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Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka

BEEP
BUILDING ENERGY EFFICIENCY PROJECT

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Dr H C Mahadevappa
Minister for Public Works, Ports and Inland Water Transport and
Mysuru Distric Incharge Minister
Government of Karnataka

The Government of Karnataka gives high priority to energy efficiency and use of renewable energy technologies in buildings. We are proud to say that Karnataka is one of the first states to have set up an ECBC (Energy Conservation Building Code) Cell within its Public Works Department (PWD). Another important step taken by the state is to update the Schedule of Rates (SoR), to include technical specifications and cost estimations for materials and technologies used in energy-efficient buildings. I have been informed that, today, some of the public buildings in the state that are being constructed will be energy-efficient once they become operational.

The PWD Team has been working with the Indo-Swiss Building Energy Efficiency Project (BEEP) for the past three years on various aspects of energy efficiency related to the building sector. It is indeed commendable that they have put all the assimilated and accumulated knowledge in the form of guidelines. The publication, titled *Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka*, being specific to the state by keeping its climatic conditions in focus, will be of immense use to architects, engineers, building project managers, and even private builders in the state.

I thank the Bureau of Energy Efficiency, Government of India, and the Swiss Agency for Development and Cooperation, Government of Switzerland, for introducing BEEP technical team to Karnataka and helping the PWD by sharing their invaluable knowledge and expertise through this publication as well as training the PWD staff.

I congratulate the whole team for developing this publication.

Best wishes!

Message

K Udaya
Principal Chief Architect
Public Works Department
Government of Karnataka

Integration of energy efficiency measures in buildings offers profound benefits of energy savings and carbon dioxide mitigation. Karnataka realizes the importance of conserving energy and is at the forefront of initiating efforts in the building sector. With the Energy Conservation Building Code (ECBC) coming into force in 2007 across the country, Karnataka was one of the first states to notify the code in 2014. However, there was a need for equipping both architects and engineers of Public Works Department with adequate knowledge. Hence BEEP supported in developing the guidelines as well as training architects and engineers connected with Karnataka's buildings sector. For over two years, architects and engineers from Public Works Department and the BEEP team have worked together as a team relentlessly to produce a document which focuses on pubic buildings.

The publication, *Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka*, is the result of such a cooperative effort that fills up the knowledge gap in the state. I thank the BEEP team for supporting the team of architects and engineers in Karnataka Public Works Department with their expertise and know-how.

I am confident that the architects and engineers of the Public Works Department would use this publication extensively in the coming years to develop energy-efficient and thermally comfortable public buildings in the state.

Foreword

Sanjay Seth
Secretary
Bureau of Energy Efficiency
Government of India

India's infrastructure sector is growing at a great pace in line with its overall economic growth. The current trends in the buildings sector indicate an urgent need to design new public and private buildings in a manner in which they are not only thermally comfortable but also require much less energy for their operations.

The Indo-Swiss Building Energy Efficiency Project (BEEP), a joint cooperation project between the Government of India and the Government of Switzerland, is a welcome initiative in this regard. Implemented by the Bureau of Energy Efficiency (BEE) with technical assistance from Switzerland, BEEP has been advocating design interventions at the conceptualisation stage itself to make buildings energy efficient and thermally comfortable.

In early 2015, BEE, with support from BEEP, had developed a publication titled, *Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings for Composite and Hot-dry Climates*. This publication was very well received by all stakeholders.

BEEP has also been supporting a few state governments in developing design guidelines based on their climatic conditions and construction practices. Among them, Karnataka has taken the lead in developing a comprehensive set of guidelines for design of energy-efficient and thermally comfortable public buildings. I am sure that this publication, would inspire public and private builders and influence the future construction of public buildings in the state. Similar guidelines for other states in the country are being developed.

I urge the agencies involved in the regulation, design, and construction of public buildings in the state to make use of these guidelines. This will not only help the country in saving energy, but also in saving precious natural resources.

Preface

Daniel Ziegerer
Director of Cooperation
Swiss Agency for Development and Cooperation (SDC)
Embassy of Switzerland, New Delhi

Already today, buildings are consuming a significant share of the energy available in India. In order to ensure energy for all in India and achieve its climate-related targets, harnessing the energy-saving potential of this sector is very important. The best way of doing this is to focus on energy efficiency right at the design stage of a new building and to adopt a systematic approach. Utmost important is that the developers of commercial, residential, and public buildings are aware of the design aspects to make the buildings energy efficient. The Energy Conservation Building Code (ECBC) serves as a guiding document for the developers. However, capacity-building, knowledge transfer, and skills development are needed at the state level for efficient implementation.

One of the objectives of the Indo-Swiss Building Energy Efficiency Project (BEEP), therefore, is to assist the State Public Works Departments (PWDs) in designing energy-efficient buildings. BEEP is a bilateral cooperation project between the Indian Ministry of Power (MoP) and the Swiss Federal Department of Foreign Affairs (FDFA). The Bureau of Energy Efficiency (BEE) is the implementing agency on behalf of the MoP while the Swiss Agency for Development and Cooperation (SDC) is the agency in charge on behalf of the FDFA. The overall objective of BEEP is to reduce energy consumption in new buildings and disseminate best practices for the construction of low-energy residential and public buildings.

This publication, *Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka,* focuses on designing public buildings in Karnataka. From the fact that Karnataka has already notified the ECBC in the state, these guidelines endeavour to assist the state agencies responsible for the construction of new buildings. It has been prepared through a close cooperation between the BEEP team and the Public Works Department (PWD) of Karnataka and by incorporating suggestions made by external reviewers and stakeholders.

I take this opportunity to thank the Karnataka PWD engineers, architects, BEE officials, and BEEP experts for their seamless efforts and support at various stages and congratulate the PWD team of Karnataka and BEEP team for preparing these important guidelines. I am convinced that this publication will become an indispensable source of knowledge for building sector professionals and will help to render new construction activities in Karnataka more energy efficient.

Acknowledgements

The publication, *Design Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka*, has been developed under the Indo-Swiss Building Energy Efficiency Project (BEEP). It is a collaborative effort between Indian and Swiss building experts and practitioners in the design, construction, and operation of energy-efficient buildings on the one hand and the engineers and architects of the Public Works Department of Karnataka on the other.

The overall guidance provided by the members of the Joint Apex Committee (JAC) and the Joint Implementing Group (JIG) of the Project is noteworthy. We are grateful to the Co-Chairs of the JAC – Mr Raj Pal, Economic Advisor, Ministry of Power, and Mr Daniel Ziegerer, Director of Cooperation and Counsellor – for their leadership. We also gratefully note the inputs provided in implementation of the project work plan by Mr P T Bhutia, Director, Ministry of Power, and Dr Anand Shukla, Sr Thematic Advisor (Energy), Embassy of Switzerland as Co-Chairs of the JIG. The comments and suggestions provided by Mr Prabhakar Singh, Assistant Director General, Central Public Works Department; Dr Arun K Tripathi, Director, Ministry of New and Renewable Energy; and Mr Sanjay Seth, Energy Secretary, Bureau of Energy Efficiency (BEE), among many others, have helped immensely in shaping this publication. We would also like to acknowledge the contribution of the previous Co-Chairs and members on the JAC and JIG in taking the project forward.

We also extend our sincere thanks to all the experts and practitioners who have generously contributed their time for the preparation of these guidelines and its review. Their suggestions have been instrumental in firming up these guidelines.

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List of Acronyms/Abbreviations

AC	air conditioner
ACH	air change rate
AHRI	Air-conditioning, Heating, and Refrigeration Institute
AHU	air handling unit
BEE	Bureau of Energy Efficiency
BEEP	Building Energy Efficiency Project
BIS	Bureau of Indian Standards
CARBSE	Centre for Advanced Research in Building Science and Energy
CFD	computational fluid dynamics
CFL	compact fluorescent lamp
CoP	coefficient of performance
DBT	dry bulb temperature
DF	daylight factor
ECBC	Energy Conservation Building Code
EET	energy-efficient technology
E–W	east–west
FDFA	Federal Department of Foreign Affairs
GHI	global horizontal irradiation
GHG	greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GSES	Global Sustainable Energy Solutions
HVAC	heating, ventilation, and air-conditioning
IDP	integrated design process
IPLV	integrated part-load value
IRRAD	Institute of Rural Research and Development
ISEER	Indian Seasonal Energy Efficiency Ratio
JAC	Joint Apex Committee
JIG	Joint Implementing Group
KREDL	Karnataka Renewable Energy Department Ltd
LED	light emitting diode
LPD	lighting power density
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
NIWE	National Institute of Wind Energy
N–S	north–south
PMTU	Project Monitoring and Technical Unit
PWD	Public Works Department
RCC	reinforced concrete cement
RH	relative humidity
SDC	Swiss Agency for Development and Cooperation

SHGC	solar heat gain coefficient
SPV	solar photovoltaic
SWH	solar water heating
TERI	The Energy and Resources Institute
TFA	treated fresh air
TR	tonnes of refrigeration
VFD	variable frequency drive
VLT	visual light transmittance
VRV	variable refrigerant volume
WBT	wet bulb temperature
WWR	window-to-wall ratio

CHAPTER 1

Introduction

1.1 Energy Conservation in Buildings

Energy has emerged as a critical issue and top priority for the country due to concerns related to energy security and global climate change. Buildings consume over 30% of electricity used in the country.[1] The amount of electricity being used in the building sector is rising fast, primarily because of addition of new building stock as well as increased use of electricity for building operation, particularly for air-conditioning. A study reveals that about 70% of the building stock that will be there in the year 2030 is yet to come up.[2] Energy-efficient buildings offer opportunities to (a) save electricity, (b) reduce greenhouse gas (GHG) emissions, (c) lower energy bills for the building owners, and (d) provide better thermal comfort to the building occupants.

1.2 BEE's Programme on Building Energy Efficiency

The Government of India realised the potential of energy efficiency in buildings and hence made it an integral part of the Energy Conservation (EC) Act, 2001. The EC Act resulted in the formation of the Bureau of Energy Efficiency (BEE) on 1 March 2002. As a first step towards promoting energy efficiency in the building sector in the country, the BEE came up with the Energy Conservation Building Code (ECBC) in May 2007. ECBC stipulates minimum requirements for energy-efficient building design and construction. It covers building envelope, heating, ventilation and air-conditioning (HVAC) systems, as well as lighting, service hot water, and electrical power systems and motors. Estimates have shown that ECBC compliance may yield 40%–60% energy savings to a building as compared to a non-ECBC-compliant building.[3] ECBC is applicable for relatively large commercial buildings, with a connected load of at least 100 kW, a contract demand of at least 120 kVA, or a conditioned area of at least 1000 m^2. The BEE is also in the process of revising the code and making it more stringent. It is expected that the new code will be released in 2017.

Construction of buildings is regulated at the state and local levels. Therefore, the role to adapt, enforce, and supervise ECBC implementation lies with state governments. Without the active involvement of state governments, the central government will not be in a position to meet the target of making 75% of all new commercial buildings ECBC-compliant by the end of the 12th five-year plan period.

1.3 Karnataka's Electricity Scenario

Karnataka has a history of struggling to meet its rising electricity demand. Despite significant capacity enhancements made since 2010, the electricity supply in the state still falls short of the demand. As on 31 March 2015, the generation capacity of the state was 15,052 MW while the electrical energy deficit was almost 10%, and the peak deficit was 15%.[4]

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[1] *Ministry of Statistics and Programme Implementation. 2010/11. Energy Statistics 2012. New Delhi: Ministry of Statistics and Programme Implementation, Government of India.*

[2] *Kumar S R. 2010. Developing an Energy Conservation Building Code Implementation Strategy in India. Energy Conservation and Commercialization (ECO-III). Energy consumption by buildings in India to reach close to 2 terawatt-hours. http://www.cseindia.org/userfiles/Energy-and-%20buildings.pdf.*

[3] *Bureau of Energy Efficiency (BEE). 2009. ECBC User Guide, 2009. New Delhi: BEE.*

[4] *http://www.gokenergy.gov.in/power_gen.html, accessed on 1 January 2016.*

The installed electricity generation capacity in the state is a mix of coal-based thermal, hydro, and wind energy, with coal-based generation having the largest share (Table 1.1).[5] To meet its peak demand, the state increasingly relies on short-term power purchases at higher prices.[6] This clearly shows that the state needs to not only produce more electricity, but also adopt strict energy efficiency measures to make optimum use of the electricity available.

Table 1.1 Source-wise installed capacity in Karnataka

Source	Capacity as on 31 March 2015 (MW)
Hydro	3773
Thermal	2720
Diesel	108
Coal seam gas	2169
Non-commercial energy sources	5082
Independent power producers	1200
Total	15052

In 2013/14, the total electricity consumption in Karnataka amounted to 45 293 GWh. Figure 1.1 shows the share of electricity consumption by sector in Karnataka. The building sector, including commercial (13%) and domestic (20%) electricity consumption, represents 33% of the total electricity consumption in the state, making it the second largest electricity consumer after agriculture.[7]

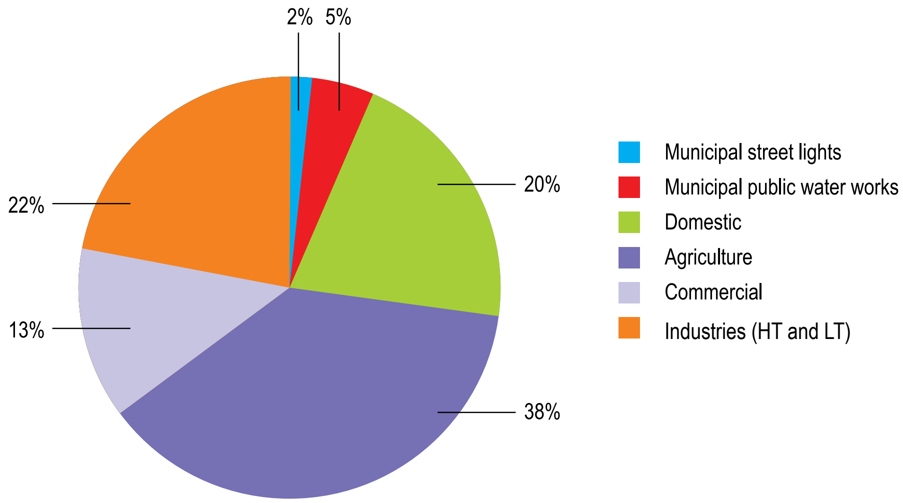

Figure 1.1 *Share of electricity consumption by sector in Karnataka in 2013/14*
Source *http://kredlinfo.in/scrollfiles/Energy%20Conservationof 20Policyof200214-19.pdf, last accessed on 15 May 2016*

[5] *http://www.gokenergy.gov.in/power_gen_1.html, accessed on 1 January 2016.*
[6] *http://www.cstep.in/uploads/default/files/publications/stuff/bf9944c1e0001c4a9021a0fab0ca7dbe.pdf, accessed on 1 January 2016.*
[7] *http://kredlinfo.in/scrollfiles/Energy%20Conservationof 20Policyof200214-19.pdf, accessed on May 2016.*

1.4 Karnataka's Initiatives on Energy Efficiency

The Government of Karnataka has recently launched an Energy Efficiency and Conservation Policy (2015–19), which aims at conserving energy in a number of sectors including buildings. The goal is to save 300 GWh in five years and to avoid the fossil fuel generation capacity of 70 MW.

To conserve energy in buildings, the Policy includes:
- energy audit of municipal buildings;
- replacement of existing air conditioners (ACs) with BEE 4 or 5 star ACs;[8]
- super-efficient ceiling fans in the commercial sector;
- energy audit programme for the commercial sector;
- mandatory installation of solar water heaters; and
- mandatory ECBC-compliance for private and public commercial buildings with a connected load above 100 kW, a contract demand above 120 kVA or a conditioned area above 500 m^2.

These activities are expected to boost energy efficiency in the state in the coming years. The adoption or revision of building bye-laws by municipalities as a follow-on action from the notification and adoption of ECBC is likely to give a strong push to energy efficiency in buildings. The application of ECBC along with the activities mentioned above will trigger synergies around the important subject of bringing energy efficiency in buildings.

1.5 ECBC Karnataka

Karnataka was one of the first states to notify ECBC in 2014. The Karnataka Renewable Energy Development Limited (KREDL) is the state designated agency for enforcing the code. As of January 2016, Karnataka is one of the seven states to have notified the code; five of the states including Karnataka have approved the code, making the needed adjustments to define the application in different climates and defining the exact eligibility criteria.

In Karnataka, apart from new buildings, the code also applies to existing buildings, under the circumstances mentioned below:
- If an extension to an existing building exceeds the conditioned floor area.
- If the existing building exceeds the conditioned floor, then the alterations will need to meet the provisions of the code.

The BEE has set up an ECBC Cell within the office of Principal Chief Architect, Public Works Department (PWD) to facilitate the Government of Karnataka in applying the code.

1.6 PWD Karnataka

At the state level, the PWD, under the Ministry of Public Works, is responsible for the construction of government buildings. In many cases, the PWD is responsible for the

[8] *BEE star rating, http://www.beestarlabel.com/#*

maintenance of such buildings. It is a critical player to bring energy efficiency in buildings in Karnataka. An organisational chart of the PWD is found in Figure 1.2.

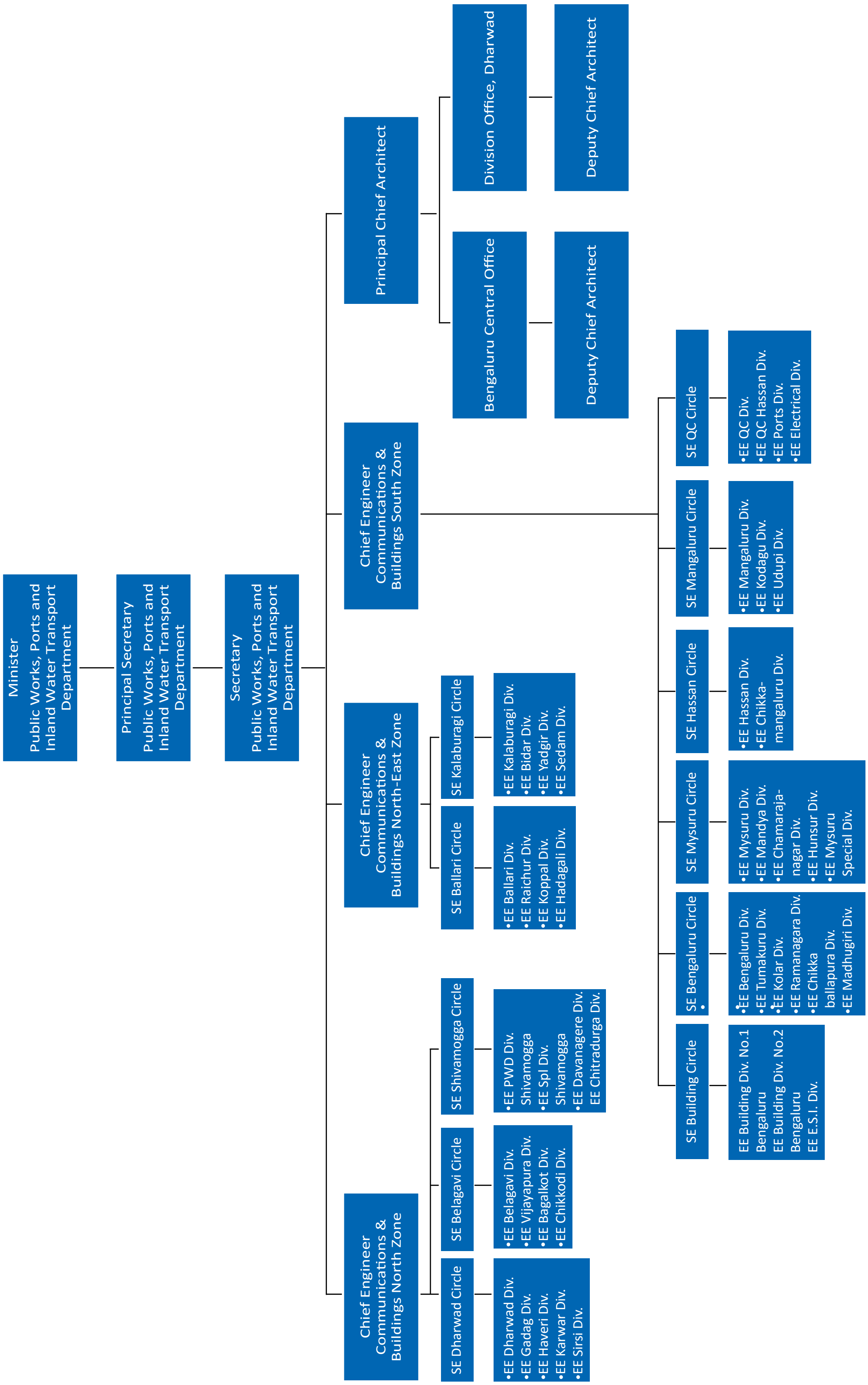

***Figure 1.2** PWD organisational structure*

***Source** www.kpwd.gov.in/organisationstructure.asp#*

The PWD Architect's office is responsible for the design of a portfolio of building construction projects worth approximately INR 500–600 crore per year[9] or around 1,50,000 m^2 of built-up area. The PWD constructs a variety of buildings:

- Institutional buildings (schools, colleges, hospitals, dispensaries, religious buildings),
- Residential buildings (government employee quarters),
- Other residential buildings (student hostels, tourist bungalows, and guest houses),
- Commercial buildings (ware-houses, business establishments, offices, and garages),
- Other buildings (libraries, entertainment buildings), and
- Industrial buildings (workshops, factories).

As indicated in Figure 1.3, the PWD has constructed 7.6 million m^2 of buildings since 1941, with approximately 30% being residential and 70% being non-residential.

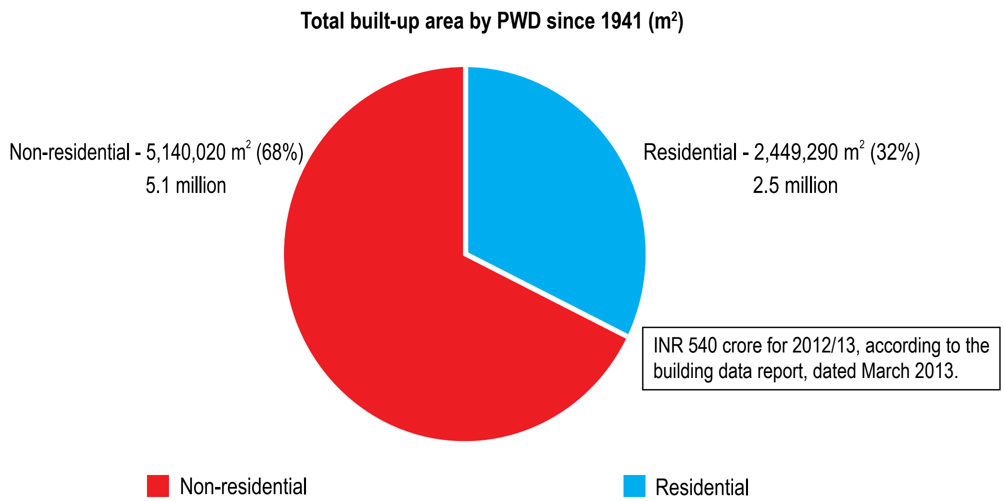

Figure 1.3 *Constructed area by PWD since 1941 (until March 2013)*
Source *PWD website http://www.kpwd.gov.in/pdf/Building_data.pdf, accessed on 1 December 2015.*

The public buildings built by PWD are visited mostly by the general public and have high visibility as well. Therefore, a well-designed energy-efficient public building also has a large demonstration effect. With public buildings using energy-efficient technologies (EETs) and materials, such specifications can be included in the schedule of rates (SoR) of PWD of Karnataka. These specifications can have an influence on the construction done by public, private builders, and other developers.

The application of ECBC in PWD-designed buildings is also expected to help in the development of market for energy-efficient materials and appliances such as insulation, double glazing, super efficient ceiling fans, and efficient lighting fixtures.

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[9] *INR 540 crore for 2012/13 according to the building data report, dated March 2013. Accessed on 1 December 2015 from the PWD website http://www.kpwd.gov.in/pdf/Building_data.pdf.*

1.7 BEEP Support to Karnataka

The PWD has been the primary source of contact for the Building Energy Efficiency Project (BEEP) in Karnataka. Under BEEP, one of the activities is aimed at providing technical support to selected state PWDs, through the development of templates and guidelines for energy-efficient public buildings. The different steps in BEEP's engagement with the Karnataka PWD resulting in the development of the guidelines are shown in Figure 1.4.

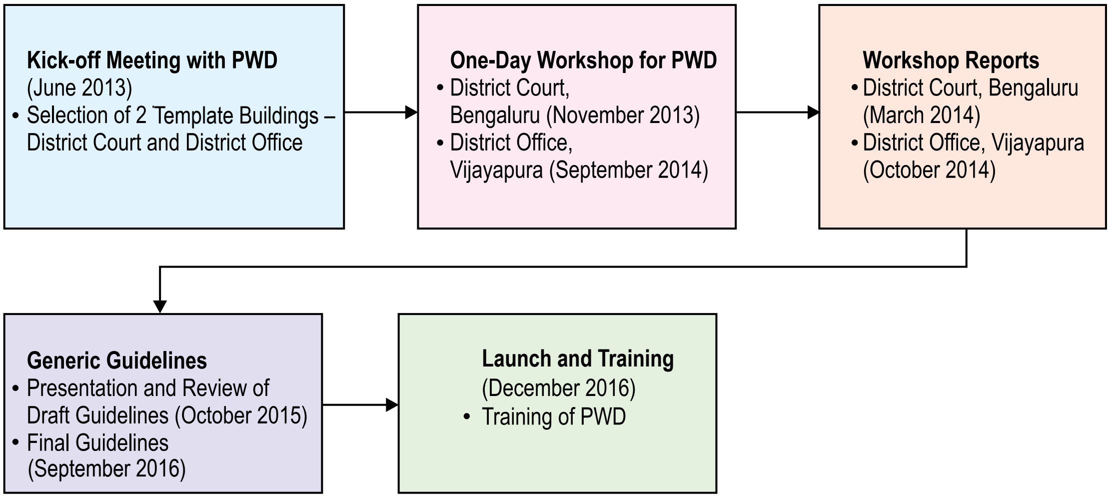

Figure 1.4 *Process followed by BEEP for developing guidelines for energy-efficient public buildings for the state of Karnataka*

BEEP support to Karnataka started with a kick-off meeting at the Principal Chief Architect's (PWD) office in June 2013. Members from BEE, BEEP, and PWD-Arch team attended this meeting.

Figure 1.5 *Kick-off meeting for BEEP support to Karnataka PWD, June 2013*

During this meeting it was informed that often the PWD constructs identical (template) public buildings, e.g., schools, hostels, office buildings, in various districts. Out of the many options available, it was decided to select District Court and District Office buildings as the two building types to develop energy-efficient design templates, as PWD was planning to construct several of these buildings in different districts of Karnataka in the near future.

This was followed by design workshops at the PWD-Arch office at Bengaluru on 7 November 2013 for a typical District Court Building of 2 storeys in Bengaluru and on 26 September 2014 for a typical District Office Building in Vijayapura. The reports of these workshops, technical analysis by the BEEP team and the discussions, and inputs received from the Karnataka PWD have resulted in the development of these generic guidelines. Going further, BEEP aims to organise training workshops for the PWD technical personnel based on the generic guidelines.

CHAPTER RECAP

1. Energy-efficient buildings are important because they offer opportunities to save electricity and hence reduces greenhouse gas (GHG) emissions
2. They lower energy bills for the building owners and provide better thermal comfort to the building occupants.
3. BEE has a buildings programme under which the ECBC was launched. It is a code that defines the energy efficiency requirements for commercial buildings.
4. Karnataka has launched a number of programmes to conserve energy. It has also adopted the ECBC and notified it as an initiative towards achieving building energy efficiency. The state PWD has been the key organisation for this initiative.
5. BEEP began its partnership with PWD Karnataka in June 2013 and has extended technical support ever since. This partnership has resulted in the formulation of this technical document, titled *Guidelines for Energy-Efficient and Thermally Comfortable Public Buildings in Karnataka*.

CHAPTER 2

Designing Energy-Efficient Buildings

2.1 Energy-Efficient Building Design

The energy performance of a building is influenced by key factors such as climate, site conditions, and building usage. Therefore, these factors will have to be taken into consideration upfront while designing an energy-efficient building. Figure 2.1 illustrates the key factors to be addressed in a design brief and a list of potential strategies to design energy-efficient buildings. These strategies have been discussed in the subsequent chapters.

Key Inputs for Design Brief

- Climate
- Site Conditions
- Building Usage

Strategies to Design Energy-Efficient Buildings

Strategy 1: Climate-responsive Building Massing
Strategy 2: Design Openings for Daylight
Strategy 3: Design Natural Ventilation
Strategy 4: Climate-responsive Envelope
Strategy 5: Design Solar Shading
Strategy 6: Efficient Cooling Systems
Strategy 7: Integration of Renewable Energy

Figure 2.1 *Key inputs required to design energy-efficient buildings and the potential strategies to address them*

2.2 Integrated Design Process

The objective of following an integrated design process (IDP) is to achieve a cost-effective energy-efficient design for a building. The IDP approach requires both the architecture and engineering teams to work together from the early design stage itself. This is to ensure that both passive architecture features and active energy-efficiency measures are incorporated in the design from the very beginning.

Indian and international experiences in the field of energy-efficient buildings have shown that an integrated approach to designing a building allows to tap the largest energy saving potential without additional costs. The more the design process evolves, the more cost-intensive and difficult it will be to integrate energy efficiency measures in a building.

In a typical design process followed by the PWD (Figure 2.2), the architecture department does the architecture design, which is then given to the engineering department. The design of mechanical systems is done by this department independently followed by cost estimates and floating of tender. The IDP lays emphasis on the two departments working together from the very beginning till the completion of the project. Any changes in the architecture/ mechanical design of the building should be reviewed together by both departments.

Figure 2.3 shows the reduction in energy saving potential and the corresponding increase in the cost of climate-responsive and energy-efficient measures as the building cycle evolves, from the formulation of the design brief to the operation and maintenance of the building.

2.3 Implications of IDP on PWD's Design Process (Improvements)

During BEEP's interactions with the PWD team, it was understood that the design process charted in Figure 2.2 is followed to design public buildings in Karnataka.

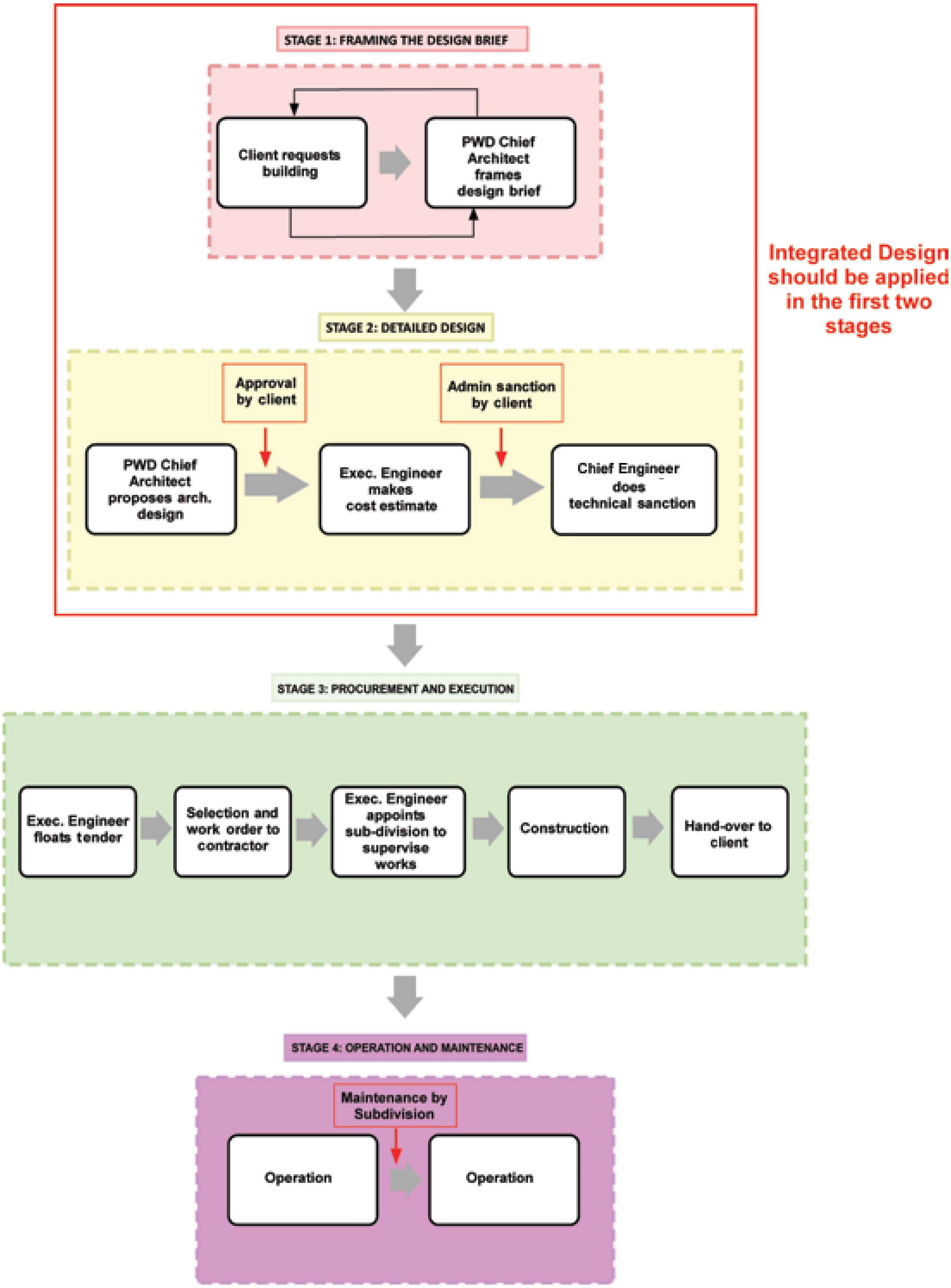

Figure 2.2 *PWD design process*

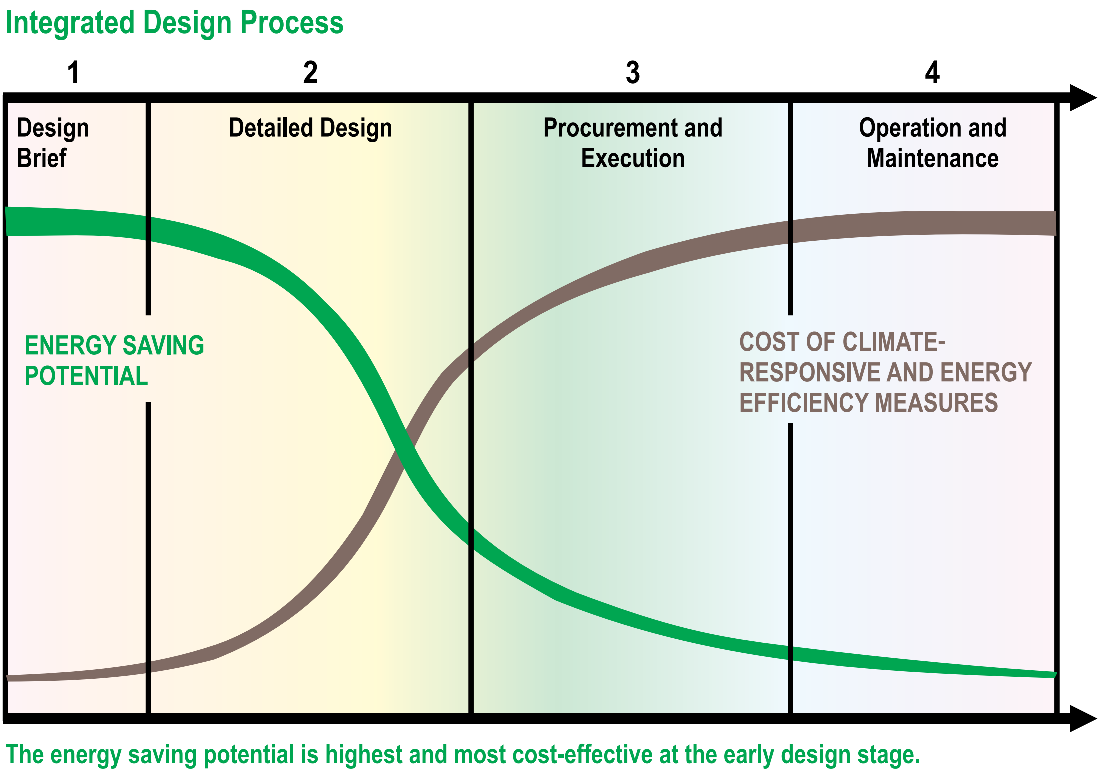

Figure 2.3 *Energy-saving potential in an integrated design process*

However, in order to practise the IDP, a few revisions are suggested in the existing design process of PWD. As per the existing PWD process, Stages 1 and 2 are crucial and require maximum attention. The integrated design approach should be adopted from here itself. The first stage requires the development of an extensive design brief, which gives a clear understanding to all concerned about the requirements of the buildings. It is only then that all the teams will know the precise requirements. The framing of design brief is crucial. This stage will involve some iterations with the client to source information, answer any queries to gradually define the project brief. In some cases, it may be that the information is not available or subject to future changes. If this is the case, the design team and the client will need to agree on assumptions. Such assumptions can be based on practices followed for similar buildings or on usual common practice. It is, however, important to record this information in such a way that they can be questioned and updated at a later stage. It is also important that the client takes responsibility for providing the information and for thinking the design brief through with the design team.

This design brief essentially consists of four sections:

1. General details
2. Site details
3. Building usage
4. HVAC and appliances requirements

A detailed checklist for the design brief is attached in Annexure 2.1.

The second stage is where all the concerned departments get together and integrate their designs. It is at this stage that the potential for energy saving is maximum, and maximum iterations can be made. The engineering and architecture departments should specially work closely to design a building that integrates both passive and active measures well. In addition to the design team, the involvement of engineers responsible for the construction of the building and the future users of the building is strongly encouraged at this stage. Figure 2.4 shows how the involvement of all stakeholders leads to designing an energy-efficient building.

