BEEP
BUILDING ENERGY
EFFICIENCY PROJECT

DESIGN GUIDELINES FOR ENERGY-EFFICIENT MULTI-STOREY RESIDENTIAL BUILDINGS

Warm–Humid Climates

Ministry of
POWER
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Disclaimer

This publication has been developed after an extensive review of all relevant data and documents and in consultation with a number of experts and stakeholders of the building energy sector, both in India and Switzerland. The analysis, interpretations, and recommendations expressed herein do not necessarily reflect the view of the Bureau of Energy Efficiency and the Swiss Agency for Development and Cooperation (SDC). BEE and SDC disclaim liability for any personal injury, property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this document.

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FOREWORD

As India gears up for rapid growth, the pace of urbanization in India is set to accelerate. As per the United Nations World Urbanization Prospects, about 33% of India's population was residing in urban areas in 2015 and this is expected to increase to 50% by 2050 (World Bank Population Estimates). This will lead to large additions to the residential building stock in existing cities as well as creation of several new cities. By the end of this period, the residential sector will emerge as the largest consumer of electricity in the country.

It is important that we prepare well in advance to address the consequential challenges. The solution lies not just in greater and more efficient electricity generation but more importantly in judicious and efficient use of electricity. Electricity savings can be achieved through the incorporation of passive design features into the building design and the proper choice of installation and use of energy-efficient space-cooling systems, appliances, and equipment. The buildings can even become net positive by installing renewable energy systems, such as solar water heating and solar photovoltaic.

There is an urgent need to design residential buildings in a manner in which they are thermally comfortable but require much less energy for their operations. The initiative to develop a comprehensive set of guidelines for designing energy-efficient multi-storey residential building was taken up under the Indo-Swiss Building Energy Efficiency Project (BEEP). The first set of guidelines applicable to composite and hot-dry climatic regions of India was well received and was also listed as one of India's Intended Nationally Determined Contribution (INDC) at the Conference of the Parties (CoP) held in Paris recently.

I am glad that the second set of guidelines for energy-efficient multi-storey residential buildings, which focuses on the warm-humid climatic regions of India, has now been prepared. I urge the agencies involved in the regulation, design, and construction of multi-storey residential buildings in urban areas to make use of these guidelines. I also urge all parties concerned for wider and more effective outreach of these guidelines.

P K Pujari
Secretary, Ministry of Power
Government of India

MESSAGE

India and Switzerland have joined hands to work on an issue that is crucial to meeting both countries' energy-related goals and ambitions. Integration of energy efficiency measures in buildings offers profound benefits of energy savings and carbon dioxide mitigation. The building sector in India is rapidly expanding, which offers immense potential for energy efficiency improvements through design, building material, and the appliances used in buildings. The Government of India gives high importance to this subject. The Energy Conservation Building Code and the Standards and Labelling Programme are essential instruments for meeting these ambitions. However, with the growing building stock in the country, India needs to create a large pool of experts on building energy efficiency and develop the capacity for scaling-up.

Realising the importance of experience sharing and know-how transfer on these matters, the Indo-Swiss Building Energy Efficiency Project (BEEP) was launched in November 2011. BEEP is a bilateral cooperation project between the Ministry of Power (MoP), Government of India, and the Federal Department of Foreign Affairs (FDFA) of the Swiss Confederation. 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.

It gives me immense pleasure in saying that BEEP stands out as a project that has further strengthened the bilateral cooperation between the two nations. The project has brought some of the best available expertise for improving energy efficiency in buildings from Switzerland to India on a single platform. I am convinced that this transfer of know-how, will go a long way in India's quest for more energy security and energy efficiency.

The guidelines for designing energy-efficient multi-storey residential buildings are a key outcome of this cooperation. With the "Smart Cities" and "Housing for All" Missions launched by the Government of India, I believe these guidelines have become more relevant for providing a comfortable environment in houses with less dependence on air conditioning.

I congratulate the entire BEEP team for developing the second set of guidelines, this time for the warm-humid climatic regions of the country. I am sure these guidelines will be a source of knowledge and guidance to the builders, architects, engineers, institutions and all stakeholders of the building sector in India.

Dr Andreas Baum
Ambassador of Switzerland to India and Bhutan

PREFACE

At the Paris climate conference in December 2015, the international community reached a landmark agreement on combating the global threat of climate change. As part of the new international climate regime, countries have pledged commitments towards limiting the average temperature rise to below 2 degrees. One of India's main pledges is to reduce its GDP emissions intensity by 33—35 % by 2030 compared to the 2005 level. In order to achieve this, India announced to be focusing particularly on the building sector. Buildings are already today one of the country's largest energy consumers and will be even more in view of the projected increase in the country's commercial and residential building stock. India therefore plans to make the current regulations for energy conservation measures in commercial buildings more stringent, promote near-zero energy buildings and recognise energy-efficient buildings through rating systems. Furthermore, India intends to set out energy-efficiency minimum standards for new residential buildings.

The residential sector occupies a large share in the total building stock in India. Under a business-as-usual scenario, the growth of the sector alone will result in a large-scale increase of energy consumption. In addition, with rising income levels and people striving for better thermal comfort in their homes through the installation of air-conditioning units, the energy consumption will augment exponentially. Therefore, it is of utmost importance for India to ensure an alternative development trajectory for its residential buildings and to incorporate energy-efficiency measures and best practices systematically in their design.

Through the development of guidelines for energy-efficient design of new multi-storey residential buildings, the Indo-Swiss BEEP is making a major contribution in this regard. The guidelines mean to provide comprehensive information on how to design energy-efficient multi-storey residential buildings. In 2014, BEEP published the first set of guidelines for the composite and hot-dry climatic regions of India. This second set of guidelines is focusing on the warm-humid climate. It recommends 14 measures that are key to an energy-efficient design of residential buildings.

I am convinced the guidelines will again prove to be a useful tool for building sector practitioners and that they will lay the grounds for securing the future energy efficiency of India's residential building sector.

Daniel Ziegerer
Director of Cooperation
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The publication, Design Guidelines for Energy-Efficient Multi-storey Residential Buildings: Warm-Humid Climate, has been developed under the Indo-Swiss Building Energy Efficiency Project (BEEP). This is the second such publication developed under BEEP. The first publication, brought out in 2014, carries design guidelines for composite and hot-dry climates in the country.

This publication draws extensively from the research and experience of Indian and Swiss building experts and practitioners in the design, construction, and operation of energy-efficient homes. I am grateful for the efforts put in by these experts, and would like to acknowledge the contribution of the teams led by Mr Pierre Jaboyedoff from the Swiss side and Dr Sameer Maithel from the Indian side.

Special thanks to the members of the Joint Apex Committee (JAC) and the Joint Implementing Group (JIG) of the Project for their guidance. I am grateful to the Co-Chairs of the JAC – Mr Raj Pal, Economic Adviser, Ministry of Power, Government of India, and Mr Daniel Ziegerer, Director of Cooperation, and Counsellor, Swiss Agency for Development and Cooperation (SDC) for their leadership.

The inputs provided towards implementation of the project work plan by Mr P T Bhutia, Director, Ministry of Power, Government of India, and Dr Anand Shukla, Senior Advisor (Energy), Embassy of Switzerland, as Co-Chairs of the JIG, have been invaluable. I thank them wholeheartedly. The comments and suggestions provided by Mr Prabhakar Singh, Chief Engineer, Central Public Works Department; Dr Arun K Tripathi, Director, Ministry of New and Renewable Energy; and Mr Sanjay Seth, the then Secretary, Bureau of Energy Efficiency (BEE), among many others have helped immensely in shaping this publication. I would also like to acknowledge the contribution of the previous Co-Chairs and members of the JAC and JIG in taking the project forward.

Special thanks to Good Earth Group, Kochi, and Mahindra Lifespaces Developers Ltd, Mumbai, for allowing their projects to be included as case studies in this publication.

There are several 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. I gratefully acknowledge the contribution of each one of them.

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ABBREVIATIONS/ACRONYMS

AAC	autoclaved aerated concrete
AC	alternating current
ACH	air changes per hour
AQL	acceptance quality limit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEE	Bureau of Energy Efficiency
BEEP	Indo-Swiss Building Energy Efficiency Project
BEP	best efficiency point
BIS	Bureau of Indian Standards
CEPT	Centre for Environmental Planning and Technology
CFL	compact fluorescent lamp
CRI	colour rendering index
DC	direct current
DF	daylight factor
DIVA	design, iterate, validate and adapt
EER	energy efficiency ratio
EPI	energy performance index
FTL	fluorescent tube light
GLR	ground-level reservoir
HPMV	high pressure mercury vapour
HPSV	high pressure sodium vapour
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt hour
LED	light emitting diode
LPG	liquefied petroleum gas
LPSV	low pressure sodium vapour
NCR	National Capital Region

ABBREVIATIONS/ACRONYMS

OHR	overhead reservoir
PV	photovoltaic
RCC	reinforced cement concrete
S&L	Standards and Labelling
SAM	System Advisory Model
SHGC	solar heat gain coefficient
SWH	solar water heater
TFL	tubular fluorescent lamp
TRNSYS	TRaNsient SYstems Simulation
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
VFD	variable frequency drive
VLT	visible light transmittance
W	watt
WWR	window-to-wall ratio

CHAPTER 1

INTRODUCTION

1.1 The Context

India is urbanising rapidly. In 2010, about 31% of India's population was residing in urban areas and this is expected to increase to 50% by 2050, adding 441 million to the urban population.[1] Projections based on 2011 census data indicate that the number of urban households is expected to double by 2032.[2] Population increase, economic development, and urbanisation are resulting in an increased demand for constructed built-up area. It is estimated that during the period 2012–47, the residential building stock is expected to see a four-fold increase from 13.4 billion to 53.6 billion m^2 of floor space.[3] Due to scarcity and high cost of land, as well as the desire to curtail suburban sprawl, there is a movement towards multi-storey buildings.

In 2012, residential buildings accounted for 22.9% of India's total electricity consumption, and the electricity consumption in residential buildings is about two times more than that in commercial buildings. Projections done by NITI Aayog show that the electricity consumption in residential buildings is expected to increase ten-fold during the period 2012 to 2047, and the residential sector will become the largest consumer of electricity in the country with a 39% share of the total electricity consumed in 2047.[4]

To understand the energy performance of multi-storey residential buildings, the Indo-Swiss Building Energy Efficiency Project (BEEP) has collected design details and monthly electricity consumption data for flats located in multi-storey building complexes in composite climate National Capital Region (NCR) and warm-humid climate (Chennai). In NCR, this data was collected for about 732 flats.[5] The average energy performance index (EPI), based on electricity bill data for the surveyed flats in 2009, was found to be 48 kWh/m^2.year.[6] In the 417 flats[7] surveyed in Chennai in the same year, the average EPI was found to be 44 kWh/m^2.year. In both the climate zones, about 16% of the surveyed flats were found to have a very high EPI of >70 kWh/m^2.year. The study also showed that fans and air-conditioners consumed the largest share of electricity in multi-storey flats (more details about this study are available in Chapter 2).

The increased use of air-conditioners in residential buildings is one of the main reasons for the rapid increase in the peak energy demand witnessed in several Indian cities. The peak demand in New Delhi has doubled since 2001 and is estimated to again double from

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[1] *United Nations Department of Economic and Social Affairs. 2014. World Urbanisation Prospects: The 2014 Revision. New York: United Nations.*

[2] *Projections done by Greentech Knowledge Solutions based on 2011 census data.*

[3] *Niti Aayog. 2015. India Energy Security Scenarios, http://www.indiaenergy.gov.in/. Accessed: 29 December 2015.*

[4] *Niti Aayog. 2015. A Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030) Using India Energy Security Scenarios, 2047. http://niti.gov.in/mgov_file/Energy_Efficiency.pdf. Accessed: 29 December 2015.*

[5] *Two–three bedroom flats with built-up area ranging from 80 m^2 to 130 m^2.*

[6] *EPI does not include electricity consumption for common services (lifts, common area lighting, water pumping, etc.).*

[7] *Two–three bedroom flats with built-up area ranging from 50 m^2 to 190 m^2.*

current levels by 2021 (Figure 1.1).[8] Recent trends show that the use of air-conditioners in homes begins in early April and continues till September. A recent study estimates that the annual sales of room air-conditioners in India has gone up from 1.7 million per year in 2009 to 6.1 million per year in 2013, or has trebled over five years.[9]

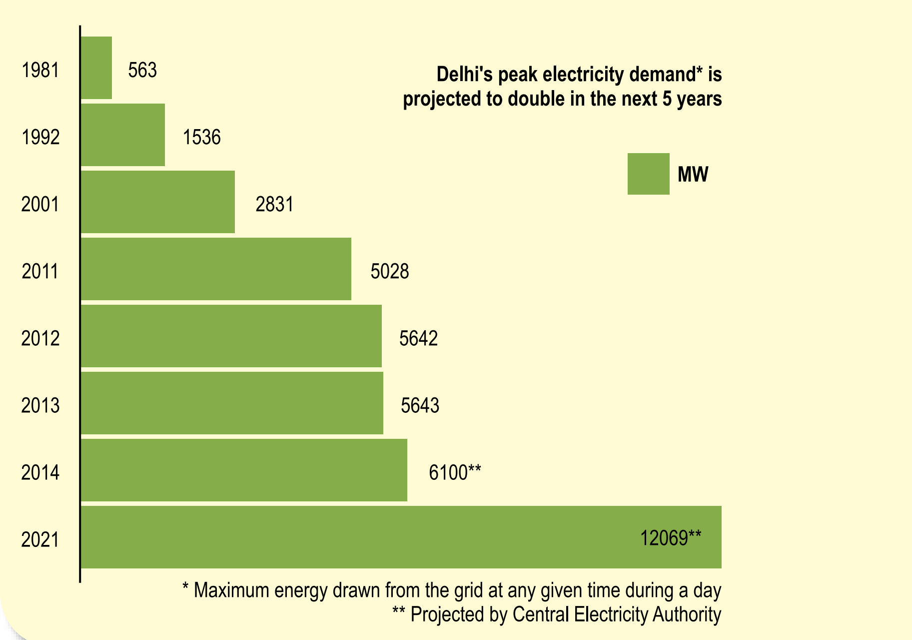

Figure 1.1

Increase in peak electricity demand in New Delhi (1981–2021)

A large potential exists for reducing electricity consumption in multi-storey residential buildings. This is confirmed by initiatives such as the National Housing Bank's Energy Efficient Homes Programme, which provides energy-saving certificates to new residential buildings that need at least 30% less electricity than conventional buildings.[10]

Electricity savings can be achieved primarily by (a) the incorporation of energy-efficiency features into the building architecture and design and (b) installation and proper use of energy-efficient appliances and equipment. The Bureau of Energy Efficiency (BEE) is addressing the issue of energy-efficient appliances through its Standards and Labelling (S&L) programme, which covers 14 appliances and has been made mandatory for eight appliances, namely, frost-free refrigerators, room air-conditioners, tube lights, distribution transformers, storage type electric water heaters, colour television, direct cool refrigerators and room air conditioners (Cassette, Floor Standing Tower, Ceiling, Corner AC). However, currently, there is no legal framework that addresses the design of energy-efficient multi-storey residential buildings in a comprehensive manner.

1.2 Objective

The objective of these design guidelines is to provide comprehensive information on how to design energy-efficient multi-storey residential buildings. The guidelines take into account

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[8] *http://www.downtoearth.org.in/content/city-trapped-solar-oven. Accessed on 23 January 2016.*

[9] *Lawrence Berkeley National Laboratory. 2013. Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners. Berkeley, CA: Lawrence Berkeley National Laboratory.*

[10] *https://ee-homes.com/. Accessed on 23 January 2016.*

different climatic conditions prevailing in the country, and this edition of the guideline document is applicable to the warm-humid regions of India.

The guidelines were developed for agencies/persons involved in the regulation, design, and construction of multi-storey residential buildings in urban areas, such as private and government-sector developers and builders, architects and other design professionals, and urban local bodies. While these guidelines are meant primarily for building designers and developers, they would be of interest to home buyers, home occupants, and users too. A programme of dissemination to raise the level of awareness and demand from consumers would be a necessary complement to these guidelines.

1.3 Warm-Humid Climate Zone

The National Building Code of India (NBC) 2005 has divided the country into five climatic zones. It classifies the warm and humid climate zones with the following temperature and relative humidity:

- mean monthly maximum temperature above 30 °C and relative humidity above 55%
- mean monthly maximum temperature above 25 °C and relative humidity above 75%.

Geographically, the warm-humid climate zone (Figure 1.2) covers:

- coastal India,
- 300–400 km inland of the coast, which covers most of southern India, and
- large part of North-east India.

The Energy Conservation Building Code (ECBC) 2007 follows the climate classification by NBC. An overview of the climates of five cities in this climate zone, namely, Mumbai, Chennai, Kolkata, Pune,[11] and Guwahati is provided in Figures 1.3 to 1.6. This climate data is a long-term average measured data for major Indian cities prepared by the Indian Society of Heating, Refrigerating, and Air Conditioning (ISHRAE). This data is available in .epw format on the website of the US Department of Energy <https://energyplus.net/weather-region/asia_wmo_region_2/IND%20%20>. The graphs in the figures provide information on monthly average values for temperature, relative humidity, and wind speed. It is observed that there are significant variations in the climate within the warm-humid zone; these variations are primarily due to factors such as distance from sea, latitude, altitude, and occurrence of monsoon. The main climate parameters for these five cities are explained in the following sections.

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[11] *Currently, ECBC classifies Pune in the warm-humid climate. However, a decision has been taken recently to classify Pune in the composite climate, which will be notified with the Maharashtra state energy conservation code.*

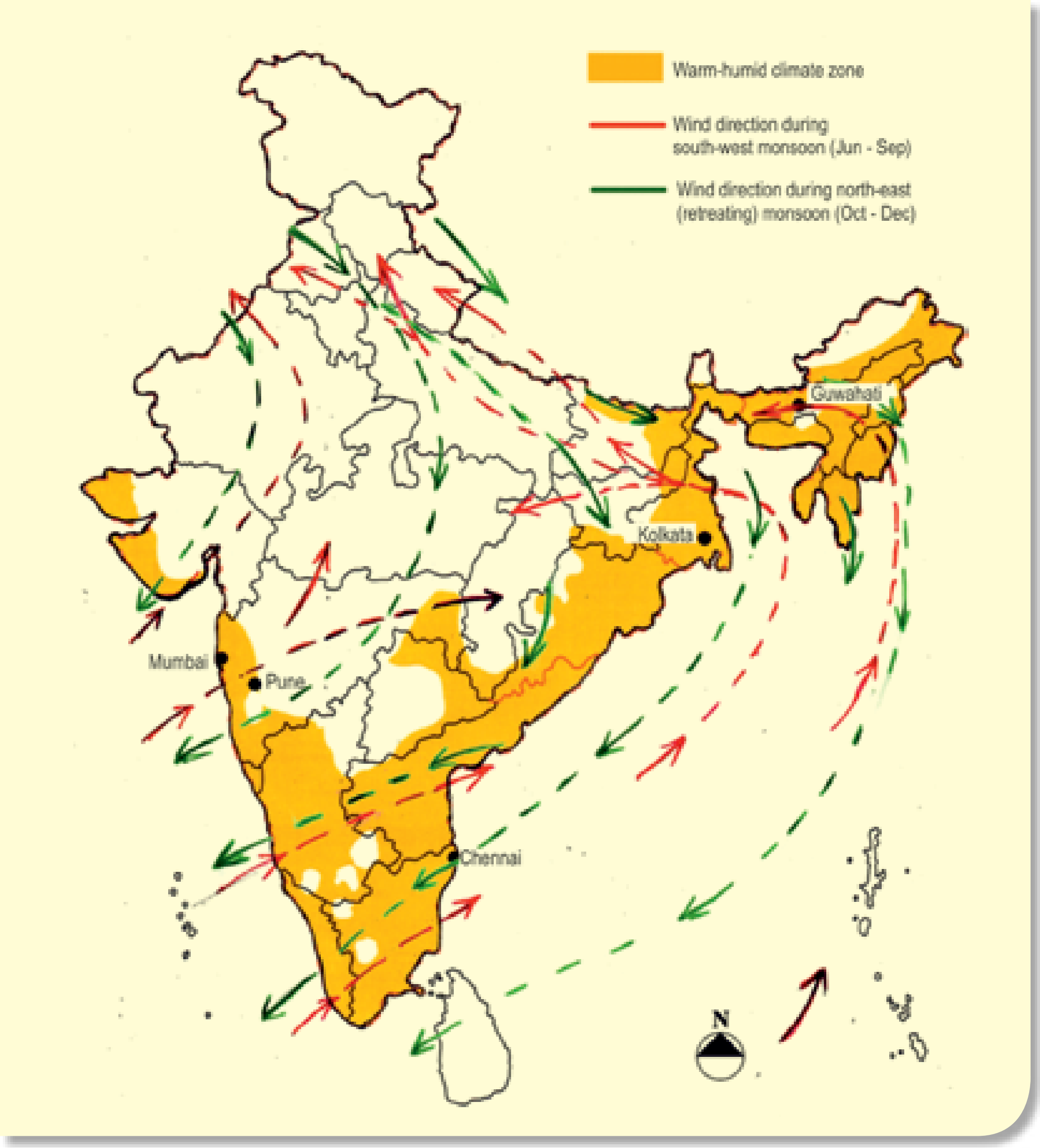

Figure 1.2 *Map showing the geographical extent of warm-humid climate zone in India with the predominant monsoon wind directions*

1.3.1 Temperature

Figures 1.3 and 1.4 show the respective monthly average of daily maximum temperature and monthly average of daily minimum temperature in the five cities. In summer (April–September), the maximum temperatures during the day range from 27 °C to 37 °C and the minimum temperatures during the night vary from 20 °C to 28 °C. In winter (November–February), the maximum temperatures during the day range from 22 °C to 33 °C and the minimum temperatures during the night vary from 11 °C to 22 °C. The diurnal range in this zone is not high.

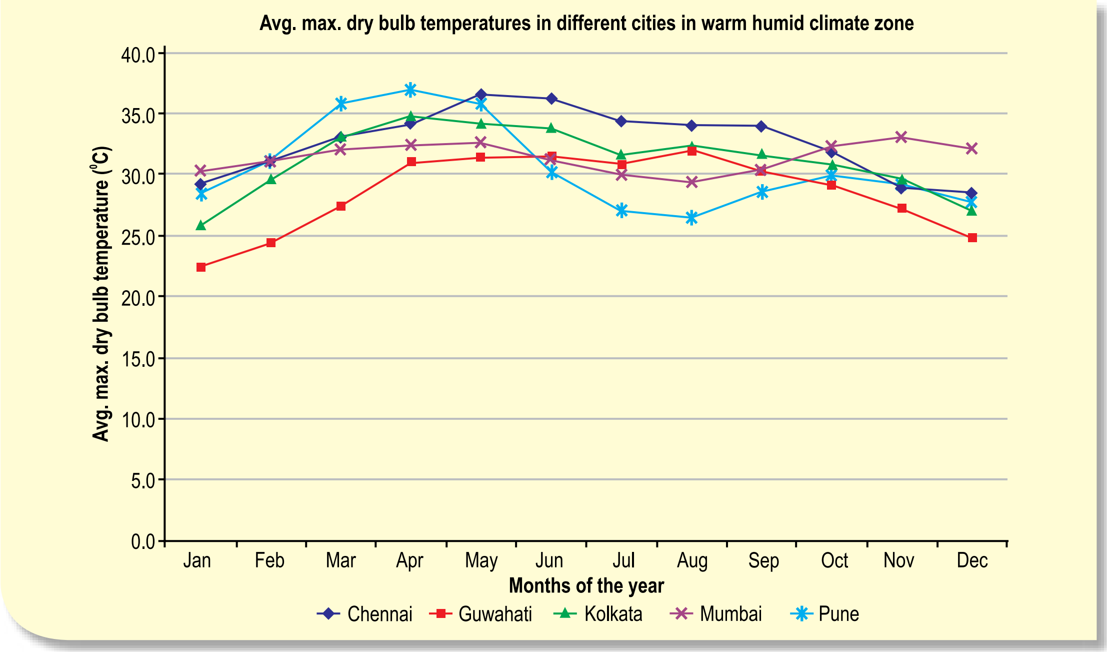

Figure 1.3 Monthly average of daily maximum temperature, in selected cities in the warm-humid climate zone

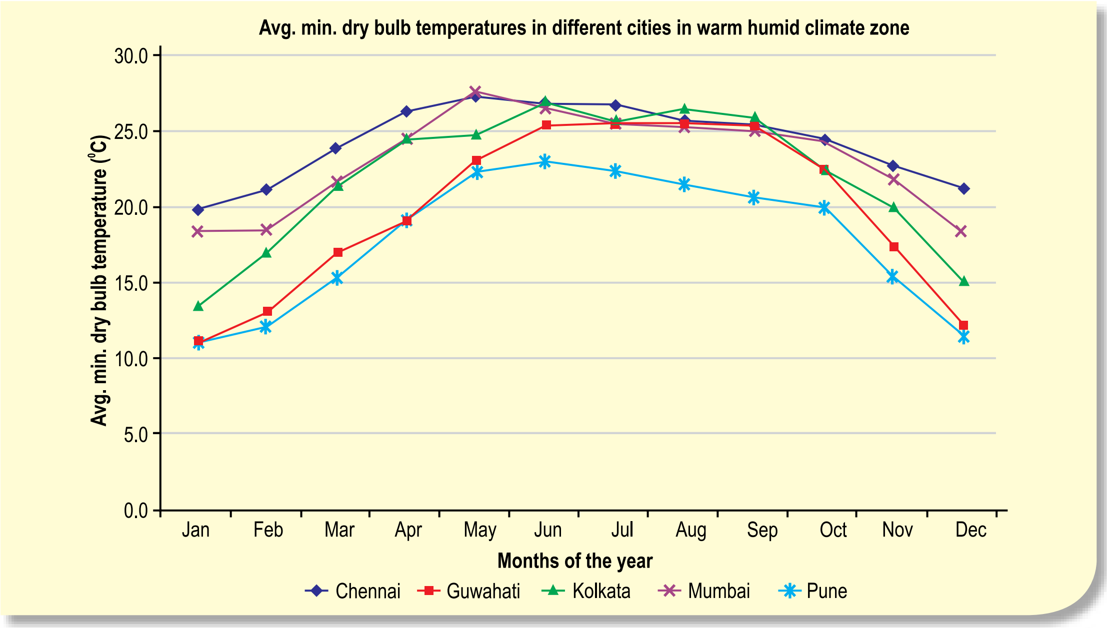

Figure 1.4 Monthly average of daily minimum temperature, in selected cities in the warm-humid climate zone

1.3.2 Relative Humidity

Figure 1.5 shows the average monthly relative humidity for the five cities. The average monthly relative humidity in this climatic zone generally remains high (60%–90%) throughout the year. This causes high discomfort even though temperatures are not excessive most

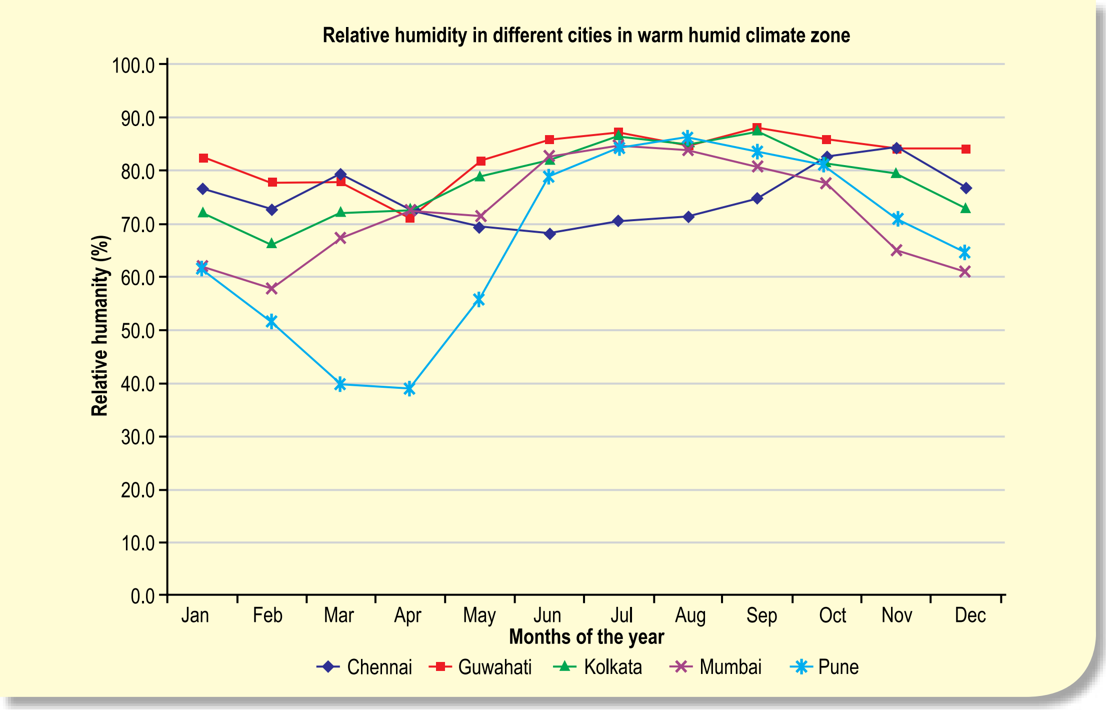

Figure 1.5 *Average relative humidity in selected cities in the warm-humid climate zone*

of the times. Some inland cities (e.g., Pune) have a dry period in early summer when the average monthly relative humidity is below 50%.

