.8	31.7	33.2	33.1	31.3	30.5	29.6	29.3	29.2	27.0	23.8	56	128	8	43
17:01-18:00	21.5	24.9	30.2	31.6	32.0	30.7	29.9	29.0	28.5	27.9	25.2	21.6	5	34	0	0
18:01-19:00	19.7	22.9	28.6	29.7	30.8	29.0	29.1	28.7	27.8	27.1	23.9	19.9	0	0	0	0
19:01-20:00	18.5	21.5	27.5	28.8	30.1	28.5	28.8	28.5	27.5	26.6	23.0	18.8	0	0	0	0
20:01-21:00	17.6	20.5	26.5	27.9	29.5	28.3	28.5	28.4	27.4	26.3	22.5	18.1	0	0	0	0
21:01-22:00	16.8	19.6	26.0	27.2	28.7	28.1	28.4	28.3	27.2	26.1	22.0	17.5	0	0	0	0
22:01-23:00	16.2	19.1	25.4	26.7	28.5	27.9	28.2	28.1	27.0	25.8	21.5	17.0	0	0	0	0
23:01-24:00	15.6	18.3	24.7	26.3	28.1	27.6	27.8	27.9	26.8	25.5	20.9	16.4	0	0	0	0
Legend	Underheated		<21.4°C			Comfortable						Overheated		>27.4°C		

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.67 Climatic data, Kota, Rajasthan

Latitude	N 25° 8'					Longitude	E 75° 50'					Altitude	274 m
Climate	Hot and dry					Köppen	BWh						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	231.3	252.3	307.6	293.1	277.8	212.8	124.7	125.8	218.1	283.3	247.5	242.2	234.7
Cloud (%)	46.1	46.6	44.1	46.9	45.7	46.1	45.7	46.0	45.3	44.6	45.5	44.0	45.56
Solar irradiation daily average (Wh/m²)													
Global	4128	5264	6415	7021	7036	6390	5134	4949	5728	5636	4558	4025	5524
Diffuse	1506	1540	1682	2032	2442	3010	3507	3355	2438	1587	1418	1324	2153
Relative Humidity (%)													
morning	69	60	52	41	40	56	84	88	78	51	83	66	64.0
evening	35	30	27	21	19	35	64	72	48	23	50	37	38.4
Dry Bulb Temperature (°C)													
max	22.5	24.6	31.2	37.9	42.0	38.3	31.7	30.1	32.7	33.4	26.7	24.0	31.3
min	12.3	14.5	20.4	26.4	30.7	30.7	27.1	26.1	25.2	22.7	18.5	13.4	22.3
mean	17.4	19.6	25.8	32.2	36.4	34.5	29.4	28.1	29.0	28.1	22.6	18.7	26.8
Neutrality	23.2	23.9	25.8	27.8	29.1	28.5	26.9	26.5	26.8	26.5	24.8	23.6	26.1
Upper limit	25.7	26.4	28.3	30.3	31.6	31.0	29.4	29.0	29.3	29.0	27.3	26.1	28.6
Lower limit	20.7	21.4	23.3	25.3	26.6	26.0	24.4	24.0	24.3	24.0	22.3	21.1	23.6
Rain (mm)^b	5.4	4.4	4	3.2	10.3	62.9	257	245.8	98.5	19.6	7.8	3.5	722.4
Wind (m/s)	1.7	1.7	1.9	2.6	3.7	3.5	3.5	3.0	1.9	1.4	1.5	1.5	2.3
HDD	46	25	0	0	0	0	0	0	0	0	0	7	78
CDD	13	63	238	429	570	489	351	310	325	304	132	18	3242



Average diurnal range (°K)	8.9
Annual mean range (°K)	29.7

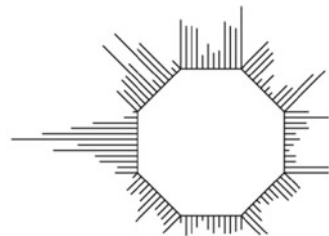
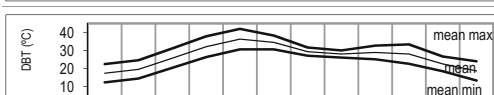
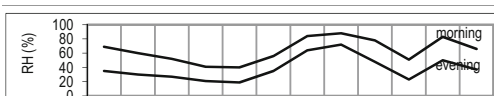
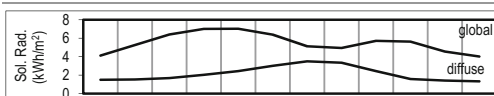


Table 5.68 Design conditions and overheated–underheated periods, Kota

Recommended “Design” conditions														
Summer	DBT (°C)		42.4											
	MCWB (°C)		22.6											
	WBT (°C)		26.8											
	MCDB (°C)		33.0											
Winter	DBT (°C)		10.8											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	14.5	16.5	22.5	28.8	33.0	32.2	28.1	27.1	26.5	24.7	20.3	15.5	0	0	0	0
1:01- 2:00	13.9	15.8	21.7	28.0	32.1	31.7	27.6	26.8	26.0	24.2	19.8	14.9	0	0	0	0
2:01- 3:00	13.3	15.5	21.0	27.1	31.3	31.3	27.4	26.5	25.5	23.3	19.3	14.3	0	0	0	0
3:01- 4:00	12.7	14.9	20.4	26.4	30.7	30.9	27.1	26.2	25.2	22.9	18.9	13.7	0	0	0	0
4:01- 5:00	12.4	14.7	20.6	26.4	30.8	30.7	27.1	26.1	25.3	22.7	18.5	13.4	0	0	0	0
5:01- 6:00	12.3	14.5	20.7	26.9	31.5	30.9	27.2	26.1	25.9	23.7	18.6	13.5	3	14	0	0
6:01- 7:00	12.7	14.9	21.4	28.1	32.7	31.6	27.7	26.5	26.8	25.0	19.2	14.1	60	98	1	0
7:01- 8:00	13.5	15.8	22.5	29.9	34.4	32.5	28.3	27.1	27.9	26.9	20.2	15.2	193	170	35	54
8:01- 9:00	15.0	17.5	24.3	32.0	36.1	33.7	29.1	27.8	29.1	28.4	21.6	16.8	352	214	148	118
9:01-10:00	16.6	19.4	26.0	33.9	37.7	34.6	29.9	28.6	30.1	30.1	23.0	18.6	494	243	273	163
10:01-11:00	18.4	21.4	27.8	35.5	39.0	35.6	30.6	29.2	31.0	31.2	24.5	20.4	601	257	374	192
11:01-12:00	19.9	22.8	29.2	36.6	40.2	36.3	31.0	29.8	31.7	32.5	25.6	22.0	658	259	435	202
12:01-13:00	21.2	23.9	30.3	37.3	41.0	37.0	31.4	30.0	32.3	33.0	26.4	23.2	652	258	438	206
13:01-14:00	22.1	24.3	30.9	37.8	41.7	37.6	31.5	30.1	32.7	33.4	26.7	23.9	586	251	389	196
14:01-15:00	22.5	24.6	31.2	37.9	42.0	38.1	31.7	30.0	32.7	32.7	26.6	24.0	465	239	295	172
15:01-16:00	22.3	24.4	31.1	37.8	41.8	38.3	31.6	29.7	32.5	32.0	26.2	23.7	320	204	173	130
16:01-17:00	21.8	24.0	30.7	37.3	41.2	38.2	31.4	29.3	31.8	30.6	25.6	22.9	162	156	57	66
17:01-18:00	20.6	23.0	29.7	36.3	40.1	37.5	30.8	28.8	30.9	29.7	24.7	21.9	42	77	4	7
18:01-19:00	19.3	21.9	28.6	35.0	38.8	36.5	30.2	28.4	29.8	28.5	23.8	20.6	2	5	0	0
19:01-20:00	17.9	20.6	27.2	33.6	37.5	35.2	29.4	28.0	28.8	27.8	22.9	19.4	0	0	0	0
20:01-21:00	16.9	19.7	26.1	32.2	36.2	34.3	29.1	27.6	28.1	26.8	22.2	18.3	0	0	0	0
21:01-22:00	16.0	18.7	25.0	31.1	35.3	33.4	28.8	27.4	27.6	26.2	21.5	17.4	0	0	0	0
22:01-23:00	15.5	18.0	24.2	30.2	34.6	33.0	28.7	27.3	27.3	25.5	21.1	16.7	0	0	0	0
23:01-24:00	14.9	17.2	23.4	29.6	34.0	32.4	28.4	27.2	27.0	25.2	20.6	16.1	0	0	0	0
Legend	Underheated		<20.7°C		Comfortable								Overheated		>29.1°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.69 Climatic data, Kurnool, Andhra Pradesh

Latitude	N 15° 48'				Longitude	E 78° 4'				Altitude	281 m		
Climate	Warm and humid				Köppen	BWh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	297.7	295.6	322.1	281.5	278.1	248.9	153.3	156.3	187.2	191.3	243.1	285.5	245.1
Cloud (%)	19.6	6.4	15.9	28.3	44.6	56.6	80.4	79.5	74.0	63.7	36.0	21.4	43.9

Solar irradiation daily average (Wh/m²)

Global	5558	6471	7044	7037	6974	6699	5375	5365	5613	5127	5237	5248	5979
Diffuse	1474	1422	1690	2106	2248	2474	3230	3133	2689	2468	1816	1449	2183

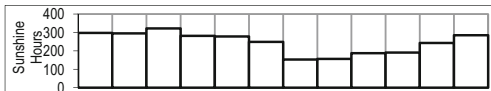
Relative Humidity (%)

morning	89	66	60	53	64	69	78	78	80	86	91	87	75.1
evening	31	22	19	21	26	35	48	54	54	59	43	35	37.3

Dry Bulb Temperature (°C)

max	30.7	33.5	37.1	39.9	39.7	36.3	32.5	31.4	31.5	30	30.2	29	33.5
min	18.9	21.2	23.6	29.0	29.2	27.3	25.2	24.6	24.6	24.2	21.1	18.6	24.0
mean	24.8	27.4	30.4	34.5	34.5	31.8	28.9	28.0	28.1	27.1	25.7	23.8	28.7
Neutrality	25.5	26.3	27.2	28.5	28.5	27.7	26.7	26.5	26.5	26.2	25.8	25.2	26.7
Upper limit	28.0	28.8	29.7	31.0	31.0	30.2	29.2	29.0	29.0	28.7	28.3	27.7	29.2
Lower limit	23.0	23.8	24.7	26.0	26.0	25.2	24.2	24.0	24.0	23.7	23.3	22.7	24.2

Rain (mm)^b	4.1	8.1	5.3	14.2	29.7	75.9	105.9	103.1	146.1	78.5	30.2	5.8	606.9
Wind (m/s)	0.61	0.73	0.64	1.20	1.09	1.83	2.02	1.33	0.91	0.59	0.67	0.60	1.0
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	210	260	384	489	499	409	328	298	299	274	225	177	3852



Average diurnal range (°K)	9.5
Annual mean range (°K)	21.3

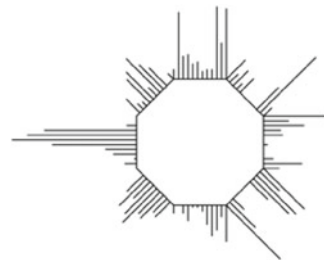
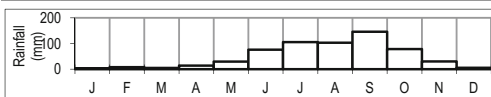
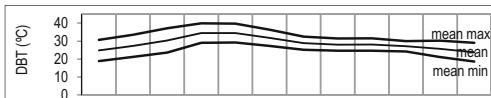
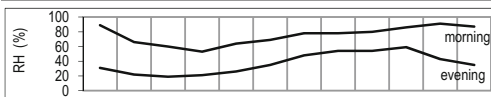
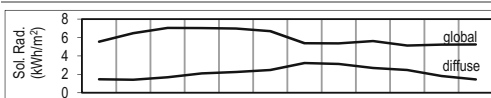


Table 5.70 Design conditions and overheated–underheated periods, Kurnool

Recommended “Design” conditions														
Summer	DBT (°C)		40.3											
	MCWB (°C)		24.6											
	WBT (°C)		28.8											
	MCDB (°C)		34.8											
Winter	DBT (°C)		4.0											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Dec			
													H _b	H _d	H _b	H _d		
Hours															H _b	H _d	H _b	H _d
0:01- 1:00	21.9	24.3	27.3	31.7	31.9	29.4	27.0	25.9	26.5	25.5	23.0	21.0	0	0	0	0		
1:01- 2:00	21.3	23.7	26.7	31.1	31.2	29.0	26.5	25.6	26.1	25.2	22.6	20.6	0	0	0	0		
2:01- 3:00	20.7	23.2	26.0	30.6	30.7	28.5	26.2	25.3	25.6	25.0	22.2	20.1	0	0	0	0		
3:01- 4:00	20.2	22.8	25.2	30.1	30.2	28.1	25.9	25.1	25.3	24.8	21.8	19.6	0	0	0	0		
4:01- 5:00	19.7	22.3	24.6	29.7	29.7	27.7	25.5	24.8	25.0	24.5	21.5	19.2	0	0	0	0		
5:01- 6:00	19.3	21.7	24.0	29.1	29.2	27.3	25.2	24.6	24.7	24.2	21.2	18.9	0	0	0	0		
6:01- 7:00	18.9	21.2	23.6	29.0	29.2	27.4	25.2	24.6	24.6	24.2	21.1	18.6	12	31	3	3		
7:01- 8:00	20.0	21.5	24.8	30.5	30.4	28.6	25.9	25.6	25.6	25.0	23.0	19.4	115	121	69	63		
8:01- 9:00	22.9	24.7	28.1	32.6	32.0	30.1	27.4	26.9	27.0	26.2	25.1	22.0	289	179	225	116		
9:01-10:00	25.4	26.9	30.7	34.4	33.4	31.4	28.3	28.0	28.1	27.3	26.8	24.2	464	212	383	151		
10:01-11:00	27.5	29.0	33.1	36.0	35.0	32.8	29.5	28.9	29.1	28.2	28.0	25.8	635	218	516	170		
11:01-12:00	28.7	30.8	34.7	37.6	36.5	34.0	30.5	29.8	29.9	29.2	28.9	27.3	734	220	607	173		
12:01-13:00	29.7	31.8	35.9	38.7	37.8	34.9	31.3	30.6	30.6	29.7	29.7	28.1	752	223	623	173		
13:01-14:00	30.4	32.8	36.7	39.6	38.8	35.8	32.0	31.1	31.1	30.0	29.9	28.7	693	225	561	173		
14:01-15:00	30.7	33.3	37.1	39.8	39.7	36.3	32.4	31.4	31.4	29.8	30.2	29.0	567	221	421	172		
15:01-16:00	30.7	33.5	36.9	39.9	39.5	36.0	32.5	31.3	31.5	29.5	30.0	29.0	402	200	263	145		
16:01-17:00	30.3	33.3	36.4	39.5	39.1	36.1	32.3	30.7	31.0	28.7	29.4	28.6	207	162	108	94		
17:01-18:00	28.8	32.4	35.2	38.5	38.0	35.6	31.3	29.6	30.2	28.1	27.9	27.3	57	86	21	16		
18:01-19:00	27.1	30.9	33.0	37.0	36.6	34.2	30.4	28.6	29.3	27.3	26.8	26.1	4	8	0	0		
19:01-20:00	26.0	29.2	31.5	35.3	35.4	32.8	29.3	27.8	28.6	27.0	25.9	24.9	0	0	0	0		
20:01-21:00	24.9	27.8	30.6	34.2	34.5	31.9	28.7	27.3	28.1	26.7	25.2	23.8	0	0	0	0		
21:01-22:00	24.0	26.8	29.9	33.4	33.8	31.2	28.0	26.8	27.8	26.4	24.6	23.0	0	0	0	0		
22:01-23:00	23.3	26.0	29.2	32.8	33.2	30.4	27.6	26.6	27.3	26.1	24.0	22.3	0	0	0	0		
23:01-24:00	22.5	24.9	28.2	32.2	32.5	29.7	27.2	26.3	27.0	25.6	23.3	21.4	0	0	0	0		
Legend	Underheated			<22.7°C			Comfortable						Overheated		>28.5°C			

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (1973)

Table 5.71 Climatic data, Lucknow, Uttar Pradesh

Latitude	N 26° 45'				Longitude	E 80° 52'				Altitude	128 m		
Climate	Composite				Köppen	BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	190.1	219.0	300.5	273.0	293.0	215.3	110.5	117.9	167.6	239.4	219.1	193.2	211.5
Cloud (%)	26.7	32.7	28.7	24.4	25.4	51.2	79.6	77.9	65.2	18.8	16.6	17.8	38.75
Solar irradiation daily average (Wh/m²)													
Global	3624	4765	6236	6714	7217	6441	4966	4833	5043	5053	4150	3463	5209
Diffuse	1630	1693	1678	2198	2253	2907	3556	3332	2664	1754	1534	1508	2226
Relative Humidity (%)													
morning	89	83	77	67	62	77	90	88	92	92	89	88	82.8
evening	54	45	27	26	27	47	70	82	70	45	35	49	48.1
Dry Bulb Temperature (°C)													
max	20.7	24.5	31.1	37.0	38.7	36.8	32.6	30.6	31.3	30.4	27.1	22.6	30.3
min	9.8	14.1	18.3	24.6	27.0	28.9	27.2	27.5	25.5	20.7	16.0	11.5	20.9
mean	15.3	19.3	24.7	30.8	32.9	32.9	29.9	29.1	28.4	25.6	21.6	17.1	25.6
Neutrality	22.5	23.8	25.5	27.3	28.0	28.0	27.1	26.8	26.6	25.7	24.5	23.1	25.7
Upper limit	25.0	26.3	28.0	29.8	30.5	30.5	29.6	29.3	29.1	28.2	27.0	25.6	28.2
Lower limit	20.0	21.3	23.0	24.8	25.5	25.5	24.6	24.3	24.1	23.2	22.0	20.6	23.2
Rain (mm) ^b	19.1	17.6	8.7	5.8	18.8	103.2	277.4	284.0	201.4	49.0	8.0	16.4	1009
Wind (m/s)	1.6	2.0	2.3	2.3	2.4	2.7	2.3	1.9	1.9	1.0	1.1	1.3	1.9
HDD	106	22	0	0	0	0	0	0	0	0	6	57	191
CDD	0	49	195	378	457	436	364	338	302	211	90	4	2824

	Average diurnal range (°K)	9.4
	Annual mean range (°K)	17.6

	Global
	Diffuse

	morning
	evening

	mean max
	mean
	mean min

	J	F	M	A	M	J	J	A	S	O	N	D
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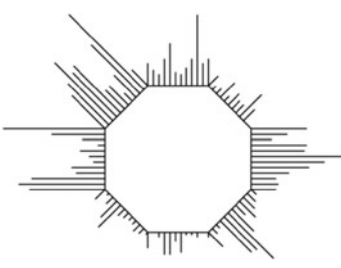


Table 5.72 Design conditions and overheated–underheated periods, Lucknow

Recommended “Design” conditions														
Summer	DBT (°C)		40.8											
	MCWB (°C)		24.8											
	WBT (°C)		28.4											
	MCDB (°C)		32.4											
Winter	DBT (°C)		8.4											

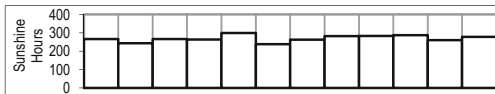
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	11.9	16.0	20.4	26.8	29.1	30.2	28.3	28.1	26.4	21.8	17.5	13.4	0	0	0	0
1:01- 2:00	11.5	15.8	20.0	26.1	28.5	29.9	28.0	27.9	26.2	21.6	17.2	13.1	0	0	0	0
2:01- 3:00	11.3	15.4	19.4	25.6	28.0	29.7	27.7	27.8	26.0	21.4	17.0	12.7	0	0	0	0
3:01- 4:00	10.9	15.0	19.0	25.2	27.7	29.4	27.5	27.7	25.9	21.2	16.7	12.4	0	0	0	0
4:01- 5:00	10.6	14.7	18.8	24.9	27.2	29.0	27.3	27.6	25.7	21.0	16.5	12.1	0	0	0	0
5:01- 6:00	10.2	14.4	18.4	24.6	27.0	28.9	27.2	27.5	25.5	20.7	16.2	11.8	1	6	0	0
6:01- 7:00	9.8	14.1	18.3	25.0	27.4	29.3	27.3	27.5	25.6	20.7	16.0	11.5	24	88	0	0
7:01- 8:00	9.8	14.8	20.0	26.8	29.2	30.3	28.0	27.6	26.3	22.2	16.5	11.8	161	170	7	37
8:01- 9:00	11.0	17.0	23.0	29.8	31.7	31.9	29.5	28.5	28.0	25.0	19.1	13.5	339	206	81	117
9:01-10:00	13.4	19.2	25.5	31.6	33.6	32.7	30.3	28.8	29.1	26.9	22.4	16.2	524	211	187	172
10:01-11:00	15.6	21.4	27.5	33.6	35.7	33.8	31.1	29.1	30.1	28.4	25.0	19.1	667	210	278	206
11:01-12:00	17.4	23.1	29.4	35.5	37.3	34.9	31.7	29.6	30.6	29.3	26.4	21.1	747	207	340	224
12:01-13:00	18.8	23.9	30.2	36.2	38.0	35.6	32.3	29.9	31.0	29.8	26.9	22.1	760	204	349	230
13:01-14:00	19.9	24.4	30.8	36.8	38.5	36.4	32.5	30.2	31.3	30.2	27.1	22.6	672	218	314	223
14:01-15:00	20.4	24.5	31.1	37.0	38.7	36.8	32.6	30.4	31.3	30.4	27.1	22.6	518	228	255	190
15:01-16:00	20.7	24.5	30.9	37.0	38.6	36.7	32.4	30.6	31.0	30.0	26.7	22.3	345	217	144	146
16:01-17:00	20.0	24.0	30.2	36.6	38.1	36.4	32.0	30.5	30.6	28.6	25.4	21.3	171	178	36	80
17:01-18:00	18.8	22.5	28.7	35.6	37.2	35.8	31.4	30.3	29.5	26.3	23.0	18.9	37	101	3	5
18:01-19:00	17.4	20.6	26.6	33.2	35.7	34.7	30.8	29.8	28.5	24.9	21.5	17.3	1	9	0	0
19:01-20:00	16.1	19.3	24.9	31.4	34.0	33.3	30.0	29.5	27.8	24.1	20.5	16.3	0	0	0	0
20:01-21:00	14.8	18.5	23.7	30.1	32.6	32.2	29.5	29.0	27.2	23.4	19.7	15.6	0	0	0	0
21:01-22:00	13.8	17.9	22.9	29.1	31.4	31.3	29.2	28.8	26.9	22.9	19.0	15.0	0	0	0	0
22:01-23:00	13.2	17.3	22.2	28.3	30.6	30.9	28.9	28.5	26.7	22.5	18.4	14.5	0	0	0	0
23:01-24:00	12.6	16.5	21.3	27.4	29.8	30.3	28.5	28.2	26.4	22.0	17.6	13.7	0	0	0	0
Legend	Underheated		<20.0°C		Comfortable								Overheated		>28.0°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.73 Climatic data, Mangaluru, Karnataka

Latitude	N 12° 55'				Longitude				E 74° 52'				Altitude	102m
Climate	Warm and humid				Köppen				Aw					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h^a	266.1	243.0	266.1	263.7	299.3	237.9	262.7	281.9	282.9	286.8	260.2	278.2	269.1	
Cloud (%)	47.1	44.0	45.5	47.3	46.2	44.6	44.8	45.6	46.0	45.8	44.4	45.6	45.58	
Solar irradiation daily average (Wh/m²)														
Global	5440	5973	6450	6814	7193	6467	6705	6970	6928	6404	5632	5408	6365	
Diffuse	1855	2052	2253	2303	2022	2458	2222	2072	1960	1853	1842	1678	2048	
Relative Humidity (%)														
morning	87	92	88	85	83	94	95	96	95	95	90	84	90.3	
evening	38	41	48	54	50	78	84	84	74	64	54	37	58.8	
Dry Bulb Temperature (°C)														
max	32.7	32.8	33.0	33.2	34.0	28.5	27.1	27.2	29.0	30.6	32.0	32.9	31.1	
min	21.3	21.9	24.1	26.0	25.6	24.4	24.2	23.9	24.2	23.6	23.3	21.8	23.7	
mean	27.0	27.4	28.6	29.6	29.8	26.5	25.7	25.6	26.6	27.1	27.7	27.4	27.4	
Neutrality	26.2	26.3	26.7	27.0	27.0	26.0	25.8	25.7	26.0	26.2	26.4	26.3	26.3	
Upper limit	28.7	28.8	29.2	29.5	29.5	28.5	28.3	28.2	28.5	28.7	28.9	28.8	28.8	
Lower limit	23.7	23.8	24.2	24.5	24.5	23.5	23.3	23.2	23.5	23.7	23.9	23.8	23.8	
Rain (mm)^b	1.1	0.2	2.9	24.4	183.2	1027	1200	787.3	292.1	190.8	70.9	16.4	3797	
Wind (m/s)	2.6	2.5	2.5	2.6	3.4	3.2	3.2	2.4	2.8	2.2	2.1	2.9	2.7	
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	
CDD	256	248	308	334	351	243	231	225	242	266	266	266	3236	



Average diurnal range (°K)	7.4
Annual mean range (°K)	4.3

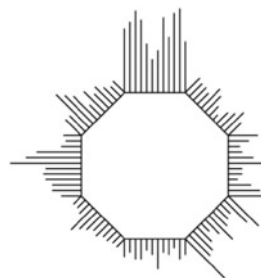
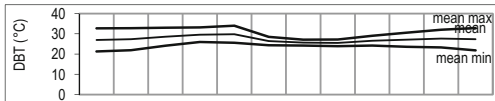
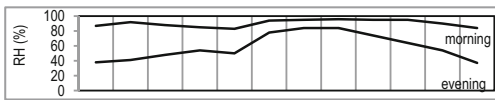
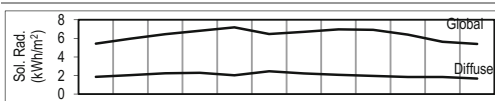


Table 5.74 Design conditions and overheated–underheated periods, Mangaluru

Recommended “Design” conditions														
Summer	DBT (°C)		33.9											
	MCWB (°C)		24.0											
	WBT (°C)		26.7											
	MCDB (°C)		31.0											
Winter	DBT (°C)		20.5											

Hourly temperature (°C) in all 12 months

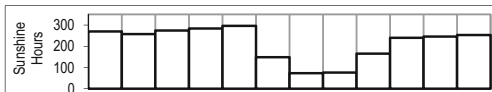
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	23.4	24.3	25.4	27.1	26.8	24.9	24.5	24.3	24.6	24.5	24.3	23.3	0	0	0	0
1:01- 2:00	22.6	23.6	24.9	26.7	26.3	24.8	24.4	24.1	24.4	24.2	23.9	22.6	0	0	0	0
2:01- 3:00	22.2	23.2	24.5	26.3	25.9	24.6	24.3	24.0	24.3	23.8	23.7	22.2	0	0	0	0
3:01- 4:00	21.6	22.5	24.1	26.0	25.6	24.5	24.2	23.9	24.2	23.6	23.4	21.8	0	0	0	0
4:01- 5:00	21.5	22.2	24.1	26.0	25.7	24.4	24.2	23.9	24.2	23.6	23.3	21.9	0	0	0	0
5:01- 6:00	21.3	21.9	24.4	26.4	26.3	24.5	24.3	24.0	24.5	24.1	23.5	22.3	2	4	0	0
6:01- 7:00	22.1	22.7	25.4	27.2	27.5	24.9	24.6	24.3	24.9	24.9	24.4	23.4	49	68	6	12
7:01- 8:00	23.4	24.1	26.8	28.5	28.9	25.4	25.0	24.8	25.5	26.0	25.6	24.9	202	135	79	82
8:01- 9:00	25.7	26.6	28.7	29.9	30.5	26.3	25.7	25.5	26.3	27.3	27.3	27.0	379	184	222	147
9:01-10:00	28.1	29.1	30.5	31.2	32.0	27.1	26.2	26.1	27.2	28.5	29.0	29.1	552	205	367	192
10:01-11:00	30.5	31.4	32.1	32.3	33.1	27.8	26.7	26.7	28.0	29.5	30.6	31.1	685	212	481	221
11:01-12:00	31.9	32.4	32.8	33.0	33.8	28.3	27.0	27.0	28.6	30.3	31.6	32.3	750	216	549	234
12:01-13:00	32.7	32.8	33.0	33.2	34.0	28.5	27.1	27.2	29.0	30.6	32.0	32.9	750	213	561	234
13:01-14:00	32.4	32.1	32.6	33.0	33.9	28.3	27.0	27.1	29.0	30.4	31.7	32.6	679	207	505	231
14:01-15:00	31.9	31.6	32.0	32.5	33.3	28.1	26.8	26.9	28.6	29.9	31.1	31.9	539	202	407	204
15:01-16:00	30.7	30.6	31.0	31.7	32.4	27.6	26.5	26.5	28.0	29.1	30.0	30.6	360	182	271	163
16:01-17:00	29.5	29.9	30.1	30.8	31.3	27.2	26.2	26.2	27.3	28.1	28.9	29.3	181	134	124	103
17:01-18:00	28.0	28.6	28.9	29.8	30.1	26.7	25.8	25.7	26.5	27.2	27.7	27.9	41	59	16	31
18:01-19:00	26.8	27.6	27.9	29.0	29.0	26.3	25.5	25.3	25.9	26.4	26.8	26.7	1	1	0	0
19:01-20:00	25.7	26.4	26.9	28.3	28.1	25.8	25.2	24.9	25.5	25.8	26.0	25.8	0	0	0	0
20:01-21:00	25.2	25.9	26.5	27.9	27.5	25.5	25.0	24.7	25.1	25.4	25.5	25.2	0	0	0	0
21:01-22:00	24.6	25.3	26.1	27.6	27.3	25.3	24.8	24.5	24.9	25.1	25.1	24.7	0	0	0	0
22:01-23:00	24.4	25.2	26.0	27.5	27.1	25.1	24.8	24.5	24.8	25.0	24.9	24.4	0	0	0	0
23:01-24:00	23.8	24.6	25.7	27.3	27.0	25.0	24.7	24.4	24.7	24.8	24.5	23.8	0	0	0	0
Legend	Underheated			<23.7°C	Comfortable								Overheated		>27.0°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.75 Climatic data, Mumbai, Maharashtra

Latitude	N 19° 7'				Longitude	E 72° 50'				Altitude	14 m		
Climate	Warm and humid				Köppen	Bsh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	269.5	257.6	274.3	283.7	296.2	148.6	73.4	75.9	165.1	240.2	245.8	253.2	215.3
Cloud (%)	10.6	10.0	10.8	17.7	35.1	70.9	83.8	82.6	71.3	40.2	13.2	11.0	38.08
Solar irradiation daily average (Wh/m²)													
Global	5110	5944	6575	7033	7066	5122	4259	4251	4827	5314	5256	4970	5477
Diffuse	1442	1574	1913	2139	2364	3084	3320	3293	2868	2097	1503	1315	2243
Relative Humidity (%)													
morning	82	77	83	84	80	86	87	90	91	85	84	76	83.8
evening	33	37	48	56	59	74	80	77	75	54	36	35	55.3
Dry Bulb Temperature (°C)													
max	30.1	31.1	31.1	31.7	32.6	30.7	29.3	29.1	29.4	32.4	32.6	32.0	31.0
min	19.6	20.0	21.9	25.4	28.1	27.6	27.3	26.7	25.7	24.4	21.7	18.8	23.9
mean	24.9	25.6	26.5	28.6	30.4	29.2	28.3	27.9	27.6	28.4	27.2	25.4	27.5
Neutrality	25.5	25.7	26.0	26.7	27.2	26.8	26.6	26.4	26.3	26.6	26.2	25.7	26.3
Upper limit	28.0	28.2	28.5	29.2	29.7	29.3	29.1	28.9	28.8	29.1	28.7	28.2	28.8
Lower limit	23.0	23.2	23.5	24.2	24.7	24.3	24.1	23.9	23.8	24.1	23.7	23.2	23.8
Rain (mm)^b	15.1	1.0	0.1	0.5	20.6	504.2	819.4	546.8	325.2	81.1	113.2	4.1	2431
Wind (m/s)	0.46	0.58	0.82	0.61	0.76	0.84	1.33	1.09	0.69	0.57	0.6	0.6	0.7
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	195	197	269	317	381	329	318	301	278	316	252	202	3355



Average diurnal range (°K)	7.1
Annual mean range (°K)	13.8

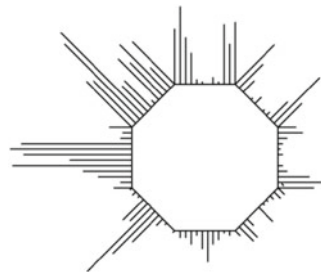
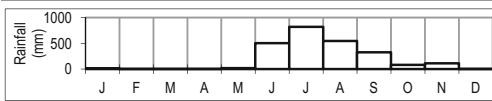
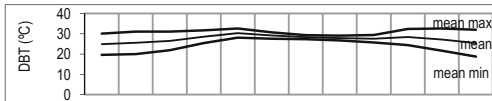
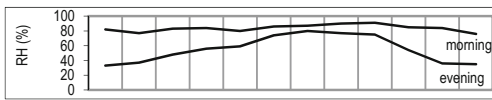
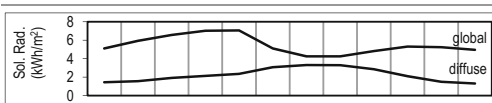


Table 5.76 Design conditions and overheated–underheated periods, Mumbai

Recommended “Design” conditions														
Summer	DBT (°C)		34.3											
	MCWB (°C)		23.3											
	WBT (°C)		27.5											
	MCDB (°C)		31.3											
Winter	DBT (°C)		17.8											

Hourly temperature (°C) in all 12 months

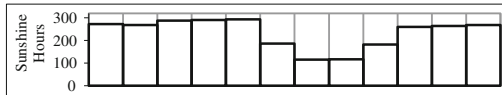
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	21.4	21.3	24.2	26.9	28.9	27.9	27.8	27.0	26.3	25.6	22.9	20.1	0	0	0	0
1:01- 2:00	20.9	20.9	23.9	26.6	28.8	27.9	27.7	27.0	26.1	25.4	22.5	19.7	0	0	0	0
2:01- 3:00	20.3	20.8	23.5	26.2	28.7	27.8	27.7	26.9	26.1	25.0	22.3	19.1	0	0	0	0
3:01- 4:00	20.0	20.7	23.1	25.9	28.5	27.7	27.6	26.8	25.8	24.9	21.9	18.9	0	0	0	0
4:01- 5:00	19.8	20.7	22.7	25.7	28.2	27.7	27.5	26.7	25.7	24.7	21.9	18.9	0	0	0	0
5:01- 6:00	19.6	20.2	22.3	25.4	28.1	27.6	27.5	26.7	25.7	24.5	21.7	18.8	0	0	0	0
6:01- 7:00	19.6	20.0	21.9	25.4	28.3	27.7	27.3	26.8	25.7	24.4	21.8	18.9	6	26	0	0
7:01- 8:00	19.8	20.6	22.8	26.3	29.6	28.3	27.5	27.2	26.1	25.2	23.7	19.8	82	119	17	15
8:01- 9:00	21.9	23.8	25.7	28.5	30.6	29.1	28.1	27.6	27.2	27.6	26.1	23.3	236	183	111	89
9:01-10:00	25.2	27.1	28.7	30.1	31.6	29.7	28.4	28.1	27.9	29.8	28.6	26.2	407	219	262	139
10:01-11:00	27.6	29.3	30.5	31.2	32.1	30.0	28.9	28.5	28.6	31.3	30.4	28.8	553	240	409	169
11:01-12:00	29.1	31.0	31.1	31.7	32.5	30.2	29.1	28.9	29.3	32.1	32.0	30.8	658	245	526	181
12:01-13:00	30.0	31.1	31.1	31.7	32.6	30.4	29.1	28.9	29.3	32.3	32.6	31.9	700	245	584	183
13:01-14:00	30.1	30.6	31.1	31.5	32.6	30.7	29.3	29.0	29.4	32.4	32.3	32.0	673	243	581	177
14:01-15:00	29.7	30.3	31.0	31.4	32.5	30.6	29.3	29.1	29.2	32.1	31.7	31.7	576	242	510	166
15:01-16:00	29.1	29.7	30.7	31.3	32.2	30.4	29.3	28.9	28.9	31.7	31.1	30.8	432	228	382	146
16:01-17:00	28.3	29.0	30.0	30.9	31.9	30.1	29.1	28.5	28.4	31.0	29.9	29.5	264	195	219	113
17:01-18:00	27.0	27.7	29.0	30.2	31.2	29.7	28.8	28.2	27.9	29.9	28.1	27.4	106	134	64	61
18:01-19:00	25.8	26.4	27.8	29.3	30.4	29.2	28.4	27.6	27.3	29.1	27.3	26.2	11	43	3	2
19:01-20:00	25.2	25.7	27.2	28.7	30.0	28.8	28.2	27.5	27.0	28.7	26.8	25.6	0	0	0	0
20:01-21:00	24.4	25.0	26.5	28.2	29.7	28.5	28.0	27.3	26.8	28.2	26.1	24.7	0	0	0	0
21:01-22:00	23.5	24.0	25.8	28.0	29.6	28.4	27.9	27.3	26.7	27.4	24.9	23.2	0	0	0	0
22:01-23:00	22.6	22.9	25.1	27.7	29.4	28.2	27.9	27.2	26.5	26.7	23.7	21.7	0	0	0	0
23:01-24:00	21.7	22.1	24.7	27.2	29.0	28.1	27.8	27.1	26.2	26.1	23.4	20.5	0	0	0	0
Legend	Underheated		<23.0°C		Comfortable								Overheated		>27.2°C	