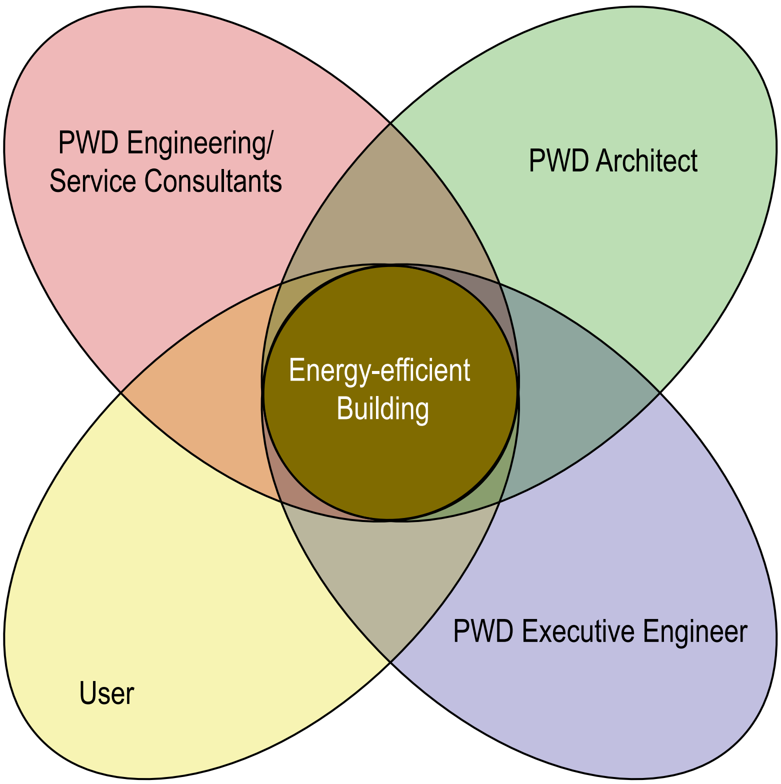

Figure 2.4 *Integrated design stakeholders for public buildings in Karnataka*

CHAPTER RECAP

- Design of energy-efficient buildings takes into account such factors as:
  - Climate
  - Site conditions
  - Building usage

  Adequate information on these factors should be collected at the stage of preparing the design brief.

  The following design strategies are important to follow in order to achieve an energy-efficient design. These may not always be followed in the same sequence and will have to be revised at various stages to reach the final design.
  - Strategy 1: Climate-responsive Building Massing
  - Strategy 2: Design Openings for Daylight
  - Strategy 3: Design Natural Ventilation
  - Strategy 4: Climate-responsive Envelope
  - Strategy 5: Design Solar Shading
  - Strategy 6: Efficient Cooling Systems
  - Strategy 7: Integration of Renewable Energy

- To achieve a cost-effective energy-efficient design, an integrated design approach should be adopted from the early design stage. This approach lays emphasis on the architects and engineers working together from the very beginning.

- The PWD design process needs to be strengthened, particularly by developing an exhaustive design brief for each project. This should be followed by an integrated design approach to achieve an energy-efficient design.

CHAPTER 3

Understanding Thermal Comfort and Climate Analysis

3.1 Thermal Comfort

Understanding the concept of thermal comfort and characteristics of different climatic regions in Karnataka is important in the process of designing energy-efficient buildings. These two subjects are introduced in this chapter.

Thermal comfort is achieved when occupants of the building express satisfaction with the thermal environment inside the building. Thermal comfort is normally attained when the heat generated by the human metabolism of the occupants of a building is equal to the heat dissipated by them, i.e., the condition of thermal neutrality is maintained. The heat losses from the occupants depend on various heat exchange mechanisms (Figure 3.1) and the type (particularly the insulation provided by it) of clothing.

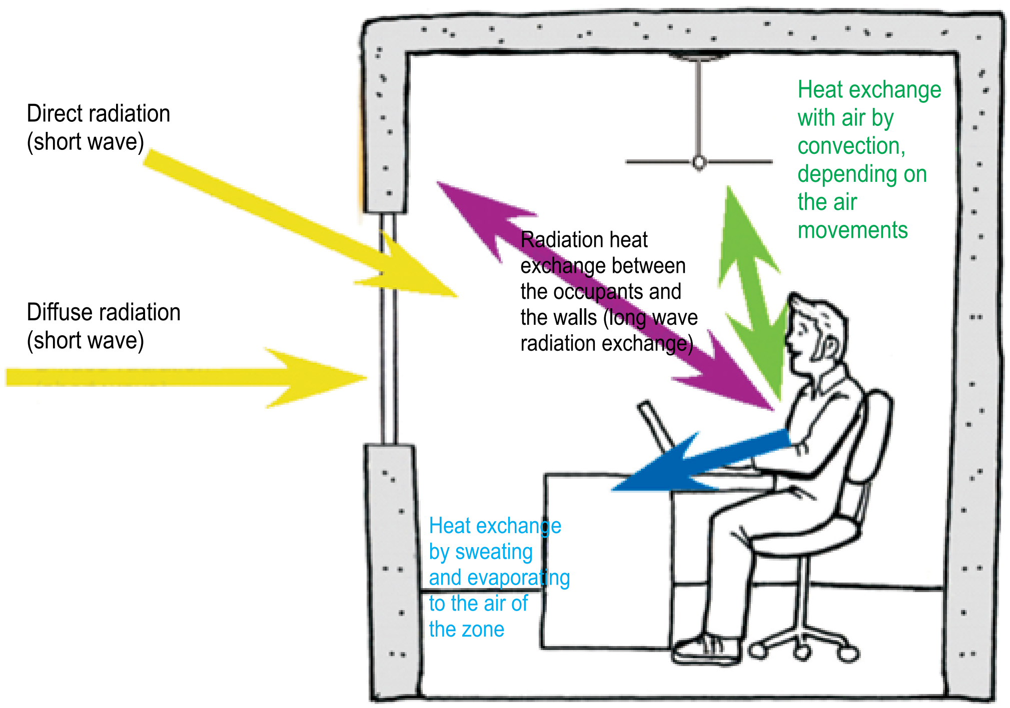

Figure 3.1 *Main heat exchange mechanisms between the occupant and his/her environment in a building*

The heat exchange mechanisms shown in Figure 3.1 are explained below.

1. *Direct and diffused solar radiation entering the building through glazing (short wave radiation):*
   During the day, solar radiation passes through the glazing and it reaches the occupants. In warm/hot climates as found in Karnataka, this phenomenon should be avoided as the heat gain from this radiation is much higher as compared to the other mechanisms of heat transfer, i.e., convection and evaporation. The objective of the building design in Karnataka should be to minimize solar radiation reaching directly to the occupants.

2. *Heat exchange between the building walls, ceilings, and floor with the occupants (long wave radiations):*

The internal building envelope surfaces (inside surfaces of walls, ceiling, glazing, and floor) exchange heat by long wave radiation with the occupants through clothing.

3. *Heat exchange with the air (convection)*
   The occupants exchange heat by convection with the air inside the building. If there is no air movement generated by ceiling fans, the heat exchange by convection will be limited to the natural draft generated by the occupants. Due to the use of ceiling fan, the heat exchanged by convection is multiplied by a factor of 2 to 3, reducing the feeling of thermal discomfort.

4. *Heat exchange with the air by sweating and evaporating (evaporation)*
   When the humidity and/or the temperature is too high, which is often the case in warm and humid climates, the occupants start sweating. Air movement around the occupants helps in the evaporation of the sweat and provide comfort to the occupants. In the case of very humid conditions, the air inside buildings can reach a relative humidity of 80% or beyond. In these conditions, the skin becomes wet on its surface and the air around the skin becomes fully saturated, thereby slowing down the evaporation of the sweat. The subsequent increase in skin temperature creates a strong feeling of discomfort. Under such conditions, it is necessary to generate higher air movements of the order of 1.5–3.0 m/s (metres per second) (through the use of fans). Higher air movements can remove the saturated air around the skin, and replace it with less saturated air. This helps in increasing the evaporation rates of the sweat on human skin. It is recommended to wear clothing, which allows the sweat to pass across the pores of the clothing. Cotton is one of the best materials for this; while most of the synthetic materials are not good in this property.

To avoid discomfort caused by heat gain through the above-mentioned mechanisms, it is suggested that the following measures be taken.

1. The glazing area should be minimized and should be appropriately shaded to avoid thermal discomfort caused by solar radiation (both direct and diffused). (Refer Section 4.3.)
2. The spaces should be naturally ventilated, as air movement both natural and that generated by ceiling fans helps in allowing evaporation and reducing the wetness of the skin. (Refer Section 4.4)
3. Appropriate wall and roof insulation helps in reducing the discomfort caused by heat ingress and heat exchange by long wave radiation with the occupant. (Refer Section 4.5.)

3.2 Adaptive Thermal Comfort Model

The adaptive thermal comfort model is based on the assumption that the outdoor climate influences the indoor comfort and that people tend to adapt to different temperatures according to their climatic environment. The ECBC refers to the adaptive model, and defines a comfort range, which evolves according to the mean outdoor temperature over the past month (Figure 3.2). The figure shows that the occupants adjust to outdoor temperatures and feel comfortable at lower temperatures in winter and at higher temperatures during summer.

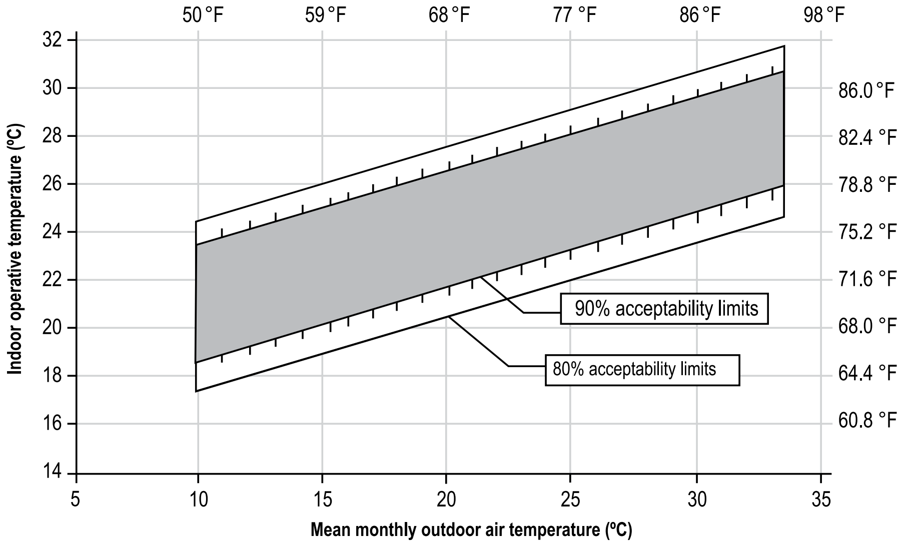

Figure 3.2 *Acceptable operative temperature ranges for naturally conditioned spaces*
Source *Ashrae 55-2004.*

Recently, a new model has been developed in India, which uses the average temperature over the past seven days as a reference.[1] These adaptive models show that in India, people tend to adapt to their environment and accept higher temperatures (up to 28.5 °C) during summer months, particularly in naturally ventilated buildings.

3.3 Climate Analysis for Karnataka

The climate of Karnataka is divided into three major types: (a) the tropical wet climate on the coast, (b) the tropical wet and dry climate in the interior, and (c) the semi-arid climate in the eastern part of the state. The climate map of Karnataka (Figure 3.3) shows the districts and major cities falling in each of these climate zones. Figure 3.4 shows the topographical map of Karnataka. It has been noted that the climate behaviour changes as the altitude rises, especially beyond 900 m.

Daily temperatures and the relative humidity for sample cities located in the three climate regions are shown in Figures 3.5 to 3.12. The cities covered are:

- Mangaluru (tropical wet climate)
- Belagavi (wet and dry climate)
- Vijayapura (semi-arid climate)
- Bengaluru (temperate climate).

On the temperature graph, the thermal comfort band, which ranges between 19 °C and 26 °C, has been marked. The second set of graphs shows the hourly frequency distribution of wet bulb and dry bulb air temperatures; these help in estimating the potential number of hours evaporative cooling can be used in a particular area.

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[1] *Model developed by the Centre for Advanced Research in Building Science and Energy (CARBSE) at CEPT University and the University of Technology of Sydney. More details on the model can be found on* <http://www.carbse.org/development-of-an-adaptive-thermal-comfort-standard-for-india/>.

These graphs help in understanding the climates and identifying potential solutions to achieve thermal comfort in various seasons. Tables 3.1–3.4 given alongside list the seasons, their characteristics, and potential strategies that can be adopted.

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1. Most of the urban centres in Karnataka fall under one of the four climatic zones – tropical wet climate (e.g., Mangaluru), wet and dry climate (e.g., Belagavi), semi-arid climate (e.g., Vijayapura), and temperate climate (e.g., Bengaluru). Different strategies are required to achieve a comfortable energy-efficient building design in each of these climates.

2. Thermal comfort is achieved when occupants of the building express satisfaction with the thermal environment inside the building. The ECBC User Guide refers to the adaptive thermal comfort model, which shows that the occupants adjust to outdoor temperatures and feel comfortable at lower temperatures in winter and at higher temperatures during summer.

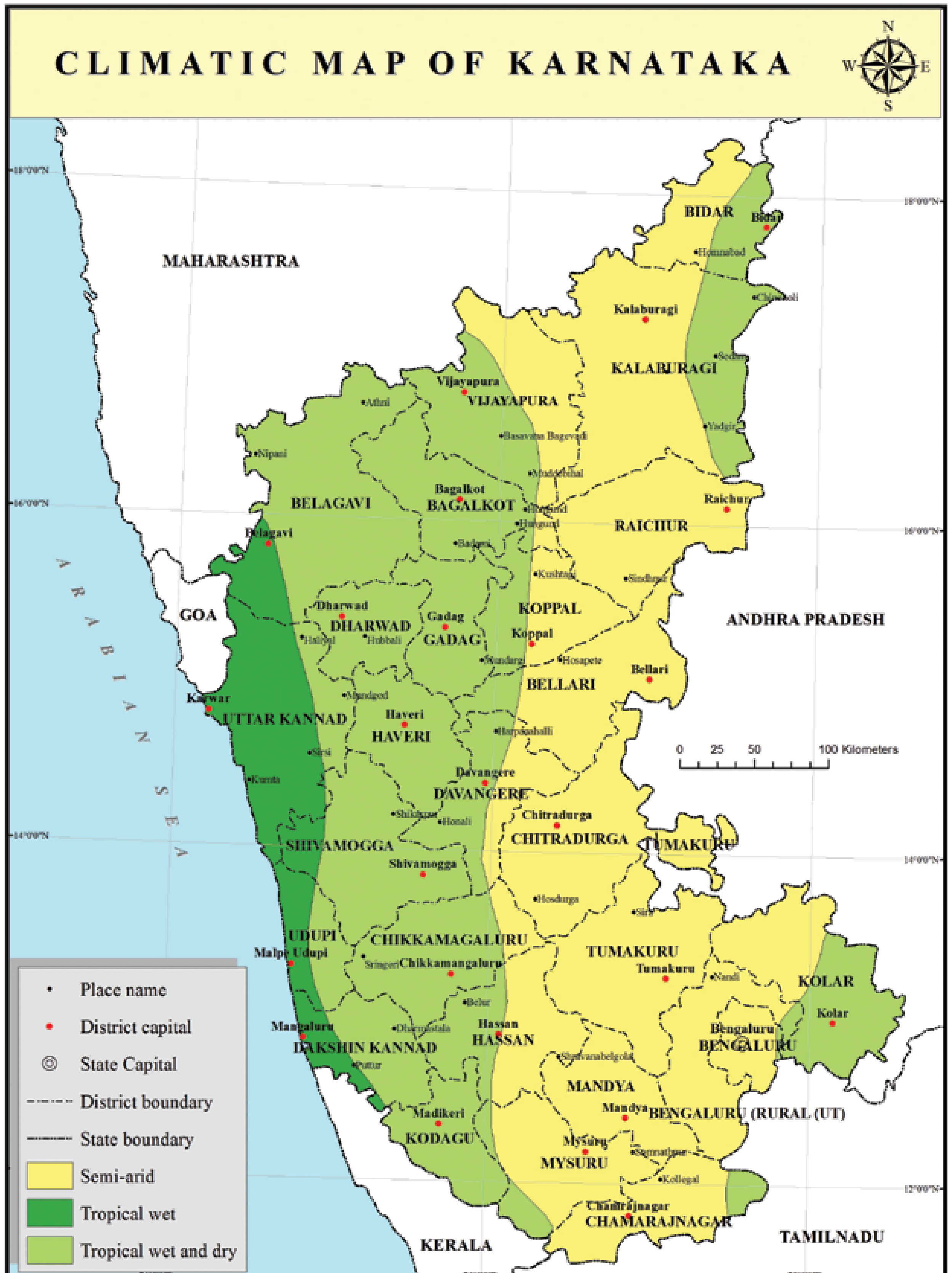


Figure 3.3 *District map of Karnataka showing the climatic zones*

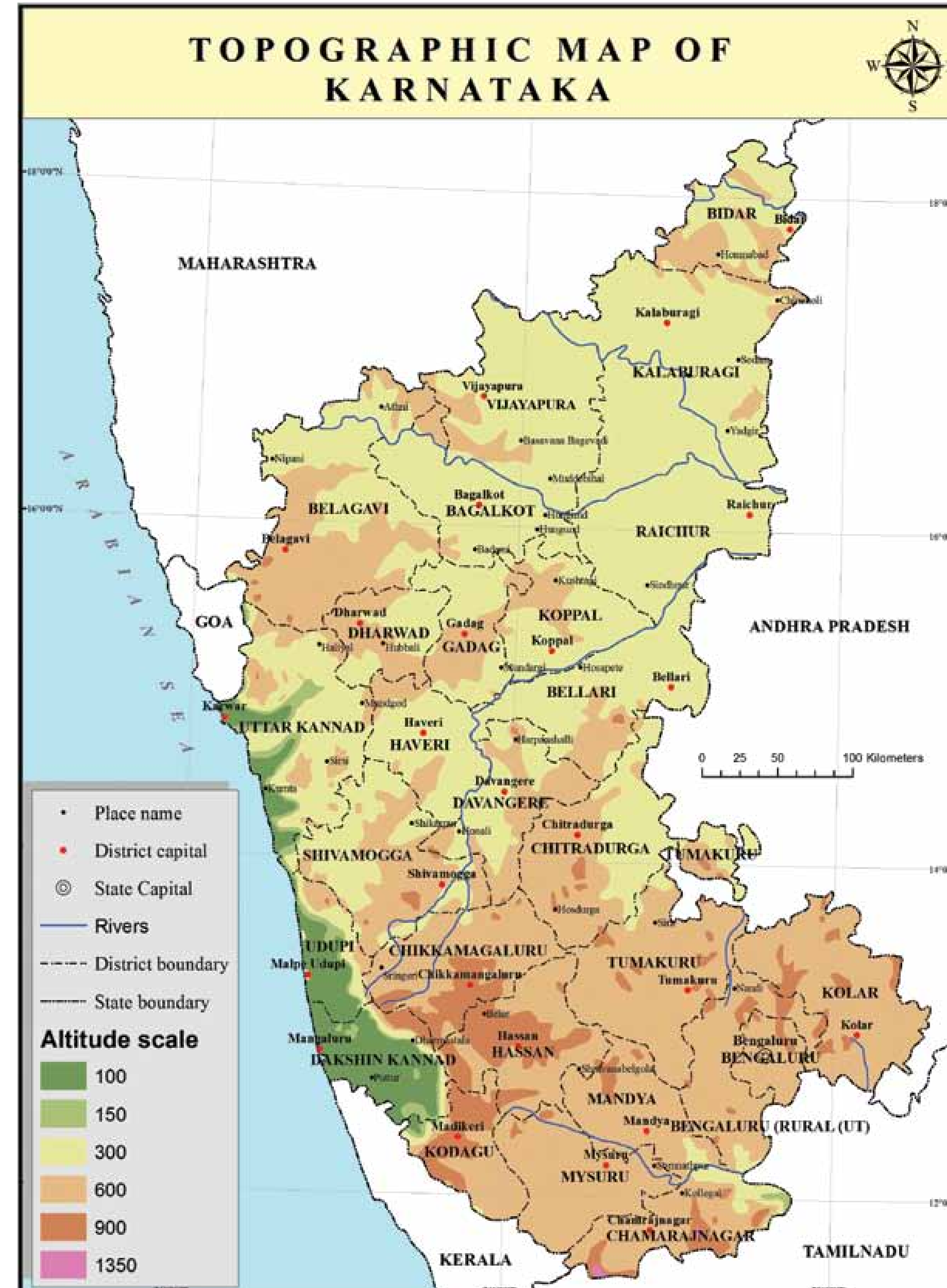


Figure 3.4 *District map of Karnataka showing the natural topography*

1) Tropical Wet Climate (Example: Mangaluru)

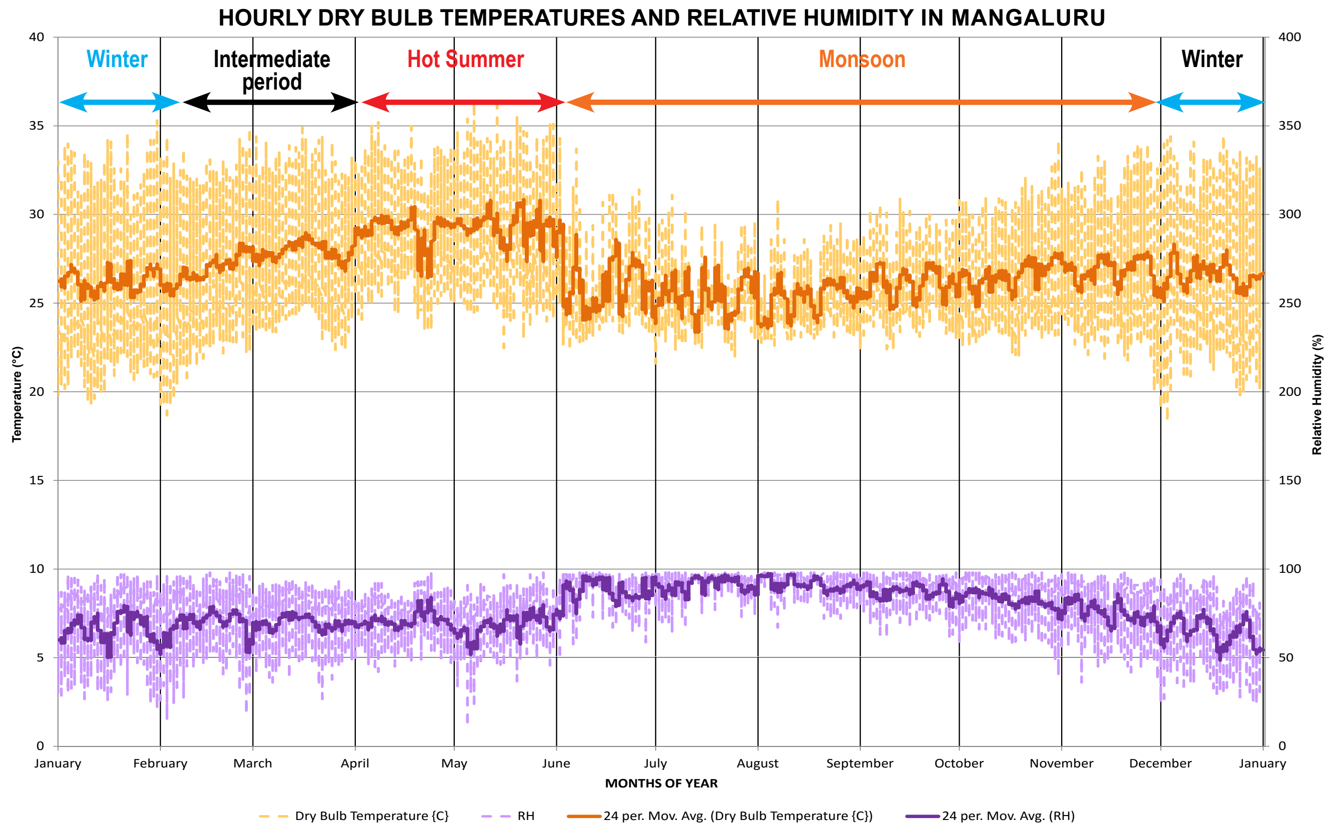


Figure 3.5 *Monthly temperature and humidity range of Mangaluru*

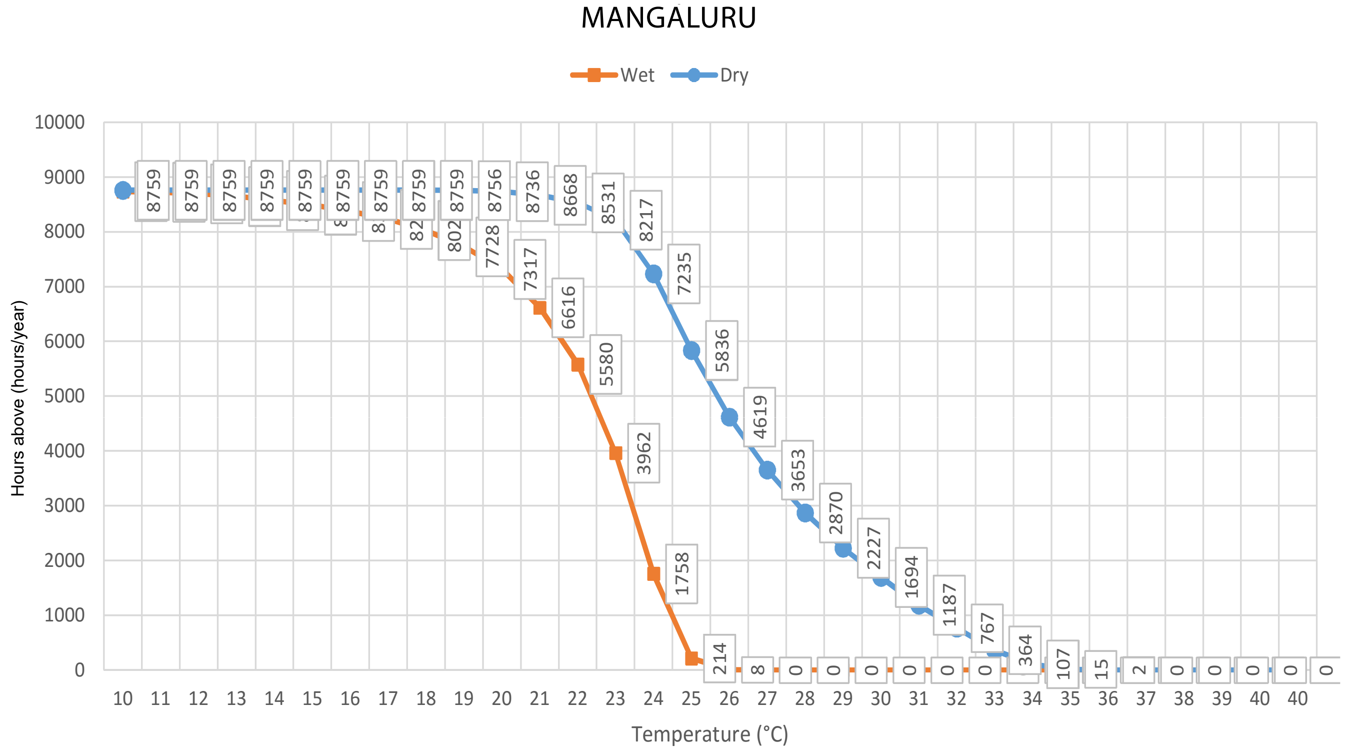


Figure 3.6 *Wet and dry bulb distribution curve for Mangaluru over 8760 hours*

Table 3.1 Characteristics and potential solutions for tropical wet climate

Season	Characteristics	Potential Solutions
Summer (March–May): The region experiences a mildly warm summer.	▪ Maximum day temperatures ~ 33 °C–35 °C. Minimum night temperatures ~ 23 °C–27 °C. Diurnal temperature difference of 8 °C–10 °C. ▪ Average daily relative humidity ~ 50%–70%.	Passive ▪ Natural ventilation is more effective during morning, evening, and night Active ▪ Ceiling fans ▪ Air conditioning
Monsoon (June–September): The region receives heavy rainfall due to South-West monsoon.	▪ Maximum day temperature ~ 27 °C–30 °C. Minimum night temperatures 23 °C–25 °C. ▪ The relative humidity (RH) is generally above 80%.	Passive ▪ Natural ventilation throughout the day Active ▪ Ceiling fans ▪ Air conditioning
Winter (October–February): The region experiences a mild winter.	▪ Temperature varies between 20 °C and 33 °C. ▪ The RH is relatively less during the day.	Passive ▪ Natural ventilation Active ▪ Ceiling fans

2) Wet and Dry Climate (Example: Belagavi)

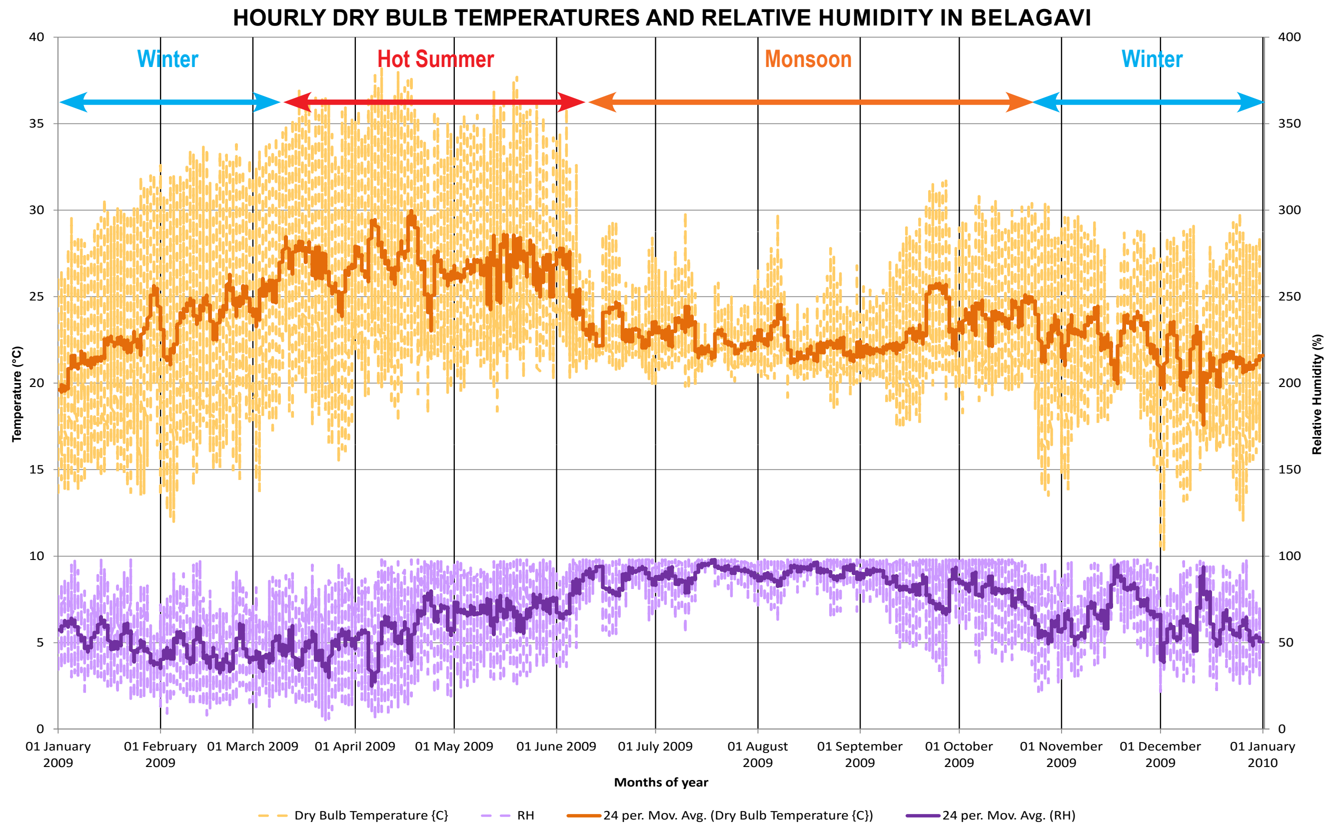


Figure 3.7 *Dry bulb temperature and relative humidity of Belagavi throughout the year*

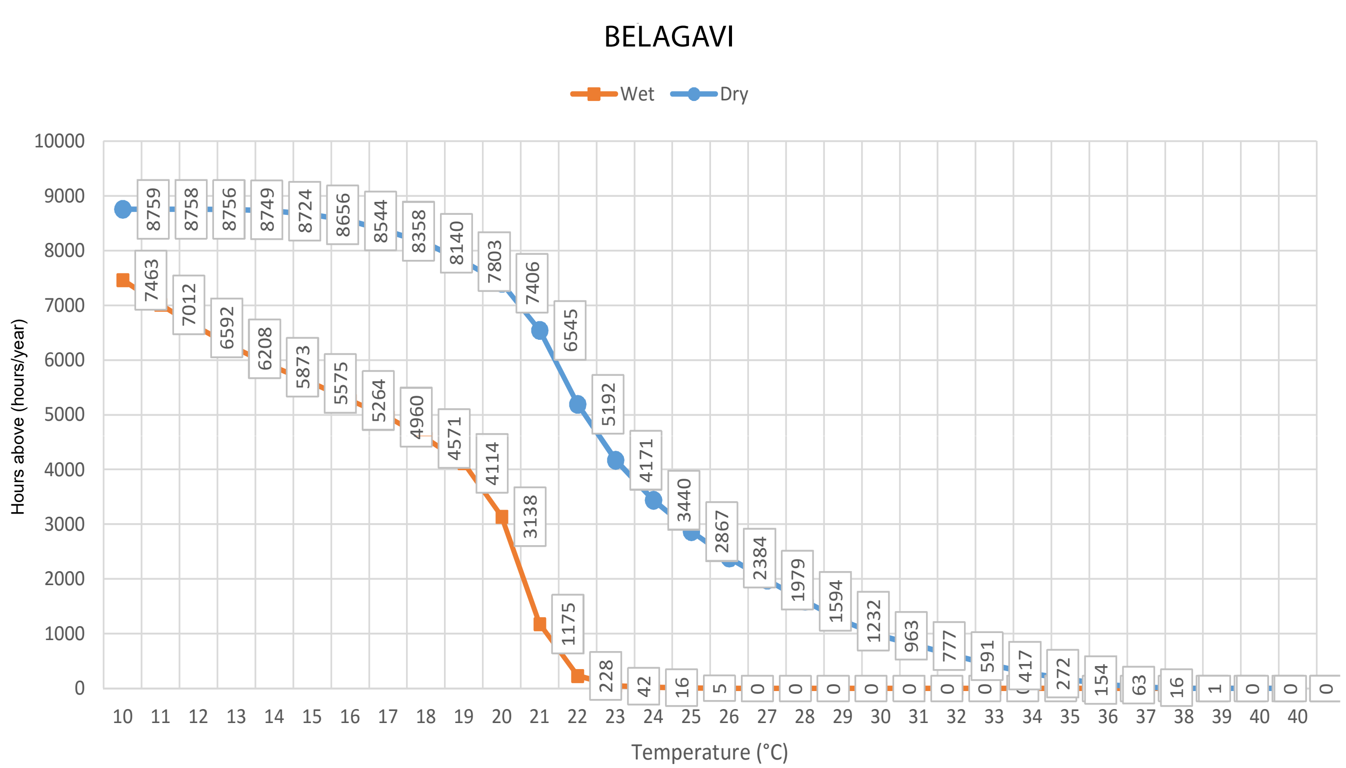


Figure 3.8 *Wet and dry bulb distribution curve for Belagavi over 8760 hours*

Table 3.2 Characteristics and potential solutions for wet-dry climate

Season	Characteristics	Potential Solutions
Summer (Mid-March to Early June): The region experiences hot summer.	▪ Maximum day temperatures above 35 °C. Minimum night temperatures ~ 24 °C–29 °C. Diurnal temperature difference of 8 °C–10 °C. ▪ Average daily RH ~ 30%. ▪ March is the hottest month.	Passive ▪ Natural Ventilation with thermal mass, especially during the night Active ▪ Ceiling fans ▪ Good potential for evaporative cooling
Monsoon (June–October): Heavy rains with very high humidity.	▪ Maximum day temperature ~ 27 °C–30 °C. Minimum night temperature 21 °C–23 °C. ▪ The average RH is generally above 80%. ▪ Low diurnal temperature variation.	Passive ▪ Natural ventilation with thermal mass Active ▪ Ceiling fans
Winter (November–February): The region experiences mild winter.	▪ Maximum daily temperature ~ 25 °C - 30 °C; Minimum temperature is around 15 °C. ▪ Very high diurnal temperature variation, at times, up to 15 °C.	Passive ▪ Natural ventilation with thermal mass ▪ Internal gains Active ▪ Ceiling fans

3) Semi-Arid Climate (Example: Vijayapura)[2]