Variations in relative humidity are also observed with the occurrence of monsoon. As can be seen, all the cities studied, except Chennai, show increasing relative humidity between June and September when the south-west monsoon occurs. Chennai receives most of its rainfall during the north-east (retreating) monsoon between October and December, showing corresponding rise in humidity.

1.3.3 Wind

India's climate is heavily influenced by the monsoon winds. At the macro-level, there are two predominant wind directions: south-west to north-east from June to September and north-east to south-west from October to December (Figure 1.2). However, factors such as physical features, distance from the sea, and temperature affect the wind characteristics significantly. For example, coastal areas show diurnal occurrences of sea and land breezes at different times of the year depending on the temperature difference over land and sea.

Figure 1.6 shows the average monthly wind speeds. The wind speeds in coastal cities such as Mumbai and Chennai are higher and range mostly between 1.5 m/s and 3.5 m/s. In cities that are situated inland, such as Pune, Guwahati, and Kolkata, the wind speeds are lower and vary mostly between 0.5 m/s and 2.0 m/s. In most cities, the highest wind speeds are

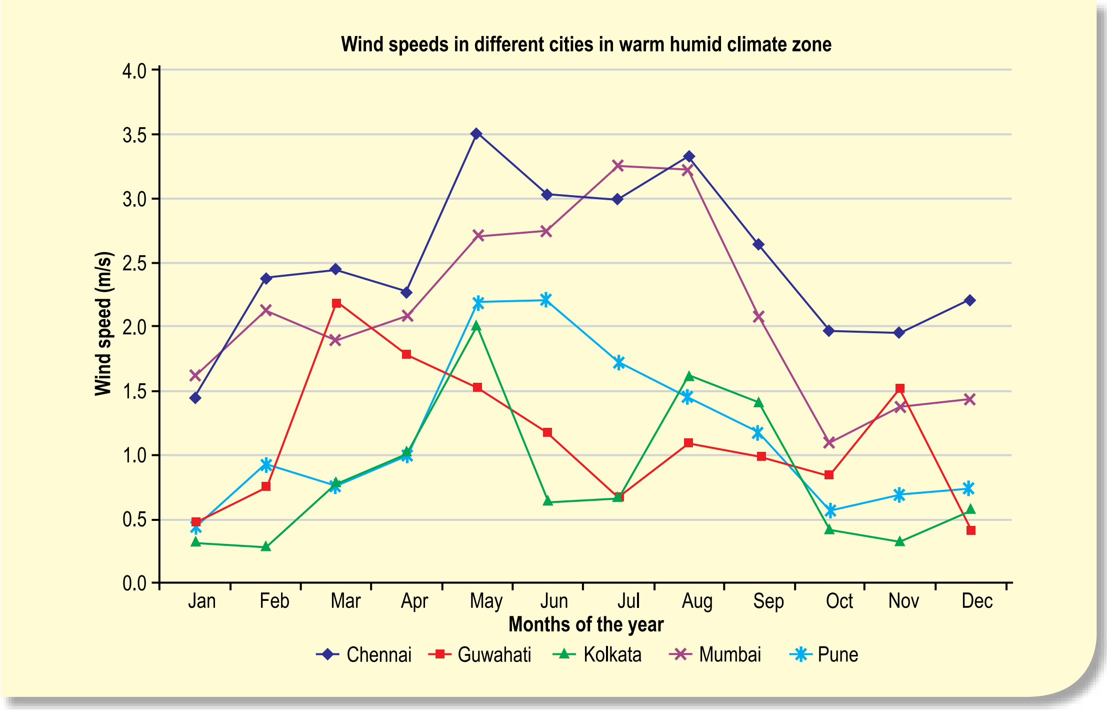

Figure 1.6 *Average wind speeds in selected cities in the warm-humid climate zone*

observed during May to August. Wind has an influence on the natural ventilation strategies, as will be explained in subsequent chapters.

1.3.4 Solar Radiation

Figure 1.7 shows the average monthly global horizontal irradiance (GHI) in kWh/m^2/day.[12] It is observed that all the cities receive high solar radiation with monthly averages ranging mostly between 4 kWh/m^2/day and 7 kWh/m^2/day. The regions located near the equator, such as Chennai (latitude of 13.08° N), receive far greater solar radiation compared to regions located farther from the equator, such as Guwahati (latitude of 26.18° N). The highest solar radiation is received during March to May. This decreases considerably during the monsoon season of the location. Diffused solar radiation is higher in this climate zone due to the cloud cover.

1.4 Methodology

The methodology followed for the development of the guidelines is shown in Figure 1.8. The first step was to collect design and electricity consumption data from sample residential buildings. This was followed by the development and validation of energy simulation models, and evaluation of different design strategies using these models. The guidelines were formulated based on the results of the simulation studies and in consultation with

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[12] *http://mnre.gov.in/sec/GHI_Data.xls. Accessed on 23 January 2016.*

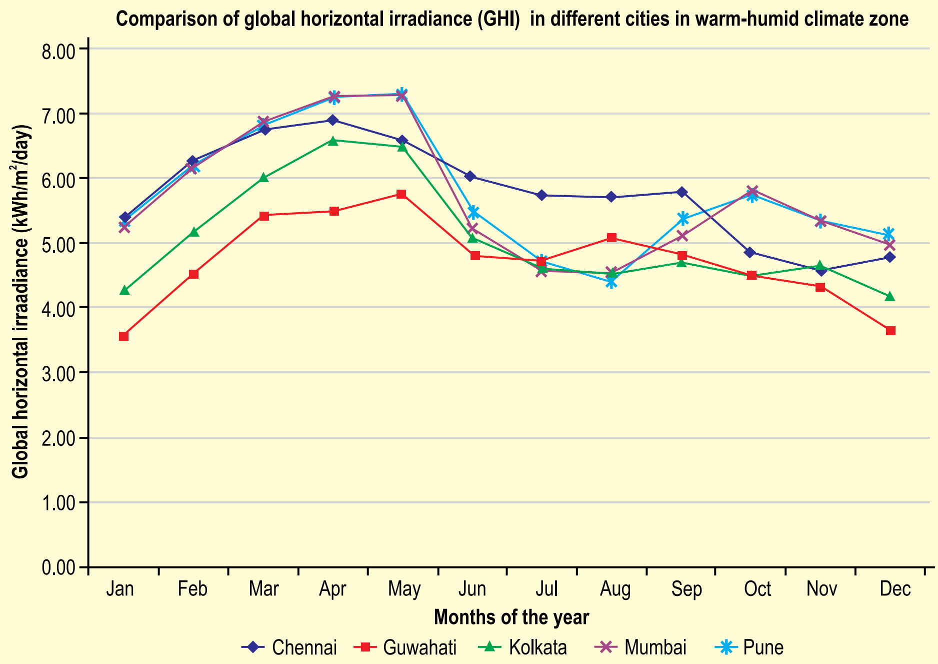

Figure 1.7 *Average GHI in selected cities in the warm-humid climate zone*

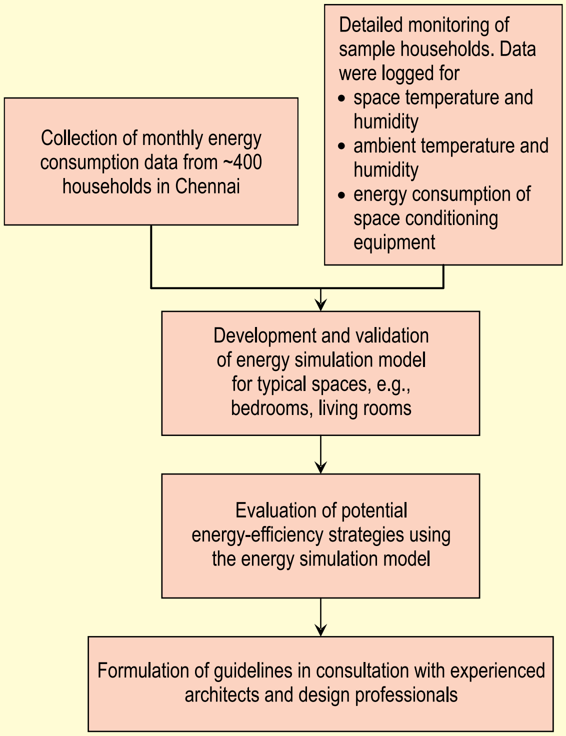

Figure 1.8
Methodology followed for developing design guidelines

experienced architects and design professionals. A variety of simulation tools have been used for analysis, such as TRNSYS for energy performance, DIVA for environmental analysis, RELUXPro for daylighting, RETScreen for solar water heaters, and SAM for solar photovoltaic (PV).

The results from energy simulation models have been used to quantify energy savings from the recommended energy-efficiency strategies and are presented in six sections: (a) building massing and spatial configuration, (b) building envelope, (c) building space cooling, (d) appliances, (e) common services, and (f) integration of renewable energy.

1.5 Organisation of the Design Guideline

The remaining content of this design guideline is organised as follows.

Chapter 2, Survey and Monitoring of Electricity Consumption, deals with the results of the survey and monitoring campaigns to monitor electricity consumption in flats located in sample multi-storey residential buildings. It also compares the results with other similar studies conducted in India.

Chapter 3, Building Massing and Spatial Configuration, discusses the results of the analysis of the impact of building shape and orientation on the solar radiation exposure on walls and wind flow analysis in a building complex.

Chapter 4, Building Envelope, presents the results of the thermal performance and daylighting analysis of typical spaces such as bedrooms and living rooms. It discusses the impact of various building envelope features, such as window-to-wall ratio, wall insulation, external finish of the wall, window design, and shading systems, on the thermal performance and daylighting of the building, and provides recommendations from an energy-efficiency perspective.

Chapter 5, Space Cooling, discusses ventilation, both natural and mechanical (ceiling fans), and the application of various types of air-conditioning systems to achieve thermal comfort and energy efficiency.

Chapter 6, Appliances, provides information and recommendations on the choice of appliances based on BEE star labelling programme.

Chapter 7, Common Services, offers an overview of electricity consumption in common services in typical multi-storey residential buildings. It provides general recommendations for energy efficiency for lighting of common areas, lifts, and water pumping.

Chapter 8, Renewable Energy Integration, discusses the design and sizing issues for rooftop solar water heaters and solar PV systems for generating energy.

The annexures provided at the end of the document give supporting information and analysis results.

CHAPTER 2

SURVEY AND MONITORING OF ELECTRICITY CONSUMPTION

2.1 Introduction

Inside residential buildings, electricity is primarily used for operating:

- indoor lights;
- space-conditioning equipment such as fans and air-conditioners;
- appliances such as televisions, computers, refrigerators, mixers, microwaves, and washing machines; and
- water heaters.

Electricity is also required outside a flat for the operation of common services utilities such as water pumps, lifts, underground parking, and outdoor lights.

When the development of these design guidelines began, the project team realised that data for computing the energy performance index (EPI)[1] of different types of multi-storey residential buildings were unavailable. Similarly, there was scarce literature that could provide insights on end-use electricity distribution in urban households and the influence of building design on electricity consumption. In 2009, during the preparation phase that preceded BEEP (Building Energy Efficiency Project), a survey was conducted to collect monthly electricity consumption data from a sample of residential units located in multi-storey residential complexes in Chennai.

Subsequent to the survey, detailed monitoring of temperature and humidity in the indoor spaces of two sample residential units, along with electricity consumption for appliances, was carried out in Chennai over a period of about one year.

The results of the survey and the monitoring exercise are presented in this chapter. As these results are based on a small sample, they should not be taken as the baseline data on EPI or electricity consumption for multi-storey residential buildings in India. However, the results do help in developing a better understanding of the current usage pattern of electricity, particularly for space conditioning. This understanding aided the development of the design guidelines explained in the subsequent chapters.

2.2 Methodology of the Survey and Monitoring

2.2.1 Survey

Electricity consumption data (in the form of monthly electricity bills) for the duration of one year (2009) were collected from 417 residential units from six residential complexes in Chennai (representing warm-humid climate). The selected residential complexes were

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[1] *Energy performance index (EPI) is defined in terms of annual purchased electricity (in kWh) divided by the built-up area (in m^2) of the flat. The area considered in the study includes the covered area of the flat and does not include balcony, shafts, semi-covered areas, and common areas like lifts and lobbies. The electricity used for common area services (like lifts, common area lighting, and water pumping) is excluded from the EPI calculation.*

multi-storey apartment buildings of 3 to 15 storeys, with a built-up area of the individual residential units ranging from 50 m^2 to 220 m^2. The residential units had one, two, or three bedrooms, a living room, and a kitchen. Apart from the electricity consumption data, architectural plans and construction details were collected for these buildings.

A mathematical model was used to filter monthly electricity consumption data. After data filtering, 86% of the data was selected for further analysis. The data were then statistically analysed to assess EPI distribution, monthly electricity consumption profiles, and electricity consumption for space conditioning.

Figure 2.1 shows the average monthly electricity consumption data for surveyed households. The average electricity consumption varies from 220 units to 430 units per month. The average electricity consumption during the peak summer month (June) is almost twice that of the peak winter month (January).

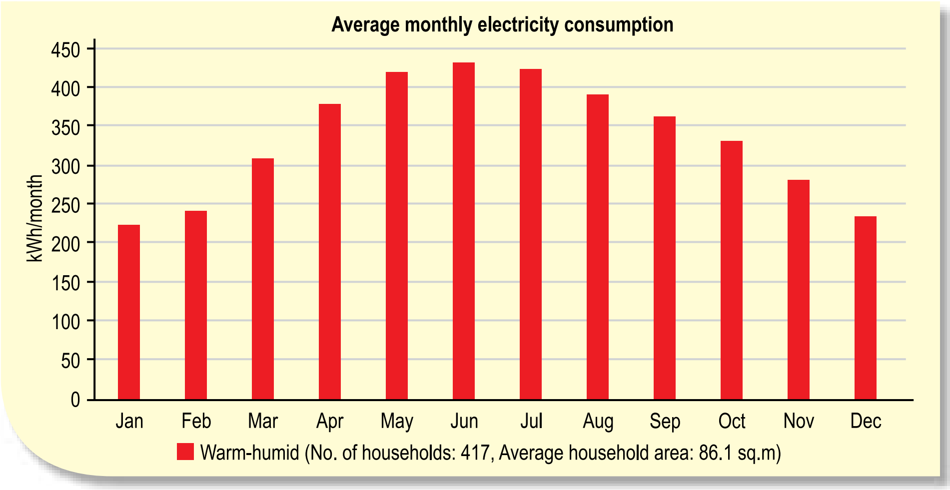

Figure 2.1 *Average monthly energy consumption profiles*

Similarly, monthly electricity data for the duration of one year (2009) were also collected from 732 residential units from four residential complexes in Delhi-NCR (representing composite climate). Figure 2.2 shows a comparative profile of the average monthly electricity consumption of surveyed residential units in the warm-humid and composite climates. The monthly electricity consumption for the residential complex in composite climate shows a steep increase in energy consumption during the summer and monsoon months (May–August). This can be attributed to the operation of air-conditioners for attaining thermal comfort in the occupied spaces. February and March can be considered as the base months, when the need for comfort cooling and comfort heating is minimal.

The monthly electricity consumption for the residential complex in warm-humid climate shows a flatter profile, with the peak appearing from May to July. December and January

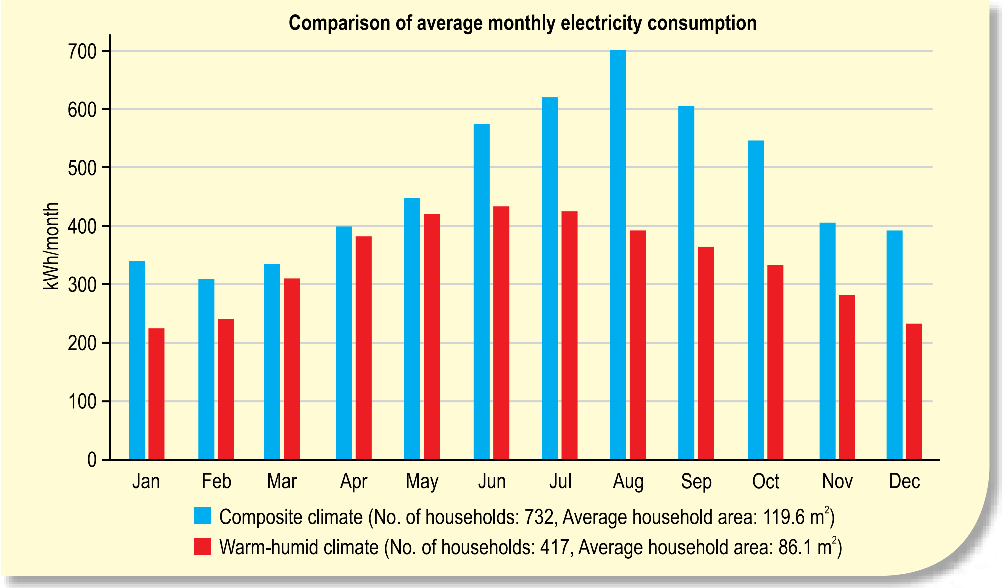

Figure 2.2 *Average monthly energy consumption profiles of residential complexes in composite and warm-humid climates*

can be considered as the base months when the requirement for space comfort cooling is minimal. The reduced amplitude of average monthly electricity consumption during the summer months in warm-humid climate compared to that of composite climate may be attributed to the late evening sea breeze providing natural ventilation and the use of ceiling fans for space conditioning.

2.2.2 Monitoring

Subsequent to the collection of monthly electricity data, a monitoring campaign was carried out in two residential units in Chennai. The monitoring included discrete logging of space and ambient hygro-thermal conditions and monitoring electricity consumption of space-conditioning equipment. The instruments used for monitoring are shown in Figure 2.3.

The monitored data for temperature, humidity, space-conditioning equipment of the sample residential units, along with their electricity consumption data, were used to define inputs and to validate outputs of the energy simulation models (developed in TRNSYS[2]) for bedrooms, living rooms, and other spaces.

2.3 Survey results

2.3.1 Energy performance index

The average EPI, based on data collected from 417 residential units for 2009 in the warm-humid climate, is calculated as 44 kWh/m^2.year (Figure 2.4). The EPI does not include the

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[2] *TRaNsientSYstems Simulation (TRNSYS) is a robust and validated tool used for building energy simulation modelling.*

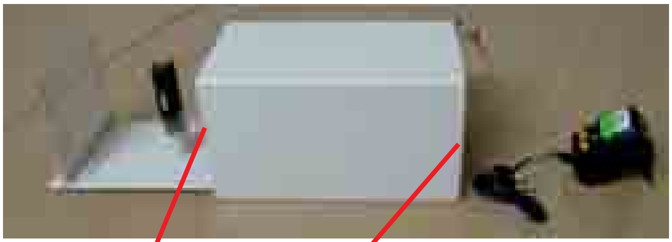

Figure 2.3a *Temperature humidity logger assembly for monitoring ambient conditions*

Figure 2.3b *Energy logger for monitoring electricity consumption of room ceiling fan*

Figure 2.3c *Energy loggers for monitoring electricity consumption of air-conditioners and geysers*

electricity consumption for common services. The EPI distribution (Figure 2.5) shows that almost 16% of the residential units have an EPI greater than 70 kWh/m².year. Most of these residential units have three or more air-conditioners and, hence, can be considered to represent the case when most of the frequently used spaces inside a flat have provision of air-conditioning. As Figure 2.5 shows, 52% households have an EPI less than 40 kWh/m².year (below average), which may be attributed to the predominant use of natural ventilation and ceiling fans during substantial time of the year. Figure 2.6 shows that the average EPI of residential units increases when the number of air-conditioners owned increases. A recent study conducted by CEPT (Centre for Environmental Planning and Technology) University, Ahmedabad,[3] reported an average EPI of 54 kWh/m².year, based on the data collected from 188 sample residential units in Mumbai for the year 2013.

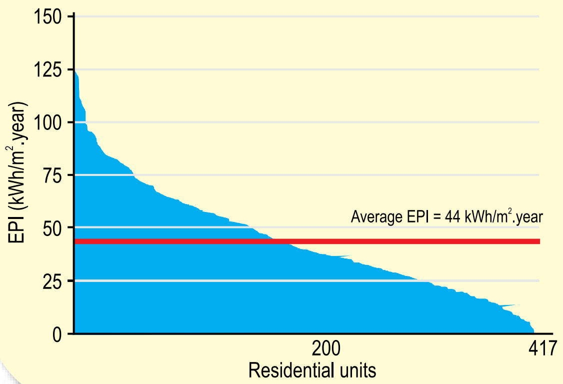

Figure 2.4 *EPI distribution of residential units in the warm-humid climatic region*

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[3] *Rawal R. and Shukla Y. 2014 (in press). Residential Energy Baseline Study for India. Paris: Global Buildings Performance Network.*

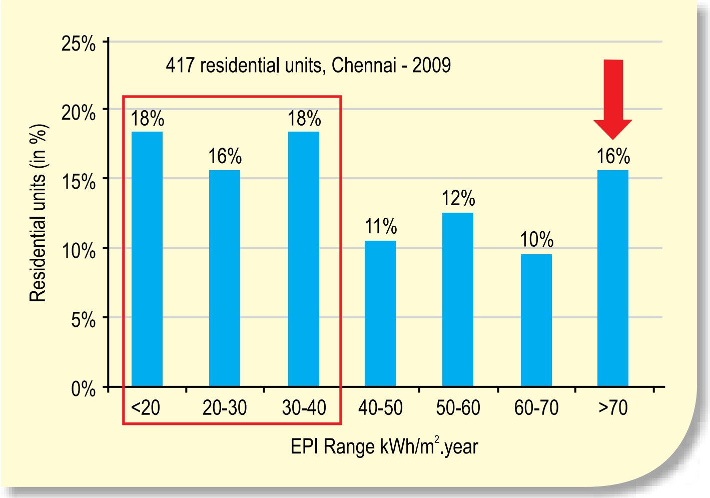

Figure 2.5 *EPI range distribution for residential units in warm-humid climate*

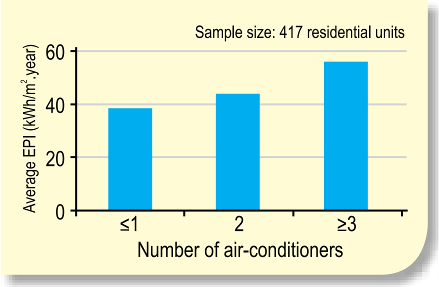

Figure 2.6 *Distribution of average EPI with respect to air-conditioner ownership*

2.3.2 Seasonal Variation and Electricity Used for Space Conditioning

For the purpose of analysis, three flats having different EPIs were selected in a single residential complex in Chennai. All these flats were of similar size (70 m^2),[4] layout (two bedrooms, living room, and kitchen), and orientation.

- Flat A had an EPI of 45 kWh/m^2.year (near average EPI): For this flat, discrete monitoring of space and ambient hygro-thermal conditions and of electricity consumption by space-conditioning equipment was conducted. There were two occupants and both of them were working professionals when the monitoring was conducted. The flat was equipped with three air-conditioners fitted in the two bedrooms and living room, respectively.
- Flat B had an EPI of 67 kWh/m^2.year (above average EPI): There were four occupants. The residential unit was equipped with three air-conditioners.
- Flat C had an EPI of 95 kWh/m^2.year (high EPI): There were five occupants. The residential unit was equipped with three air-conditioners.

An analysis of these flats is provided below (Figures 2.7 and 2.8).

Figure 2.7 plots the total annual electricity consumption of Flat A (3168 kWh) and the percentage contribution of electricity consumption for space conditioning (space-cooling equipment and fans). The monitored data shows that 46% of the annual electricity consumption is attributed to the operation of equipment for space cooling and fans. Ceiling fans were used throughout the year as the primary means for attaining thermal comfort by the occupants. The remaining 54% of electricity was consumed

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[4] *The area considered in the study includes the covered area of the flat and does not include balcony, shafts, semi-covered areas, and common areas like lifts and lobbies.*

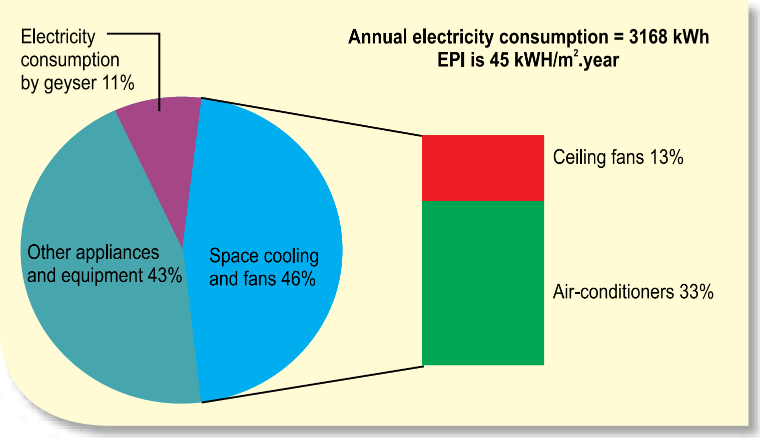

Figure 2.7 *Electricity consumption break-up of monitored residential unit (Flat A)*

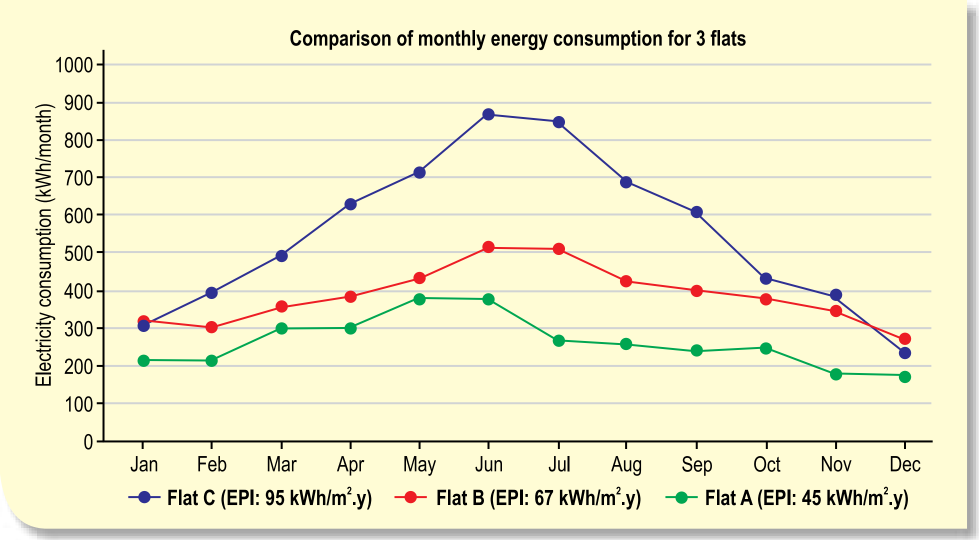

Figure 2.8 *Monthly electricity consumption profiles of three residential units*

by refrigerator, lighting equipment, washing machine, electric geysers, kitchen appliances, television, computers, etc.