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.77 Climatic data, Nagpur, Maharashtra

Latitude	N 21° 6'					Longitude	E 79° 3'					Altitude	310 m	
Climate	Composite					Köppen	BWh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	272.0	268.3	287.6	290.8	293.8	186.6	115.4	116.7	182.5	260.4	264.1	268.8	233.9	
Cloud (%)	24.3	18.2	19.9	30.5	31.8	62.6	79.9	84.0	65.2	37.5	18.6	9.5	40.15	
Solar irradiation daily average (Wh/m²)														
Global	4624	5805	6534	6938	7363	5906	4770	4165	5724	5387	5009	4886	5593	
Diffuse	1533	1481	1807	2134	2156	3002	3214	3358	2454	1971	1503	1166	2148	
Relative Humidity (%)														
morning	84	68	55	57	44	70	88	92	89	85	84	81	74.8	
evening	37	27	26	21	22	45	70	76	62	49	40	30	42.1	
Dry Bulb Temperature (°C)														
max	27.6	29.6	33.3	37.4	41.3	36.6	30.0	28.6	31.0	30.6	28.7	26.9	31.8	
min	16.0	17.2	19.8	25.0	29.3	28.3	25.4	24.4	24.6	22.0	17.4	13.3	21.9	
mean	21.8	23.4	26.6	31.2	35.3	32.5	27.7	26.5	27.8	26.3	23.1	20.1	21.2	
Neutrality	24.6	25.1	26.0	27.5	28.7	27.9	26.4	26.0	26.4	26.0	24.9	24.0	24.4	
Upper limit	27.1	27.6	28.5	30.0	31.2	30.4	28.9	28.5	28.9	28.5	27.4	26.5	26.9	
Lower limit	22.1	22.6	23.5	25.0	26.2	25.4	23.9	23.5	23.9	23.5	22.4	21.5	21.9	
Rain (mm) ^b	12.5	20.7	17.6	14.3	19.2	190.1	341.7	280.5	183.1	56.8	16.6	13.2	1166	
Wind (m/s)	1.44	1.62	2.18	1.8	1.97	2.8	2.57	2.54	2.13	1.48	1.19	0.91	1.6	
HDD	2	0	0	0	0	0	0	0	0	0	0	2	4.0	
CDD	98	142	265	396	541	420	295	250	282	243	132	48	3112	



Average diurnal range (°K)	9.9
Annual mean range (°K)	28.0

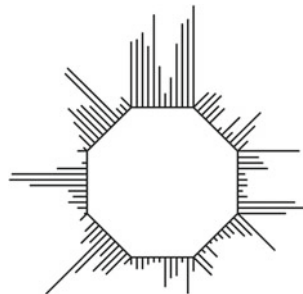
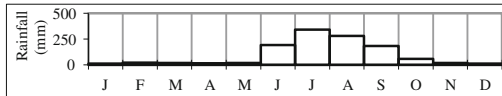
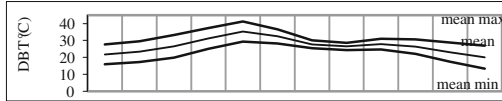
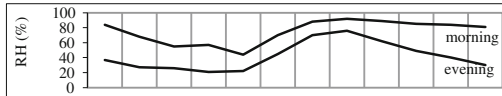
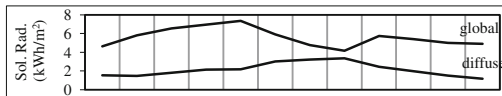


Table 5.78 Design conditions and overheated–underheated periods, Nagpur

Recommended “Design” conditions															
Summer	DBT (°C)		42.6												
	MCWB (°C)		23.9												
	WBT (°C)		26.6												
	MCDB (°C)		33.2												
Winter	DBT (°C)		12.8												

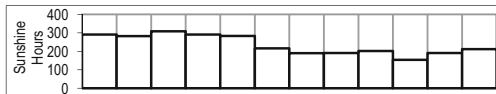
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec		
													H _b	H _d	H _b	H _d	
0:01- 1:00	17.9	19.4	22.6	27.2	31.7	29.5	26.0	24.8	25.3	23.2	19.3	15.8	0	0	0	0	
1:01- 2:00	17.6	19.0	22.2	26.7	31.3	29.1	25.8	24.7	25.1	22.9	18.9	15.2	0	0	0	0	
2:01- 3:00	17.3	18.6	21.6	26.4	30.8	28.8	25.7	24.6	25.0	22.7	18.5	14.7	0	0	0	0	
3:01- 4:00	16.9	18.3	20.9	26.0	30.2	28.6	25.5	24.5	24.9	22.5	18.3	14.3	0	0	0	0	
4:01- 5:00	16.6	18.1	20.4	25.4	29.7	28.4	25.5	24.4	24.7	22.3	17.9	14.0	0	0	0	0	
5:01- 6:00	16.3	17.7	19.9	25.0	29.3	28.3	25.4	24.4	24.6	22.0	17.6	13.6	1	4	0	0	
6:01- 7:00	16.0	17.2	19.8	25.5	30.2	29.0	25.6	24.5	24.7	22.0	17.4	13.3	30	69	2	0	
7:01- 8:00	16.6	18.8	22.5	28.4	33.0	30.3	26.2	25.0	26.0	23.6	19.3	14.8	150	151	54	54	
8:01- 9:00	19.6	22.0	26.0	30.9	35.4	31.8	27.3	26.0	27.7	26.1	22.6	19.1	328	195	209	101	
9:01-10:00	22.3	24.6	28.4	32.9	37.1	33.3	28.1	26.6	28.9	27.8	24.9	22.2	510	213	379	126	
10:01-11:00	24.3	26.3	30.2	34.5	38.7	34.4	28.8	27.2	29.9	29.2	26.6	24.2	668	211	519	137	
11:01-12:00	25.9	27.9	31.3	35.9	39.8	35.4	29.2	28.0	30.6	30.1	27.8	25.7	772	201	607	138	
12:01-13:00	27.0	28.8	32.4	36.8	40.7	35.8	29.7	28.4	31.0	30.5	28.4	26.6	780	204	619	138	
13:01-14:00	27.4	29.3	33.0	37.3	41.3	36.2	30.0	28.5	31.0	30.6	28.7	26.9	730	200	554	138	
14:01-15:00	27.6	29.6	33.2	37.4	41.1	36.6	30.0	28.6	30.6	30.4	28.5	26.9	576	212	428	131	
15:01-16:00	27.2	29.5	33.3	37.4	41.1	36.2	30.0	28.2	30.2	29.9	27.9	26.4	390	207	257	114	
16:01-17:00	26.0	29.0	32.5	36.9	40.7	35.4	29.5	27.5	29.9	29.1	26.7	24.9	204	172	88	74	
17:01-18:00	23.8	27.1	31.2	36.1	39.0	34.4	29.0	27.1	28.9	27.5	24.0	21.8	61	100	7	13	
18:01-19:00	22.1	24.7	28.9	33.1	37.6	33.1	28.2	26.4	27.7	26.1	22.6	20.0	8	15	0	0	
19:01-20:00	21.0	23.4	27.3	31.5	36.2	32.2	27.7	25.6	27.0	25.4	21.5	18.8	0	0	0	0	
20:01-21:00	20.0	22.4	26.1	30.6	35.1	31.6	27.3	25.4	26.5	24.7	20.8	17.9	0	0	0	0	
21:01-22:00	19.4	21.5	25.3	29.7	34.3	30.6	27.0	25.2	26.1	24.3	20.1	17.3	0	0	0	0	
22:01-23:00	19.0	20.8	24.4	28.9	33.6	29.8	26.6	25.0	25.7	23.9	19.7	16.8	0	0	0	0	
23:01-24:00	18.5	20.1	23.6	27.9	32.7	29.6	26.2	24.8	25.4	23.5	19.3	16.3	0	0	0	0	
Legend	Underheated		<21.5°C	Comfortable								Overheated		>28.7°C			

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.79 Climatic data, Nellore, Andhra Pradesh

Latitude	N 14° 26'				Longitude				E 79° 58'				Altitude	20 m
Climate	Warm and humid				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	291.1	282.5	308.3	290.9	283.9	215.9	190.2	191.2	202.0	153.8	191.2	212.0	234.4	
Cloud (%)	18.5	11.4	11.6	24.0	26.2	48.6	62.6	64.3	56.6	58.3	45.1	46.9	39.51	
Solar irradiation daily average (Wh/m²)														
Global	5598	6393	6926	7172	7025	6225	5816	5809	5835	4738	4744	4599	5907	
Diffuse	1597	1611	1860	2065	2189	2719	2810	2784	2608	2509	2078	1943	2231	
Relative Humidity (%)														
morning	85	87	90	85	79	69	82	82	82	91	90	88	84.2	
evening	56	52	45	43	39	46	52	57	51	74	72	68	54.6	
Dry Bulb Temperature (°C)														
max	29.7	32.0	34.1	36.9	38.6	36.8	33.5	33.1	33.9	30.1	28.2	26.8	32.8	
min	20.4	22.6	24.8	27.4	28.4	29.3	27.7	27.3	27.3	25.6	24.7	23.0	25.7	
mean	25.1	27.3	29.5	32.2	33.5	33.1	30.6	30.2	30.6	27.9	26.5	24.9	29.3	
Neutrality	25.6	26.3	26.9	27.8	28.2	28.0	27.3	27.2	27.3	26.4	26.0	25.5	26.9	
Upper limit	28.1	28.8	29.4	30.3	30.7	30.5	29.8	29.7	29.8	28.9	28.5	28.0	29.4	
Lower limit	23.1	23.8	24.4	25.3	25.7	25.5	24.8	24.7	24.8	23.9	23.5	23.0	24.4	
Rain (mm) ^b	32.0	6.9	6.9	9.7	36.6	36.6	70.6	75.9	110.2	266.2	317.5	88.1	1057	
Wind (m/s)	1.26	1.60	1.62	1.65	1.91	2.20	1.83	1.99	1.75	1.42	1.05	1.43	1.6	
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	
CDD	205	245	327	393	452	433	383	369	360	297	250	212	3926	



Average diurnal range (°K)	7.1
Annual mean range (°K)	18.2

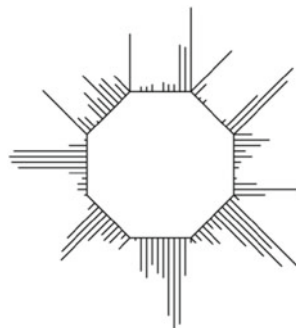
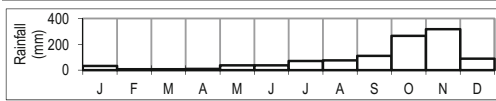
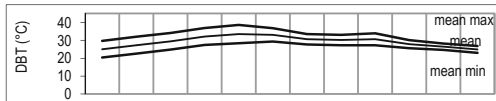
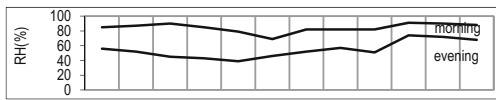
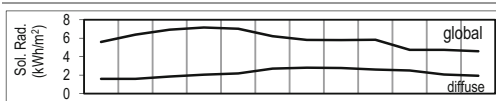


Table 5.80 Design conditions and overheated–underheated periods, Nellore

Recommended “Design” conditions														
Summer	DBT (°C)		39.0											
	MCWB (°C)		28.1											
	WBT (°C)		29.4											
	MCDB (°C)		35.4											
Winter	DBT (°C)		20.2											

Hourly temperature (°C) in all 12 months

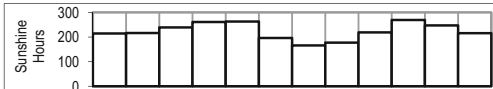
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	22.3	24.3	26.0	28.4	30.0	30.0	28.9	28.6	28.2	26.4	25.2	23.8	0	0	0	0
1:01- 2:00	21.9	24.0	25.7	28.2	29.8	30.2	28.7	28.4	28.0	26.3	25.1	23.6	0	0	0	0
2:01- 3:00	21.5	23.6	25.4	28.0	29.6	30.0	28.4	28.1	27.8	26.1	25.0	23.5	0	0	0	0
3:01- 4:00	21.1	23.3	25.2	27.8	28.9	29.7	28.2	27.8	27.7	25.9	25.0	23.4	0	0	0	0
4:01- 5:00	20.9	23.1	25.1	27.7	28.7	29.5	28.0	27.6	27.5	25.8	24.9	23.3	0	0	0	0
5:01- 6:00	20.5	22.7	24.8	27.4	28.4	29.3	27.7	27.3	27.3	25.6	24.8	23.1	1	1	0	0
6:01- 7:00	20.4	22.6	24.9	27.4	28.6	29.6	27.7	27.3	27.3	25.7	24.7	23.0	27	60	4	11
7:01- 8:00	20.7	23.1	25.9	28.6	30.4	30.8	28.4	28.0	28.0	26.4	25.0	23.2	166	136	57	77
8:01- 9:00	22.9	25.5	27.8	31.4	32.5	32.6	29.7	29.3	29.3	27.6	25.8	23.8	341	183	166	150
9:01-10:00	25.6	27.6	29.7	33.3	34.3	33.6	30.3	30.0	30.3	28.5	26.5	24.8	516	207	277	206
10:01-11:00	27.5	29.6	31.5	35.0	35.9	35.0	31.2	31.0	31.4	29.4	27.2	25.8	643	221	367	242
11:01-12:00	28.8	31.0	33.0	36.3	37.9	36.0	32.3	31.9	32.5	30.0	28.0	26.5	710	229	418	260
12:01-13:00	29.3	31.7	33.9	36.9	38.6	36.5	32.8	32.5	32.9	30.1	28.1	26.7	742	219	418	266
13:01-14:00	29.7	32.0	34.1	36.7	38.6	36.8	33.3	32.9	33.4	30.1	28.2	26.8	644	233	374	252
14:01-15:00	29.7	32.0	33.6	35.9	38.2	36.1	33.5	33.1	33.9	29.6	28.1	26.8	496	235	295	216
15:01-16:00	29.2	31.6	32.5	34.8	36.8	35.8	33.4	33.0	33.5	29.2	27.9	26.8	331	214	192	158
16:01-17:00	28.2	30.6	31.2	33.2	35.5	34.8	33.1	32.4	32.8	28.6	27.6	26.5	172	162	80	88
17:01-18:00	26.5	28.7	29.6	31.7	33.8	33.5	32.5	31.6	31.8	27.9	27.1	25.9	43	81	10	15
18:01-19:00	25.4	27.3	28.7	30.7	32.0	32.7	31.6	30.7	30.8	27.6	26.8	25.6	2	9	0	0
19:01-20:00	24.8	26.6	28.1	30.1	31.3	31.9	30.7	29.9	30.1	27.5	26.6	25.3	0	0	0	0
20:01-21:00	24.2	25.9	27.7	29.7	31.0	31.4	30.1	29.5	29.4	27.3	26.4	25.0	0	0	0	0
21:01-22:00	23.8	25.7	27.4	29.5	30.7	31.1	29.6	29.2	29.1	27.1	26.3	24.8	0	0	0	0
22:01-23:00	23.3	25.3	27.1	29.2	30.5	30.9	29.3	28.9	28.9	26.9	26.0	24.5	0	0	0	0
23:01-24:00	22.7	24.7	26.3	28.6	30.3	30.5	29.0	28.6	28.3	26.5	25.3	23.8	0	0	0	0
Legend	Underheated			<23.0°C	Comfortable							Overheated		>28.2°C		

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.81 Climatic data, New Delhi

Latitude	N 28° 34'				Longitude	E 77°11'				Altitude	216 m		
Climate	Composite				Köppen	Bwh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	214.6	216.1	239.1	261	263.1	196.5	165.9	177	219	269.3	247.2	215.8	223.7
Cloud (%)	12.5	29.0	20.0	17.6	20.4	47.6	56.1	61.3	42.2	11.8	1.5	19.4	28.28
Solar irradiation daily average (Wh/m²)													
Global	3533	4644	6101	6831	7049	6408	5455	5256	5235	4889	4014	3345	5230
Diffuse	1453	1527	1666	2067	2290	2560	2739	2772	2111	1701	1419	1280	1965
Relative Humidity (%)													
morning	89	93	85	55	52	66	88	81	87	82	84	90	79.3
evening	52	33	28	20	29	41	62	67	61	37	35	43	42.3
Dry Bulb Temperature (°C)													
max	18.8	22.5	28.8	37.0	39.1	36.3	32.6	33.1	32.6	33.3	28.1	21.5	30.3
min	8.5	12.5	16.0	23.1	27.9	28.8	27.9	27.8	26.5	20.9	14	10.2	20.3
mean	13.7	17.5	22.4	30.1	33.5	32.6	30.3	30.5	29.6	27.1	21.1	15.9	25.3
Neutrality	22.0	23.2	24.7	27.1	28.2	27.9	27.2	27.2	27.0	26.2	24.3	22.7	25.7
Upper limit	24.5	25.7	27.2	29.6	30.7	30.4	29.7	29.7	29.5	28.7	26.8	25.2	28.2
Lower limit	19.5	20.7	22.2	24.6	25.7	25.4	24.7	24.7	24.5	23.7	21.8	20.2	23.2
Rain (mm) ^b	18.9	16.6	10.8	30.4	29.0	54.3	216.8	247.6	133.8	15.4	6.6	15.2	795.4
Wind (m/s)	0.45	0.53	0.65	0.55	0.76	0.61	0.63	0.57	0.45	0.17	0.25	0.25	0.5
HDD	166	43	1	0	0	0	0	0	0	0	7	101	318
CDD	0	11	131	354	467	426	375	376	339	252	62	0	2793



Average diurnal range (°K)	10.0
Annual mean range (°K)	30.6

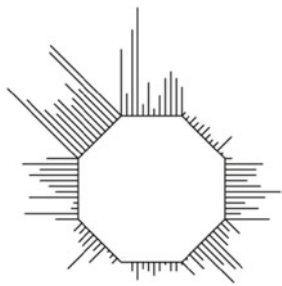
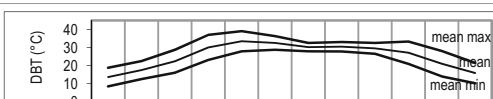
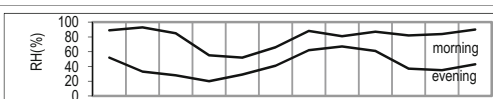
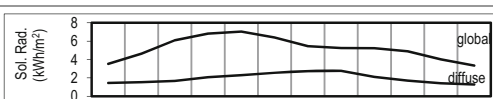


Table 5.82 Design conditions and overheated—underheated periods, New Delhi

Recommended “Design” conditions														
Summer	DBT (°C)		40.6											
	MCWB (°C)		23.8											
	WBT (°C)		28.0											
	MCDB (°C)		33.3											
Winter	DBT (°C)		7.1											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
Hours													H _b	H _d	H _b	H _d
0:01- 1:00	9.8	13.9	18.8	25.6	29.8	30.2	28.7	28.7	27.6	22.5	15.7	11.7	0	0	0	0
1:01- 2:00	9.5	13.5	18.3	25.1	29.5	29.7	28.5	28.5	27.4	22.2	15.3	11.3	0	0	0	0
2:01- 3:00	9.2	13.2	17.8	24.6	29.0	29.5	28.4	28.3	27.2	21.9	14.9	10.9	0	0	0	0
3:01- 4:00	9.0	13.0	17.3	24.2	28.7	29.3	28.2	28.1	26.9	21.6	14.7	10.7	0	0	0	0
4:01- 5:00	8.9	12.8	16.8	23.7	28.3	29.0	28.1	28.0	26.8	21.4	14.5	10.5	0	0	0	0
5:01- 6:00	8.7	12.6	16.3	23.3	27.9	28.8	27.9	27.8	26.7	21.1	14.2	10.2	0	2	0	0
6:01- 7:00	8.5	12.5	16.0	23.1	28.3	29.0	27.9	27.8	26.5	20.9	14.0	10.2	14	63	0	0
7:01- 8:00	8.5	12.5	16.9	24.8	29.9	29.8	28.6	28.3	26.6	21.7	14.5	10.2	126	149	10	12
8:01- 9:00	9.7	14.0	19.7	28.8	32.3	31.1	29.4	29.7	28.1	25.1	18.4	11.9	295	194	67	89
9:01-10:00	11.9	16.3	22.8	31.4	34.3	32.3	30.2	30.7	29.5	28.0	22.1	14.9	454	222	185	140
10:01-11:00	14.1	18.7	25.1	33.4	36.1	33.4	31.1	31.8	30.5	30.1	25.0	17.6	590	231	277	176
11:01-12:00	16.0	20.4	26.6	34.8	37.5	34.7	31.8	32.6	31.4	31.7	26.8	19.5	693	226	328	202
12:01-13:00	17.6	21.5	27.9	35.8	38.1	35.6	32.4	33.1	32.1	32.6	27.6	20.6	703	231	350	209
13:01-14:00	18.4	22.2	28.5	36.6	38.8	36.1	32.6	32.9	32.3	33.2	28.1	21.3	678	216	338	200
14:01-15:00	18.8	22.5	28.8	37.0	39.1	36.3	32.6	32.9	32.6	33.3	28.1	21.5	548	219	276	178
15:01-16:00	18.7	22.5	28.7	36.9	38.8	36.2	32.5	32.4	32.6	33.1	27.7	21.4	381	219	173	143
16:01-17:00	18.1	22.3	28.3	36.3	37.8	35.7	32.2	31.9	32.5	31.7	25.7	20.3	210	177	65	89
17:01-18:00	16.5	21.3	26.8	35.1	37.3	34.9	32.0	31.6	31.9	29.0	22.2	18.0	65	117	8	16
18:01-19:00	14.3	19.4	24.8	32.9	35.4	34.0	31.3	30.9	30.9	26.7	20.0	15.5	2	24	0	0
19:01-20:00	12.9	17.5	23.5	30.8	33.3	32.8	30.5	30.3	29.9	25.3	18.7	14.6	0	0	0	0
20:01-21:00	12.0	16.5	22.2	29.2	31.9	31.8	29.9	29.8	29.1	24.4	17.8	13.7	0	0	0	0
21:01-22:00	11.4	15.8	21.2	28.0	31.0	31.2	29.5	29.5	28.6	23.7	17.1	12.9	0	0	0	0
22:01-23:00	10.7	15.1	20.3	27.0	30.6	30.8	29.1	29.1	28.0	23.3	16.5	12.3	0	0	0	0
23:01-24:00	10.1	14.4	19.7	26.5	30.2	30.4	28.8	28.9	27.6	22.8	16.0	11.8	0	0	0	0
Legend	Underheated			<19.5°C	Comfortable								Overheated		>28.2°C	

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.83 Climatic data, Panjim, Goa

Latitude	N 15° 28'				Longitude	E 73° 49'				Altitude	60 m		
Climate	Warm and humid				Köppen	Aw							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	311.8	290.2	291	289	296.5	125.1	105.7	122.1	177.1	247.7	272.6	299.3	235.7
Cloud (%)	32.8	11.5	27.0	44.5	64.0	89.3	91.5	86.3	78.6	68.8	49.1	26.7	55.84

Solar irradiation daily average (Wh/m²)

Global	5607	6593	7296	7288	6819	4898	4802	5113	5759	5532	5628	5589	5910
Diffuse	1481	1379	1523	1949	2407	3423	3414	3316	2796	2303	1617	1269	2240

Relative Humidity (%)

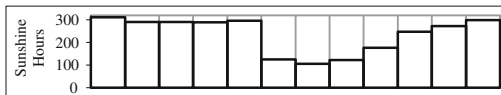
morning	91	89	91	84	84	91	92	94	94	92	91	84	89.8
evening	41	49	57	63	66	80	87	86	75	69	45	41	63.3

Dry Bulb Temperature (°C)

max	31.9	30.9	31.9	32.4	32.2	29.7	27.8	28.0	29.4	30.7	33.2	32.5	30.9
min	20.8	21.8	23.7	26.2	26.4	25.8	25.3	25.2	24.9	25.0	23.0	20.9	24.1
mean	26.4	26.4	27.8	29.3	29.3	27.8	26.6	26.6	27.2	27.9	28.1	26.7	27.5
Neutrality	26.0	26.0	26.4	26.9	26.9	26.4	26.0	26.0	26.2	26.4	26.5	26.1	26.3
Upper limit	28.5	28.5	28.9	29.4	29.4	28.9	28.5	28.5	28.7	28.9	29.0	28.6	28.8
Lower limit	23.5	23.5	23.9	24.4	24.4	23.9	23.5	23.5	23.7	23.9	24.0	23.6	23.8

Rain (mm)^b	0.9	0.1	0.4	10.2	66.7	874	949.5	515.9	231	102.6	30.2	8.8	2790
Wind (m/s)	1.7	1.87	1.82	1.99	2.56	3.06	3.59	2.77	1.91	1.87	1.73	1.51	2.2

HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	240	225	300	340	347	289	262	258	263	290	283	248	3345



Average diurnal range (°K)	6.8
Annual mean range (°K)	12.4

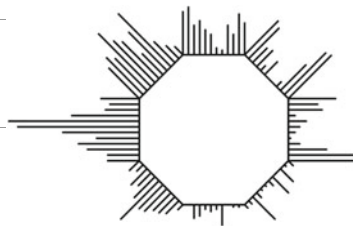
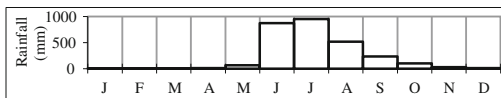
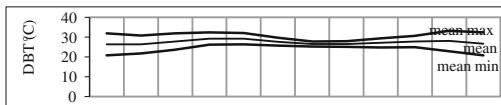
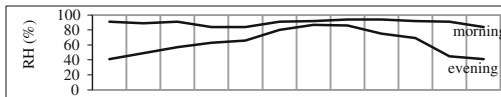
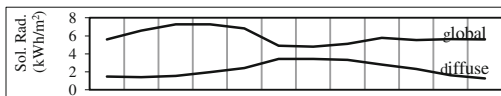


Table 5.84 Design conditions and overheated–underheated periods, Panjim

Recommended “Design” conditions														
Summer	DBT (°C)		33.5											
	MCWB (°C)		25.2											
	WBT (°C)		27.4											
	MCDB (°C)		31.5											
Winter	DBT (°C)		20.3											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Jan	
Hours													H _b	H _d	H _b	H _d
0:01- 1:00	23.4	23.7	25.8	28.0	27.9	26.6	25.6	25.5	25.4	25.7	24.9	23.4	0	0	0	0
1:01- 2:00	22.9	23.3	25.4	27.7	27.6	26.7	25.6	25.4	25.3	25.5	24.5	22.6	0	0	0	0
2:01- 3:00	22.3	22.8	25.0	27.3	27.2	26.6	25.6	25.4	25.2	25.3	24.0	22.2	0	0	0	0
3:01- 4:00	22.0	22.5	24.7	27.0	27.0	26.5	25.6	25.3	25.1	25.3	23.7	21.7	0	0	0	0
4:01- 5:00	21.7	22.3	24.3	26.7	26.8	26.1	25.5	25.2	25.0	25.1	23.5	21.5	0	0	0	0
5:01- 6:00	21.3	22.0	24.0	26.4	26.5	25.8	25.3	25.2	24.9	25.0	23.2	21.1	0	0	0	0
6:01- 7:00	21.0	21.8	23.7	26.2	26.4	26.0	25.4	25.2	24.9	25.0	23.0	20.9	7	9	0	0
7:01- 8:00	20.8	22.0	24.0	26.7	27.2	26.4	25.5	25.4	25.0	25.5	23.2	21.2	78	99	22	31
8:01- 9:00	22.4	24.9	26.1	28.8	29.1	27.7	26.3	26.3	26.4	27.3	25.5	23.4	258	160	145	100
9:01-10:00	25.0	26.8	28.8	30.6	30.1	28.1	26.6	26.6	27.3	28.1	27.9	26.3	460	190	284	157
10:01-11:00	27.8	29.3	31.0	31.6	31.2	28.9	27.2	27.1	28.2	29.5	30.4	29.1	637	201	449	180
11:01-12:00	30.5	30.7	31.7	32.2	31.9	29.4	27.7	27.9	29.1	30.5	32.2	31.3	759	202	594	178
12:01-13:00	31.6	30.9	31.9	32.4	32.0	29.7	27.6	28.0	29.3	30.7	33.2	32.4	808	200	634	188
13:01-14:00	31.9	30.9	31.9	32.2	32.1	29.6	27.7	27.8	29.4	30.6	33.2	32.5	774	200	679	159
14:01-15:00	31.0	30.9	31.5	32.2	32.2	29.7	27.8	27.8	29.4	30.3	32.7	31.2	663	200	599	148
15:01-16:00	30.4	30.2	31.1	31.9	31.7	29.4	27.6	27.7	29.0	29.6	32.3	31.1	491	193	432	143
16:01-17:00	29.8	29.2	30.4	31.3	31.2	28.9	27.3	27.4	28.4	28.9	31.1	29.8	292	166	229	123
17:01-18:00	28.2	28.0	29.3	30.5	30.2	28.4	27.2	26.8	27.6	28.1	29.4	28.1	105	110	55	70
18:01-19:00	27.3	26.8	28.4	29.9	29.7	28.1	26.6	26.5	27.1	27.5	28.4	27.5	10	18	3	4
19:01-20:00	26.6	26.2	27.8	29.5	29.2	27.6	26.4	26.2	26.7	27.1	27.7	26.8	0	0	0	0
20:01-21:00	25.9	25.8	27.4	29.2	28.9	27.1	26.2	25.9	26.3	26.7	27.0	26.1	0	0	0	0
21:01-22:00	25.3	25.3	27.1	29.0	28.5	27.1	26.2	25.8	26.1	26.5	26.5	25.4	0	0	0	0
22:01-23:00	24.7	24.6	26.7	28.7	28.2	26.7	26.0	25.8	25.9	26.3	25.8	24.7	0	0	0	0
23:01-24:00	23.9	24.1	26.2	28.3	27.9	26.5	25.8	25.6	25.6	26.0	25.4	24.0	0	0	0	0
Legend	Underheated			<23.5°C	Comfortable							Overheated		>26.9°C		

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.85 Climatic data, Patna, Bihar

Latitude	N 25° 36'				Longitude				E 85° 5'				Altitude	60 m
Climate	Composite				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	194.9	258.2	275.3	267.8	284.2	223.9	139.5	156.9	133.2	331.3	248.6	198.0	226	
Cloud (%)	46.0	43.9	44.8	43.5	45.4	44.1	45.3	45.2	42.8	44.8	44.0	45.5	44.61	

Solar irradiation daily average (Wh/m²)

Global	3323	4766	6131	6767	6516	5787	4966	5033	5053	4851	4183	3490	5072
Diffuse	1874	1829	1857	2159	2718	3136	3405	3228	2715	2022	1572	1544	2338

Relative Humidity (%)

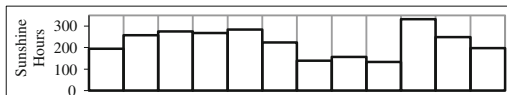
morning	94	83	79	68	80	84	95	94	95	95	93	94	87.8
evening	56	35	31	32	37	52	80	75	74	66	47	44	52.4

Dry Bulb Temperature (°C)

max	22.0	26.4	32.5	36.5	36.9	35.7	30.9	31.1	31.1	29.3	27.8	25.4	30.5
min	10.9	12.0	17.4	23.1	24.6	27.4	26.9	26.5	26.7	22.8	16.2	9.2	20.3
mean	16.5	19.2	25.0	29.8	30.8	31.6	28.9	28.8	28.9	26.1	22.0	17.3	20.3
Neutrality	22.9	23.8	25.5	27.0	27.3	27.6	26.8	26.7	26.8	25.9	24.6	23.2	24.1
Upper limit	25.4	26.3	28.0	29.5	29.8	30.1	29.3	29.2	29.3	28.4	27.1	25.7	26.6
Lower limit	20.4	21.3	23.0	24.5	24.8	25.1	24.3	24.2	24.3	23.4	22.1	20.7	21.6

Rain (mm)^b	20.4	11.1	11.4	9.0	35.6	141	319.2	279.3	212.6	72.3	8.2	7.4	1128
Wind (m/s)	0.5	1.6	1.2	2.0	2.4	2.8	1.5	2.6	1.9	0.9	0.4	0.5	1.5

HDD	75	6	0	0	0	0	0	0	0	0	2	47	130
CDD	1	26	213	354	405	401	336	347	320	246	98	1	2748



Average diurnal range (°K)	10.2
Annual mean range (°K)	27.7

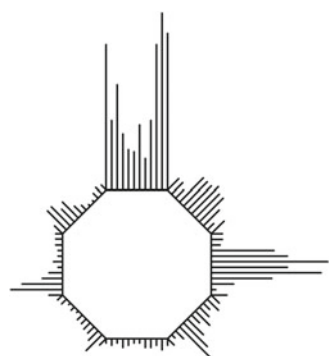
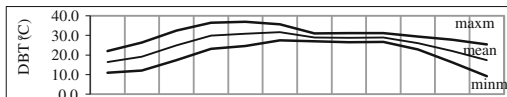
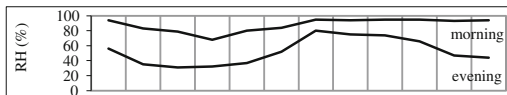
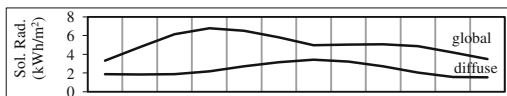


Table 5.86 Design conditions and overheated–underheated periods, Patna

Recommended “Design” conditions														
Summer	DBT (°C)		39.5											
	MCWB (°C)		23.7											
	WBT (°C)		28.6											
	MCDB (°C)		33.1											
Winter	DBT (°C)		9.2											