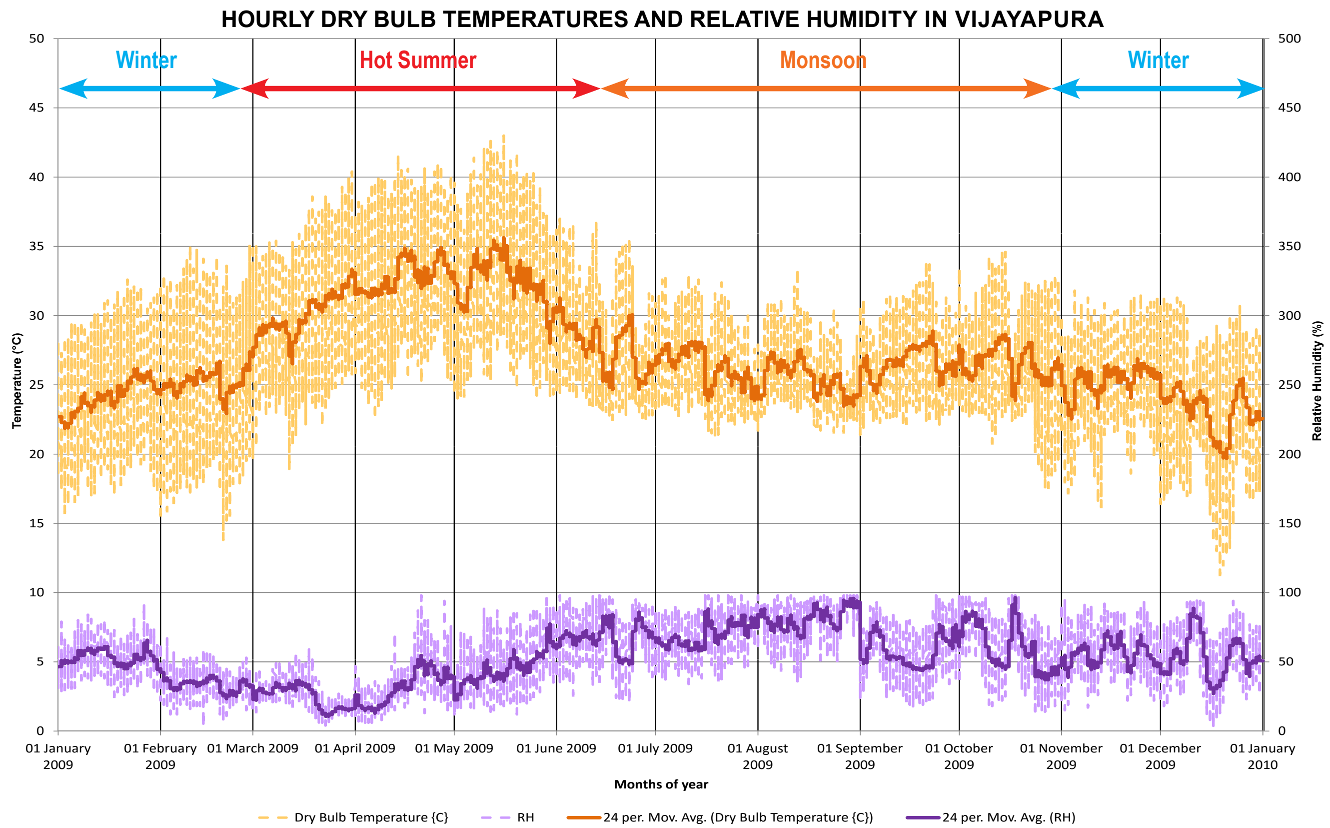


Figure 3.9 *Monthly temperature and humidity range of Vijayapura*

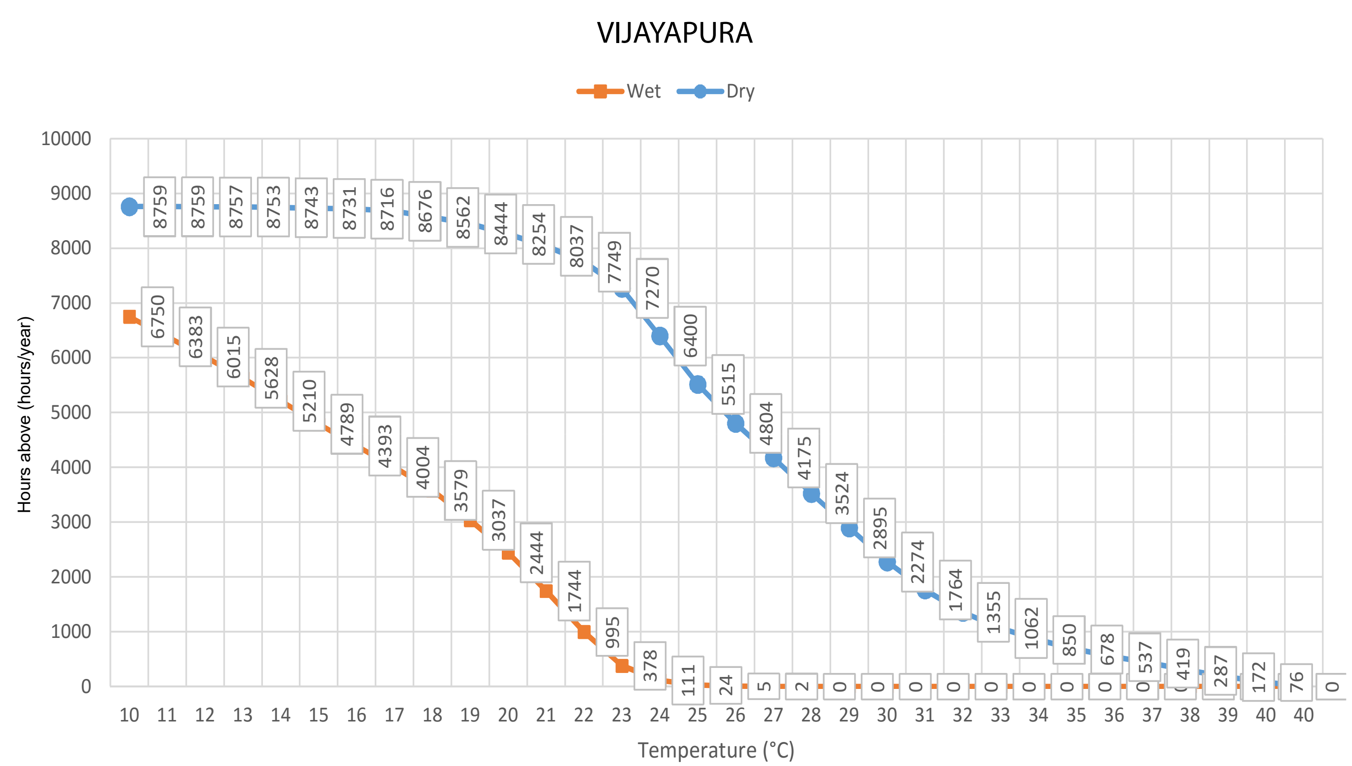


Figure 3.10 *Wet and dry bulb distribution curve for Vijayapura over 8760 hours*

[2] *The epw file used is that of Solapur as the same was not available for Vijayapura.*

Table 3.3 Characteristics and potential solutions for semi-arid climate

Season	Characteristics	Potential Solutions
Summer (Mid-March to Mid-June): The region experiences very hot and dry summer.	▪ Maximum day temperatures ~ 40 °C–43 °C; Minimum night temperatures ~ 25 °C–30 °C. Diurnal temperature difference of 10 °C–15 °C. ▪ Average daily RH ~ 50%–60%.	Passive ▪ Natural ventilation with thermal mass especially during night Active ▪ Ceiling fans ▪ Evaporative cooling
Monsoon (Mid-June to October): The region has very long monsoon with mild temperatures and high humidity.	▪ Maximum day temperature ~ 23 °C–30 °C. Minimum night temperatures 22 °C–24 °C. ▪ The average RH is generally above 80%.	Passive ▪ Natural ventilation with thermal mass Active ▪ Ceiling fans
Winter (November–February): The region experiences very mild winter.	▪ Maximum daily temperature is between 13 °C and 30 °C; Minimum temperature is around 15 °C. ▪ Very high diurnal temperature variation.	Passive ▪ Natural ventilation with thermal mass Active ▪ Ceiling fans

4) Temperate Climate (Example: Bengaluru)

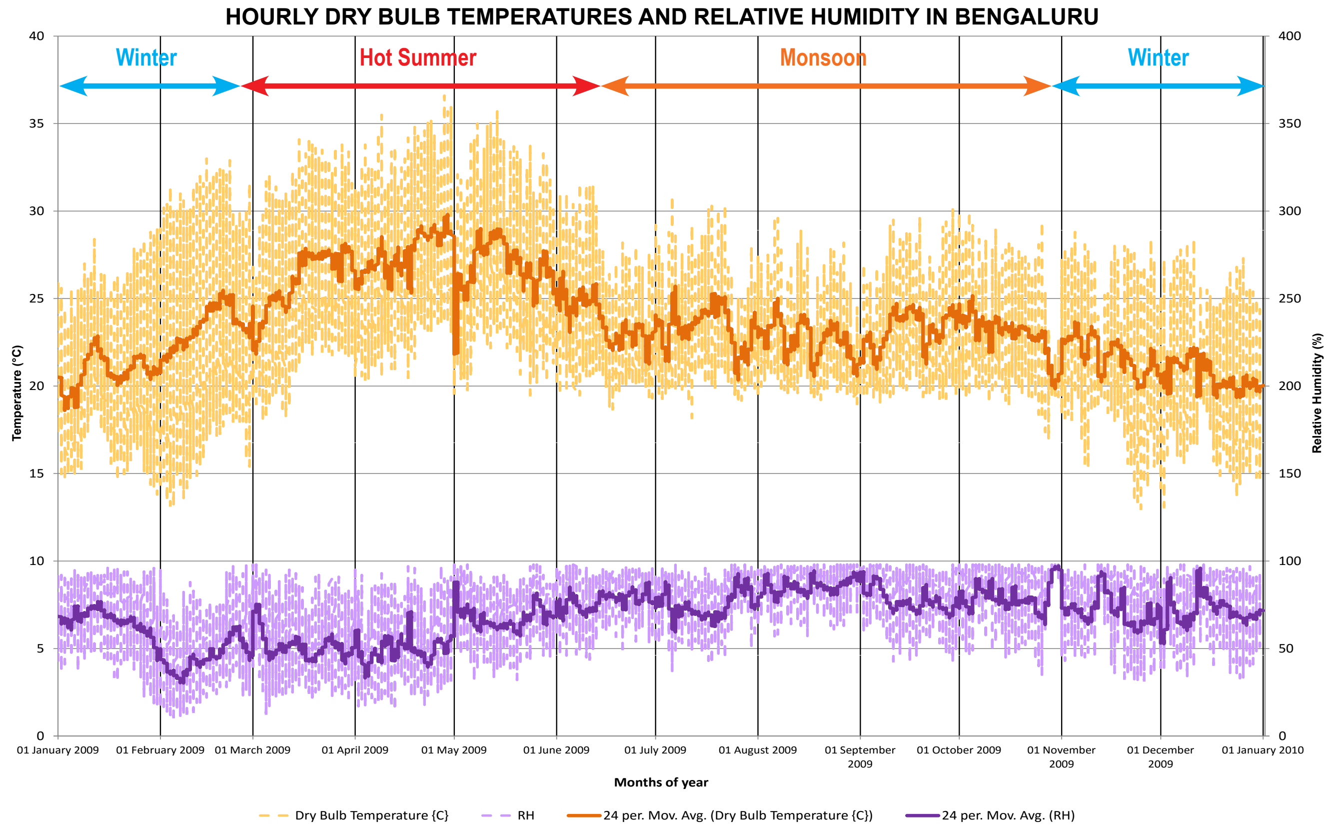


Figure 3.11 *Monthly temperature and relative humidity throughout the year in Bengaluru*

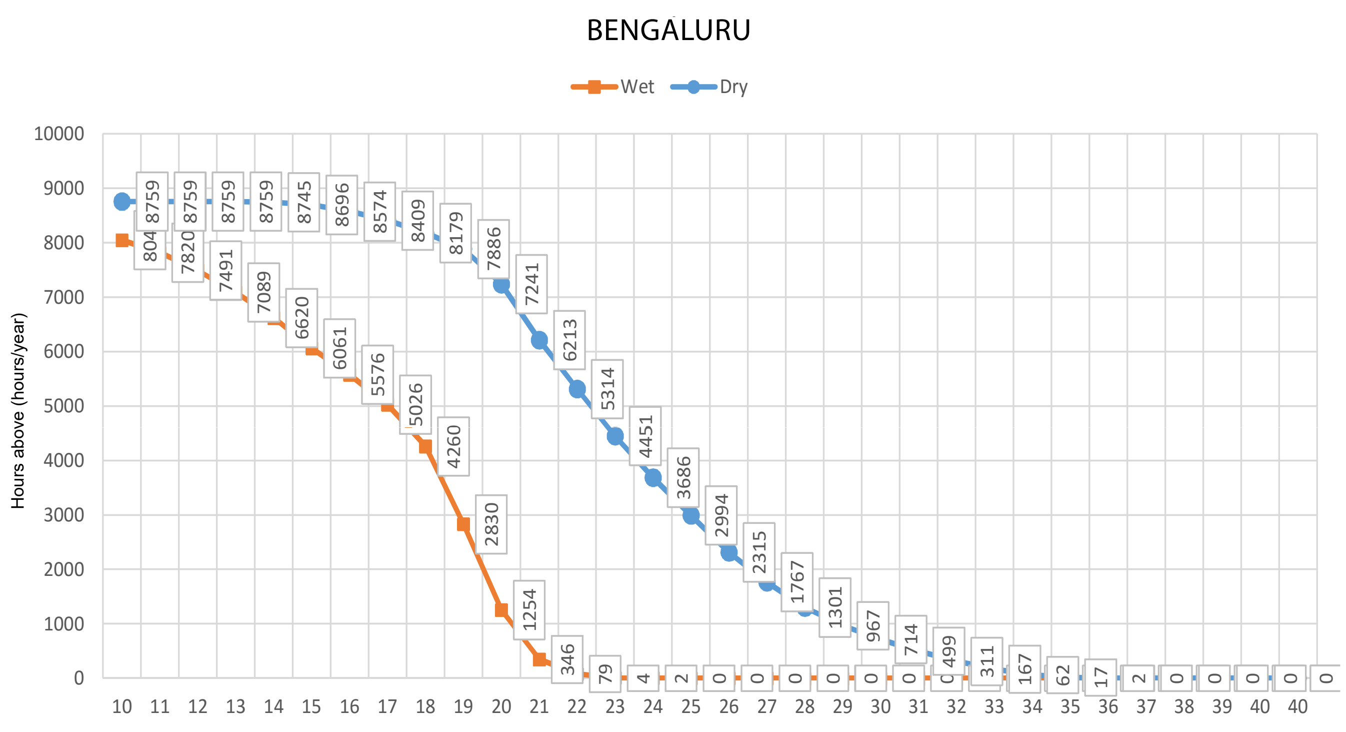


Figure 3.12 *Wet and dry bulb distribution curve for Bengaluru over 8760 hours*

Table 3.4 Characteristics and potential solutions for temperate climate

Season	Characteristics	Potential Solutions
Summer (Mid-March to Mid-June): The region experiences a moderate summer.	▪ Maximum day temperatures ~ 26 °C–27 °C with maximum temperature of 35 °C on hottest days. Minimum night temperatures ~ 23 °C–25 °C. Diurnal temperature difference of 7 °C–10 °C. ▪ Average daily RH ~ 30%–60%.	Passive ▪ Natural ventilation with thermal mass especially at night Active ▪ Ceiling fans ▪ Evaporative cooling
Monsoon (Mid-June to October): The region has a very long monsoon with high humidity.	▪ Maximum day temperature ~ 19 °C–27 °C. ▪ The RH is generally 80%–90%.	Passive ▪ Natural ventilation with thermal mass Active ▪ Ceiling fans
Winter (November – mid February): The region experiences a mild winter.	▪ Maximum daily temperature is between 25 °C and 27 °C; Minimum temperature is around 14 °C–15 °C. ▪ Very high diurnal temperature variation.	Passive ▪ Natural ventilation with thermal mass Active ▪ Ceiling fans

CHAPTER 4

Climate-responsive Design

4.1 Introduction

After the design brief has been prepared, the process of designing the building is initiated. This chapter presents five design strategies to achieve a climate-responsive design.

Figure 4.1 lists the strategies covered in this chapter. All the five strategies are important and are inter-dependent. Due to their inter-dependence, an iterative design approach that involves going back and forth on the different strategies is needed. **This iterative process requires architects and engineers to work together, and apply building simulation tools/ calculations from the outset to come up with a climate-responsive design.**

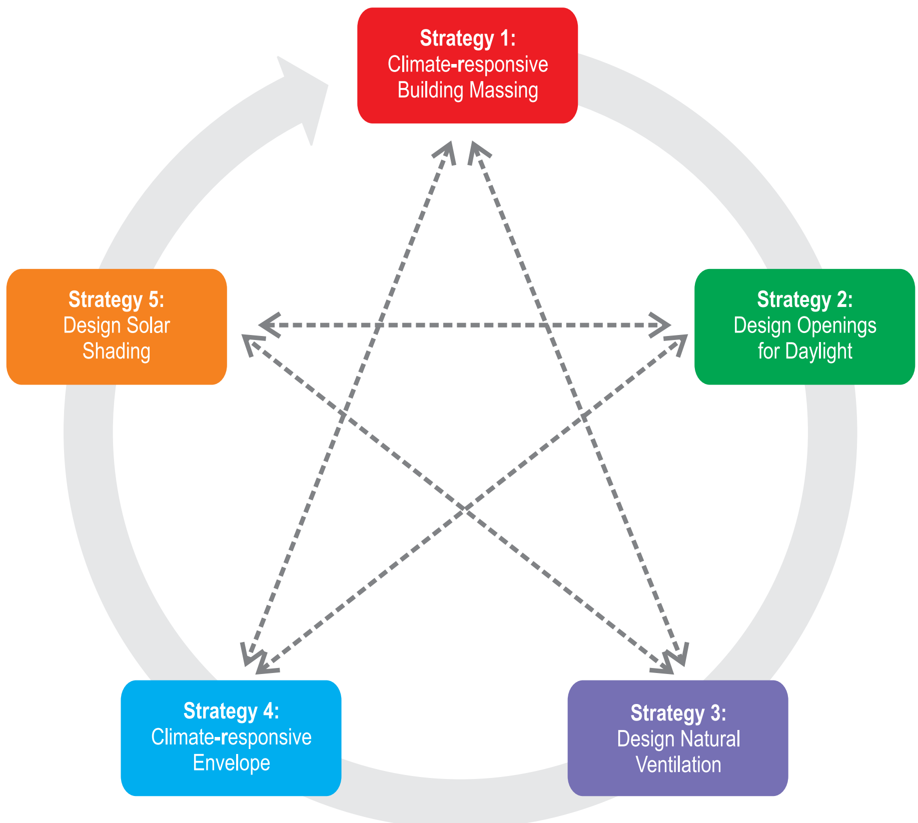


Figure 4.1 *Design strategies to be followed while designing energy-efficient buildings*

4.2 Strategy 1: Climate-responsive Building Massing and Orientation

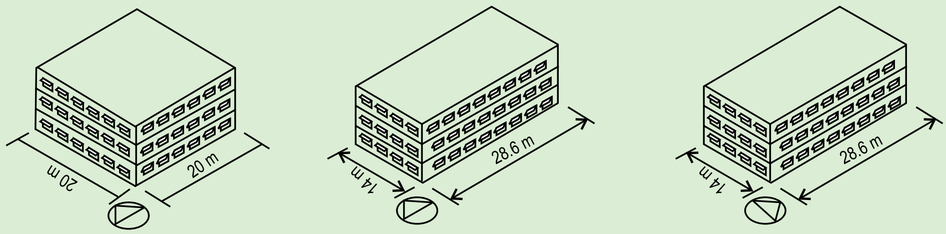
Strategy 1: Climate-responsive Building Massing and Orientation	▪ Reduces heat gains by proper orientation and mutual shading ▪ Enables access to daylight ▪ Facilitates natural ventilation

Building massing refers to the overall shape and size of the building. Building massing affects:

- Access to daylight first in the building massing
- Rate of heat gain or loss from the building envelope
- Access to natural ventilation

Box 4.1 Simulations carried out on reference buildings to explain the strategies

To explain the strategies, a hypothetical case of a small office building, three storeys high, having a total built-up area of 1200 m^2 was considered. For a building in Belagavi, simulations of cooling demand, daylight access, and natural ventilation were carried out for different options (shapes, orientation, openings, etc.). This analysis was carried out using two software—Design Builder (cooling loads and daylighting) and FloVENT (natural ventilation).



4.2.1 Effect of building massing on cooling load

Three cases of the reference building, situated at Belagavi, have been simulated for analysing the effect of building massing and orientation on cooling loads. The three cases are as follows:

- Case 1: Square building with the same area on all four façades.
- Case 2: Rectangular building, oriented N–S.
- Case 3: Rectangular building, oriented E–W.

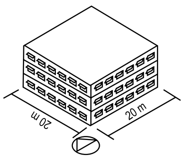
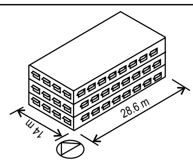
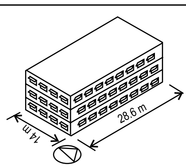
The results of this analysis on cooling loads for the intermediate floor during the peak summer months (March–May) is shown in Table 4.1. The cooling loads for Cases 1, 2, and 3 are shown. The intermediate floor negates the impact of heat exchange through the roof or ground.

The explanation of the results is as follows:

- Comparison of Case 1 with Case 2: The cooling demand for Case 1 is marginally higher (3%) when compared to Case 2 (rectangular building with N–S orientation). The reduction in the façade area on the eastern and western faces of the building in Case 2 is responsible for this reduction in the cooling demand.
- Comparison between Case 2 and Case 3: The cooling demand for Case 3 is significantly higher (17%) compared to Case 2. In Case 3, the building is oriented E–W, while in Case 2, the orientation is N–S. For Case 3, the façade area on the eastern and western faces of the building is much higher compared to that in Case 2.

Hence, it can be concluded that a linear building form in which the longer sides are oriented towards the north and south will receive lower solar radiation on its surface and, in turn, would have lower cooling loads.

Table 4.1 Results of the analysis of the effect of building massing on cooling load for an intermediate floor (Belagavi)

Case	Model	Properties	Total cooling load (kWh) on an intermediate floor for March to May period
Case 1	 Built-up area: 1200 m^2 Floor-plate dimension: 20 x 20 m	WWR: 20% on all façades, Overhangs: 600 mm fixed, Glazing type: Single clear 6 mm (U-value: 6.1 W/m^2.K, VLT: 88%, SHGC: 0.81), Level: Intermediate floor 6 inch RCC slab with plaster (U-value: 3.8 W/m^2.K) Intermediate floor (no heat exchange through the floor and the ceiling with other floors), No internal loads considered, Cooling set-point: 26 °C, Fresh air + Infiltration: 1 ach	3782
Case 2	 Built-up area: 1200 m^2 Floor-plate dimension: 14.0 x 28.6 m Orientation: N–S		3677 GOOD
Case 3	 Built-up area: 1200 m^2 Floor-plate dimension: 14.0 x 28.6 m Orientation: E–W		4305

Note: SHGC - solar heat gain coefficient; RCC - reinforced concrete slab; WWR - window-to-wall ratio; and VLT - visual light transmittance

4.2.2 Effect of building massing on access to daylight

The same building forms (Cases 1 and 2) were simulated to check the access to daylight inside the buildings[1] (refer Table 4.2). It is seen that the central part of the square building (Case 1) did not receive adequate daylight (area marked black receives <100 lux) while the areas close to the window (area marked red receives >500 lux) had excessive glare. However, in Case 2, the daylight distribution is better. The central part has better daylight penetration (area marked blue receives 100–200 lux), though the areas close to the windows still have the problem of excessive glare.

Hence, it can be concluded that a linear building form in which the longer sides are oriented towards the north and south will have better daylight access. However, it should be mentioned here that the width of the floor plate (in Case 2 it is 14 m) also has a bearing. Usually, the maximum width suggested for good daylight is 14–18 m.[2]

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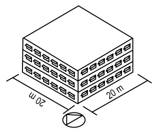
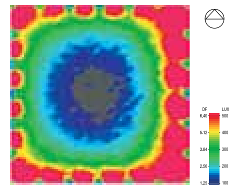
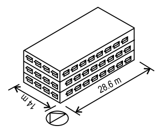
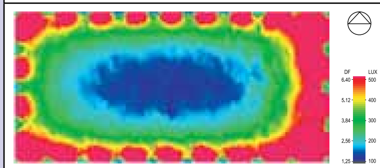
[1] *Daylight access checked for a clear day (9 September).*

[2] *Considering the lintel height of 3.5 m and windows on both façades, the daylight reaches up to 2.5 H from both façades.*

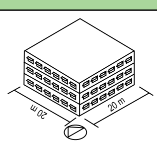
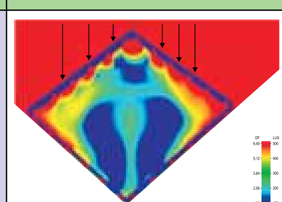
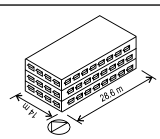
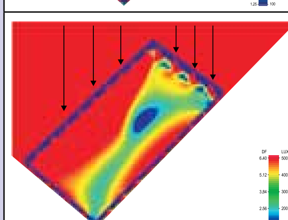
Table 4.2 Results of daylight access in Cases 1 and 2

Case	Model	Properties	Daylight
Case 1	 Built-up area: 1200 m^2 Floor-plate dimensions: 20 x 20 m	WWR: 20% on all façades Overhangs: 600 mm fixed Glazing type: Single clear 6 mm (U-value: 6.1 W/m^2.K, VLT: 88%, SHGC: 0.81)	
Case 2	 Built-up area: 1200 m^2 Floor-plate dimensions: 14.0 x 28.6 m Orientation: N–S		 GOOD

4.2.3 Effect of building massing on natural ventilation

The effect of building massing on natural ventilation inside the building was studied using computational fluid dynamic (CFD) modelling. The analysis was done for Case 1 and Case 2. It is assumed that air blows at an angle of 45 degrees to the buildings and the wind speed is 2 m/s. The results are shown in Table 4.3. It is seen that in Case 1, most of the central part of the building has low air velocities and this area does not get the benefit of sufficient air movement (area marked dark blue has wind velocity <0.1 m/s). For Case 2, the air distribution is even and the wind velocities are higher. Except for a small area (marked in dark blue), all the other areas have higher wind velocities (>0.1 m/s).

Table 4.3 Analysis of natural ventilation in Cases 1 and 2

Case	Model	Properties	Wind distribution inside the building
Case 1	 Built-up area: 1200 m^2 Floor-plate dimension: 20 x 20 m	WWR: 20% on all façades Overhangs: 600 mm fixed Sliding windows with 50% area open Wind direction: 45 degrees Wind speed: 2 m/s	
Case 2	 Built-up area: 1200 m^2 Floor-plate dimension: 14.0 x 28.6 m Orientation: N–S		 GOOD

4.2.4 Conclusions on building massing and orientation

The simple analysis presented in this section on the effect of building massing on cooling loads, access to daylight, and natural ventilation shows that a linear building form with shallow floor plates (<16–18 m) and with the longest façades towards north and south should be preferred. Some examples of such buildings forms are shown in Figure 4.2. These building forms are appropriate to manage the solar gains, daylight, as well as natural ventilation.

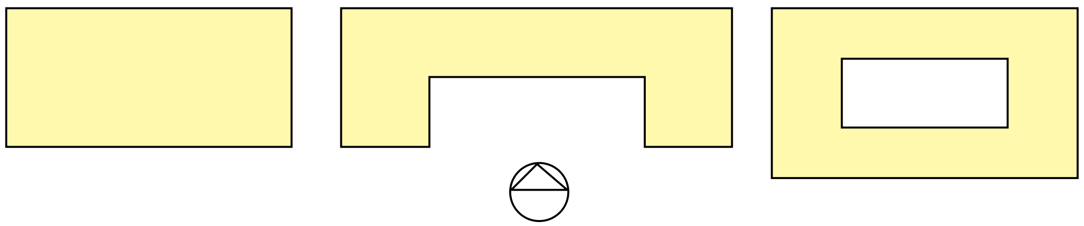


Figure 4.2 *Recommended building forms for climate-responsive building massing*

4.3 Strategy 2: Design Openings for Daylight

Strategy 2: Design Openings for Daylight	▪ Optimises daylight openings/location ▪ Reduces heat gain through windows ▪ Reduces glare

Optimising daylight inside the regularly occupied spaces is an important part of designing energy-efficient buildings. Daylight should neither be too much nor too less; a certain optimal level should be reached as both conditions are uncomfortable for the user. Poor daylight will lead to poor visual comfort and, which, in turn, will prompt occupants to switch on electric lights. The excessive use of artificial lighting will not only lead to higher electricity consumption, but also generate additional internal heat gains, which, in turn, will require more energy to cool the building. Annexure 4.1 gives an outline on how to use efficient lighting. Excessive daylight on the other hand will produce more glare.

4.3.1 Daylight autonomy and daylight factor

Figure 4.3 gives the daylight autonomy[3] in relation to daylight factors (DFs)[4] for different set points in Bengaluru. The curves give the level of autonomy of daylight, for given lighting set points, according to the daylight factors during one whole year. The percentage refers to the autonomy of daylight during the whole year, from 9 a.m. to 6 p.m. Autonomy tables for the other climates of Karnataka are found in Annexure 4.2.

In Karnataka, it is recommended to reach at least 75% daylight autonomy, i.e., for 75% of the time during the day, the daylight levels within a building should be above a specified target illuminance (refer Table 4.4). The specific target illuminance may vary from space to space depending on the function for which it is used, e.g., in normal office spaces the recommended illuminance level is 300–500 lux. From Figure 4.3, it can be inferred that in an

[3] *Daylight autonomy is the percentage of time that daylight levels are above a specified target illuminance within a physical space or building.*

[4] *Daylight factor (DF) is the quantity of daylight available in a building, calculated for a normal day, with a typical sky. Expressed in percentage, the DF is the ratio between the light received on a plane surface in the room (li) and the light that the same plane surface would receive outside, without any obstacles to natural illumination.*

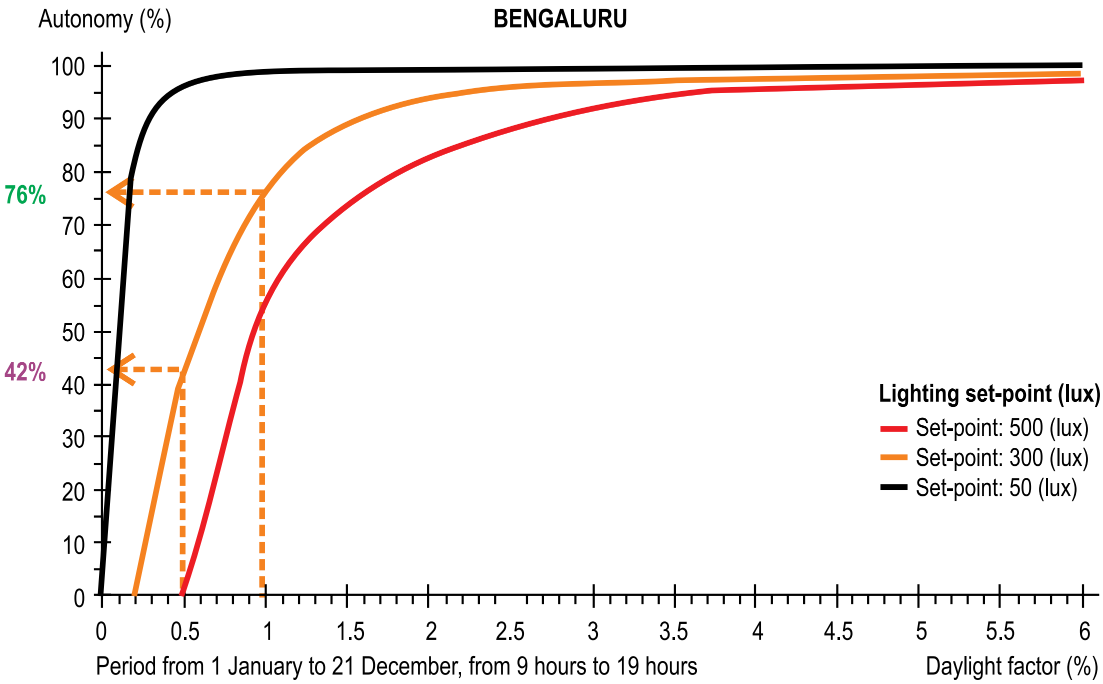


Figure 4.3 *Autonomy of lighting in relation to daylight factors for different set-points*

office space in Bengaluru, to attain lighting set-point of 300 lux and 75% daylight autonomy, the DF will be around 1.

Table 4.4 gives an indication of the recommended illuminance levels[5] and the corresponding DFs to be achieved for different kinds of buildings and spaces in Karnataka.

Table 4.4 Recommended illuminance levels and daylight factors (DFs) for different kinds of building spaces in Karnataka

Building space	Recommended illuminance levels (lux)	Recommended daylight factor (%)
Offices		
Standard office use *Detailed drawing / sketching*	300–500 500–1000	≥1 ≥3
Circulation areas	70–500	≥0.3
Staircases	100–150	≥0.5
Libraries	250–500	≥1
Schools (Classrooms)	300–500	≥1
Source Table adapted from J K Nayak and J A Prajapati, Handbook on Energy Conscious Buildings, 2006; and Dominique Chuard, Daylighting in Schools,Research Project on Energy Efficiency in Schools, May 1992, Swiss Federal Office for Energy (SFOE)		

4.3.2 Designing for good daylight

Some general rules that should be taken into consideration while designing openings for daylight are listed below.

[5] *Illuminance is the total luminous flux incident on a surface, per unit area.*

- Openings for daylight should be close to the ceiling as it ensures maximum penetration, limited heat gains, and glare control.
- The space depth should not generally exceed 2.5 times the floor to lintel height. Figure 4.4 illustrates this design principle. Usually, daylight is available up to 6 or 8 metres from the window.
- For good daylight, the visual light transmittance (VLT)[6] of the glazing should be high. In most cases, the VLT of clear float glass is high. A balance has to be made in the daylight entering the building and the heat. This can be further controlled by the use of external movable shading (refer Section 4.6).
- The room finishes, i.e., ceilings, walls, etc., should be white or in light shades as light shades reflects light.
- To avoid glare,[7] interior blinds may be provided, as they can be pulled down whenever needed. Note that this does not replace the solar control device, as interior blinds will let the solar heat gain inside the building.

One of the important decisions to be taken during the building design is to fix the size and location of the openings. The results shown earlier in Table 4.2 shows that for the specific example of the linear shape (Case 2), a window-to-wall ratio (WWR) of 20%, with windows distributed uniformly on all the façades, provides better daylight compared to the square building (Case 1). Proper location of the windows can further improve daylight; this is shown in Table 4.5.

In Table 4.5, two cases have been considered:

- Case 2: Linear shape-oriented N–S having a WWR of 20% and with windows distributed uniformly on all the façades.
- Case 4: This is a variation of Case 2. In this case, the orientation (N–S) and WWR (20%) remain the same, but now the windows of larger size (to maintain overall WWR of 20%) are provided only on the north and south façades; and no windows are provided on the east and west façades.

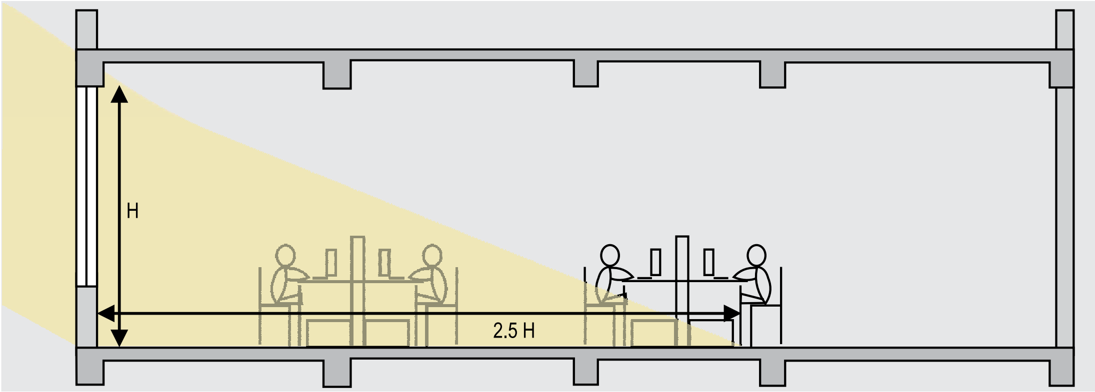


Figure 4.4 *Illustration of a typical daylight penetration in a room*

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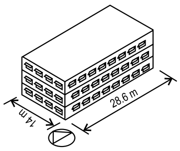
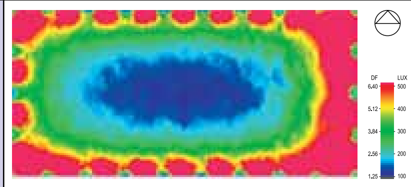
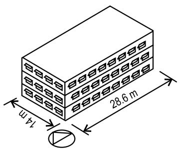
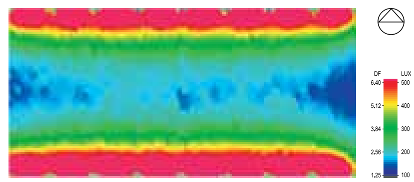
[6] *The quantity of light transmitted by glazing is called visual light transmittance (VLT) and represents the quantity of daylight, which penetrates through the glass, as in percentage of the total daylight.*

[7] *Glare is a visual sensation caused by excessive and uncontrolled brightness. It can be disabling or simply uncomfortable.*

Table 4.5 Analysis for daylight access: effect of window location

Case	Model	Properties	Daylighting
Case 2	 Built-up area: 1200 m^2 Floor-plate dimension: 14.0 x 28.6 m Orientation: N-S	WWR: 20% on all façades Overhangs: 600 mm fixed Glazing type: Single clear 6 mm (U-value: 6.1 W/ m^2.K, VLT: 88%, SHGC: 0.81)	
Case 4	 Built-up area: 1200 m^2 Floor-plate dimension: 14.0 x28.6 m Orientation: N–S No windows on east and west	WWR: 28% on north and south façades Overhangs: 600 mm fixed Glazing type: Single clear 6 mm (U-value: 6.1 W/ m^2.K, VLT: 88%, SHGC: 0.81)	 GOOD

It can be observed that the daylight distribution in Case 4 improves drastically over Case 2. Heat gain reduction from these openings have been discussed in Section 4.5.3.

It can be concluded that for typical office buildings in Karnataka, a WWR of 20%–30% is sufficient to provide good daylight (daylight autonomy of around 75%). For achieving good daylight, the building should be linear-shaped (14–18 m width[8]) in which the longer sides are oriented towards the north and south and the windows are provided only on the north and south façades.

4.4 Strategy 3: Design for Natural Ventilation

Strategy 3: Design for Natural Ventilation	▪ Facilitates natural ventilation

Natural ventilation can be used in many ways in the buildings of Karnataka. Natural ventilation works on certain principles, which are explained below.

4.4.1 Wind-driven natural ventilation

In this case, wind-induced pressure differences drive the air across the building. Cross-ventilation (when there are openings on opposite walls) is more effective than single-sided ventilation (having opening on only one wall), particularly for deeper spaces. Effective cross-ventilation requires an unrestricted flow path through the building. Single-sided ventilation is effective if the space has less than 6 metres depth, whereas cross-ventilation can cater for spaces up to a depth of 15 metres.