Figure 2.8 shows the monthly electricity consumption for Flats A, B, and C. Electricity consumption for space cooling and fans was calculated as 36% for Flat B and 60% for Flat C of the total annual electricity consumption.

2.3.3 Electricity Use for Common Services[5]

Data collected from a multi-storey residential complex (seven storeys, 90 flats) in Delhi show that the electricity consumed for the three common services (lifts, common area lighting,

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[5] *Although the reported data of this section were collected from a residential complex in Delhi, the information will be applicable to most multi-storey residential complexes in India. The intent of this section is to understand the broad conclusions on electricity consumption in common services in multi-storey residential complexes.*

and water pumping) was around 16% of the total annual electricity consumption of the complex (Figure 2.9). Further breakdown of the common area electricity consumption (Figure 2.10) shows that electricity consumption in lifts was the largest (62%), followed by lighting of common areas (21%), and pumping water to overhead tanks (17%).

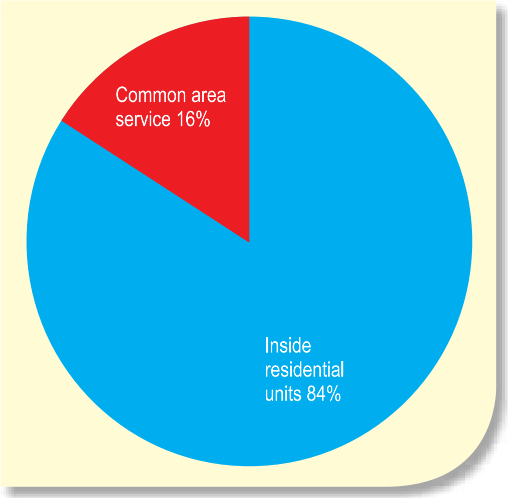


Figure 2.9 *Breakdown of total electricity consumption of a small multi-storey residential complex in Delhi*

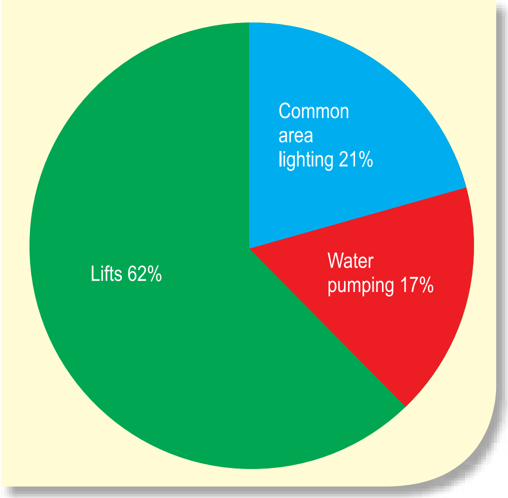


Figure 2.10 *Share of electricity consumption for common services (lighting, pumping, and lifts) in a small multi-storey residential complex in Delhi*

CONCLUSIONS

1. The average EPI for sample two–three bedroom residential flats in warm-humid climate (417 flats) for the year 2009 is calculated as 44 kWh/m^2.year.
2. Space cooling and fans form a significant part of the total electricity consumption. Detailed analysis of electricity consumption in three sample flats shows that electricity consumption for space cooling and fans increases with the increase in EPI (and increased use of air-conditioners), and varies between 36% and 60% of the total electricity consumption.
3. It is to be anticipated that better thermal comfort is an aspirational trend and this leads to a greater demand for installing air-conditioning systems. Use of refrigerant-based air-conditioning will be the chief contributor to the increase in energy consumption in residential buildings.
4. Analysis of electricity consumption data of a residential complex in Delhi shows that the electricity consumed for common area services (lifts, water pumping, and common area lighting) accounts for ~16% of the total electricity consumed in the complex. The bulk of the electricity is consumed by the operation of lifts (62%), followed by common area lighting (21%), and water pumping (17%).
5. Significant energy savings can be achieved by designing climatically appropriate buildings so as to minimise the seasonal periods and daily durations when air-conditioning is used. Savings can also be increased by more efficient design and selection of lifts and pumps, as well as improving the efficiency of space-cooling equipment.

CHAPTER 3

BUILDING MASSING AND SPATIAL CONFIGURATION

AT A GLANCE

Building massing refers to the shape and size of the building blocks; ‘spatial configuration’ is how the buildings are arranged in the given plot of land.

In office buildings, cooling loads are often dominated by internal heat gains through computers, lighting, people, etc. However, in residential buildings, most of the cooling load originates from solar heat gains through the building envelope. The thermal quality of the building envelope of residential buildings is usually poor due to absence of good shading for windows, single-glazed windows, and uninsulated roof and walls. This allows solar heat gains through windows and walls in large amounts.

While deciding on building massing and spatial configuration in the warm-humid climate, the two main considerations are:

1. Reduction of solar exposure on the building envelope. This helps in managing solar heat gain through the building envelope (walls, roof, windows).
2. Utilisation of wind flow to ventilate internal spaces to evacuate heat and provide thermal comfort to the occupants.

The requirements of managing solar gains and utilising wind flows may often lead to conflicting results. Such conflicts need to be analysed for each individual case to find an optimum solution.

The decisions on building massing and spatial configuration for residential complexes are influenced by several parameters such as land use, floor space index, ground coverage, residential unit densities, adjacent road width, fire regulations, height restrictions due to nearby airports, and market demand. A recommended good practice is to conduct a solar exposure analysis and wind flow analysis before deciding on building massing and spatial configuration.

AT A GLANCE

RECOMMENDATIONS FOR BUILDING MASSING AND SPATIAL CONFIGURATION

Recommendation 1: Orient the buildings to minimise solar exposure on vertical surfaces and for proper utilisation of wind flow for ventilation.

Orient the buildings to minimise solar exposure on vertical surfaces (e.g., the larger façade faces north and south). For utilising the wind flow, buildings need to be oriented at an angle (usually ±45 degrees) to the prevailing wind direction.

Recommendation 2: Select the building shape to minimise solar exposure on vertical surfaces

Proper choice of building shape for a particular orientation can reduce the solar radiation exposure (kWh/m^2 of flat built-up area) by 20%–30%. If there is flexibility of orienting the building correctly (i.e., larger façade in a north and south direction), then the preferences of typologies in terms of reduced solar radiation exposure are:

1. Linear double-loaded corridor typology
2. Linear typology
3. Tower typology

Note: These recommendations have less impact on solar heat gains when the building envelope is well insulated and has very efficient external solar protection for windows in the form of external movable shutters as explained in Chapter 4. In other words, if the external surfaces are substantially exposed on the eastern and western faces, then it becomes necessary to insulate them well.

3.1 Introduction

In the context of this chapter, 'building massing' refers to the shape and size of a building, and 'spatial configuration' is how the buildings are arranged in a residential complex to define built and open spaces.

While deciding on building massing and spatial configuration in the warm-humid climate, the two main considerations are:

1. Reduction of solar exposure on the building envelope. This helps in managing solar heat gain through the building envelope (walls, roof, windows).
2. Utilisation of wind flow to ventilate internal spaces to evacuate heat and provide thermal comfort to the occupants.

This chapter deals with appropriate selection of building forms (exposed surface area/ built-up area), building orientation (façade orientation), and spatial configuration (building location and spacing) to reduce solar exposure and improve the ventilation potential of residential spaces.

3.2 Typologies of multi-storey residential buildings

The building massing of multi-storey residential buildings can be broadly classified into the following three typologies:

1. Tower typology
2. Linear typology
3. Linear double-loaded corridor typology

Several mixed typologies are possible through a combination of the three primary typologies.

3.2.1 Tower typology

Tower typology is the most common typology considered for multi-storey residential buildings because of its modular design. The tower blocks can be repeated across the site to generate a variety of spatial enclosures. The tower typology is usually characterised by three or more flats per floor arranged around the central service core (Figures 3.1a and 3.1b).

3.2.2 Linear housing typology

Linear typology is characterised by linear arrangements of building blocks usually defined by either linear streets or by a linear edge of the open space. The adjacent flats on each floor will share at least one common wall. The vertical service core at each floor is usually shared by two or four flats (Figures 3.2a to 3.2c).

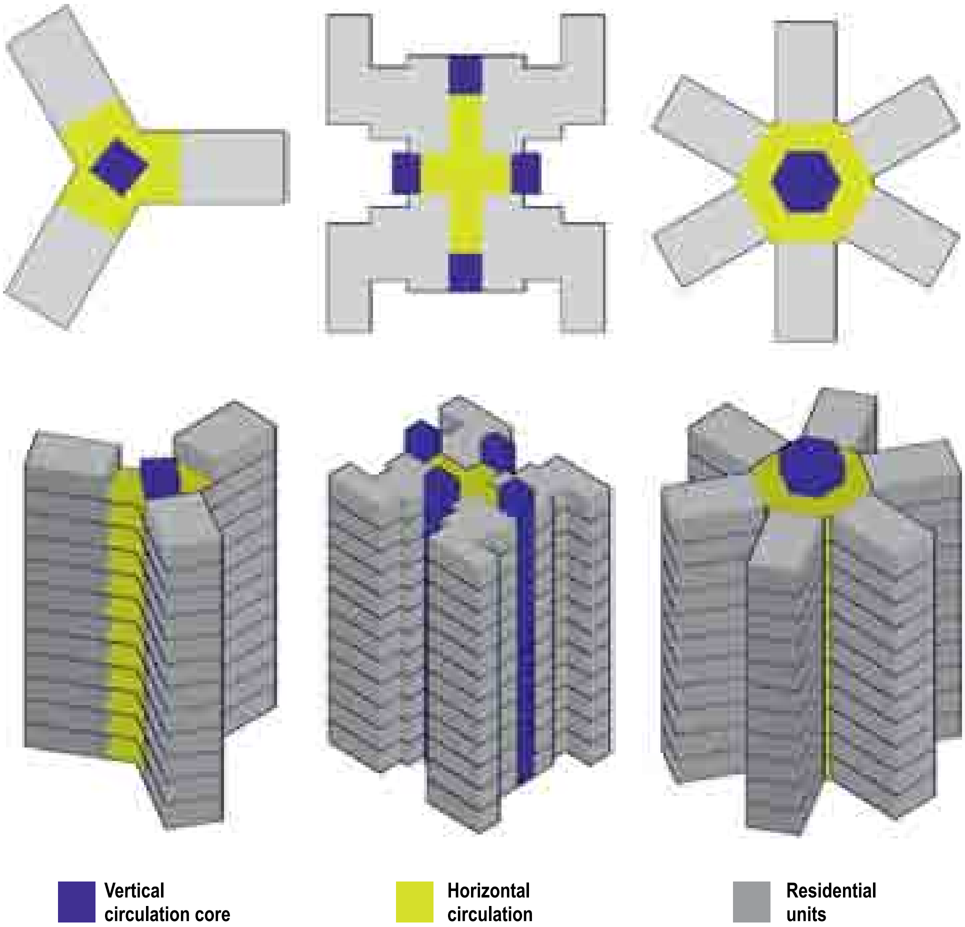


Figure 3.1a Possible configurations for tower typology

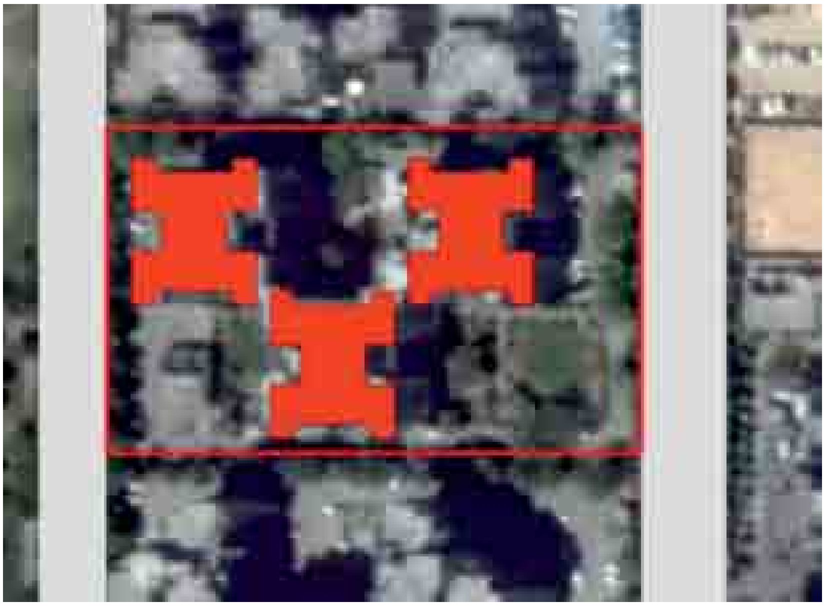


Figure 3.1b
Example layout of a tower typology

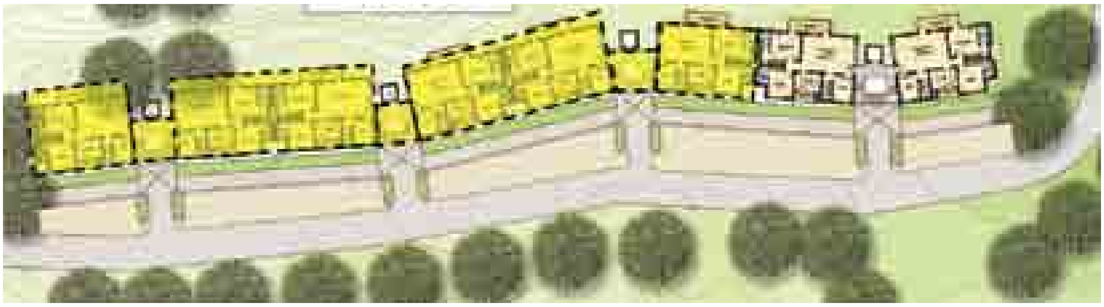
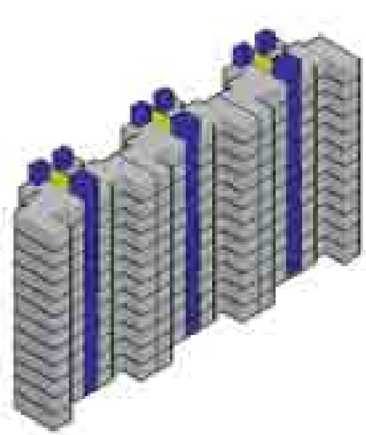


Figure 3.2a *Typical layout of a linear typology*
Source *Ashok B Lall Architects*



🟦 **Vertical circulation core** 🟨 **Horizontal circulation** ⬜ **Residential units**

Figure 3.2b *Schematic 3-D view of a typical linear typology*

Figure 3.2c *Schematic spatial configuration of a typical linear typology*

3.2.3 Linear double-loaded corridor typology

Linear double-loaded typology is characterised by linear blocks with flats arranged along both sides of the circulation corridor (Figures 3.3a and 3.3b). The vertical cores open into the double-loaded corridor and are distributed across the linear blocks.

3.3 Solar exposure analysis for different building typologies and orientations

3.3.1 Methodology

The main objective of the analysis was to estimate 'solar radiation exposure on vertical surfaces in kWh/m^2 in the flat built-up area for different building typologies and building orientation, and to come up with recommendations to reduce solar exposure. The analysis was carried out for three typical building typologies located in Chennai (Ground + 11 storey residential blocks) for the warm months (1 April–30 September).

Figure 3.3a *Typical layout of a linear double-loaded corridor typology*
Source *Ashok B Lall Architects*

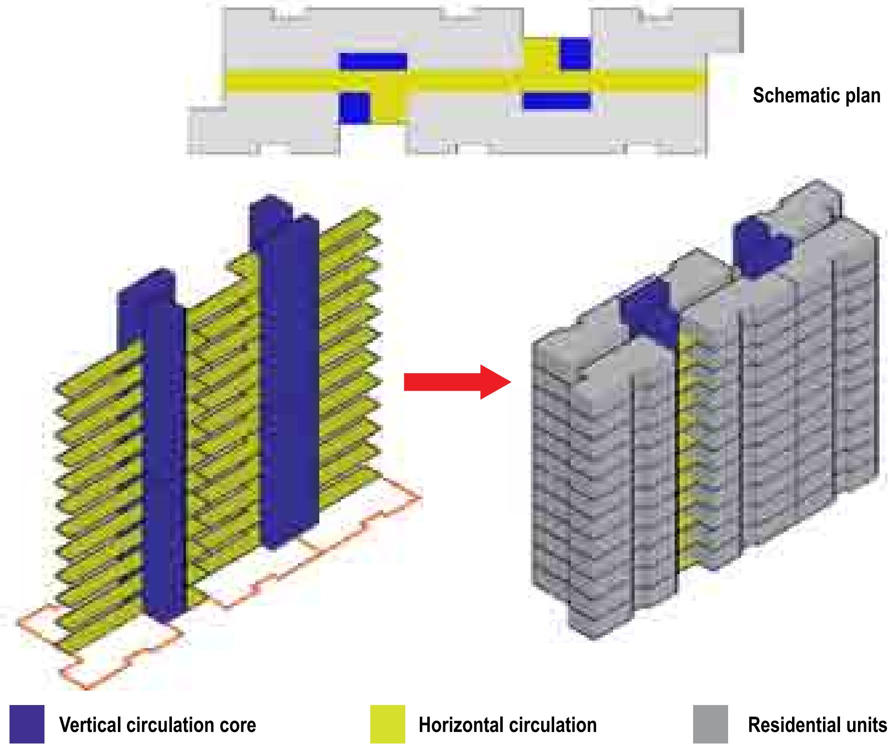


Figure 3.3b
Schematic of typical linear double-loaded corridor typology

The solar radiation analysis was performed using DIVA[1] (design, iterate, validate, and adapt) plug-in for Rhinoceros.

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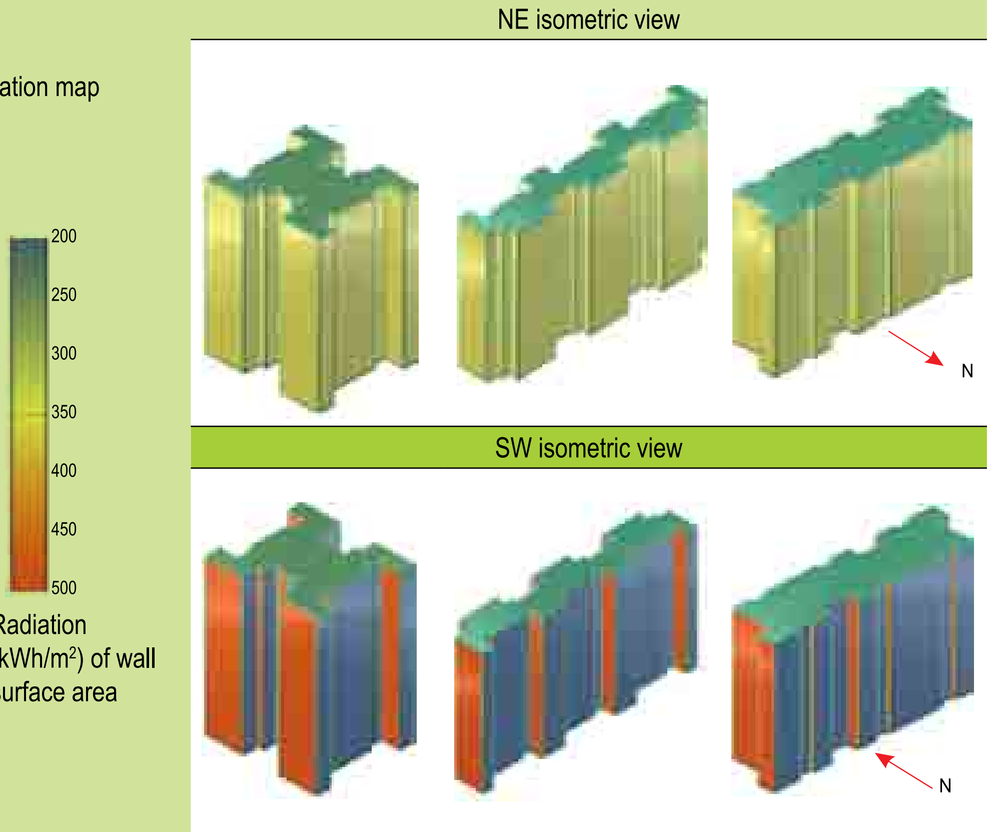
[1] *DIVA calculates irradiation at the node locations for a defined period. DIVA uses the Daysim-based hourly calculation method, which utilises the Radiance module to produce an hourly result file in addition to the time cumulative irradiation map.*

3.3. Results

The results of the analysis for two different orientations are shown in Tables 3.1 and 3.2. Table 3.1 shows the solar radiation distribution over the vertical surfaces for the three typologies when the larger façades are facing north and south. Table 3.2 shows the solar radiation distribution over the vertical surfaces for the three typologies when the larger façades are facing east and west.

Table 3.1 Solar radiation distribution with larger façades facing north and south*

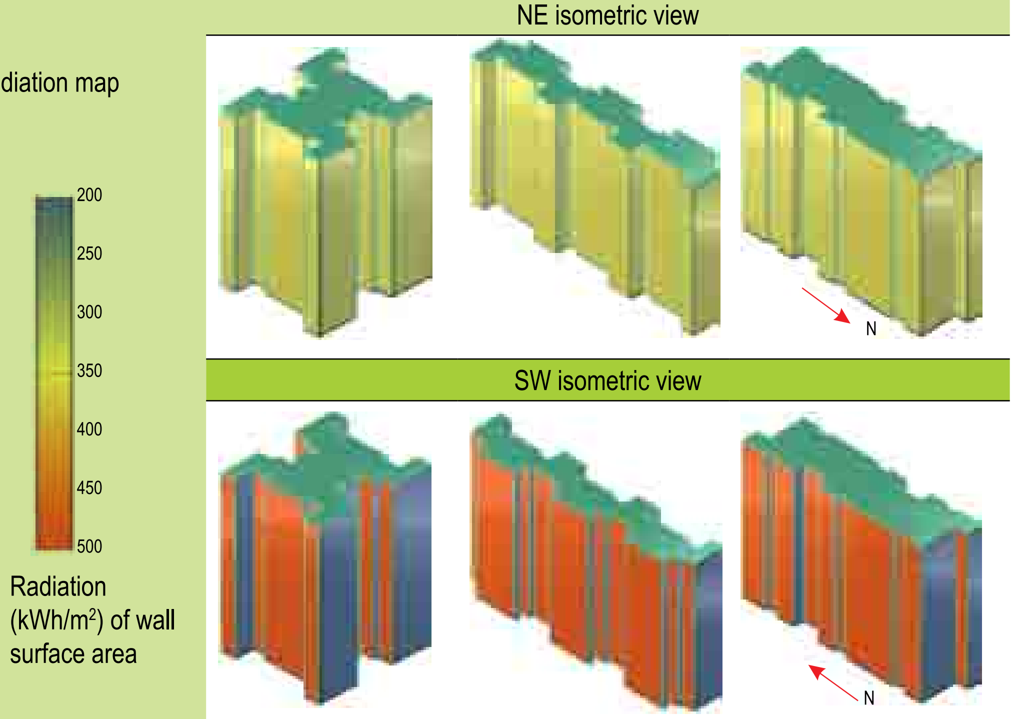
Typology	**Tower**	**Linear**	**Linear double-loaded corridor**
No. of flats/block	48	72	72
Cumulative wall surface area in m^2/total flat built-up area in m^2	1.3	1.3	1.0
Cumulative radiation exposure in kWh/total flat built-up area in m^2 (from 1 April to 30 September)	473	432	331
Solar radiation map			

* Roof solar radiation is not included for the analysis

Table 3.2 Solar radiation distribution with larger façades facing east and west*

Typology	Tower	Linear	Linear double-loaded corridor
No. of flats/block	48	72	72
Cumulative wall surface area in m^2/total flat built-up area in m^2	1.3	1.3	1.0
Cumulative radiation exposure in kWh/total flat built-up area in m^2 (from 1 April to 30 September)	477	485	375

Solar radiation map



* Roof solar radiation is not included for the analysis

The analysis shows the following results.

- There is a large difference in solar radiation exposure during the summer months (April–September) depending on building typology and orientation. The solar radiation exposure on vertical surfaces increases by 46% from a minimum of 331 kWh/m^2 of flat built-up area for a north–south oriented linear double-loaded corridor to a maximum of 485 kWh/m^2 of flat built-up area for an east–west oriented linear typology.
- A linear double-loaded corridor, if oriented properly (north–south orientation), is the best option in terms of both the lowest exposed vertical surface area and also the lowest solar radiation exposure on vertical surfaces. However, if not oriented properly

(i.e., east–west orientation), the solar radiation exposure on vertical surfaces increases by 13% compared to proper orientation (i.e., north–south).

- For the tower typology, there is almost no effect of orientation on the solar radiation exposure on the vertical surfaces.

3.4 Wind flow analysis around buildings

Air movement is essential for human comfort in the warm-humid climate. Natural ventilation is an important passive strategy to maintain comfortable conditions inside residences. But to enable good natural ventilation inside, adequate wind flow must be available to the flats.

The rapid urbanisation in India, our population, and availability of land have led to dense, tall residential buildings with very less space left between buildings. The 'free' wind velocity only reaches the first windward facing building, that too when the adjoining surroundings do not block the wind.

3.4.1 Methodology

The objective of the wind flow analysis was to get an idea on the availability of wind on the building façade, and to come up with recommendations to improve wind flow for better natural ventilation.

Computational Fluid Dynamics (CFD) analysis was carried out on two buildings of the tower typology (Ground + 11 storey), having four flats on each floor. These two buildings (buildings A and B) are placed 9 m apart from each other, one directly behind the other. Figure 3.4 shows the arrangement of the two buildings in plan view.