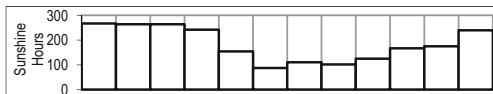
Hourly temperature (°C) in all 12 months
 Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	12.5	14.5	20.3	25.8	28.4	29.2	27.8	28.1	27.4	24.2	18.2	16.5	0	0	0	0
1:01- 2:00	12.1	13.5	19.1	24.9	26.5	28.7	27.6	27.3	27.2	23.9	17.7	12.0	0	0	0	0
2:01- 3:00	11.6	12.8	18.2	23.8	25.4	28.0	27.3	26.8	26.9	23.3	17.0	10.0	0	0	0	0
3:01- 4:00	11.0	12.0	17.4	23.1	24.6	27.6	27.1	26.5	26.7	23.0	16.5	9.2	0	0	0	0
4:01- 5:00	10.9	12.0	17.9	23.3	25.2	27.4	26.9	26.8	26.7	22.8	16.2	11.0	0	2	0	0
5:01- 6:00	11.0	12.4	18.7	24.2	26.1	27.9	27.1	27.4	26.9	23.5	16.9	12.3	5	53	0	0
6:01- 7:00	12.0	14.0	20.7	26.0	27.8	28.8	27.6	28.3	27.5	24.6	18.3	14.4	58	158	5	25
7:01- 8:00	13.5	16.1	23.0	28.2	29.4	30.1	28.3	29.1	28.3	26.0	20.4	15.1	166	226	51	102
8:01- 9:00	15.6	18.9	25.9	30.5	31.4	31.3	28.9	29.9	29.2	27.2	22.6	16.0	250	300	125	175
9:01-10:00	17.7	21.5	28.2	32.4	32.8	32.5	29.6	30.4	30.0	28.3	24.7	15.3	342	330	195	228
10:01-11:00	19.6	23.9	30.2	34.0	34.3	33.5	30.1	30.8	30.6	28.9	26.3	15.1	393	353	236	266
11:01-12:00	21.0	25.3	31.2	35.1	35.2	34.4	30.6	30.9	31.0	29.3	27.5	13.8	403	361	258	271
12:01-13:00	21.8	26.3	32.0	35.9	36.1	35.1	30.8	31.0	31.1	29.3	27.8	13.7	371	356	231	269
13:01-14:00	22.0	26.4	32.3	36.4	36.5	35.6	30.9	31.1	31.1	29.3	27.5	13.5	294	343	187	232
14:01-15:00	21.7	26.4	32.5	36.5	36.9	35.7	30.8	31.1	30.8	28.8	26.5	15.0	210	292	116	179
15:01-16:00	20.7	25.5	31.9	36.1	36.2	35.5	30.6	30.9	30.4	28.3	25.2	16.1	115	220	43	104
16:01-17:00	19.5	24.3	30.9	35.0	35.3	34.7	30.2	30.5	29.9	27.5	23.5	18.1	41	118	5	21
17:01-18:00	17.9	22.2	28.7	33.3	33.4	33.6	29.8	29.8	29.3	26.6	22.0	19.1	1	26	0	0
18:01-19:00	16.2	20.1	26.4	31.4	32.0	32.3	29.2	29.3	28.7	25.7	20.6	21.2	0	0	0	0
19:01-20:00	14.7	18.0	24.1	29.7	30.7	31.2	28.7	28.9	28.2	25.0	19.5	22.7	0	0	0	0
20:01-21:00	13.7	16.8	22.6	28.4	30.7	30.4	28.2	28.9	27.8	24.4	18.8	25.0	0	0	0	0
21:01-22:00	13.0	15.9	21.7	27.6	30.6	29.9	28.0	29.0	27.6	24.2	18.4	25.4	0	0	0	0
22:01-23:00	12.9	15.7	21.6	27.1	30.7	29.6	27.9	29.1	27.5	24.1	18.2	24.7	0	0	0	0
23:01-24:00	12.7	15.1	21.1	26.7	29.7	29.5	27.9	28.8	27.4	24.2	18.2	20.9	0	0	0	0
Legend	Underheated			<20.4°C	Comfortable								Overheated		>27.6°C	

Sources of data: ISHRAE (2014), ^aTyagi (2009 pp 3505-3510), ^bIndia Meteorological Department (nd)

Table 5.87 Climatic data, Port Blair, Adman Nicobar

Latitude	N 11° 40'				Longitude	E 92° 43'				Altitude	79 m		
Climate	Warm and humid				Köppen	Am							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	267.3	263.9	263.6	242.1	154.0	87.0	110.6	101.6	124.6	167.0	174.9	239.2	182.9
Cloud (%)	55.1	52.7	45.8	52.0	79.2	83.5	83.3	83.0	81.5	71.8	65.4	63.3	68.04
Solar irradiation daily average (Wh/m²)													
Global	5541	6095	6681	6630	4865	4591	4672	4734	4701	5046	4972	4938	5289
Diffuse	1938	2075	2184	2491	3407	3378	3409	3413	3321	2902	2400	2117	2753
Relative Humidity (%)													
morning	85	88	93	90	87	93	92	91	93	93	91	78	89.5
evening	67	62	63	64	76	82	81	81	82	80	76	66	73.3
Dry Bulb Temperature (°C)													
max	28.9	29.4	30.6	31.7	29.5	28.1	28.2	28.1	27.9	28.3	28.7	29.0	29.0
min	24.5	23.7	24.0	26.1	26.9	25.8	26.0	25.9	25.4	25.0	25.1	25.7	25.3
mean	26.7	26.6	27.3	28.9	28.2	27.0	27.1	27.0	26.7	26.7	26.9	27.4	27.2
Neutrality	26.1	26.0	26.3	26.8	26.5	26.2	26.2	26.2	26.1	26.1	26.1	26.3	26.2
Upper limit	28.6	28.5	28.8	29.3	29.0	28.7	28.7	28.7	28.6	28.6	28.6	28.8	28.7
Lower limit	23.6	23.5	23.8	24.3	24.0	23.7	23.7	23.7	23.6	23.6	23.6	23.8	23.7
Rain (mm) ^b	46.4	26.5	29.3	69.0	360.4	501.1	423.7	425.1	463.0	300.7	235.0	154.6	3035
Wind (m/s)	1.53	1.11	0.65	0.67	2.74	2.49	3.33	2.96	1.76	1.03	1.38	1.9	1.8
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	265	239	286	324	311	265	282	276	255	261	259	282	3305



Average diurnal range (°K)	3.7
Annual mean range (°K)	8.0

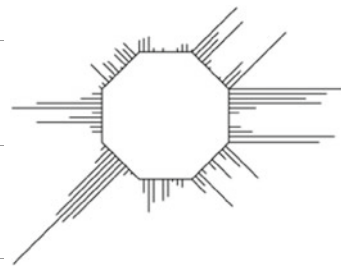
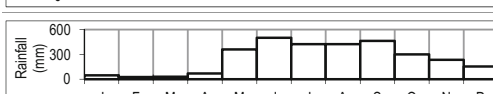
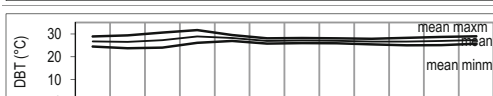
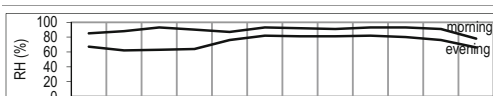
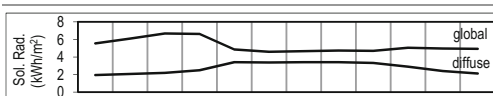


Table 5.88 Design conditions and overheated–underheated periods, Port Blair

Recommended “Design” conditions		
Summer	DBT (°C)	32.0
	MCWB (°C)	26.2
	WBT (°C)	27.1
	MCDB (°C)	30.1
Winter	DBT (°C)	22.5

Hourly temperature (°C) in all 12 months

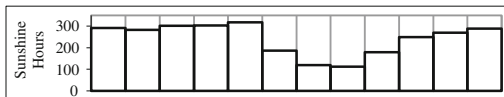
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Feb	
													H _b	H _d	H _b	H _d
0:01- 1:00	24.9	24.3	24.9	26.9	27.2	26.0	26.3	26.1	25.6	25.1	25.4	26.0	0	0	0	0
1:01- 2:00	24.6	24.1	24.7	26.7	27.0	25.9	26.2	26.0	25.6	25.0	25.3	25.8	0	0	0	0
2:01- 3:00	24.5	23.9	24.5	26.5	26.9	25.9	26.1	25.9	25.5	25.0	25.2	25.8	0	0	0	0
3:01- 4:00	24.5	23.8	24.3	26.3	26.9	25.8	26.1	25.9	25.5	25.0	25.2	25.7	0	0	0	0
4:01- 5:00	24.5	23.7	24.0	26.1	26.9	25.8	26.0	25.9	25.4	25.0	25.1	25.7	0	0	0	0
5:01- 6:00	25.2	24.5	24.9	26.9	27.3	26.2	26.4	26.2	25.9	25.7	25.7	26.3	22	24	2	1
6:01- 7:00	26.1	25.7	26.2	28.3	27.9	26.8	27.0	26.7	26.6	26.6	26.5	27.1	116	113	54	67
7:01- 8:00	27.1	27.0	27.6	29.7	28.5	27.4	27.5	27.2	27.2	27.4	27.4	27.9	260	184	195	143
8:01- 9:00	27.8	28.0	28.8	30.8	28.9	27.8	27.9	27.6	27.6	28.0	28.1	28.5	397	241	351	199
9:01-10:00	28.3	28.6	29.6	31.4	29.2	28.0	28.1	27.8	27.8	28.2	28.5	28.9	508	279	487	234
10:01-11:00	28.7	29.0	30.1	31.7	29.4	28.1	28.2	27.9	27.8	28.3	28.7	29.0	580	298	582	251
11:01-12:00	28.9	29.3	30.4	31.6	29.5	28.1	28.2	28.1	27.9	28.2	28.7	29.0	598	302	617	256
12:01-13:00	28.8	29.4	30.6	31.3	29.5	28.0	28.2	28.1	27.9	28.1	28.5	28.9	560	293	588	252
13:01-14:00	28.7	29.4	30.4	30.9	29.4	27.9	28.2	28.1	27.7	27.8	28.2	28.6	472	269	500	236
14:01-15:00	28.2	29.0	29.9	30.4	29.1	27.6	28.0	28.0	27.4	27.4	27.7	28.1	347	227	365	205
15:01-16:00	27.6	28.3	29.3	29.8	28.7	27.2	27.7	27.7	27.0	27.0	27.2	27.5	203	166	209	152
16:01-17:00	27.1	27.7	28.6	29.3	28.2	26.9	27.4	27.3	26.5	26.6	26.8	27.0	71	85	65	76
17:01-18:00	26.6	27.1	28.0	28.9	27.8	26.7	27.2	26.9	26.2	26.2	26.4	26.7	4	11	3	5
18:01-19:00	26.4	26.7	27.5	28.7	27.5	26.6	26.9	26.7	26.0	26.1	26.2	26.5	0	0	0	0
19:01-20:00	26.1	26.2	26.9	28.3	27.4	26.4	26.8	26.5	26.0	25.9	26.0	26.4	0	0	0	0
20:01-21:00	25.9	25.8	26.4	28.0	27.3	26.3	26.6	26.3	25.8	25.7	25.9	26.4	0	0	0	0
21:01-22:00	25.6	25.4	25.9	27.7	27.3	26.2	26.5	26.3	25.8	25.5	25.7	26.3	0	0	0	0
22:01-23:00	25.4	25.0	25.4	27.4	27.3	26.1	26.5	26.2	25.7	25.3	25.6	26.2	0	0	0	0
23:01-24:00	25.1	24.7	25.1	27.1	27.3	26.0	26.3	26.2	25.6	25.2	25.5	26.1	0	0	0	0
Legend	Underheated			<23.5°C	Comfortable								Overheated		>26.8°C	

Sources of data: ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd), ISHRAE (2014), http://climate.onebuilding.org/WMO_Region_2_Asia/IND_India/index.html

Table 5.89 Climatic data, Pune, Maharashtra

Latitude	N 18° 31'				Longitude	E 73° 50'				Altitude	559 m		
Climate	Warm and humid				Köppen	BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	291.8	282.2	300.8	302.6	317.0	186.9	119.9	112.7	178.5	249.3	269.7	288.7	241.7
Cloud (%)	19.9	19.3	5.8	22.8	26.5	71.2	81.7	81.5	66.5	64.8	42.7	25.6	44.01
Solar irradiation daily average (Wh/m²)													
Global	5212	6084	6827	7162	7158	5408	4327	4415	5204	5552	5172	5025	5629
Diffuse	1436	1520	1736	2022	2226	3322	3441	3413	2942	2117	1653	1344	2264
Relative Humidity (%)													
morning	91	84	70	61	79	88	91	93	94	95	93	89	85.7
evening	36	24	16	18	33	66	76	77	69	57	42	40	46.2
Dry Bulb Temperature (°C)													
max	28.2	30.8	35.7	36.9	35.7	29.6	26.6	26.1	28.1	29.5	28.8	27.6	30.3
min	11.5	13.1	16.0	19.5	22.9	23.8	22.7	22.0	21.4	20.6	16.3	12.3	18.5
mean	19.9	22.0	25.9	28.2	29.3	26.7	24.7	24.1	24.8	25.1	22.6	20.0	20.2
Neutrality	24.0	24.6	25.8	26.5	26.9	26.1	25.4	25.3	25.5	25.6	24.8	24.0	24.1
Upper limit	26.5	27.1	28.3	29.0	29.4	28.6	27.9	27.8	28.0	28.1	27.3	26.5	26.6
Lower limit	21.5	22.1	23.3	24.0	24.4	23.6	22.9	22.8	23.0	23.1	22.3	21.5	21.6
Rain (mm)^b	1.6	1.1	2.7	13.6	33.3	120.4	179.0	106.4	129.1	78.8	28.6	5.3	699.9
Wind (m/s)	0.4	0.9	0.8	1.0	2.2	2.2	1.7	1.4	1.2	0.6	0.7	0.7	1.2
HDD	5	0	0	0	0	0	0	0	0	0	0	4	9
CDD	62	102	243	311	344	245	199	176	188	194	116	47	2227



Average diurnal range (°K) 11.8

Annual mean range (°K) 25.4

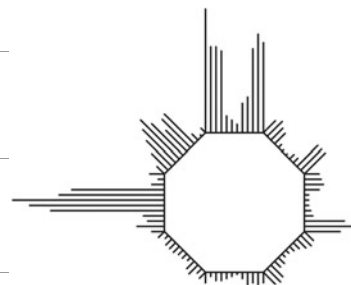
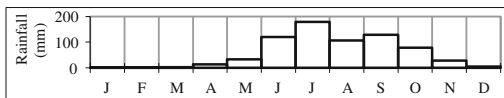
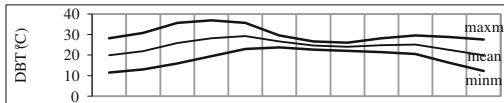
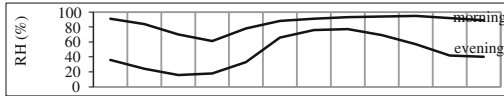
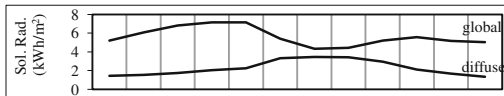


Table 5.90 Design conditions and overheated–underheated periods, Pune

Recommended “Design” conditions		
Summer	DBT (°C)	37.4
	MCWB (°C)	20.4
	WBT (°C)	24.4
	MCDB (°C)	30.6
Winter	DBT (°C)	10.3

Hourly temperature (°C) in all 12 months

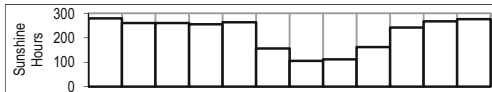
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m^2) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H_b	H_d	H_b	H_d
0:01- 1:00	15.2	16.2	19.2	22.6	24.9	24.4	23.3	22.4	22.3	21.7	18.1	14.7	0	0	0	0
1:01- 2:00	14.5	15.0	18.0	21.4	24.0	24.2	23.1	22.2	22.0	21.4	17.4	13.7	0	0	0	0
2:01- 3:00	14.2	14.3	17.1	20.2	23.4	24.0	22.9	22.1	21.6	21.1	16.9	13.2	0	0	0	0
3:01- 4:00	13.2	13.3	16.1	19.5	22.9	23.8	22.7	22.0	21.4	20.9	16.3	12.3	0	0	0	0
4:01- 5:00	12.3	13.3	16.0	19.9	23.1	23.8	22.8	22.1	21.4	20.6	16.3	12.5	0	0	0	0
5:01- 6:00	11.5	13.1	16.4	21.0	24.0	24.2	23.0	22.2	21.9	20.9	16.6	12.5	2	5	0	0
6:01- 7:00	12.3	14.4	18.3	23.0	25.6	24.8	23.5	22.7	22.7	21.6	18.0	13.9	42	76	2	1
7:01- 8:00	14.0	16.5	21.1	25.7	27.6	25.7	24.2	23.3	23.9	22.9	19.8	15.8	180	149	60	59
8:01- 9:00	17.5	20.2	24.9	28.7	29.8	26.7	24.9	24.1	25.2	24.4	22.4	19.0	352	195	213	114
9:01-10:00	21.1	23.7	28.6	31.5	31.8	27.7	25.6	24.9	26.4	26.1	24.6	21.9	515	221	376	149
10:01-11:00	24.6	27.2	32.0	33.8	33.4	28.6	26.1	25.6	27.4	27.7	26.7	24.8	645	228	509	169
11:01-12:00	26.6	29.2	34.1	35.5	34.6	29.2	26.5	25.9	28.0	28.8	27.8	26.3	715	231	585	182
12:01-13:00	27.9	30.5	35.4	36.5	35.3	29.6	26.6	26.1	28.1	29.5	28.7	27.4	711	236	603	182
13:01-14:00	28.0	30.6	35.7	36.9	35.7	29.6	26.6	25.9	28.0	29.5	28.7	27.4	645	233	551	177
14:01-15:00	28.2	30.8	35.7	36.7	35.6	29.3	26.3	25.7	27.4	28.9	28.8	27.6	523	221	443	161
15:01-16:00	27.8	30.0	35.0	35.9	35.1	28.7	25.9	25.2	26.6	28.0	28.0	26.7	364	194	291	133
16:01-17:00	27.3	29.2	34.2	34.7	34.0	27.8	25.3	24.8	25.7	26.8	26.8	25.8	185	155	126	88
17:01-18:00	25.7	27.2	32.5	33.1	32.4	26.8	24.7	24.2	24.8	25.5	24.6	23.5	49	78	16	22
18:01-19:00	24.0	25.4	30.5	31.3	30.6	25.9	24.1	23.6	23.9	24.3	22.6	21.5	2	6	0	0
19:01-20:00	21.4	22.9	28.0	29.5	28.9	25.2	23.7	23.1	23.3	23.3	20.5	19.0	0	0	0	0
20:01-21:00	19.5	21.3	25.7	27.8	27.6	24.7	23.5	22.8	22.8	22.6	19.4	17.7	0	0	0	0
21:01-22:00	17.5	19.5	23.5	26.4	26.7	24.5	23.4	22.6	22.6	22.1	18.6	16.5	0	0	0	0
22:01-23:00	16.5	18.6	21.9	25.2	26.1	24.4	23.4	22.6	22.5	21.9	18.6	16.1	0	0	0	0
23:01-24:00	15.5	17.2	20.4	24.1	25.5	24.4	23.4	22.5	22.5	21.7	18.3	15.3	0	0	0	0
Legend	Underheated			<21.5°C	Comfortable								Overheated		>26.9°C	

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.91 Climatic data, Raipur, Chhattisgarh

Latitude	N 21° 13'				Longitude				E 81° 39'				Altitude	298 m	
Climate	Composite				Köppen				BWh						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year		
Sunshine h ^a	279.0	260.4	260.4	255.0	263.5	156.0	105.4	111.6	162.0	241.8	267.0	275.9	219.8		
Cloud (%)	44.3	46.4	46.2	45.1	44.4	45.0	45.2	46.8	44.8	44.6	43.5	44.4	45.05		
Solar irradiation daily average (Wh/m²)															
Global	4634	5620	6431	7054	6951	5617	4534	4233	5182	5337	4925	4592	5426		
Diffuse	1580	1624	1895	2091	2487	3298	3553	3413	2905	2094	1543	1356	2320		
Relative Humidity (%)															
morning	74	74	66	54	51	72	92	93	92	86	90	91	77.9		
evening	29	37	29	25	23	53	74	75	67	41	54	44	45.9		
Dry Bulb Temperature (°C)															
max	27.6	30.4	34.6	39.0	40.8	34.7	29.8	29.3	31.0	31.7	27.9	26.7	32.0		
min	12.7	17.7	21.2	26.1	27.8	27.3	25.2	24.9	25.0	20.8	19.0	14.5	21.9		
mean	20.2	24.1	27.9	32.6	34.3	31.0	27.5	27.1	28.0	26.3	23.5	20.6	21.3		
Neutrality	24.0	25.3	26.4	27.9	28.4	27.4	26.3	26.2	26.5	25.9	25.1	24.2	24.4		
Upper limit	26.5	27.8	28.9	30.4	30.9	29.9	28.8	28.7	29.0	28.4	27.6	26.7	26.9		
Lower limit	21.5	22.8	23.9	25.4	25.9	24.9	23.8	23.7	24.0	23.4	22.6	21.7	21.9		
Rain (mm) ^b	11.7	21.0	19.6	15.5	22.9	209.4	369.1	365.4	216.6	52.1	11.4	4.2	1319		
Wind (m/s)	0.33	0.78	1.48	1.29	1.49	2.33	1.80	1.48	1.94	0.67	0.79	0.68	1.3		
HDD	6	0	0	0	0	0	0	0	0	0	0	0	6		
CDD	57	160	304	424	499	380	288	276	292	247	152	64	3143		



Average diurnal range (°K)	10.1
Annual mean range (°K)	28.1

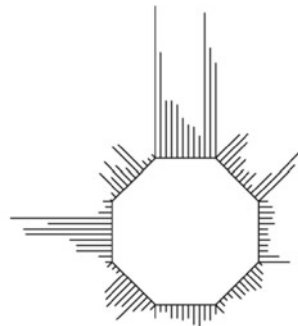
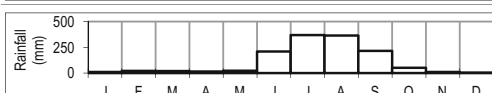
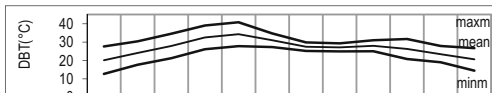
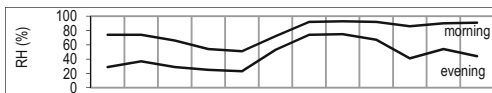
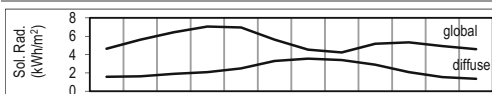


Table 5.92 Design conditions and overheated–underheated periods, Raipur

Recommended “Design” conditions														
Summer	DBT (°C)		42.2											
	MCWB (°C)		23.3											
	WBT (°C)		26.8											
	MCDB (°C)		32.0											
Winter	DBT (°C)		12.6											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	15.9	20.4	23.9	28.5	30.0	28.4	25.9	25.6	25.9	22.7	20.7	16.6	0	0	0	0
1:01- 2:00	14.9	19.5	22.9	27.8	29.3	28.0	25.6	25.3	25.6	22.2	20.4	15.9	0	0	0	0
2:01- 3:00	13.9	18.6	22.0	26.7	28.3	27.6	25.4	25.1	25.2	21.3	19.7	15.0	0	0	0	0
3:01- 4:00	12.9	17.7	21.2	26.1	27.8	27.3	25.2	24.9	25.0	20.9	19.3	14.5	0	0	0	0
4:01- 5:00	12.7	17.7	21.5	26.2	28.0	27.3	25.2	24.9	25.0	20.8	19.0	14.5	0	0	0	0
5:01- 6:00	13.3	18.2	22.3	27.2	29.2	27.7	25.4	25.1	25.5	21.9	19.6	15.5	13	40	0	0
6:01- 7:00	15.2	19.6	24.0	28.7	30.9	28.6	25.9	25.7	26.4	23.6	20.7	17.1	105	124	13	17
7:01- 8:00	17.6	21.5	26.0	30.8	33.0	29.7	26.5	26.4	27.5	25.7	22.3	19.3	248	190	97	92
8:01- 9:00	20.4	23.7	28.3	32.7	34.9	30.9	27.3	27.2	28.7	27.7	23.9	21.5	399	232	234	149
9:01-10:00	22.8	25.7	30.2	34.5	36.6	32.0	28.0	27.9	29.8	29.4	25.4	23.4	528	257	367	182
10:01-11:00	24.9	27.5	31.9	35.9	37.9	32.9	28.7	28.6	30.5	30.4	26.6	24.9	615	268	462	201
11:01-12:00	26.1	28.7	32.9	37.3	39.2	33.6	29.1	29.0	31.0	31.2	27.5	26.0	649	267	504	208
12:01-13:00	27.1	29.7	33.8	38.3	40.1	34.2	29.5	29.2	31.0	31.6	27.9	26.6	616	266	487	205
13:01-14:00	27.5	30.2	34.3	39.0	40.8	34.5	29.7	29.3	30.8	31.7	27.9	26.7	529	255	412	192
14:01-15:00	27.6	30.4	34.6	38.9	40.8	34.7	29.8	29.2	30.4	31.2	27.4	26.2	399	232	293	164
15:01-16:00	26.8	29.9	34.2	38.2	40.3	34.4	29.6	28.8	29.8	30.4	26.6	25.2	249	189	153	118
16:01-17:00	25.3	28.8	33.1	36.8	38.9	33.8	29.2	28.4	29.1	29.1	25.4	23.6	103	126	32	52
17:01-18:00	22.9	27.0	31.4	35.1	37.3	32.7	28.5	27.8	28.3	27.6	24.3	21.8	12	40	1	0
18:01-19:00	20.4	25.1	29.4	33.1	35.3	31.5	27.8	27.2	27.6	26.0	23.1	20.0	0	0	0	0
19:01-20:00	18.0	23.3	27.6	31.5	33.8	30.3	27.1	26.6	27.1	24.7	22.1	18.5	0	0	0	0
20:01-21:00	16.7	22.1	26.3	30.1	32.4	29.4	26.7	26.2	26.7	23.7	21.4	17.6	0	0	0	0
21:01-22:00	16.2	21.5	25.6	29.5	31.7	28.9	26.4	26.0	26.4	23.3	21.1	17.2	0	0	0	0
22:01-23:00	16.3	21.3	25.3	29.1	31.1	28.7	26.3	25.9	26.3	23.0	20.8	17.1	0	0	0	0
23:01-24:00	16.3	20.9	24.8	29.0	30.8	28.5	26.1	25.7	26.2	23.0	20.8	17.0	0	0	0	0
Legend	Underheated		<21.5°C		Comfortable					Overheated			>28.4°C			

Sources of data: ISHRAE (2014), ^aIMD (1981), ^bIndia Meteorological Department (nd)

Table 5.93 Climatic data, Rajkot, Gujarat

Latitude	N 22° 17'				Longitude	E 70° 46'				Altitude	138 m		
Climate	Composite				Köppen	BWh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	289.1	283.0	323.3	320.1	324.5	233.8	92.5	118.6	223.5	265.4	276.6	288.8	253.3
Cloud (%)	9.4	5.5	9.1	9.4	9.8	37.0	62.4	59.2	33.8	22.3	14.3	10.6	23.56
Solar irradiation daily average (Wh/m²)													
Global	4917	5844	6757	7444	7633	6634	4696	4877	5901	5629	5092	4705	5844
Diffuse	1238	1361	1562	1740	1930	2691	3465	3333	2376	1768	1321	1165	1996
Relative Humidity (%)													
morning	57	69	71	71	83	83	90	93	91	78	55	50	74.3
evening	23	25	19	13	26	42	64	65	47	31	19	22	33.0
Dry Bulb Temperature (°C)													
max	28.2	31.5	34.9	39.0	39.3	36.9	32.1	31.0	33.3	36.4	33.8	30.4	33.9
min	15.0	17.8	20.2	24.7	26.7	27.9	26.2	25.3	23.6	24.2	20.3	16.6	22.4
mean	21.6	24.7	27.6	31.9	33.0	32.4	29.2	28.2	28.5	30.3	27.1	23.5	28.1
Neutrality	24.5	25.4	26.3	27.7	28.0	27.8	26.8	26.5	26.6	27.2	26.2	25.1	26.5
Upper limit	27.0	27.9	28.8	30.2	30.5	30.3	29.3	29.0	29.1	29.7	28.7	27.6	29.0
Lower limit	22.0	22.9	23.8	25.2	25.5	25.3	24.3	24.0	24.1	24.7	23.7	22.6	24.0
Rain (mm) ^b	1.0	1.0	1.0	1.6	3.9	98.9	242.5	174.3	101.0	53.2	10.0	0.8	689.2
Wind (m/s)	2.85	2.93	3.60	4.26	6.10	5.90	5.05	4.82	4.35	2.18	1.72	2.33	3.8
HDD	3	0	0	0	0	0	0	0	0	0	0	0	3
CDD	92	174	293	399	434	406	331	305	299	364	261	161	3519
												Average diurnal range (°K)	11.5
												Annual mean range (°K)	24.3

Table 5.94 Design conditions and overheated–underheated periods, Rajkot

Recommended “Design” conditions														
Summer	DBT (°C)		39.9											
	MCWB (°C)		23.8											
	WBT (°C)		27.6											
	MCDB (°C)		33.3											
Winter	DBT (°C)		12.2											

Hourly temperature (°C) in all 12 months

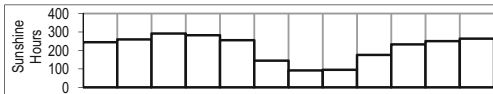
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
Hours													H _b	H _d	H _b	H _d
0:01- 1:00	17.1	20.8	23.8	27.3	28.5	29.0	26.9	26.0	25.2	26.4	23.4	19.9	0	0	0	0
1:01- 2:00	16.6	20.1	23.1	26.7	27.9	28.6	26.7	25.9	24.9	25.9	22.7	19.3	0	0	0	0
2:01- 3:00	16.3	19.4	22.1	26.1	27.4	28.4	26.5	25.8	24.5	25.4	22.1	18.6	0	0	0	0
3:01- 4:00	16.1	19.0	21.6	25.6	27.2	28.2	26.4	25.6	24.2	24.9	21.5	18.1	0	0	0	0
4:01- 5:00	15.6	18.6	21.1	25.3	27.0	28.1	26.3	25.6	24.0	24.5	21.0	17.5	0	0	0	0
5:01- 6:00	15.1	18.3	20.6	25.0	26.7	27.9	26.2	25.3	23.8	24.3	20.6	17.1	0	0	0	0
6:01- 7:00	15.0	17.9	20.2	24.7	26.7	28.0	26.2	25.4	23.6	24.2	20.3	16.6	2	19	0	0
7:01- 8:00	15.1	17.8	20.5	25.3	27.2	28.4	26.5	25.7	24.0	24.6	20.7	16.7	69	114	5	9
8:01- 9:00	17.1	20.1	23.7	28.2	29.1	30.2	28.4	26.7	26.4	27.8	24.1	20.0	239	172	89	69
9:01-10:00	19.8	23.3	26.8	31.1	31.0	31.5	29.1	27.4	28.0	30.0	27.0	23.5	425	202	255	110
10:01-11:00	22.8	26.2	29.6	34.0	33.3	33.1	29.9	28.4	29.8	32.4	29.8	26.5	625	196	414	133
11:01-12:00	25.0	28.2	31.6	36.3	35.5	34.5	30.9	29.5	31.1	34.2	31.8	28.4	777	181	539	145
12:01-13:00	26.5	29.6	33.1	37.8	37.3	35.7	31.6	30.3	32.2	35.3	33.0	29.6	866	163	600	152
13:01-14:00	27.6	30.8	34.1	38.5	38.6	36.5	32.0	30.6	32.9	35.9	33.6	30.1	859	157	592	154
14:01-15:00	28.1	31.5	34.7	39.0	39.3	36.9	32.1	31.0	33.3	36.4	33.8	30.4	752	165	514	151
15:01-16:00	28.2	31.5	34.9	39.0	39.3	36.4	31.9	31.0	33.1	36.3	33.7	30.3	563	180	380	139
16:01-17:00	27.9	31.3	34.6	38.3	38.8	35.7	31.2	30.9	32.8	35.7	33.2	29.7	350	177	221	110
17:01-18:00	26.7	30.3	34.1	37.2	37.6	34.3	30.2	30.5	31.7	34.1	31.4	28.2	149	142	66	62
18:01-19:00	24.4	28.1	32.2	35.0	35.4	33.0	29.6	29.8	30.0	32.3	29.0	25.8	22	63	3	4
19:01-20:00	22.4	26.2	30.3	32.9	33.5	31.8	28.7	28.8	28.8	30.7	27.4	24.4	1	1	0	0
20:01-21:00	21.0	24.8	28.3	31.2	31.8	31.0	28.2	27.8	27.8	29.5	26.4	23.0	0	0	0	0
21:01-22:00	19.8	23.4	27.0	29.9	30.6	30.3	27.8	27.2	27.0	28.5	25.6	22.0	0	0	0	0
22:01-23:00	18.9	22.4	25.8	29.0	29.8	29.7	27.4	26.8	26.4	27.7	24.6	21.1	0	0	0	0
23:01-24:00	18.0	21.6	24.6	28.0	28.9	29.3	27.0	26.2	25.7	27.0	24.0	20.4	0	0	0	0
Legend	Underheated		<22.0°C				Comfortable						Overheated		>28.0°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIndia Meteorological Department (nd)

Table 5.95 Climatic data, Ramagundam, Telangana

Latitude	N 18° 46'				Longitude	E 79° 25'				Altitude	156 m		
Climate	Warm and humid				Köppen	BSH							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	245.2	259.8	292.1	282.7	255.8	145.1	91.7	95.1	176.0	233.3	250.3	264.5	215.9
Cloud (%)	45.5	45.1	47.0	44.7	43.9	42.6	44.5	44.5	44.7	45.9	44.8	44.0	44.76
Solar irradiation daily average (Wh/m²)													
Global	4779	5821	6553	7020	6728	5397	4637	4583	5399	5470	5098	4787	5523
Diffuse	1737	1702	1925	2162	2600	3415	3520	3454	2902	2178	1706	1504	2400
Relative Humidity (%)													
morning	87	85	78	61	64	74	87	89	91	93	90	89	82.3
evening	38	41	37	27	31	51	70	67	61	53	44	42	46.8
Dry Bulb Temperature (°C)													
max	31.3	33.2	35.8	39.9	41.8	35.5	30.6	30.6	33.0	32.9	31.2	29.2	33.8
min	16.2	19.3	23.2	27.0	28.5	27.9	25.7	25.4	25.1	22.0	18.2	15.0	22.8
mean	23.8	26.3	29.5	33.5	35.2	31.7	28.2	28.0	29.1	27.5	24.7	22.1	28.3
Neutrality	25.2	25.9	26.9	28.2	28.7	27.6	26.5	26.5	26.8	26.3	25.5	24.7	26.6
Upper limit	27.7	28.4	29.4	30.7	31.2	30.1	29.0	29.0	29.3	28.8	28.0	27.2	29.1
Lower limit	22.7	23.4	24.4	25.7	26.2	25.1	24.0	24.0	24.3	23.8	23.0	22.2	24.1
Rain (mm) ^b	5.0	21.9	11.7	23.1	22.2	137.7	251.6	178.7	173.8	64.6	20.5	3.4	914.2
Wind (m/s)	0.15	0.33	0.50	0.70	0.87	1.10	0.83	0.69	0.35	0.44	0.06	0.25	0.5
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	140	205	338	448	519	396	309	298	312	272	179	110	3526



Average diurnal range (°K)	11.0
Annual mean range (°K)	26.8

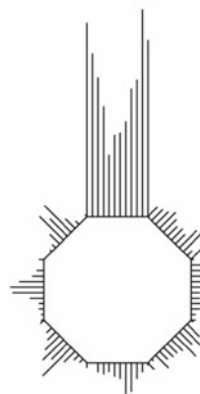
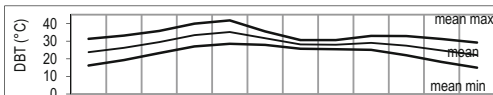
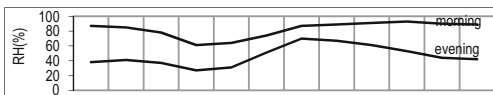
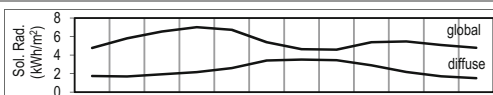


Table 5.96 Design conditions and overheated–underheated periods, Ramagundam

Recommended “Design” conditions														
Summer	DBT (°C)		42.2											
	MCWB (°C)		25.1											
	WBT (°C)		27.9											
	MCDB (°C)		35.6											
Winter	DBT (°C)		13.7											