[8] *Considering the lintel height of 3.5 m and windows on both façades, the daylight reaches up to 2.5 H from both façades.*

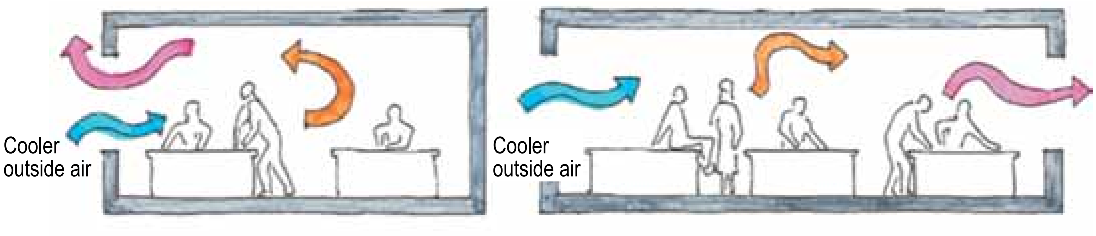


Figure 4.5 *Principles of single-sided ventilation and cross-ventilation*

Facilitating wind-driven cross-ventilation

We have seen in the previous sections that linear north–south oriented buildings having openings on the southern and northern façades or windows are better in terms of reducing cooling loads and improving daylight. For such buildings, if the wind direction is exactly from the north or south, the cross-ventilation will be excellent. Even when the wind direction is from the north or south but at an angle (0–60 degrees from the north or south as shown in the plan of the building in Figure 4.6), the natural ventilation will still be quite good. The natural ventilation will not be good if the wind is predominantly from the east or west (or 60–90 degrees from the north or south as shown in Figure 4.7); in such a case, the provision of vertical deflectors does help in getting the cross-ventilation efficient. Figure 4.8 shows the principle of deflectors to increase the cross-ventilation when the wind is not facing the façades and their openings.

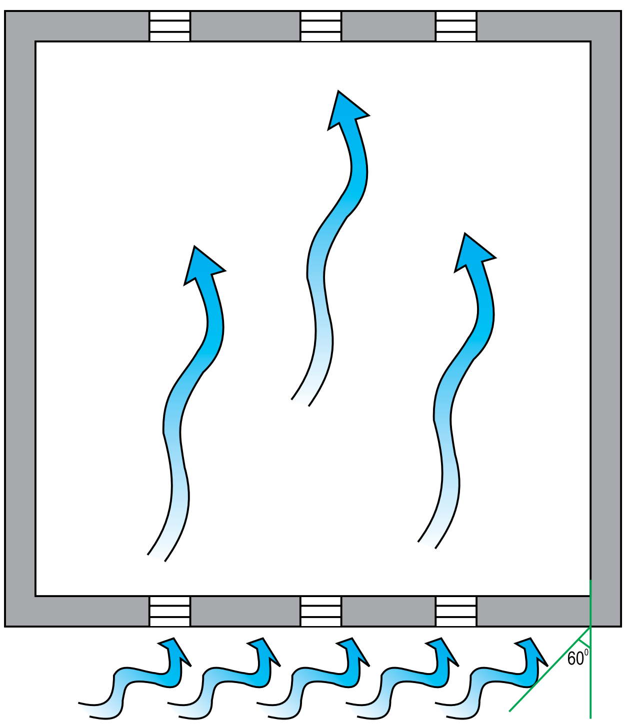


Figure 4.6 *Wind blowing at an angle of 60° from the perpendicular axis of the façade*

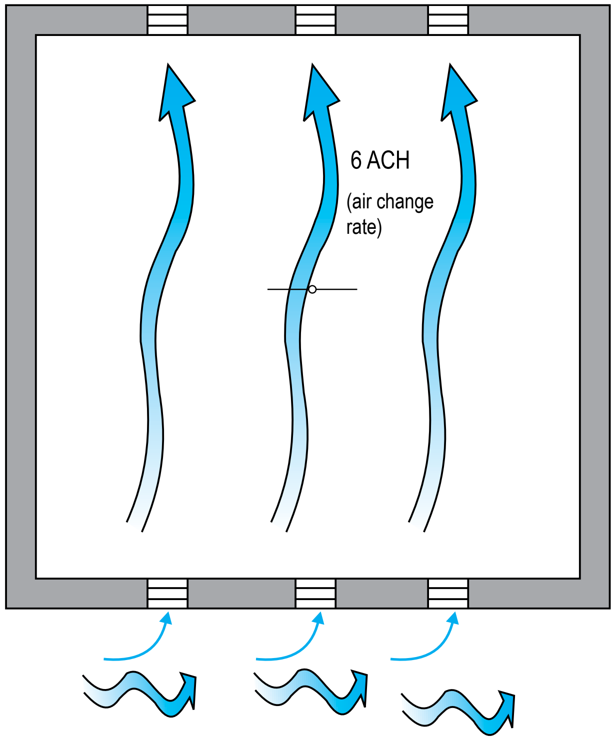


Figure 4.7 Wind blowing parallel to the façade

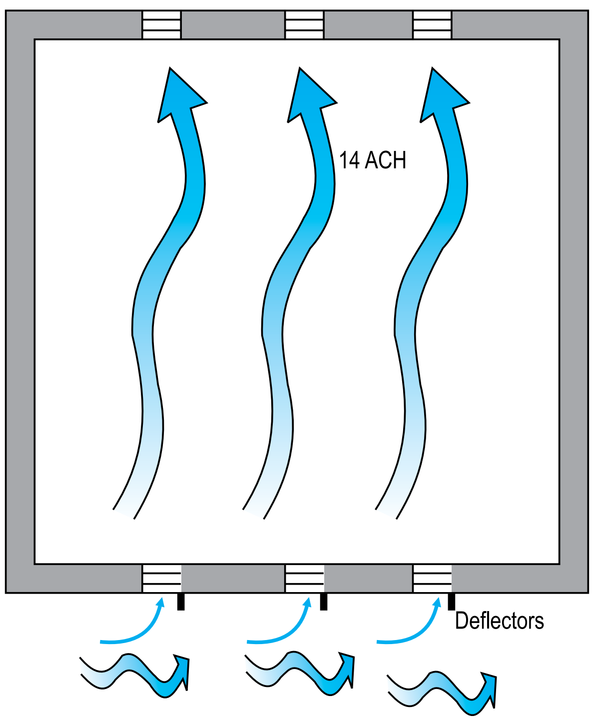


Figure 4.8 Deflectors that help in harnessing wind for natural ventilation

The effect of deflectors is quantified by carrying out a CFD simulation on a space of 10 × 10 × 3 m having three windows on north and south (1.5 x 1.5 m). The wind speed is 2 m/s and the direction is east–west, i.e., the wind direction is parallel to the façade windows.

Figure 4.7 shows the case without deflectors, while Figure 4.8 shows the case with deflectors. The result of the simulation in terms of air change rate (ACH) is shown in Figure 4.7 and Figure 4.8. It is shown that the ACH improved from 6 ACH per hour to 14 ACH per hour with the use of the deflectors.

4.4.2 Stack ventilation

When the building is shielded from the wind by other nearby buildings, one method to generate natural ventilation is to use the chimney effect. In this case, the driving force is the density difference between the warmer air inside the chimney and the cooler and denser air outside.

The air flow due to stack effect in a building is shown in Figure 4.9, in which the cooler air from the outside pushes the air inside the building and exhausts it at a high level through the stack opening.

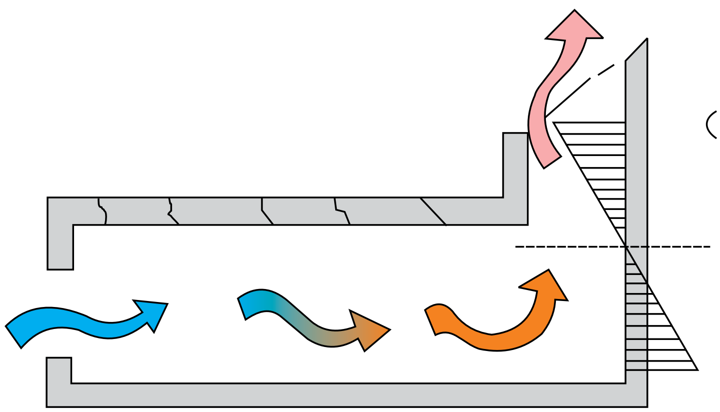


Figure 4.9 *Stack effect when the inside temperature is above the outside temperature*
Source *Adapted from Claude Alain Roulet, Energy efficient Buildings for Tanzania, and Practical Guide CIBSE 237*

When using stack effect ventilation, the designer must take into account the fact that the negative pressure generated is decreasing with the height of the building. As shown in Figure 4.10, the negative pressure that drives natural ventilation is higher for lower floor (floor A), compared to the upper floor (floor C). Care should be taken to design the stack exit. Normally, stack exhaust must be one floor higher than the top floor, as well as the exhaust opening should be of adequate size, to ensure that (a) the upper floor also gets the benefit of the stack ventilation and (b) the heated air from lower floors exits from the top and does not enter the upper floor as shown in Figure 4.11.

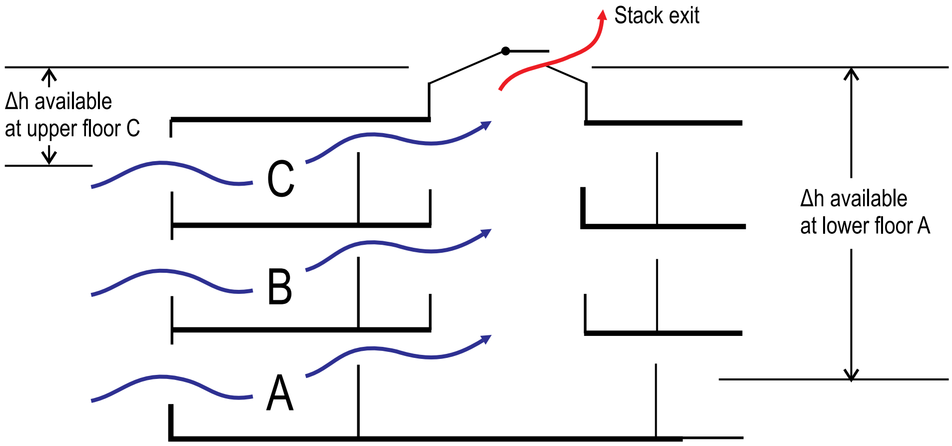


Figure 4.10 *Air flow in a properly designed stack ventilation system*

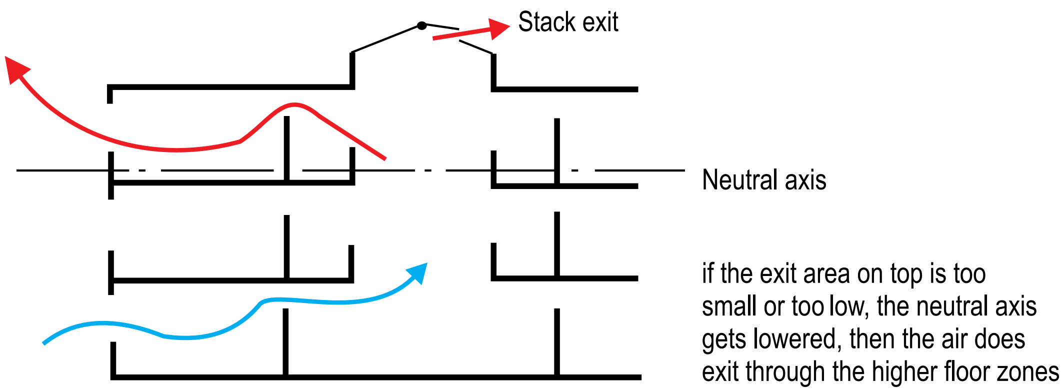


Figure 4.11 *Air flow in a wrongly designed stack ventilation system*

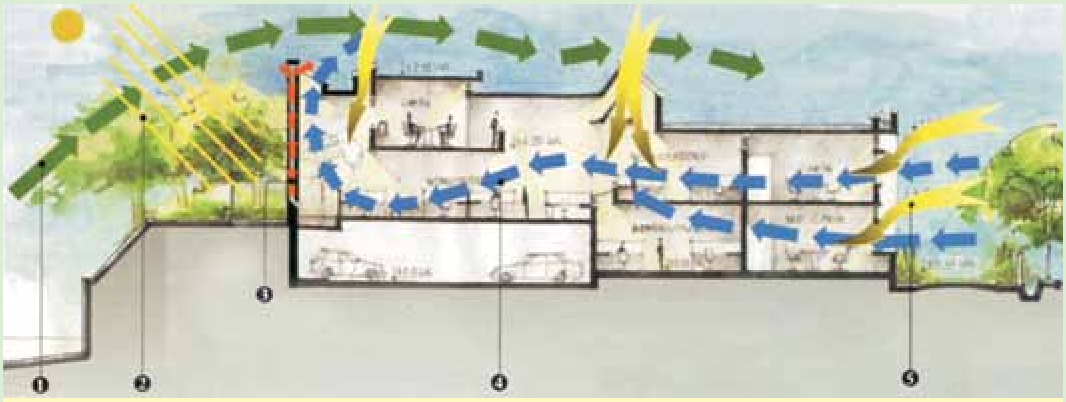
4.4.3 Night ventilation and thermal mass

Night ventilation takes advantage of lower night-time temperatures to flush heat out of the building and pre-cool the building structure. As the inside surfaces of the building are at a lower temperature during the early part of the day, this not only helps in reducing the inside air temperature but also improves thermal comfort of the occupants due to higher radiant heat exchange with these cool surfaces. For night cooling to be efficient, the thermal mass of the building structure needs to be accessed by the air flowing through the building. One has to avoid thermally closed false ceilings (air circulation across the ceiling by opening of at least 40% of its area).

It can be concluded that for typical office buildings in Karnataka, the buildings should be designed for cross-ventilation. Cross-ventilation works well up to building depths of around 15 m and when the predominant wind direction is ±60° from the axis perpendicular to the building façade. If the predominant air direction is parallel to the building façade, the use of deflectors is helpful in increasing the flow. In certain cases, stack effect can be used to enhance natural ventilation. However, to be effective, due care should be exercised in designing the height and dimensions of the opening of the stack.

Box 4.2 TERI's ECO-complex at Bengaluru

This building demonstrates the combination of wind and stack-driven natural ventilation. The south façade is opaque and dark; being heated by the solar radiation, it acts as the chimney (air is heated by the dark façade wall). The wind coming from the south creates a negative pressure by passing above the exhaust of the chimney and reinforces the draught upward. The air ingress is on the opposite northern façade.



1 Unhygienic foul breeze flowing from south (high pressure zone)
2 Heat from solar rays falling on the south-west wall
3 Conventional current rising up due to heating of air in cavity wall (low pressure zone)
4 Cool breeze drawn in by conventional current system to equalize pressure
5 Day lighting

Figure 4.12 *TERI's ECO-complex at Bengaluru*
Source *Mili Majumdar (ed.). 2001. Energy-efficient Buildings in India. New Delhi: TERI.*

4.5 Strategy 4: Climate-responsive Envelope

Strategy 4:
Climate-responsive Envelope

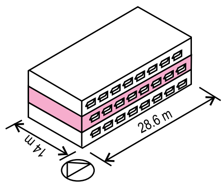
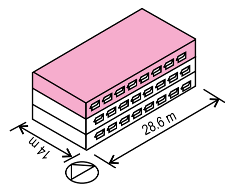
- Reduces heat gain through roof
- Reduces heat gain through walls
- Reduces heat gain through windows

Strategies 1, 2, and 3 help us define the basic geometry of the building and the location and sizes of its openings. The next step in the design process is to address the heat gains through the building envelope.

The building envelope refers to the boundary between the interior conditioned space and the outside. The building envelope includes all the components of the building's shell, i.e., walls, roofs, slabs on grade (in touch with ground), basement walls, doors, and windows.

To understand the quantum of heat gain through various components of the envelope, the top and intermediate floors of the N–S oriented rectangular building with no windows on the east and west was simulated. Table 4.6 shows the heat gain on different components of the envelope for three months (March–May) for an intermediate floor and top floor.

Table 4.6 Comparison of heat gain through different components of building envelope on an intermediate floor and top floor

Components of a building envelope	Properties	Heat gain from roof (kWh)	Heat gain from wall (kWh)	Heat gain through windows (kWh)
 Level: Intermediate floor 6 inch RCC slab with plaster (U-value: 3.8 W/m^2.K)	Built-up area: 1200 m^2 Floor-plate dimension: 14.0 x 28.6 m Orientation: N–S No windows on east and west Overhangs: 600 mm fixed Glazing type: Single clear 6 mm (U-value: 6.1 W/m^2.K, VLT: 88%, SHGC: 0.81) No heat exchange through upper and lower floors No internal loads Cooling set-point: 26 °C Fresh air + Infiltration: 1 ACH	0	93	3106
 Roof: 150 mm RCC slab with plaster (U-value: 3.8 W/m^2.K)		7293	–791[9]	2770

It is seen that:

- For the intermediate floor, the heat gained through windows is much higher compared to the heat gained through walls.
- For the top floor, it is seen that the heat gain from the roof is highest, while the heat gain from windows is also significant.

Thus the analysis suggests that reducing heat gains from the roof and windows should be a priority.

4.5.1 Insulation of roofs

As seen in Table 4.6, the roof contributes to maximum heat gain in the building. Hence, it is vital to insulate the roof to prevent this heat gain. Figure 4.13 shows that the solar radiation falling on the roof surface is 628.8 kWh/m^2 (March–May) and the total heat absorbed in the building through conduction, convection, and radiation together is 32.8 kWh/m^2, which is 5.2% of the total heat falling on the roof surface.

[9] *During the day, the ambient temperature is usually higher and the space gains heat. During night, the wall and inside temperatures are usually higher than the ambient temperature and hence the walls lose heat due to radiation to the sky and lower outside temperature. The negative value shows that between March and May, all the heat flow through the walls gets accumulated; the heat lost by the walls is higher compared to the heat gain.*

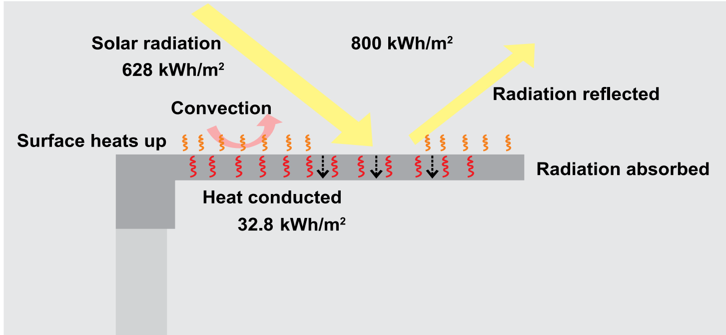


Figure 4.13 *Heat absorption through roof*

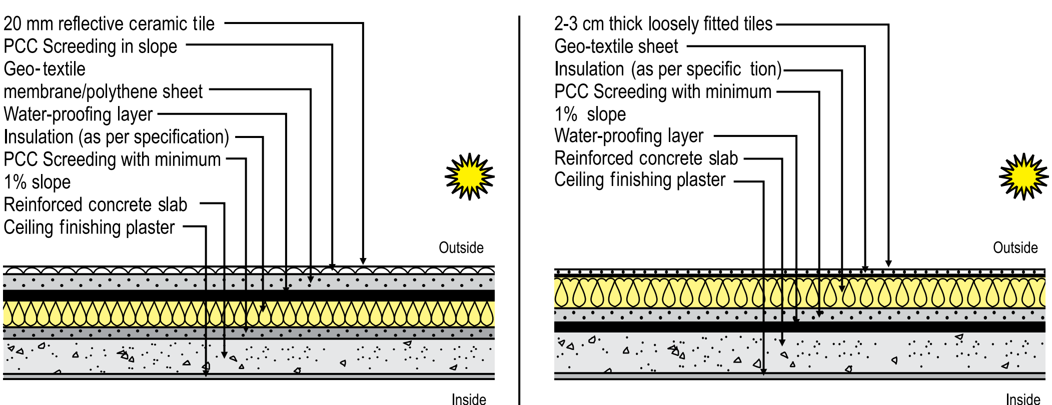
It is recommended to use insulation in roof assemblies. The ECBC, which has been notified and is about to be implemented in Karnataka, recommends roof insulation to reach U-values of 0.4 W/m.K, as shown in Table 4.7.

Table 4.7 ECBC-recommended U-values for roofs in Karnataka

Envelope component	Climate zone	Daytime use buildings and other building types	
		Max. U-value (W/(m²K)	Min. R-value of insulation alone (m² K/W)
Roofs	All	0.409	2.1

Over deck insulation, e.g., with 10 cm of extruded polystyrene or 7.5 cm of polyurethane foam, is a standard suitable solution for roof insulation. The sketches in Figure 4.14 show two examples of insulated roof compositions, with a U-value around 0.4 W/m^2.K.

Highly reflective tiles or finishes may also be used in addition to the insulation. However, it should be noted that (a) periodic maintenance of the roof is required, if the reflective properties are to remain, and (b) reflective coatings cannot replace insulation, as they do not provide sufficient insulation properties.



Roof composition with water-proofing above the insulation

Roof composition with water-proofing above the insulation

Figure 4.14 *Example of an energy-efficient roof composition for Karnataka climates*

A step-by-step description of how to calculate the U-value of a roof or wall assembly through an online tool is found in Annexure 4.3. Further information on thermal insulation and its application can be found in the BEEP Manual, *Training Manual on Application of Building Insulation Material,* by the India Insulation Forum.

4.5.2 Insulation of walls

In Karnataka, the contribution of heat ingress from walls is relatively small.

Table 4.8 gives the ECBC-recommended U-values for walls. To achieve these values, some form of insulation is required.

Table 4.8 ECBC-recommended U-values for walls in Karnataka

Envelope component	Climate zone	Buildings for daytime use and other building types	
		Max. U-value (W/(m^{2}K)	Min. R-value of insulation alone (m^2 K/W)
Opaque walls	Tropical wet, wetand dry, semi-arid, and temperate climates	0.440	2.10

Fenestration

An energy-efficient envelope also requires efficient fenestration solutions. This section discusses overall fenestration choices and other characteristics of glazing, which are important to ensure an energy-efficient envelope. Figure 4.15 shows factors that affect heat transfer through windows. It should be noted that the heat gain by radiation is much higher than the heat gained by conduction and convection.

Limited window-to-wall ratio

The first important point that requires attention when designing fenestration is to limit the window area, so as to keep heat gains as low as possible, while still offering sufficient access to daylight. Karnataka ECBC recommends to keep WWR below 40%. However, it is

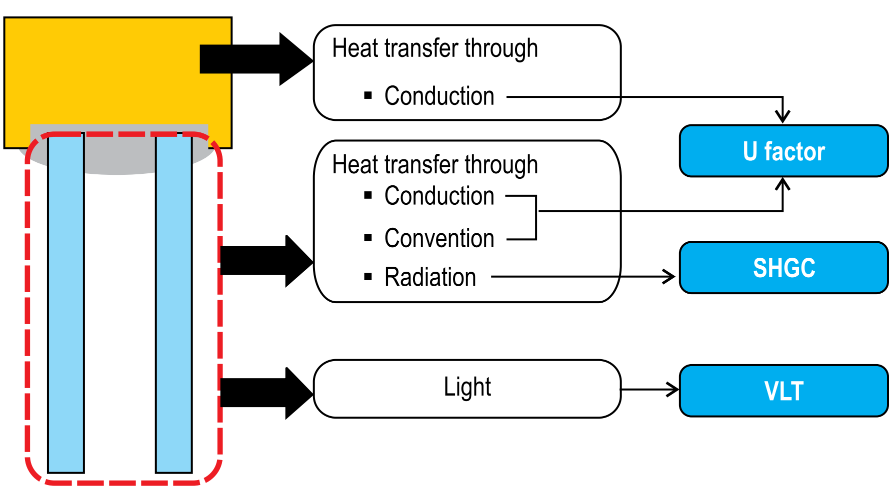


Figure 4.15 *Factors affecting heat transfer through windows*

recommended to keep the WWR close to 20% for best results. In the simulations done for heat gain in this chapter, the WWR has been limited between 20% and 30%.

The U-factor measures thermal conductivity through the window components. Hence, windows with lower U-values are preferred. Table 4.9 shows the U-values for windows prescribed by the Karnataka ECBC.

Solar protection and solar heat gain coefficient

For solar control, one refers to the solar heat gain coefficient (SHGC).[10] The lower the SHGC, the better the solar control. Solar control of windows is an important aspect of climate-responsive design, especially in the hot climates of Karnataka.

Table 4.9 ECBC Karnataka recommendations for U-values of windows

Envelope component	Climate zone	Max. U-value (W/(m^2K)
Windows	All except moderate	3.3
	Temperate	6.9

Hence, a trade-off has to be made between the SHGC (for heat gain) and the VLT (for daylight) in order to select the best option. Table 4.10 gives a few examples of the glazing assemblies and their properties.

Table 4.10 Properties of different glazing assemblies (to be used as indicative for schematic design only, for detailed design use data from manufacturers in India)

Glazing type	Glass pane thickness (mm)	U-factor W/(m^2K)	Solar heat gain coefficient (SHGC)	Visual light transmittance (VLT)
Single clear glazing	6	6.0	0.81	0.89
Double glazing (clear)	6	2.7	0.70	0.79
Double glazing (low-e)	3	1.8	0.71	0.75
Double glazing, argon filled (low-e)	6	1.4	0.57	0.73

Source www.wbdg.org/resources/windows.php, Whole Building Design Guide

Further heat gain can be reduced by using external movable shading solutions explained in the next section.

It can be concluded that for typical office buildings in Karnataka, roof needs to be insulated and treated to reflect the solar radiation. To minimise heat gains through the windows, the WWR should be around 20%–30%, the U-value of the windows should be low and a trade-off is to be made between SHGC (heat gains) and the VLT (for daylight).

[10] *Solar heat gain coefficient (SHGC) is an indicator of the total solar heat gain. SHGC is the ratio of the total transmitted solar heat to incident solar energy, typically ranging from 0.9 to 0.1, where lower values indicate lower solar gain.*

4.6 Strategy 5: Solar Shading Solutions

Strategy 5: Solar Shading Solutions	▪ Minimises heat gain through openings ▪ Optimises daylight/management

Once the massing, orientation, WWR, and envelope have been defined, it is essential for the designers to define effective solar shading solutions. When defining the types of devices for solar shading, it is important to take into account the effectiveness of both shading and daylight. Optimising daylight and curtailing solar gains are both essential functions, which the envelope must ensure.

The best solutions for solar shading are exterior dynamic shading solutions, such as shutters or external movable blinds. The major advantage of such solutions are described below.

- Flexibility of use according to weather conditions and seasons
- Controlled by the user
- Provide good daylight
  - when opened
  - when closed, by tilting the slats in case of lamella
- Effectively cut 80%–90% of the solar gains
- Can be applied on any façade, which gives more flexibility for the orientation of the building
- Can work as security grid, and thereby allow for night ventilation.

In the case of a window having internal blinds, the blinds are effective in controlling the daylight or glare, but are not effective in reducing the solar heat coming inside; for the single-glazed windows, almost 80% of the solar heat falling on the window enters the space.

External movable shading systems can be lowered to shade the glazing. These systems are effective in reducing the solar gains through glazings (Figures 4.16 and 4.17). Use of such shading systems can reduce the amount of heat entering through the windows to around 15% of the solar heat falling on the window.

In Figure 4.18, it is shown that the use of external movable shading system is specifically effective for openings facing east and west directions. The angle of the incident radiation falling on the east and west façades is low, and hence, fixed shades are not effective. The use of external movable shading on windows facing east and west can reduce the solar heat gains by 60%–80%. There are many options that can be used for external movable shading and are shown in Figure 4.19.

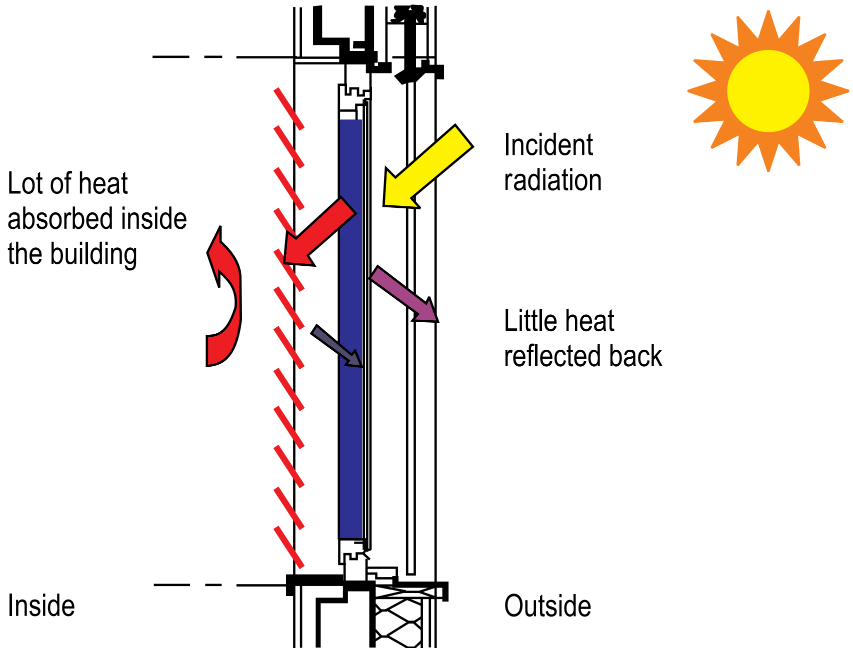


Figure 4.16 *Heat absorbed inside the building in case of no external movable shading (south façade)*

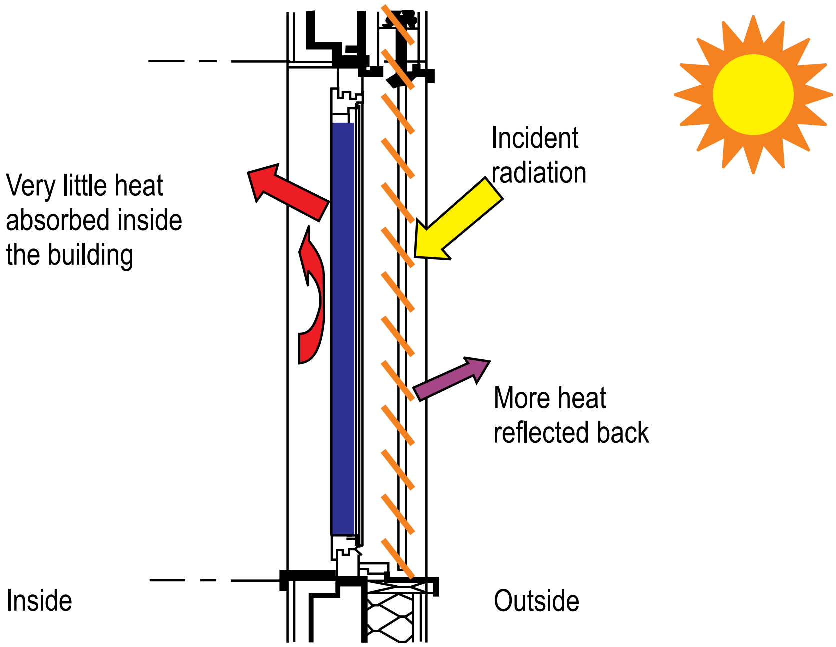


Figure 4.17 *Heat absorbed inside the building in case of external movable shading closed partly (south façade)*

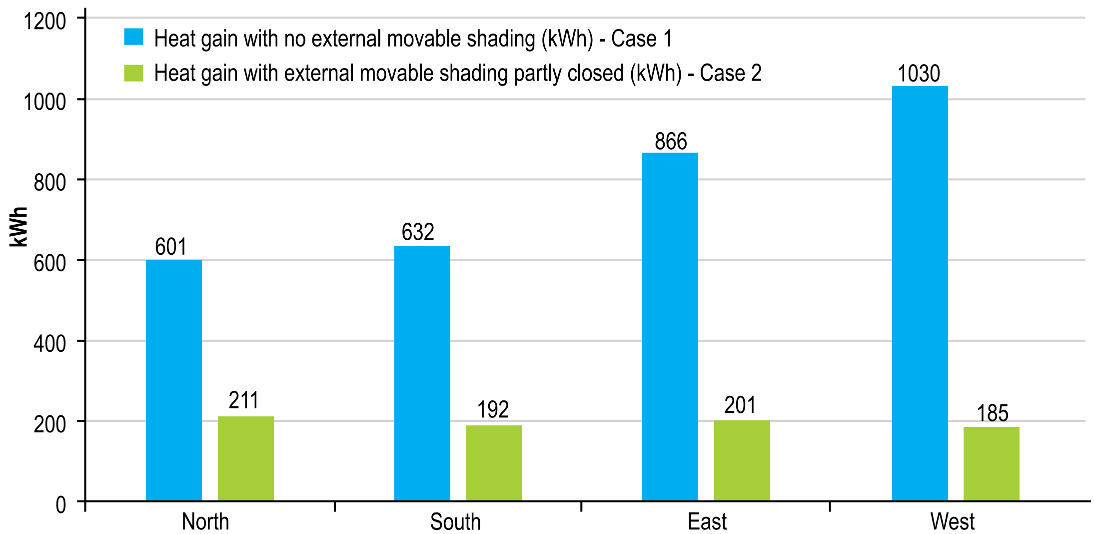


Figure 4.18 *Reduction in heat gain by using external movable blinds*

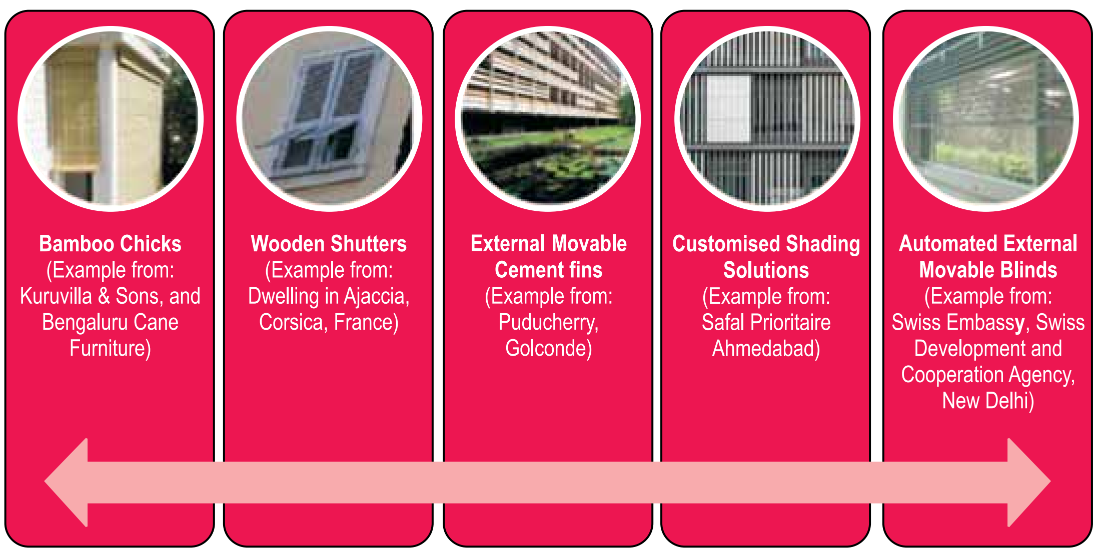


Figure 4.19 *Different types of external shading*

4.7 Case Studies

Boxes 4.3, 4.4, and 4.5 give examples of some of the exemplary climate-responsive buildings, which have incorporated many of the strategies covered in this chapter.

Box 4.3 Infosys, Mysuru Campus (Source: Infosys Ltd)

Figure 4.20 shows the typical floor plan of a building in the Infosys Mysuru campus. It can be seen that the longer sides are facing the north and south, while the east and west façades are shorter and do not have any windows. The building span has also been restricted to 18 m, which ensures sufficient daylight. Figure 4.21 shows the measures adopted for improving daylight within the spaces. Light shelves have been given to ensure adequate daylight inside the building as can be seen in the image. To cut off excessive heat through direct radiation, external fixed shading has been given.

Figure 4.20 *Typical plan of the building and 3-D view*

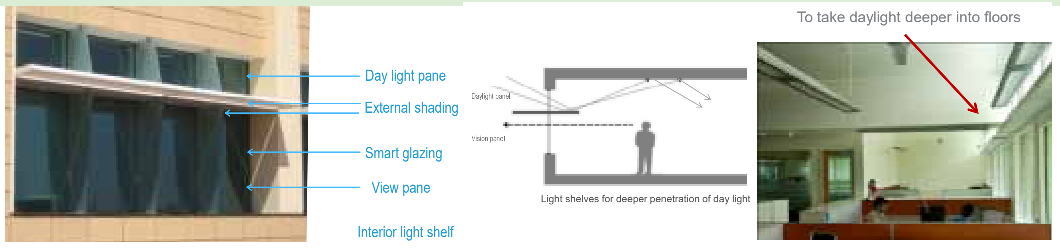


Figure 4.21 *Measures for daylight*

Box 4.4 IRRAD, Gurgaon (Source: Ashok B Lall Architects)

The Institute of Rural Research and Development (IRRAD), Gurgaon, is the headquarters of The Sehgal Foundation, which is an NGO devoted to rural development. The campus was developed in two phases. This case study is of Phase 1, which comprises the office space.

The building has a linear shape. The width of the building is 18.7 m with a 5.7 m wide internal courtyard. Due to site constraints, the building could not be oriented absolute N–S and has been kept at an angle. The longer façades are NE–SW as shown in Figure 4.22. The shorter façades do not have any window openings to prevent heat gain.

Figure 4.22 *Floor plans of the building*

Figure 4.23 shows a section of the building. It has a central atrium to ensure adequate daylight and also to create a stack effect for better ventilation.

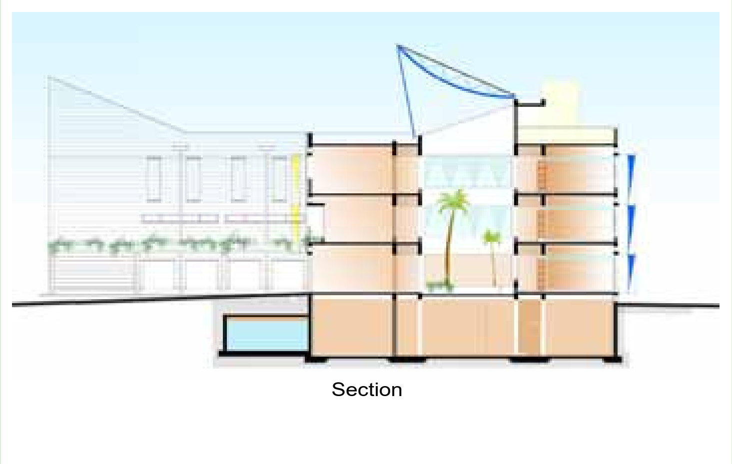


Figure 4.23 *Section of the building*

Box 4.5 IRRAD, Gurgaon (Source: Ashok B Lall Architects)

Figures 4.24 and 4.25 show the external shading used to prevent heat gain inside the building. These have been mounted on an external frame to minimise the heat gains by solar radiation passing through these shading devices.