3.4.2 Results

The study was done at a height of 20 m above ground in a wind-free environment, i.e. no object obstructing the wind flow around the buildings studied. The wind is incident perpendicular to the building façades. The results of the analysis are shown in Figure 3.5. It shows that the wind reaches the windward façade of Building A but not its leeward façade

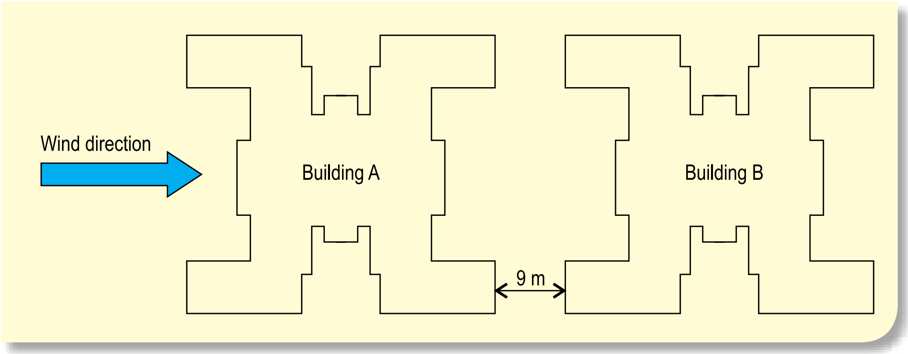


Figure 3.4
Building layout used for wind flow analysis. Wind direction is perpendicular to the building facade

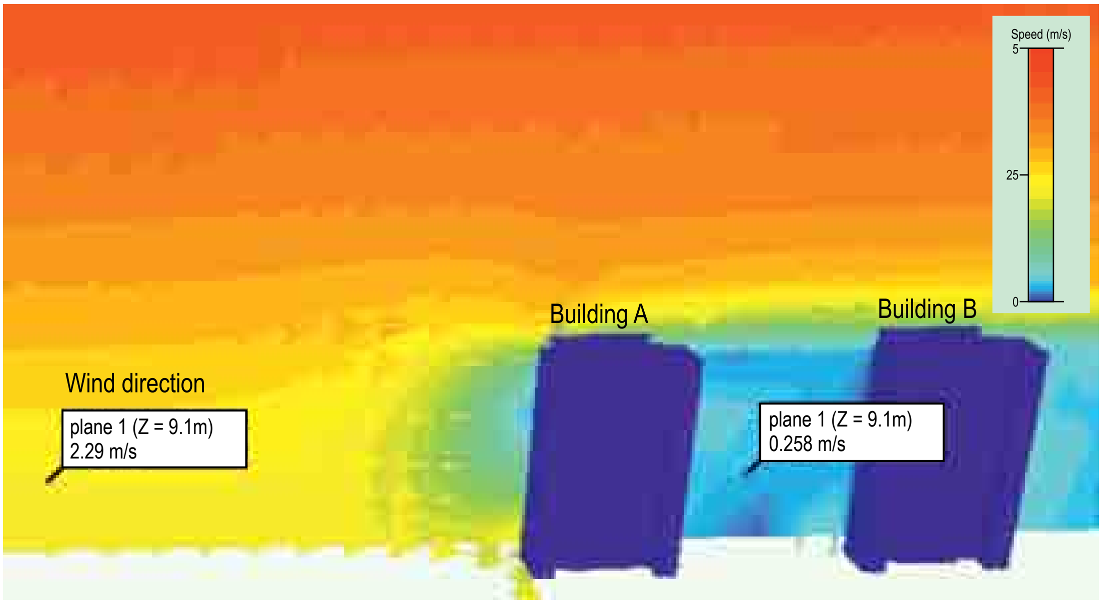
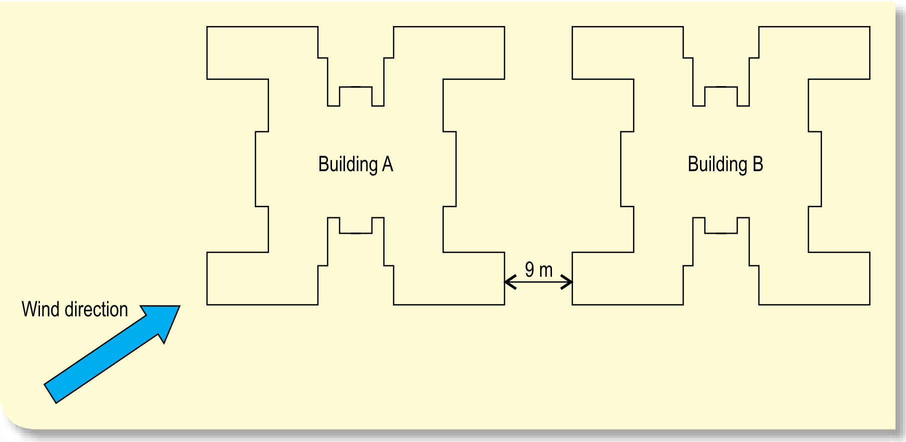


Figure 3.5 *Wind velocity when wind is perpendicular to the building façade*

or Building B. Wind velocity in the space between the buildings is drastically reduced to almost zero (Figure 3.5).

Figure 3.6 shows another case where the buildings are oriented in such a manner that the wind is incident on the building façades at an angle of 30° to 60°. The results of the CFD analysis are shown in Figure 3.7. It is seen that the results in terms of access to wind by the two building façades is better when compared with the earlier case. In this case, wind reaches three of the flats on each floor for both buildings A and B, with very less drop in the wind velocity. However, the fourth flat (located in the leeward region) in both buildings will still not get any wind.

Figure 3.6
Building layout used for wind flow analysis. Wind direction is between 30° to 60° to the building façade



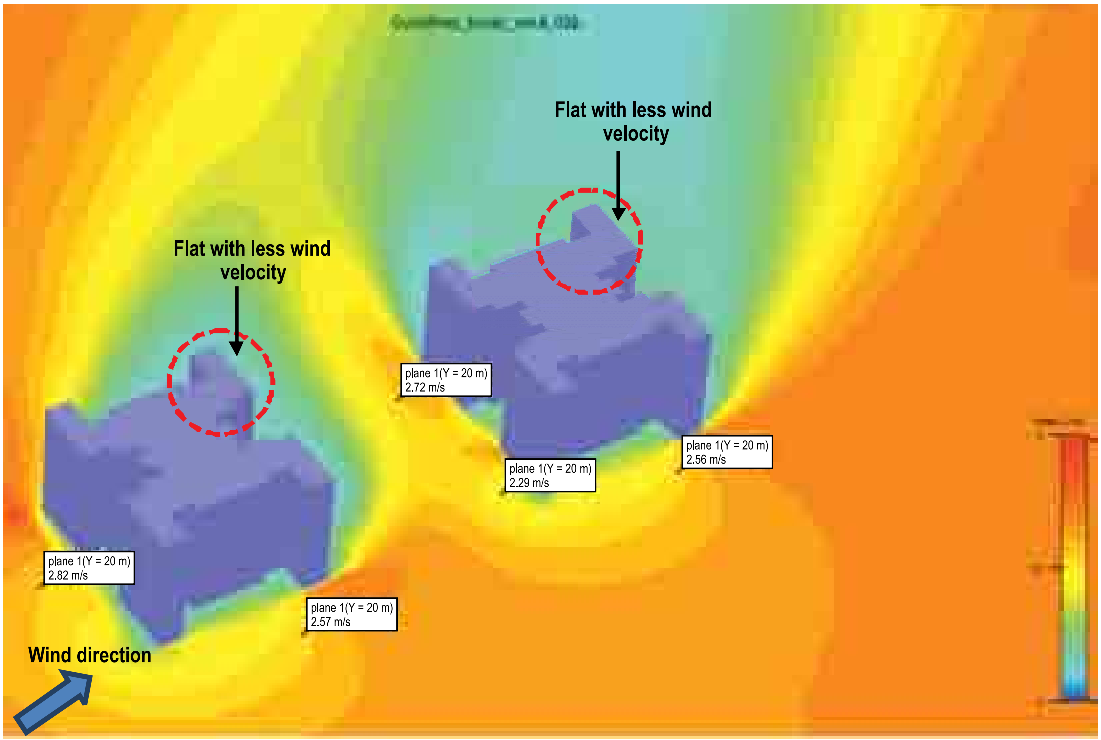


Figure 3.7 *Wind velocity when wind is between 30° to 60° to the building façade*

3.5 New strategies to improve cross ventilation in large dense residential projects

The lack of wind velocity between the buildings leads to inefficient use of natural ventilation in many situations. But the wind velocity on the roof-top of buildings is almost undisturbed by other buildings (unless much higher buildings are located nearby and are blocking the main wind direction).

Figure 3.8 shows an example of wind distribution between the buildings and also above the roof. The wind velocity above the roof is consistently about five times higher than the velocity in between the buildings. Ways to exploit the wind energy available on the roof for providing natural ventilation in the buildings is being studied and experiments are under way.

3.6 Remarks

In this chapter, an analysis was presented on the two main considerations of reducing solar exposure and utilisation of wind flow, while deciding on building massing and spatial configuration in the warm-humid climate.

The analysis and recommendations for reducing solar exposure on vertical surfaces through building massing and spatial configuration have high importance in the context of current

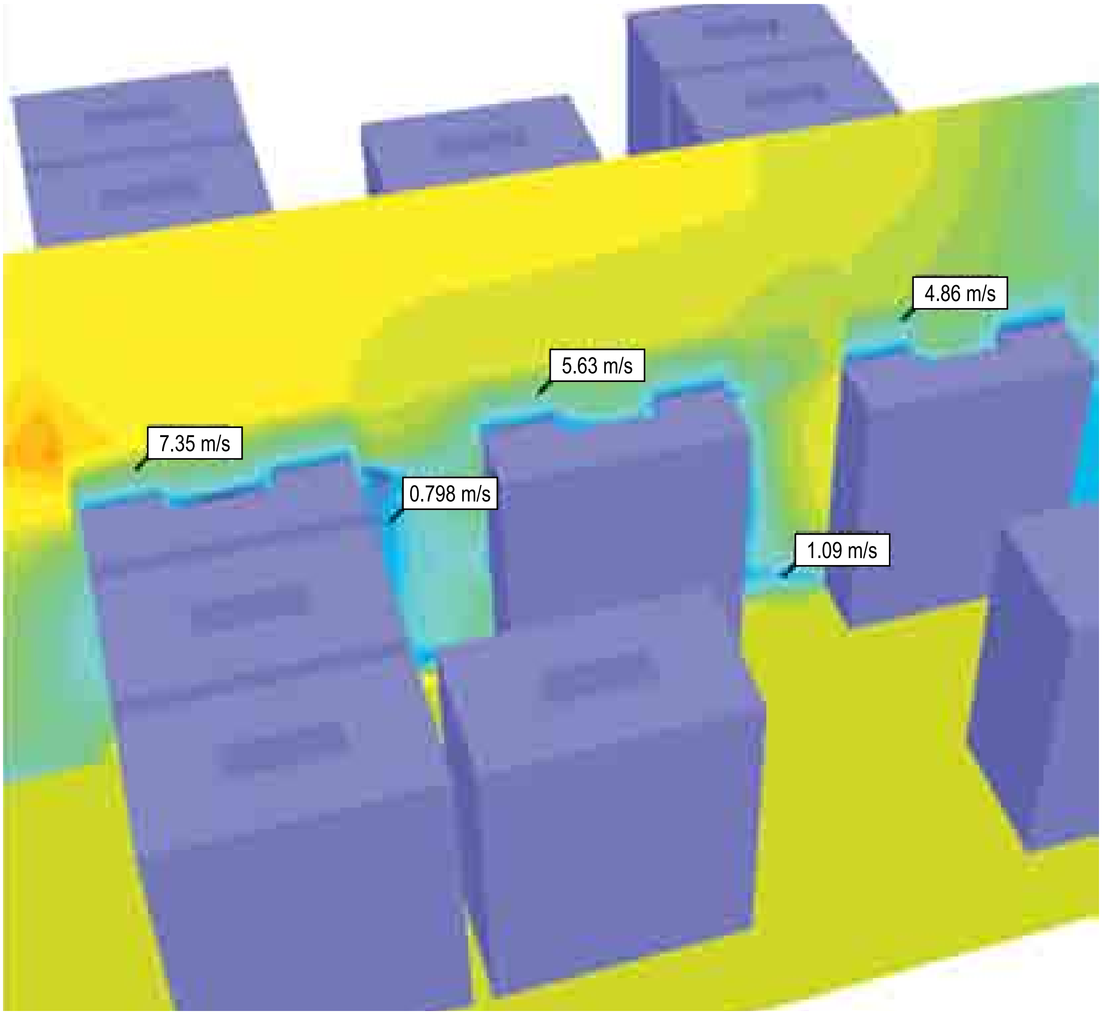


Figure 3.8 *Wind distribution between buildings and above the roof*

multistorey residential building design and construction practices. The present stock of residential buildings is characterised by poor thermal quality of the building envelope (uninsulated walls, single-glazed windows, absence of good external shading). A reduction in solar exposure on vertical surfaces will lead to a reduction in heat gain through the building envelope and hence create better thermal comfort in the inside spaces and less requirement for space cooling. It should be noted that when the building façade is well insulated and the fenestrations are properly shaded by external shading devices, then the impact of building massing and spatial configuration is less critical for reducing heat gains.

The analysis and recommendations for utilising wind flow for the ventilation of flats are also highly important in warm and humid climate, where for a large part of the year, thermal comfort can be achieved through natural ventilation and use of fans. The CFD analysis also shows the challenges as well as some solutions in utilising the wind flow in high density housing developments. This area requires more research.

It should be noted that the requirements to manage solar gains and utilise wind flows may often lead to conflicting results. For managing the solar heat gains, the best arrangement would be to orient the buildings with the long axes in the east–west direction. On the other hand, the prominent wind direction in most parts of India is from the west or the east, for most of the year. The CFD analysis has shown that for proper utilisation of the wind, buildings need to be oriented at an angle (usually ±45 degrees) to the prevailing wind direction. This consideration would require that the long axes of the building should be at an angle to the east–west direction. Such conflicts need to be analysed for each individual case to find the optimum solution.

The decisions on building massing and spatial configuration for residential complexes are influenced by several parameters such as land use, floor space index, ground coverage, residential unit densities, adjacent road width, fire regulations, height restrictions due to nearby airports, and market demand. A recommended good practice is to conduct a solar exposure analysis and wind-flow analysis before deciding on building massing and spatial configuration.

RECOMMENDATIONS

Recommendation 1: Orient the buildings to minimise solar exposure on vertical surfaces and for proper utilisation of wind flow for ventilation.

Orient the buildings to minimise solar exposure on vertical surfaces (e.g., the larger façade faces north and south). For utilising the wind flow, buildings need to be oriented at an angle (usually ±45 degrees) to the prevailing wind direction.

Recommendation 2: Select the building shape to minimise solar exposure on vertical surfaces

Proper choice of building shape for a particular orientation can reduce the solar radiation exposure (kWh/m^2 of flat built-up area) by 20%–30%. If there is flexibility of orienting the building correctly (i.e., larger façade in a north and south direction), then the preferences of typologies in terms of reduced solar radiation exposure are:

1. Linear double-loaded corridor typology
2. Linear typology
3. Tower typology

Note: These recommendations have less impact on solar heat gains when the building envelope is well insulated and has very efficient external solar protection for windows in the form of external movable shutters as explained in Chapter 4. In other words, if the external surfaces are substantially exposed on the eastern and western faces, then it becomes necessary to insulate them well.

CHAPTER 4

BUILDING ENVELOPE

AT A GLANCE

In residential buildings, most of the cooling load is caused by solar heat gains and heat transmissions through windows, walls, and roof. Thus, special attention should be paid to minimise the cooling load by reducing solar heat gains and heat transmission through the building envelope, which includes the windows, walls, and roof.

The features of the main building envelope that influence the demand for cooling thermal energy and thermal comfort in a residential unit are listed below.

- Size and location of window openings
- Shading system for windows
- Window properties
- Insulation properties of walls
- Insulation properties of roof
- Colour and finish of exterior surfaces (walls and roofs)
- Natural ventilation
- Air-tightness in the building

The main building envelope features that influence daylighting in a residential unit are listed below.

- Size and location of window openings
- Shading system for windows
- Window glazing light transmission properties
- Colour and finish of nearby surfaces
- Colour of internal surfaces

The building envelope design should aim at achieving reduction in cooling thermal energy demand, improvement in thermal comfort, and provision of adequate daylighting in typical spaces such as bedroom, living room, and kitchen.

RECOMMENDATIONS FOR BUILDING ENVELOPE

Recommendation 3: Passive measures for walls and windows to reduce the cooling energy

- Limit glazed area. Window-to-wall ratio (WWR) of 10%–30% in bedrooms and 20%–30% in living rooms allow a good balance between adequate daylight and reduced heat gains (see also Recommendation 4).
- Ventilation is of prime importance (for more details, see Chapter 5).
- It is more important to shade the windows than increase wall insulation or use double-glazed units.
- The northern façade of a building needs better protection from sun as we go further south in India.

Reduction in cooling energy can be brought about by following adequate measures. A couple of them are listed below.

- Package of Measures I that can bring about 7%–20% reduction in cooling energy: Use of light colors on walls (absorptivity ≤0.4) + window shades with extended overhangs + insulated walls (U-value: 0.7 $W/m^2.K$) + optimised natural ventilation.
- Package of Measures II that can bring about 40%–65% reduction in cooling energy: Package of Measures I + external movable shutters on windows.

Recommendation 4: Daylighting

- Usually 10% WWR in bedrooms and 20% WWR in living rooms are needed to provide sufficient daylight.
- However, when building blocks in a residential complex are located near each other, daylighting in bedrooms and living rooms located on lower floors is reduced substantially. The daylight on the lower floors can be improved by: (a) increasing the window area (maximum WWR 30%), (b) using light colours with smooth finishes on the wall opposite to the window, and (c) using light colour interiors.

Recommendation 5: Passive measures for the roof

- Provide over-deck insulation and high reflective surfaces on the roof to minimise heat gain through the roof.

4.1 Introduction

The building envelope is the interface between the indoor spaces of the building and the outdoor environment. The envelope essentially comprises two components—opaque component and fenestration component.

The opaque components of the envelope are: (a) walls; (b) roofs; (c) slab-on-grade, i.e., the slab in contact with the ground; (d) basement walls; and (e) opaque doors.

The fenestration component consists mainly of (a) windows and (b) ventilators. The building envelope acts as a thermal barrier and plays an important role in regulating interior temperatures and influencing the amount of electricity required to maintain thermal comfort. It also regulates the amount of daylight that can enter the interiors. This chapter will discuss envelope design with special focus on bedrooms and living rooms.

In hot climates, a properly designed building envelope can help improve thermal comfort and reduce the energy required for cooling. During monitoring of sample apartments, it was observed that bedrooms, occupied during night, and living rooms, occupied during the day and evening, consume most of the electricity used for space cooling. In office buildings, cooling loads are often dominated by internal heat gains caused by computers, lighting, etc. However, in residential buildings, cooling loads are made up of the heat gains through the envelope. Heat gains through the envelope include: solar heat gain through windows; heat ingress across the walls and roof; and uncontrolled air infiltration. To minimise cooling loads, it is necessary to reduce heat gains into the building from outside.

Ensuring optimum daylight is also an important part of designing energy-efficient buildings. Badly optimised designs for daylight will lead to poor visual comfort. This would prompt occupants to switch on electric lights, thereby increasing electricity consumption. In addition, the excessive use of artificial lighting will not only consume more electricity, but will also generate additional internal heat gains, which, in turn, will make it more difficult to cool the building.

4.2 Bedrooms

4.2.1 Thermal performance analysis

4.2.1.1 Methodology

To understand thermal performance, an energy simulation model for bedrooms was developed in TRNSYS.[1] The model developed for bedrooms (3 x 3.7 x 3 m) is for the intermediate floor with the ceiling and the floor modelled as adiabatic, i.e., where no heat

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[1] *TRaNsientSYstems Simulation (TRNSYS) is a software used for building energy simulation.*

flux occurs across the components. During research, it was found that mostly bedrooms had two exterior walls. Thus, for the base case, a bedroom having two external walls was taken. The other two internal walls were modelled as adiabatic surfaces (Figure 4.1). The input parameters used for simulating the base case are given in Table 4.1.

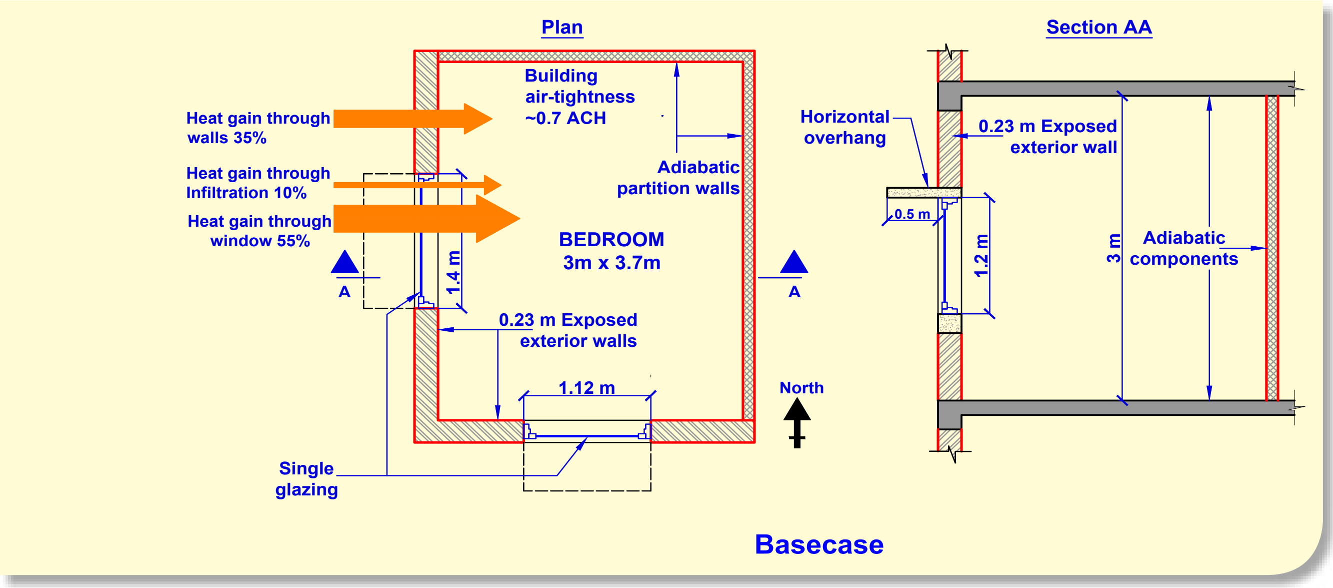

Figure 4.1 *Schematic of base case model for bedroom developed in TRNSYS*

Table 4.1 Important inputs for the simulation of the base case for bedrooms

Parameter	Values
Wall External wall: 230-mm brick wall Internal wall: 115-mm brick wall	 U-value[a]: 2.0 W/m^2.K; surface absorptivity: 0.65 U-value: 3.2 W/m^2.K; adiabatic
Glazing: 6-mm single clear glass	U-value: 6.1 W/m^2.K; SHGC[b]: 0.85; VLT[c]: 0.9
Shading on the window	500-mm horizontal static overhang at lintel level
Intermediate floor: 150-mm RCC slab	U-value: 3.0 W/m^2.K; Adiabatic
Window-to-floor area ratio	27%
External wall-to-floor area ratio	181%
Window-to-wall area ratio	15%
Occupancy load and schedule	*Schedule for weekdays:* 2 persons (21:00–07:00 hours) *Schedule for weekend:* 2 persons (23:00–07:00 hours and 14:00–17:00 hours)
Set-point temperature	26 °C
Locations	Mumbai and Chennai

[a] U-value is the heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side.

[b] Solar heat gain coefficient (SHGC) is the ratio of the solar heat gain entering the space through fenestration area to the incident solar radiation.

[c] Visible light transmittance (VLT) is the amount of visible light that passes through a glazing system and is expressed in percentage.

An hour-by-hour simulation covering an entire year (8760 hours) was carried out by varying parameters as listed in Table 4.1. The simulation resulted in various outputs, most importantly the cooling thermal energy demand per hour, per month, and per year.[2]

The cooling energy demand of the base case, as defined by Table 4.1, is considered as 100%. The results of all other cases are expressed in percentage in relation to this.

4.2.1.2 Effect of orientation on cooling thermal energy demand

In most of the warm-humid climate zone, there is a higher component of diffused solar radiation than direct solar radiation in the summer months. The diurnal temperature variation and seasonal temperature variation are also less. This leads to the fact that orientation of the rooms in relation to the sun has less effect on the annual cooling energy demand, provided the glazed area is kept to a minimum. For example, in Mumbai, changing the orientation of the bedroom results in a difference of 4% to 8% in the cooling energy. The following points need to noted:

- In summer, apart from the roof, the heat gain from solar radiation from the western façade is the highest.
- In winter, heat gains from solar radiation are highest from the southern façade.
- In fact, over the entire year, besides the roof, the south wall receives the highest solar radiation. This is due to the fact that temperature variation between summer and winter is not very high.
- Thus, protecting the southern façade also becomes important.

Chennai presents a unique case within the warm-humid climate zone (Figure 4.2).

- First, due to the prominence of the north-east monsoon (November–January) over the south-west monsoon (July–September), there is more direct radiation during the summer months in Chennai than most of the other places in the warm-humid climate. In summer, apart from the roof, heat gains from solar radiation are highest on the western wall. Over the year, too, the western wall gets more solar radiation than the other faces.
- Second, due to its proximity to the equator, the northern face also receives a considerable amount of radiation from the afternoon sun, making the northern face equally, if not more, critical than the southern face.

4.2.1.3 Effect of the number of external walls on the cooling thermal energy demand

Having only one wall exposed to the ambient air, instead of two, does not necessarily reduce cooling energy demand (Figures 4.3 and 4.4). It is rather more dependent on the size of the windows.

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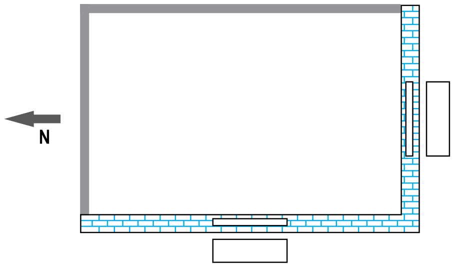
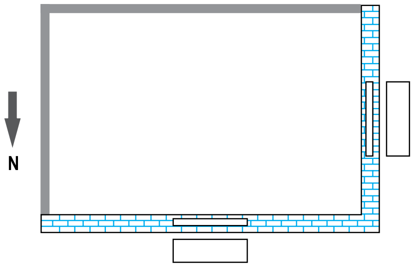
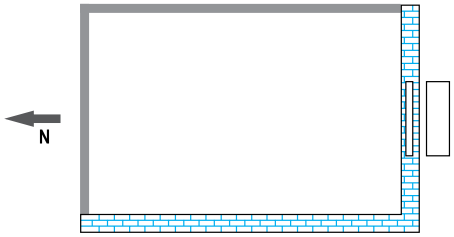
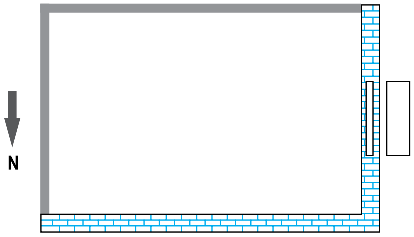
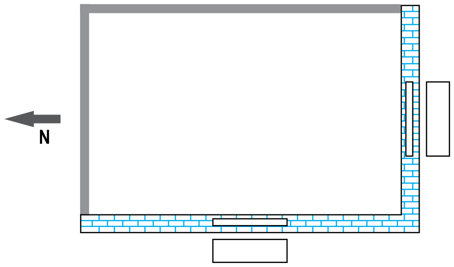
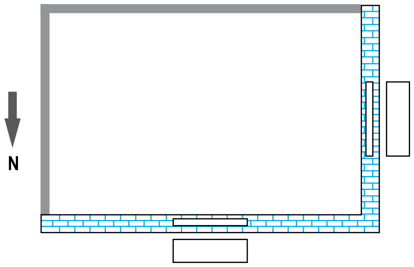
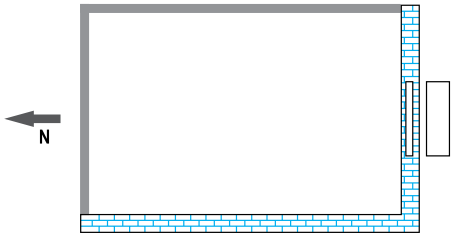
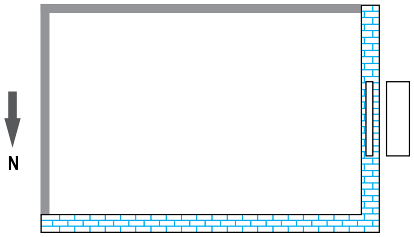
[2] *Other outputs include air and mean radiant temperatures; specific surface temperatures; air change by infiltration; natural ventilation air change; air mass flow rate; air change cooling power.*

Case a: For a bedroom having two external walls, each wall having windows (Windows-to-floor area ratio 27%)	
Two external walls facing south and west*	The two external walls facing north and west
 Cooling energy = 100%	 Cooling energy = 99%
Case b: For a bedroom having one external wall with window (Windows-to-floor area ratio 27%)	
External walls facing south	External walls facing west
 Cooling energy = 100%	 Cooling energy = 103%
Case c: For a bedroom having two external walls, each wall having windows (Windows-to-floor area ratio 54%)	
Two external walls facing south and west*	The two external walls facing north and west
 Cooling energy = 130%	 Cooling energy = 125%
Case d: For a bedroom having one external wall with window (Windows-to-floor area ratio 54%)	
External walls facing south	External walls facing west
 Cooling energy = 138%	 Cooling energy = 142%

* This is the base case for parametric analysis. Cooling thermal energy demand for this case is taken as 100%. For all other cases, cooling thermal energy demand is presented relative to this case.