Hourly temperature (°C) in all 12 months

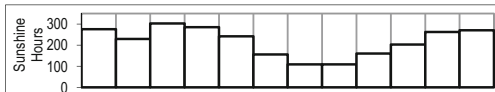
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H _b	H _d	H _b	H _d
0:01- 1:00	17.4	21.4	25.2	29.8	31.0	28.9	26.5	26.1	25.7	23.3	19.8	16.8	0	0	0	0
1:01- 2:00	16.8	20.5	24.6	28.6	30.0	28.6	26.2	25.8	25.5	23.0	19.2	16.2	0	0	0	0
2:01- 3:00	16.6	20.0	23.9	27.8	29.1	28.3	26.0	25.6	25.4	22.4	18.6	15.5	0	0	0	0
3:01- 4:00	16.2	19.3	23.3	27.0	28.5	28.0	25.8	25.4	25.2	22.1	18.2	15.0	0	0	0	0
4:01- 5:00	16.2	19.7	23.2	27.1	28.8	27.9	25.7	25.4	25.1	22.0	18.3	15.2	0	0	0	0
5:01- 6:00	16.7	20.0	23.9	27.6	29.5	28.1	25.8	25.5	25.5	22.8	19.3	16.1	10	23	0	0
6:01- 7:00	18.3	21.5	25.3	29.0	31.2	28.7	26.2	26.0	26.4	24.2	21.0	17.8	86	104	16	30
7:01- 8:00	20.2	23.1	27.2	30.7	33.0	29.5	26.8	26.7	27.6	26.2	23.3	20.1	210	183	131	89
8:01- 9:00	23.1	25.7	29.3	32.9	35.3	30.5	27.6	27.6	29.1	28.2	25.6	22.6	349	236	273	141
9:01-10:00	25.6	27.7	31.1	34.8	37.0	31.6	28.4	28.4	30.5	30.1	27.7	24.9	472	269	403	171
10:01-11:00	28.0	29.9	32.7	36.7	38.7	32.8	29.3	29.3	31.8	31.5	29.4	26.8	556	289	490	192
11:01-12:00	29.4	31.0	33.9	37.9	39.7	33.9	29.9	29.9	32.6	32.6	30.5	28.2	590	297	525	200
12:01-13:00	30.6	32.3	34.8	39.1	40.8	34.8	30.3	30.4	33.0	32.9	31.1	29.0	571	293	508	192
13:01-14:00	31.0	32.7	35.5	39.6	41.3	35.3	30.5	30.6	33.0	32.8	31.2	29.2	498	280	429	180
14:01-15:00	31.3	33.2	35.8	39.9	41.8	35.5	30.6	30.6	32.6	32.0	30.7	28.9	389	248	308	153
15:01-16:00	30.5	32.5	35.4	39.3	41.3	35.2	30.4	30.3	31.9	31.0	29.6	28.0	256	198	168	105
16:01-17:00	29.2	31.2	34.3	38.0	40.4	34.5	30.1	29.8	30.9	29.7	28.0	26.6	122	129	32	51
17:01-18:00	26.5	28.6	32.5	36.0	38.3	33.4	29.5	28.9	29.7	28.3	26.0	24.6	18	51	0	0
18:01-19:00	23.7	26.0	30.3	33.9	36.2	32.3	28.8	28.0	28.5	26.9	23.9	22.6	0	0	0	0
19:01-20:00	20.8	23.5	28.2	32.1	34.0	31.3	28.1	27.1	27.4	25.7	22.1	20.6	0	0	0	0
20:01-21:00	19.1	22.4	26.6	31.1	32.7	30.6	27.6	26.6	26.7	24.5	20.9	19.1	0	0	0	0
21:01-22:00	17.9	21.8	25.8	30.6	31.9	30.0	27.2	26.3	26.2	23.9	20.3	18.2	0	0	0	0
22:01-23:00	17.7	22.2	25.6	30.6	31.8	29.7	27.0	26.2	26.0	23.4	20.1	17.7	0	0	0	0
23:01-24:00	17.3	21.9	25.5	30.3	31.4	29.4	26.7	26.1	25.8	23.2	20.0	17.3	0	0	0	0
Legend	Underheated		<22.2°C	Comfortable									Overheated		>28.7°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (1973)

Table 5.97 Climatic data, Ranchi, Jharkhand

Latitude	N 23° 19'				Longitude				E 85° 19'				Altitude	652 m
Climate	Composite				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	276.0	229.6	303.4	285.8	242.1	156.0	108.9	109.1	160.7	203.4	262.5	271.1	217.4	
Cloud (%)	45.04	45.38	42.83	44.17	47.38	47.17	44.33	46.83	43.79	44.83	45.75	44.75	45.19	
Solar irradiation daily average (Wh/m²)														
Global	4406	5362	6320	6870	6654	5624	4681	4728	4797	5014	4691	4298	5287	
Diffuse	1504	1581	1831	2180	2647	3146	3467	3352	2918	2135	1516	1318	2300	
Relative Humidity (%)														
morning	78	68	77	61	77	81	91	96	94	89	81	89	81.8	
evening	38	34	42	27	34	52	69	76	68	51	41	47	48.3	
Dry Bulb Temperature (°C)														
max	21.9	24.6	30.0	34.5	35.3	32.6	29.1	27.9	28.2	27.9	25.8	23.3	28.4	
min	11.1	13.4	18.7	22.6	23.9	24.7	23.7	23.2	22.8	19.4	15.8	11.7	19.3	
mean	16.5	19.0	24.4	28.6	29.6	28.7	26.4	25.6	25.5	23.7	20.8	17.5	23.8	
Neutrality	22.9	23.7	25.3	26.7	27.0	26.7	26.0	25.7	25.7	25.1	24.2	23.2	25.2	
Upper limit	25.4	26.2	27.8	29.2	29.5	29.2	28.5	28.2	28.2	27.6	26.7	25.7	27.7	
Lower limit	20.4	21.2	22.8	24.2	24.5	24.2	23.5	23.2	23.2	22.6	21.7	20.7	22.7	
Rain (mm) ^b	20.5	25.7	18.9	41.2	58.5	216.3	337.9	326.8	273.2	99.7	16.0	6.1	1441	
Wind (m/s)	2.01	3.28	2.26	3.31	3.68	3.7	3.57	2.94	2.43	1.67	1.57	1.68	2.7	
HDD	61	8	0	0	0	0	0	0	0	0	4	34	107	
CDD	3	36	188	319	359	304	247	223	217	167	69	2	2134	



Average diurnal range (°K)	9.2
Annual mean range (°K)	24.2

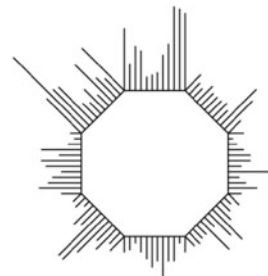
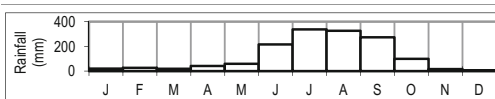
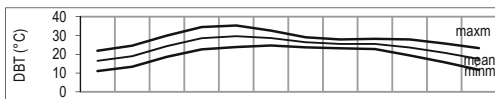
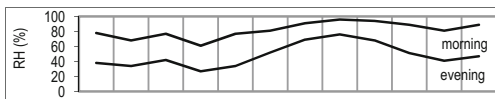
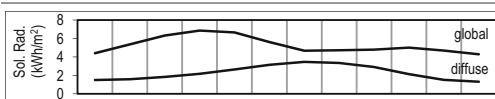


Table 5.98 Design conditions and overheated–underheated periods, Ranchi

Recommended “Design” conditions														
Summer	DBT (°C)		37.7											
	MCWB (°C)		21.8											
	WBT (°C)		25.6											
	MCDB (°C)		30.4											
Winter	DBT (°C)		10.4											

Hourly temperature (°C) in all 12 months

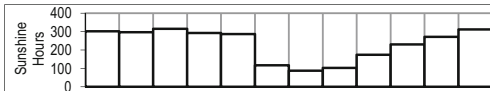
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	13.1	15.9	20.6	25.0	26.0	25.5	24.2	23.5	23.6	20.7	17.3	13.3	0	0	0	0
1:01- 2:00	12.4	14.9	19.9	24.2	25.3	25.2	24.0	23.4	23.3	20.3	17.2	12.7	0	0	0	0
2:01- 3:00	11.7	14.1	19.1	23.1	24.4	24.8	23.7	23.2	22.9	19.6	16.4	12.0	0	0	0	0
3:01- 4:00	11.1	13.4	18.7	22.6	23.9	24.7	23.7	23.2	22.8	19.4	16.0	11.7	0	0	0	0
4:01- 5:00	11.1	13.4	18.9	22.7	24.3	24.9	23.8	23.2	22.8	19.5	15.8	11.8	1	2	0	0
5:01- 6:00	11.4	14.0	19.8	23.9	25.4	25.6	24.4	23.7	23.5	20.7	16.8	12.7	22	61	0	0
6:01- 7:00	12.4	15.4	21.2	25.8	27.0	26.7	25.3	24.2	24.4	22.0	18.4	14.2	121	145	11	36
7:01- 8:00	13.8	17.2	23.0	28.2	29.1	28.1	26.4	24.9	25.5	23.8	20.5	16.2	250	215	113	100
8:01- 9:00	15.7	19.2	24.8	30.1	31.0	29.5	27.4	25.6	26.5	25.1	22.3	18.2	384	260	248	154
9:01-10:00	17.6	21.0	26.4	31.7	32.6	30.8	28.2	26.3	27.4	26.3	23.9	20.2	493	286	383	175
10:01-11:00	19.4	22.5	27.7	32.7	33.8	31.7	28.8	26.9	27.9	27.0	24.8	21.7	559	300	463	196
11:01-12:00	20.7	23.5	28.8	33.6	34.7	32.4	29.1	27.6	28.2	27.7	25.6	22.8	585	291	493	199
12:01-13:00	21.6	24.2	29.6	34.1	35.1	32.6	29.1	27.8	28.2	27.9	25.8	23.3	545	283	464	190
13:01-14:00	21.9	24.5	30.0	34.5	35.3	32.5	28.8	27.9	28.0	27.9	25.8	23.3	454	266	369	181
14:01-15:00	21.8	24.6	29.9	34.4	34.9	31.9	28.3	27.4	27.5	27.2	24.9	22.6	327	235	241	150
15:01-16:00	21.2	24.2	29.2	33.9	34.1	31.0	27.7	26.9	26.9	26.4	24.0	21.5	189	181	103	98
16:01-17:00	20.2	23.4	28.0	32.7	32.9	29.9	26.8	26.1	26.2	25.1	22.4	20.0	73	100	11	28
17:01-18:00	18.8	21.9	26.4	31.4	31.5	28.8	26.0	25.6	25.5	24.1	20.9	18.5	6	20	0	0
18:01-19:00	17.4	20.4	24.7	29.6	30.1	27.8	25.3	25.1	24.8	23.0	19.3	17.1	0	0	0	0
19:01-20:00	16.1	19.0	23.4	28.2	29.0	27.0	24.8	24.9	24.4	22.3	18.1	16.0	0	0	0	0
20:01-21:00	15.2	18.0	22.4	26.9	28.1	26.4	24.4	24.6	24.0	21.7	17.0	15.1	0	0	0	0
21:01-22:00	14.5	17.4	22.0	26.3	27.6	26.0	24.3	24.4	23.9	21.5	16.8	14.6	0	0	0	0
22:01-23:00	14.1	17.1	21.7	25.8	27.2	25.8	24.3	24.1	23.7	21.1	16.7	14.1	0	0	0	0
23:01-24:00	13.7	16.6	21.4	25.6	26.9	25.7	24.3	23.9	23.7	21.1	17.2	13.8	0	0	0	0
Legend	Underheated		<20.4°C		Comfortable								Overheated		>27.0°C	

Sources of data: ISHRAE (2014), ^aTyagi (2009 p 304, 2979-2984), ^bIndia Meteorological Department (nd)

Table 5.99 Climatic data, Ratnagiri, Maharashtra

Latitude	N 16° 58'					Longitude	E 73° 19'					Altitude	67 m
Climate	Warm and humid					Köppen	Aw						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	301.9	296.6	315.7	292.9	286.8	116.6	87.7	103.1	174.4	230.5	271.7	312.1	232.5
Cloud (%)	16.4	7.0	15.0	32.9	54.0	81.9	89.5	87.3	71.8	53.0	27.2	12.2	45.69
Solar irradiation daily average (Wh/m²)													
Global	5505	6403	6918	7178	7105	4980	4554	4682	5421	5532	5468	5416	5764
Diffuse	1384	1427	1743	1991	2261	3398	3483	3452	2845	2225	1564	1240	2251
Relative Humidity (%)													
morning	71	79	77	83	81	92	89	89	93	87	78	74	82.8
evening	39	44	51	58	62	79	84	85	78	59	41	33	59.4
Dry Bulb Temperature (°C)													
max	30.3	29.8	30.7	31.0	31.2	29.3	27.5	27.3	28.4	31.0	32.6	31.3	30.0
min	20.7	20.0	22.4	25.0	27.0	25.7	25.8	25.5	24.7	24.7	22.6	20.7	23.7
mean	25.5	24.9	26.6	28.0	29.1	27.5	26.7	26.4	26.6	27.9	27.6	26.0	26.9
Neutrality	25.7	25.5	26.0	26.5	26.8	26.3	26.1	26.0	26.0	26.4	26.4	25.9	26.1
Upper limit	28.2	28.0	28.5	29.0	29.3	28.8	28.6	28.5	28.5	28.9	28.9	28.4	28.6
Lower limit	23.2	23.0	23.5	24.0	24.3	23.8	23.6	23.5	23.5	23.9	23.9	23.4	23.6
Rain (mm) ^b	1.5	0.1	0.2	3.6	42.7	831.7	929.7	629.8	322.2	107.2	38.3	6.7	2914
Wind (m/s)	1.64	1.63	1.42	1.91	1.90	1.41	2.13	2.27	1.12	1.11	1.49	1.68	1.6
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	223	189	267	298	343	284	264	259	251	291	269	234	3172



Average diurnal range (°K)	6.3
Annual mean range (°K)	12.6

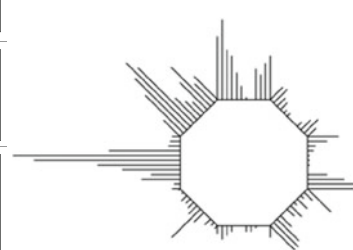
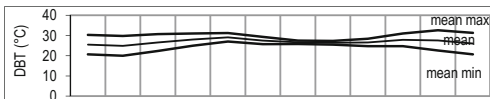
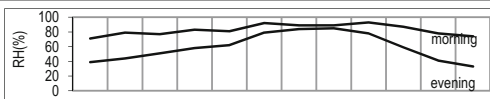
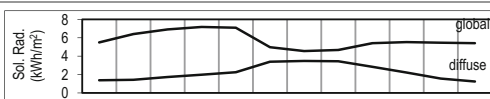


Table 5.100 Design conditions and overheated–underheated periods, Ratnagiri

Recommended “Design” conditions														
Summer	DBT (°C)	33.4												
	MCWB (°C)	23.4												
	WBT (°C)	27.3												
	MCDB (°C)	30.8												
Winter	DBT (°C)	19.2												

Hourly temperature (°C) in all 12 months

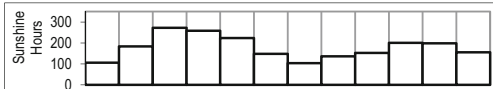
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m^2) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Feb	
													H_b	H_d	H_b	H_d
0:01- 1:00	22.7	22.2	24.4	26.4	28.1	26.3	25.9	25.7	25.2	25.1	24.0	22.6	0	0	0	0
1:01- 2:00	22.2	21.7	24.0	26.1	27.8	26.2	25.9	25.7	25.1	25.1	23.6	22.0	0	0	0	0
2:01- 3:00	21.7	21.2	23.7	25.8	27.6	26.1	25.9	25.7	24.9	24.9	23.3	21.5	0	0	0	0
3:01- 4:00	21.4	20.8	23.1	25.6	27.5	26.0	25.9	25.6	24.8	24.8	23.0	21.2	0	0	0	0
4:01- 5:00	21.1	20.6	22.9	25.3	27.2	25.9	25.9	25.7	24.8	24.8	22.9	20.9	0	0	0	0
5:01- 6:00	20.8	20.1	22.6	25.0	27.0	25.7	25.8	25.5	24.7	24.7	22.7	20.7	0	0	0	0
6:01- 7:00	20.7	20.0	22.4	25.0	27.0	25.7	25.8	25.5	24.7	24.7	22.6	20.8	7	25	0	0
7:01- 8:00	21.0	20.0	23.2	25.6	27.5	26.2	25.9	25.5	24.8	24.9	23.4	21.3	88	116	29	33
8:01- 9:00	23.9	23.0	26.3	27.8	29.3	28.0	27.2	26.5	26.1	27.1	26.5	24.6	249	177	176	98
9:01-10:00	26.3	25.7	28.2	29.3	30.0	28.3	27.1	26.6	26.8	27.6	28.3	27.1	423	213	369	138
10:01-11:00	28.4	28.2	29.5	30.3	30.7	28.7	27.0	26.8	27.5	28.5	30.1	29.1	575	230	553	157
11:01-12:00	29.6	29.4	30.5	30.8	30.9	29.3	27.5	27.3	28.2	31.0	31.7	30.5	682	233	693	161
12:01-13:00	30.3	29.8	30.7	30.9	31.1	29.3	27.4	27.2	28.4	30.9	32.2	31.3	721	235	764	160
13:01-14:00	30.2	29.8	30.7	31.0	31.2	29.3	27.3	27.3	28.4	30.8	32.6	31.2	688	235	750	161
14:01-15:00	29.9	29.8	30.5	30.8	31.2	29.3	27.4	27.3	28.2	30.8	32.5	30.9	589	232	664	157
15:01-16:00	29.4	29.4	30.2	30.6	30.9	29.2	27.2	27.3	28.2	30.6	31.8	30.4	441	218	515	146
16:01-17:00	28.8	28.5	29.6	30.0	30.6	28.7	26.9	27.2	27.9	30.2	30.3	29.3	267	185	326	121
17:01-18:00	27.5	27.3	28.6	29.3	30.1	28.4	26.8	26.9	27.3	28.6	28.7	27.7	105	125	126	80
18:01-19:00	26.3	26.0	27.6	28.2	29.3	27.9	26.8	26.7	27.0	28.2	27.9	26.7	10	36	11	15
19:01-20:00	25.7	25.4	27.1	28.0	28.9	27.6	26.6	26.6	26.7	28.0	27.1	26.2	0	0	0	0
20:01-21:00	25.1	24.7	26.5	27.6	28.7	27.2	26.3	26.3	26.0	27.1	26.5	25.4	0	0	0	0
21:01-22:00	24.6	24.0	26.0	27.4	28.5	27.0	26.2	26.2	25.9	26.9	25.9	24.7	0	0	0	0
22:01-23:00	23.8	23.5	25.6	27.1	28.4	26.7	26.2	26.1	25.8	26.7	25.2	24.0	0	0	0	0
23:01-24:00	23.1	22.6	25.0	26.7	28.2	26.4	25.9	25.6	25.2	25.1	24.3	23.1	0	0	0	0
Legend	Underheated	<23.0°C			Comfortable				Overheated	>26.8°C						

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (2005)

Table 5.101 Climatic data, Raxaul, Bihar

Latitude	N 26° 58'				Longitude	E 84° 50'				Altitude	79 m		
Climate	Warm and humid				Köppen	BSh							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	105.5	183.8	272.5	258.1	223.4	148.3	103.8	136.2	152.5	200.6	198.1	155.2	178.2
Cloud (%)	45.67	44.67	44.75	45.75	45.71	45.5	44.71	44.88	45.33	46.92	45.83	44.71	45.37
Solar irradiation daily average (Wh/m²)													
Global	2858	4356	5904	6519	6336	5557	4881	5060	4851	4626	3930	3123	4833
Diffuse	1926	1930	1886	2316	2888	3341	3493	3228	2735	2099	1615	1643	2425
Relative Humidity (%)													
morning	95	95	88	79	85	88	92	94	95	97	93	95	91.3
evening	66	47	38	35	53	63	73	75	68	53	40	53	55.3
Dry Bulb Temperature (°C)													
max	20.4	23.8	28.3	33.7	33.5	33.1	31.3	31.3	31.2	30.9	28.7	23.9	29.2
min	9.6	10.4	13.6	19.9	25.1	26.9	26.3	26.6	25	20.6	13.9	11.5	19.1
mean	15.0	17.1	21.0	26.8	29.3	30.0	28.8	29.0	28.1	25.8	21.3	17.7	24.1
Neutrality	22.5	23.1	24.3	26.1	26.9	27.1	26.7	26.8	26.5	25.8	24.4	23.3	25.3
Upper limit	25.0	25.6	26.8	28.6	29.4	29.6	29.2	29.3	29.0	28.3	26.9	25.8	27.8
Lower limit	20.0	20.6	21.8	23.6	24.4	24.6	24.2	24.3	24.0	23.3	21.9	20.8	22.8
Rain (mm) ^b	20.3	11	13.7	52.2	97.2	215.9	402.5	226.4	211.9	84.0	8.5	7.9	1352
Wind (m/s)	0.45	0.96	1.43	2.13	3.07	1.98	1.98	1.22	0.92	0.51	0.48	0.81	1.3
HDD	99	44	0	0	0	0	0	0	0	0	0	52	195
CDD	1	14	111	285	361	357	334	342	305	233	83	8	2434



Average diurnal range (°K)	10.1
Annual mean range (°K)	24.1

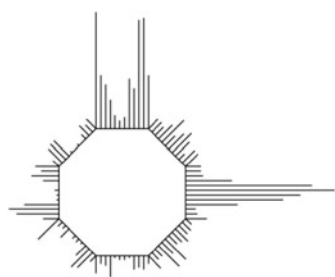
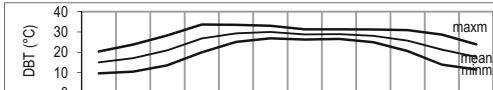
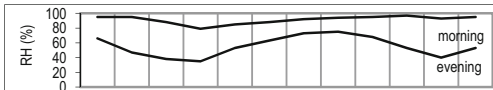
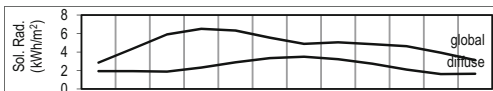


Table 5.102 Design conditions and overheated–underheated periods, Raxaul

Recommended “Design” conditions		
Summer	DBT (°C)	36.9
	MCWB (°C)	24.5
	WBT (°C)	28.4
	MCDB (°C)	32.0
Winter	DBT (°C)	8.5

Hourly temperature (°C) in all 12 months

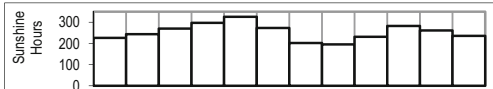
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	11.3	13.2	16.9	23.6	27.5	27.9	27.2	27.7	26.5	22.8	16.2	13.2	0	0	0	0
1:01- 2:00	10.5	12.3	15.9	22.4	26.8	27.5	26.9	27.3	25.9	22.2	15.4	12.8	0	0	0	0
2:01- 3:00	10.3	11.4	14.5	20.8	25.7	27.0	26.4	26.8	25.3	21.4	14.5	12.2	0	0	0	0
3:01- 4:00	9.6	10.6	13.7	19.9	25.2	26.9	26.3	26.6	25.0	20.8	13.9	11.8	0	0	0	0
4:01- 5:00	9.9	10.4	13.6	20.2	25.1	27.0	26.4	26.8	25.1	20.6	14.1	11.5	0	2	0	0
5:01- 6:00	9.8	11.0	15.0	21.7	25.9	27.7	27.0	27.5	25.9	21.4	15.4	12.0	7	52	0	0
6:01- 7:00	11.3	12.5	17.2	23.9	27.0	28.5	27.6	28.6	26.9	23.0	17.6	13.1	50	157	3	16
7:01- 8:00	13.0	14.6	20.2	26.6	28.6	29.5	28.4	29.8	28.1	24.9	20.3	14.8	132	243	30	95
8:01- 9:00	15.9	17.0	22.8	28.6	29.7	30.4	28.8	30.8	29.1	26.9	23.1	17.1	211	314	78	177
9:01-10:00	18.1	19.3	25.1	30.3	30.9	31.2	29.3	31.3	29.8	28.5	25.4	19.5	275	365	124	239
10:01-11:00	20.1	21.3	26.5	31.2	31.6	31.7	29.7	31.3	30.1	29.6	27.1	21.6	323	388	155	279
11:01-12:00	20.3	22.7	27.6	32.2	32.5	32.3	30.3	31.1	30.5	30.3	28.2	23.2	332	398	161	298
12:01-13:00	20.4	23.5	28.0	32.8	33.0	32.8	30.8	30.9	30.8	30.8	28.7	23.9	305	391	157	278
13:01-14:00	19.8	23.8	28.3	33.5	33.5	33.1	31.3	30.8	31.1	30.9	28.6	23.6	265	346	116	248
14:01-15:00	20.1	23.6	28.1	33.7	33.4	33.1	31.3	30.8	31.2	30.7	28.1	22.6	185	299	74	181
15:01-16:00	19.7	22.9	27.7	33.5	33.3	32.8	31.1	30.7	31.0	30.0	26.9	21.1	96	231	29	97
16:01-17:00	19.5	21.7	26.7	32.5	32.6	32.1	30.5	30.3	30.4	28.9	25.1	19.3	34	126	4	18
17:01-18:00	17.9	20.1	25.6	31.3	32.1	31.3	30.0	29.7	29.6	27.3	22.9	17.6	2	29	0	0
18:01-19:00	16.3	18.4	24.0	29.6	31.1	30.4	29.4	28.9	28.6	25.6	20.7	16.2	0	0	0	0
19:01-20:00	14.0	16.8	22.5	28.2	30.5	29.7	29.0	28.2	27.8	24.1	18.8	15.2	0	0	0	0
20:01-21:00	13.0	15.6	20.9	26.8	29.6	29.1	28.5	27.7	27.2	23.2	17.5	14.4	0	0	0	0
21:01-22:00	11.9	14.9	19.7	26.0	29.1	28.8	28.3	27.5	26.9	22.8	16.9	14.0	0	0	0	0
22:01-23:00	12.0	14.4	18.7	25.3	28.5	28.5	27.9	27.6	26.8	22.8	16.7	13.6	0	0	0	0
23:01-24:00	11.5	14.0	18.0	24.9	28.2	28.4	27.7	27.7	26.7	22.9	16.5	13.3	0	0	0	0
Legend	Underheated	<20.0°C				Comfortable						Overheated	>27.1°C			

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (2011)

Table 5.103 Climatic data, Saharangpur, Uttar Pradesh

Latitude	N 29° 51'				Longitude				E 77° 52'				Altitude	274 m
Climate	Composite				Köppen				BSh					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	226.3	243.6	269.7	297.0	325.5	273.0	201.5	195.3	231.0	282.1	261.0	235.6	253.5	
Cloud (%)	44.58	44.5	44.58	47.25	45.29	45.58	44.63	45.67	45.04	45.46	47.13	45.38	45.42	
Solar irradiation daily average (Wh/m²)														
Global	3734	4940	5815	7088	7271	7283	6931	6101	5533	5070	4332	3634	5644	
Diffuse	1256	1319	1816	1843	2275	2444	2567	2716	2344	1599	1092	1057	1861	
Relative Humidity (%)														
morning	95	93	91	85	87	86	91	95	96	94	95	95	91.9	
evening	53	34	39	27	38	45	60	73	66	45	33	42	46.3	
Dry Bulb Temperature (°C)														
max	20.1	24.8	27.2	35.1	34.4	35.5	33.6	31.4	31.1	30.8	27.3	22.3	29.5	
min	5.5	5.5	12.0	15.8	19.8	23.6	25.9	25.7	23.3	14.4	6.4	5.1	15.3	
mean	12.8	15.2	19.6	25.5	27.1	29.6	29.8	28.6	27.2	22.6	16.9	13.7	22.4	
Neutrality	21.8	22.5	23.9	25.7	26.2	27.0	27.0	26.7	26.2	24.8	23.0	22.0	24.7	
Upper limit	24.3	25.0	26.4	28.2	28.7	29.5	29.5	29.2	28.7	27.3	25.5	24.5	27.2	
Lower limit	19.3	20.0	21.4	23.2	23.7	24.5	24.5	24.2	23.7	22.3	20.5	19.5	22.2	
Rain (mm)^a	37.6	36.1	23.4	11.2	14.2	95.8	261.4	248.9	164.6	22.3	5.1	15.5	936.1	
Wind (m/s)	1.06	1.7	1.97	1.63	2.05	1.41	1.77	1.38	1.23	0.91	0.48	1.27	1.4	
HDD	199	100	9	0	0	0	0	0	0	1	81	178	568	
CDD	0	1	43	224	282	340	358	316	262	124	0	0	1950	



Average diurnal range (°K)	14.2
Annual mean range (°K)	30.4

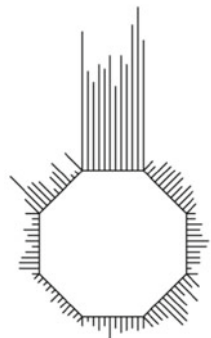
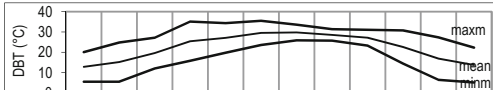
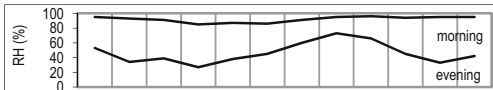
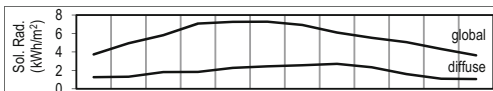


Table 5.104 Design conditions and overheated–underheated periods, Saharangpur

Recommended “Design” conditions															
Summer	DBT (°C)		39.6												
	MCWB (°C)		24.6												
	WBT (°C)		28.1												
	MCDB (°C)		32.9												
Winter	DBT (°C)		3.0												

Hourly temperature (°C) in all 12 months

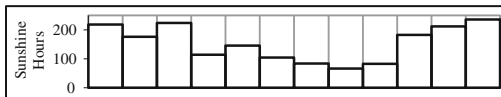
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan		
													H _b	H _d	H _b	H _d	
0:01- 1:00	7.3	8.8	14.7	19.4	21.9	25.8	27.1	26.6	24.4	17.2	9.2	7.5	0	0	0	0	
1:01- 2:00	6.3	7.4	13.8	18.0	21.1	25.0	26.7	26.2	23.9	16.3	8.1	6.5	0	0	0	0	
2:01- 3:00	6.2	6.7	13.0	16.6	20.1	24.2	26.3	26.0	23.5	15.1	7.3	6.0	0	0	0	0	
3:01- 4:00	5.5	5.6	12.2	15.8	19.8	23.6	25.9	25.7	23.3	14.4	6.4	5.1	0	0	0	0	
4:01- 5:00	5.8	5.6	12.0	16.3	20.2	23.9	26.0	25.8	23.3	14.5	6.6	5.2	0	0	0	0	
5:01- 6:00	5.5	5.5	12.6	18.2	22.1	25.0	26.5	26.0	23.7	16.1	7.3	5.2	9	36	0	0	
6:01- 7:00	6.2	7.0	14.3	21.3	24.6	26.8	27.6	26.6	24.6	18.6	9.7	6.5	91	115	1	0	
7:01- 8:00	7.5	9.2	16.6	24.9	27.5	28.7	28.9	27.4	25.7	21.7	12.7	8.5	225	182	41	48	
8:01- 9:00	10.5	13.2	19.6	28.3	29.6	30.5	30.2	28.3	27.1	24.6	16.9	12.0	383	217	151	106	
9:01-10:00	13.5	16.8	22.3	30.8	31.3	31.7	31.4	29.1	28.3	27.0	20.7	15.4	523	238	275	141	
10:01-11:00	16.8	20.7	24.7	32.5	32.1	32.6	32.2	29.9	29.4	28.6	24.2	18.9	633	239	371	162	
11:01-12:00	18.6	22.8	26.1	33.5	32.8	33.3	32.7	30.4	30.2	29.8	26.1	21.0	684	239	424	170	
12:01-13:00	20.1	24.5	27.1	34.3	33.4	34.1	33.1	30.9	30.9	30.5	27.3	22.3	665	246	417	174	
13:01-14:00	19.9	24.6	27.2	34.8	34.2	34.9	33.4	31.2	31.1	30.8	27.1	22.1	595	241	361	165	
14:01-15:00	19.8	24.8	27.2	35.1	34.4	35.5	33.6	31.4	31.0	30.4	26.4	21.5	478	228	263	142	
15:01-16:00	18.5	23.7	26.2	34.4	34.1	35.4	33.3	31.2	30.5	29.3	24.3	19.7	329	203	143	101	
16:01-17:00	17.2	22.4	24.8	32.8	32.8	34.5	32.7	30.7	29.6	27.2	21.8	17.7	172	160	31	47	
17:01-18:00	14.7	19.7	22.5	30.0	30.8	32.7	31.6	29.7	28.3	24.5	18.2	15.0	49	89	1	0	
18:01-19:00	12.7	17.3	20.3	26.9	28.3	30.6	30.3	28.7	27.0	21.6	15.0	12.7	2	11	0	0	
19:01-20:00	10.5	14.6	18.0	24.0	26.1	28.7	29.0	27.6	25.9	19.2	12.0	10.6	0	0	0	0	
20:01-21:00	9.6	13.2	16.7	22.0	24.3	27.3	28.1	27.1	25.3	17.7	10.6	9.5	0	0	0	0	
21:01-22:00	8.7	11.7	15.8	21.0	23.4	26.7	27.5	26.8	24.9	17.2	9.8	8.7	0	0	0	0	
22:01-23:00	8.6	11.2	15.7	20.6	22.8	26.5	27.4	26.8	24.9	17.2	9.9	8.5	0	0	0	0	
23:01-24:00	7.7	9.9	15.2	20.2	22.6	26.3	27.3	26.7	24.6	17.3	9.5	7.9	0	0	0	0	
Legend	Underheated			<19.3°C				Comfortable			Overheated			>27.0°C			

Sources of data: ISHRAE (2014), ^aIMD (1989)

Table 5.105 Climatic data, Shillong, Meghalaya

Latitude	N 25° 34'					Longitude	E 91° 52'					Altitude	1598 m
Climate	Cold					Köppen	Cfb						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h^a	218.7	175.4	223.7	113.7	145.3	104.6	83.9	66.9	82.4	182	211.7	235.5	153.7
Cloud (%)	44.96	45.04	44.46	46.96	46.04	44.33	43.75	42.92	45.00	44.58	43.96	44.63	44.72
Solar irradiation daily average (Wh/m²)													
Global	3898	4470	5188	5287	4884	4131	4305	4445	4001	4121	4158	3769	4388
Diffuse	1564	2031	2380	3019	3419	3446	3486	3368	3022	2384	1605	1429	2596
Relative Humidity (%)													
morning	98	93	90	88	94	96	97	95	97	96	95	96	94.6
evening	58	48	51	49	71	83	87	80	81	72	64	58	66.8
Dry Bulb Temperature (°C)													
max	12.4	13.9	17.7	20.4	20.2	21.3	21.0	21.9	20.9	20.4	16.5	15.0	18.5
min	2.1	4.0	5.9	11.1	13.5	16.6	17.0	16.6	15.5	11.5	5.7	2.5	10.2
mean	7.3	9.0	11.8	15.8	16.9	19.0	19.0	19.3	18.2	16.0	11.1	8.8	14.3
Neutrality	20.0	20.6	21.5	22.7	23.0	23.7	23.7	23.8	23.4	22.7	21.2	20.5	22.2
Upper limit	22.5	23.1	24.0	25.2	25.5	26.2	26.2	26.3	25.9	25.2	23.7	23.0	24.7
Lower limit	17.5	18.1	19.0	20.2	20.5	21.2	21.2	21.3	20.9	20.2	18.7	18.0	19.7
Rain (mm)^b	13.7	22.7	53.7	130.1	273.7	468.8	394.5	317.5	293.8	192.4	37.3	9.3	2208
Wind (m/s)	0.99	1.55	1.42	3.79	2.38	2.84	2.71	1.9	1.65	0.75	0.6	0.95	1.8
HDD	347	257	179	64	37	1	0	0	7	64	204	294	1454
CDD	0	0	0	0	6	30	32	41	12	0	0	0	121