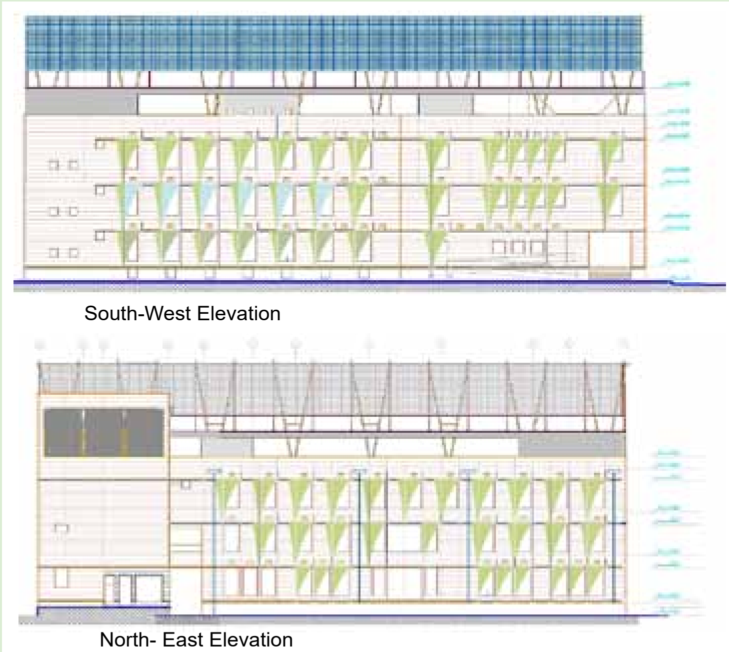


Figure 4.24 *Elevations of the building*

Figure 4.25 *Shading on different façades*

CHAPTER RECAP

Strategy 1 Climate-responsive Building Massing and Orientation

- Building massing refers to the shape, size, and orientation of a building. It is important to orient the building and organise the spaces and forms so as to minimise the heat gains from solar radiation, provide good daylight access, and facilitate natural ventilation.
- Analysis carried out to study the effect of building massing on cooling loads, daylight access, and natural ventilation show that a linear building form with shallow floor plates (<16–18 m) and with the longest façades towards north and south should be preferred.

Strategy 2 Design Openings for Daylight

- For a typical office building in Karnataka, WWR of 20%–30% is sufficient to provide good daylight (daylight autonomy of around 75%).
- To achieve good daylight, the building shape should be linear (14–18 m width) in which the longer sides are oriented towards the north and south and the windows are provided only on the north and south façades.
- Other measures such as use of clear glass for best VLT in combination with adequate shading devices to cut off glare and heat and use of light-coloured finishes help in maintaining good daylight.

Strategy 3 Design for Natural Ventilation

- A typical office building in Karnataka should be designed for cross-ventilation. Cross-ventilation works well up to building depths of around 15 m and when the predominant wind direction is ±60 °C from the axis perpendicular to the building façade.
- If the predominant air direction is parallel to the building façade, the use of deflectors is helpful in increasing the flow.
- In certain cases, stack effect can be used to enhance natural ventilation. However, to be effective, due care should be exercised in designing the height and dimensions of the opening of the stack.
- Night ventilation takes advantage of lower night-time temperatures to flush heat out of the building and pre-cool the building structure. For night cooling to be efficient, the thermal mass of the building structure needs to accessed by the air flowing through the building and thermally closed false ceilings should be avoided.

Strategy 4 Design Openings for Daylight

- Roof needs to be insulated and treated to reflect the solar radiation. The ECBC for Karnataka recommends roof insulation to reach U-values of 0.4 W/m.K.
- Buildings should have an optimum WWR, which helps in admitting adequate daylight yet limits heat gain. ECBC Karnataka recommends the WWR to be below 40%. However, as shown in the analysis even WWR of around 20%–30% may be adequate.
- The U-value of the windows should be low and a trade-off is to be made between SHGC (heat gains) and the VLT (for daylight).

Strategy 5 Solar Shading Solutions

- The best solutions for solar shading are exterior dynamic shading solutions such as shutters or external movable blinds. The major advantage of such solutions are listed below:
  - Flexibility of use according to weather conditions and seasons
  - Provide good daylight, when opened
  - Effectively cut 80% to 90% of the solar gains
  - Can be applied on any façade, which gives more flexibility for the orientation of the building.

CHAPTER 5

Efficient Cooling Systems

5.1 Strategy 6: Efficient Cooling Systems

Strategy 6: Efficient Cooling Systems	▪ Reduces cooling loads ▪ Determines type of cooling requirement ▪ Selects efficient system

In the previous chapter, various methods to achieve thermal comfort through passive strategies were explained. This chapter aims at giving the reader an understanding of the main choices and parameters to be considered for designing an energy-efficient cooling system. The choice of the cooling system for a building depends on factors such as the local climate and the type of the building (its size, usage, area to be conditioned, etc.).

5.2 Classification of Buildings

The various kinds of buildings designed by the PWD can be broadly classified into two types based on certain factors, as shown in Table 5.1.

- Type 1: Buildings that require decentralised systems for space cooling
- Type 2: Buildings that require centralised systems for space cooling

Table 5.1 PWD buildings (decentralised versus centralised space cooling systems)

Type 1. Buildings in which decentralised systems for space conditioning are generally used		
Public health centres Police stations Schools Colleges Hostels District courts District offices	Small- and medium-size buildings with limited space cooling	Large part of the building is naturally ventilated. A few rooms/spaces need air-conditioning/air cooling. Such buildings could use unitary/packaged solutions of air-conditioning or evaporative cooling.
Type 2. Buildings in which centralised systems for space cooling are generally used		
Hospitals Auditoriums Large government offices	Large buildings with large areas that require cooling, often having stringent thermal comfort criteria	Full/major part of the building needs air-conditioning/ air cooling. Central air-conditioning/ evaporative cooling systems can be used.

If the building is of Type 1, the option of cooling through natural ventilation is explored first, and then the mechanical option through decentralised cooling systems. If the building is of Type 2 (large sizes, having high duration of occupation and stringent thermal control), then centralised cooling systems are preferred.

5.3 Decision Process for Strategies

Figure 5.1 is an example of a process chart for deciding the cooling system of a building. The process chart helps a building design team in understanding the different cooling systems that can be considered and selected during the project design, depending upon the type of the building and the climate.

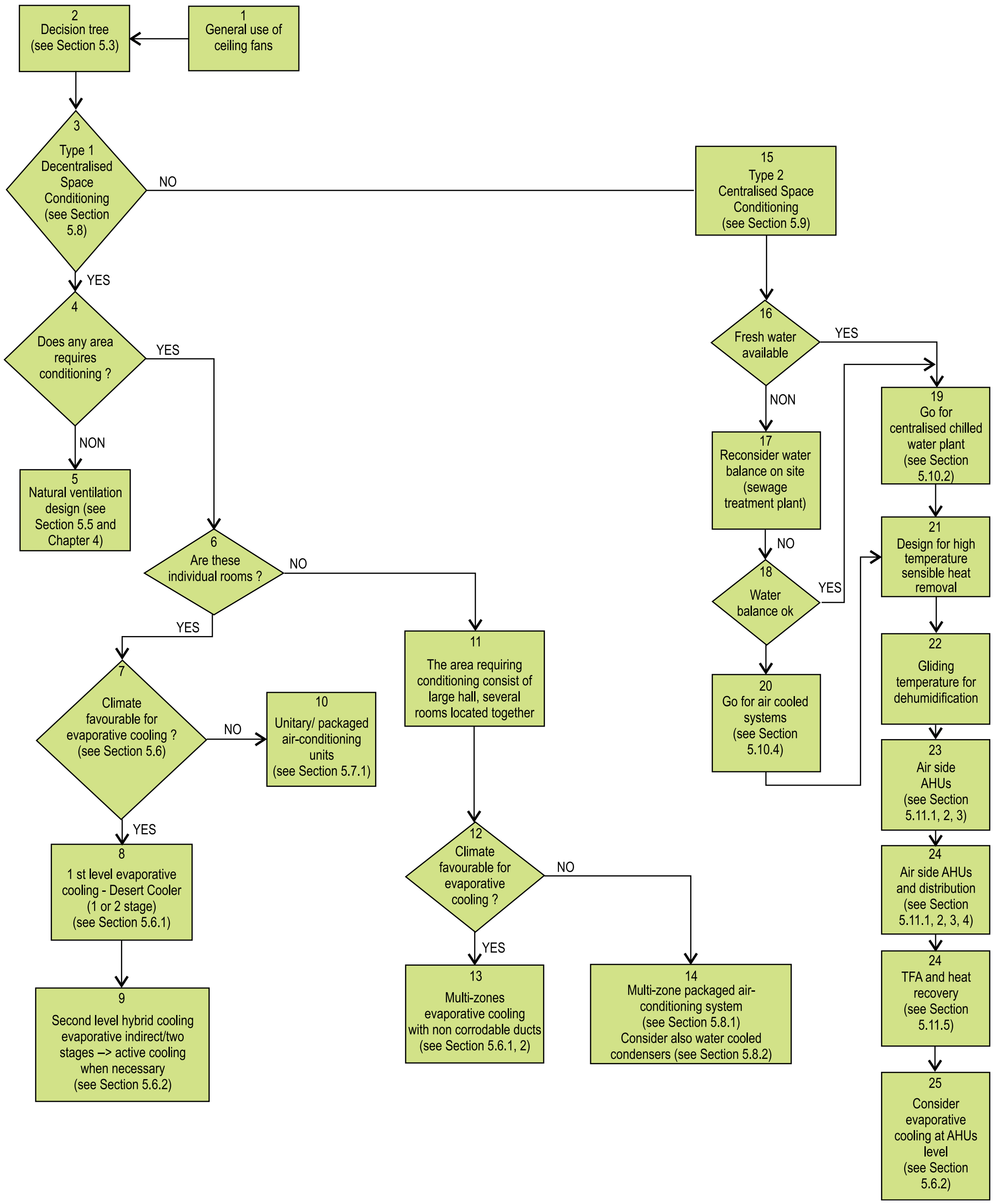


Figure 5.1 *The process chart for deciding the cooling system of a building*

5.4 High Performance Ceiling Fans

As explained in Chapter 3, the air movement helps in achieving thermal comfort and in warm climates, the ceiling fans have an important role to play in all types of buildings. Table 5.2 explains the effect of air (wind speed) on achieving thermal comfort.

Table 5.2 shows that with increase in dry bulb temperature (DBT) and relative humidity (RH), higher wind speeds are needed to achieve thermal comfort. For example, for DBT of 32 °C and low RH (30%), thermal comfort can be achieved at a low wind speed of 0.2 m/s.

Table 5.2 Desirable wind speeds (m/s) for thermal comfort conditions

Dry bulb temperature	Relative humidity (%)						
°C	30	40	50	60	70	80	90
28	*	*	*	*	*	*	*
29	*	*	*	*	*	0.06	0.19
30	*	*	*	0.06	0.24	0.53	0.85
31	*	0.06	0.24	0.53	1.04	1.47	2.10
32	0.20	0.46	0.94	1.59	2.26	3.04	**
33	0.77	1.36	2.12	3.00	**	**	**
34	1.85	2.72	**	**	**	**	**
35	3.20	**	**	**	**	**	**

Source NBC. 2005. Part 8, Section 5, Ventilation (5.3.2.1 Limits of comfort). New Delhi: National Building Code

However, for the same DBT of 32 °C, but with high RH (80%), a higher wind speed of 3.04 m/s is required to achieve thermal comfort.

The use of ceiling fans must be encouraged in all types of buildings, not only for non air-conditioned buildings, but also for air-conditioned buildings, as they provide thermal comfort at low energy consumption. It has been shown that with the use of ceiling fans, the set-point temperature of air conditioning can be easily be raised to 26 °C–28 °C. To reduce the amount of electricity used in fan operation, it is important to select only efficient fans.

Figure 5.2 *Use of ceiling fans in an air-conditioned IT office*
Source *Infosys Ltd*

5.4.1 BEE star rating for ceiling fans

The Bureau of Energy Efficiency (BEE) has developed a star rating system for ceiling fans. Ceiling fans covering up to 1200 mm sweep[1] are considered under the BEE star labelling programme. The star rating of ceiling fans is based on the 'service value', which is defined as the air delivery in m^3/min divided by the electrical power input to the fan in watts at the

[1] *The diameter of the circle traced out by the extreme tips of the fan blades.*

voltage and frequency specified for the tests. The testing of ceiling fans is done as per the Indian Standard IS 374: 1979 (Specification for Ceiling Type Fans and Regulators) with all amendments, as applicable. Table 5.3 gives the star rating and the corresponding service value for ceiling fans.

Table 5.3 Star rating for ceiling fans

Star rating	Service value for ceiling fans*
1 Star	≥3.2 to 3.4
2 Star	≥3.4 to 3.6
3 Star	≥3.6 to 3.8
4 Star	≥3.8 to 4.0
5 Star	≥4.0

*This table is based on a base service value of 3.2. However, BIS and BEE have proposed to revise the minimum service value of 3.5. All ceiling fans covered under this standard shall comply with minimum air delivery of 210 m^3/min.

It is recommended to opt for ceiling fans having 5-Star rating. An indicative electricity consumption graph is shown in Figure 5.3, which compares the performance of 1-Star and 5-Star rated ceiling fans. Depending on the usage of the ceiling fan, the energy saving[2] (with 5 Star over 1 Star) during a year may range from 12 kWh/year to 75 kWh/year.

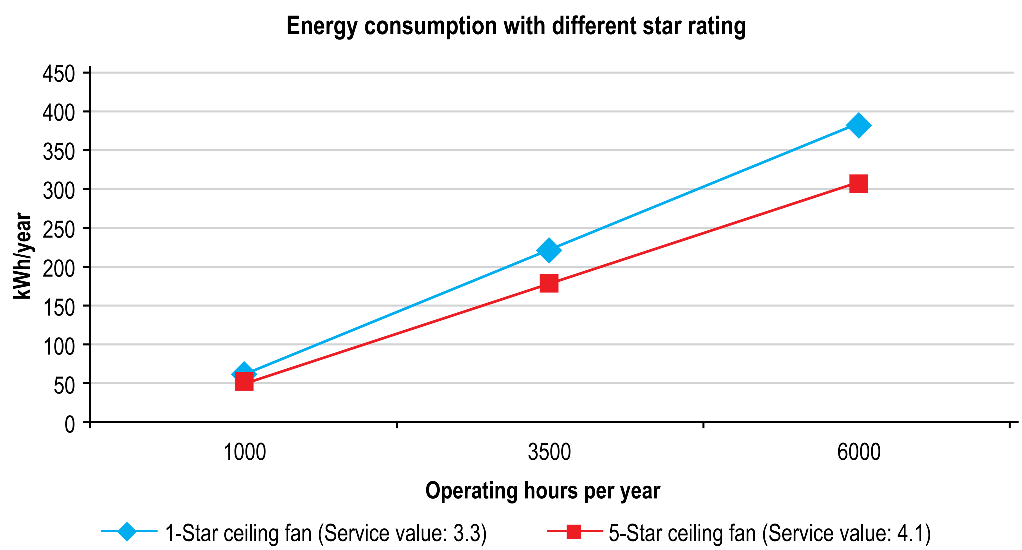


Figure 5.3 *Electricity consumption for ceiling fans of 1 Star and 5 Star ratings*

5.4.2 Super-efficient fans

There has been significant improvement in the energy efficiency of ceiling fans with the BEE star rating programme. However, now there are super-efficient fans available in the market, which consumes even lesser electricity as compared to 5-Star rated fans. To achieve energy

[2] *For calculations, a flow rate of 210 m^3/min and average value of service value range is taken (e.g., for 1-Star rated fan, service value of 3.3 is taken.)*

efficiency, super-efficient fans use an efficient brushless DC motor and improved blade designs. Thus, they are able to achieve a service value of more than six. A super-efficient fan would consume 30–35 watts of electricity as compared to 45–50 watts of electricity consumption by a BEE 5-Star rated ceiling fan, resulting in ~30% of energy saving. Till now, super-efficient fans have not been rated under the BEE Standards and Labelling programme.

5.5 Natural Ventilation

For zones that do not require any specific thermal condition requirement, ways to improve natural ventilation can be considered. These have already been described in Chapter 4.

5.6 Evaporative Cooling Systems

Evaporative cooling can be an energy-efficient solution if the climate is suitable and there is sufficient quantity and quality of water available. Chapter 3 has already identified the regions in Karnataka where better potential for evaporative cooling exist. A recap is provided in Table 5.4.

Table 5.4 Potential of evaporative cooling in different climate regions of Karnataka

Potential for evaporative cooling	Climate and cities
Very favourable	Semi-arid region (Raichur, Ballari, etc.)
Favourable	Parts of semi-arid region (e.g., Bengaluru) and tropical wet and dry region (Vijayapura, Davangare, Dharwad, etc.)
Not favourable	Tropical wet region (Mangaluru, Karwad, Udipi, etc.)

5.6.1 Single-stage direct evaporative cooler

An evaporative cooler is a device that cools air through the evaporation of water. For the evaporation of water droplets into water vapour, heat is required (latent heat of evaporation). In an evaporative cooling system, the water droplets absorb this heat from the surrounding hot air, making it cooler. However, as water vapour is added to the air, the humidity of the air increases. The air coming out of a direct evaporative cooler is thus cooler as well as more humid. There are essentially two kinds of direct evaporative cooling systems:

- the evaporative cooler with humidifying pad (called desert cooler in India) and
- the evaporative cooler with high pressure pumps, which create a fine mist, without humidifying pad.

Evaporative cooler with humidifying pad (desert cooler)

A schematic of single-stage direct evaporative cooling system is shown in Figure 5.4.

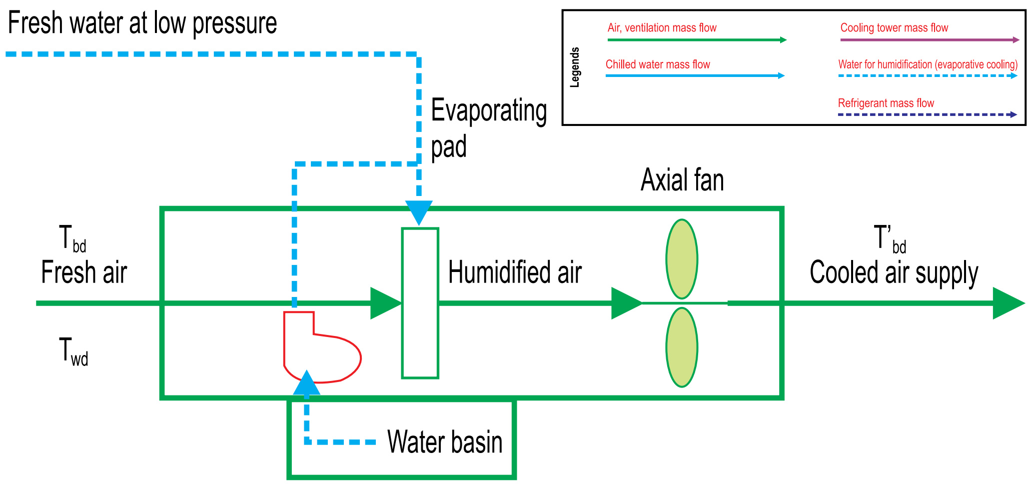


Figure 5.4 *Direct evaporative cooler (desert cooler, low pressure water, and with humidifying pad)*

Desert coolers are used extensively in offices and residences during hot and dry months in several regions of India. The Indian Standard (IS:3315) for evaporative coolers specifies the formula for calculating the cooling efficiency.

$$\textit{Cooling efficiency} = \frac{T_{db} - T'_{db}}{T_{db} - T_{wb}} \times 100$$

where,

T_{db} = DBT of inlet air
T'_{db} = DBT of outlet air
T_{wb} = WBT (wet bulb temperature) of inlet air

It further specifies that the minimum efficiency of evaporative cooling should not be less than 65%.

For the cooling efficiency of 65%, the typical water consumption in a desert cooler is about 8 l/h supplying air at a rate of 1000 m^3/h.

In suitable climates, desert coolers offer the following advantages over a room air conditioner:

- lower first cost (up to 75% lower).
- low energy consumption (typically 0.2 kWh per hour compared to 1.0–1.5 kWh per hour for room air-conditioners for cooling a room of 20 m^2).

The following points require consideration at the design stage while opting for desert coolers.

- If the desert cooler is to be placed outside the window, the window should be properly sized and designed to accommodate the cooler so that the placement of the cooler does not hinder daylighting. Secure support to place the desert cooler outside should be designed, which have access for maintenance as well as water supply.

- In several cases, it is possible to place the desert cooler on the roof and connect the air supply duct to the space to be conditioned. This is a much better way as it does not obstruct daylighting from the window and the noise in the room due to the fan/blower of the desert cooler is less.
- In the case of ducted systems, special attention must be paid to the corrosion risk and to avoid droplets entering the ducts.

Evaporative coolers with high pressure pumps that create a fine mist

This type of direct evaporative cooling system is based on generating mist by using a high pressure pump and fine nozzles. The mist evaporates in the air thus cooling the air. With this system, higher evaporation cooling efficiency of about 90% is reached as compared to ~65% for the pad systems, as explained in the psychometric chart shown in Figure 5.5. The schematic of the system is shown in Figure 5.6. The mist system requires a much more stringent water quality control. In case there is salt content or impurities in water, the fine nozzle may be blocked rapidly.

5.6.2 Indirect evaporative cooling (two stage)

The schematic of an indirect evaporative cooling system is shown in Figure 5.7. In this case, the fresh air is first cooled in an indirect heat exchanger[3] by exchanging hot air with cool

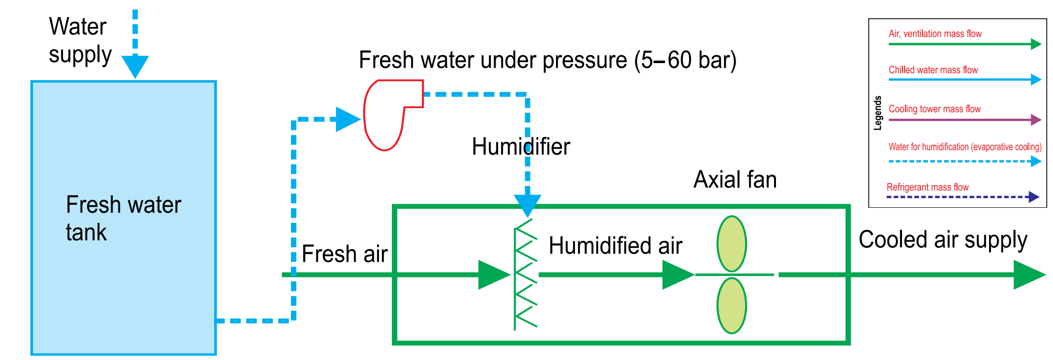


Figure 5.6 *Direct evaporative cooler (mist evaporative cooler with high pressure pump)*

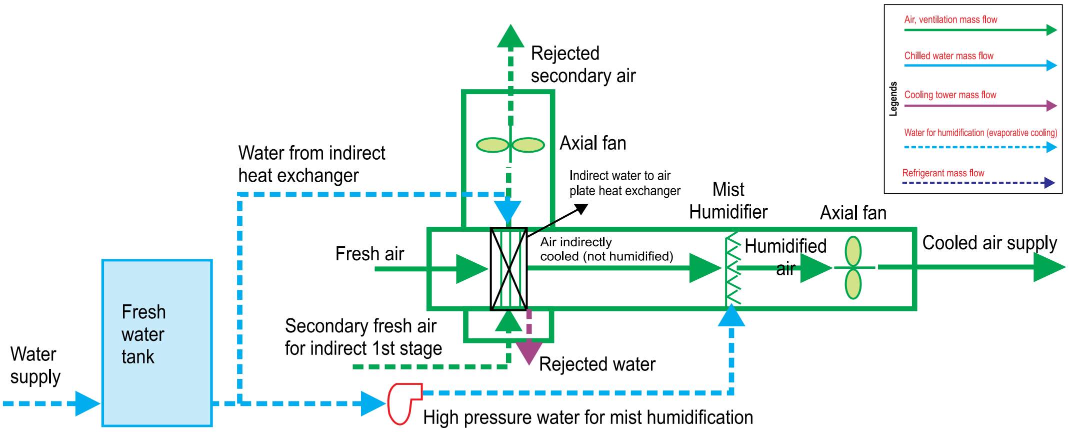


Figure 5.7 *Indirect evaporative cooling (two-stage example)*

[3] *In an indirect heat exchanger, the two streams exchanging heat do not come in contact with each other.*

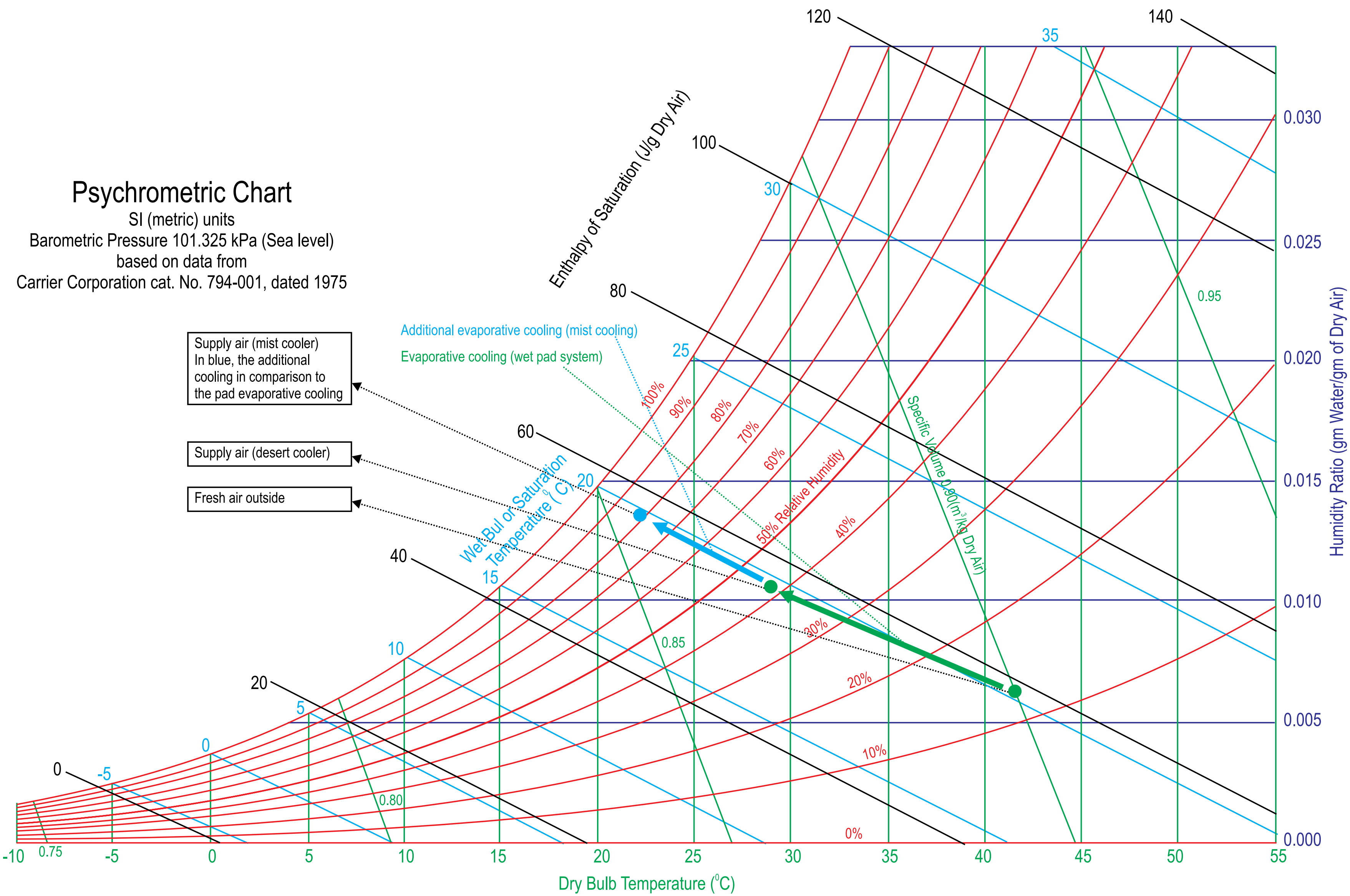


Figure 5.5 *Evaporative cooling process (approximate comparison between wet pad and mist systems)*

secondary air. The cool secondary air is generated by passing the fresh secondary air on wet pads. The cool secondary air is exhausted after the heat exchange. The partly cooled fresh air is then cooled further by direct evaporative cooling. In such a system, one can reach supply air temperature below the ambient WBT, achieving more than 100% in cooling efficiency as per the IS 3315 definition. However, the water consumption is higher in this case, compared to single-stage systems.

5.7 Single-zone Air-conditioning Systems

5.7.1 Unitary AC

Unitary air-conditioners (ACs) are installed in an open window. The interior air is cooled as a fan blows it over the evaporator. On the exterior, the heat drawn from the interior is dissipated into the environment as a second fan blows outside air over the condenser. BEE star-rated ACs should be used.

5.7.2 Split AC

A split AC follows the same principle as that of a unitary system. It has two units; the evaporator and fan unit located inside the space to be conditioned while the compressor and the condenser units are located outside the building. These are also available as packaged units, which can cater to a set of spaces located close to each other. The efficiency of both unitary units and split units should be as per Table 5.5. From the energy conservation point of view, a 5-Star air-conditioner should be selected.

Table 5.5 BEE star rating for unitary and split air-conditioners (1 January 2016 to 31 December 2017)

Star Rating	EER (W/W)	
	Min	Max
1 Star *	2.70	2.89
2 Star **	2.90	3.09
3 Star ***	3.10	3.29
4 Star ****	3.30	3.49
5 Star *****	3.50	-

5.7.3 Inverter AC

Inverter-equipped ACs have a variable frequency drive (VFD) that incorporates an adjustable electrical inverter to control the speed of the motor and thus the compressor and cooling output. While traditional ACs regulate the temperature by using a compressor that is periodically either working at maximum capacity or switched off entirely, an inverter in an air-conditioner is used to control the speed of the compressor motor to drive variable refrigerant flow in an AC system to regulate the temperature of the conditioned space. This control of the motor speed increases the efficiency of an AC by eliminating its stop–start cycle.

Being a relatively new technology, the BEE has launched a voluntary label for these, which ends in 2017. Henceforth, a BEE star label shall be mandatory for Inverter ACs as well. Table 5.6 lists the efficiency values for these ACs.

Table 5.6a BEE star rating for inverter ACs during the voluntary phase (valid from 29 June 2015 to 31 December 2017)

Star rating	Minimum ISEER*	Maximum ISEER
1 Star	3.10	3.29
2 Star	3.30	3.49
3 Star	3.50	3.99
4 Star	4.00	4.49
5 Star	4.50	–

Table 5.6b BEE star rating for inverter ACs during the mandatory phase (1 January 2018 to 31 December 2019)

Star rating	Minimum ISEER*	Maximum ISEER
1 Star	3.10	3.29
2 Star	3.30	3.49
3 Star	3.50	3.99
4 Star	4.00	4.49
5 Star	4.50	–

** Indian Seasonal Energy Efficiency Ratio (ISEER) – Ratio of the total annual amount of heat that the equipment can remove from the indoor air when operated for cooling in active mode to the total annual amount of energy consumed by the equipment during the same period.*

5.8 Energy-efficient Small-/Medium-sized Centralised Multi-zone Air-Conditioning Systems

When a big space or several small spaces located adjacent to each other are to be cooled, instead of using a number of single units, it is preferable to use a centralised system supplying air to multiple zones. It is recommended to go for variable refrigerant volume (VRV) technology. It is a good technology for small-/medium-sized multi-zone systems. The efficiency of such systems is generally better than single-zone AC or split systems.

5.8.1 VRV systems

Variable refrigerant volume (VRV) systems have emerged as an efficient technology for small- and medium-sized multi-zone cooling. As the cooling demand varies, the compressor adapts its capacity. These systems use a VFD for the motor of the compressor, which helps in reducing the energy consumption at part load. The most common VRV systems are air-cooled. Some manufacturers do propose VRV systems, which can be water-cooled. This allows to reach a higher efficiency than the common air-cooled VRV systems.

5.8.2 Water-cooled split ACs using a centralised cooling tower

In split air-conditioning systems (Section 5.6.2), the condenser is cooled by the outside air. The efficiency of such systems decreases rapidly with an increase in the outside air temperature.

An alternative solution is to have a centralised water loop, in which the water cooled in a cooling tower is supplied to split units to cool the condensers (Figure 5.8). In this case, while the indoor unit (evaporator) remains the same as that in an air-cooled split AC, the outdoor unit is replaced by a connected water-cooled condensing unit. The condensing unit houses a compressor and a heat exchanger with a provision of letting water in and out connected to the cooling tower.

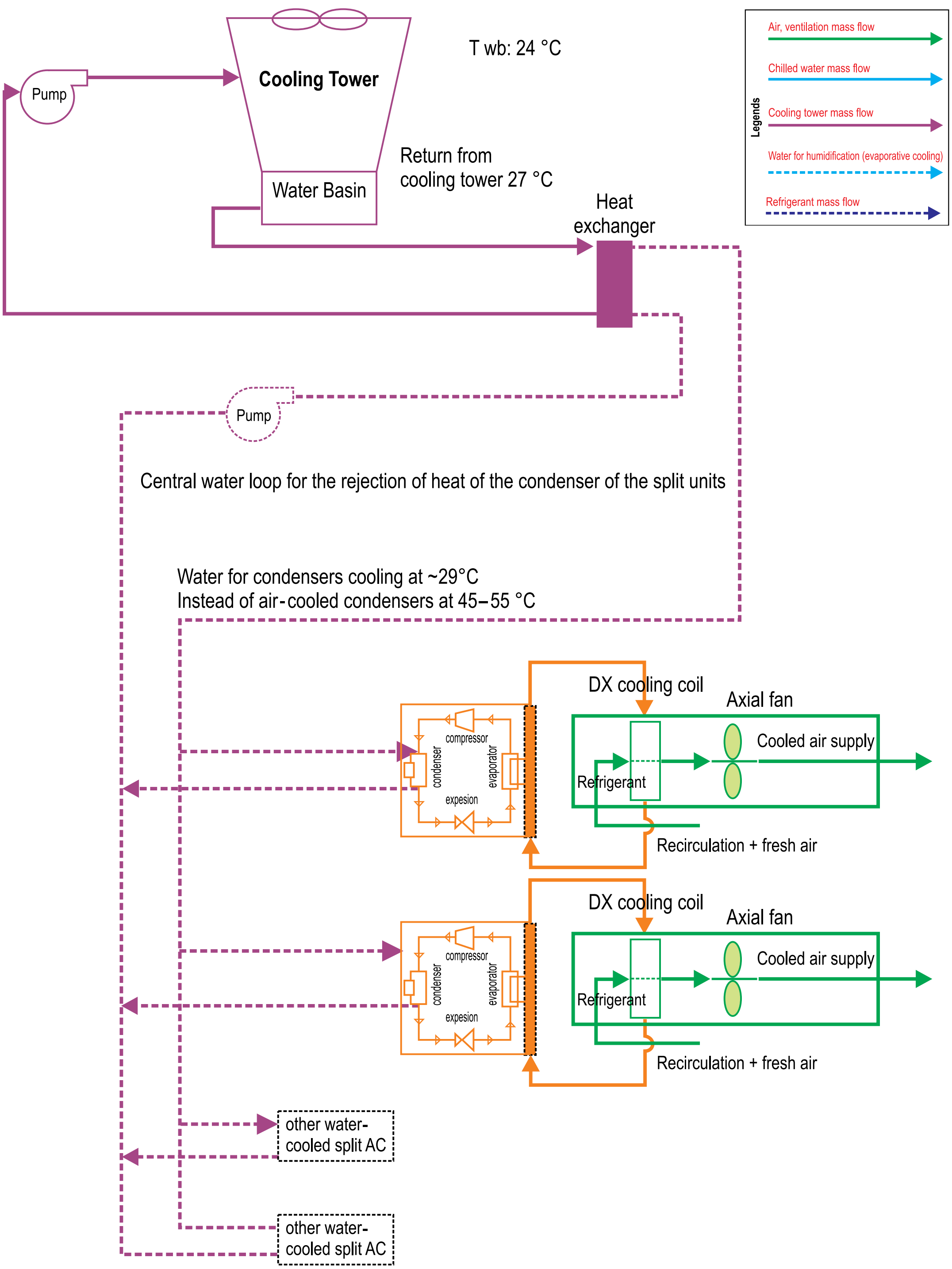


Figure 5.8 *Water-cooled split units (representation of the principle with 2 units and others in a simplified form)*

In water-cooled split ACs, the cooling water temperature would be much lower compared to the ambient dry air temperature. Therefore, in hot climates, approximately 30%–40% savings in electricity is possible in water-cooled ACs compared to standard air-cooled split unit systems. This solution is feasible if several rooms in a building/office are to be conditioned. The spaces/rooms should also be relatively close to each other so that the cooling water network can connect those spaces. Cooling towers of small sizes, starting from about 10 TR (tonnes of refrigeration) are readily available in the market.

5.9 Centralised Chilled Water Air-conditioning Systems

Centralised cooling systems generate cooling (in the form of chilled water) at one location in the building. This chilled water is distributed to various air handling units (AHUs) located at multiple locations in the building. The cooled air from these AHUs is then supplied to the spaces. Hence, these systems essentially comprise two parts:

- cooling generation side (chilled water generation and distribution side) and
- cooling distribution side (air/building side).

Figure 5.9 gives the schematic of a centralised cooling system. In the following sections, the options to increase the system efficiency are discussed. Section 5.9 discusses the options to increase efficiency in the production of chilled water, and Section 5.10 discusses various air/ building side options. Different combinations of water and air side options can be adopted to improve the efficiency of a cooling system in a building.