Figure 4.2 *Effect of orientation on cooling thermal energy demand for Chennai*

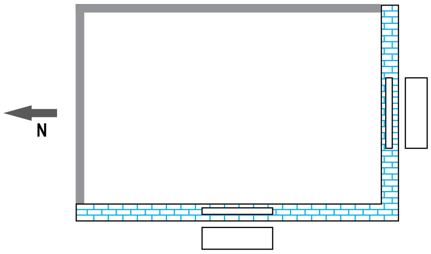
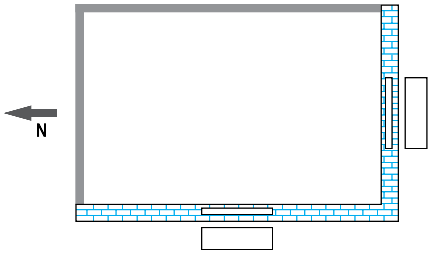
(Windows-to-floor area ratio 27%)	
The two external walls facing south and west	One external wall facing south
 Cooling energy = 100%	 Cooling energy = 99%
(Windows-to-floor area ratio 54%)	
The two external walls facing south and west	One external wall facing south
 Cooling energy = 135%	 Cooling energy = 158%

Figure 4.3 *Effect of number of external walls on cooling thermal energy demand for Mumbai*

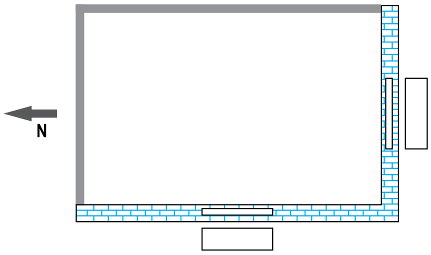
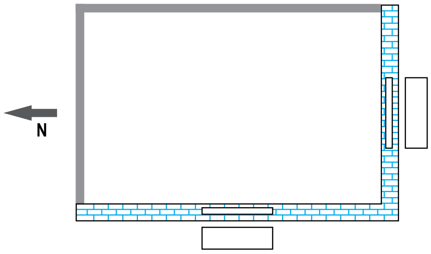
(Windows-to-floor area ratio 27%)	
The two external walls facing south and west	One external wall facing south
 Cooling energy = 100%	 Cooling energy = 100%
(Windows-to-floor area ratio 54%)	
The two external walls facing south and west	One external wall facing south
 Cooling energy = 130%	 Cooling energy = 138%

Figure 4.4 *Effect of number of external walls on cooling thermal energy demand for Chennai*

For example, given a fixed window-to-floor area ratio, the window sizes will be less if two exposed walls have windows *vis-à-vis* one exposed wall with one window. Thus, the case with the larger window size shows greater cooling energy demand.

The other important issue is that of cross-ventilation—a room with two walls having windows has better potential of cross-ventilation than a room with single window (see Chapter 5).

4.2.1.4 Passive energy-efficiency solution packages for bedrooms

Parametric analyses were performed on the base-case simulation model to understand the potential of various passive energy-efficiency measures. Instead of presenting the results for several hundred individual cases for which the parametric analysis was carried out, the results are presented for three solution packages. The packages are designed to reduce heat gains, caused by the building envelope, in bedrooms.

Package I

Package I consists of solutions that are commercially available and are being implemented in some of the multi-storey residential buildings.

- *Use of light colours on external walls (absorptivity ≤0.4):* Surfaces having higher absorptivity absorbs larger fraction of the solar radiation incident on them. By using light colour finishes/paints on the exterior surfaces of the external wall, lower absorptivity of around 0.4 can be obtained. This will require periodic maintenance of the exterior wall surface in order to retain the reflective characteristics of the finishes/paints.
- *Window shades with extended overhangs:* The overhang on top of the window lintel is extended sideways on both sides by 0.5 m (Figure 4.5). This extension helps in cutting the solar radiation falling on the window.

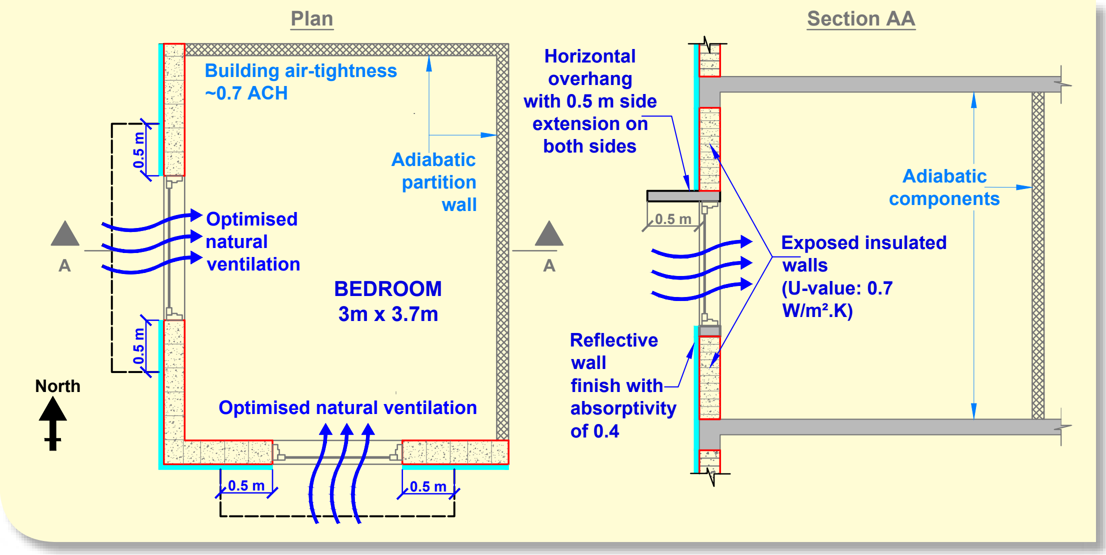


Figure 4.5 Schematic of Package I measures

- *Insulated walls (U-value: 0.7 W/m^2.K):* A typical 9-inch (230 mm) brick wall has a U-value of around 2.0 W/m^2.K. If the U-value for the external walls is reduced, then the heat transmission due to conduction through external walls can be reduced. A U-value of around 0.7 W/m^2.K can be achieved by using 200-mm-thick autoclaved aerated concrete (AAC) block or 200-mm-thick hollow concrete, or fired clay blocks filled with insulation materials, or a combination of 230-mm brick wall along with suitable insulation thickness.
- *Optimised natural ventilation:* This strategy considers the opening of 50% of the effective window area to facilitate natural ventilation whenever the outside temperature is ≥2 °C cooler than the indoor temperature.

Application of the measures suggested in Package I can reduce the demand for cooling thermal energy by 20% over the base case in Mumbai and 18% in Chennai, as shown in Figures 4.8a and 4.8b, respectively (see pages 48 and 49). A number of simulation runs showed that Package I measures when applied to different bedroom configurations, shown in Annexure 1, result in 7%–20% savings in cooling thermal energy demand compared to the base case. The Package I measures are more effective when glazed area is kept reduced.

Package II

Package II consists of measures suggested in Package I, along with the addition of external movable window shutters as shown in Figure 4.6.

Figure 4.1 shows that on a typical hot day, for the base case, the solar heat gained through the windows contribute about 55% of the heat gains in the bedroom. A substantial reduction in cooling thermal energy demand can be achieved by cutting off the solar heat gains from the windows. This objective is achieved through the addition of external movable shutters to windows. Examples of some of the external movable shutters are shown in Figures 4.7a and 4.7b. The external movable shutters can be of various types and can be made of a variety of materials, such as treated wood, bamboo, and aluminium. They can have sliding, top rolling, or hinged configuration.[3] It should be noted that though the concept of external movable shutters is not totally new to India, both the use and availability of modern external movable shutters are rather limited.

For the purpose of simulation, semi-opaque shutters (with 10% transmission) were modelled. The shutters are in closed position whenever incident solar radiation on the windows is more than 140 W/m^2.

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[3] *External frames with movable awnings; bamboo chick or blinds can also be installed. Important characteristics of such external movable shading arrangements are that they are lightweight and lightly connected to the building structure: this means they do not store and re-radiate or conduct heat into the building.*

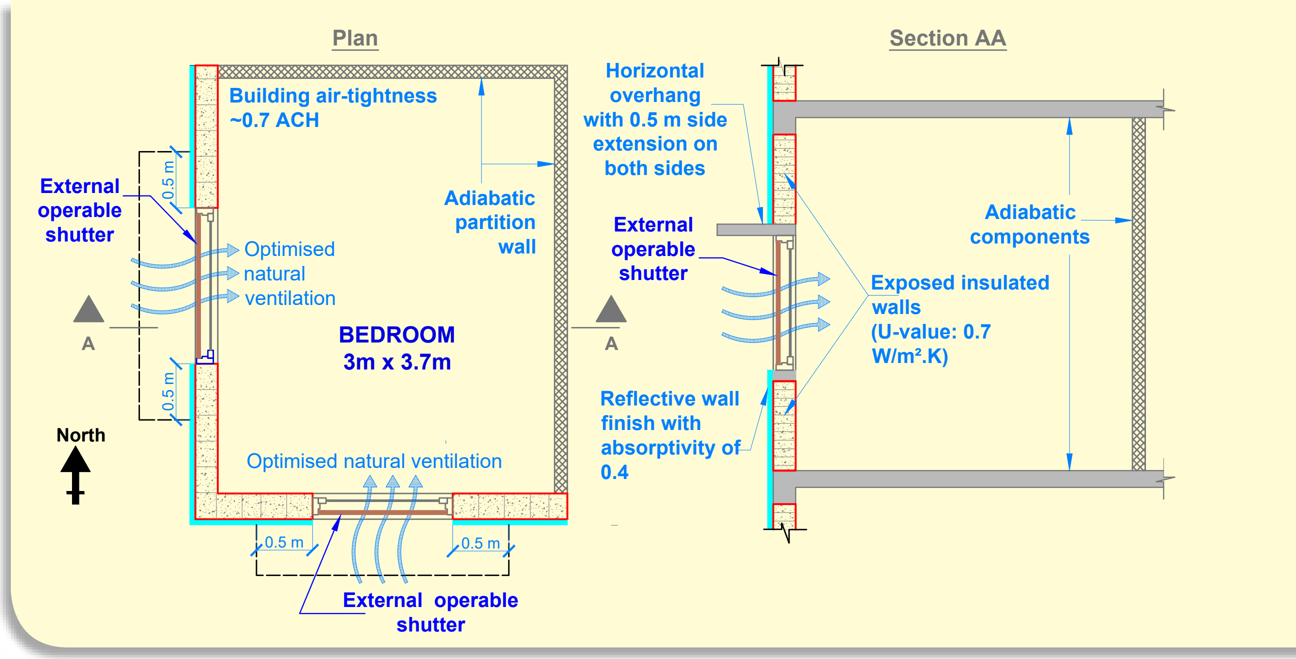

Figure 4.6 *Schematic of Package II measures*

Figure 4.7a *Sliding shutters*

Figure 4.7b *Hinged shutters and top rolling shutters*

Application of the measures suggested in Package II can reduce the demand for cooling thermal energy by 53% over the base case in Mumbai and 44% in Chennai as shown in Figures 4.8a and 4.8b, respectively. A large number of simulation runs showed that for different bedroom configurations, Package II measures result in 42%–67% savings in cooling thermal energy demand compared to the base case.

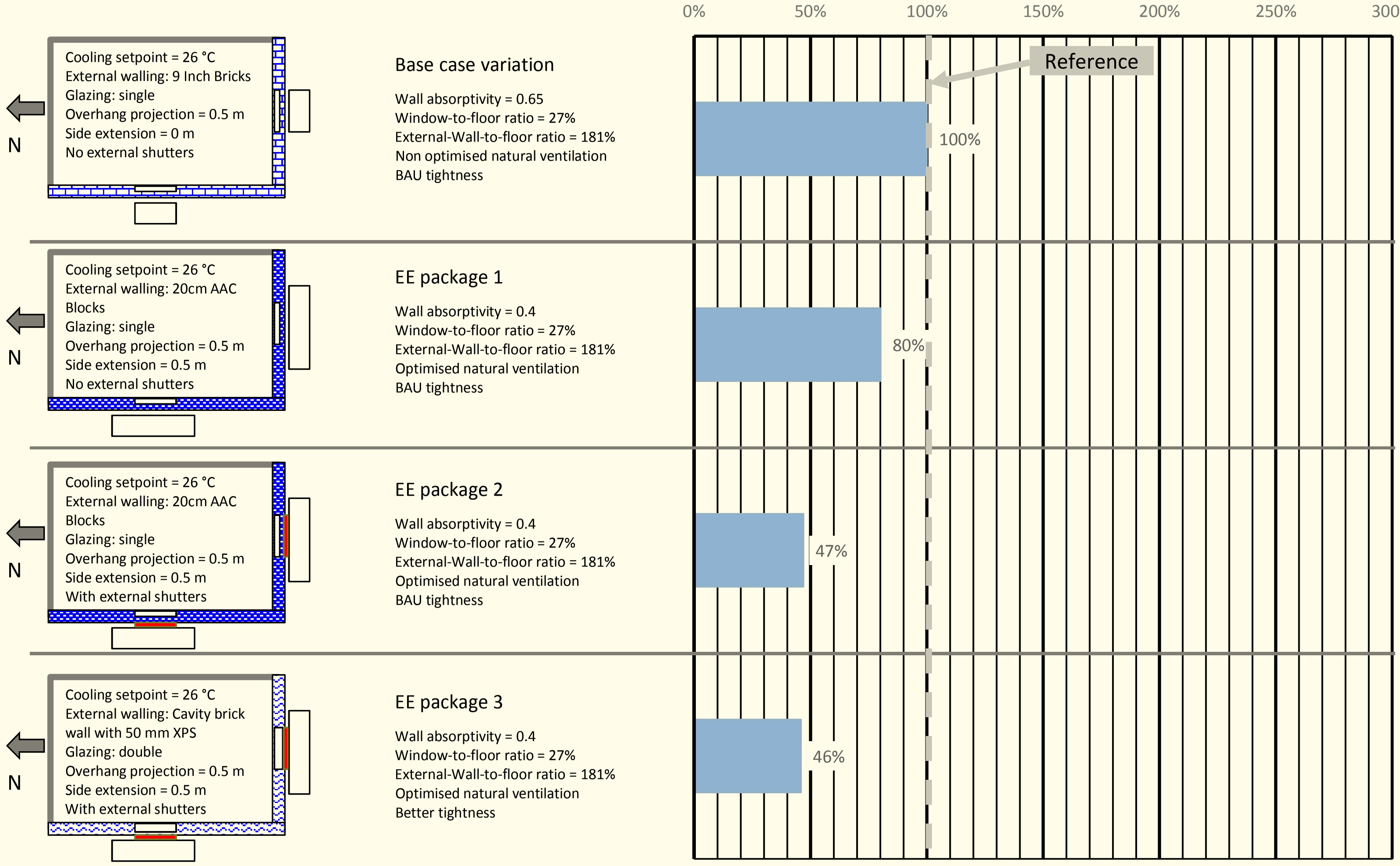

Figure 4.8a *Effect of energy-efficiency measures on the cooling thermal energy demand for the base case of the bedroom in Mumbai*

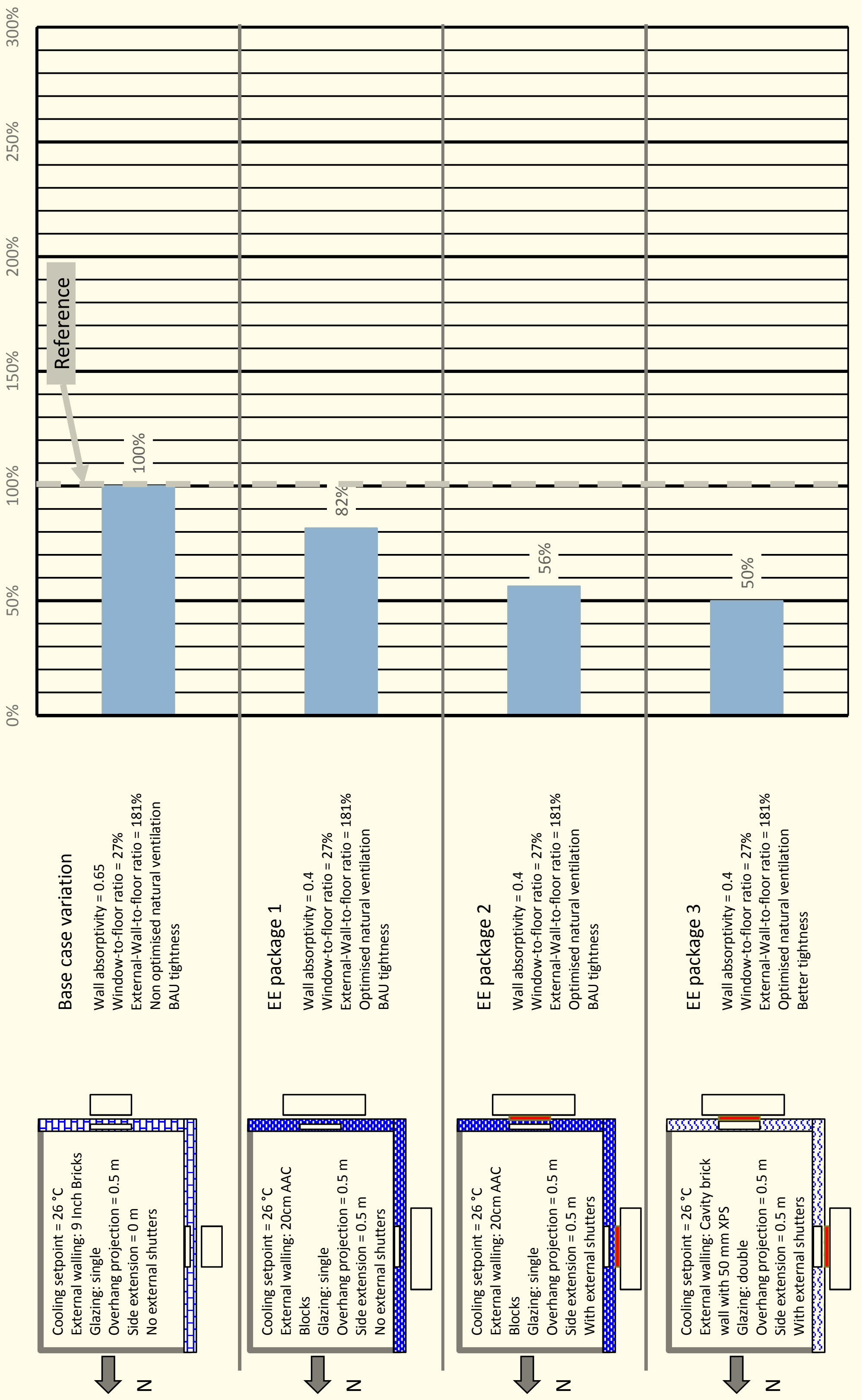

Figure 4.8b *Effect of energy-efficiency measures on the cooling thermal energy demand for the base case of the bedroom in Chennai*

Higher insulation does not help in warm-humid climate zone

Another package of measures (Package III) was analysed in addition to the measures described in Packages I and II. This included:

- *Insulated walls (U-value: 0.5 W/m^2.K):* Use of better insulated walls to achieve U-value 0.5 W/m^2.K. For example, a cavity wall with about 50 mm of modern insulation materials.
- *Double-glazed windows:* Use of double clear glazing on windows with the following properties (U-value: 2.8 W/m^2.K, SHGC: 0.75).
- *Better building air-tightness:* Infiltration losses from the building envelope can be reduced to ~0.35 ACH by improving building air-tightness. This is achieved by effectively sealing the joints in the building envelope by using caulks, gaskets, and weather strips.

The above-mentioned measures essentially provide a better insulated envelope. While in composite and hot-dry climates, these measures lead to reduction in cooling energy, in warm-humid climates, they are not so effective. A large number of simulation runs showed that Package III measures, when applied to different bedroom configurations, do not reduce cooling energy demand more than that resulting from Package II measures (see Annexure 1). In fact, in some cases, it may increase the cooling energy demand.

As the diurnal and seasonal temperature differences are low, difference between inside and outside temperatures is also low. Hence, higher insulation for walls and windows is not very effective. An optimum insulation is required but it is more important to ensure protection from solar radiation.

4.2.1.5 Results of energy-efficiency measures for different types of bedrooms

Figures 4.9a and 4.9b show the comparison of thermal performance of typical bedroom (3 x 3.7 x 3 m) configurations in Mumbai and Chennai for the following four cases.

Two exposed walls

- Case 1 (lower window-to-floor ratio): There are two exposed walls on the south and west with windows on both the exposed walls; window-to-floor area ratio is 0.27.
- Case 2 (higher window-to-floor ratio): Similar to Case 1, there are two exposed walls on the south and west with windows on both the exposed walls. However, in this case, the window-to-floor area ratio is 0.54, i.e., the window area is twice of that in Case 1.

One exposed wall

- Case 3 (lower window-to-floor ratio): There is one exposed wall on the southern side with window; window-to-floor area ratio is 0.27.
- Case 4 (higher window-to-floor ratio): There is one exposed wall on the southern side with window; window-to-floor area ratio is 0.54.

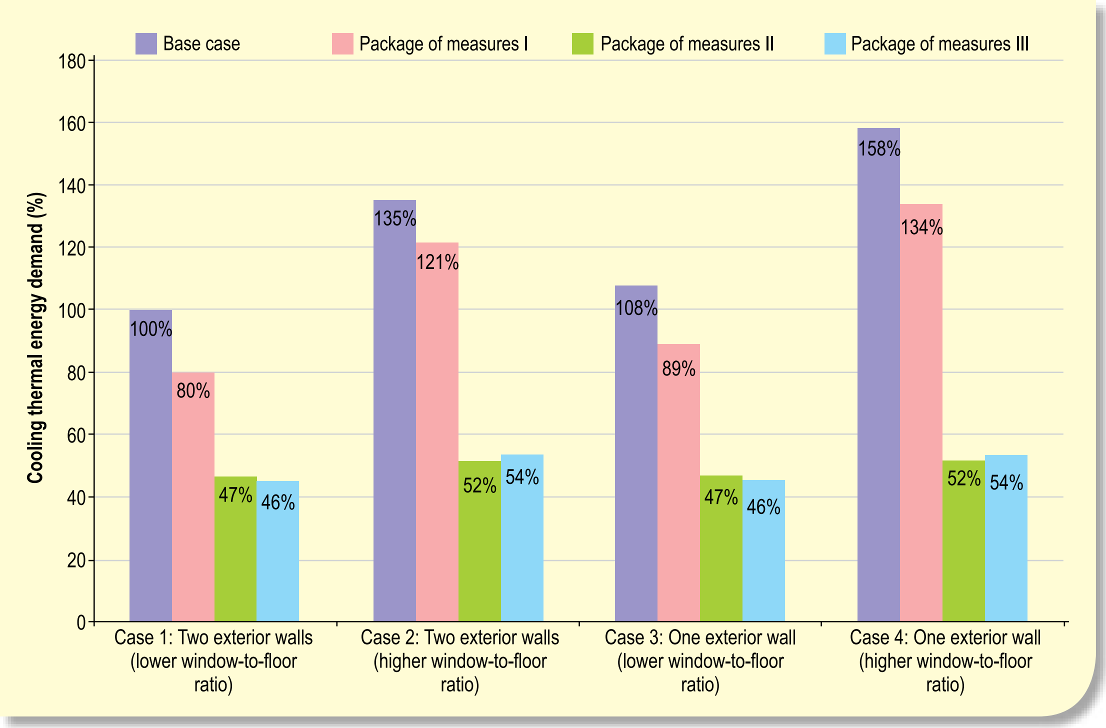

Figure 4.9a *Comparison of cooling thermal energy demands of different bedroom configurations for Mumbai*

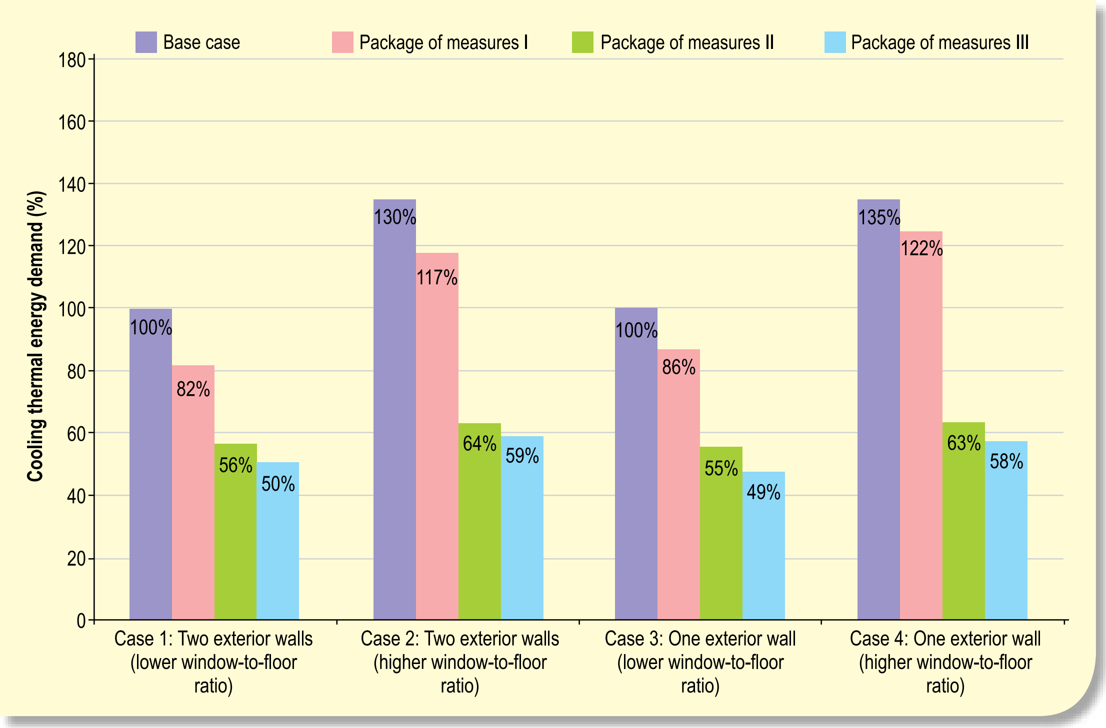

Figure 4.9b *Comparison of cooling thermal energy demand of different bedroom configurations for Chennai*

The interpretation of the results is as follows:

- Cases 2 and 4 have higher glazed area higher (WWR) hence, higher cooling thermal energy demand.
- In all the cases, the highest reduction in cooling thermal energy demand occurs due to the introduction of external movable shutters (Package II).
- Package III measures, i.e., higher wall insulation and double glazed windows, result in less savings in comparison to Package II measure of external movable shading.
- Once the building envelope is optimally insulated, windows are well protected with external movable shading and natural ventilation is optimised, the impact of factors such as the orientation, number of external walls, and glazed area on the cooling energy demand is much lower.