Average diurnal range (°K) 8.3

Annual mean range (°K) 19.8

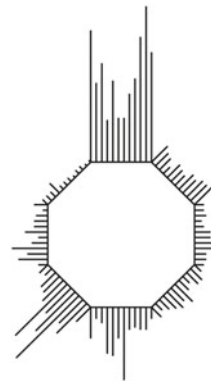
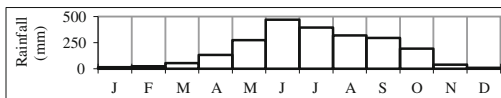
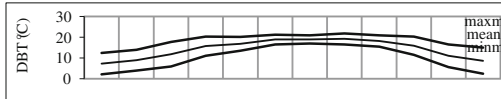
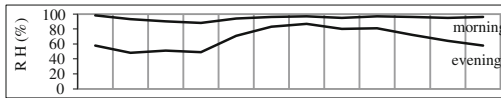
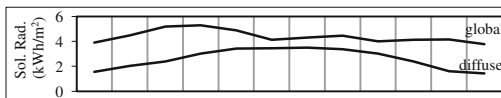


Table 5.106 Design conditions and overheated–underheated periods, Shillong

Recommended “Design” conditions															
Summer	DBT (°C)		23.5												
	MCWB (°C)		19.4												
	WBT (°C)		20.3												
	MCDB (°C)		22.7												
Winter	DBT (°C)		0.1												

Hourly temperature (°C) in all 12 months

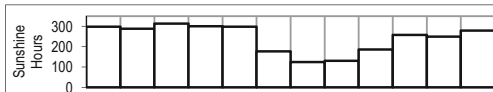
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	2.9	5.1	8.3	12.6	14.7	17.7	17.9	17.7	16.6	13.4	8.4	4.2	0	0	0	0
1:01- 2:00	2.4	4.5	7.4	11.9	14.3	17.2	17.5	17.3	16.2	12.8	7.5	3.5	0	0	0	0
2:01- 3:00	2.1	4.0	6.1	11.1	13.6	16.6	17.1	16.6	15.6	11.7	6.0	2.6	0	0	0	0
3:01- 4:00	2.3	4.0	5.9	11.1	13.5	16.6	17.0	16.6	15.5	11.5	5.7	2.5	0	0	0	0
4:01- 5:00	2.4	4.6	6.9	12.1	14.1	17.2	17.4	17.2	15.9	11.9	6.0	2.8	0	18	0	0
5:01- 6:00	3.8	6.2	9.5	14.2	15.8	18.6	18.5	18.6	17.2	14.1	8.4	5.6	13	90	2	1
6:01- 7:00	6.7	8.7	12.5	16.6	17.6	20.0	19.7	20.1	18.7	16.5	11.2	8.8	32	187	40	55
7:01- 8:00	9.8	11.2	15.5	18.8	19.4	21.1	20.7	21.5	20.2	19.0	14.3	12.2	56	277	140	123
8:01- 9:00	11.6	12.9	17.1	20.0	20.1	21.3	21.0	21.9	20.8	20.1	15.8	14.0	76	353	251	171
9:01-10:00	12.4	13.9	17.7	20.4	20.2	20.9	20.8	21.8	20.9	20.4	16.5	15.0	90	407	351	191
10:01-11:00	12.0	13.9	17.2	19.9	19.6	20.1	20.1	21.1	20.3	19.6	15.7	14.5	89	441	383	222
11:01-12:00	11.7	13.7	16.8	19.7	19.2	19.5	19.7	20.8	20.0	19.0	15.2	14.2	95	430	388	219
12:01-13:00	11.1	13.3	16.4	19.3	18.9	19.4	19.6	20.7	19.7	18.3	14.4	13.5	89	395	340	207
13:01-14:00	11.0	13.2	16.6	19.4	19.2	19.9	20.0	21.0	19.9	18.4	14.4	13.3	65	344	254	177
14:01-15:00	10.6	12.9	16.4	19.2	19.4	20.4	20.5	21.2	19.8	18.2	14.0	12.5	45	262	141	132
15:01-16:00	10.2	12.4	16.2	18.9	19.5	20.8	20.8	21.2	19.8	18.2	13.9	11.8	26	165	41	63
16:01-17:00	9.0	11.3	15.0	17.8	18.9	20.6	20.5	20.5	19.2	17.5	13.0	10.2	8	70	2	5
17:01-18:00	7.7	9.8	13.6	16.6	18.0	19.9	19.8	19.8	18.6	16.9	12.2	9.1	0	7	0	0
18:01-19:00	5.9	8.1	11.7	15.0	16.7	18.8	18.8	18.7	17.6	15.6	10.9	7.5	0	0	0	0
19:01-20:00	4.6	6.6	10.3	13.9	15.7	18.0	18.0	18.1	17.0	14.8	10.0	6.6	0	0	0	0
20:01-21:00	3.5	5.6	9.2	13.1	15.0	17.4	17.5	17.6	16.4	13.8	9.0	5.4	0	0	0	0
21:01-22:00	3.3	5.3	9.1	13.0	14.9	17.5	17.5	17.7	16.4	13.6	8.9	5.2	0	0	0	0
22:01-23:00	3.1	5.3	9.1	13.0	14.9	17.7	17.7	17.8	16.5	13.4	8.7	4.8	0	0	0	0
23:01-24:00	3.4	5.4	9.2	13.1	15.1	17.9	18.0	18.0	16.7	13.7	8.9	4.9	0	0	0	0
Legend	Underheated			<17.5°C				Comfortable			Overheated			>23.7°C		

Sources of data: ISHRAE (2014), ^aTyagi (2009 p 3400-5), ^bIndia Meteorological Department (nd)

Table 5.107 Climatic data, Solapur, Maharashtra

Latitude	N 17° 40'					Longitude	E 75° 54'					Altitude	479 m
Climate	Hot and dry					Köppen	BWh						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	297.6	288.4	313.1	300.0	297.6	177.0	124.0	130.2	186.0	257.3	249.0	279.0	241.6
Cloud (%)	7.3	14.7	12.3	34.8	34.4	66.9	77.3	72.7	70.0	47.5	32.0	18.8	40.72
Solar irradiation daily average (Wh/m²)													
Global	5656	6264	6893	7082	7050	5866	5230	5108	5624	5389	5267	5178	5884
Diffuse	1201	1431	1706	2089	2183	2928	3293	3283	2625	2112	1646	1271	2147
Relative Humidity (%)													
morning	60	64	54	64	77	82	89	86	90	84	76	68	74.5
evening	27	27	26	26	31	48	63	61	55	49	32	31	39.7
Dry Bulb Temperature (°C)													
max	31.2	32.9	36.6	38.4	37.3	34.3	30.7	29.3	31.0	30.3	31.9	30.7	32.9
min	17.3	21.5	24.6	26.6	27.2	26.7	24.3	23.9	23.9	22.2	21.2	18.1	23.1
mean	24.3	27.2	30.6	32.5	32.3	30.5	27.5	26.6	27.5	26.3	26.6	24.4	28.0
Neutrality	25.3	26.2	27.3	27.9	27.8	27.3	26.3	26.0	26.3	25.9	26.0	25.4	26.5
Upper limit	27.8	28.7	29.8	30.4	30.3	29.8	28.8	28.5	28.8	28.4	28.5	27.9	29.0
Lower limit	22.8	23.7	24.8	25.4	25.3	24.8	23.8	23.5	23.8	23.4	23.5	22.9	24.0
Rain (mm)^b	4.7	4.4	5.0	12.4	27.6	116.9	129.9	119.8	182.4	85.4	26.4	7.8	722.7
Wind (m/s)	0.69	0.82	0.95	1.20	1.26	1.21	1.20	1.03	1.04	0.69	0.68	0.95	1.0
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	179	252	394	438	432	358	282	254	267	251	254	192	3553



Average diurnal range (°K)	9.8
Annual mean range (°K)	21.1

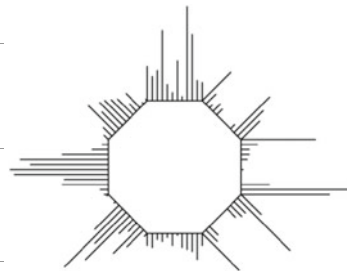
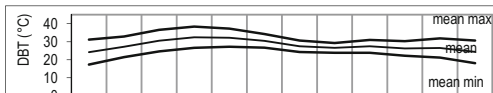
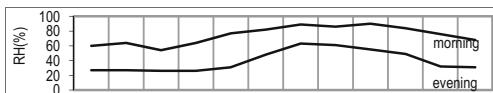
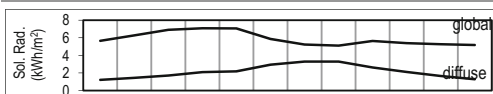


Table 5.108 Design conditions and overheated–underheated periods, Solapur

Recommended “Design” conditions														
Summer	DBT (°C)		40.1											
	MCWB (°C)		21.6											
	WBT (°C)		25.8											
	MCDB (°C)		32.1											
Winter	DBT (°C)		17.2											

Hourly temperature (°C) in all 12 months

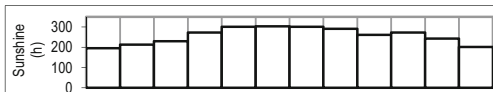
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Jan	
Hours													H _b	H _d	H _b	H _d
0:01- 1:00	20.0	24.5	28.1	30.1	29.5	28.0	25.3	24.5	25.2	23.6	23.5	21.1	0	0	0	0
1:01- 2:00	19.5	23.9	27.4	29.3	28.9	27.9	25.0	24.3	24.9	23.2	23.0	20.6	0	0	0	0
2:01- 3:00	19.0	23.5	26.8	28.7	28.5	27.4	24.8	24.2	24.6	22.9	22.5	20.0	0	0	0	0
3:01- 4:00	18.5	23.0	26.1	27.9	28.0	27.2	24.6	24.2	24.3	22.6	22.2	19.5	0	0	0	0
4:01- 5:00	18.0	22.5	25.5	27.4	27.6	27.0	24.5	24.0	24.1	22.4	21.8	19.0	0	0	0	0
5:01- 6:00	17.7	21.9	24.9	26.7	27.2	26.8	24.3	23.9	23.9	22.2	21.4	18.5	0	0	0	0
6:01- 7:00	17.3	21.5	24.6	26.6	27.3	26.7	24.4	23.9	23.9	22.2	21.2	18.1	14	22	0	0
7:01- 8:00	17.8	22.2	25.5	27.7	28.2	27.4	25.0	24.4	24.3	23.3	23.0	19.2	74	117	24	39
8:01- 9:00	21.6	24.5	27.8	29.8	29.7	28.5	26.2	25.6	25.6	25.9	26.0	22.1	233	188	166	99
9:01-10:00	24.4	27.0	30.5	32.2	31.2	29.7	27.2	26.3	27.1	27.7	28.0	24.7	408	227	362	127
10:01-11:00	26.8	29.1	32.6	34.3	32.9	30.9	28.4	27.3	28.5	29.1	29.5	26.5	566	241	540	137
11:01-12:00	28.5	30.8	34.3	35.9	34.4	32.2	29.3	28.4	29.6	29.9	30.5	28.1	712	225	676	133
12:01-13:00	29.8	31.9	35.3	37.0	35.7	33.2	29.8	28.8	30.4	30.3	31.3	29.4	818	192	733	129
13:01-14:00	30.7	32.6	36.0	37.8	36.6	33.9	30.4	29.3	31.0	30.3	31.7	30.2	806	177	704	127
14:01-15:00	31.1	32.9	36.5	38.4	37.3	34.2	30.7	29.2	30.7	30.3	31.9	30.7	651	193	586	130
15:01-16:00	31.2	32.7	36.6	38.4	37.2	34.3	30.5	28.9	30.1	30.2	31.7	30.7	424	209	413	124
16:01-17:00	30.7	32.3	36.3	38.1	37.1	33.3	30.0	28.6	29.5	29.5	31.0	30.1	219	180	211	103
17:01-18:00	29.4	31.3	35.4	37.4	36.3	32.6	29.2	27.9	28.6	28.4	29.6	28.6	61	107	41	52
18:01-19:00	26.6	29.5	33.8	35.8	35.0	31.5	28.4	27.1	27.9	27.1	28.0	26.6	5	11	1	0
19:01-20:00	24.5	27.8	32.3	34.4	33.6	30.3	27.5	26.5	27.3	26.2	26.9	25.3	0	0	0	0
20:01-21:00	23.2	26.7	31.4	33.5	32.5	29.5	26.8	25.9	26.7	25.4	26.1	24.2	0	0	0	0
21:01-22:00	22.2	26.0	30.6	32.7	31.5	29.0	26.3	25.7	26.3	24.8	25.4	23.2	0	0	0	0
22:01-23:00	21.4	25.4	29.7	31.5	30.6	28.7	25.9	25.2	25.9	24.3	24.7	22.4	0	0	0	0
23:01-24:00	20.6	24.8	29.0	30.7	29.9	28.2	25.4	24.8	25.5	23.9	24.0	21.7	0	0	0	0
Legend	Underheated			<22.8 °C	Comfortable								Overheated		>27.9°C	

Sources of data: ISHRAE (2014), ^aIMD (2005), ^bIndia Meteorological Department (nd)

Table 5.109 Climatic data, Srinagar, Jammu Kashmir

Latitude	N 34° 4'				Longitude				E 74° 49'				Altitude	1587 m
Climate	Cold				Köppen				Cfa					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	195.3	212.8	229.4	273.0	300.7	303.0	300.7	291.4	261.0	272.8	243.0	201.5	257.1	
Cloud (%)	72.4	63.7	60.3	55.6	36.6	40.4	47.2	42.6	35.7	25.1	30.2	48.5	46.51	
Solar irradiation daily average (Wh/m²)														
Global	2489	3053	4419	5767	7196	7797	6949	6452	6045	5097	3421	2932	5135	
Diffuse	1208	1448	1914	2054	1960	1962	2391	2033	1526	1015	1031	837	1615	
Relative Humidity (%)														
morning	83	87	85	83	86	80	80	85	94	87	89	89	85.7	
evening	51	58	47	41	38	34	46	50	38	37	46	51	44.8	
Dry Bulb Temperature (°C)														
max	6.4	8.8	12.5	19.9	23.7	27.5	29.8	29.0	27.1	21.7	13.6	9.8	19.2	
min	1.2	2.1	4.8	10.0	12.5	16.2	20.7	19.0	15.1	8.2	2.3	0.6	9.4	
mean	3.8	5.5	8.7	15.0	18.1	21.9	25.3	24.0	21.1	15.0	8.0	5.2	14.3	
Neutrality	19.0	19.5	20.5	22.4	23.4	24.6	25.6	25.2	24.3	22.4	20.3	19.4	22.2	
Upper limit	21.5	22.0	23.0	24.9	25.9	27.1	28.1	27.7	26.8	24.9	22.8	21.9	24.7	
Lower limit	16.5	17.0	18.0	19.9	20.9	22.1	23.1	22.7	21.8	19.9	17.8	16.9	19.7	
Rain (mm)^b	62.2	71.4	101.1	90.7	68.2	36.3	54.3	64.6	35.4	30.9	19.7	41.4	676.2	
Wind (m/s)	0.46	0.45	0.61	0.63	0.61	0.61	0.49	0.54	0.50	0.40	0.43	0.42	0.51	
HDD	456	366	297	96	46	5	0	0	12	124	335	430	2167	
CDD	0	0	0	1	44	115	212	168	74	0	0	0	614	



Average diurnal range (°K)	9.8
Annual mean range (°K)	29.2

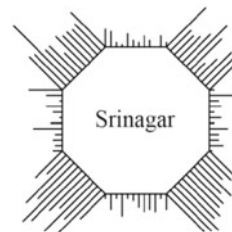
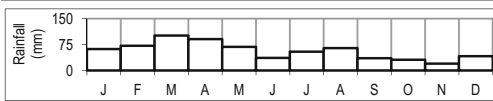
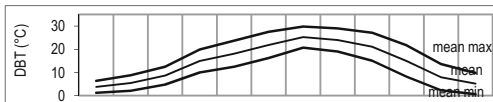
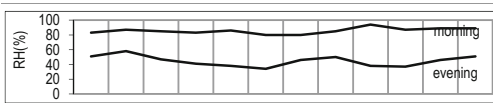
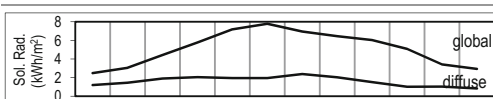


Table 5.110 Design conditions and overheated–underheated periods, Srinagar

Recommended “Design” conditions														
Summer	DBT (°C)		32.7											
	MCWB (°C)													
	WBT (°C)													
	MCDB (°C)													
Winter	DBT (°C)		-2.4											

Hourly temperature (°C) in all 12 months

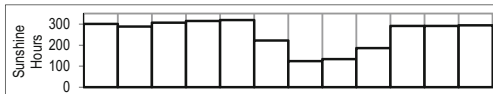
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jul		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	2.3	3.3	6.5	12.1	14.7	18.5	22.6	20.9	17.0	10.5	3.9	1.8	0	0	0	0
1:01- 2:00	2.1	3.1	6.1	11.6	14.0	17.8	22.1	20.5	16.6	10.0	3.6	1.6	0	0	0	0
2:01- 3:00	1.9	2.8	5.8	11.1	13.6	17.3	21.7	20.1	16.2	9.6	3.3	1.4	0	0	0	0
3:01- 4:00	1.7	2.6	5.5	10.8	13.3	16.8	21.4	19.7	15.9	9.3	3.0	1.2	0	0	0	0
4:01- 5:00	1.5	2.4	5.3	10.5	12.9	16.4	21.1	19.4	15.6	8.9	2.7	0.9	0	0	0	0
5:01- 6:00	1.3	2.2	5.0	10.0	12.5	16.2	20.7	19.0	15.3	8.5	2.5	0.8	1	4	0	0
6:01- 7:00	1.2	2.1	4.8	10.1	12.7	16.6	20.8	19.1	15.1	8.2	2.3	0.6	27	58	0	0
7:01- 8:00	1.2	2.1	4.9	11.2	14.5	18.2	21.5	19.9	15.5	8.7	2.3	0.6	125	125	1	4
8:01- 9:00	1.3	3.0	6.6	13.6	17.5	20.4	23.5	21.9	17.8	11.3	4.1	1.3	287	147	30	51
9:01-10:00	2.1	4.1	7.6	15.1	18.4	21.9	24.5	23.4	19.5	14.0	6.3	2.9	426	178	90	111
10:01-11:00	3.4	5.3	8.8	16.8	19.7	23.6	25.7	24.9	21.5	16.6	8.6	4.9	534	206	152	153
11:01-12:00	4.6	6.7	10.3	18.1	20.8	24.8	27.0	26.1	23.4	18.8	10.8	6.8	587	244	204	173
12:01-13:00	5.3	7.6	11.2	19.0	21.7	25.9	27.7	27.0	24.6	20.0	11.9	8.0	610	256	222	185
13:01-14:00	5.7	8.3	11.6	19.4	22.6	26.5	28.5	28.0	25.7	21.1	12.8	8.5	579	264	209	184
14:01-15:00	6.2	8.7	12.2	19.8	23.3	27.2	29.2	28.8	26.5	21.7	13.6	9.5	512	252	176	159
15:01-16:00	6.4	8.8	12.5	19.9	23.7	27.5	29.8	29.0	27.1	21.7	13.6	9.8	403	234	125	115
16:01-17:00	6.1	8.6	12.5	19.4	23.7	27.3	29.6	28.6	26.8	20.5	12.9	9.3	276	197	60	62
17:01-18:00	5.3	7.8	12.0	18.5	23.6	26.6	28.7	27.7	24.9	18.1	10.2	7.1	146	143	11	12
18:01-19:00	4.3	6.5	11.1	17.4	21.8	24.9	27.6	25.7	22.1	15.6	8.2	5.6	42	75	0	0
19:01-20:00	3.7	5.6	10.0	16.3	19.4	23.1	26.2	24.2	20.5	14.3	7.0	4.6	3	7	0	0
20:01-21:00	3.2	4.9	9.1	15.1	17.9	21.9	25.1	23.1	19.5	13.3	6.0	3.8	0	0	0	0
21:01-22:00	3.0	4.3	8.3	14.4	16.8	21.0	24.3	22.4	18.6	12.4	5.3	3.2	0	0	0	0
22:01-23:00	2.7	3.9	7.6	13.7	16.0	20.2	23.7	21.7	17.8	11.6	4.7	2.7	0	0	0	0
23:01-24:00	2.4	3.5	7.1	12.9	15.4	19.3	23.0	21.1	17.3	10.8	4.1	2.3	0	0	0	0
Legend	Underheated			<16.5°C			Comfortable						Overheated		>25.6°C	

Sources of data: ^aTyagi (2009 p 850), ^bIndia Meteorological Department (nd), ISHRAE (2014), http://climate.onebuilding.org/WMO_Region_2_Asia/IND_India/index.html

Table 5.111 Climatic data, Surat, Gujarat

Latitude	N 21° 12'				Longitude				E 72° 49'				Altitude	12 m
Climate	Warm and humid				Köppen				BSH					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Sunshine h ^a	300.7	288.4	306.9	315.0	319.3	222.0	124.0	133.3	186.0	291.4	291.0	294.5	256.0	
Cloud (%)	43.9	43.3	45.3	44.6	46.8	43.2	45.1	45.0	44.7	44.4	45.3	44.2	44.65	
Solar irradiation daily average (Wh/m²)														
Global	4791	5775	6698	7176	7198	5828	4447	4324	5195	5697	4973	4621	5560	
Diffuse	1482	1518	1700	1961	2209	3191	3481	3383	2847	1805	1536	1339	2204	
Relative Humidity (%)														
morning	71	76	73	70	85	83	91	93	93	79	65	72	79.3	
evening	42	39	36	37	48	66	78	80	77	53	38	33	52.3	
Dry Bulb Temperature (°C)														
max	28.9	30.4	33.5	34.3	35.6	32.3	30.1	29.4	30.4	32.7	31.2	29.6	31.5	
min	17.3	18.8	21.0	26.4	27.5	28.2	26.7	26.3	26.6	25.8	21.5	17.0	23.6	
mean	23.1	24.6	27.3	30.4	31.6	30.3	28.4	27.9	28.5	29.3	26.4	23.3	27.6	
Neutrality	25.0	25.4	26.2	27.2	27.6	27.2	26.6	26.4	26.6	26.9	26.0	25.0	26.3	
Upper limit	27.5	27.9	28.7	29.7	30.1	29.7	29.1	28.9	29.1	29.4	28.5	27.5	28.8	
Lower limit	22.5	22.9	23.7	24.7	25.1	24.7	24.1	23.9	24.1	24.4	23.5	22.5	23.8	
Rain (mm)^b	2.1	1.0	0.8	2.2	6.4	212.8	440.8	233.4	169.7	33.5	12.4	2.1	1117	
Wind (m/s)	1.84	1.29	1.18	2.17	1.73	2.30	2.37	2.18	1.05	1.21	1.27	1.29	1.7	
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	
CDD	142	170	263	355	400	363	321	299	304	337	241	156	3351	



Average diurnal range (°K)	7.9
Annual mean range (°K)	18.6

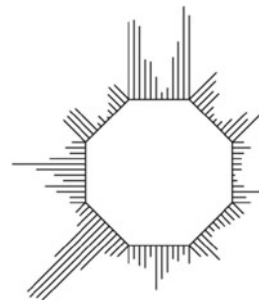
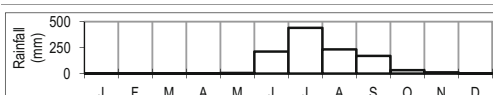
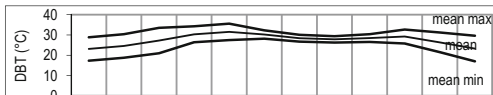
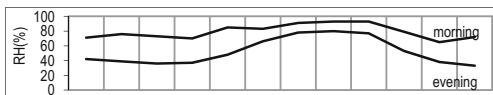
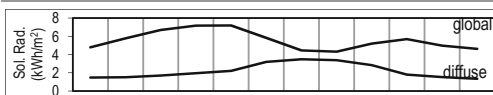


Table 5.112 Design conditions and overheated–underheated periods, Surat

Recommended “Design” conditions														
Summer	DBT (°C)		36.9											
	MCWB (°C)		23.9											
	WBT (°C)		27.9											
	MCDB (°C)		31.7											
Winter	DBT (°C)		16.2											

Hourly temperature (°C) in all 12 months

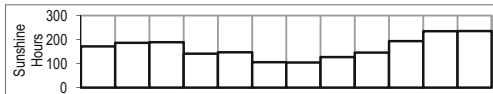
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	20.7	21.4	23.2	27.5	28.7	29.1	27.5	26.9	27.2	27.4	24.1	20.7	0	0	0	0
1:01- 2:00	19.8	20.6	22.4	27.1	28.2	28.7	27.2	26.7	27.0	26.8	23.3	19.7	0	0	0	0
2:01- 3:00	19.7	20.2	21.9	26.5	27.7	28.5	26.9	26.5	26.8	26.7	22.9	19.6	0	0	0	0
3:01- 4:00	18.8	19.4	21.2	26.4	27.5	28.2	26.7	26.3	26.6	26.2	22.2	18.5	0	0	0	0
4:01- 5:00	18.5	19.2	21.1	26.5	27.6	28.3	26.7	26.3	26.6	26.2	21.8	18.2	0	0	0	0
5:01- 6:00	17.3	18.8	21.0	27.3	28.1	28.5	26.9	26.4	26.7	25.8	21.5	17.0	0	3	0	0
6:01- 7:00	17.3	19.4	21.8	28.1	29.0	29.0	27.3	26.7	26.9	26.2	22.2	17.3	26	72	0	0
7:01- 8:00	17.5	20.5	23.2	29.2	30.1	29.5	27.9	27.2	27.4	26.6	23.0	17.9	154	156	35	56
8:01- 9:00	19.6	22.8	25.5	30.0	31.2	30.1	28.6	27.6	28.0	28.0	24.9	20.6	338	197	174	109
9:01-10:00	21.6	25.1	27.9	31.1	32.4	30.5	29.1	28.1	28.8	29.0	26.5	23.0	516	215	325	147
10:01-11:00	24.3	27.5	30.4	31.9	33.6	31.0	29.6	28.6	29.5	30.4	28.3	26.0	654	222	441	178
11:01-12:00	25.7	29.1	32.1	33.1	34.6	31.3	29.9	29.0	30.1	30.9	29.2	27.2	729	227	517	191
12:01-13:00	27.3	30.2	33.3	33.8	35.3	31.8	30.1	29.2	30.4	31.7	30.2	28.6	738	225	536	193
13:01-14:00	27.8	30.3	33.5	34.3	35.6	32.1	30.1	29.4	30.4	32.0	30.6	28.7	674	222	492	188
14:01-15:00	28.9	30.4	33.3	33.9	35.3	32.3	30.1	29.2	30.2	32.7	31.2	29.6	547	216	397	170
15:01-16:00	28.8	29.6	32.3	33.1	34.4	32.3	29.9	28.9	29.7	32.7	31.1	29.4	374	200	264	137
16:01-17:00	28.6	28.6	31.0	31.9	33.1	32.0	29.5	28.5	29.1	32.6	30.7	29.3	191	161	116	88
17:01-18:00	26.6	26.8	29.1	30.9	31.8	31.2	29.0	28.1	28.5	31.3	29.2	27.3	44	89	13	24
18:01-19:00	25.0	25.3	27.5	30.0	30.6	30.5	28.5	27.7	28.0	30.2	27.8	25.6	1	6	0	0
19:01-20:00	22.8	23.6	25.9	29.5	29.8	29.8	28.1	27.4	27.7	28.6	26.0	23.2	0	0	0	0
20:01-21:00	22.1	22.8	25.1	29.0	29.4	29.5	27.8	27.2	27.5	28.1	25.1	22.3	0	0	0	0
21:01-22:00	21.2	22.1	24.5	28.8	29.2	29.3	27.7	27.1	27.4	27.5	24.4	21.2	0	0	0	0
22:01-23:00	21.5	22.1	24.3	28.3	29.2	29.4	27.7	27.1	27.3	27.7	24.5	21.4	0	0	0	0
23:01-24:00	20.8	21.6	23.8	28.1	29.1	29.3	27.6	27.0	27.2	27.4	24.1	20.6	0	0	0	0
Legend	Underheated			<22.5°C	Comfortable								Overheated		>27.6°C	

Sources of data: ISHRAE (2014), ^aIMD (1995), ^bIndia Meteorological Department (nd)

Table 5.113 Climatic data, Tezpur, Assam

Latitude	N 26° 37'				Longitude	E 92° 46'				Altitude	79 m		
Climate	Warm and humid				Köppen	Cfa							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	171.8	186.5	188.9	141.5	147.1	105.7	104.4	126.9	145.6	193.7	234.7	235.4	165.2
Cloud (%)	45.0	42.5	45.0	46.7	45.0	44.8	47.1	48.0	44.8	43.4	44.3	46.3	45.24
Solar irradiation daily average (Wh/m²)													
Global	3471	4411	4969	5041	5368	4993	4887	4948	4778	4575	4308	3833	4632
Diffuse	1743	1943	2436	3167	3358	3546	3499	3226	2840	2164	1425	1288	2553
Relative Humidity (%)													
morning	94	91	87	86	95	94	95	96	97	94	94	96	93.3
evening	53	52	58	51	70	74	80	77	80	64	59	59	64.8
Dry Bulb Temperature (°C)													
max	23.4	24.2	27.4	29.2	29.8	31.7	30.0	31.2	29.7	30.2	27.0	24.1	28.2
min	12.0	14.3	18.9	19.3	22.5	26.1	26.0	26.3	24.8	21.6	16.7	13.1	20.1
mean	17.7	19.3	23.2	24.3	26.2	28.9	28.0	28.8	27.3	25.9	21.9	18.6	24.1
Neutrality	23.3	23.8	25.0	25.3	25.9	26.8	26.5	26.7	26.2	25.8	24.6	23.6	25.3
Upper limit	25.8	26.3	27.5	27.8	28.4	29.3	29.0	29.2	28.7	28.3	27.1	26.1	27.8
Lower limit	20.8	21.3	22.5	22.8	23.4	24.3	24.0	24.2	23.7	23.3	22.1	21.1	22.8
Rain (mm)^b	10.8	12	19.1	89.2	185.5	185.9	194.2	217.3	158.6	74.4	52.5	2.7	1202
Wind (m/s)	1.4	1.9	2.2	1.9	1.3	1.0	0.4	0.8	1.1	0.8	0.8	1.1	1.2
HDD	38	13	0	0	0	0	0	0	0	0	1	20	72
CDD	3	26	147	177	252	318	305	325	269	229	91	4	2146



Average diurnal range (°K)	8.0
Annual mean range (°K)	19.7

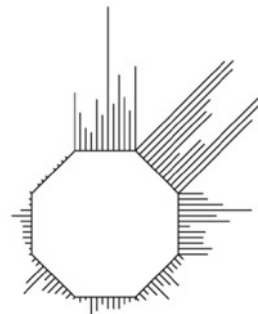
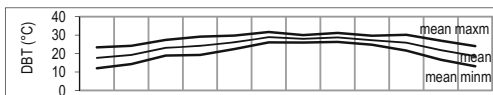
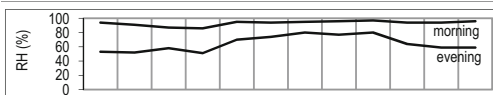
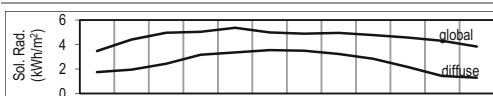


Table 5.114 Design conditions and overheated–underheated periods, Tezpur

Recommended “Design” conditions														
Summer	DBT (°C)		33.3											
	MCWB (°C)		26.5											
	WBT (°C)		28.4											
	MCDB (°C)		31.8											
Winter	DBT (°C)		12.4											

Hourly temperature (°C) in all 12 months

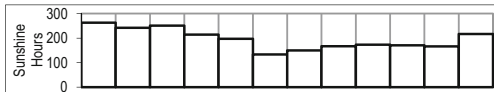
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	13.6	15.7	20.2	20.7	23.4	26.7	26.5	26.9	25.4	22.9	18.1	14.3	0	0	0	0
1:01- 2:00	12.9	15.1	19.8	20.1	22.8	26.5	26.3	26.7	25.1	22.5	17.8	13.9	0	0	0	0
2:01- 3:00	12.3	14.5	19.1	19.4	22.5	26.1	26.0	26.3	24.8	21.8	17.0	13.4	0	0	0	0
3:01- 4:00	12.0	14.3	18.9	19.3	22.6	26.1	26.0	26.3	24.8	21.6	16.9	13.2	0	0	0	0
4:01- 5:00	12.1	14.3	19.0	19.6	23.2	26.3	26.1	26.4	24.9	21.6	16.7	13.1	2	24	0	0
5:01- 6:00	12.7	15.0	19.7	20.6	24.1	27.0	26.5	27.1	25.5	22.6	17.8	13.9	27	108	1	3
6:01- 7:00	13.8	16.0	20.7	21.8	25.3	27.8	27.1	27.7	26.1	23.9	19.1	15.1	67	208	31	59
7:01- 8:00	15.5	17.4	22.1	23.5	26.5	28.7	27.7	28.6	27.0	25.7	21.1	17.0	120	291	104	137
8:01- 9:00	17.5	18.9	23.5	25.0	27.5	29.5	28.3	29.1	27.7	27.0	22.7	19.0	162	362	191	193
9:01-10:00	19.6	20.7	25.0	26.5	28.4	30.2	28.9	29.7	28.4	28.3	24.5	21.1	182	420	257	233
10:01-11:00	21.5	22.2	26.1	27.7	29.0	30.8	29.4	30.1	28.9	29.2	25.7	22.8	213	426	292	252
11:01-12:00	22.8	23.6	27.1	28.8	29.6	31.3	29.8	30.7	29.5	30.0	26.9	23.9	198	433	288	254
12:01-13:00	23.4	24.2	27.4	29.2	29.8	31.6	30.0	31.0	29.7	30.2	27.0	24.1	181	398	247	237
13:01-14:00	23.1	24.1	27.3	29.2	29.8	31.7	30.0	31.2	29.7	30.1	26.7	23.6	137	350	190	186
14:01-15:00	22.0	23.0	26.4	28.3	29.4	31.4	29.8	30.9	29.3	29.1	25.3	22.1	96	268	100	132
15:01-16:00	20.5	21.6	25.4	27.3	28.7	30.8	29.4	30.4	28.7	27.9	23.8	20.5	48	176	27	54
16:01-17:00	18.9	20.0	24.1	25.9	27.8	29.9	28.8	29.6	27.9	26.4	22.0	18.7	14	75	1	2
17:01-18:00	17.6	18.9	23.3	24.8	26.9	29.2	28.3	29.0	27.2	25.4	20.8	17.5	0	7	0	0
18:01-19:00	16.6	18.0	22.6	23.9	26.1	28.4	27.8	28.3	26.6	24.5	19.9	16.5	0	0	0	0
19:01-20:00	16.1	17.8	22.3	23.4	25.6	27.8	27.5	28.0	26.3	24.2	19.5	16.0	0	0	0	0
20:01-21:00	15.8	17.4	21.9	22.8	25.2	27.4	27.2	27.6	26.0	23.7	19.0	15.6	0	0	0	0
21:01-22:00	15.5	17.3	21.7	22.4	24.9	27.2	27.1	27.5	25.9	23.7	18.9	15.3	0	0	0	0
22:01-23:00	15.0	16.8	21.2	21.8	24.5	27.0	26.9	27.2	25.7	23.4	18.5	14.9	0	0	0	0
23:01-24:00	14.5	16.4	20.9	21.4	24.0	27.0	26.8	27.2	25.6	23.3	18.4	14.6	0	0	0	0
Legend	Underheated			<20.8°C	Comfortable								Overheated		>26.8°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (2013)