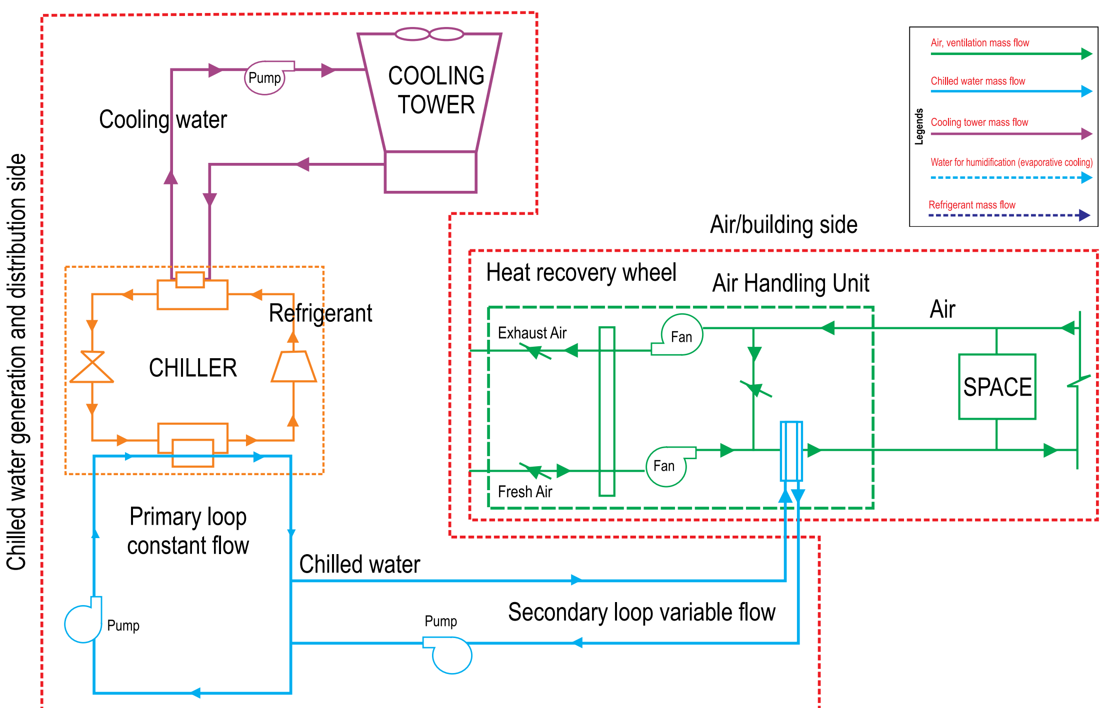


Figure 5.9 Schematic of centralized air-conditioning system

5.10 Efficiency Improvements in Chilled Water Systems

5.10.1 Chiller selection: water-cooled versus air-cooled chillers

Chiller is the most important component of the cooling generation side. Chillers extract heat from the evaporator side, consume electrical energy at the compressor, and reject heat on the condenser side.

Figure 5.10 gives the schematic of a chiller with its key components. On the evaporator side, the water is cooled (12 °C to 7 °C), which goes to the distribution (air/building) side. On the condenser side, the cooling water is heated (30 °C to 35 °C), which goes to the cooling tower. If this water is cooled through the evaporation process in an open loop, then the chiller is called as water-cooled chiller. If this water flows in a closed loop and cooled by air, then the chiller is called as air-cooled chiller.

Water-cooled chillers are much more efficient than air-cooled chillers. The efficiency (CoP[4]) of water-cooled chiller systems is higher than that of air-cooled chillers. Figure 5.11 shows the range of difference in the CoP of the water- and air-cooled chillers when the ambient air temperature is about 42 °C. It can be seen that while for an air-cooled chiller, the condensing temperature is above 50 °C and the CoP is around 3; for a water-cooled chiller, the condensing temperature is around 30 °C and as a result the CoP doubles to 6.

Air-cooled centralised chilled water plants are generally not a good option. The main reason is that, as mentioned above, in summer, the condensing temperature goes so high, sometimes beyond the operation range of many chillers (centrifugal). The chillers operating under such high condensing temperature have poor CoPs. Designers often opt for air-cooled chillers because of shortage of water. However, it is suggested that if fresh water is not available, the possibility of getting treated water using waste water treatment should be

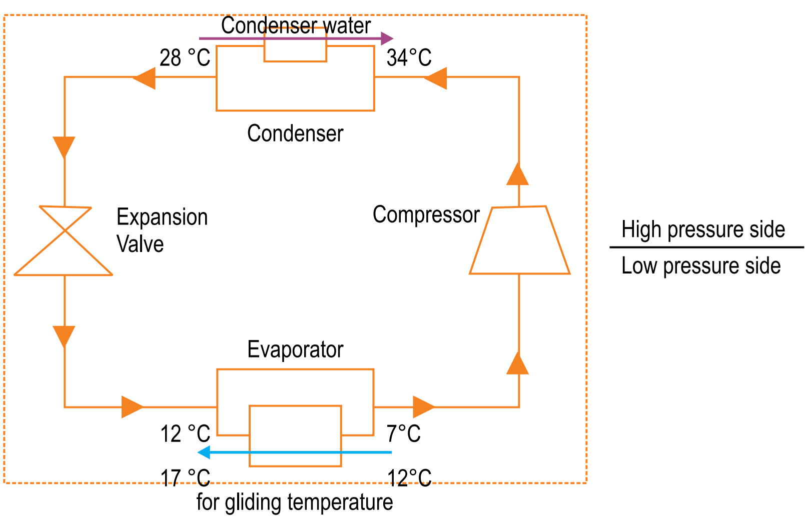


Figure 5.10 *Schematic of a chiller with key components*

[4] *CoP (Coefficient of performance) is the ratio of cooling delivered at the evaporator side to the electrical power consumed at the compressor.*

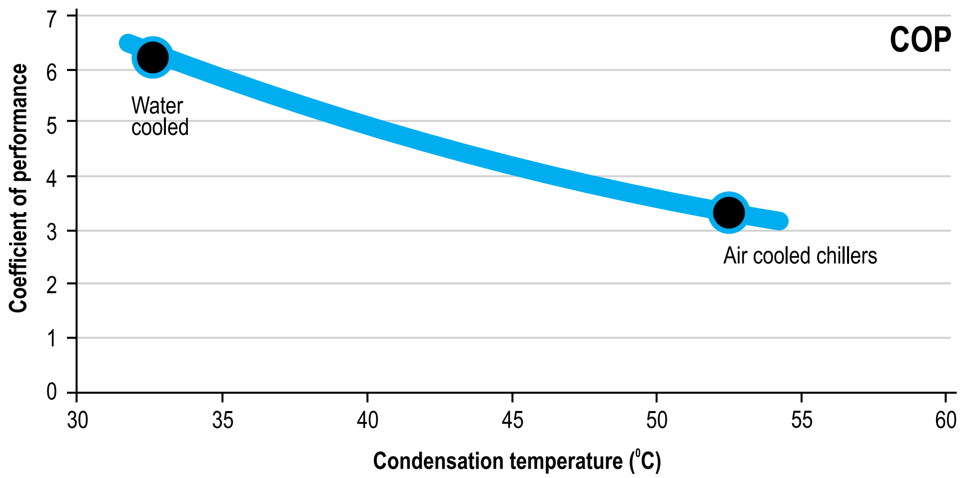


Figure 5.11 *Indicative impact of the condensing temperature on the coefficient of performance (CoP) of chillers*

ascertained and if sufficient treated water is available, the designers should opt for a water-cooled chiller.

5.10.2 Chiller selection: types of chillers

There are four main types of liquid chillers and depending on the cooling capacity they can be selected. Figure 5.12 shows the types of chillers and their cooling capacities. For the individual chiller capacity above 300 TR, centrifugal chillers are preferred, while between 100 TR and 300 TR capacity, centrifugal or screw chillers are preferred; scroll and reciprocating chillers are preferred for capacities below 100 TR.

5.10.3 Chiller selection: part-load performance

Chillers rarely operate at their peak load capacity. Thus the part-load performance of a chiller is more important than its peak-load performance in order to achieve energy efficiency. The CoP of a chiller at rated conditions indicates its performance at maximum capacity while

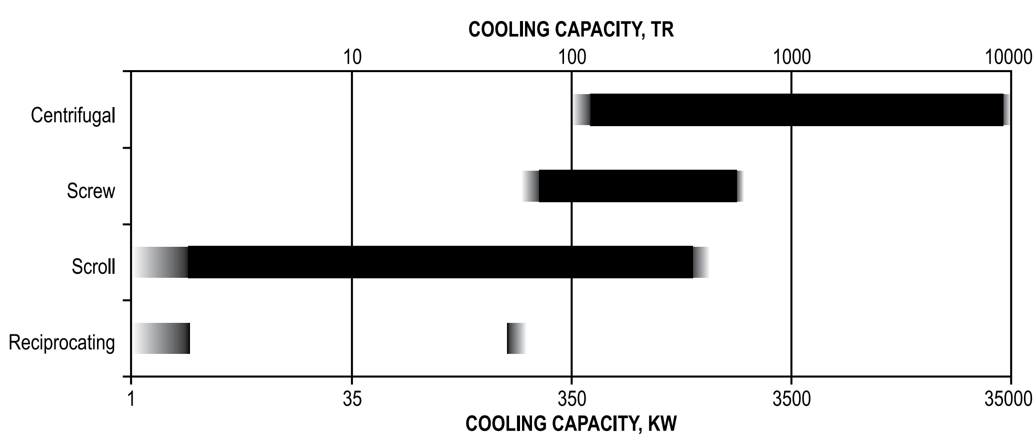


Figure 5.12 *Chiller types and their capacities*

Source *ASHRAE. 2008. ASHRAE Handbook 2008: HVAC Systems and Equipment. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.*

the integrated part-load value (IPLV[5]) considers the performance at part loads. Three key features that help in getting a good IPLV are listed below.

- VFD for chiller compressor motor: Applying a VFD to the compressor provides energy-efficient capacity modulation, which ensures that the compressor motor consumes less power at part loads. This generally comes with screw and centrifugal types of chillers.
- Magnetic levitation bearings (commonly known as turbocor): These bearings prevent direct contact between the moving (rotor) and the stationary part. They help in reducing the losses and thereby improving the efficiency of a chiller. Small capacity (~100 TR) centrifugal chillers are also available with magnetic levitation bearings, which are more efficient than screw chillers.
- Gliding chiller water control: The chiller should have anautomated control system to raise the chilled water supply temperature depending on the load. For example, if the chilled water supply/return temperature is 6 °C/12 °C for 100% load, it should be automatically changed to chilled water supply/return temperature of 9 °C/12 °C, if the load is 50%, following the actual temperature level by the AHUs. In the case of high de-humidification load (in monsoon) or peak summer, the chilled water supply temperature remains at 7 °C. As a rule of thumb, every 1 °C increase in chilled water temperature will increase efficiency by 2.7%.

Figure 5.13 compares the performance data for different types of chillers (capacity 250 TR) at part load. The figure shows that at part loads, the centrifugal chiller with magnetic levitation

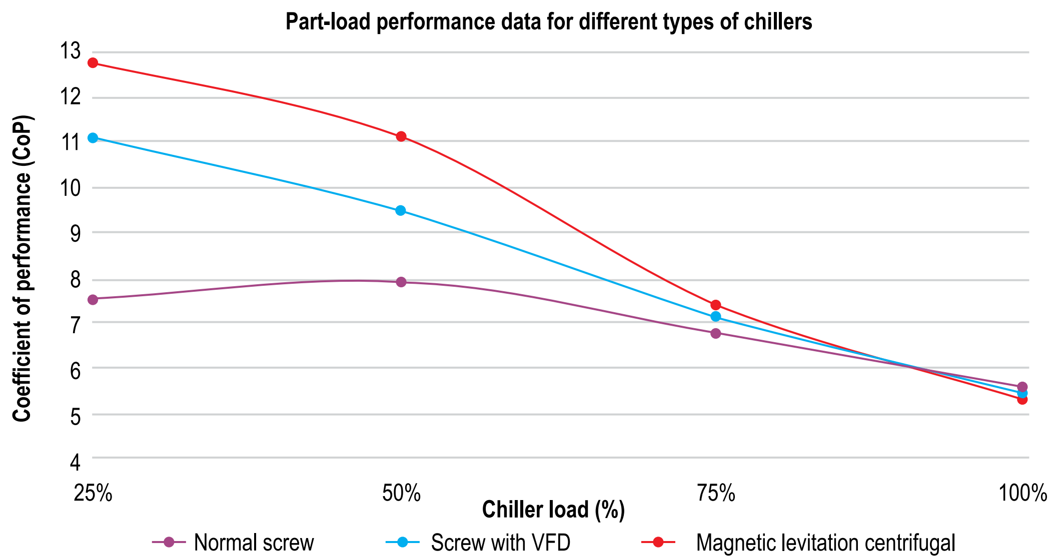


Figure 5.13 *Comparison of performance of different types of chillers (based on AHRI 550 part-load performances)*

[5] *IPLV is a performance characteristic developed by the Air-Conditioning, Heating and Refrigeration Institute (AHRI).*
IPLV = 0.01A + 0.42B + 0.45C + 0.12D
where,
A = COP or EER @ 100% Load
B = COP or EER @ 75% Load
C = COP or EER @ 50% Load
D = COP or EER @ 25% Load

bearing is the most efficient, followed by the screw chiller with VFD and then the normal screw chiller. The chiller that has the best IPLV as against the cost should be selected.

5.10.4 Pumps and motor selection

Figure 5.14 shows various pumps and fans in a centralised air-conditioning system. Right sizing of these fans and pumps helps in achieving energy efficiency. Similar to star rating of appliances, there is energy rating for motors. All motors for fans and pumps should be Eff1 or IE2, IE3 labelled, which are the most energy efficient. Similar to chiller, pumps/fans also operate on part loads. Installation of VFDs on pumps and fans operating at variable flow rates ensures good energy efficiency at part loads.

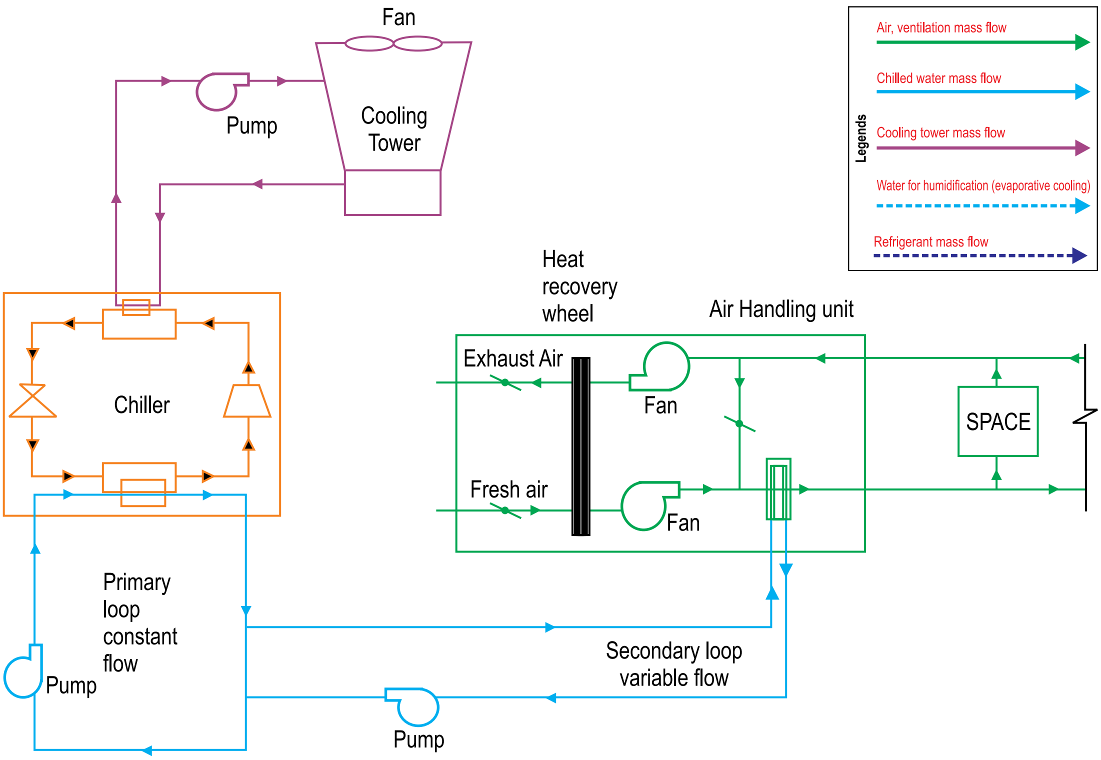


Figure 5.14 *Pumps and fans in a centralised air-conditioning system*

Figure 5.15 shows the best efficiencies one can expect from using high performance pumps with motor. It shows that while a small pump of a few watt capacity can have maximum efficiency of around 20%, a pump of large capacity of 10,000 watts has a higher efficiency of around 80%. During the call for tenders, one should aim at specifying the efficiency of the pump using this figure.

5.10.5 Water piping selection and design

Chilled and condenser water piping selection

The chilled water piping network should be designed to minimize frictional losses. The frictional losses or pressure drop in chilled water steel pipe could be obtained from new charts. As an example, for a pipe having a diameter of 4 inch (10.16 cm) for a water flow rate of 10 l/s (36 m^3/h), the pressure loss would be around 15,000 Pa/100 m, or 150 Pa/m.

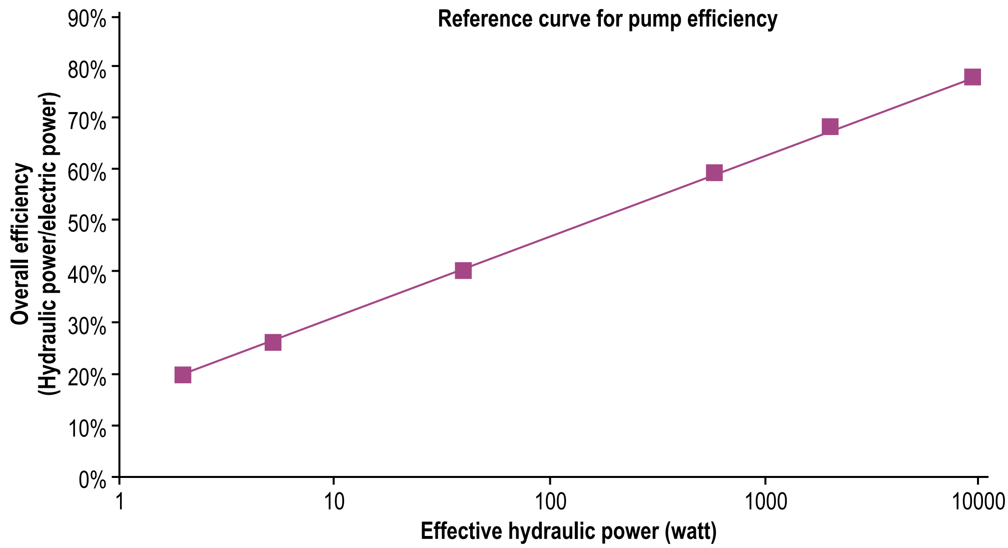


Figure 5.15 *Representative pump efficiencies as a function of the hydraulic power delivered*

Chilled and condenser water piping design

The design of pipes is critical and it should be done properly to minimise the pressure losses and hence minimising the pumping energy. The size of pipes should be properly selected and the piping network should be designed to minimise bends. Target values of specific pressure losses are of the order of 120–200 Pa/m. Water balancing should be done properly during the commissioning so that all the spaces catered by the cooling system get the required chilled water for cooling. Chilled water pipes should be adequately insulated to minimise the loss of cooling.

Optimised chilled water systems

Figure 5.16 shows the schematic of an optimised chilled water system in which many energy efficiency features have been incorporated in the design. For clarity, only one chiller is shown in the figure. The key energy-efficiency features in the chilled water system are as listed below.

- Cooling towers equipped with VFD
- Primary pump loop with VFD with a bypass to guarantee the minimum flow rate in the evaporator
- Secondary pumps with VFD maintaining a differential pressure at the AHU cooling coil loops level
- Controls allowing gliding the temperature of the chilled water between typically 7 °C and 12 °C depending on the dehumification needs
- Low pressure losses in the pipes and cooling depending on the dehumidification and cooling needs.

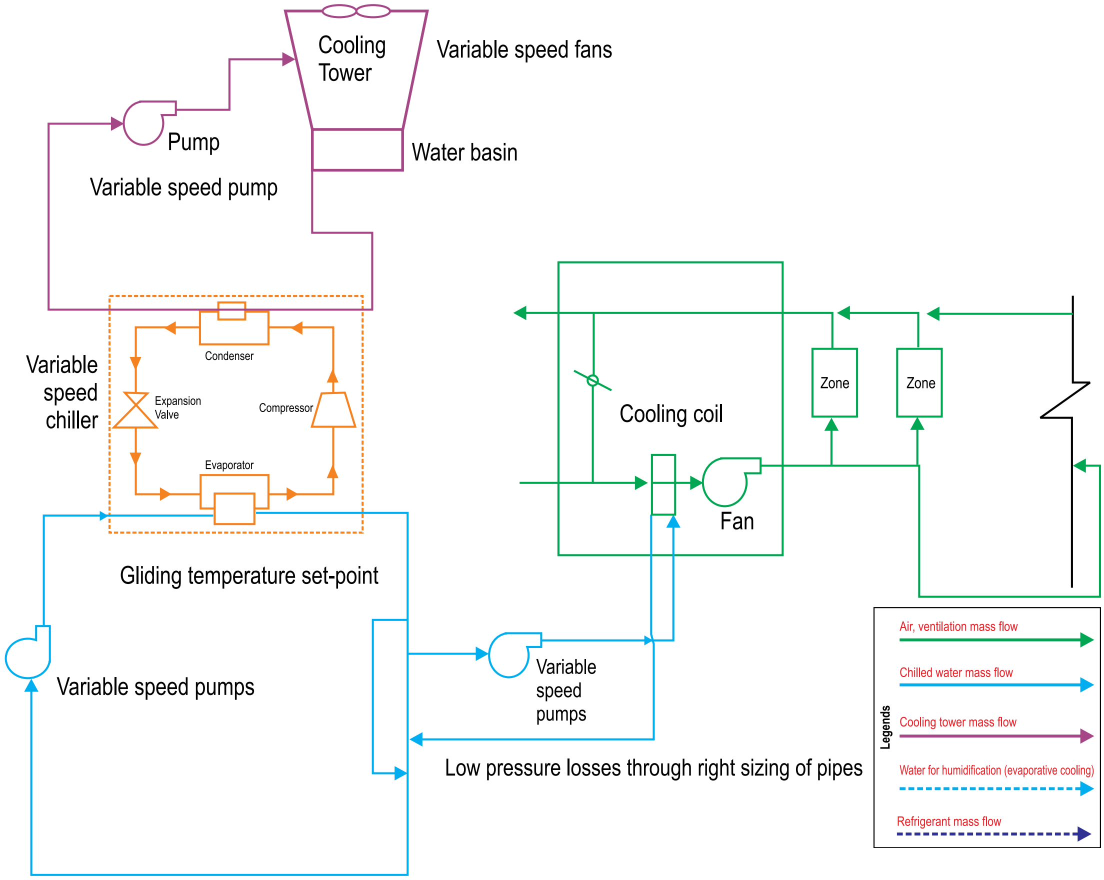


Figure 5.16 *Example of an optimised chiller water system*

5.11 Efficiency Improvements on the Cooling Distribution Side

5.11.1 Selection of fans

Figure 5.17 shows the best efficiencies one can expect from high performance fans with belt and motor. This cart can be used to specify the desired efficiency in the call for tenders for buying fans. Apart from the selection of fans that have good efficiencies, it is also important to select the right diameter of the air duct to minimise pressure drops in the air distribution systems. Figures 5.19 and 5.20 provide a nomogram to estimate pressure drops in ducts carrying air.

5.11.2 Mechanical ventilation design optimisation

All-air systems are the most common systems of cooling in India. A number of strategies can be applied to reduce the electrical energy consumption for such systems as shown in Figure 5.18. The key strategies are as given below.

- Use a VFD (vary between 20% and 100%) instead of constant flow drive in all fans.
- Operate the system in such a way that the minimum fresh air rate ensuring sufficient flow per person is always maintained (10–15 l/s-person).
- When the ambient temperatures are lower than the space temperature (by at least 2 °C), outside air can be introduced in the space using fans to cool the space. This is called free cooling. In most regions of Karnataka, there is good potential for free cooling and hence

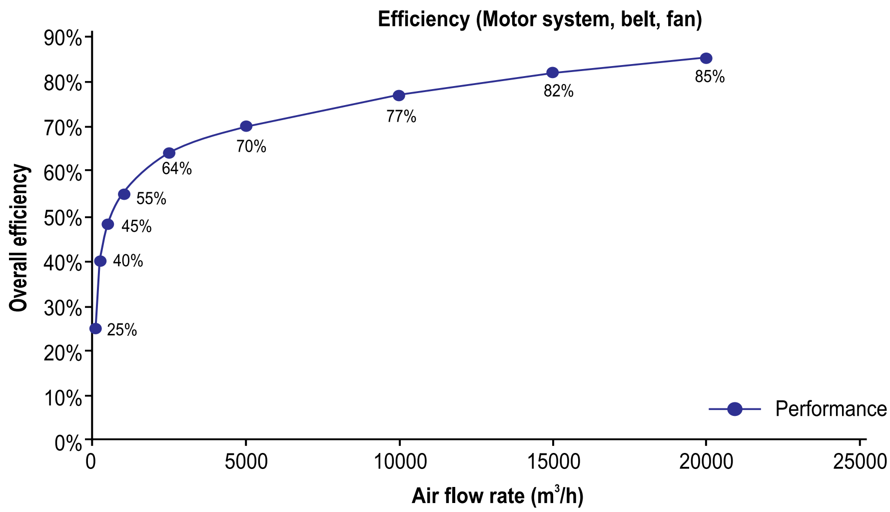


Figure 5.17 *Efficiencies that can be expected from high-performance fans, motors, and belt*

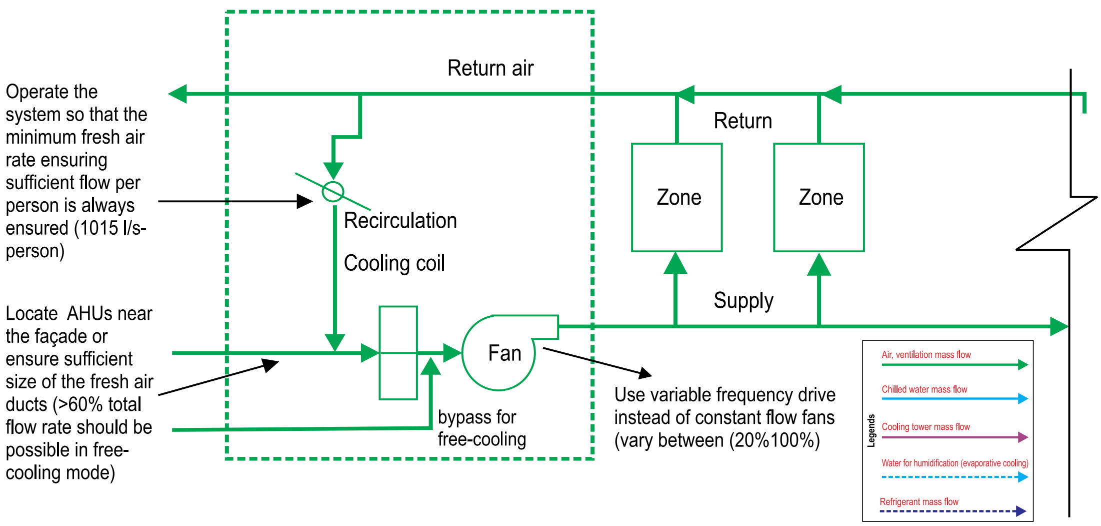


Figure 5.18 *Optimised energy-efficient conventional all air side cooling system*

the fresh-air ducts should be large enough to bring in at least 60% of the total flow rate. Also, the AHUs should be located near the façade.

Total pressure loss on the air side =

pressure loss across the AHU + pressure loss in main duct × fittings

It is important to size the AHUs and ducts for minimal pressure losses. The following diagram (Figure 5.19) shows how to reach target values for low duct pressure losses.

The figure shows how the hydraulic diameter varies as a function of the air flow rate for each branch and for different specific pressure losses (Pa/m). The target values are 0.4 to 0.5 Pa/m. it is interesting to visualise with theses curves that by increasing the hydraulic diameter by about 10%–15% only, the pressure loss in ducts is reduced by a factor of two, reducing in the same ratio the electric power for air distribution.

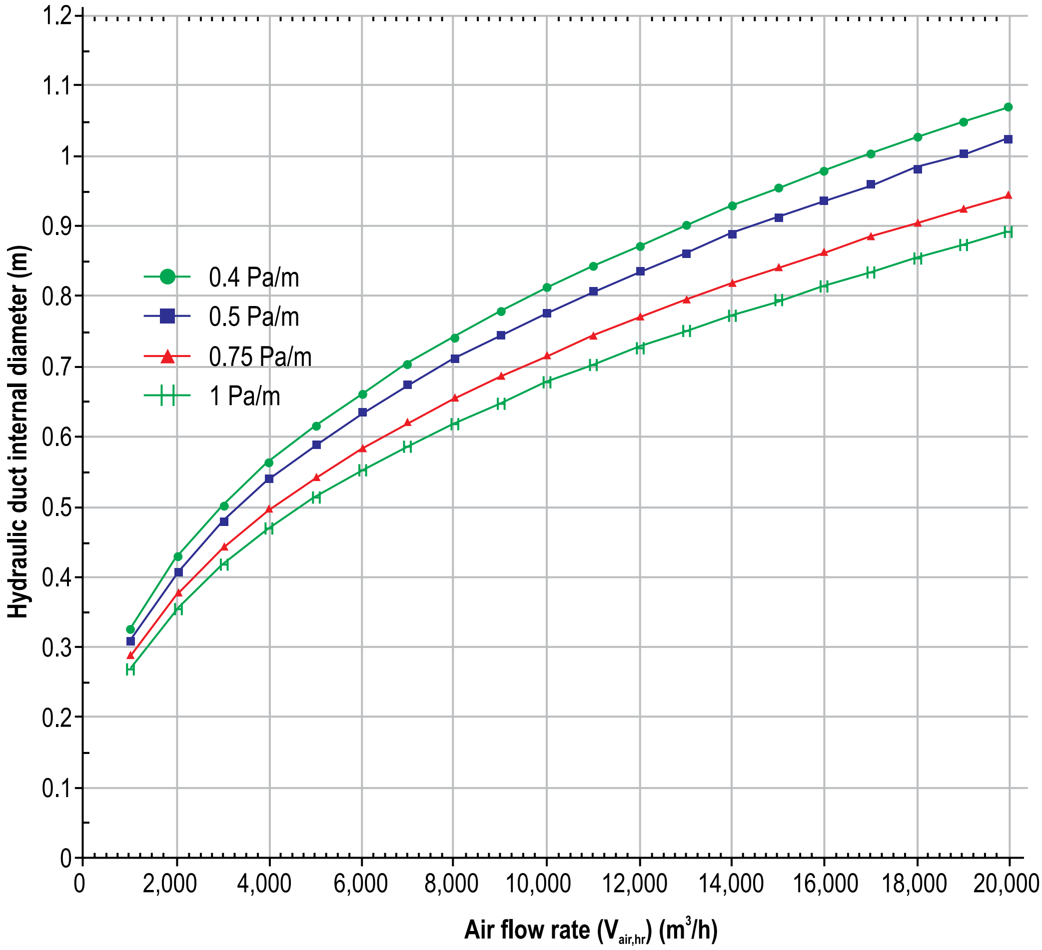


Figure 5.19 *Main duct equivalent diameter as a function of the air flow rate in an AHU for a specific electricity power demand of 0.4 W/(m^3-h) and a total length of 300 m*

Where,

Hydraulic diameter = dh = 4 A/p

dh = hydraulic diameter (m, ft)

A = area section of the duct (m^2, ft^2)

p = wetted perimeter of the duct (m, ft)

The other way at looking at the duct size is to minimise the air velocity to the curves with specific pressure losses of 0.4–0.5 Pa/m. Figure 5.20 shows the main variation of air flow rate and its influence on the allowable velocity for a given specific pressure loss (Pa/m).

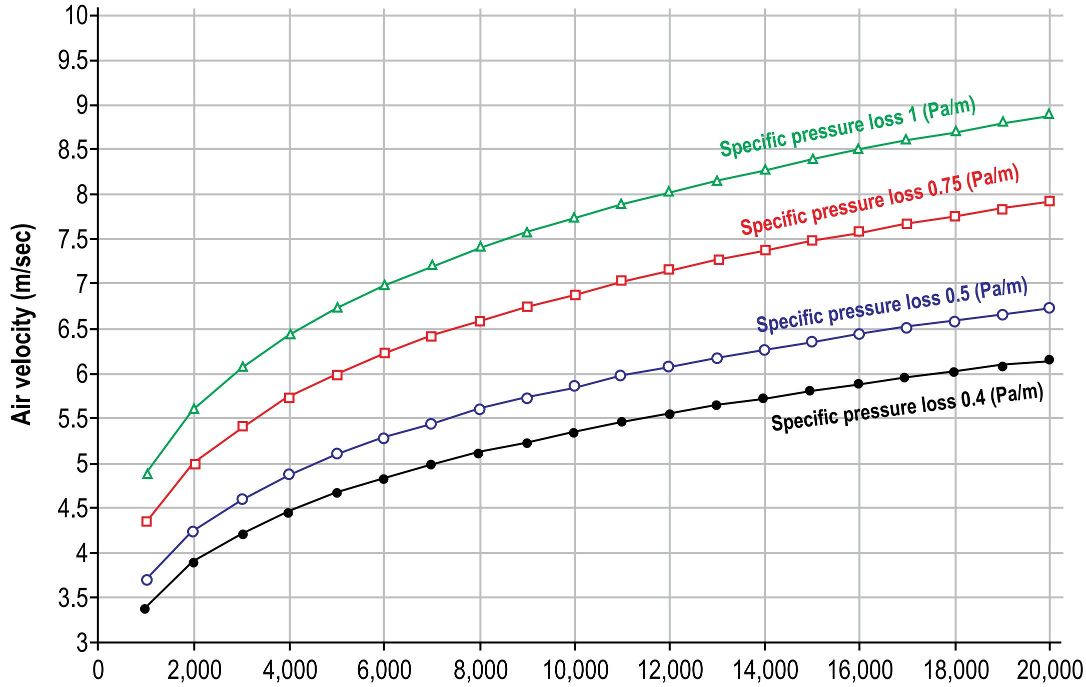


Figure 5.20 *Variation of air flow rate and its influence on the allowable velocity for a given specific pressure loss (Pa/m).*

5.11.3 Size of cooling coils for removing sensible loads at 12 °C supply water temperature

Generally, the cooling coils (area and number of rows) are designed to remove the maximum sensible and latent load at 7 °C water supply temperature. We have seen earlier that if we are able to operate the chiller at higher temperature (i.e., increasing the chilled water supply temperature up to 12 °C), then the CoP of the chillers is higher. The cooling coils should be designed for removing maximum sensible loads at 12 °C supply water temperature. With such a design, one can glide the chilled water temperature (from 12 °C down to 7 °C), only to ensure dehumidification requirements.

5.11.4 Fan coil instead of all-air cooling for areas having high thermal loads

In conventional systems, all-air systems are used to remove the heat load, i.e., the cold air from AHU is supplied. However, for areas that have high thermal loads (regularly more than 60 W/m^2, 10 hours or more per day), it is recommended to consider using fan coils or even radiant cooling instead of all-air systems. Energy savings by the use of a fan coil in such a case is explained with an example below.

Example

Comparison of electricity consumption for cooling a 1000 m^2 zone having an average heat gain of 80 W/m^2 during the day.

- All-air system: The assumption is that the total pressure differential is of 800 Pa for the air loop. Air supply temperature is at 16 °C, return air at 26 °C. The corresponding air flow rate is 6700 m^3/h. When taking into account a CoP of 6 for the chiller, the total power for ventilation and chiller system is 21.6 kW.

- Fan coil with fresh air rate at 15 l/s-person: The air flow rate is reduced to 540 m^3/h, the supply temperature of air is around 22 °C. The total electricity consumption for the air transport for cooling the air and for cooling by the fan coils is 13.6 kW. Thus in this case, there is electricity saving of about 40% in the fan coil system (without considering dehumidification of the air from outside).

5.11.5 Treated fresh air with heat recovery

Conventional systems do not have heat recovery in the air loop. One can reduce significantly the dehumidification and sensible cooling energy demand for the fresh air, by adding a treated fresh air (TFA or DOAS) unit with a heat recovery, which supplies fresh air to all AHUs.

When outdoor air is warm and very humid, the chilled water is maintained at a low temperature (7 °C) so as to remove the high humidity content. The TFA with heat recovery (enthalpy wheel) has the function to reduce the cooling load (sensible heat load and a large part of the latent load) of the fresh air before being despatched to the AHUs. In order to be able to get sufficient air flow for free-cooling, one has to keep a bypass of the TFA with larger ducts to bring fresh air into the zones with AHUs. This configuration is illustrated in Figure 5.21.