4.2.1 Daylighting analysis for bedrooms

In dwellings, requirements for daylight vary significantly according to different spaces and their usage. Bedrooms typically require illuminance levels between 120 lux and 300 lux, depending on their usage. Living rooms may have slightly higher requirements if they are used more often for eating, reading, and computer work. Kitchens typically require 200 lux to 500 lux because kitchen space has more detailed usage. In all these spaces, it is recommended to have lighting for specific tasks (chopping, reading, writing, etc.), i.e., task lighting, which allows to lower general lighting set points. Table 4.2 below gives an indication of the recommended illuminance levels in different spaces.

Table 4.2 Recommended illuminance levels

Area	Illuminance levels (lux)
Corridors, staircases, toilets	50–120
Entrance lobbies, bedrooms, living rooms	120–300
Kitchens, bathrooms	200–500
Reading and writing, computer work	250–500

Sources Adapted from J K Nayak and JA: *Prajapati, Handbook on energy conscious buildings*, 2006,and Dominique Chuard, *Balanced Climatic Architecture*, Federal Office for Cyclical Questions, Construction & Energy, 1996

Daylight is usually assessed using the following criteria:

- Daylight Factor (DF) is expressed as a percentage and refers to the ratio between the light received on a plane surface in the room (Ii) and the light that the same plane surface would receive outside (Io), without any obstacles to natural illumination, as explained in Figure 4.10.
- According to a parametric study carried out by BEEP (details in Annexure 2), the optimum daylight factor (DF) in bedrooms and living rooms, considering both available daylight and cooling demand, lies between 0.8% and 1.6% in the middle of the room

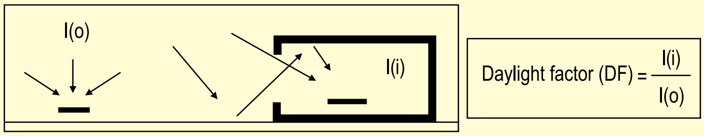

Figure 4.10 Daylight factor

(living room or bedroom). In addition, to ensure good daylight in the further part of the room, the DF in that part of the room should be above 0.5%.[4]

- Daylight Autonomy (DA) is the percentage of the time-in-use that the daylight levels exceed a specified target illuminance or lighting set-point. In other words, the percentage of time that an occupant can work through the use of just daylight without supplemental electric lighting.

Figure 4.11 gives a ranking of the exterior illuminance levels for Chennai (based on the Chennai epw weather file) for one year. The figure shows the percentage of time when daylight will be enough to achieve a required lighting set-point, according to the DF during the whole year from 9 a.m. to 6 p.m. For example, with a DF of 0.5, and for a set-point of 300 lux, 35% of the time daylight is sufficient. DA is increased to 75% with a DF of 1. Similar charts for other cities in the warm-humid zone are found in Annexure 3.

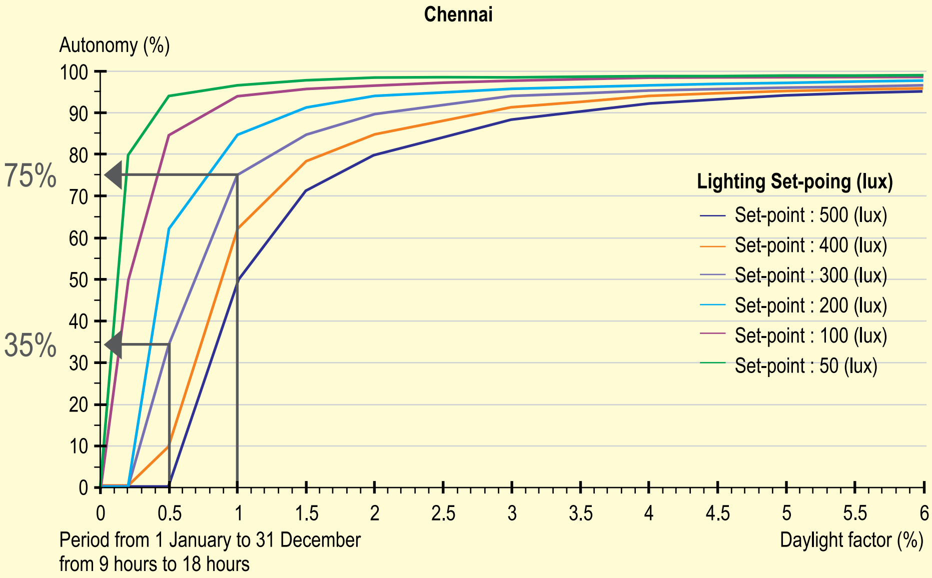

Figure 4.11 *Variation of daylight autonomy in relation to daylight factors for different lighting set-points in Chennai for usage from 9 a.m. to 6 p.m. all year round*

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[4] *One can use a measuring point situated 0.6–1 m from the inside wall.*

4.2.1.1 Methodology

The analysis was performed using Radiance software with the ReluxPro interface,[5] with a uniform skytype.[6] The uniform sky type represents an overcast sky where daylight is evenly spread out in the sky dome. This sky type was selected as it reflects the period of lowest illuminance levels in the warm-humid climate zone. This period corresponds to the time of the year when the diffuse illuminance is two to four times higher than the direct illuminance. For most cities in the warm-humid climate zone, this corresponds to the extended monsoon period.

The same geometry as for the thermal performance analysis was used, with one exposed wall. The dwelling is situated in Chennai, and the simulation was performed with a uniform sky type (see Annexure 4 for details concerning sky type). The base case for daylight analysis has a WWRs of 10% and an overhang of 0.5 m depth over the window (Figure 4.12)

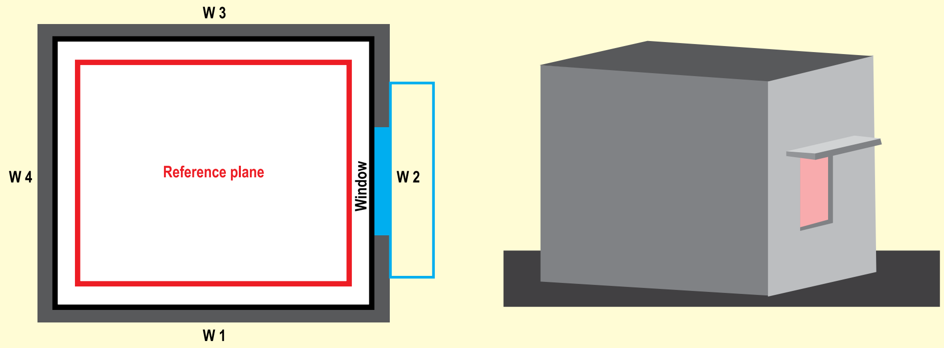

Figure 4.12 *Base case for bedroom with 10% WWR and an overhang of 0.5 m depth*

4.2.2.2 Results

The analysis highlighted that a WWR of 10% provides good daylight in a standard small bedroom (Figure 4.13). In this case, the average DF in the middle of the room is 1.1%, which meets the requirements for dwellings (0.8%–1.6%). In addition, the DF at the end of the room is 0.5%, which ensures satisfactory daylight in the further part of the room. For Chennai, and for usage between 9 a.m. and 6 p.m., this corresponds to more than 75% DA.

In a large multi-storey complex of 12 floors or more, the available daylight is substantially reduced on the lower floors. The daylight analysis performed for the same bedroom on the second floor, with another residential block situated 18 m from the façade, showed that the

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[5] *Date and time: 21 December at 12 p.m. East orientation. However, these results are valid for other times and orientation, since the sky is of uniform type.*

[6] *In order to select the most suited sky for performing daylight simulations in the warm-humid climatic zone of India, a comparative analysis was carried out. See details in Annexure 4.*

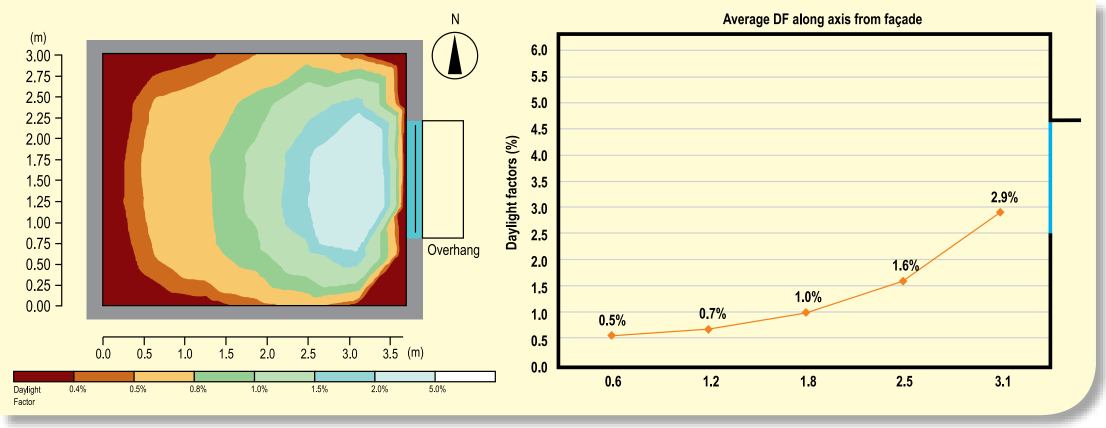

Figure 4.13 *Floor plan of bedroom with DFs in different colours and section of the bedroom representing average DF along axis from façade. Case with 10% WWR.*

DF in the middle of the room is reduced to 0.2%. In this case, the following solutions should be applied to ensure satisfactory daylight:

1. Use light coloured finishes on the façades (reflectivity of 60%). This measure is proposed in Package I and is advantageous for the thermal performance of the building as well as for sufficient daylight in the living spaces.
2. Withdraw the overhangs at lower levels. For the lower floors, the neighbouring building acts as a mask and ensures some solar protection of the bedroom. A solar path analysis performed for the latitude of Chennai showed that the bedroom was exposed to one hour of direct solar radiation, in mid-morning, throughout the year, when the sun is already high.
3. Increase the WWR to 20%.

By applying these three measures for lower floors, it is possible to achieve satisfactory daylighting levels. The analysis performed integrating these three measures for the second floor apartment resulted in a DF of 0.9% in the centre of the room, and 0.5% in the further part of the room (Figure 4.14).

Similar analysis was performed with neighbouring buildings situated at 9 m and 12 m. The results are shown in Table 4.3.

Table 4.3 Measures to improve daylight (in the bedroom) on lower floors in case of shading by adjoining building

Situation	Measures required	WWR required	Results
Apartment block is shaded by building situated 9 m apart	- Light coloured finishes - No overhangs	WWR 30%	- DF in middle of the room = 0.9% - DF in further part of the room = 0.6%
Apartment block is shaded by building situated 12 meters apart	- Light coloured finishes - No overhangs	WWR 25%	- DF in middle of the room = 0.9% - DF in further part of the room = 0.5%

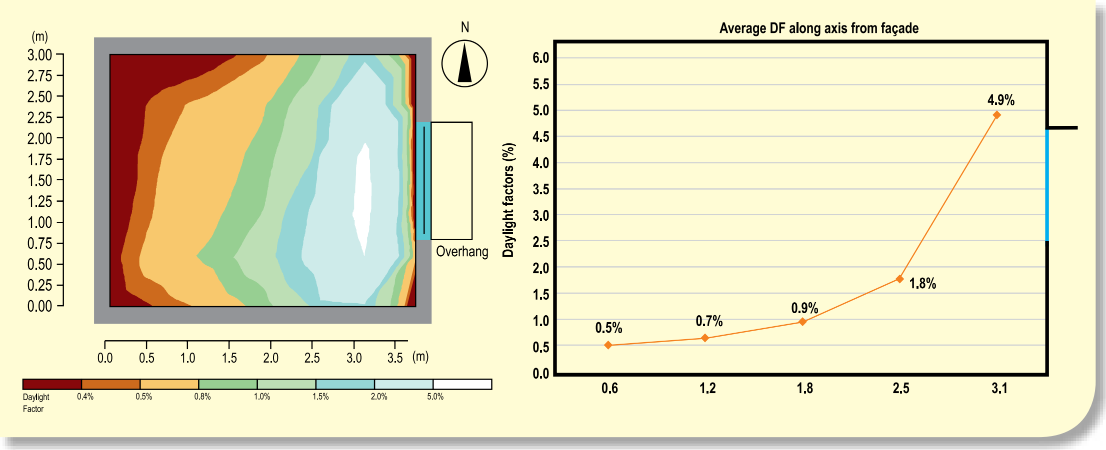

Figure 4.14 *Floor plan of bedroom with daylight factors in different colours and section of the bedroom representing average DF along axis from façade. Case with neighbouring building at 18 m, bedroom on lower floor with 20% WWR, no overhangs light coloured finishes*

4.3 Living rooms

4.3.1 Thermal performance of living rooms

4.3.1.1 Methodology

The model developed for living rooms (3.6 x 6.7 x 3 m, floor area: 24.5 m^2) is for intermediate floor with the ceiling and floor modelled as adiabatic (i.e., no heat flux occurs across these components). The base-case model has two external walls on the south and west direction and other two walls are modelled as adiabatic surfaces (Figure 4.15). The input parameters for simulating the base case are given in Table 4.4. The main difference between the bedroom and the living room is in the occupancy schedule. While the bedroom is occupied mainly in the night, the living room is occupied during the day and evening hours.

4.3.1.2 Passive energy-efficiency solution packages for living rooms

An analysis similar to the bedrooms, as described in Section 4.2.1.4, was carried out for living rooms by carrying out simulations for the base case and then with three passive energy-efficiency solution packages. The results of the simulations are shown in Figures 4.16a and 4.16 b. The results are similar to that of the bedroom. The cooling thermal energy demand is expected to reduce by 3%–12% by using Package I measures, while it is expected to reduce by 35%–50% for Package II. Package III measures show little or no reduction in cooling thermal energy demand in comparison to Package II measures. Once again, the largest reduction in cooling thermal energy demand is attributed to the introduction of external movable shutters.

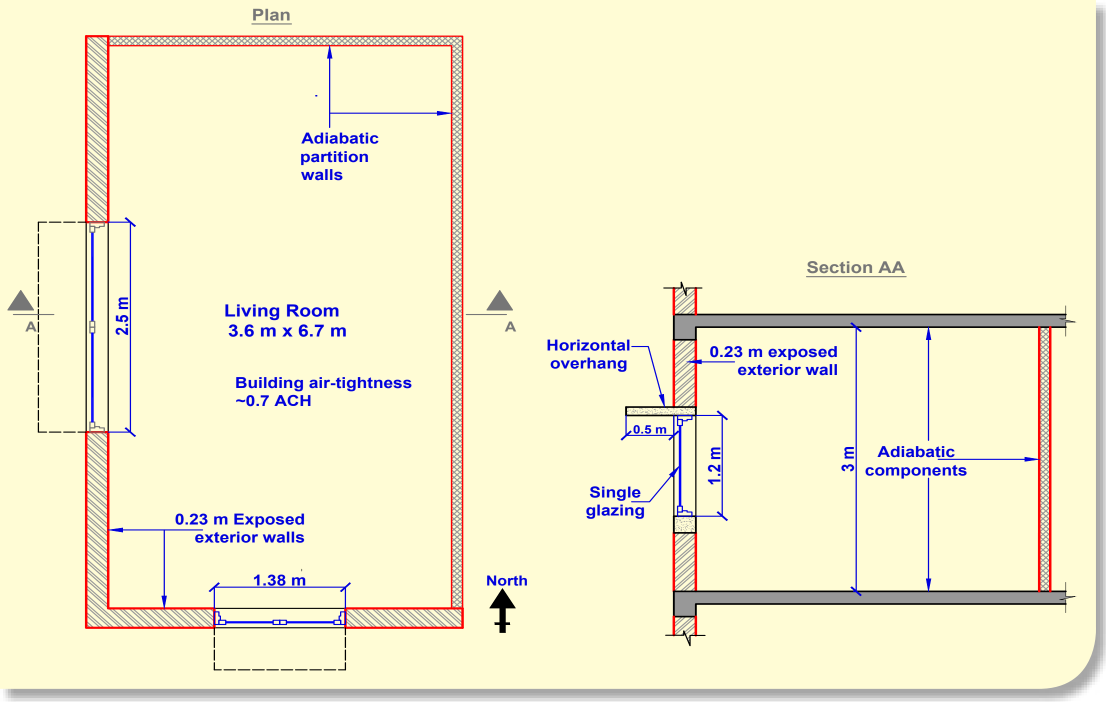

Figure 4.15 *Schematic of base-case model for living room developed in TRNSYS*

Table 4.4 Base-case simulation inputs for a living room

Parameter	Values
Wall External wall: 230-mm brick wall Internal wall: 115-mm brick wall	 U-value: 2.0 W/m^2.K; Surface absorptivity: 0.65 U-value: 3.2 W/m^2.K; Adiabatic
Glazing 6-mm single clear glass	U-value: 6.1 W/m^2.K; SHGC: 0.85 VLT: 0.9
Shading on the window	500-mm horizontal static overhang at lintel level
Intermediate floor 150-mm RCC slab	U-value: 3.0 W/m^2.K Adiabatic
Infiltration	~0.7 ACH
Window-to-floor area ratio	19%
External wall-to-floor area ratio	129%
Occupancy load and schedule	Schedule for weekdays: (4 persons, 7:00–08:00 hours; 1 person, 8:00–14:00 hours; 4 persons, 18:00–21:00 hours) TV: 7:00–8:00 hours, 17:00–21:00 hours Schedule for weekend: (4 persons, 8:00–14:00 hours; 1 person, 14:00–18:00 hours, 4 persons, 18:00–23:00 hours) TV: 7:00–8:00 hours, 17:00–23:00 hours
Set-point temperature	26 °C
Locations	Mumbai and Chennai

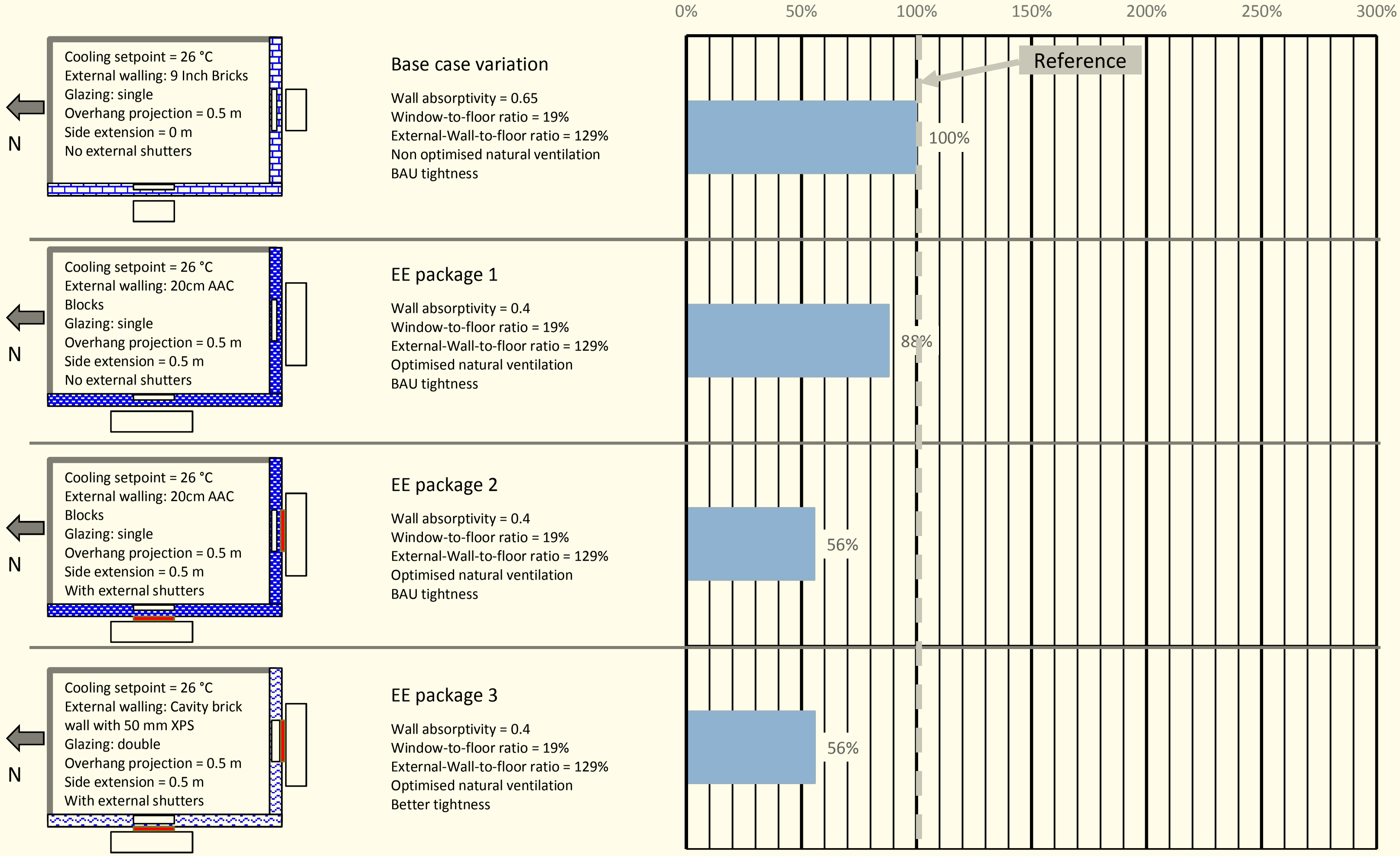

Figure 4.16a *Effect of energy-efficiency measures on the cooling thermal energy demand for the base case of the living room in Mumbai*

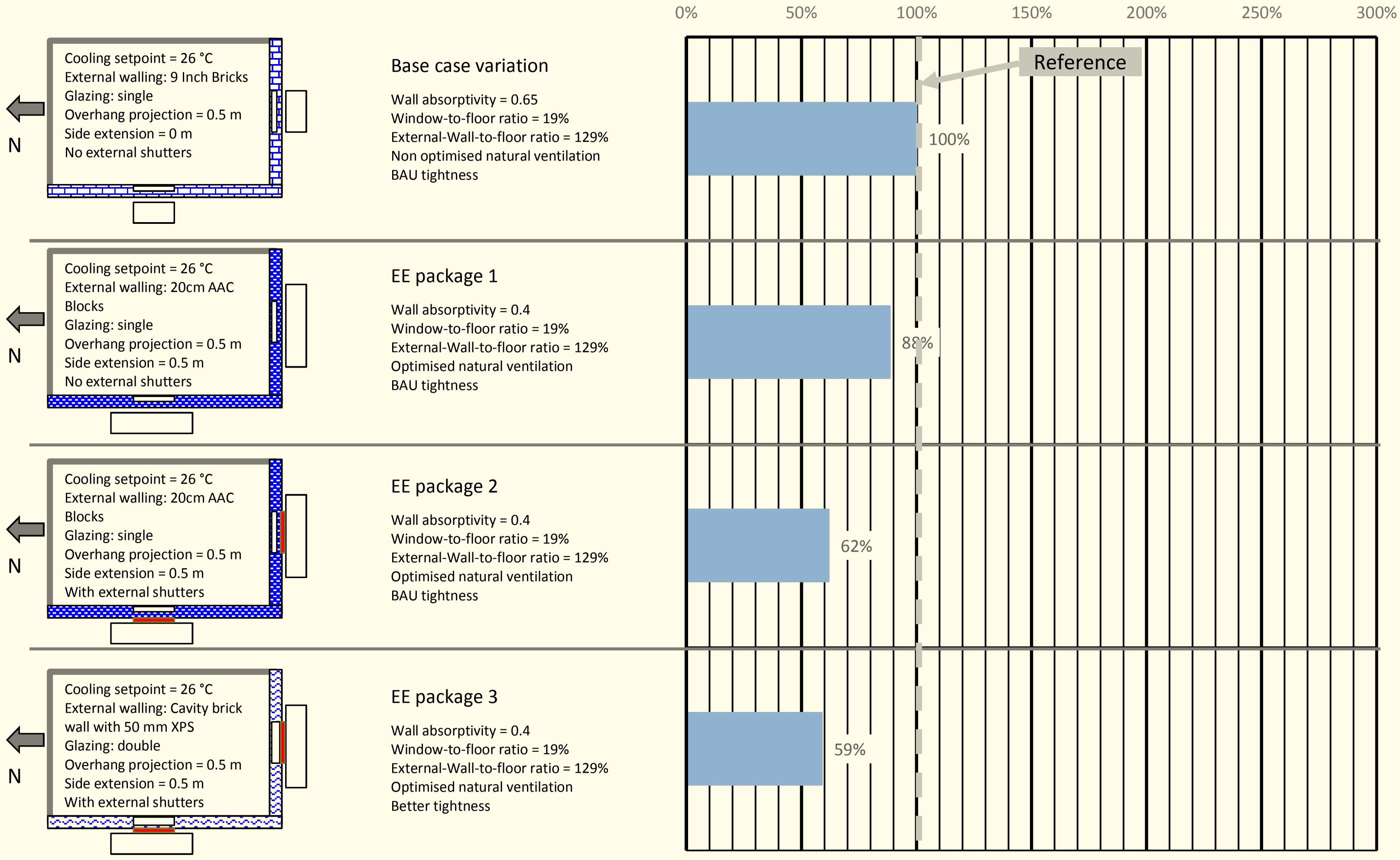

Figure 4.16b *Effect of energy-efficiency measures on the cooling thermal energy demand for the base case of the living room in Chennai*

4.3.2 Daylighting analysis for living rooms

The daylighting analysis for living rooms was carried out using the same methodology as described for bedrooms. The geometry is the same as the one used for thermal performance analysis with one exterior wall. The parametric study showed that for a standard living room with no shading from mutual buildings, a WWR of 25% is sufficient to ensure daylight in the living room (Figure 4.17), when the windows are evenly spread out on the exterior façade. The resulting DF in the middle of the room is 1.1%. For an apartment situated in Chennai, and for use from 9 a.m. to 6 p.m. and for a set-point of 300 lux, this results in a DA of 78%.

If the building is situated in a multi-storey complex, then the requirements for the lower floors will vary as indicated in Table 4.5.

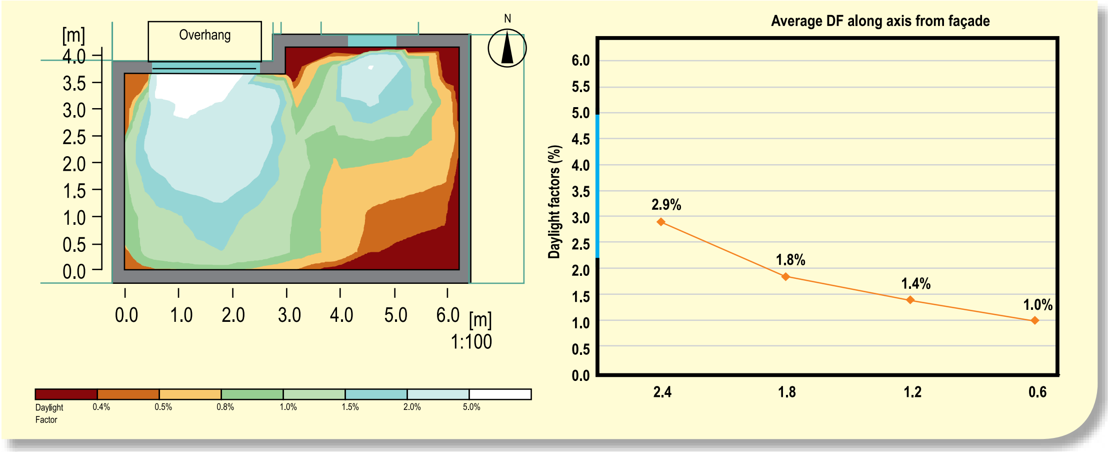

Figure 4.17 *Floor plan of living room with iso-daylight factors in different colours and section of the living room representing average DF along axis from façade. Case with 25% WWR.*

Table 4.5 Measures to improve daylight (in the living room) on lower floors in case of shading by adjoining building

Situation	Measures required	WWR required	Results
Apartment block is shaded by building situated 9 m apart	- Light coloured finishes - No overhangs on lower floors	30%	DF in middle of the room = 1.2%
Apartment block is shaded by building situated 12 m apart	- Light coloured finishes - No overhangs on lower floors	30%	DF in middle of the room = 1.5%
Apartment block is shaded by building situated 18 m apart	- Light coloured finishes - No overhangs on lower floors	20%	DF in middle of the room = 1.1%

4.4 Roofs

Roofs receive approximately four times more solar radiation (kWh/m^2) than walls during summer months. For the flats located on the topmost floor, heat gain through the roof forms a significant portion of the overall heat load. The increased indoor surface temperature of the roof also reduces the thermal comfort of the occupants.