Table 5.115 Climatic data, Thiruvananthapuram, Kerala

Latitude	N 8° 28'				Longitude				E 76° 56'				Altitude	64 m	
Climate	Warm and humid				Köppen				Af						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year		
Sunshine h ^a	262.8	242.3	250.7	214.0	197.3	133.5	149.7	166.6	173.4	170.8	166.3	216.6	195.3		
Cloud (%)	51.0	43.4	42.2	59.2	70.3	74.2	79.8	72.1	63.0	73.4	68.5	49.0	62.18		
Solar irradiation daily average (Wh/m²)															
Global	5592	6545	6767	6442	5852	5646	5496	5640	6468	5064	5035	5419	5831		
Diffuse	2108	1916	2113	2474	2611	2786	2883	2819	2274	2800	2455	2051	2441		
Relative Humidity (%)															
morning	91	93	84	87	92	90	90	92	94	94	88	92	90.6		
evening	54	53	60	66	65	77	75	72	66	74	71	58	65.9		
Dry Bulb Temperature (°C)															
max	30.4	30.7	32.2	32.3	31.0	29.2	28.6	28.8	29.9	28.6	29.5	30.3	30.1		
min	23.9	24.3	25.1	26.2	26.1	25.3	24.6	24.8	24.6	24.6	24.5	24.1	24.8		
mean	27.2	27.5	28.7	29.3	28.6	27.3	26.6	26.8	27.3	26.6	27.0	27.2	27.5		
Neutrality	26.2	26.3	26.7	26.9	26.7	26.2	26.0	26.1	26.2	26.0	26.2	26.2	26.1		
Upper limit	28.7	28.8	29.2	29.4	29.2	28.7	28.5	28.6	28.7	28.5	28.7	28.7	28.6		
Lower limit	23.7	23.8	24.2	24.4	24.2	23.7	23.5	23.6	23.7	23.5	23.7	23.7	23.6		
Rain (mm) ^b	22.9	21.9	36.4	110.5	210	343.5	218.6	143.2	152.5	267.9	199	70.2	1797		
Wind (m/s)	0.28	0.4	0.44	0.42	0.65	0.83	0.54	0.58	0.62	0.43	0.27	0.12	0.5		
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0		
CDD	276	266	327	323	313	272	257	265	267	255	261	279	3361		



Average diurnal range (°K)	5.3
Annual mean range (°K)	2.7

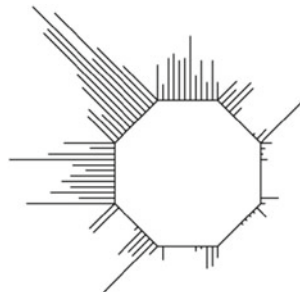
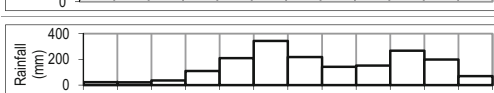
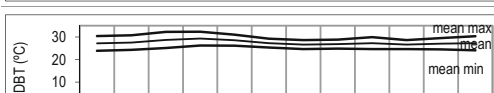
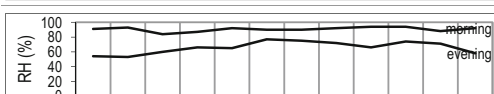
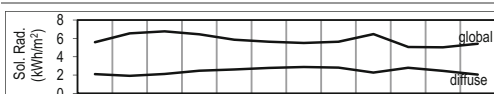


Table 5.116 Design conditions and overheat–underheated periods, Thiruvananthapuram

Recommended “Design” conditions														
Summer	DBT (°C)	33.4												
	MCWB (°C)	26.1												
	WBT (°C)	27.4												
	MCDB (°C)	31.9												
Winter	DBT (°C)	22.2												

Hourly temperature (°C) in all 12 months

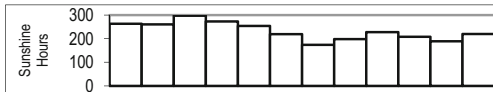
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	25.3	26.0	26.9	26.9	26.5	25.9	25.1	25.2	25.3	24.8	25.2	25.2	0	0	0	0
1:01- 2:00	25.0	25.8	26.7	26.8	26.4	25.7	25.0	25.1	25.2	24.8	25.0	25.0	0	0	0	0
2:01- 3:00	24.7	25.4	26.2	26.6	26.3	25.6	24.9	25.0	25.0	24.7	24.9	24.7	0	0	0	0
3:01- 4:00	24.4	25.1	25.9	26.5	26.2	25.5	24.8	24.9	24.9	24.7	24.8	24.5	0	0	0	0
4:01- 5:00	24.2	24.8	25.6	26.4	26.2	25.5	24.8	24.9	24.8	24.6	24.6	24.4	0	0	0	0
5:01- 6:00	24.0	24.5	25.1	26.2	26.1	25.3	24.6	24.8	24.6	24.6	24.5	24.2	0	0	0	0
6:01- 7:00	23.9	24.3	25.1	26.3	26.1	25.4	24.7	24.8	24.6	24.6	24.5	24.1	12	16	2	1
7:01- 8:00	24.0	24.8	25.5	27.3	26.9	25.7	25.0	25.2	25.3	25.0	24.8	24.6	89	108	47	64
8:01- 9:00	25.7	26.1	27.8	29.4	28.6	27.2	26.1	26.2	27.0	26.3	26.6	26.7	228	186	172	141
9:01-10:00	27.7	28.2	29.7	30.5	29.4	28.1	26.9	27.0	28.2	27.3	28.0	28.5	376	238	308	202
10:01-11:00	29.2	30.0	31.3	31.7	30.2	28.9	27.6	28.0	29.2	28.2	28.8	29.4	493	277	424	244
11:01-12:00	30.0	30.6	32.2	32.3	30.8	29.2	28.2	28.7	29.7	28.6	29.2	30.2	567	298	507	264
12:01-13:00	30.4	30.7	32.2	32.3	31.0	29.2	28.3	28.8	29.9	28.5	29.4	30.3	588	304	537	270
13:01-14:00	30.4	30.7	32.2	32.0	31.0	29.1	28.6	28.7	29.8	28.5	29.5	30.3	552	295	510	264
14:01-15:00	30.1	30.6	31.9	31.5	30.7	28.9	28.4	28.8	29.7	28.5	29.4	30.2	466	269	431	243
15:01-16:00	29.8	30.2	31.3	31.1	30.3	29.0	28.2	28.6	29.3	28.2	29.0	29.8	340	226	316	201
16:01-17:00	29.3	29.6	30.6	30.4	29.6	28.6	27.8	28.1	28.4	27.7	28.4	29.2	191	167	177	144
17:01-18:00	28.4	28.8	29.8	29.3	28.8	27.9	27.3	27.5	27.5	26.8	27.5	28.1	60	84	52	67
18:01-19:00	27.7	28.1	29.2	28.7	28.2	27.0	26.5	27.0	26.9	26.2	26.9	27.5	5	7	2	3
19:01-20:00	27.3	27.8	28.9	28.3	27.5	26.7	26.1	26.7	26.6	25.9	26.5	27.1	0	0	0	0
20:01-21:00	26.8	27.6	28.3	28.0	27.2	26.5	25.7	26.3	26.3	25.6	26.2	26.6	0	0	0	0
21:01-22:00	26.4	27.3	28.0	27.8	27.1	26.3	25.5	26.0	26.0	25.4	25.9	26.3	0	0	0	0
22:01-23:00	26.0	26.9	27.7	27.6	26.9	26.1	25.4	25.7	25.8	25.3	25.6	26.0	0	0	0	0
23:01-24:00	25.4	26.2	27.1	26.9	26.6	25.9	25.2	25.4	25.5	24.9	25.3	25.3	0	0	0	0
Legend	Underheated	<23.7°C			Comfortable				Overheated	>26.9°C						

Sources of data: ISHRAE (2014), ^ahttp://www.wmo.int/datastat/wmodata_en.htm, ^bIndia Meteorological Department (nd)

Table 5.117 Climatic data, Tiruchirappalli, Tamil Nadu

Latitude	N 10° 46'				Longitude				E 78° 43'				Altitude	88 m	
Climate	Warm and humid				Köppen				BSH						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year		
Sunshine h ^a	263.5	260.4	297.6	273.0	254.2	219.0	173.6	198.4	228.0	207.7	189.0	220.1	232.0		
Cloud (%)	46.2	33.8	34.9	47.1	54.6	61.0	72.5	61.9	61.8	67.1	62.6	53.8	54.77		
Solar irradiation daily average (Wh/m²)															
Global	5368	6259	6776	6517	6265	6159	5643	6196	6188	5074	4398	4738	5798		
Diffuse	2099	2004	2129	2531	2649	2636	2990	2633	2499	2770	2559	2177	2473		
Relative Humidity (%)															
morning	89	95	80	87	76	71	71	71	80	93	91	97	83.4		
evening	50	37	36	39	47	44	46	46	46	59	62	58	47.5		
Dry Bulb Temperature (°C)															
max	29.8	33.2	35.4	36.9	36.6	35.9	34.8	35.6	34.2	31.7	30.2	28.9	33.6		
min	21.1	22.2	24.5	27.6	27.2	27.1	27.1	27.3	26.0	25.2	23.9	22.7	25.2		
mean	25.5	27.7	30.0	32.3	31.9	31.5	31.0	31.5	30.1	28.5	27.1	25.8	29.4		
Neutrality	25.7	26.4	27.1	27.8	27.7	27.6	27.4	27.5	27.1	26.6	26.2	25.8	26.9		
Upper limit	28.2	28.9	29.6	30.3	30.2	30.1	29.9	30.0	29.6	29.1	28.7	28.3	29.4		
Lower limit	23.2	23.9	24.6	25.3	25.2	25.1	24.9	25.0	24.6	24.1	23.7	23.3	24.4		
Rain (mm) ^b	25.3	8.0	9.4	45.2	76.7	36.2	45.7	92.9	132.8	184.5	146.1	70.0	872.8		
Wind (m/s)	1.35	1.22	1.33	0.87	1.58	1.90	2.61	2.27	1.60	1.47	1.12	1.27	1.50		
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0		
CDD	220	255	357	408	413	389	384	402	341	300	259	229	3957		



Average diurnal range (°K)	8.4
Annual mean range (°K)	15.8

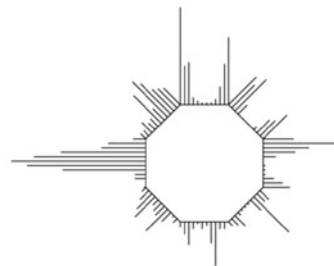
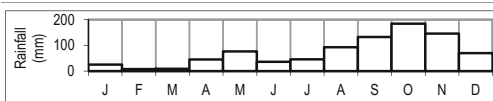
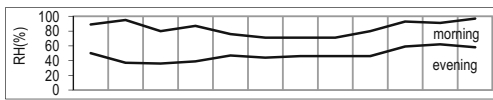
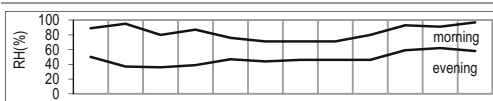


Table 5.118 Design conditions and overheat–underheated periods, Tiruchirappalli

Recommended “Design” conditions														
Summer	DBT (°C)		38.7											
	MCWB (°C)		25.1											
	WBT (°C)		27.2											
	MCDB (°C)		33.7											
Winter	DBT (°C)		20.1											

Hourly temperature (°C) in all 12 months

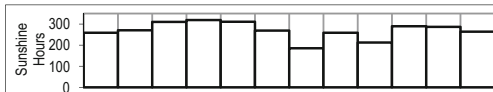
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr		Jan	
Hours													H _b	H _d	H _b	H _d
0:01- 1:00	22.4	23.5	26.3	29.0	28.5	28.4	28.1	28.6	27.0	26.0	24.7	23.6	0	0	0	0
1:01- 2:00	22.2	23.0	25.8	28.7	28.2	28.0	27.9	28.3	26.8	25.9	24.5	23.5	0	0	0	0
2:01- 3:00	22.0	22.7	25.3	28.4	27.9	27.8	27.7	28.1	26.6	25.8	24.3	23.3	0	0	0	0
3:01- 4:00	21.7	22.5	25.1	28.1	27.6	27.5	27.5	27.8	26.4	25.6	24.2	23.1	0	0	0	0
4:01- 5:00	21.5	22.4	24.9	27.9	27.5	27.3	27.3	27.6	26.3	25.4	24.1	23.1	0	0	0	0
5:01- 6:00	21.3	22.2	24.6	27.6	27.2	27.1	27.1	27.3	26.0	25.2	23.9	22.8	0	0	0	0
6:01- 7:00	21.1	22.2	24.5	27.6	27.4	27.1	27.1	27.4	26.1	25.2	24.0	22.7	13	30	2	3
7:01- 8:00	22.0	23.6	25.6	28.9	28.3	28.2	28.1	28.3	27.1	26.0	24.9	23.6	98	127	50	69
8:01- 9:00	24.2	26.0	27.9	30.2	30.1	29.9	29.6	29.8	28.6	27.3	26.4	24.9	240	204	170	148
9:01-10:00	25.8	27.9	29.6	31.9	31.5	31.5	31.0	31.5	30.1	28.4	27.4	26.1	382	259	303	206
10:01-11:00	27.2	29.6	31.5	33.6	32.9	32.9	32.3	32.9	31.5	29.3	28.5	27.1	505	286	417	243
11:01-12:00	28.2	31.1	33.1	35.0	34.1	34.2	33.7	34.4	32.8	30.5	29.2	28.1	584	296	488	266
12:01-13:00	29.0	32.3	34.2	36.1	35.1	35.0	34.5	35.0	33.6	31.1	29.7	28.4	602	297	508	274
13:01-14:00	29.5	32.9	34.9	36.8	35.9	35.6	34.8	35.6	34.2	31.7	30.1	28.7	558	288	476	265
14:01-15:00	29.8	33.2	35.4	36.9	36.5	35.9	34.7	35.6	34.0	31.4	30.2	28.9	459	267	395	241
15:01-16:00	29.7	33.1	35.3	36.7	36.6	35.7	34.3	35.2	33.0	30.8	30.1	28.5	322	228	278	198
16:01-17:00	29.4	32.5	35.0	36.0	36.3	35.3	33.5	34.6	32.1	29.6	29.5	27.8	176	163	147	134
17:01-18:00	28.2	31.2	33.8	34.6	35.3	34.1	32.4	33.4	31.3	28.4	28.1	26.9	48	78	35	52
18:01-19:00	26.6	29.2	31.9	32.9	33.4	32.5	31.4	32.1	30.3	27.5	27.2	25.9	2	6	0	0
19:01-20:00	25.4	27.8	30.7	31.8	32.1	31.1	30.4	31.2	29.7	27.1	26.5	25.3	0	0	0	0
20:01-21:00	24.6	26.6	29.7	30.8	31.2	30.3	29.6	30.3	28.7	26.9	26.1	24.7	0	0	0	0
21:01-22:00	23.9	25.7	28.6	30.2	29.9	29.8	29.1	29.7	28.0	26.7	25.5	24.4	0	0	0	0
22:01-23:00	23.5	24.8	27.8	29.7	29.4	29.1	28.7	29.3	27.6	26.4	25.2	23.9	0	0	0	0
23:01-24:00	22.7	24.1	27.0	29.3	28.9	28.9	28.3	29.0	27.3	26.2	24.8	23.8	0	0	0	0
Legend	Underheated			<23.2°C	Comfortable								Overheated		>27.8°C	

Sources of data: ISHRAE (2014), ^aIMD (1999), ^bIndia Meteorological Department (nd)

Table 5.119 Climatic data, Varanasi, Uttar Pradesh

Latitude	N 25° 27'				Longitude				E 82° 52'				Altitude	85 m	
Climate	Composite				Köppen				BSh						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year		
Sunshine h^a	258.7	270.6	310.7	319.5	311.1	269.2	185.5	258.8	212.7	290.3	287.0	264.4	269.9		
Cloud (%)	15.8	23.4	11.3	23.0	27.6	54.2	73.4	72.0	62.6	17.9	3.7	8.7	32.78		
Solar irradiation daily average (Wh/m²)															
Global	3635	4839	6330	6860	7058	6003	5039	5077	5062	5071	4391	3471	5236		
Diffuse	1762	1802	1761	2117	2422	3034	3445	3224	2742	1956	1485	1642	2283		
Relative Humidity (%)															
morning	84	66	50	58	63	70	82	82	79	82	82	75	72.8		
evening	66	56	37	19	36	55	74	78	77	66	39	65	55.7		
Dry Bulb Temperature (°C)															
max	19.4	25.5	33.7	36.2	38.4	35.4	32.5	31	32	29.9	29.1	23.1	30.5		
min	10.5	15.2	20.0	23.1	27.2	27.5	27.4	27.6	27.3	22.7	16.8	12.9	21.5		
mean	15.0	20.4	26.9	29.7	32.8	31.5	30.0	29.3	29.7	26.3	23.0	18.0	26.0		
Neutrality	22.4	24.1	26.1	27.0	28.0	27.5	27.1	26.9	27.0	26.0	24.9	23.4	25.9		
Upper limit	24.9	26.6	28.6	29.5	30.5	30.0	29.6	29.4	29.5	28.5	27.4	25.9	28.4		
Lower limit	19.9	21.6	23.6	24.5	25.5	25.0	24.6	24.4	24.5	23.5	22.4	20.9	23.4		
Rain (mm)^b	17.6	15.0	7.9	4.4	10.5	96.6	309.9	273.2	246.4	35.1	10.7	6.5	1034		
Wind (m/s)	0.95	1.55	1.32	1.66	2.30	2.25	1.56	1.76	1.80	0.45	0.39	0.64	1.4		
HDD	127	13	0	0	0	0	0	0	0	0	0	40	180		
CDD	3	67	263	362	447	397	361	344	332	243	123	10	2952		



Average diurnal range (°K)	9.0
Annual mean range (°K)	27.9

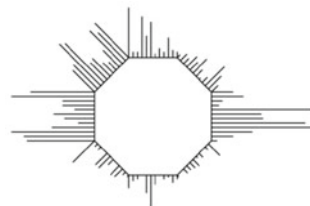
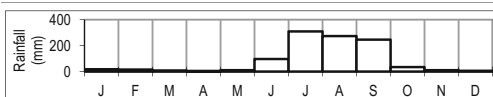
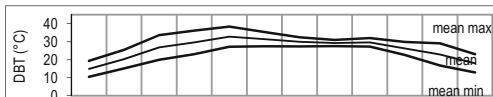
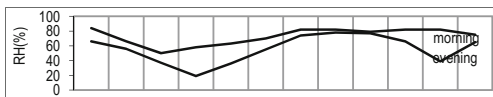
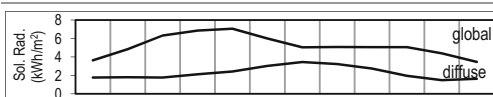


Table 5.120 Design conditions and overheat–underheated periods, Varanasi

Recommended “Design” conditions ^c														
Summer	DBT (°C)		41.8											
	MCWB (°C)		22.7											
	WBT (°C)		28.6											
	MCDB (°C)		33.2											
Winter	DBT (°C)		8.9											

Hourly temperature (°C) in all 12 months

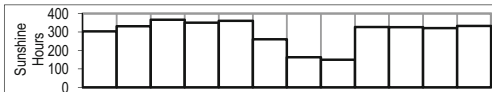
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	12.0	17.0	22.2	26.2	29.5	28.6	28.2	28.1	27.6	23.9	18.6	14.1	0	0	0	0
1:01- 2:00	11.7	16.6	21.7	25.7	29.0	28.3	28.1	28.0	27.5	23.6	18.2	13.8	0	0	0	0
2:01- 3:00	11.3	16.2	21.2	25.1	28.6	28.1	27.9	27.9	27.4	23.3	17.8	13.6	0	0	0	0
3:01- 4:00	11.2	15.8	20.7	24.6	28.1	27.9	27.7	27.7	27.3	23.1	17.5	13.3	0	0	0	0
4:01- 5:00	10.9	15.6	20.4	23.9	27.4	27.6	27.5	27.6	27.3	22.9	17.3	13.1	0	0	0	0
5:01- 6:00	10.7	15.4	20.0	23.1	27.2	27.5	27.4	27.6	27.3	22.8	17.0	13.0	2	9	0	0
6:01- 7:00	10.5	15.2	20.2	23.2	27.9	28.1	27.6	27.6	27.3	22.7	16.8	12.9	35	97	0	0
7:01- 8:00	10.7	16.2	23.1	25.0	29.5	29.6	28.3	28.0	27.7	23.6	18.3	13.4	182	173	8	45
8:01- 9:00	10.7	18.9	25.9	30.3	30.8	31.3	29.2	29.2	29.1	25.5	21.0	15.6	355	214	72	137
9:01-10:00	12.2	20.9	28.6	31.7	32.8	32.6	29.9	29.6	29.6	26.8	23.5	17.9	510	234	174	199
10:01-11:00	14.0	22.9	30.8	32.9	34.8	33.8	30.7	30.0	30.5	27.9	25.7	19.9	639	236	271	232
11:01-12:00	16.0	24.2	32.3	35.3	36.4	34.8	31.6	30.6	31.6	29.5	27.7	21.5	693	241	356	235
12:01-13:00	17.4	24.8	33.1	35.7	37.4	35.4	32.0	30.9	31.7	29.8	28.5	22.5	662	254	351	241
13:01-14:00	18.6	25.4	33.6	36.0	37.9	35.4	32.4	30.8	32.0	29.9	29.0	23.1	597	249	308	231
14:01-15:00	19.2	25.5	33.7	36.2	38.3	35.1	32.5	30.9	31.5	29.6	29.1	23.1	469	241	208	209
15:01-16:00	19.4	25.2	33.4	36.2	38.4	34.9	32.4	31.0	31.1	29.2	29.0	22.8	317	215	106	156
16:01-17:00	18.8	24.4	32.8	36.0	38.0	34.6	31.8	30.6	30.8	28.5	27.4	21.3	146	168	20	73
17:01-18:00	17.3	22.8	30.8	35.9	36.7	34.0	31.3	29.9	30.0	27.0	24.7	19.1	30	84	1	2
18:01-19:00	15.7	21.2	28.2	33.7	34.3	32.4	30.4	29.5	29.5	26.3	22.9	17.7	1	6	0	0
19:01-20:00	14.8	20.3	26.5	31.4	32.6	31.2	29.5	29.1	28.8	25.6	21.6	16.6	0	0	0	0
20:01-21:00	14.1	19.5	25.3	29.9	31.5	30.4	29.1	28.8	28.3	25.2	20.7	15.9	0	0	0	0
21:01-22:00	13.6	18.8	24.4	28.8	30.9	29.9	28.9	28.7	28.1	24.8	20.0	15.3	0	0	0	0
22:01-23:00	13.0	18.2	23.7	27.9	30.4	29.5	28.6	28.5	27.8	24.4	19.3	14.9	0	0	0	0
23:01-24:00	12.5	17.7	23.0	26.9	29.9	29.0	28.4	28.3	27.7	24.0	18.8	14.5	0	0	0	0
Legend	Underheated		<19.9°C			Comfortable						Overheated		>28.0°C		

Sources of data: ISHRAE (2014) ^aTyagi (2009 p 3619-24), ^bIndia Meteorological Department (nd), ^chttp://climate.onebuilding.org/WMO_Region_2_Asia/IND_India/index.html

Table 5.121 Climatic data, Veraval, Gujarat

Latitude	N 20° 53'					Longitude	E 70°22'					Altitude	8 m
Climate	Warm and humid					Köppen	Aw						
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	300.7	286.8	336.6	336.2	352.0	226.9	132.1	120.3	257.3	271.3	289.3	291.0	266.7
Cloud (%)	7.3	8.2	6.3	16.0	24.7	52.8	75.5	76.3	33.1	21.1	11.6	10.1	28.59
Solar irradiation daily average (Wh/m²)													
Global	5151	5944	6832	7389	7558	6122	4866	4640	6127	5649	5295	4849	5869
Diffuse	1252	1426	1617	1827	1961	2964	3382	3311	2197	1813	1334	1221	2025
Relative Humidity (%)													
morning	57	64	76	85	87	87	87	88	88	79	64	68	77.5
evening	37	41	49	64	73	75	84	84	77	56	36	40	59.7
Dry Bulb Temperature (°C)													
max	28.8	27.8	29.3	31.2	31.6	31.9	29.5	29.2	30.3	32.4	31.6	29.3	30.2
min	17.4	18.5	21.4	25.0	26.8	28.6	28.1	27.1	26.8	25.4	22.7	19.2	23.9
mean	23.1	23.2	25.4	28.1	29.2	30.3	28.8	28.2	28.6	28.9	27.2	24.3	27.1
Neutrality	25.0	25.0	25.7	26.5	26.9	27.2	26.7	26.5	26.7	26.8	26.2	25.3	26.2
Upper limit	27.5	27.5	28.2	29.0	29.4	29.7	29.2	29.0	29.2	29.3	28.7	27.8	28.7
Lower limit	22.5	22.5	23.2	24.0	24.4	24.7	24.2	24.0	24.2	24.3	23.7	22.8	23.7
Rain (mm)^b	1.0	1.7	0.9	1.8	5.8	128.0	250.5	133.6	75.7	19.4	5.1	1.3	624.8
Wind (m/s)	3.18	3.52	3.73	4.27	4.94	5.63	7.13	5.75	3.39	3.00	3.00	2.97	4.2
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	146	146	229	300	344	361	330	304	309	326	274	179	3248



Average diurnal range (°K)	6.3
Annual mean range (°K)	15.0

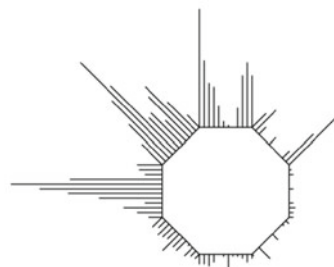
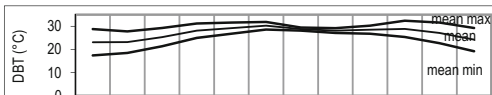
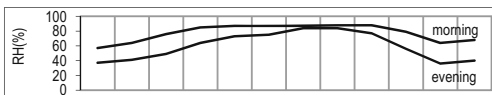


Table 5.122 Design conditions and overheat–underheated periods, Veraval

Recommended “Design” conditions														
Summer	DBT (°C)		33.8											
	MCWB (°C)		23.5											
	WBT (°C)		28.7											
	MCDB (°C)		31.6											
Winter	DBT (°C)		15.6											

Hourly temperature (°C) in all 12 months

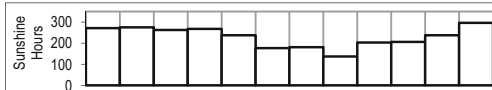
Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m²) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun		Jan	
													H _b	H _d	H _b	H _d
0:01- 1:00	20.5	21.2	23.3	26.4	27.6	29.0	28.2	27.2	27.1	26.8	24.8	20.8	0	0	0	0
1:01- 2:00	19.9	20.6	22.9	26.2	27.4	28.9	28.2	27.2	27.0	26.4	24.4	20.2	0	0	0	0
2:01- 3:00	19.4	20.3	22.4	26.0	27.2	28.8	28.2	27.2	27.0	26.2	24.1	19.8	0	0	0	0
3:01- 4:00	18.9	19.8	22.0	25.7	27.0	28.7	28.2	27.1	26.9	25.9	23.8	19.4	0	0	0	0
4:01- 5:00	18.5	19.5	21.7	25.5	26.8	28.6	28.1	27.1	26.8	25.7	23.3	19.3	0	0	0	0
5:01- 6:00	18.1	19.1	21.6	25.2	26.9	28.7	28.1	27.1	26.8	25.5	23.0	19.2	0	0	0	0
6:01- 7:00	17.6	18.7	21.4	25.0	27.3	29.2	28.1	27.2	26.8	25.4	22.7	19.2	3	17	0	0
7:01- 8:00	17.4	18.5	21.6	25.5	28.0	29.6	28.1	27.2	27.0	25.6	22.7	19.3	43	105	6	10
8:01- 9:00	17.9	20.3	24.1	27.7	29.3	30.2	28.4	27.3	27.6	27.5	25.0	20.7	136	192	90	72
9:01-10:00	19.9	23.3	27.1	29.4	29.8	30.5	28.5	27.5	28.0	30.1	27.9	23.2	245	260	255	116
10:01-11:00	22.4	25.4	28.7	30.4	30.2	30.9	28.7	27.8	28.9	31.8	30.0	26.1	345	307	420	141
11:01-12:00	25.0	27.5	29.3	31.2	31.1	31.7	29.3	28.7	29.8	32.4	31.5	28.4	425	330	549	152
12:01-13:00	26.8	27.8	29.2	30.6	31.3	31.8	29.4	28.9	30.0	32.3	31.5	29.0	461	342	625	153
13:01-14:00	28.1	27.8	29.0	30.6	31.6	31.9	29.4	29.0	30.0	31.8	31.5	29.3	450	342	629	149
14:01-15:00	28.7	27.5	29.0	30.8	31.5	31.6	29.4	29.2	30.3	31.5	31.6	29.3	403	320	559	144
15:01-16:00	28.8	27.1	28.7	30.6	31.2	31.4	29.5	28.9	30.2	31.2	31.2	29.0	317	286	426	133
16:01-17:00	28.3	26.7	28.2	30.3	30.9	31.1	29.2	28.7	30.0	30.3	30.4	28.4	207	235	253	110
17:01-18:00	27.4	25.7	27.5	29.5	30.5	30.8	28.9	28.2	29.4	29.6	29.4	27.2	102	159	81	67
18:01-19:00	26.3	24.7	26.3	28.6	29.7	30.2	28.8	27.9	29.0	28.9	28.6	26.0	22	68	5	6
19:01-20:00	25.2	24.2	25.8	28.1	28.9	29.7	28.7	27.7	28.6	28.5	28.1	25.0	0	3	0	0
20:01-21:00	23.8	23.9	25.4	27.5	28.6	29.4	28.6	27.5	28.2	28.3	27.5	24.2	0	0	0	0
21:01-22:00	22.8	23.4	25.2	27.4	28.6	29.5	28.6	27.6	28.2	28.0	27.0	23.6	0	0	0	0
22:01-23:00	22.0	22.7	24.9	27.2	28.7	29.6	28.6	27.6	28.2	27.6	26.1	22.8	0	0	0	0
23:01-24:00	21.2	21.8	23.9	26.6	27.9	29.2	28.2	27.2	27.3	27.1	25.2	21.5	0	0	0	0
Legend	Underheated		<22.5°C		Comfortable								Overheated		>27.2°C	

Sources of data: ISHRAE (2014), ^aEstimated using the equation given by Muneer (2004), ^bIMD (1995)

Table 5.123 Climatic data Vishakhapatnam, Andhra Pradesh

Latitude	N 17° 42'				Longitude	E 83° 18'				Altitude	66 m		
Climate	Warm and humid				Köppen	Am							
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sunshine h ^a	271.9	275.2	262.5	268.1	238.0	176.5	180.9	136.7	203.1	206.3	237.8	296.9	229.5
Cloud (%)	45.8	46.2	45.0	45.0	45.0	45.5	43.8	45.2	46.1	46.5	44.3	46.4	45.4
Solar irradiation daily average (Wh/m²)													
Global	4894	5868	6469	6797	6194	5235	4828	4764	4893	4864	4969	4667	5370
Diffuse	1755	1738	2032	2302	2913	3394	3484	3401	3133	2594	1839	1686	2523
Relative Humidity (%)													
morning	93	94	86	86	87	86	90	92	95	88	88	86	89.3
evening	47	57	46	53	59	65	74	73	70	78	74	54	62.5
Dry Bulb Temperature (°C)													
max	30.5	30.1	32.9	34.6	34.7	33.2	31.6	31.6	32.1	28.8	27.2	27.9	31.3
min	18.4	21.6	23.1	26.6	27.2	27.6	27.1	26.4	25.9	26.6	24.2	19.2	24.5
mean	24.5	25.9	28.0	30.6	31.0	30.4	29.4	29.0	29.0	27.7	25.7	23.6	27.9
Neutrality	25.4	25.8	26.5	27.3	27.4	27.2	26.9	26.8	26.8	26.4	25.8	25.1	26.4
Upper limit	27.9	28.3	29.0	29.8	29.9	29.7	29.4	29.3	29.3	28.9	28.3	27.6	28.9
Lower limit	22.9	23.3	24.0	24.8	24.9	24.7	24.4	24.3	24.3	23.9	23.3	22.6	23.9
Rain (mm)^b	14.2	21.1	8.3	25.6	68.7	124.6	142.1	165.2	164	238.2	124	6.7	1103
Wind (m/s)	2.4	3.2	3.2	5.2	4.1	4.3	4.9	4.2	2.2	3.4	2.0	3.4	3.5
HDD	0	0	0	0	0	0	0	0	0	0	0	0	0
CDD	181	210	302	359	384	364	343	330	312	302	222	159	3468



Average diurnal range (°K)	6.8
Annual mean range (°K)	16.3

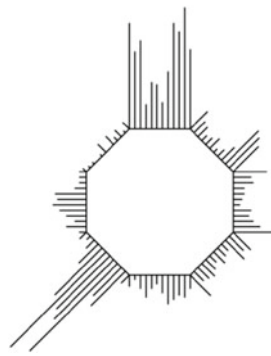
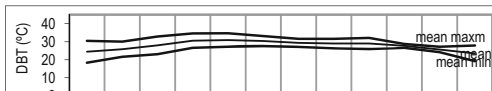
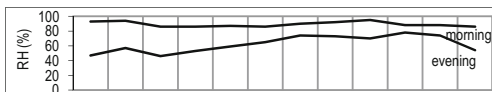
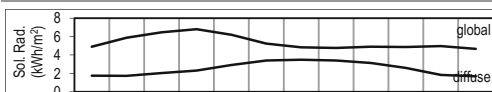


Table 5.124 Design conditions and overheated–underheated periods, Vishakhapatnam

Recommended “Design” conditions														
Summer	DBT (°C)		35.6											
	MCWB (°C)		27.3											
	WBT (°C)		28.8											
	MCDB (°C)		33.0											
Winter	DBT (°C)		16.8											

Hourly temperature (°C) in all 12 months

Hourly Direct (H_b) and diffuse (H_d) horizontal irradiation (Wh/m^2) in summer and winter months

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May		Dec	
													H_b	H_d	H_b	H_d
0:01- 1:00	20.2	23.1	25.0	27.7	28.1	28.4	27.7	27.1	26.7	27.7	25.4	20.5	0	0	0	0
1:01- 2:00	19.5	22.7	24.4	27.4	27.8	28.2	27.5	26.9	26.5	27.4	25.2	20.1	0	0	0	0
2:01- 3:00	19.1	22.1	23.6	26.9	27.4	27.9	27.3	26.6	26.2	27.0	24.6	19.4	0	0	0	0
3:01- 4:00	18.5	21.7	23.1	26.6	27.2	27.7	27.1	26.5	26.0	26.7	24.4	19.2	0	0	0	0
4:01- 5:00	18.4	21.6	23.1	26.8	27.4	27.6	27.1	26.4	25.9	26.6	24.2	19.2	0	0	0	0
5:01- 6:00	18.8	22.1	23.9	27.4	28.2	28.0	27.3	26.9	26.4	26.7	24.4	20.1	7	40	0	0
6:01- 7:00	20.2	23.1	25.3	28.5	29.3	28.7	27.7	27.5	27.1	27.0	24.8	21.4	80	131	27	51
7:01- 8:00	22.3	24.8	27.3	30.0	30.8	29.7	28.4	28.4	28.3	27.3	25.5	23.2	187	217	140	120
8:01- 9:00	25.0	26.5	29.4	31.7	32.2	30.7	29.2	29.1	29.5	27.7	26.0	24.9	303	279	275	172
9:01-10:00	27.4	28.2	31.2	33.2	33.5	31.7	30.1	29.9	30.6	28.0	26.6	26.4	403	318	393	202
10:01-11:00	29.4	29.4	32.4	34.2	34.3	32.4	30.8	30.5	31.5	28.2	27.0	27.3	470	337	468	219
11:01-12:00	30.3	30.1	32.9	34.6	34.7	33.0	31.4	31.2	32.1	28.5	27.2	27.9	492	339	494	219
12:01-13:00	30.5	30.0	32.8	34.4	34.5	33.2	31.6	31.5	32.1	28.7	27.2	27.9	454	339	456	214
13:01-14:00	29.8	29.6	32.3	33.7	34.0	33.2	31.5	31.6	31.8	28.8	26.9	27.5	382	313	367	195
14:01-15:00	29.0	28.7	31.6	32.7	33.0	32.9	31.2	31.2	31.0	28.7	26.3	26.8	285	261	242	159
15:01-16:00	27.9	27.8	30.7	31.7	32.0	32.4	30.7	30.6	30.1	28.5	25.7	25.9	161	202	107	104
16:01-17:00	26.9	26.9	29.7	30.7	30.9	31.7	30.2	29.8	29.1	28.2	25.0	24.8	55	115	13	31
17:01-18:00	25.5	26.2	28.7	29.9	30.2	30.9	29.6	29.1	28.3	27.9	24.7	23.8	5	20	0	0
18:01-19:00	24.4	25.7	27.8	29.3	29.6	30.2	29.2	28.5	27.6	27.6	24.5	22.8	0	0	0	0
19:01-20:00	23.1	25.3	27.0	28.8	29.3	29.5	28.8	28.2	27.3	27.7	24.6	22.0	0	0	0	0
20:01-21:00	22.3	24.8	26.4	28.5	28.9	29.0	28.5	27.8	27.0	27.7	24.7	21.3	0	0	0	0
21:01-22:00	21.6	24.4	26.0	28.3	28.8	28.7	28.3	27.7	26.9	27.8	24.9	21.0	0	0	0	0
22:01-23:00	21.2	24.0	25.8	28.2	28.6	28.5	28.1	27.4	26.8	27.9	25.0	20.8	0	0	0	0
23:01-24:00	20.7	23.7	25.5	28.0	28.4	28.5	27.9	27.3	26.8	27.9	25.1	20.7	0	0	0	0
Legend	Underheated			<22.6°C	Comfortable							Overheated		>27.4°C		