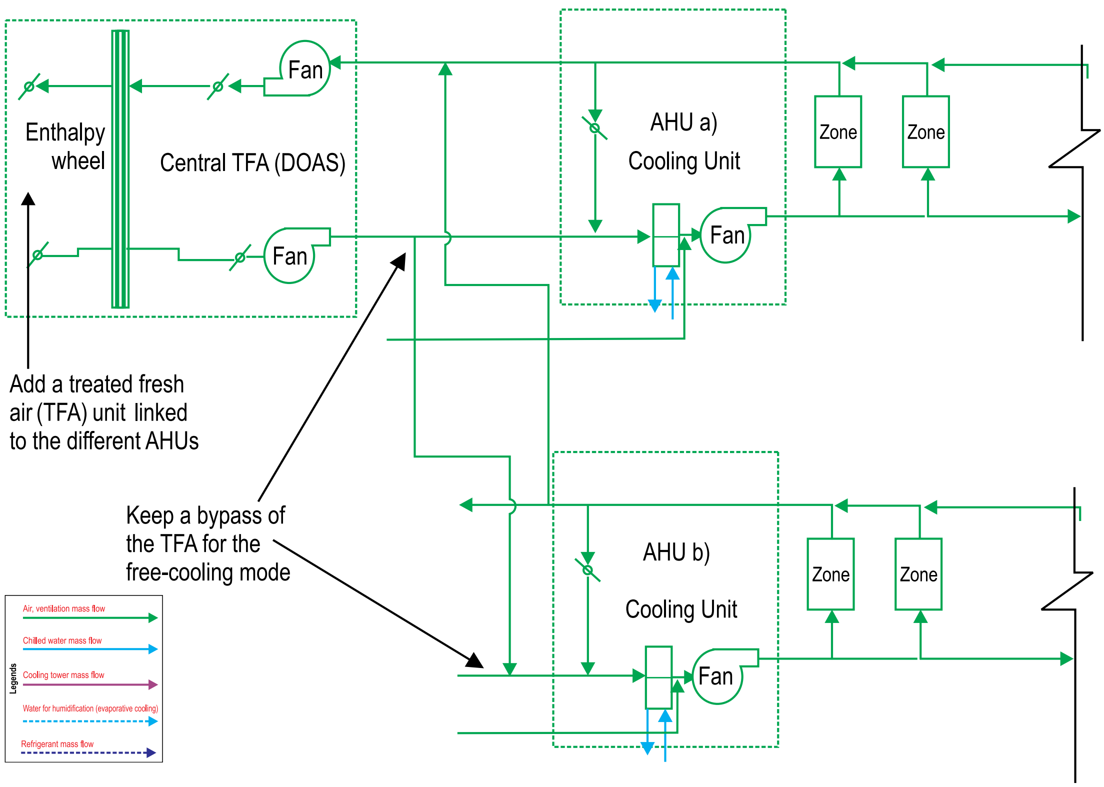


Figure 5.21 *Treated fresh air with heat recovery and AHUs (only two for illustration)*

5.11.6 Indirect evaporative cooling AHU

In hot and dry climates, and where direct evaporative cooling results in uncontrolled high humidity, an indirect evaporative cooling AHU can be used. In this case, the incoming fresh air is not humidified, but is cooled by the humidified (almost 100% saturation) return air (refer Figure 5.22). The process with indicative values is shown in the psychrometric chart shown in Figure 5.23.

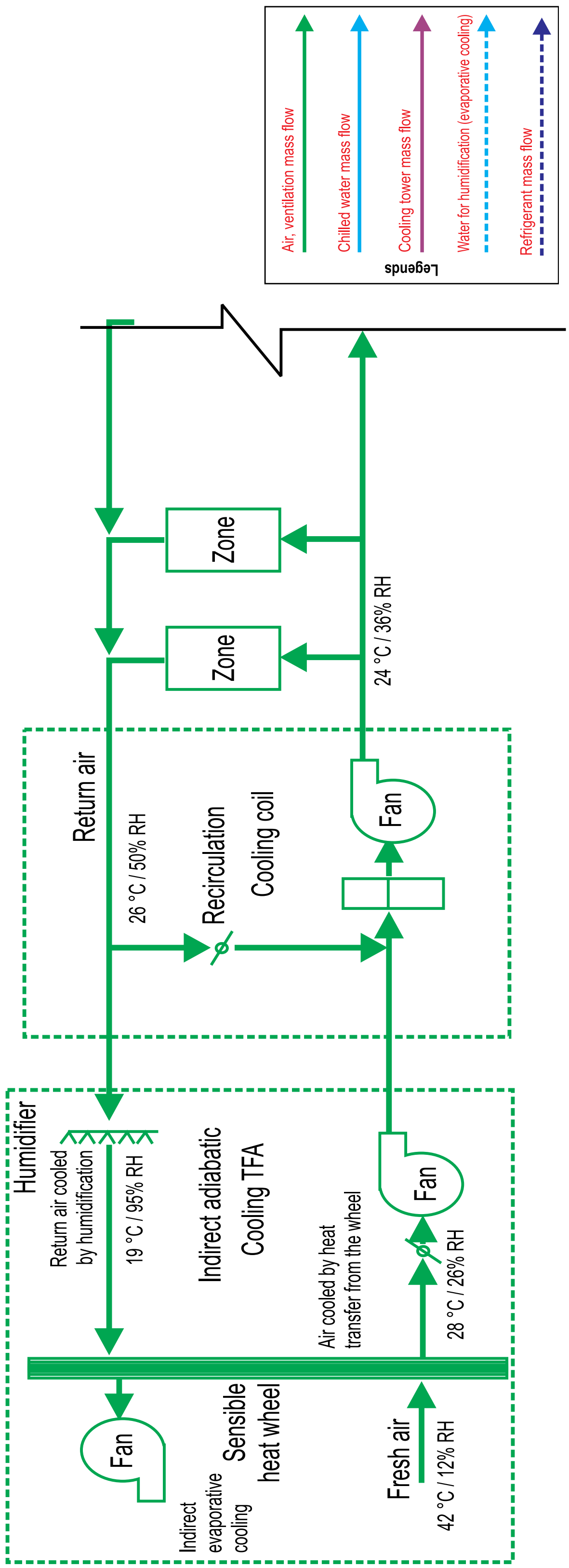


***Figure 5.22** AHU with indirect evaporative cooling*

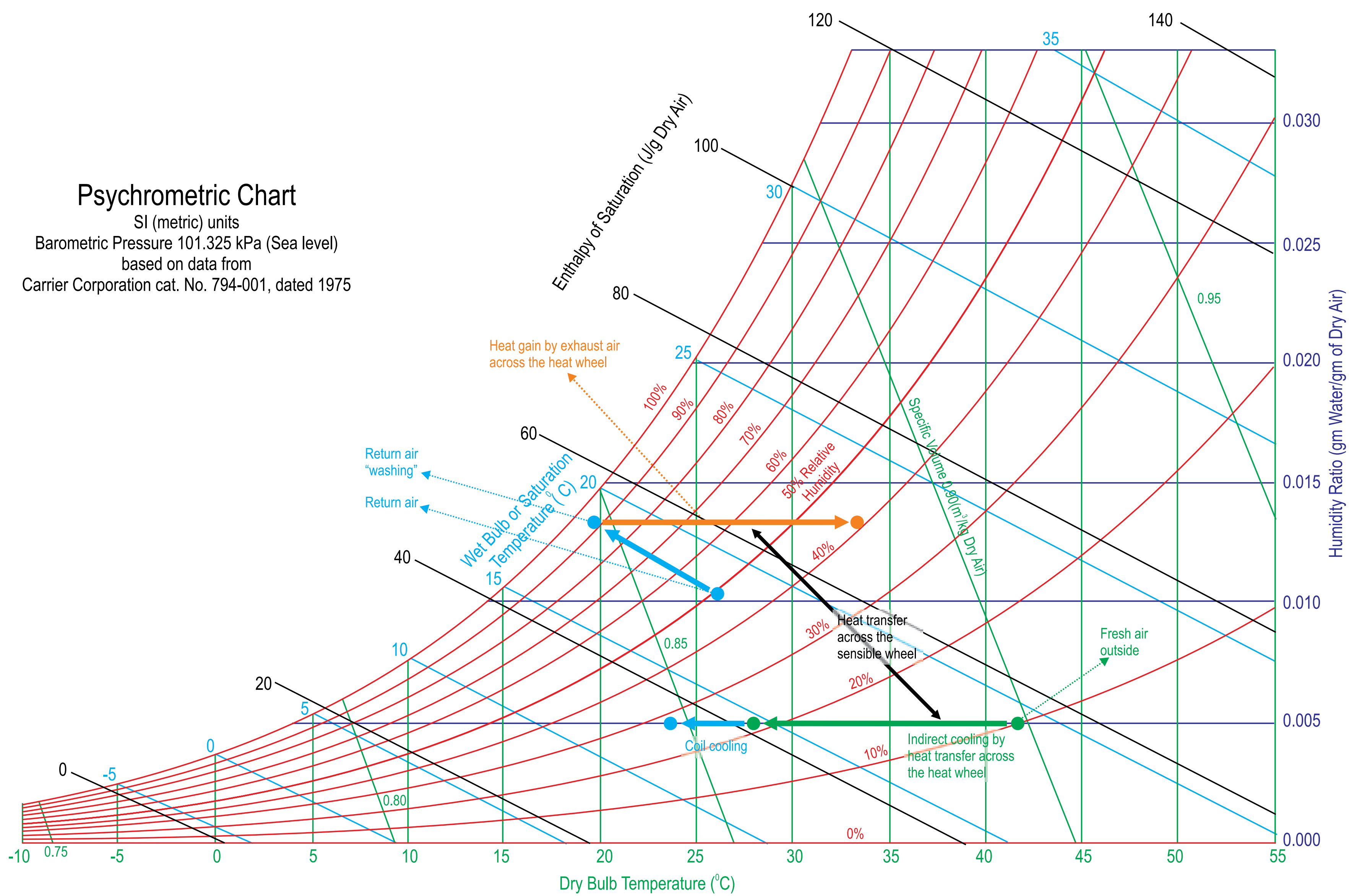


Figure 5.23 *AHU with indirect evaporative cooling on a psychometric chart*

CHAPTER RECAP

- The choice of the cooling system for a building depends on factors such as the local climate and the type of the building (its size, usage, area to be conditioned, etc.).
- Air movement helps in achieving thermal comfort; in warm climates, ceiling fans have an important role to play in all types of buildings. BEE 5-Star labelled ceiling fans or super-efficient ceiling fans should be used.
- Evaporative cooling can be an energy-efficient solution if the climate is suitable (e.g., semi-arid, and parts of tropical wet and dry region) and sufficient quantity and quality of water is available. Direct evaporative cooling systems with humidifying pad (desert cooler) or with high pressure pumps, which create a fine mist, can be used. Use of two-stage indirect evaporative cooling systems can result in achieving more than 100% cooling efficiency.
- For single zones, BEE star labeled unitary, split or inverter ACs can be used. All these are air-cooled systems. An alternative solution would be to have a centralised water loop, in which the water cooled in a cooling tower is supplied to the split units to cool the condensers, thus increasing the efficiency.
- In the case of centralised air-conditioning systems, the main strategies for improving energy efficiency on the chilled water side are listed below.
  - Use of water-cooled chillers, instead of air-cooled chillers.
  - Select efficient chillers as per the need.
  - Select chillers with good part-load performance.
  - Select efficient pumps and motors.
  - Reduce pressure drop in the water circuit.
  - Use of VFDs on pumps and cooling tower.
  - Use controls to allow gliding of the temperature of the chilled water from 7 °C to 12 °C depending on the dehumification needs.
- In the case of centralised air-conditioning systems, the main strategies for improving energy efficiency on the cooling distribution sides are as listed below.
  - Select efficient fans.
  - Reduce pressure drops in the air circuit.
  - Use VFDs on fan motors.
  - Utilise free cooling potential.
  - Size the cooling coils for removing sensible loads at 12 °C supply water temperature.
  - Use treated fresh air with heat recovery.
  - Use indirect evaporative cooling AHU.

CHAPTER 6

Integration of Solar Energy

6.1 Strategy 7: Integration of Solar Energy

Strategy 7: Solar Shading Solutions	▪ Generates electricity using solar energy ▪ Reduces the electricity purchased ▪ Supplies excess energy to grid

6.2 Introduction

The largest and most easily accessible source of renewable energy that can be integrated with buildings is solar energy. Solar radiation received by Karnataka is higher than many other Indian states. The global horizontal irradiance (GHI) ranges between 1600 and 2000 kWh/m^2.y or between 4.5 and 5.5 kWh/m^2.d in Karnataka (Figure 6.1).

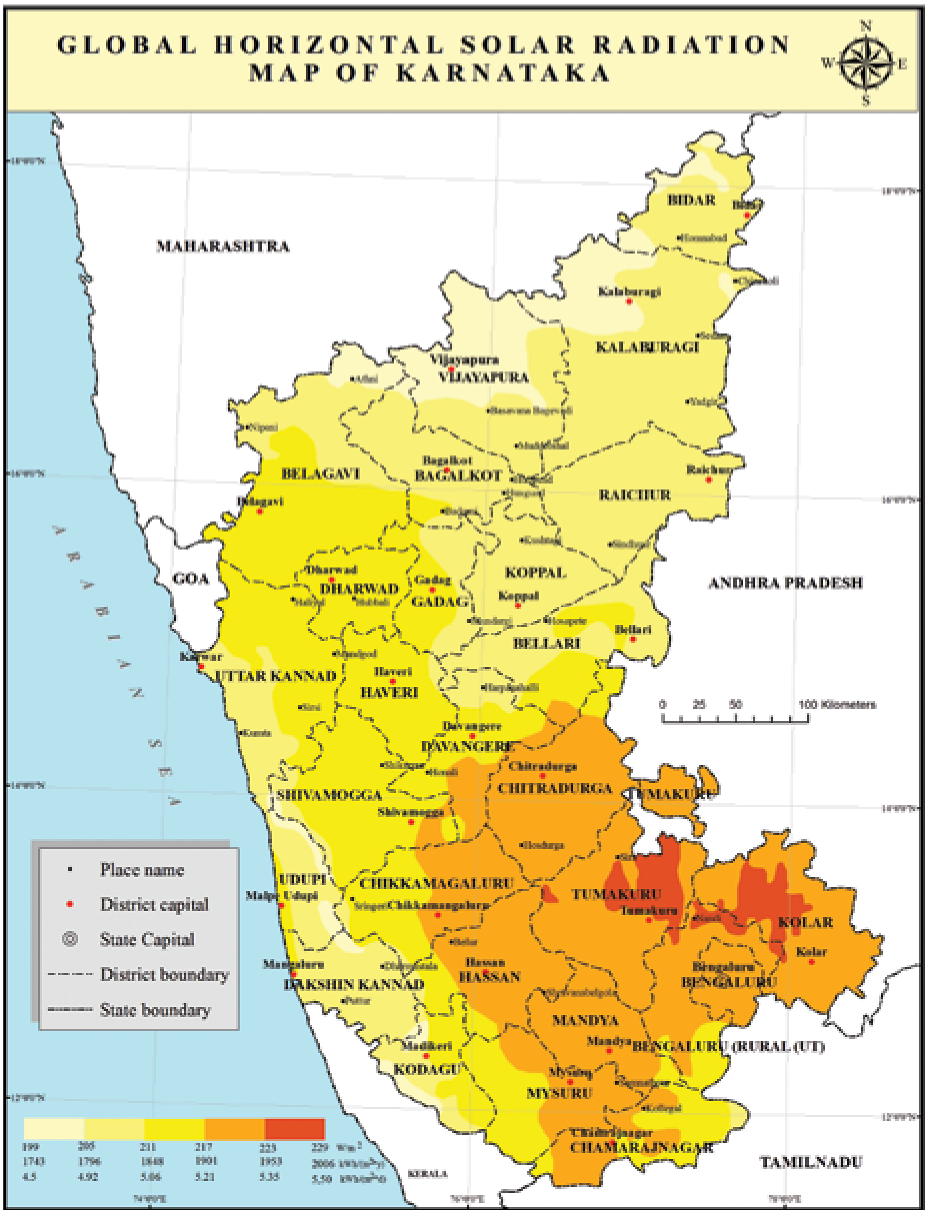


Figure 6.1 *Global horizontal irradiation (GHI) of Karnataka*
Source *'Indian Solar Radiation Atlas' prepared by NIWE, MNRE, and GIZ*

In case of buildings, the roof receives the highest solar radiation, but it is important to understand how much solar radiation falls on the façade. Therefore, identifying the façade that is most suitable for solar energy integration is the first step. Figure 6.2 shows the incident solar radiation on roof and all façades for four locations of Karnataka.

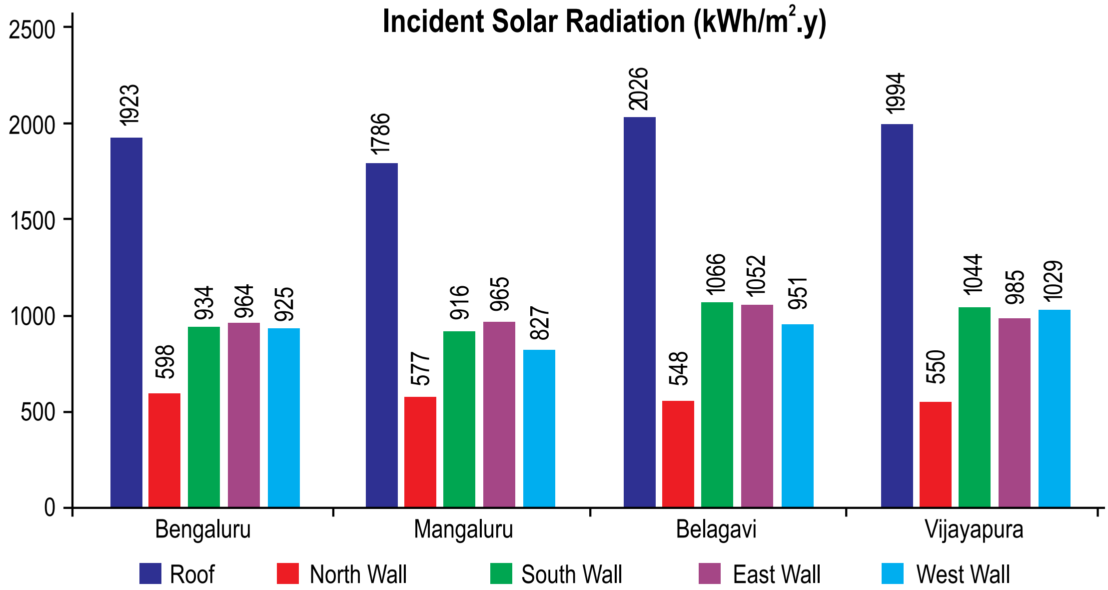


Figure 6.2 *Average annual solar radiation on roof and walls for different cities*

As can be seen in Figure 6.2, the incident solar radiation (kWh/m^2/year) on the roof is 3.4 times more than that on the north walls and double as compared to other walls. Thus, the roof has the highest potential for harnessing solar energy.

Solar energy can be harnessed through two main technologies: (a) solar hot water panels to produce hot water and (b) photovoltaic panels, which convert solar energy into electricity. Figures 6.3 and 6.4 show images of these systems.

Figure 6.3 *Solar water heater*

Figure 6.4 *Solar photovoltaic system*

6.3 Solar Photovoltaic (SPV) System

An SPV system can be installed on the roof or any other available free space to generate electricity, which can be used either for meeting part of the electricity demand for the building or can be exported to the grid. To illustrate the benefits of the SPV system, a simple exercise was undertaken to calculate the energy generation potential from a 1 kW_p SPV system and examples are shown for a typical building with a roof area of 400 m^2, in four locations in Karnataka.

6.3.1 Electricity generation with SPV technology

RET Screen[1] was used to estimate the electricity generation potential from a 1 kW_p SPV system in the four locations (Bengaluru, Mangaluru, Belagavi, and Vijayapura) of Karnataka.

Figure 6.5 and Table 6.1 show the annual electricity generation and monthly variation in the output of the SPV system at the four locations in Karnataka. As can be seen, there is not much difference in the electricity yield.

Table 6.1 Annual electricity generation from 1 kW_p SPV system in Karnataka

Place	Annual electricity generation ($kWh/kW_p.y$)
Bengaluru	1476
Mangaluru	1404
Belagavi	1450
Vijayapura	1501

[1] *RETScreen is an excel-based clean energy decision-making software developed by the Government of Canada. It is widely used for renewable energy project analysis. Details are available on the website www.retscreen.net.*

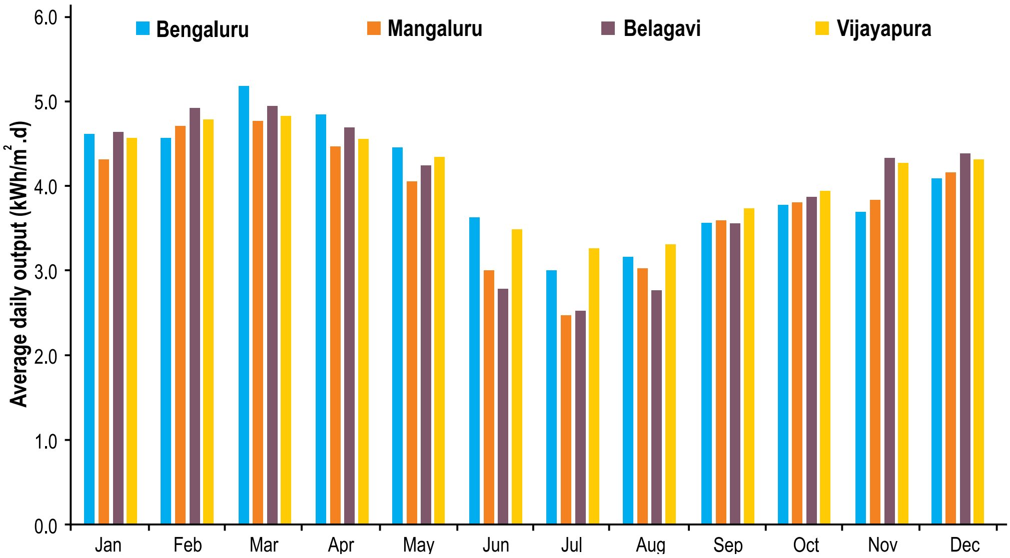


Figure 6.5 *Monthly average daily output from 1 kW_p SPV system in Karnataka*

6.3.2 Sizing of the SPV system

The sizing of an SPV system for a public building is determined by the available roof area.

A simple example of a typical public building with a roof area of 400 m^2 is taken to illustrate the energy generation potential at the four locations in Karnataka.

Table 6.2 Sizing and output of the proposed SPV solution in a typical building

Solar photovoltaic technology	Poly crystalline silicon			
Efficiency of solar panel at standard test conditions (%)*	13.5			
Size of 1 kW_p solar panel (m^2)	7.4			
Roof area required for 1 kW_p solar panel (m^2)	10			
Roof area of the building (m^2)	400			
Available shadow-free roof area for solar# (%)	75			
Available shadow-free roof area for solar (m^2)	300			
Maximum size of photovoltaic system possible on roof (kW_p)	30			
	Bengaluru	Mangaluru	Belagavi	Vijayapura
Annual electricity generation (kWh/year)	44,280	42,120	43,500	45,030

* Efficiency of the poly crystalline solar panel lies between 11% and 14%.[2]
\# Available shadow-free roof area may vary from 60% to 80%. Here, 75% is taken for calculations.

The economics with the SPV system works out best when it is designed with no (or very small) energy storage and yet all the SPV-generated energy is utilized. The first preference for SPV system would be to opt for a grid-connected system. Karnataka has net-metering policy in place; hence, the best configuration for SPV system would be to install a grid-connected

[2] *Handbook for Solar Photovoltaic Systems, Building and Construction Authority, Singapore.*

system with net-metering.[3] Other possibilities are to utilize the SPV system for catering to the energy demand for daytime loads. Figure 6.6 gives a simple flow chart to decide the SPV system configuration.

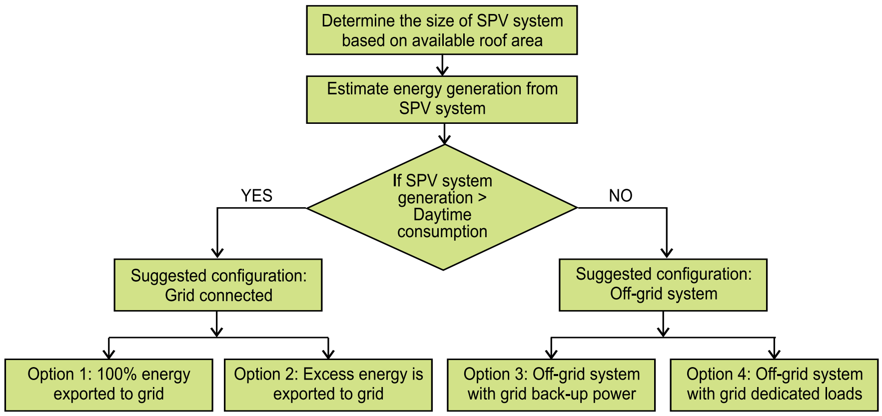


Figure 6.6 *Selection of SPV system configuration*

6.3.3 Configuration of the SPV system[4]

The output of the SPV system can be utilized in four configurations.

1. **Grid-connected with net metering and 100% export:** In this system, the building has two meters. One meter measures the electricity generated from the SPV system, which is fed to the grid. The other meter measures the electricity consumed by the building, which is taken from the grid. Depending on the SPV-generated electricity and its tariff, and the electricity consumed from the grid and its tariff, the electricity bill is calculated. The schematic of this configuration (Option 1) is shown in Figure 6.7.

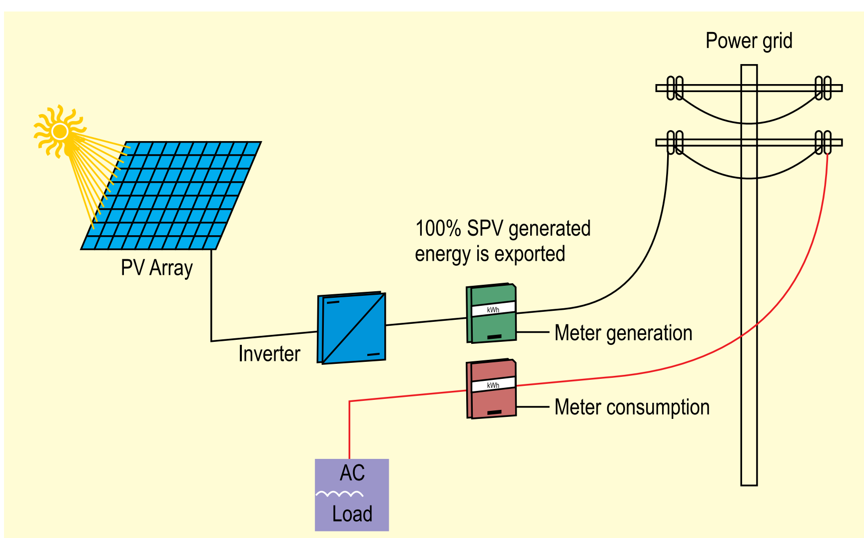


Figure 6.7 *SPV schematic for grid-connected with net metering and 100% export*[5]

[3] *http://bescom.org/wp-content/uploads/2014/10/19.-Guidelines-to-BESCOM-officials1.pdflast accessed on 29 April 2016.*

[4] *http://energyinformative.org/grid-tied-off-grid-and-hybrid-solar-systems/ last accessed on 29 April 2016.*

[5] *Grid-Connected PV Systems Design and Installation, prepared by Global Sustainable Energy Solutions (GSES).*

2. **Grid-connected with net metering and excess energy export:** This configuration is exactly the same as the previous one; the only difference is that part of the energy generated by the SPV system is utilized to meet the energy requirement of daytime loads, and excess energy is fed to the grid. The schematic of this configuration (Option 2) is shown in Figure 6.8.

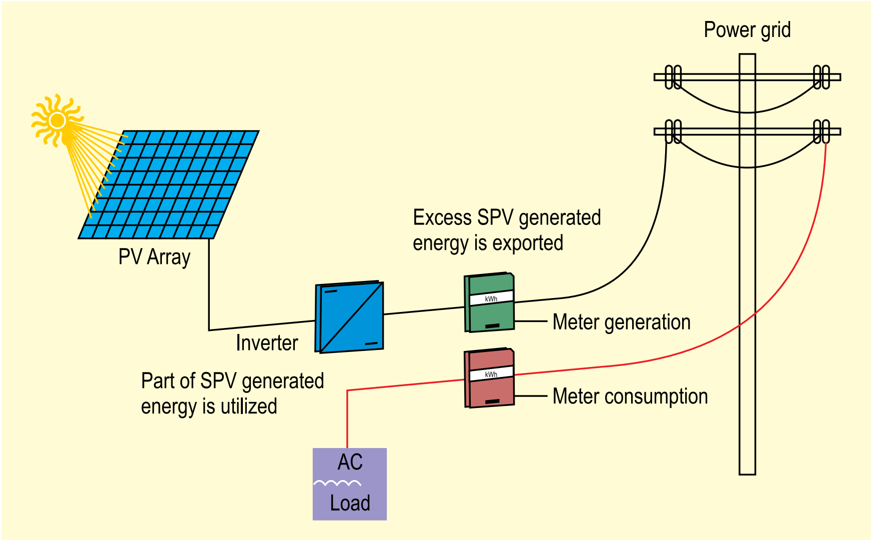


Figure 6.8 *SPV schematic for grid-connected with net metering and excess energy export*

3. **Off-grid system with grid back-up power:** This is a modification of the grid-connected configuration. The building has two parallel power supplies, one from the SPV system and the other from the grid. The two power supplies are combined to meet the total electricity load of the building. However, in this case, the grid acts only as a back-up power source and there is no provision for exporting excess generation to the grid. A battery bank is provided for storing the excess generation from the SPV system. There is an option to switch to grid-connected configuration with minimal cost. The schematic of the configuration (Option 3) is presented in Figure 6.9.

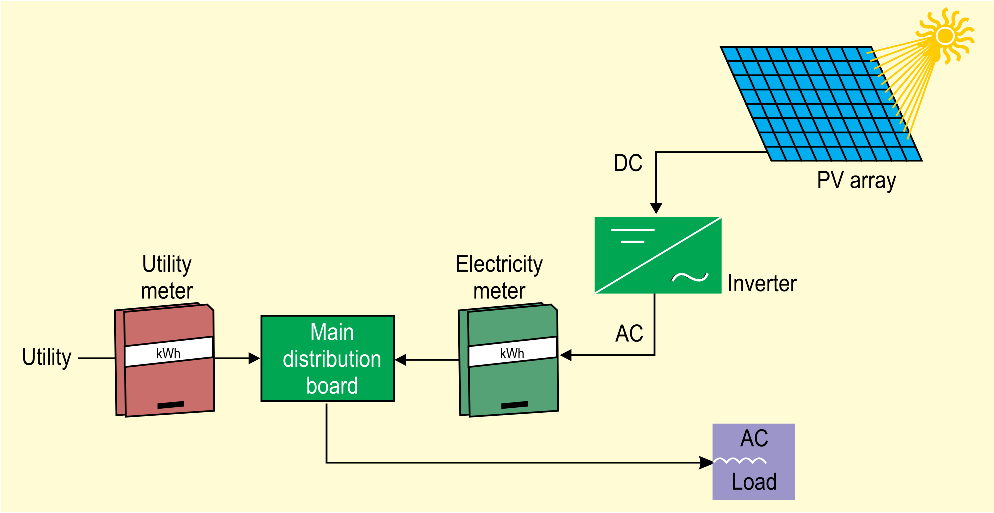


Figure 6.9 *SPV schematic for hybrid system (system with grid back-up power)*

4. **Stand-alone (off-grid) solar PV system with dedicated loads:** In this configuration, the SPV system is not connected with the grid. Electricity generated from the SPV system is used for either meeting certain dedicated loads during daytime or for storing the energy by charging batteries for night-time loads. Electricity for water pumping and lifts during daytime can be directly supplied by the SPV system. The energy stored in the batteries can be used to meet the requirement of lighting and operating lifts during the night. This configuration requires a substantial battery bank to store electricity for the night. The schematic of this system (Option 4) is shown in Figure 6.10.

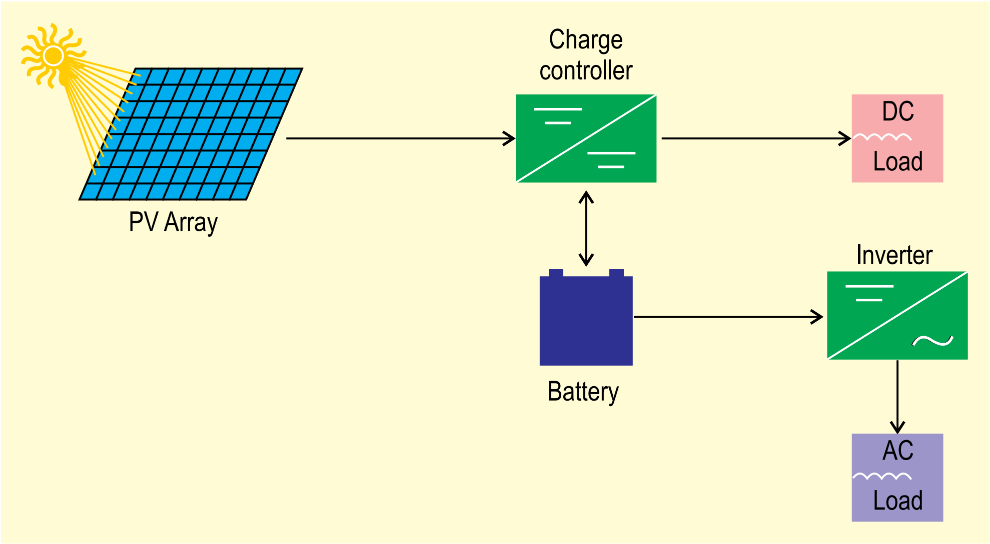


Figure 6.10 *SPV schematic for stand-alone off-grid configuration*

6.4 Solar Water Heaters

Figure 6.11 shows the regional market segmentation for solar water heaters in India. Karnataka falls under Zone 1 and detailed requirements of this zone are listed in Table 6.3.

Table 6.3 Hot water demand in Zone 1[6]

Type of building	Hot water requirement period	Demand norm[7] @ 40 °C
Hospital	Round the year	65 litres per day per bed
Hostel	July–April (10 months)	65 litres per day per person

[6] *Chapter 4, 'Capturing Sun for Heat, Status of Solar Thermal Technologies and Markets', Greentech Knowledge Solutions (P) Ltd. and Shakti Sustainable Foundation, 2015.*

[7] *International Copper Promotion Council (India). User's Handbook on Solar Water Heaters, UNDP–GEF and MNRE, 2010.*

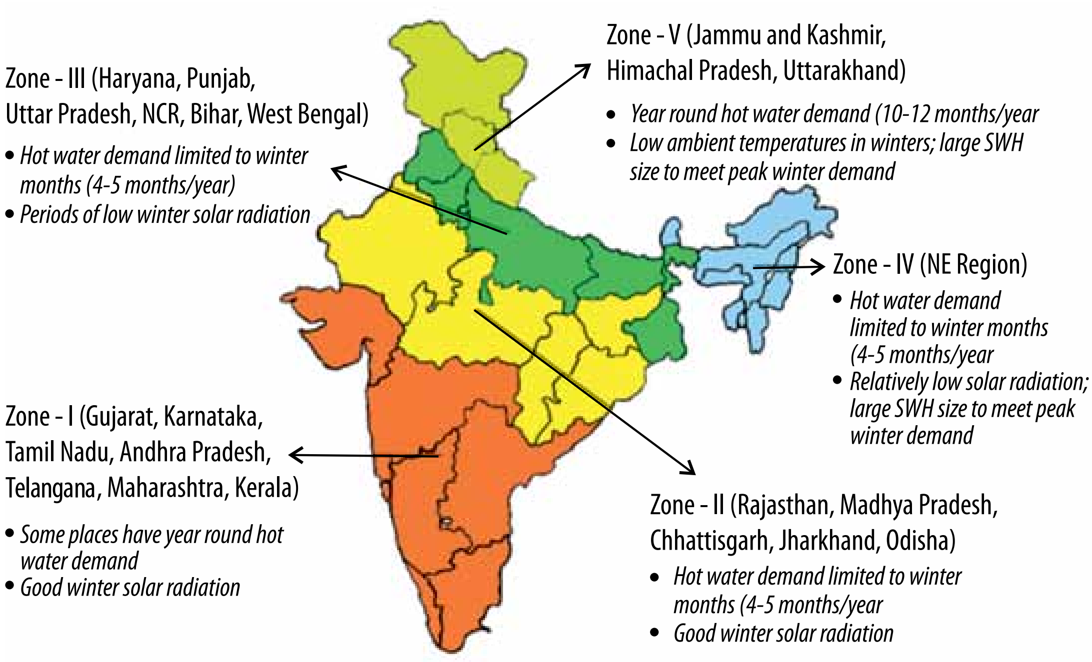


Figure 6.11 *Regional segmentation of for solar water heaters*[8]

Small public buildings in Karnataka do not have requirement for hot water. However, as per the classification of buildings in Chapter 5 on efficient cooling systems, Table 6.3 shows the hot water requirements in these buildings.

6.4.1 Electricity consumption for generation of hot water

In the business-as-usual case, individual electric geysers are used. Tables 6.4 and 6.5 show the estimated annual electricity consumption for generation of hot water using electric geysers for hospitals and hostels, respectively.

Table 6.4 Electricity consumption for generation hot water for a typical hospital in Karnataka

Useful energy required for hot water generation per bed				
	Bengaluru	**Mangaluru**	**Belagavi**	**Vijayapura**
Mean temperature of cold water (°C) (January–December)	24.3	27.1	24.1	26.7
Useful energy required for heating (kWh/bed.y)	437	358	443	372
Electric energy consumed in water heating (kWh/bed.y)*	486	398	492	413
Hot water requirement @60 °C for average cold water temp. per bed (litres/day)	28.6	25.5	28.8	26.0
*Assuming storage type geysers with 90% efficiency				

[8] *Greentech Knowledge Solutions (P) Ltd. and Shakti Sustainable Foundation. 2015. Chapter 3.* Capturing Sun for Heat: Status of Solar Thermal Technologies and Markets. *New Delhi.*

Table 6.5 Electricity consumption for generation of hot water for a typical hostel in Karnataka

Useful energy required for hot water generation per student				
	Bengaluru	Mangaluru	Belagavi	Vijayapura
Mean temperature of cold water (°C) (July–April)	24.3	27.1	24.1	26.7
Useful energy required for heating (kWh/student.y)	367	300	371	312
Electric energy consumed in water heating (kWh/student.y)*	408	333	412	347
Hot water requirement @60 °C for average cold water temp. per student (litres/day)	28.6	25.5	28.8	26.0
*Assuming storage type geysers with 90% efficiency				

6.4.2 Solar water heater sizing

The general strategy for designing solar water heaters is to optimise the system size for its annual output. RETScreen software was used to calculate the size and output of solar water heating (SWH) system for hospital and hostel buildings. The results are presented below.

- An optimally sized SWH system can meet 57%–67% of the annual energy required for heating water for hospital buildings located at four locations in Karnataka (refer Table 6.6).
- An optimally sized SWH system can meet 58%–67% of the annual energy required for heating water for hostel building located at four locations in Karnataka (refer Table 6.7).

Table 6.6 Size and output of solar water heaters for a hospital building in Karnataka

Solar water heater technology	Flat-plate collector			
Typical size of solar collector (m²)	2			
Roof area required for one solar collector (m²)	3			
Roof area of the building (m²)	400			
Available shadow-free roof area for solar* (%)	75			
Available shadow-free roof area for solar (m²)	300			
Number of solar collectors	100			
Number of hospital beds	500			
Hot water demand	January–December (12 months)			
Location	Bengaluru	Mangaluru	Belagavi	Vijayapura
Total heating energy required (kWh/y)	2,18,731	1,79,026	2,21,278	1,85,997
Heating delivered from SWH (kWh/y)	1,29,050	1,13,951	1,26,476	1,24,541
Solar fraction (%)	59.0%	63.7%	57.2%	67.0%
Electricity saved# (kWh/y)	1,43,389	1,26,612	1,40,528	1,38,379
* Available shadow-free roof area may vary from 60% to 80%. Here, 75% is taken for calculations. # Assuming storage type geysers with 90% efficiency.				