The heat flux through the roof can be reduced by using over deck insulation (insulation placed above the structural slab) and by using high reflective (absorptivity <0.4) finishes/ paints (Figure 4.18). Periodic maintenance of the roof is required to retain the reflective characteristics of the surface.

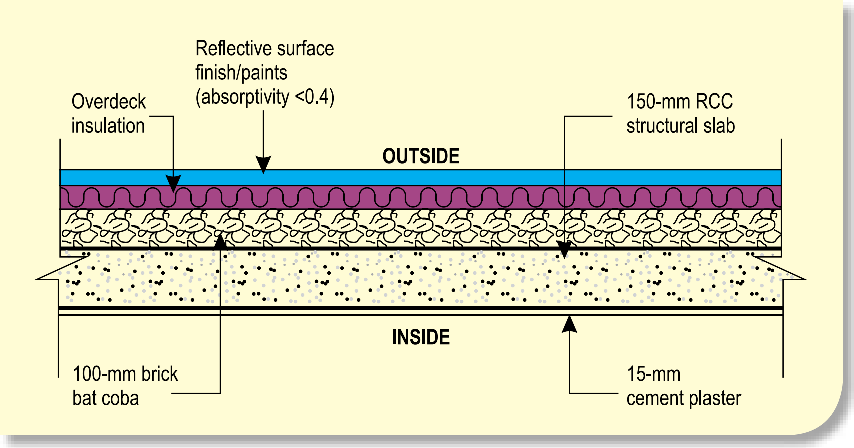

Figure 4.18 *Typical section of the roof showing over-deck insulation and reflective surface finish*

RECOMMENDATIONS

Recommendation 3: Passive measures for walls and windows to reduce the cooling energy

- Limit glazed area. Window-to-wall ratio (WWR) of 10%–30% in bedrooms and 20%–30% in living rooms allow a good balance between adequate daylight and reduced heat gains (see also Recommendation 4).
- Ventilation is of prime importance. More details on ventilation is given in Chapter 5.
- It is more important to shade the windows than increase the wall insulation and use double-glazed units.

contd...

contd...

The northern façade of a building needs better protection from sun as we go further south in India.

- Package of Measures I that can bring about 7%–20% reduction in cooling energy: Use of light colours on walls (absorptivity ≤0.4) + window shades with extended overhangs + insulated walls (U-value: 0.7 $W/m^2.K$) + optimised natural ventilation.
- Package of Measures II that can bring about 40%–65% reduction in cooling energy: Package of measures I + external movable shutters on windows.

Recommendation 4: Daylighting

- Usually 10% WWR in bedrooms and 20% WWR in living rooms are needed to provide sufficient daylight.
- However, when building blocks in a residential complex are located near each other, daylighting in bedrooms and living rooms located on lower floors is reduced substantially. The daylight on the lower floors can be improved by: (a) increasing the window area (maximum WWR 30%), (b) using light colours with smooth finishes on the wall opposite to the window, and (c) using light colour interiors.

Recommendation 5: Passive measures for the roof

- Provide over-deck insulation and high reflective surfaces on the roof to minimise heat gain through the roof.

CHAPTER 5

NATURAL VENTILATION AND SPACE COOLING

AT A GLANCE

Space cooling and fans take up a significant share of the total electricity consumption. Detailed analysis of electricity consumption in some sample flats shows that the contribution of electricity consumption for space cooling and fans can vary from 36% to 60% of the total electricity consumption.

In the warm-humid climate, it is important to (a) restrict solar heat gains into the building during the day; (b) maintain good air ventilation inside the flat to remove heat generated inside (by humans, cooking, etc.); and (c) maintain good air movement for achieving thermal comfort of the occupants. Natural ventilation potential is influenced by wind direction, wind velocity, and design of openings.

When it is not possible to achieve thermal comfort by ventilation and air movement, one can opt for air conditioning. The electricity consumption in an air-conditioning system primarily depends upon:

- the cooling set-point temperature and
- the choice of space-cooling technology and system configuration.

RECOMMENDATIONS FOR NATURAL VENTILATION AND SPACE COOLING

Recommendation 6: Design and position windows to improve natural ventilation

- Wherever possible, provision for cross-ventilation at the flat or room level is to be made. Cross-ventilation brings about higher air-change rates, i.e., better ventilation. In the case of cross-ventilation, openable window area should be at least 10%–15% of the floor area, for both inlet and outlet openings.
- In the case of single-sided ventilation, i.e., having window(s) on one wall of the room, tall windows should be designed. These windows should have openings at the bottom (for entry of cold air into the room) and at the top (for the exit of warm air to the outside). The height/width ratio of 2 is practically feasible for such windows for regular bedroom sizes.

- As far as possible, openings should be placed normal to the prevalent wind direction. If the wind direction is >60° from the normal direction of the opening, i.e. parallel to the wall, design features like wing walls or providing louvres on the outside surface of the wall can help in steering the wind inside.
- Casement windows are recommended over sliding windows as they allow more openable window area.

Recommendation 7: Use of efficient ceiling fans

- Use BEE star-rated or super-efficient ceiling fans.

Recommendation 8: Raise the cooling set-point

- Raising the cooling set-point from 24 °C to 28 °C (~adaptive comfort temperature for summer as per ASHRAE 55) can bring ~55%–60% reduction in cooling demand.

Recommendation 9: Use energy-efficient air-conditioning system

- When using conventional air-cooled windows or split units, use the highest star rating possible.
- Incorporate new and innovative ways to improve efficiency of room air-conditioners. For example, an individual water-cooled split unit cooled through a central loop attached to a cooling tower (ultimate potential ~40% savings against air-cooled split).

5.1 Introduction

In warm-humid climate, in general, daytime temperatures are high (~25 °C–35 °C), day–night temperature difference is less (~5 °C–10 °C) and humidity is high (>50%). In this climate, it is important to (a) restrict solar heat gains into the building during the day; (b) maintain good air ventilation inside the flat to remove the heat generated inside (by humans, cooking, etc.); and (c) maintain good air movement for achieving thermal comfort of the occupants. When it is not possible to achieve thermal comfort by ventilation and air movement, cooling through air conditioning is to be employed. The building envelope measures to reduce heat gains have already been described in Chapter 4. This chapter deals with the issue of ventilation and air circulation (through natural or mechanical means) and cooling (air conditioning). As seen in Chapter 2, in warm-humid climate, space cooling and fans account for a large share of the total electricity consumption. Hence, the objective should be to optimise natural ventilation in the flats and increase the efficiency of fans and air conditioning.

5.2 Strategies to improve natural ventilation

Natural ventilation serves two main purposes: first, it provides fresh air for an acceptable indoor quality; and, second, it removes heat from inside the building and facilitates cooling. Standard ventilation rates are given in the National Building Code (Part 8; Section 1; 5. Ventilation) or ASHRAE 62.1–2016. However, ventilation rates for cooling should not be confused with these standard rates. These standard rates are the minimum requirement for maintaining acceptable indoor air quality (oxygen, carbon dioxide, and other air quality levels), and for the removal of odour. To remove heat, a larger volume of air flow is required and hence, ventilation rates for cooling are usually higher compared to the standard rates.

In warm-humid climate, the ambient air temperature is lower compared to the temperatures inside the building for several hours particularly during morning, evening, and night. During these hours, natural ventilation strategies to bring in cool ambient air inside the building can be employed effectively. A large part of the warm-humid zone in India consists of coastal areas with good wind velocities, which facilitates natural ventilation.

Designing for natural ventilation deals with two subjects: (a) the wind available at the location; and (b) the design features of the building to use the wind. The design features primarily refer to the design of the windows or other elements that create pressure differences between the outside and inside of the building to induce air flow. The characteristics of the wind, mainly velocity and direction of flow with respect to the window opening, and the number, size, and location of window openings in the building impact how effectively it can be ventilated naturally.

One of the parameters to measure the effectiveness of natural ventilation is hourly air change rate (ACH), which is a measure of how many times the air volume inside a room is replaced by fresh air in an hour. Greater the number, better is the cooling potential through natural ventilation. Usually, 5 to 20 ACH provides good natural ventilation.

The impact of wind direction at the building massing level has been described in Section 3.5. In the following sections, the influence of wind direction, wind velocity, number and position of windows, etc. on the ACH, as well as its implication on window design have been described.

5.2.1 Natural ventilation analysis: ventilation rate

5.2.1.1 Methodology

Model

To assess the impact of wind characteristics and window layout on the air change rate, a simulation model was developed in TRNSYS 17 / TRNFlow.[1] The model was developed for a bedroom of a flat, as shown in Figure 5.1. The bedroom has a size of 5 × 3 × 3 m with windows on two adjacent exposed walls, W1 and W2, respectively. The internal wall also has a window, W3, situated on the top of the door, connecting the bedroom with the rest of the flat. W4 refers to another window in the flat, which is open to the atmosphere.

The inputs for the model are given in Table 5.1.

Wind direction

W1 of the model faces the south, W2 faces the west, and W4 faces the north. Simulation was carried out for various wind directions, where 0° means wind flowing from the south and 90° means wind flowing from the west (Figure 5.1).

Wind velocity

This simulation was carried out for four wind velocities—0.2 m/s, 1 m/s, 3 m/s, and 5 m/s. This was done to account for varying outside wind velocities at the site. Apart from the broader macro-level factors, wind velocity varies as per the height of the building and surrounding obstructions at the micro level. Coastal cities have higher wind velocities than inland cities.

Along with the parameters of wind direction and velocity, the simulation also considered different window-operation combinations.

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[1] *TRaNsient SYstems Simulation (TRNSYS) is a software used for building energy simulation. TRNFlow is an add-on to TRNSYS for air-flow simulation in buildings.*

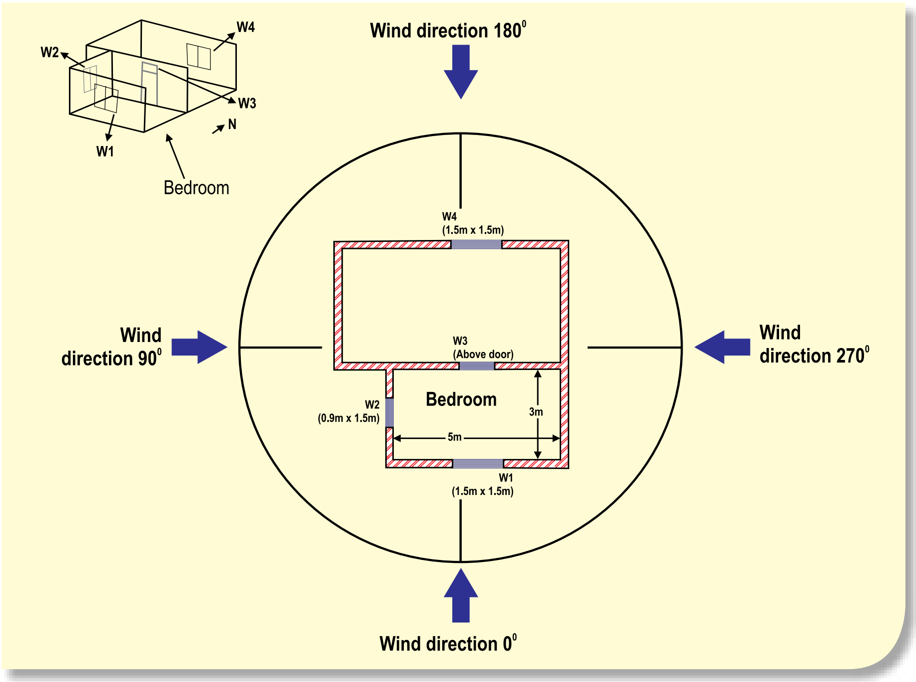


Figure 5.1 *Schematic of the model developed in TRNSYS for air-flow*

Table 5.1 Inputs for the simulation of air-flow simulation

Parameter	Values
Room length	5 m
Room width	3 m
Room height	3 m
Window W1	1.5 × 1.5 m (taking window area as 15% of the wall area)
Window W2	0.9 × 1.5 m (taking window area as 15% of the wall area)
Window W3	1.5 × 0.5 m
Window W4	1.5 × 1.5 m (taking window area as 15% of the wall area)
Maximum window opening for natural ventilation	50% openable (taking sliding window as the base case)
Coefficient of discharge of flow[a]	0.25 (taking into account wire mesh on window for insect protection)

[a] The coefficient of discharge is the ratio of the actual discharge to the theoretical discharge.

5.2.1.2 Results

Single-side ventilation (Case 1)

When a room has only one window for ventilation (W1 open, while W2, W3, and W4 are closed), the impact of wind is relatively weak. This is due to the fact that in the absence of an outlet, the wind pressure cannot push the air through the room. The results of the analysis are plotted in Figure 5.2. The ACH is plotted on the y-axis, while the wind direction is plotted on the x-axis. As can be seen from the figure, at lower wind velocities (0.2 m/s and 1 m/s), the hourly ACH is around 3 and remains unchanged, irrespective of the wind direction. At

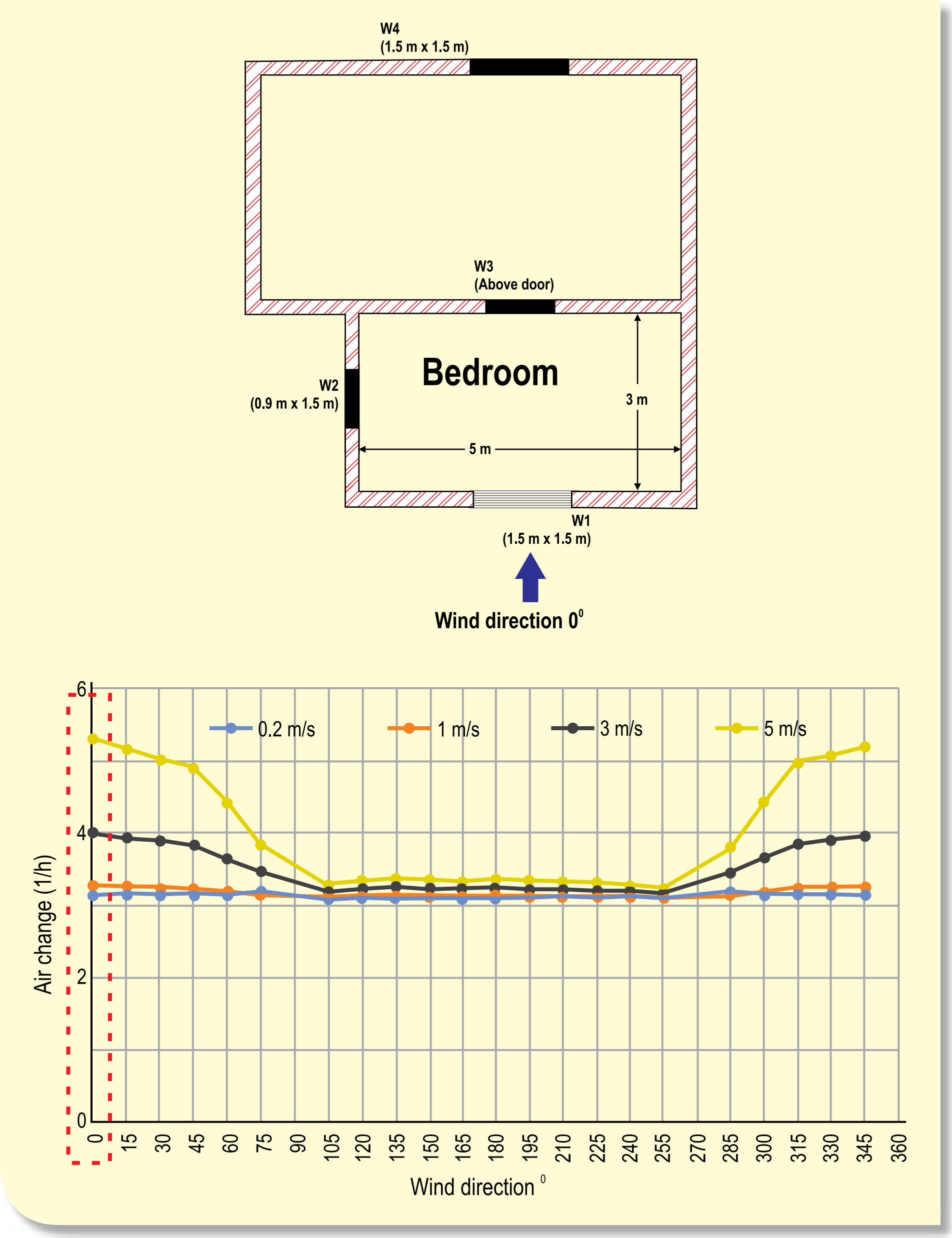


Figure 5.2 *Hourly air change rates inside in the case of single side ventilation for different wind velocities*

higher wind velocities (3 m/s and 5 m/s), some improvement in the ACH is observed when the wind is perpendicular to the window. This is due to leaks and turbulences, which allow more air into the room when the wind velocity increases. However, even when the outside wind velocities are higher, the ACH remains small and does not increase beyond 5.

Cross-ventilation through the room (Case 2)

In a room with windows on two adjacent walls (W1 and W2 open while W3 and W4 are closed), ventilation rates are better (Figure 5.3). A minimum air change rate of 5 ACH is

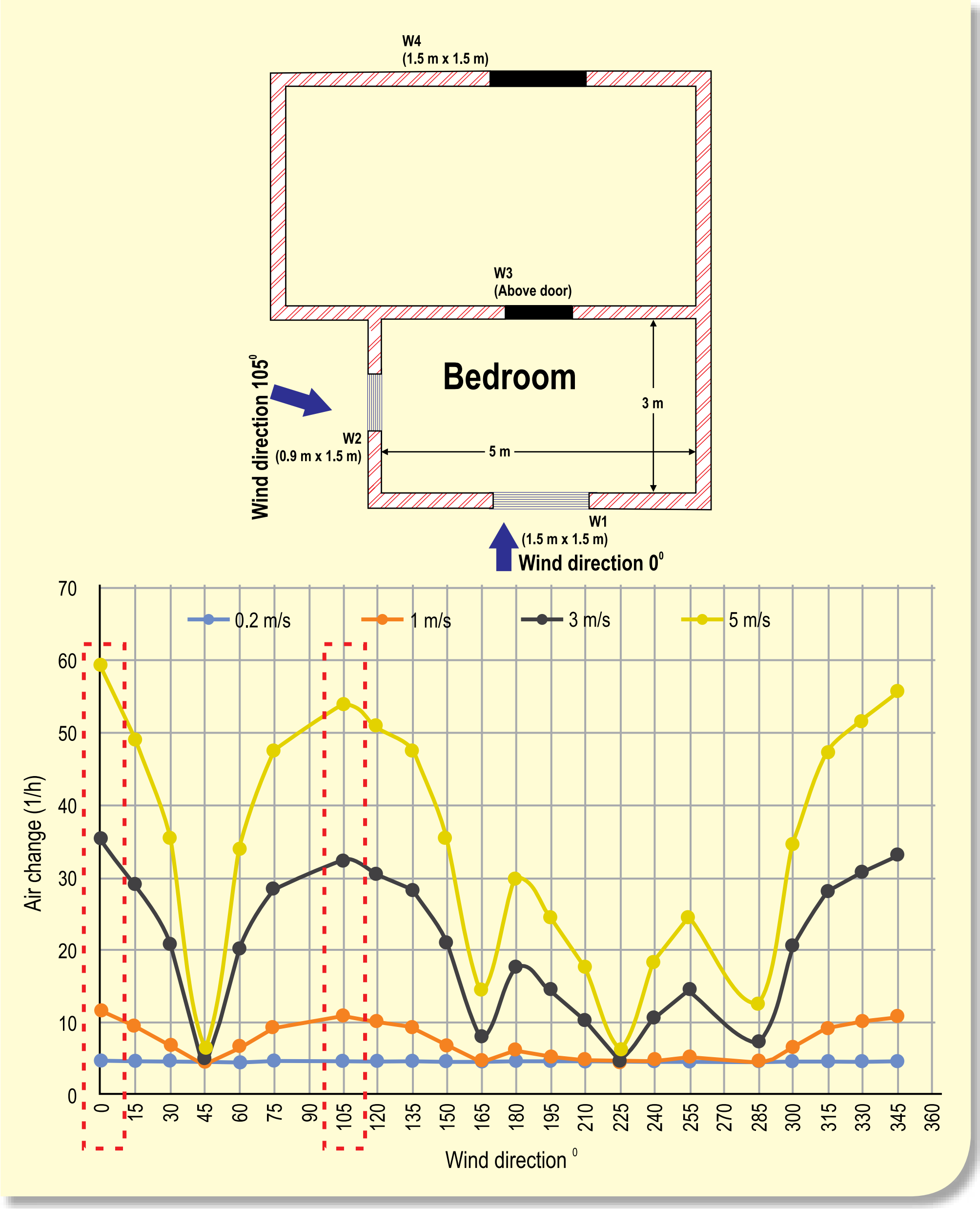


Figure 5.3 *Hourly air change rates inside in the case of cross-ventilation through the room for different wind velocities*

achieved even with low wind velocity, irrespective of wind direction. High ventilation rates are achieved when the wind direction is near perpendicular to one of the windows (in the model 0°, 105°).

Cross-ventilation through the flat (Case 3)

In this case, the room has a window on one external wall (W1). Additionally, the internal wall opposite the window has an opening over the door (W3) and the adjoining room also has a window (W4). Thus, W1, W3, and W4 are open and W2 is closed. Minimum ventilation rate of 3 ACH is achieved with low wind velocity. With higher wind velocities, very high air change rates are achieved, especially when the wind direction is perpendicular to either W1 or W4 (Figure 5.4).

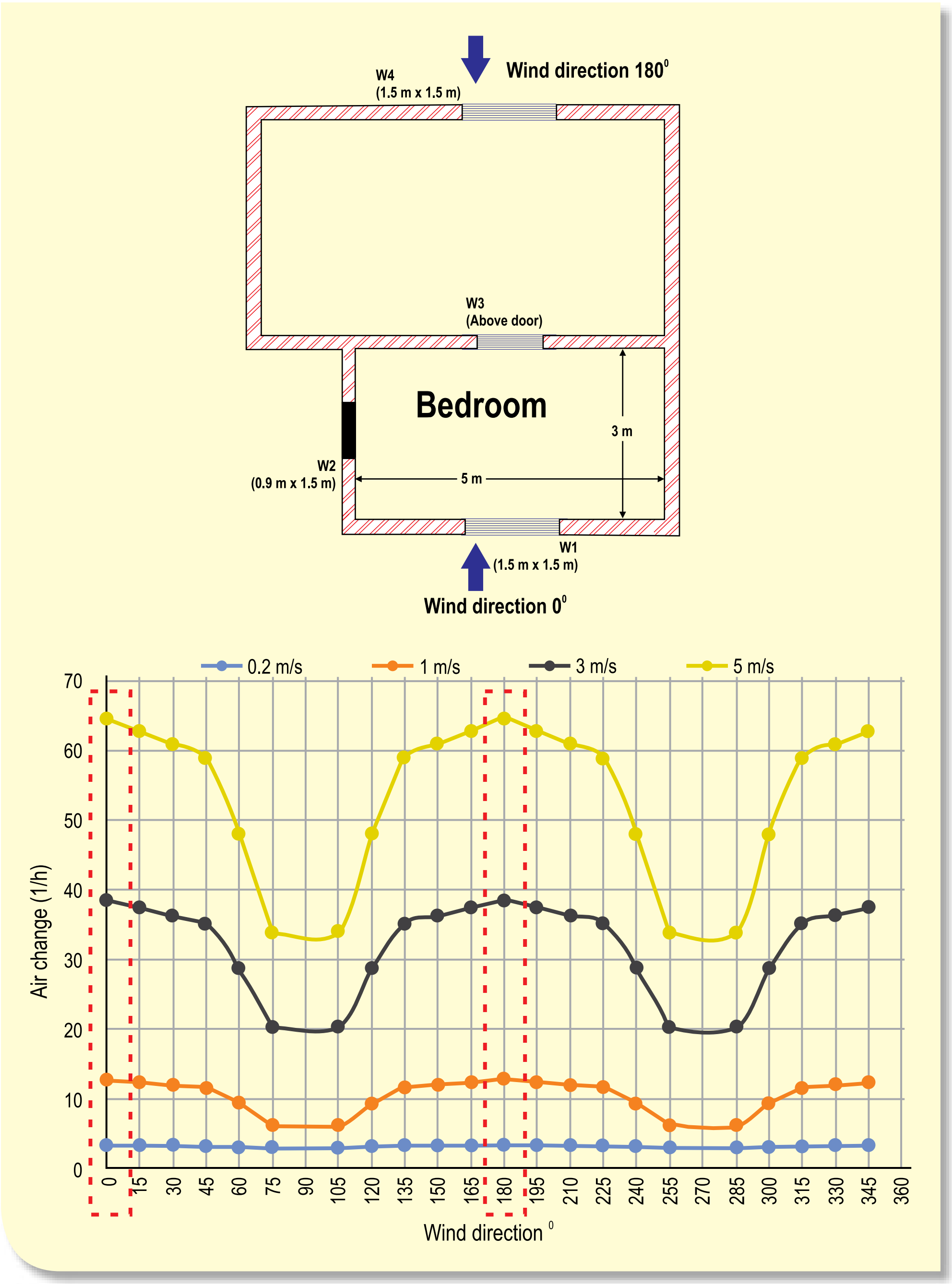


Figure 5.4 Hourly air change rates inside in the case of cross-ventilation through the apartment for different wind velocities

Conclusions

The analysis above shows that:

- Single-sided ventilation (Case 1) only provides the minimum ventilation required for health requirements given in the standards.
- Cross-ventilation, through the room or through the flat (Cases 2 and 3), can generate good ventilation rates to make passive cooling possible.
- Cross-ventilation through the flat (Case 3) gives better uniformity of ventilation rates over different wind directions.

5.2.2 Natural Ventilation Analysis: Window Design

Window design – its size, location and other features – influences the air change rates inside the room, as well as the distribution of air within the room.

5.2.2.1 Single-sided ventilation

Air change rates achieved by single-sided ventilation are low. However, given the dense urban settlements in India, in many cases, this may be the only option. Wind velocities available at the site may also be very low.

In such cases, tall and narrow windows help improve the air change rate. Tall windows result in stack effect or buoyancy effect, where warm air rises and exits through openings at the top and is replaced by cooler air entering lower in the room. Figure 5.5 shows the optimum aspect ratio (height/width) of the window opening to achieve specific air change rates for different window areas, in the absence of any wind and with a temperature difference of 3 °C between the inside and the outside.

For example, to achieve ACH of 8, with window area of 2 m^2, an aspect ratio of 2 is required. Thus, the optimum window dimension will be 1 m width × 2 m height. It must be noted that the window area and sizes mentioned are for openable window area. A fly mesh is also included in the window design.

For single-sided ventilation, two well-placed windows may slightly improve ventilation instead of having one window (Figure 5.9).