Sources of data: ISHRAE (2014), ^aTyagi (2009 p 304, 2979–2984), ^bIndia Meteorological Department (nd)

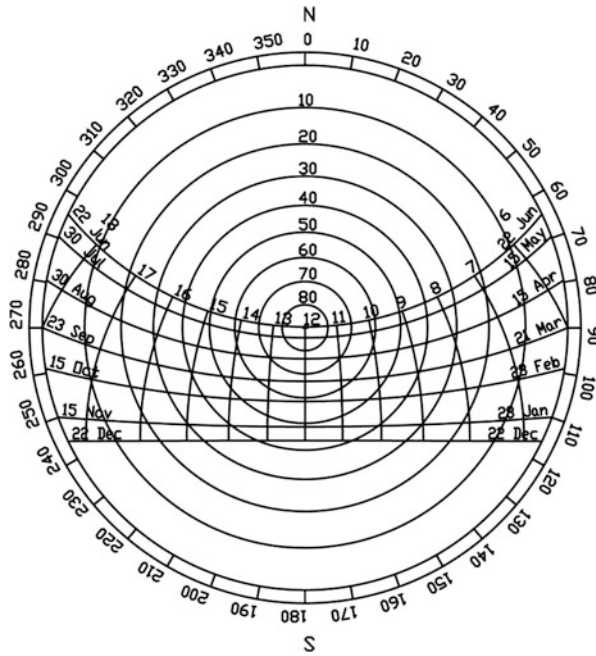


Fig. 5.2 A stereographic sun-path diagram for Ahmedabad, latitude $N 23^{\circ} 4'$

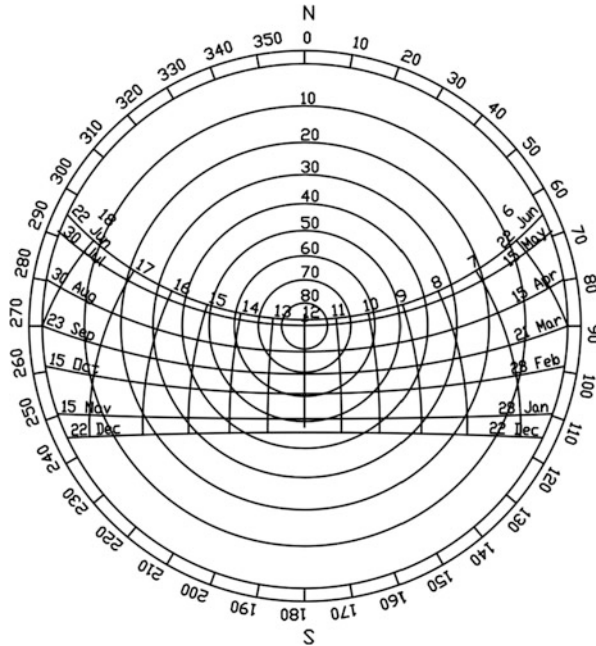


Fig. 5.3 A stereographic sun-path diagram for Akola, latitude $N 20^{\circ} 42'$

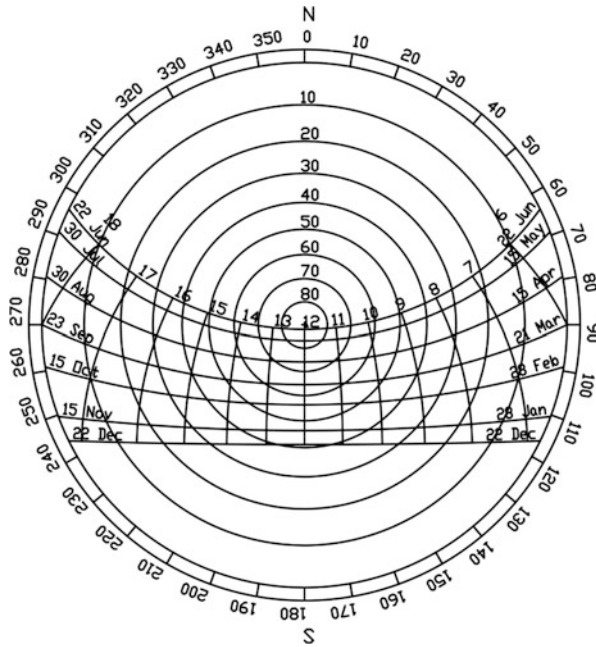


Fig. 5.4 A stereographic sun-path diagram for Allahabad, latitude N 25° 27'

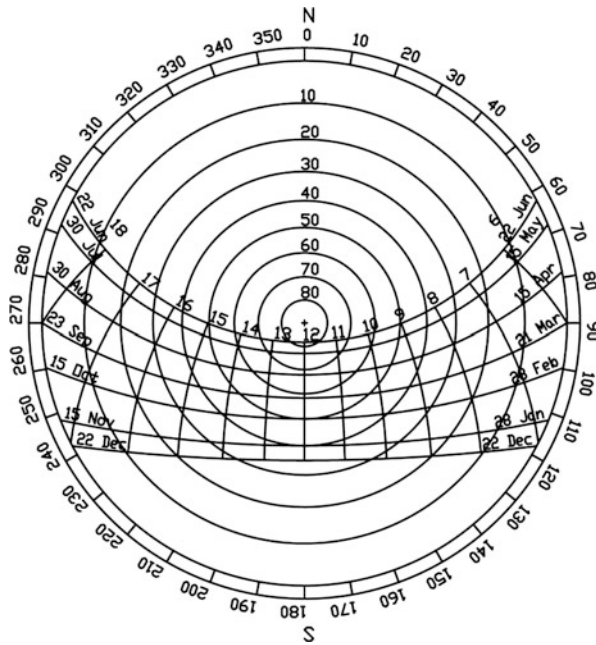


Fig. 5.5 A stereographic sun-path diagram for Amritsar, latitude N 31° 22'

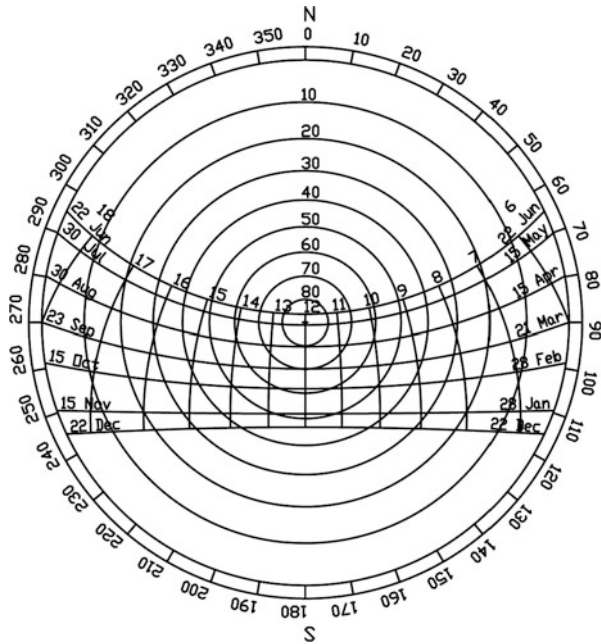


Fig. 5.6 A stereographic sun-path diagram for Aurangabad, latitude N 19° 51'

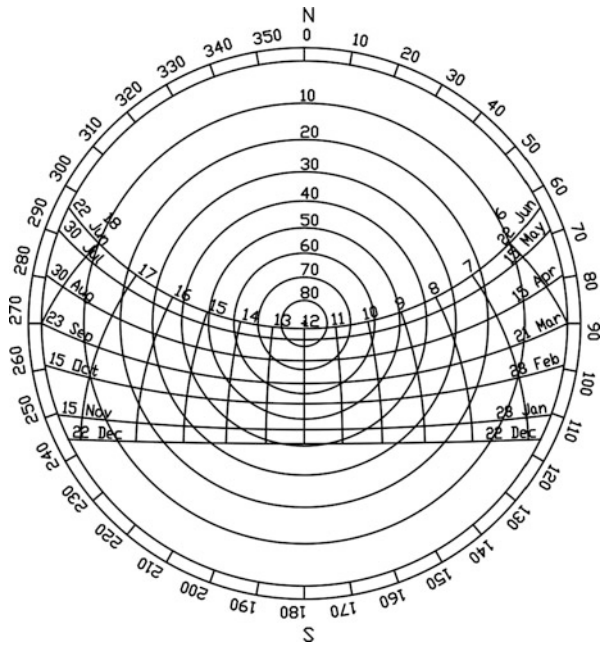


Fig. 5.7 A stereographic sun-path diagram for Barmer, latitude N 25° 45'

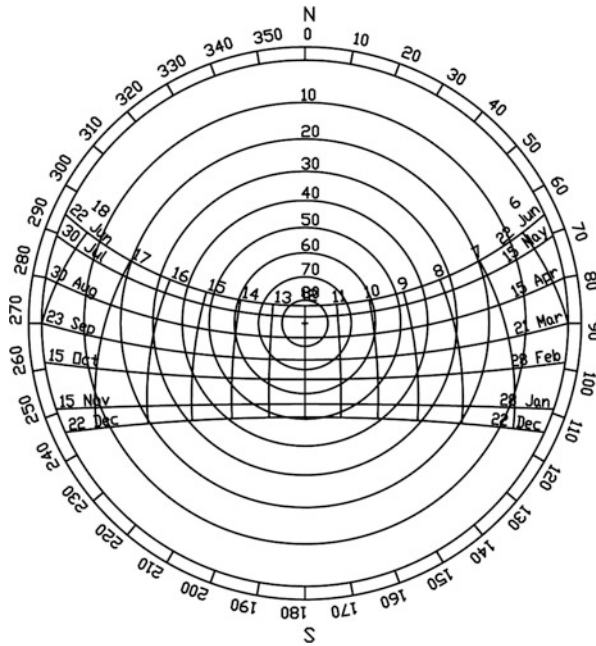


Fig. 5.8 A stereographic sun-path diagram for Belgaum, latitude N 15° 51'

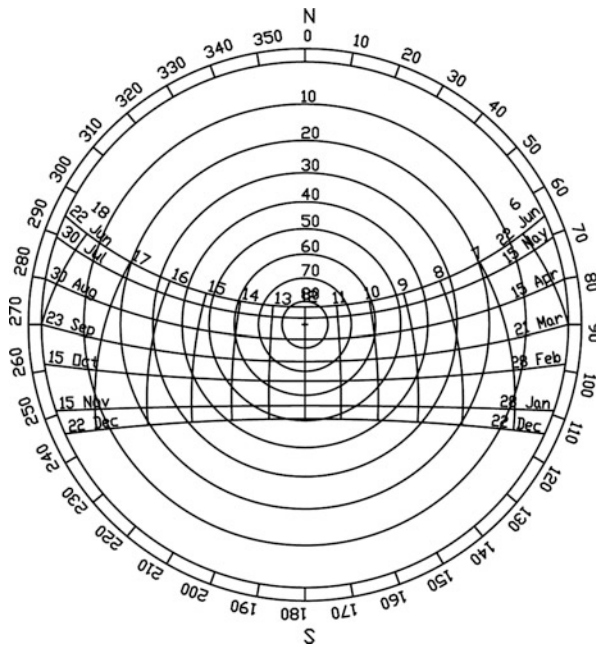


Fig. 5.9 A stereographic sun-path diagram for Bengaluru, latitude N 12° 58'

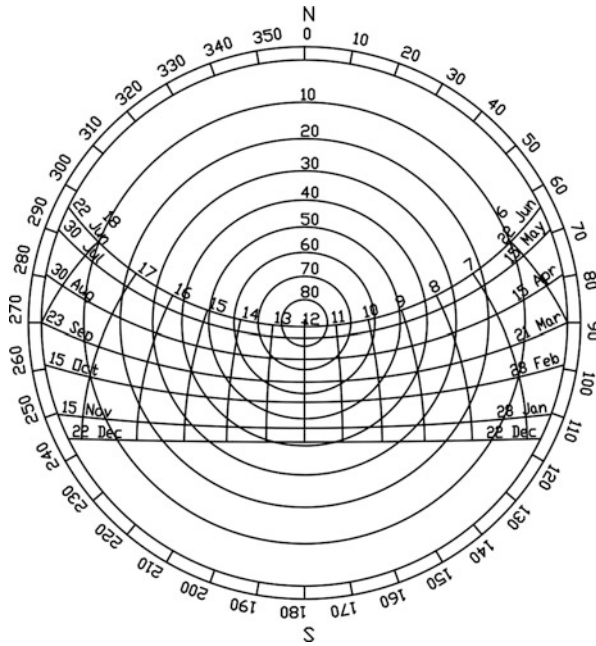


Fig. 5.10 A stereographic sun-path diagram for Bhagalpur, latitude $N 25^{\circ} 13'$

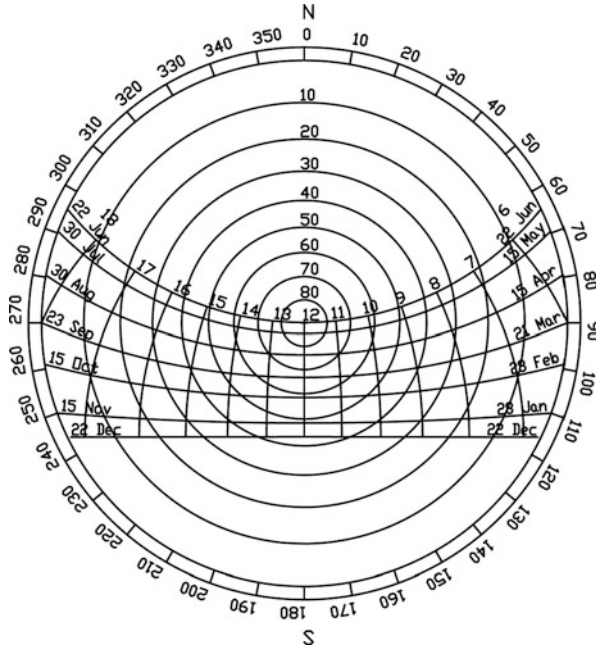


Fig. 5.11 A stereographic sun-path diagram for Bhopal, latitude $N 23^{\circ} 16'$

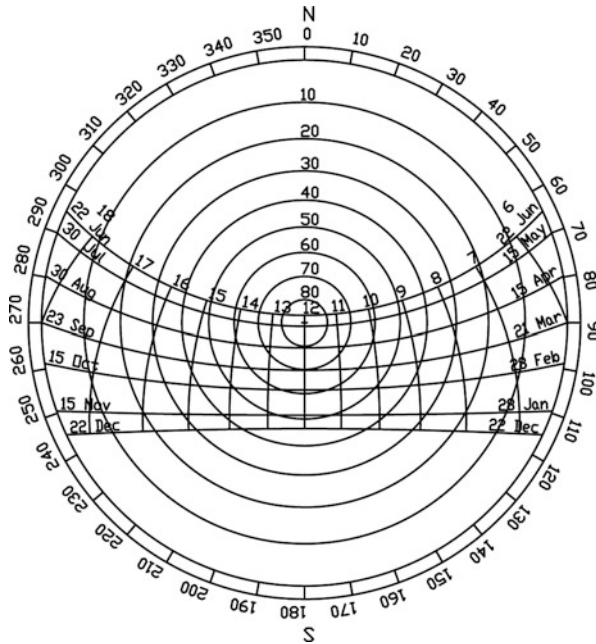


Fig. 5.12 A stereographic sun-path diagram for Bhubaneswar, latitude N 20° 15'

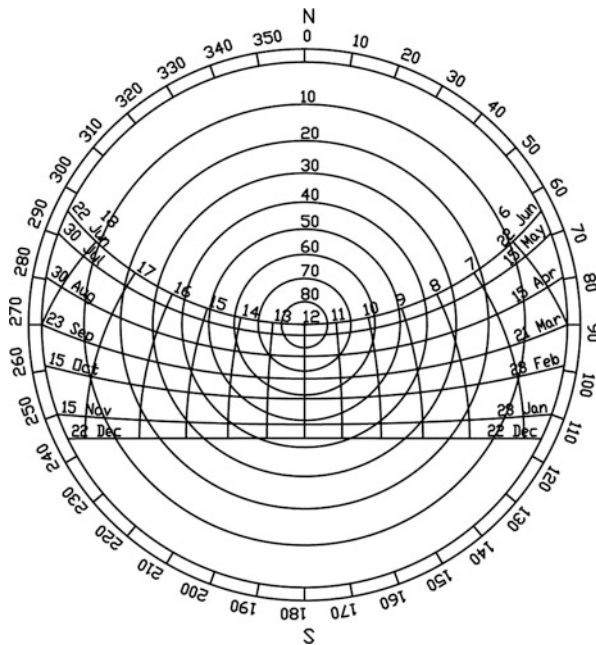


Fig. 5.13 A stereographic sun-path diagram for Bhuj, latitude N 23° 15'

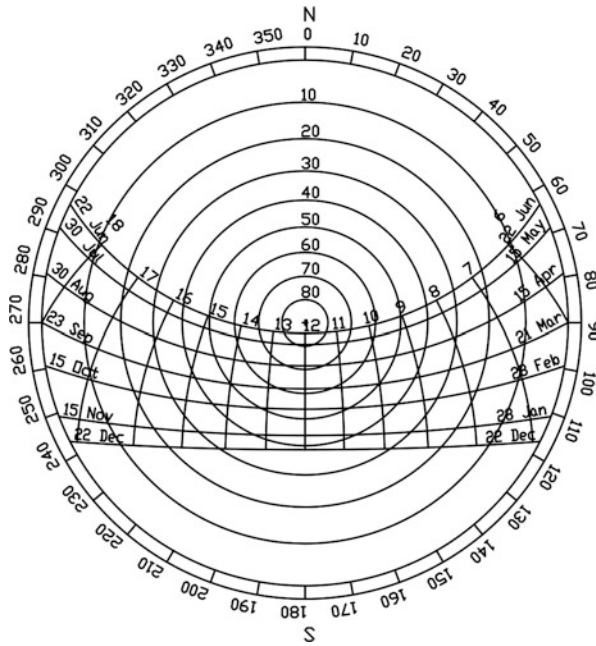


Fig. 5.14 A stereographic sun-path diagram for Bikaner, latitude N 28° 0'

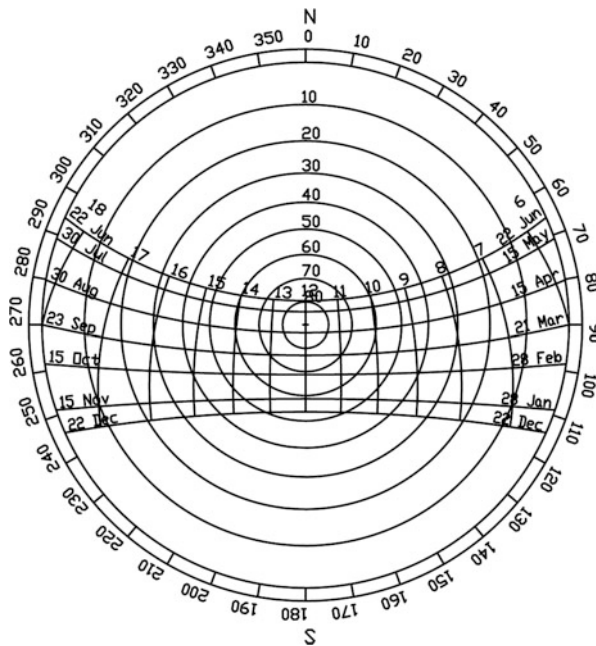


Fig. 5.15 A stereographic sun-path diagram for Chennai, latitude N 13° 0'

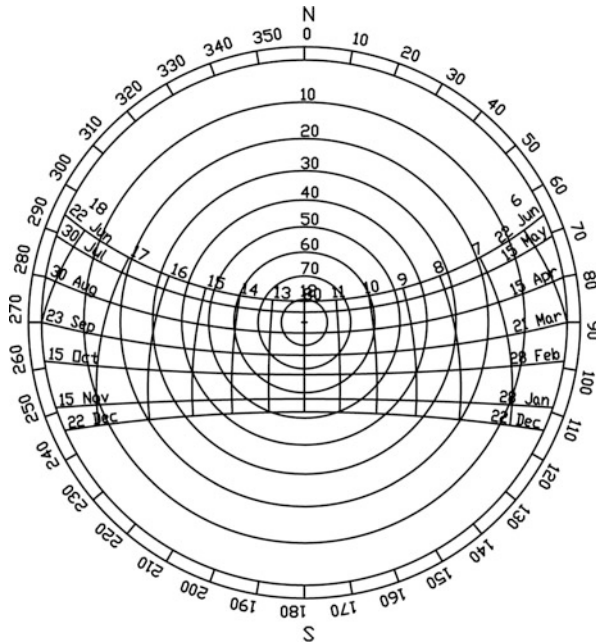


Fig. 5.16 A stereographic sun-path diagram for Chitradurga, latitude N 14° 13'

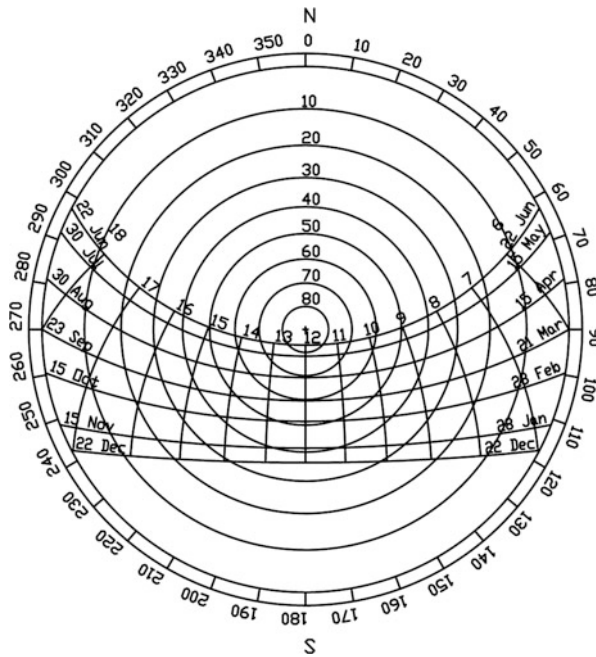


Fig. 5.17 A stereographic sun-path diagram for Dehradun, latitude N 30° 19'

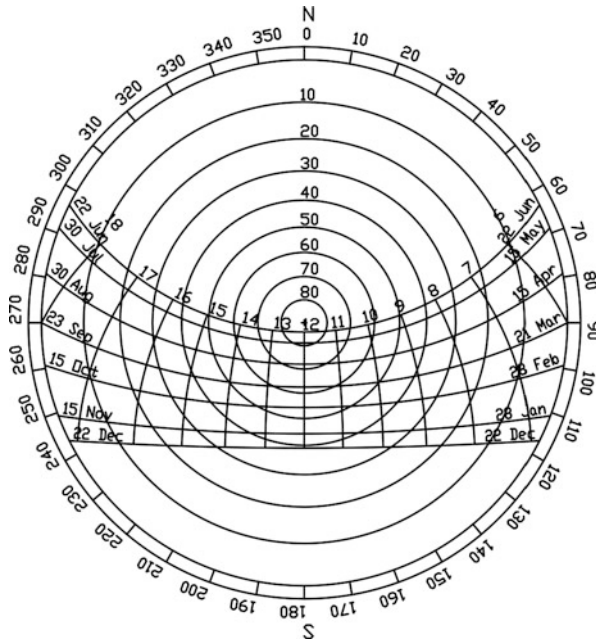


Fig. 5.18 A stereographic sun-path diagram for Dibrugarh, latitude N 27° 28'

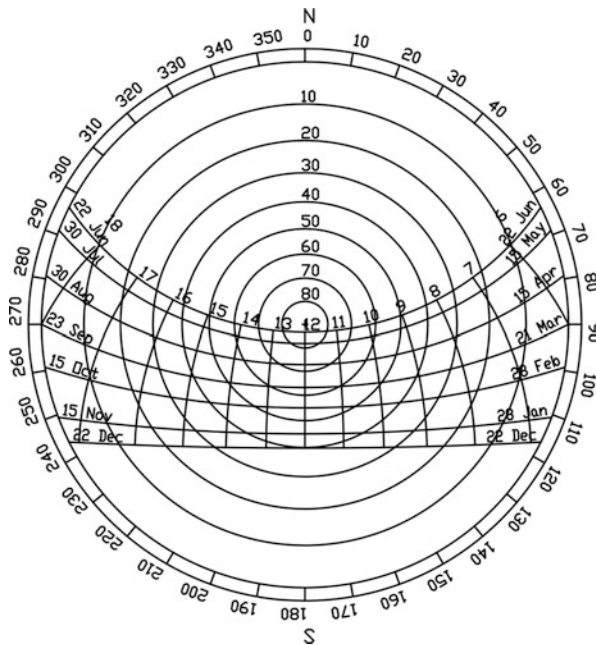


Fig. 5.19 A stereographic sun-path diagram for Gorakhpur, latitude N 26° 45'

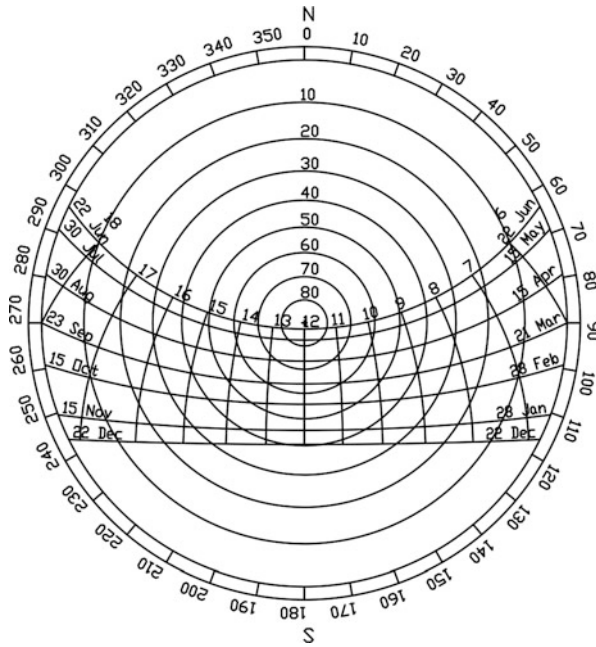


Fig. 5.20 A stereographic sun-path diagram for Guwahati, latitude N 26° 6'

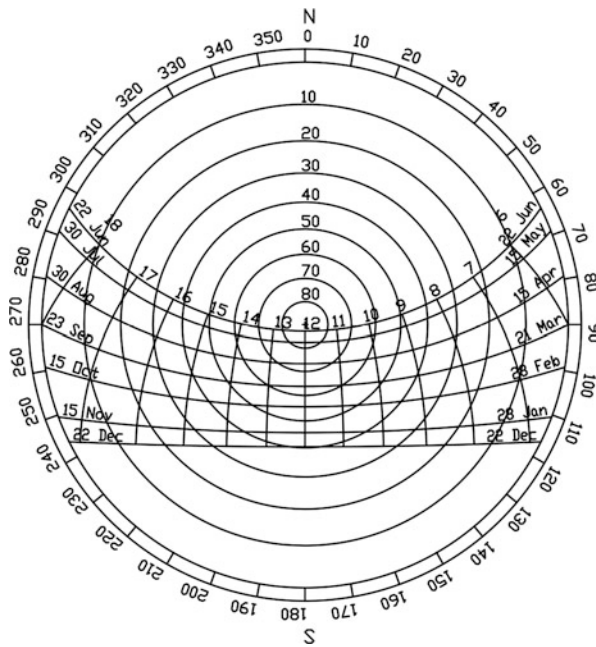


Fig. 5.21 A stereographic sun-path diagram for Gwalior, latitude N 26° 13'

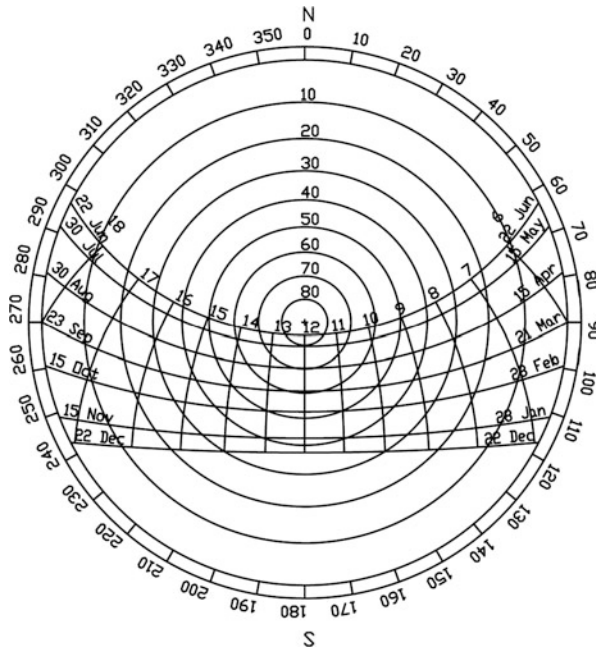


Fig. 5.22 A stereographic sun-path diagram for Hissar, latitude $N 29^{\circ} 10'$

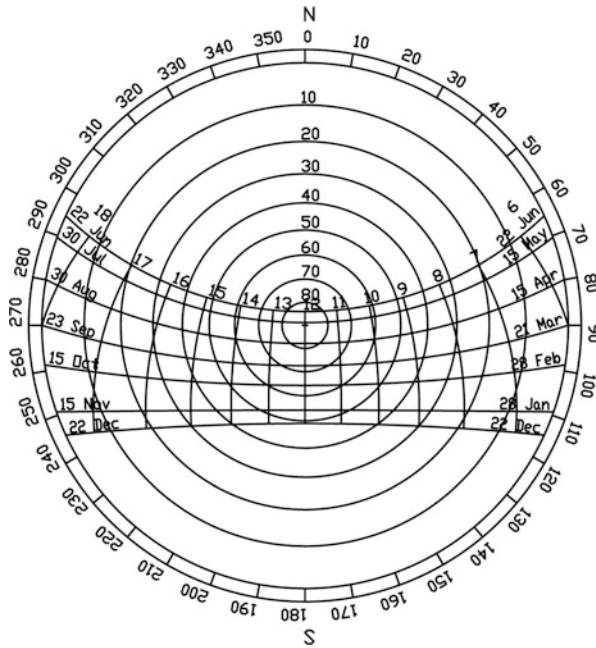


Fig. 5.23 A stereographic sun-path diagram for Hyderabad, latitude $N 17^{\circ} 27'$

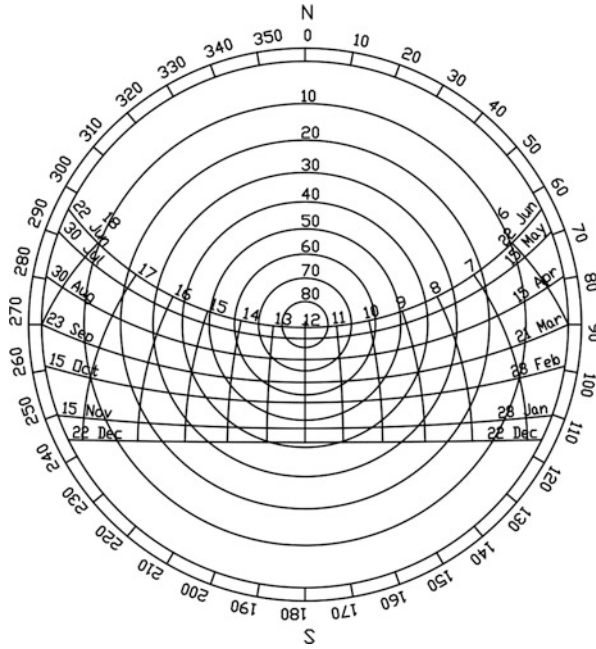


Fig. 5.24 A stereographic sun-path diagram for Imphal, latitude N 24° 40'

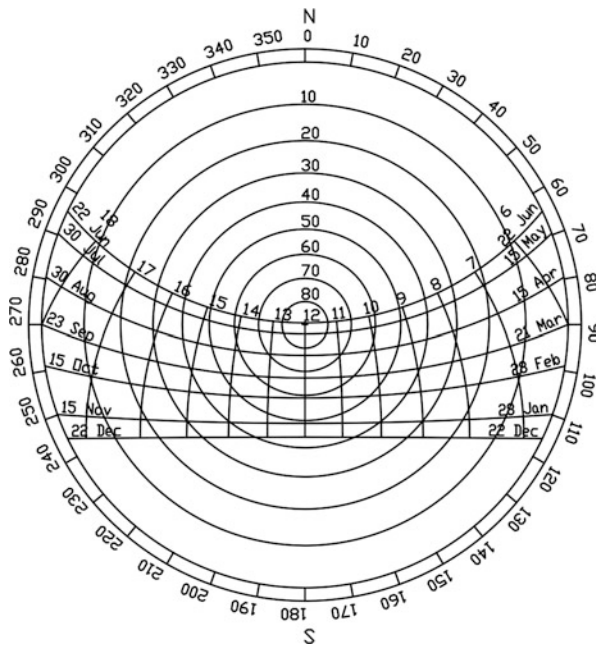


Fig. 5.25 A stereographic sun-path diagram for Indore, latitude N 22° 43'

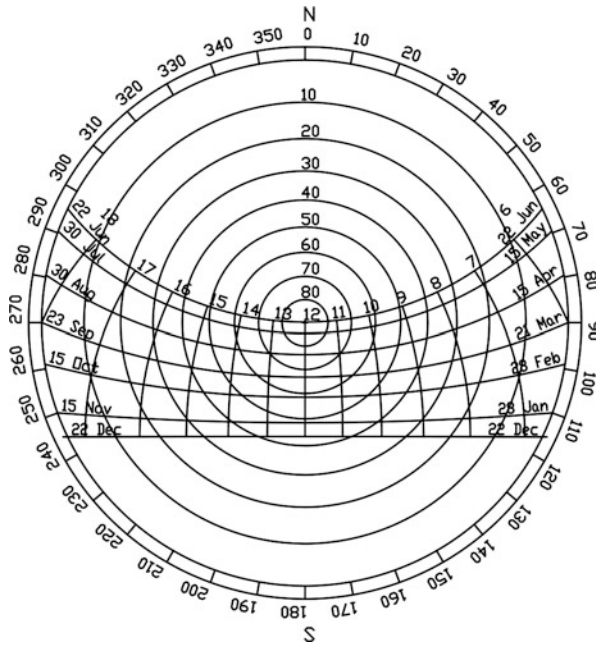


Fig. 5.26 A stereographic sun-path diagram for Jabalpur, latitude N 23° 12'

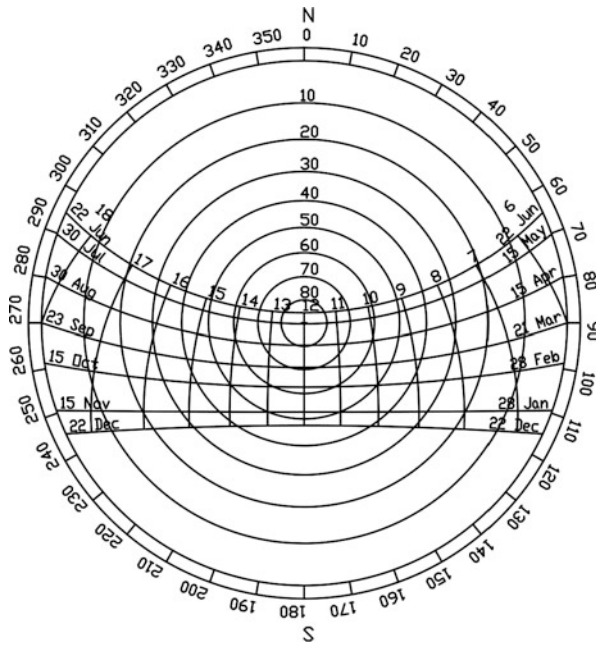


Fig. 5.27 A stereographic sun-path diagram for Jagdalpur, latitude N 19° 4'