Table 6.7 Size and output of solar water heaters for a hostel building in Karnataka

Solar water heater technology	Flat-plate collector
Typical size of solar collector (m²)	2
Roof area required for one solar collector (m²)	3
Roof area of the building (m²)	400
Available shadow-free roof area for solar* (%)	75

Continued

Table 6.7 Contd...

Solar water heater technology	Flat-plate collector			
Available shadow-free roof area for solar (m^2)	300			
Number of solar collectors	100			
Number of hostel students	500			
Hot water demand	July–April (10 months)			
Location	Bengaluru	Mangaluru	Belagavi	Vijayapura
Total heating energy required (kWh/y)	1,83,454	1,49,781	1,85,467	1,56,205
Heating delivered from SWH (kWh/y)	1,07,385	96,695	1,08,022	1,05,008
Solar fraction (%)	58.5%	64.6%	58.2%	67.2%
Electricity saved# (kWh/y)	1,19,317	1,07,439	1,20,024	1,16,676

* Available shadow free roof area may vary from 60% to 80%. Here, 75% is taken for calculations.
\# Assuming storage type geysers with 90% efficiency.

It should be noted that the solar fraction varies significantly over different months and this monthly variation needs to be conveyed to the users.

6.4.3 Solar water heater configuration

For public buildings such as the ones developed by the Public Works Department (PWD), the community-type SWH system works best. In this configuration, a large SWH system, capable of providing hot water to the entire building, is installed on the roof of the building. The hot water from the system is supplied through a common pipe network (Figure 6.12). This configuration costs lesser comparatively and occupies lesser area on roof than the individual-type configuration. However, in the community-type configuration, ensuring equal hot water sharing among all users is a challenge.

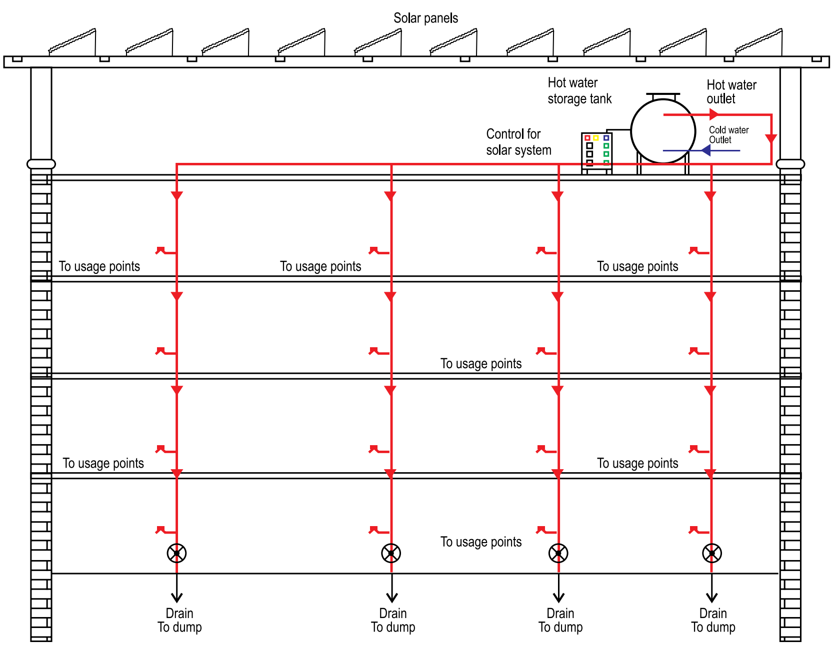


Figure 6.12 *Schematic for community-type system*

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Karnataka receives a GHI between 1600 and 2000 kWh/m^2.y or between 4.5 and 5.5 kWh/m^2.d. The solar radiation availability (kWh/m^2/ year) on the roof is 3.4 times as compared to its availability on north walls and double as compared to other walls. Hence, roof is the best place to install solar energy devices.

Solar energy can be harnessed through two main technologies: solar hot water panels, to produce hot water, and photovoltaic panels, which convert solar energy into electricity.

Solar photovoltaic (SPV)

The output of the SPV system can be utilized in four configurations.

- *Grid-connected with net metering and 100% export:* In this system, the building has two meters to calculate the electricity consumed from the grid and electricity supplied to the grid. Depending on the SPV-generated electricity and its tariff, and the electricity consumed from the grid and its tariff, the electricity bill is calculated.
- *Grid-connected with net metering and excess energy export:* This configuration is exactly the same as the previous one; the only difference is that part of the energy generated by the SPV system is utilized to meet the energy requirement of daytime loads and the excess energy is fed to the grid.
- *Off-grid system with grid back-up power:* This is a modification of the grid-connected configuration. The building has two parallel power supplies, one from the SPV system and the other from the grid. The two power supplies are combined to meet the total electricity load of the building.
- *Stand-alone (off-grid) SPV system with dedicated loads:* In this configuration, the SPV system is not connected with the grid. Electricity generated from the SPV system is used for either meeting certain dedicated loads in the daytime or storing the energy by charging the batteries for night-time loads. This configuration requires a substantial battery bank to store the electricity for the night.

Solar water heaters

The small public buildings in Karnataka do not have hot water requirement; however, hospitals and hostels do need hot water. The general strategy for designing solar water heaters is to optimise the system size for its annual output.

- An optimally sized SWH system can meet 57%–67% of the annual energy required for heating water for hospital buildings, located at four locations in Karnataka.
- An optimally sized SWH can meet 58%–67% of the annual energy required for heating water for hostel buildings located at four locations in Karnataka.

For public buildings such as the ones developed by the PWD, the community-type SWH system works best. In this configuration, a large SWH system, capable of providing hot water to the entire building, is installed on the roof of the building.

Annexures

Annexure 2.1
Framing the Design Brief

BUILDING NAME	
Address of building/site	
Climate zone	
OWNER	
Name/Department/Organisation	
Address	
Contact person	
Contact e-mail	
Contact phone numbers	
User (If different, include details contact person, address, etc.)	
BUILDING USAGE	
Type of building (office, administrative, commercial, housing, hospitality, hotel, restaurant/ catering, sport facilities, other, public, private, central, state….)	
Built-up area	
Site regulations in the area (FAR, etc.)	
Occupation (total no. of occupants)	
Occupation hours	
Types of spaces required	
Usage pattern (description of occupation hours in different spaces)	
Operation and maintenance (kind of operation envisaged, how installation, repairs/replacement of systems will be achieved)	
Billing and financial management (responsibility for energy bills, replacement of equipment…)	
SITE	
Site dimensions	
Description of surroundings on all sides of the building (site topography, urban/rural, dense, presence of tall buildings or trees, vegetation, noise, traffic…) Photos to document	
Description of local climate (temperature, humidity, wind directions, heat island, etc.)	
Source of water (water situation in general, any sources to get reused/treated water)	
Potential of renewable source of energy (solar/wind, etc.)	
Native trees and shrubs	
Local/vernacular materials available and construction techniques	

HVAC	
Description of cooling requirements (conditioned and/or non-conditioned or mixed, set-points)	
Non-conditioned built-up area (m^2 and % of total)	
Conditioned built-up area (m^2 and % of total)	
Description of mechanical ventilation requirements (airflow for ventilation, if relevant)	
APPLIANCES	
Lighting requirements (kind of lighting required)	
Equipment requirement (computers, printers, geysers, ceiling fans, transformers, and any other equipment.)	

Annexure 4.1
Daylight Potential: Autonomy tables for different cities in Karnataka

Section 4.3.1 mentions the need to achieve 75% daylight autonomy. The following figures give the daylight autonomy during the whole year, from 9 a.m. to 6 p.m. for Bengaluru, Belagavi, Vijayapura, and Mangaluru.

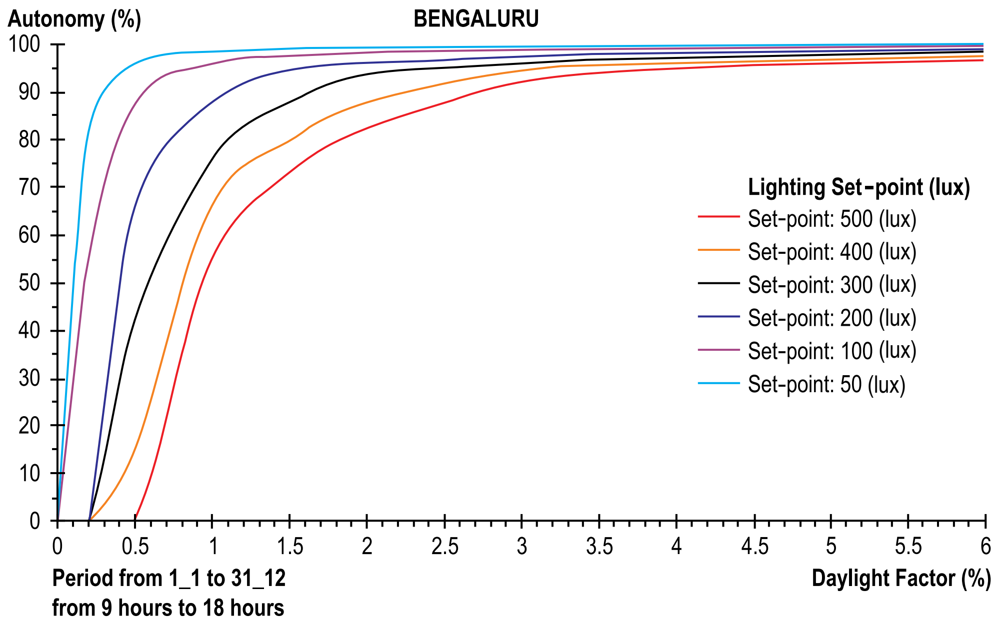

Figure 1 *Daylight autonomy for Bengaluru*

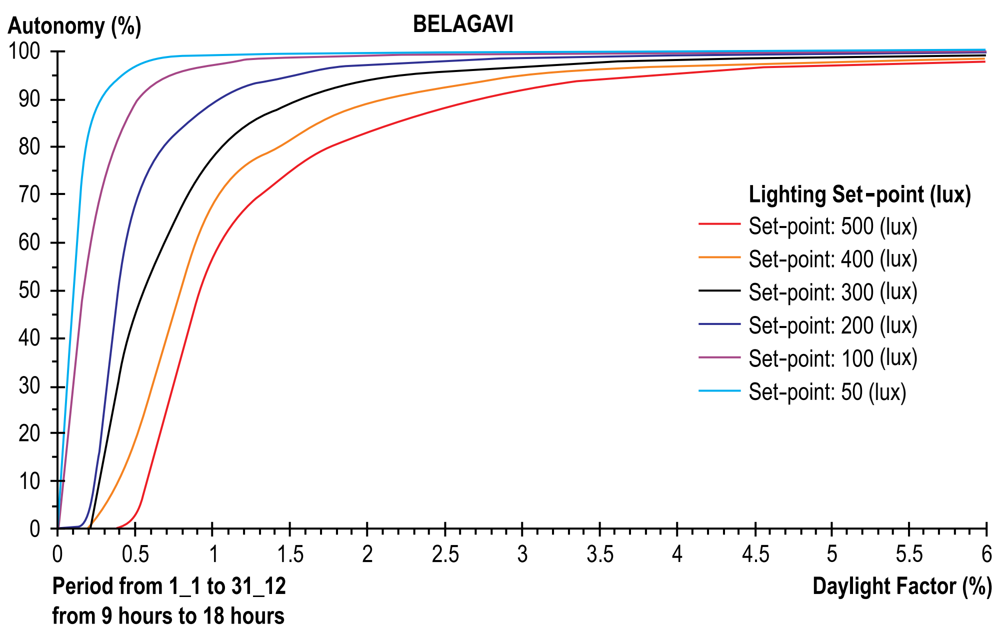

Figure 2 *Daylight autonomy for Belagavi*

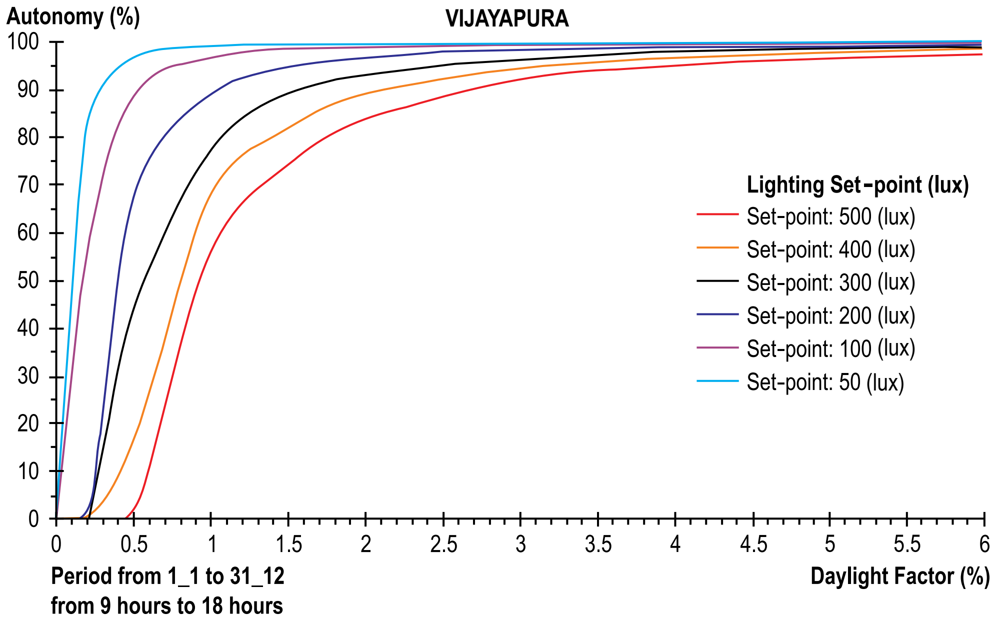

Figure 3 *Daylight autonomy for Vijayapura*[1]

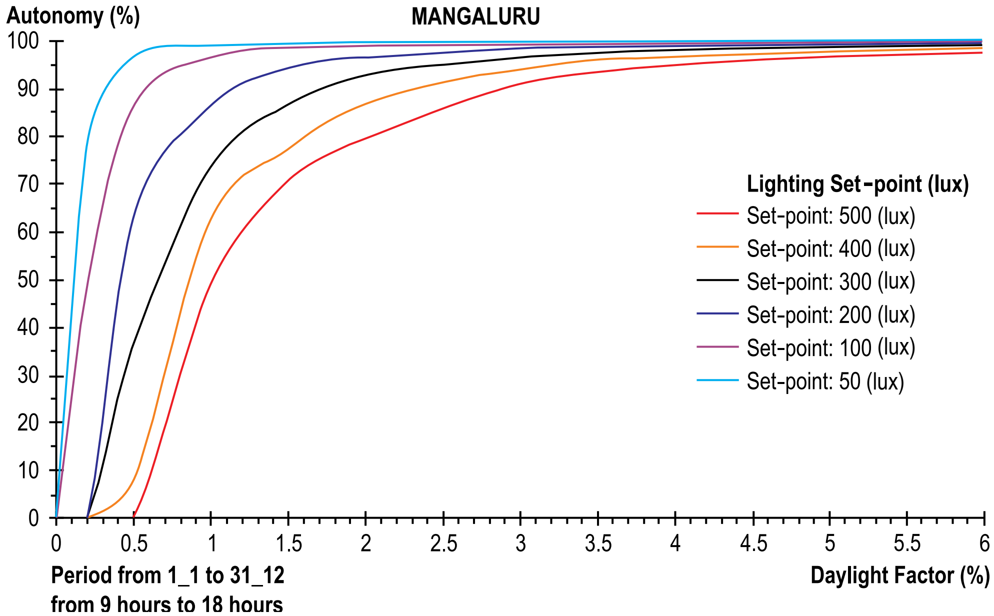

Figure 4 *Daylight autonomy for Mangaluru*

[1] *Since the epw file for Vijayapura is not available, the epw file of Sholapur has been used.*

Annexure 4.2
Efficient Lighting

The lighting design for an office building should be done in steps. These steps include designing for appropriate daylight as mentioned in section 4.3 and then for artifical lighting. The steps to be followed are given below.

Careful lighting design with zoning of spaces

The first step in lighting design is to identify the different zones, which have different requirements in terms of lighting. For example the periphery of a conference room can be fitted with different lighting fixtures because the requirement is different (no reading or writing takes place on the periphery), as shown in the plans below The setpoints, fixtures and controls will be defined according to the planned usage.

Privilege ask lighting

The most pragmatic and efficient approach to lighting, is to privilege task lighting. Overall, a low level of lighting is provided for the working space, and specific task lighting is provided for the desk area. Such solutions are common in offices and libraries or restaurants.

Efficient luminaires

High performance luminaires have a good system performance of each component. These include Compact Fluorescent Lamp (CFL), T-5 tubular fluorescent lamp (BEE 4/5 star label) or Light Emitting Diode (LED) lights. As far as possible, BEE 5 star labelled products should be used.

Controls for artificial lighting

It is important to carefully design the controls, so that the operation is both functional and energy efficient. For example, "daylight sensors" and "occupancy sensors" may be used in places where a lot of people come and go (such as bathrooms and toilets). It should be noted however that the controls for daylight sensors should be used to switch the light off, but the on-switch should be manually controlled, otherwise there will be situations where the light comes on when it is not required (use of computer, projection, unoccupied space)

By implementing the steps above, it is possible to reduce the Lighting Power Density substantially. For public offices in Karnataka, it should be possible to reduce the LPD can be reduced to 8-10 W/m^2.

Annexure 4.3
Calculating Assembly U-factor

To calculate the U-factor of an assembly, an online tool has been developed by the Centre for Advanced Research in Building Science and Energy (CARBSE) at CEPT University. Follow the link to use the tool http://www.carbse.org/resource/tools/.

Register through a simple process on the website, and use the calculator. The weather files for Karnataka are already loaded on the tool. Fill in details of the design and calculate the U-value of either the roof or the wall.

Annexure 4.4
Heat Gains in Different Cases

Section 4.2.1 discusses the effect of building massing on cooling loads. The graphs below (Figure 5–7)show the contribution of heat gain through radiation in windows and conduction through walls and windows for all the three Cases. A summary of these graphs is given in Table 4.1 in Chapter 4.

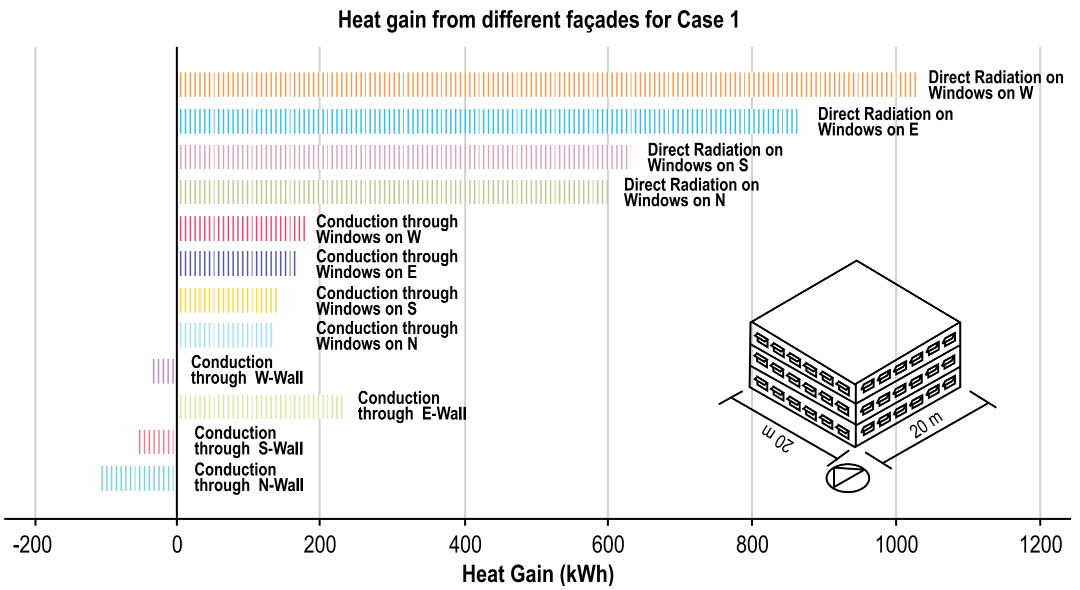

Figure 5 *Heat gain from different façades for Case 1*

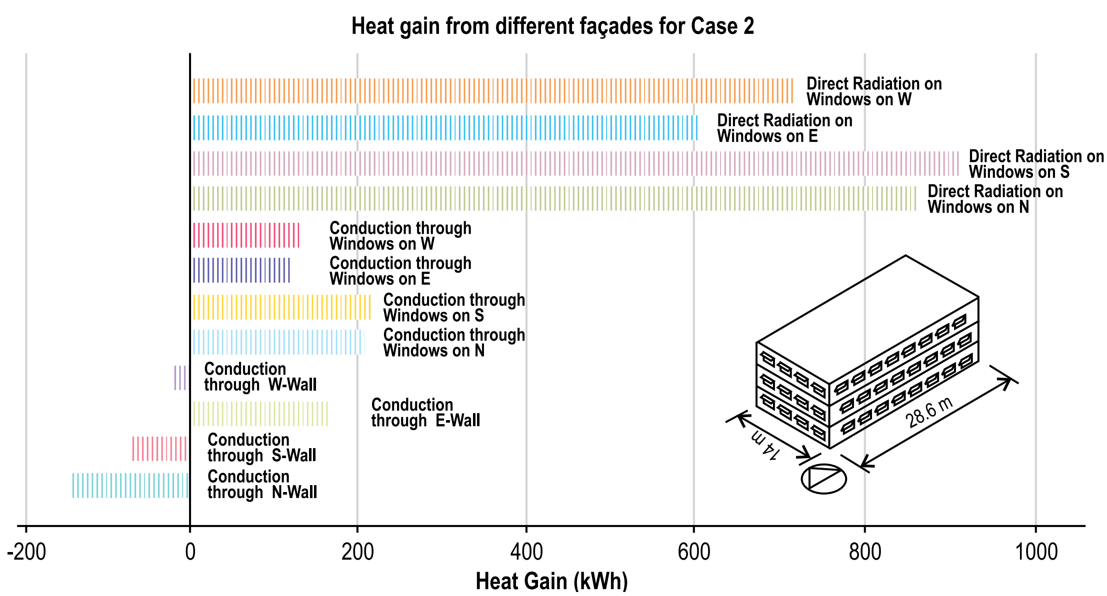

Figure 6 *Heat gain from different façades for Case 2*

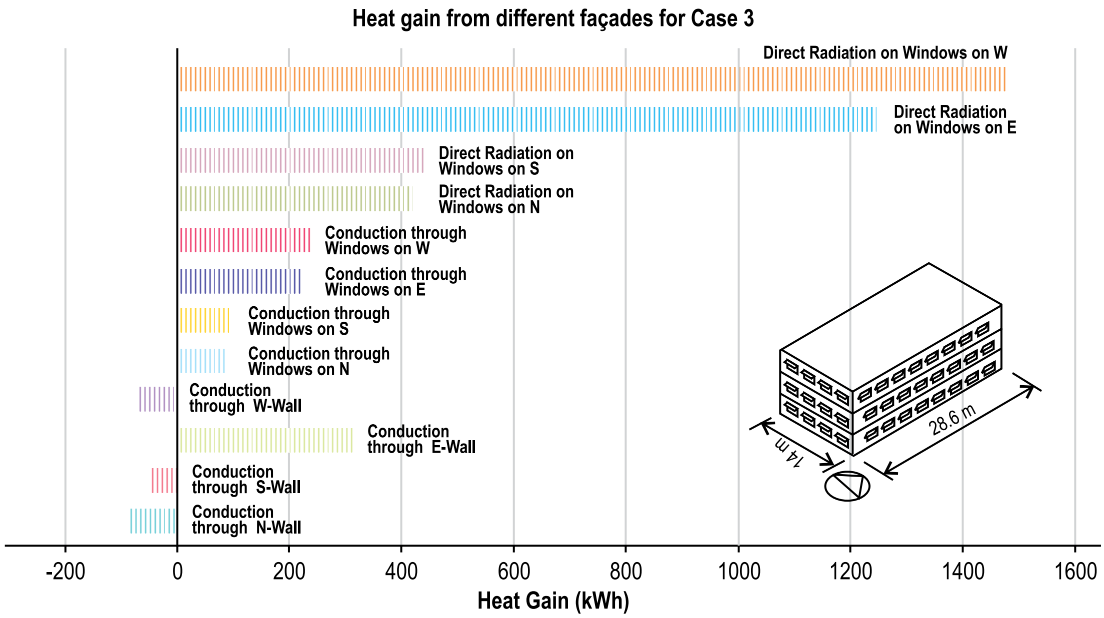

Figure 7 *Heat gain from different façades for Case 3*

Figure 8 and Figure 9 show the heat gain through different building components for the top floor (exposed roof) and for an intermediate floor, respectively. It is clearly seen that the heat gain through the roof is very high. The summary of the analysis is given in Table 4.6 in Chapter 4.

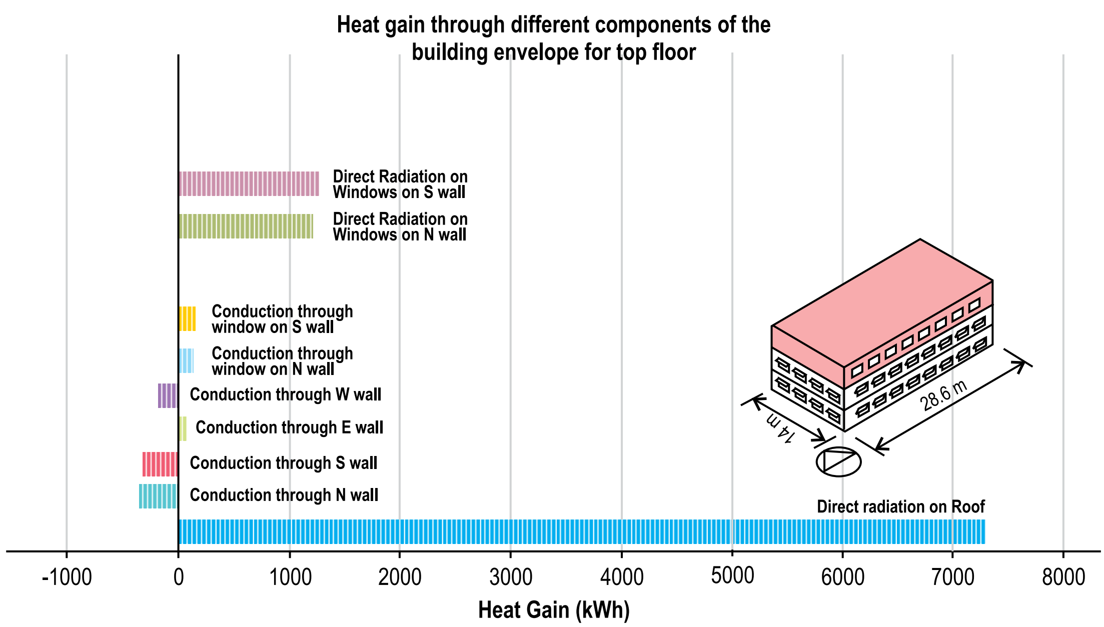

Figure 8 *Heat gain through different components of the building envelope for top floor*

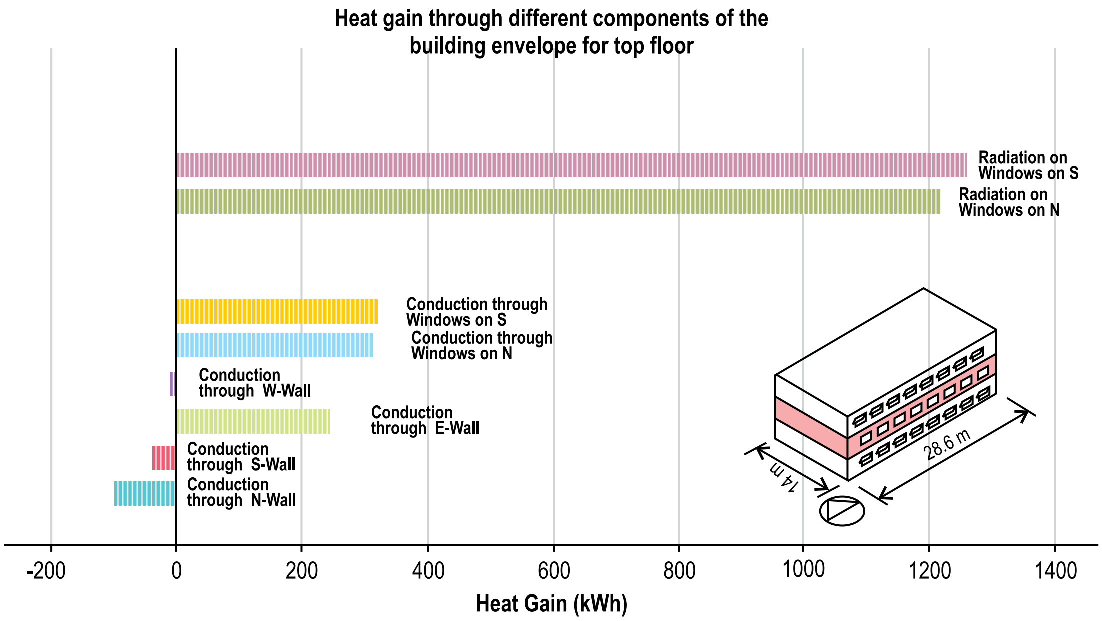

Figure 9 *Heat gain through different components of the building envelope for intermediate floor*

Annexure 4.5
Heat Gain Comparison for Solar Shading

The difference in heat gain for the three cases has been shown in Figure 10, Figure 11, and Figure 12. Case 1 shows heat gain when no external movable shading is used while Case 2 and Case 3 show heat gains when external movable blinds are partially and completely closed. A summary of the three cases is shown in Figure 4.22 in Section 4.6.

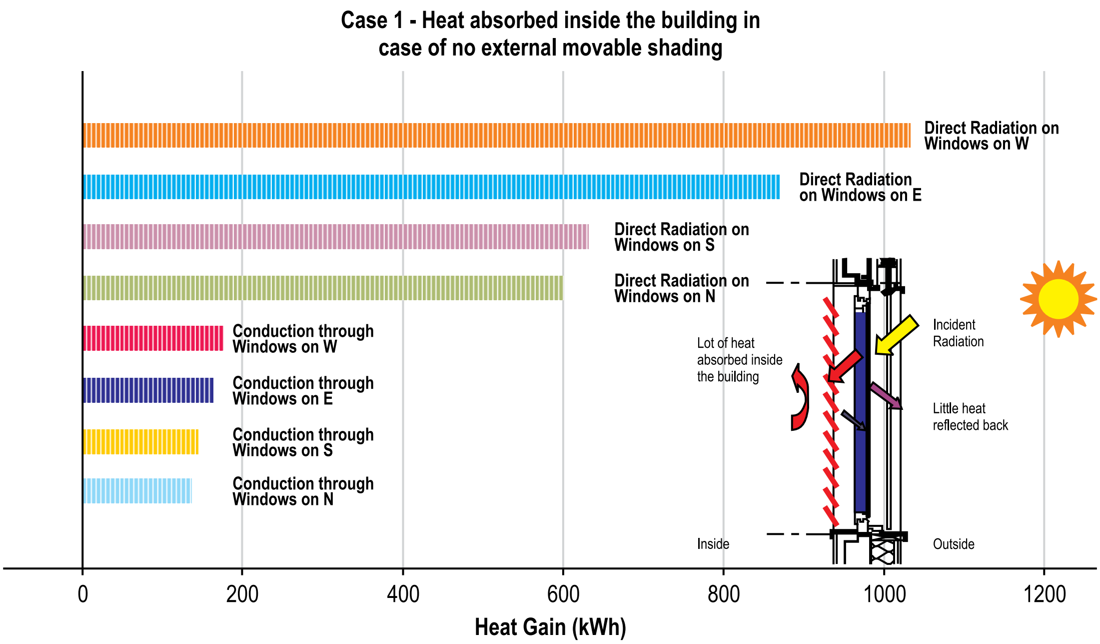

Figure 10 *Case 1 - Heat absorbed inside the building in case of no external movable shading*

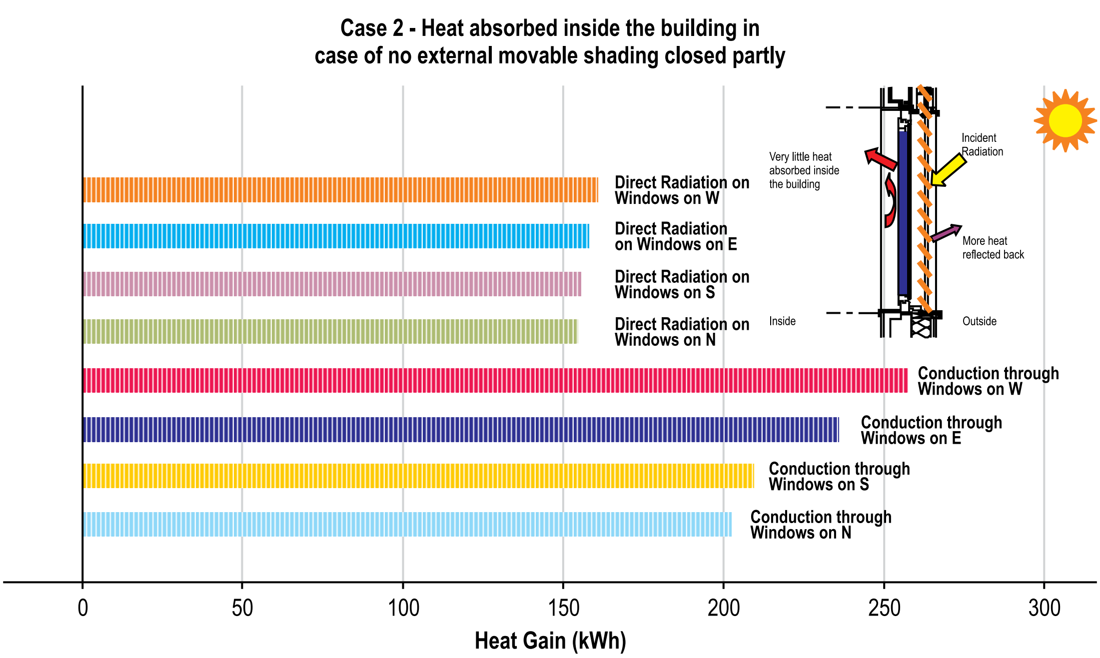

Figure 11 *Case 2 - Heat absorbed inside the building in case of external movable shading closed partly*

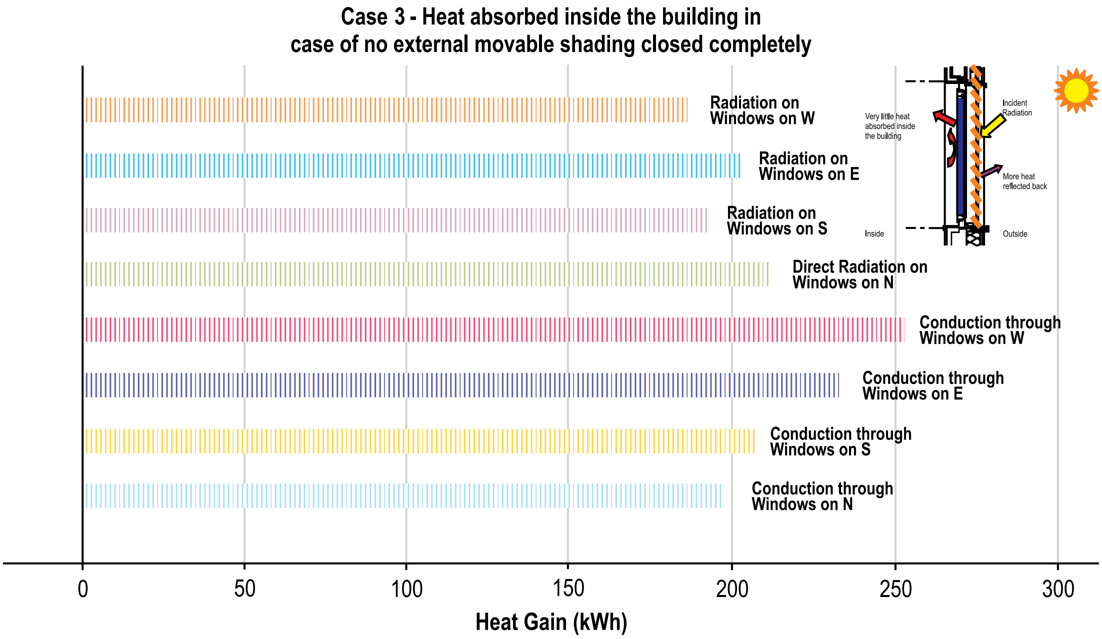

Figure 12 *Case 3 - Heat absorbed inside the building in case of external movable shading closed completely*

Indo-Swiss Building Energy Efficiency Project (BEEP)

The Indo-Swiss Building Energy Efficiency Project (BEEP) is a bilateral cooperation project between the Ministry of Power, Government of India, and the Federal Department of Foreign Affairs (FDFA) acting through the Swiss Agency for Development and Cooperation (SDC). The Bureau of Energy Efficiency (BEE) is the steering agency on behalf of the Ministry of Power, Government of India.

The overall objective of the project 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. The specific objective is to build capacities and knowledge of builders, architects, engineers, labs, institutions and others, in the area of building energy efficiency in India by utilising/adapting Swiss experience and expertise, and by following a multi-stakeholders cooperation process. This 5-year project (2012-16) has the following components:

- Component 1: Design workshops (charrettes) with public / private builders
- Component 2: Technical assistance in developing building material testing infrastructure
- Component 3: Developing design guidelines and tools for the design of energy-efficient residential buildings.
- Component 4: Production and dissemination of knowledge products

The day-to-day implementation of the project would be managed by a project management and technical unit based at Effin'Art Sàrl (Lausanne, Switzerland) and Greentech Knowledge Solutions (New Delhi, India).

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