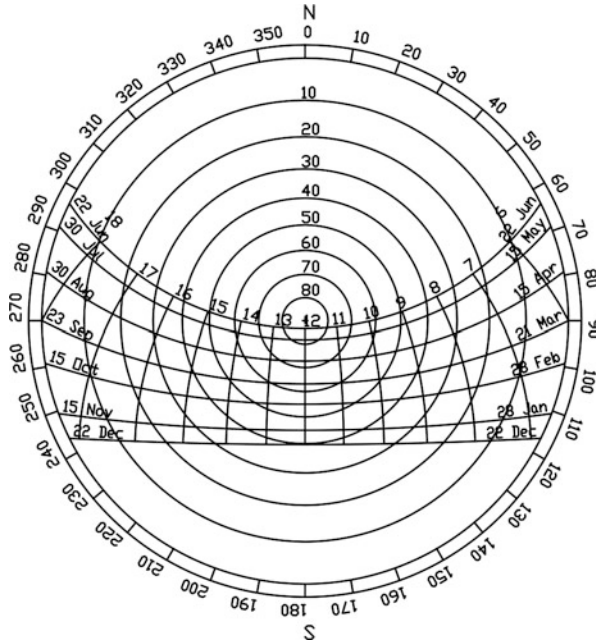


Fig. 5.28 A stereographic sun-path diagram for Jaipur, latitude N 26° 49'

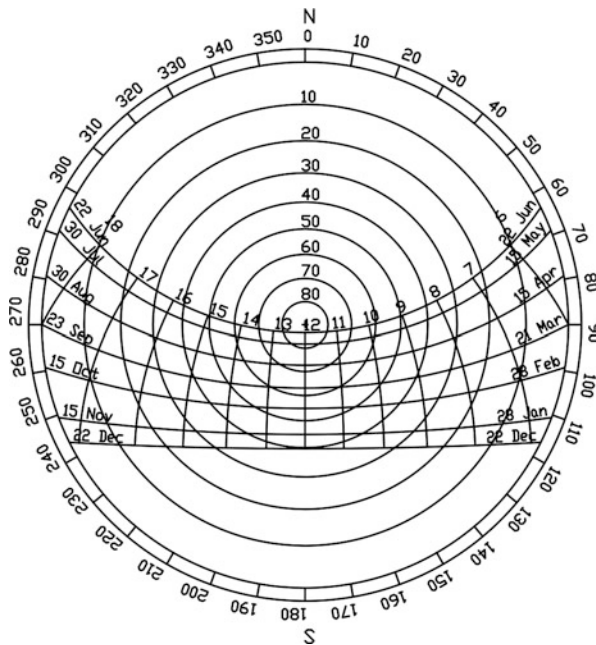


Fig. 5.29 A stereographic sun-path diagram for Jaisalmer, latitude N 26° 53'

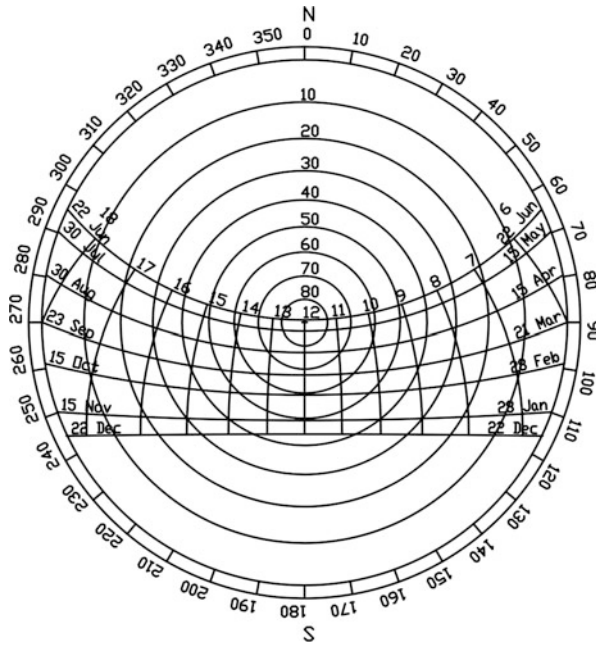


Fig. 5.30 A stereographic sun-path diagram for Jamnagar, latitude $N 22^{\circ} 27'$

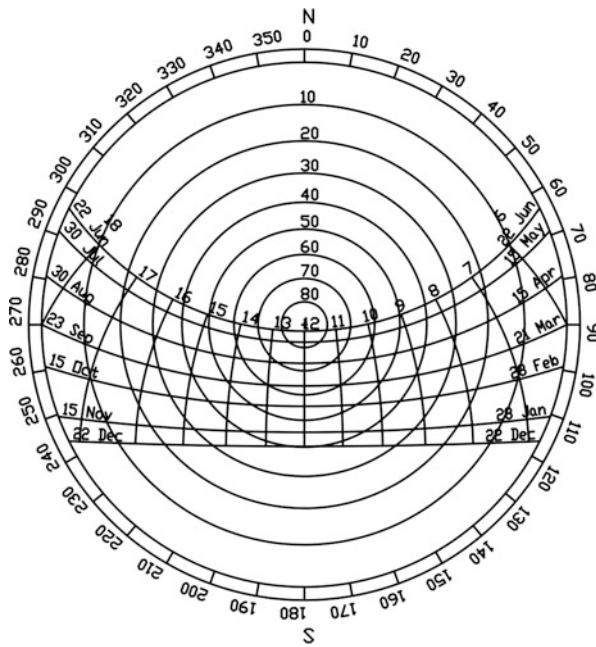


Fig. 5.31 A stereographic sun-path diagram for Jodhpur, latitude $N 26^{\circ} 17'$

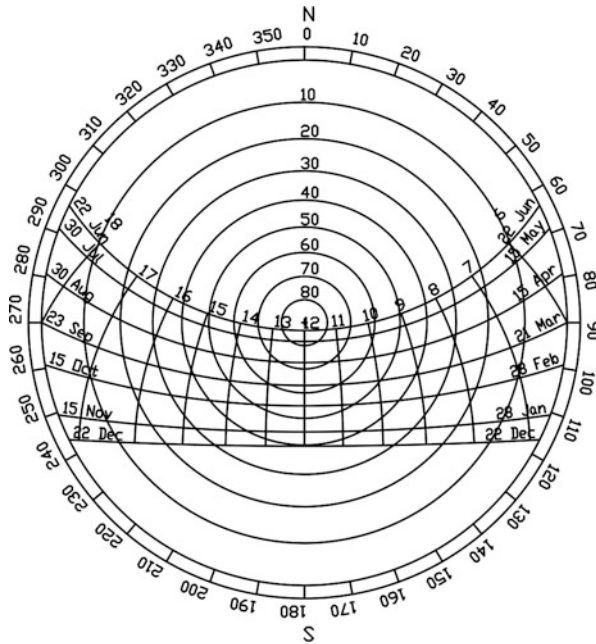


Fig. 5.32 A stereographic sun-path diagram for Jorhat, latitude N 26° 53'

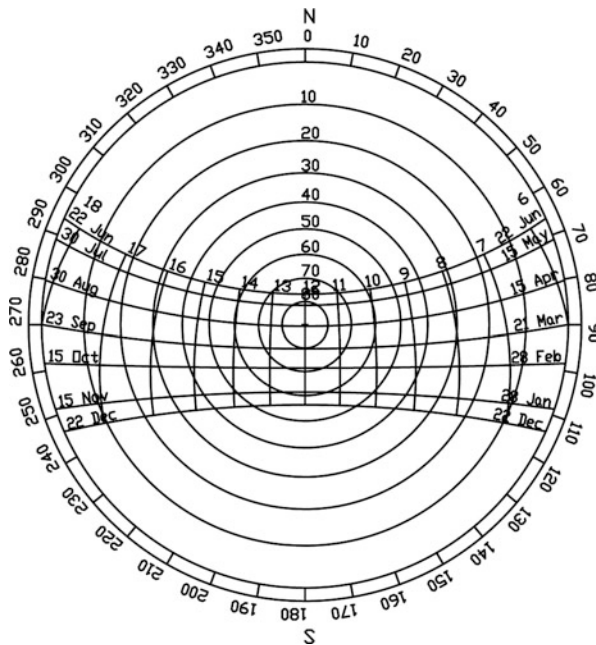


Fig. 5.33 A stereographic sun-path diagram for Kodaikanal, latitude N 10° 13'

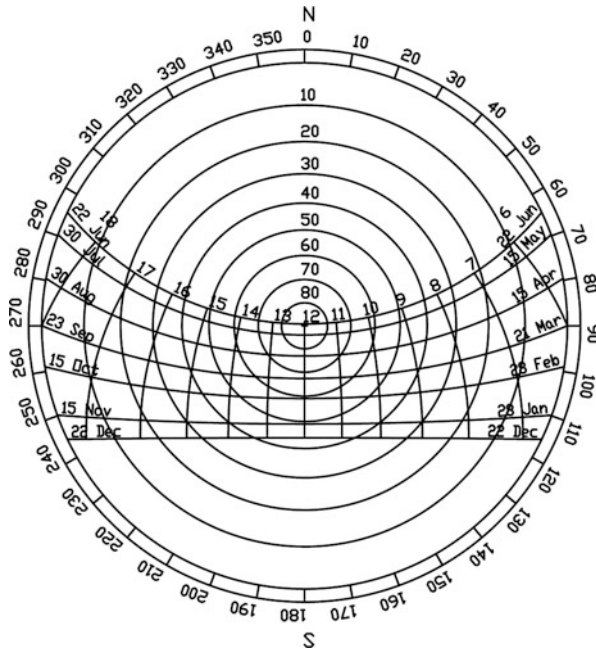


Fig. 5.34 A stereographic sun-path diagram for Kolkata, latitude $N 22^{\circ} 38'$

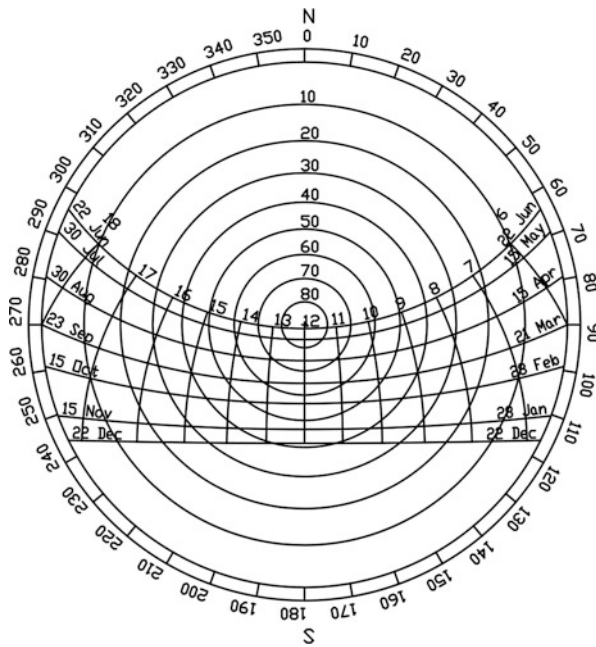


Fig. 5.35 A stereographic sun-path diagram for Kota, latitude $N 25^{\circ} 8'$

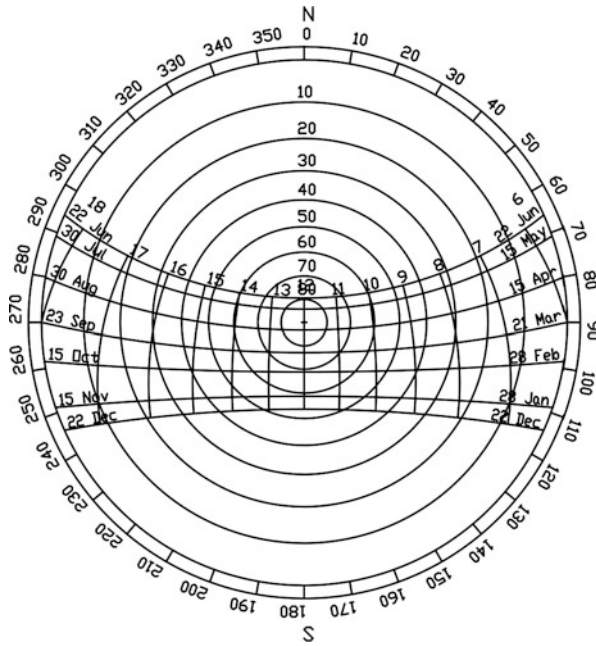


Fig. 5.38 A stereographic sun-path diagram for Mangaluru, latitude N 12° 55'

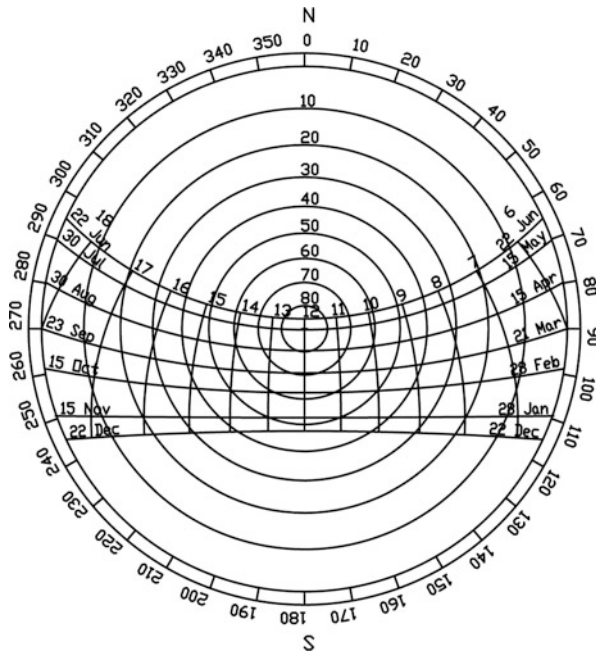


Fig. 5.39 A stereographic sun-path diagram for Mumbai, latitude N 19° 7'

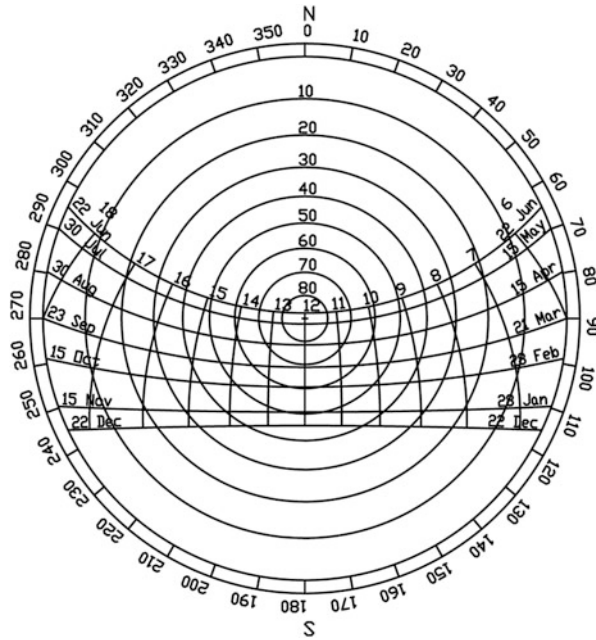


Fig. 5.40 A stereographic sun-path diagram for Nagpur, latitude N 21° 6'

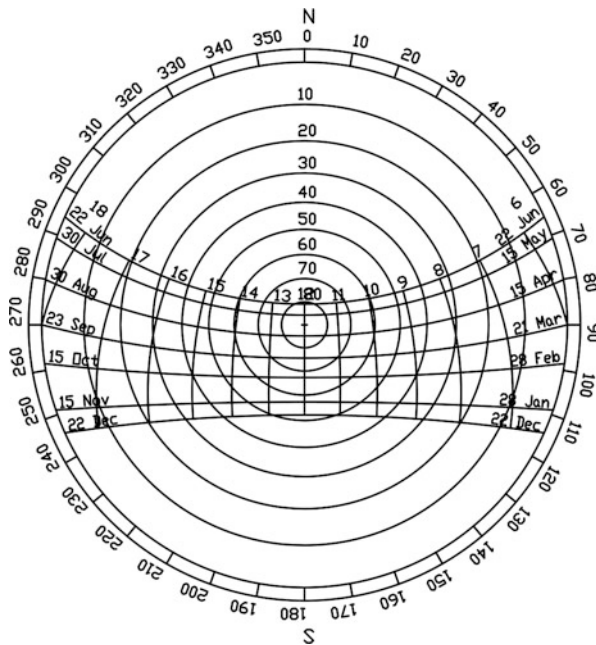


Fig. 5.41 A stereographic sun-path diagram for Nellore, latitude N 14° 26'

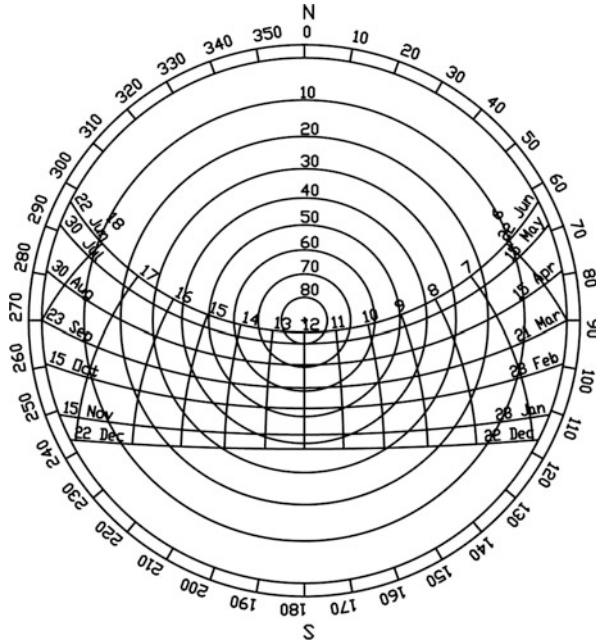


Fig. 5.42 A stereographic sun-path diagram for New Delhi, latitude N 28° 34'

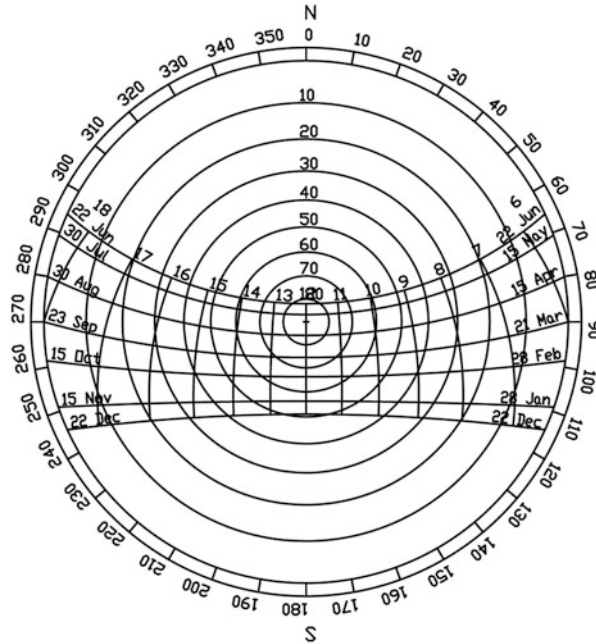


Fig. 5.43 A stereographic sun-path diagram for Panjim, latitude N 15° 28'

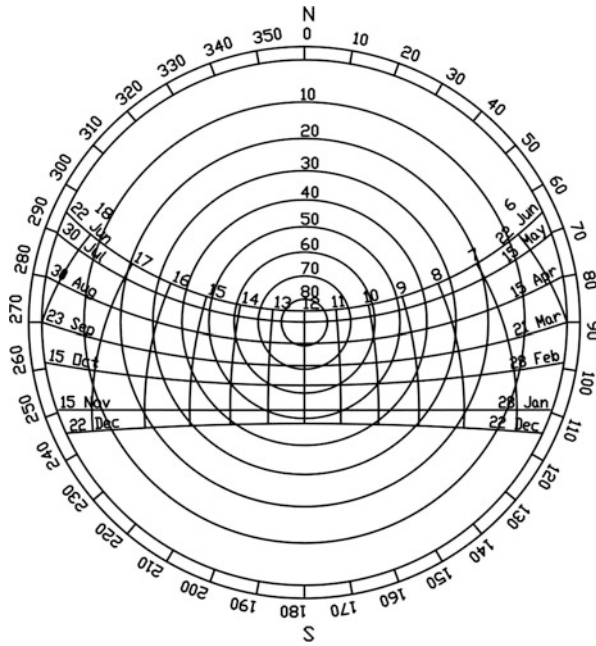


Fig. 5.46 A stereographic sun-path diagram for Pune, latitude N 18° 31'

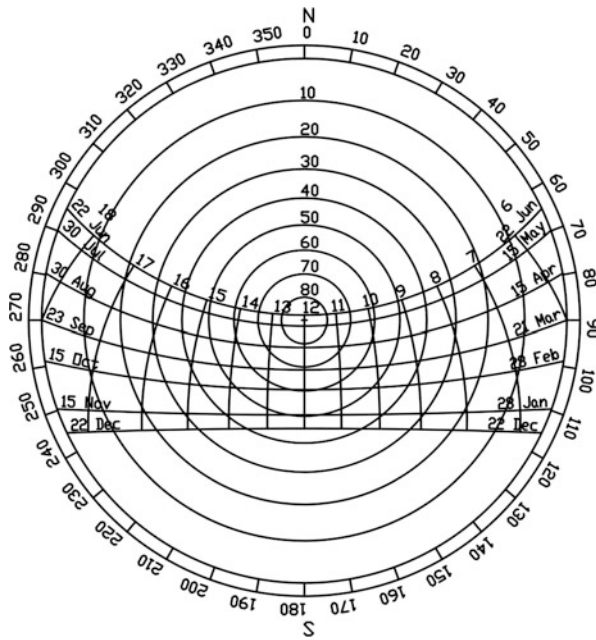


Fig. 5.47 A stereographic sun-path diagram for Raipur, latitude N 21° 13'

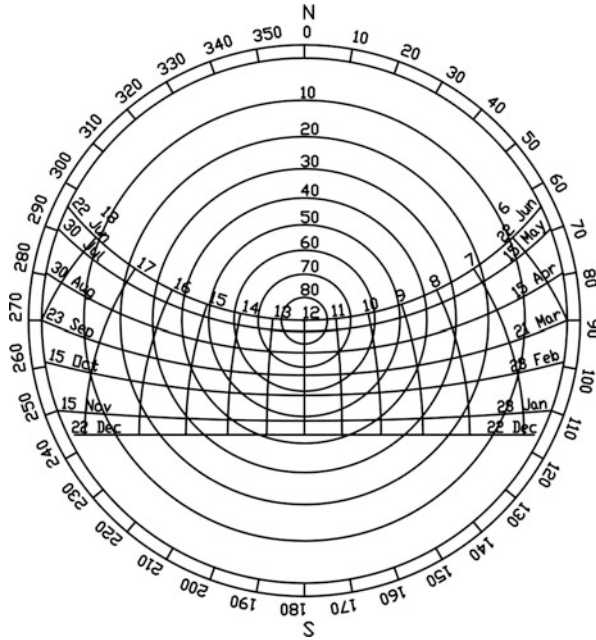


Fig. 5.50 A stereographic sun-path diagram for Ranchi, latitude N 23° 19'

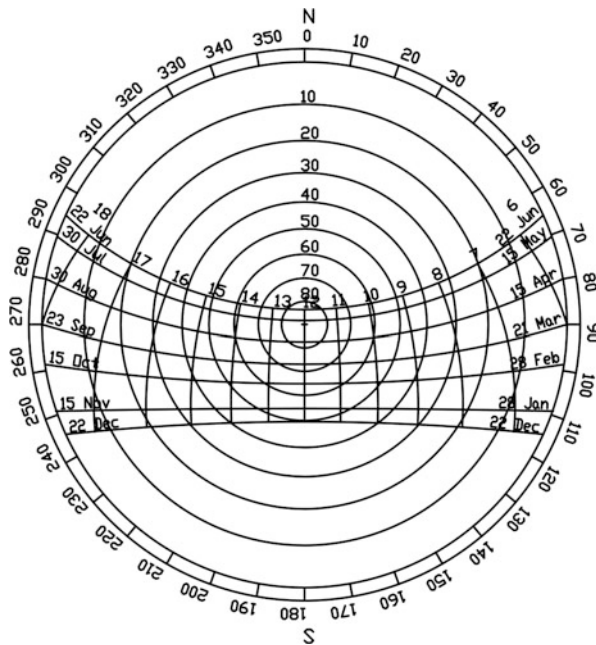


Fig. 5.51 A stereographic sun-path diagram for Ratnagiri, latitude N 16° 58'

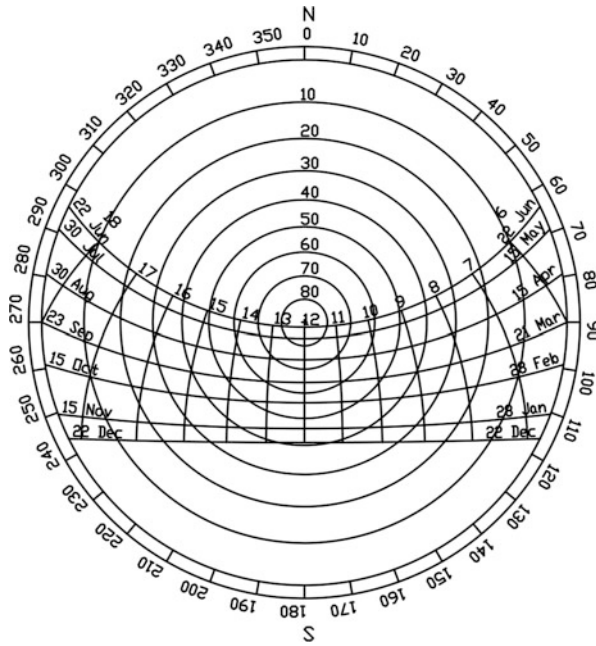


Fig. 5.54 A stereographic sun-path diagram for Shillong, latitude $N 25^{\circ} 34'$

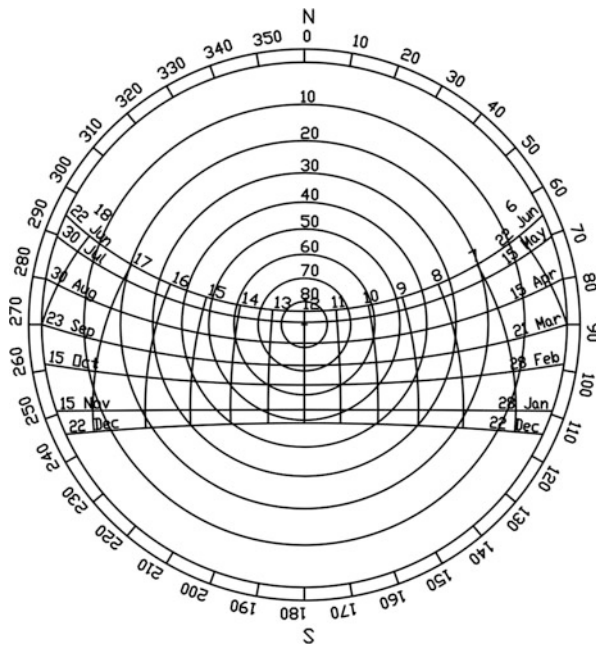


Fig. 5.55 A stereographic sun-path diagram for Solapur, latitude $N 17^{\circ} 40'$

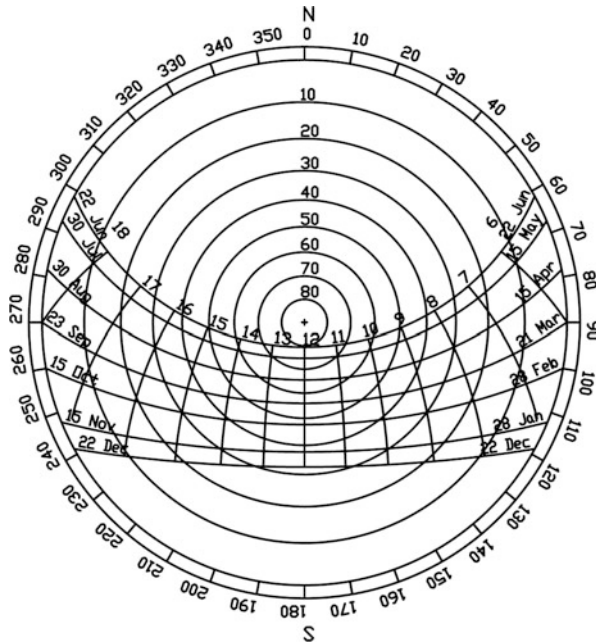


Fig. 5.56 A stereographic sun-path diagram for Srinagar, latitude $N 34^{\circ} 4'$

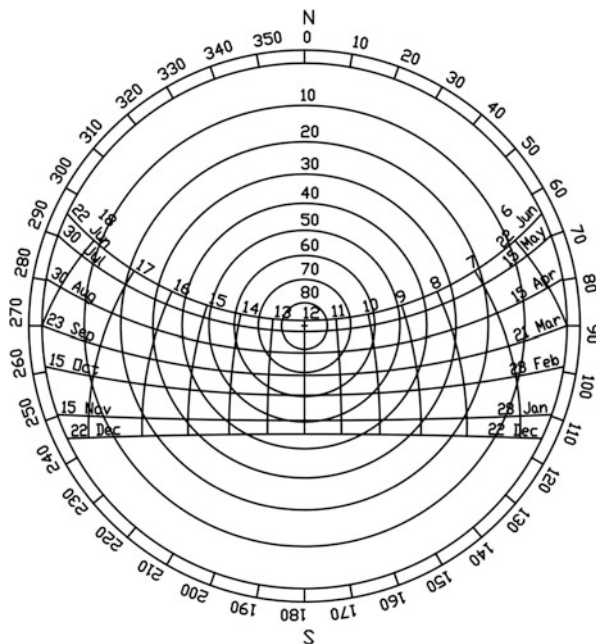


Fig. 5.57 A stereographic sun-path diagram for Surat, latitude $N 21^{\circ} 12'$

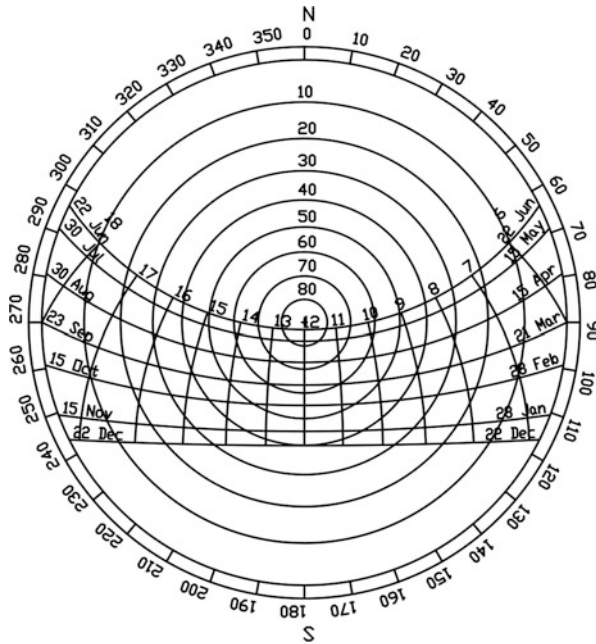


Fig. 5.58 A stereographic sun-path diagram for Tezpur, latitude N 26° 37'

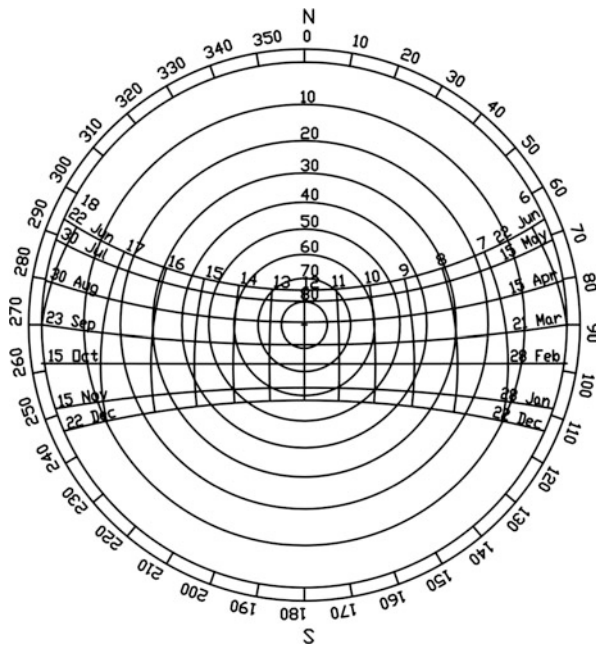


Fig. 5.59 A stereographic sun-path diagram for Thiruvananthapuram, latitude N 8° 28'

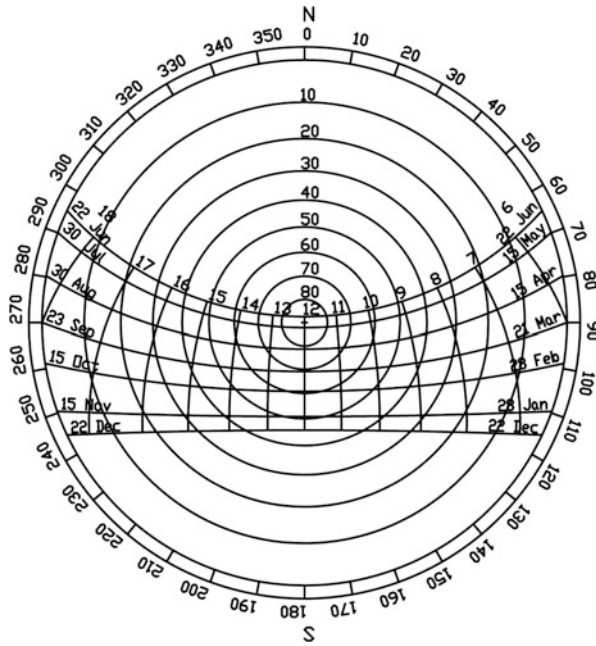


Fig. 5.62 A stereographic sun-path diagram for Veraval, latitude N 20° 53'

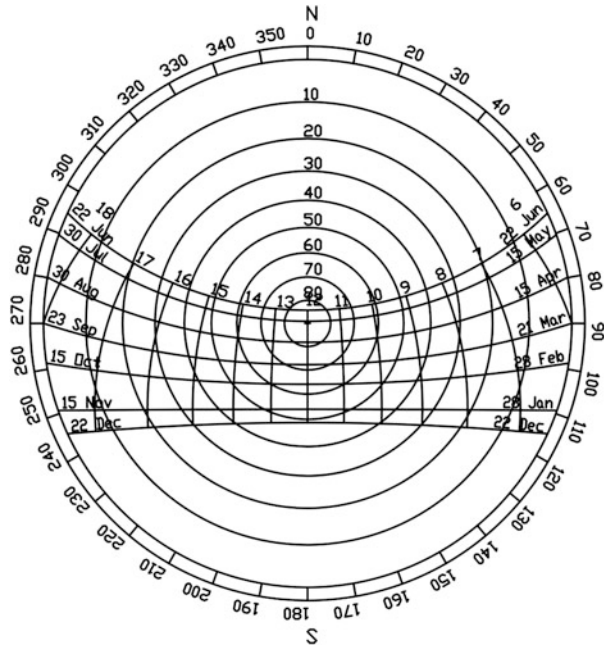


Fig. 5.63 A stereographic sun-path diagram for Vishakhapatnam, latitude N 17° 42'

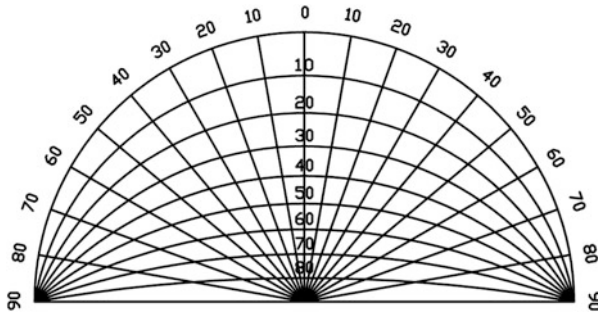


Fig. 5.64 Shadow protractor

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