5.2.2.2 Cross-ventilation

Window size

As seen in Section 5.2.1, cross-ventilation results in good air change rates. Further analysis shows that optimum window area is required to achieve specific air change rates at a given air velocity. This is shown in Figure 5.6.

For example, to achieve ACH of 30 with an air velocity of 1 m/s, the optimum openable window area of both inlet and outlet windows is 1.9 m^2 each. The same windows will generate an ACH of 45 at 1.5 m/s. As a general rule, the inlet and outlet openings should be of the same size.

Figure 5.5 *Optimum aspect ratio of window opening to achieve specific air change rates for different opening areas, for single sided ventilation.*

(Based on calculations by: C. Ghiaus, F. Allard, J. Axley, C. A. Roulet. Natural Ventilation: Principles, Solutions and Tools.)

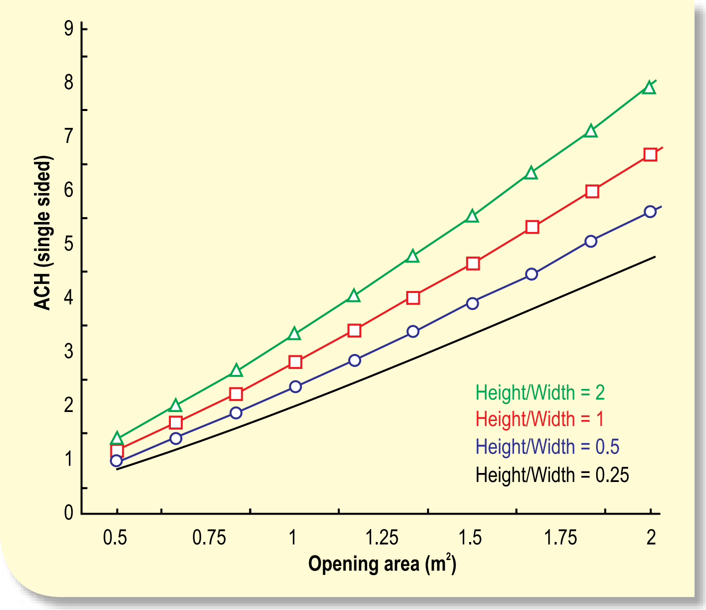
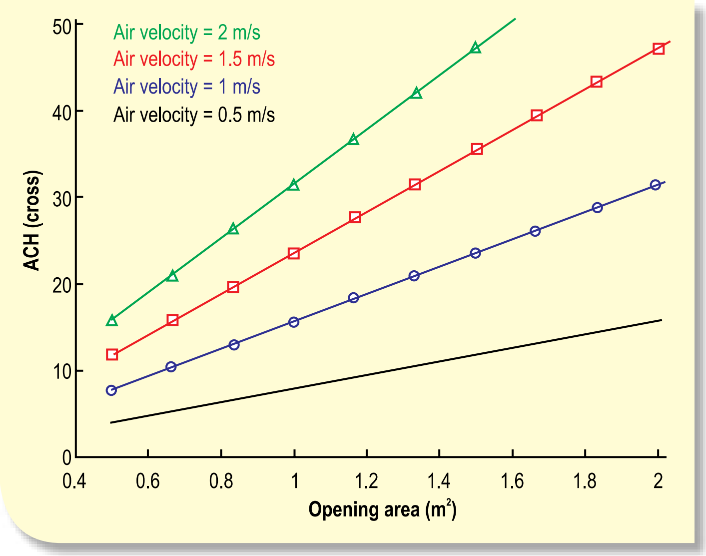


Figure 5.6 *Optimum window area to achieve specific air change rates at specific air velocities, for cross-ventilation*

(Based on calculations by: C. Ghiaus, F. Allard, J. Axley, C. A. Roulet. Natural Ventilation: Principles, Solutions and Tools.)



Window position

The windows for cross-ventilation must be located in such a way that the incoming air is well distributed within the room and is available at the level of the occupants. For example, windows directly opposite each other will result in some areas of the room not receiving enough air flow. Also, if both inlet and outlet openings are located high in the room, the effect of natural ventilation will not be felt at the occupant level.

Figures 5.7 and 5.8 show a few configurations of inlet and outlet openings in plan and section along with their effectiveness.

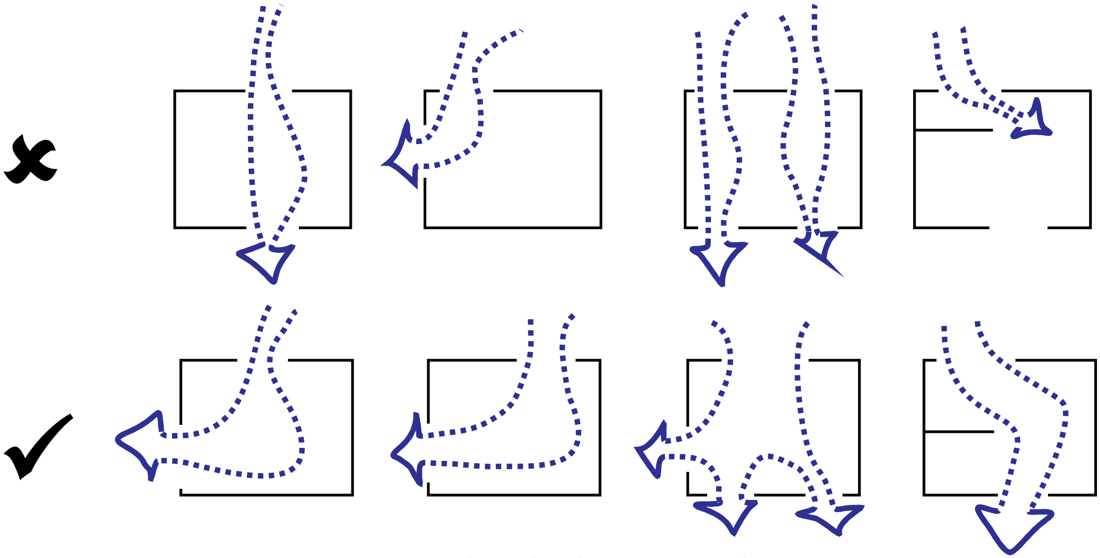


Figure 5.7 *Inlet and outlet openings in plan*
(Modified from: http://www.nzeb.in/knowledge-centre/passive-design/natural-ventilation/)

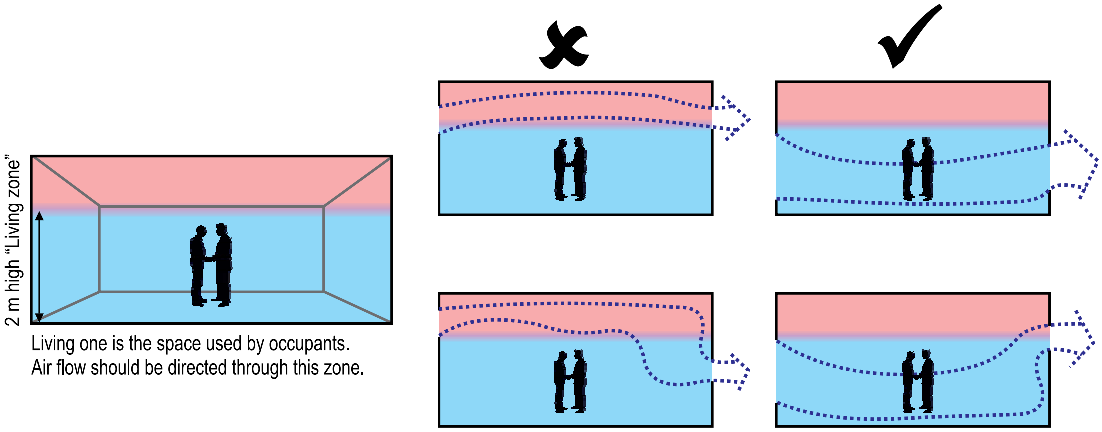


Figure 5.8 *Inlet and outlet openings in section*
(Modified from: http://www.nzeb.in/knowledge-centre/passive-design/natural-ventilation/)

Other design features to improve ventilation

- Different design features can help steer outside air into the building. Architectural features like wing walls, louvres, window shutters, and even well-placed vegetation can direct air into the room. Generally, if the prevalent wind direction is at an angle >60° to the surface normal of the window, wing walls are recommended to steer the air into the room. Figure 5.9 shows the effectiveness of different wing walls in different situations and can act as a guide to locating wing walls. The wind-rose gives the prevailing wind direction for which air velocity inside the room is improved by the wing walls. The depth

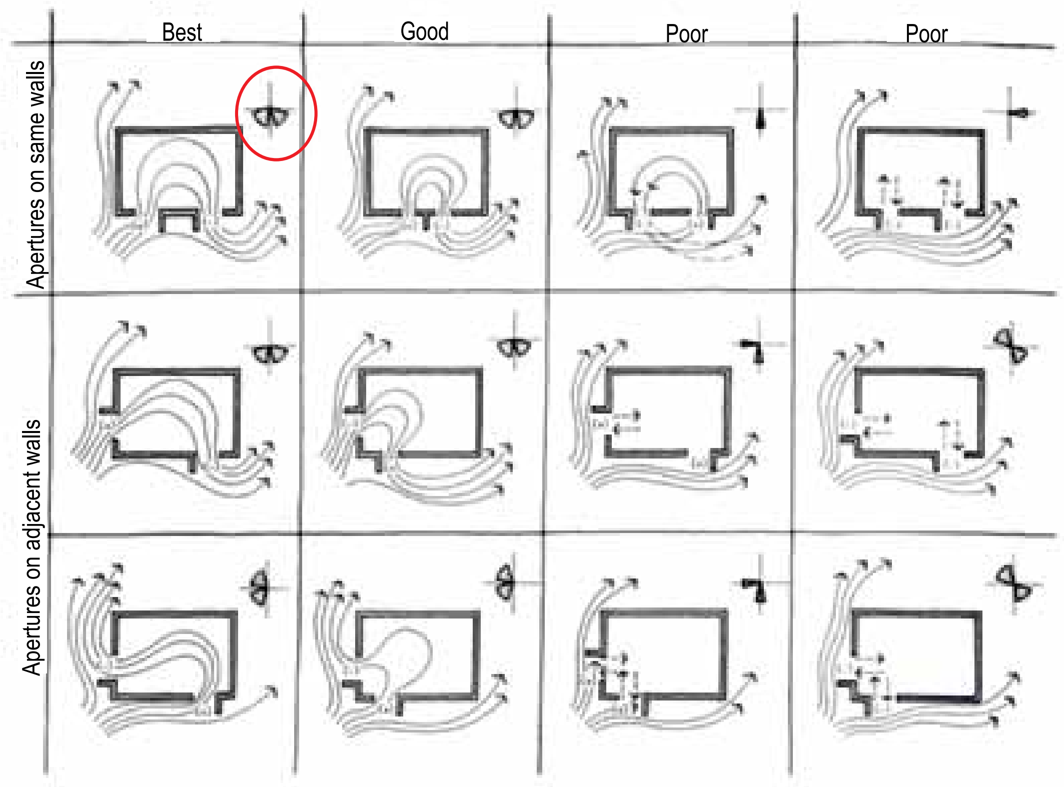


Figure 5.9 *Different wing walls of better and worse effectiveness on the same wall and adjacent walls. The wind rose (circled in red) gives the prevailing wind direction for which air velocity inside the room is improved by the wing walls.*

Source *Brown G Z and Mark DeKay. 2000. Sun, Wind, and Light, p. 184. Wiley.*

of the wing wall should be at least 0.5–1 times the width of the window. The spacing between wing walls should be at least twice the width of the window.[2]

- Casement windows are especially recommended in warm-humid climate. They allow twice the openable area for natural ventilation, in comparison to sliding windows (Figure 5.10). The shutters of these windows can also act as wind steering features in different combinations.

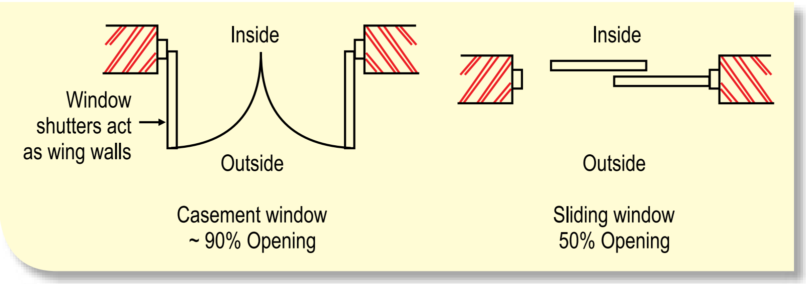


Figure 5.10 *Casement and sliding windows*

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[2] *Brown G Z and Mark DeKay. 2000. Sun, Wind, and Light, p. 184. Wiley.*

Other building design features such as solar chimneys help induce air flow in the building. However, these need to be designed carefully on a case-by-case basis depending on the specific building context and design.

5.3 Mechanical Ventilation with Ceiling Fans

Most of the time, the natural wind velocity or the wind direction will not be conducive for cooling. Hence, mechanical means will be required for cooling. In residences, ceiling fans are the most commonly used mechanical means of cooling. They are immensely effective in warm-humid climate. Ceiling fans can bring down the 'apparent temperature' or the 'felt air temperature' by 2 °C–4 °C. In most of the warm-humid areas of India, ceiling fans are used almost all the year round.

Energy-efficient ceiling fans can make a huge impact in reducing energy costs while improving thermal comfort in warm-humid climate. Currently, super-efficient fans and BEE star-rated fans are available in the market, which consume less electricity than regular fans. Typical ceiling fans available in the market consume 70–80 watts whereas BEE star-rated fans consume 45–50 watts, while super-efficient fans use 30–35 watts. The air delivery of super-efficient fans is also comparable to that of regular fans. While super-efficient fans cost double that of regular fans, with the savings in energy cost, the additional cost can be recovered within two to three years. A comparison of regular, BEE star-rated, and super-efficient fans is given in Table 5.2.

Table 5.2 Comparison of regular, BEE star-rated, and super-efficient fans

Parameter	Regular fan	BEE 5 Star-rated fan	Super-efficient fan
Wattage	75 W	50 W	35 W
Yearly units consumption (assuming 8 hours usage everyday)	219 units	146 units	102 units
Yearly electricity cost (at Rs 5 per unit)	Rs 1095/-	Rs 730/-	Rs 511/-
Cost of buying	Rs 1200/-	Rs 1600/-	Rs 3000/-

Source www.bijlibachao.com; 26 August 2015

5.4 Strategies to reduce electrical energy for air conditioning

Even with good natural ventilation and use of ceiling fans, there may be times of the year when air conditioning will be required. Measures to make air conditioning more energy efficient are given below.

5.4.1 Raising the cooling set-point

Used in conjunction with ceiling fans, the cooling set-point can be raised up to 28 °C. Based on a parametric study carried out on the base case model for bedrooms, as described in

Section 4.2.1.1, the saving potential in cooling energy demand with an increase in cooling temperature set-point from 26 °C to 28 °C is at least 35% and at least 55% for an increase from 24 °C to 28 °C.

5.4.2 Energy-efficient windows or split air-conditioners

The chapter on appliances (Section 6.2) shows the potential increase in performance and energy savings by opting for an air-conditioner having a higher BEE star rating. Higher the BEE star rating, higher is the energy saving.

5.4.3 Split air-conditioners cooled through a centralised water cooling system

The condensers of conventional split or window air-conditioners are cooled by the ambient air. The very high temperature of the air in summer causes the conventional split or window air-conditioners to operate at a high condensing temperature of the refrigerant (up to 55 °C), reducing significantly the efficiency of the air-conditioner during this period. By having a central water-cooled loop, the condensing temperature of the refrigerant can be brought down to 30 °C or even less. A thermodynamic analysis using properties of the refrigerant R134a shows that the theoretical savings in energy could be of the order of 50% during peak summer periods.

Figure 5.11 shows a schematic diagram of split air-conditioners cooled by a central water loop. The system has two water loops. The return hot water (primary circuit) from the split units is cooled in a plate heat exchanger. The water in the secondary circuit rejects heat in a cooling tower. It is possible to use treated grey water in the secondary loop, thus reducing drastically the demand for fresh water for operating the system. Some air-conditioning companies are currently offering these systems in India.

The potential energy savings from this technology can be up to 40% compared to conventional air-cooled split air-conditioners. One architectural advantage is that because it is water-cooled, the condenser need not access fresh air. So the cooling units can be installed inside. For the developer, the provision of a central water loop and cooling tower requires some additional investment, but the possible reduction in the peak power demand allows him/her to reduce the size of the transformer and the electrical system, which should offset the additional cost. With proper design and maintenance, this technology has the potential to significantly reduce the energy used for cooling in new residential building projects.

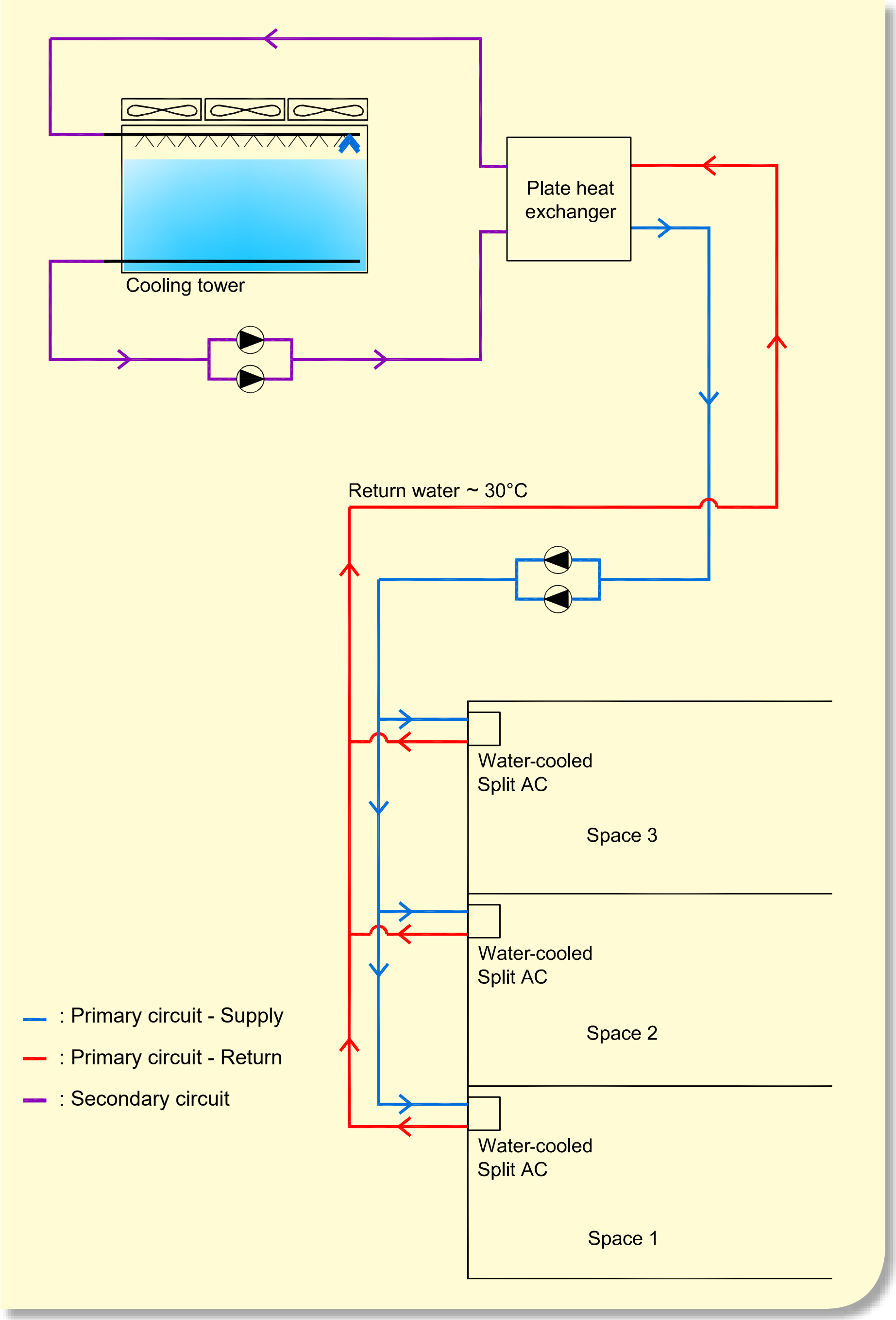

Figure 5.11 *Schematic diagram of split air-conditioners cooled by a central water loop*

5.5 Ventilation for kitchens

Kitchen is often the most uncomfortable thermal space in a flat because of the large amount of heat generated during cooking. The provision of a good ventilation system that can efficiently extract hot air from the kitchen before it mixes with the surrounding air can help reduce the intensity of heat in the kitchen and attached spaces.

Computational fluid dynamics (CFD) simulations for a typical kitchen for different ventilation strategies were carried out using Mentor Graphics Flovent version 9.3.5. A detailed study is presented in Annexure 5.

5.5.1 Strategies of natural ventilation in winter and mid-season

In the warm-humid climate zone, early mornings and evenings generally have outside conditions suitable for natural ventilation. Figure 5.12 shows the case where the kitchen has only one window opening. The outside air temperature is 28 °C and the kitchen window is open for ventilating the kitchen (conventional window opening case). It is observed that the ventilation provided by the window opening is not enough and the entire kitchen gets overheated. The average temperature in the zone occupied by the person cooking the food is around 36 °C.

Figure 5.13 shows an improved case of natural ventilation. In this case, an additional opening is provided below the window opening. This opening, which is located near to the floor, allows the entry of outside cool air into the kitchen and improves the natural ventilation. In this case, the average temperature in the zone occupied by the person cooking the meal is reduced to 31 °C, i.e., a reduction of about 5 °C.

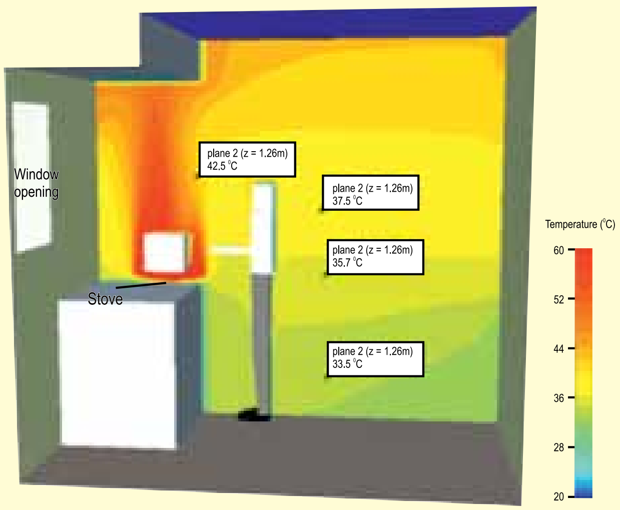

Figure 5.12 *Natural ventilation with a conventional window opening. Average air temperature of 36 °C between 1 m and 1.6 m above the floor*

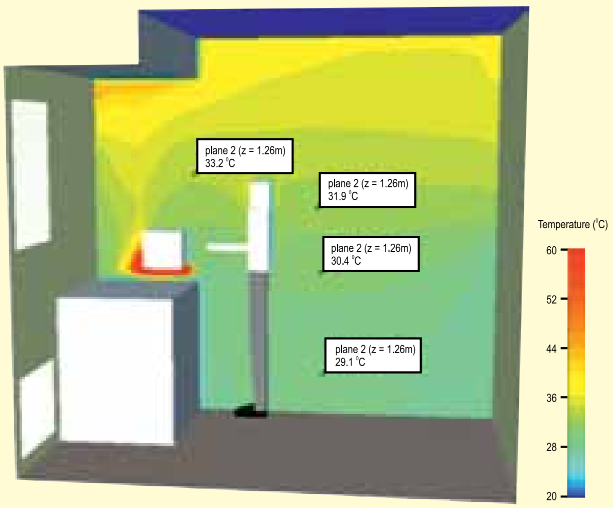

Figure 5.13 *Natural ventilation with a conventional window and an additional bottom opening. Average air temperature of 31 °C between 1 m and 1.6 m above the floor*

5.5.2 Strategies during hot summer, the importance of proper height and flow rate of the extraction hood

Figure 5.14 shows the case of a typical hot summer day. The windows of the kitchen are closed and the door between the kitchen and the internal spaces of the house (maintained at a temperature of 28 °C) is partly open. The kitchen is ventilated using an extraction hood. When the hood is at a height of 1.5 m (from the gas fire source) and the flow rate is 500 m^3/h, the ventilation provided by the hood is not very effective and the average temperature in the zone occupied by the person cooking the meal is around 33 °C.

In Figure 5.15, the height between the hood and the gas fire source is reduced to 1 m. For the same flow rate of 500 m^3/h, the ventilation improves and the temperature in the zone occupied by the person cooking the meal is reduced to 30 °C.

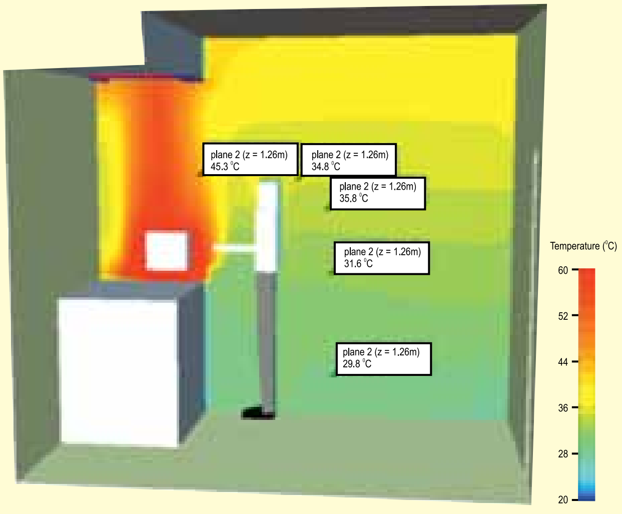

Figure 5.14 *Door between the kitchen and the living room partly opened, hood 1.5 m above the gas fire, flow rate: 500 m^3/h. Average air temperature of 33 °C between 1 m and 1.6 m above the floor*

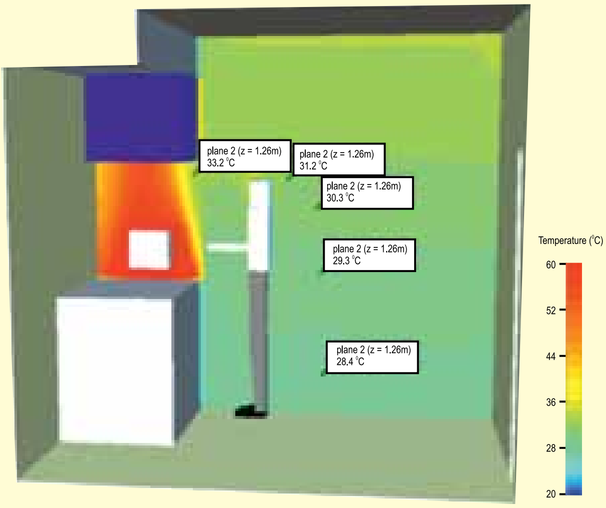

Figure 5.15 *Door between the kitchen and the living room partly opened, hood 1 m above the gas fire, flow rate: 500 m^3/h. Average air temperature of 30 °C between 1 and 1.6 m above the floor*

In Figure 5.16, the height of the hood is 1 m and the flow rate is increased to 800 m^3/h. In this case, the ventilation improves further. There is almost no heating in the kitchen and the temperature in the zone occupied by the person cooking the meal is reduced to 29 °C.

Figure 5.17 gives an estimate of the influence of the height difference between the hood and the gas fire on the necessary flow rate extraction for a 2-kW gas burner (correlation adapted from the German standard VDI Standard 2052). Lower the hood, better is the efficiency and lower the necessary flow rate for an efficient capture. There is a need to confirm these observations by the manufacturer or measured data in the Indian context. Hoods having provision for adjusting the height can help in improving the efficiency.

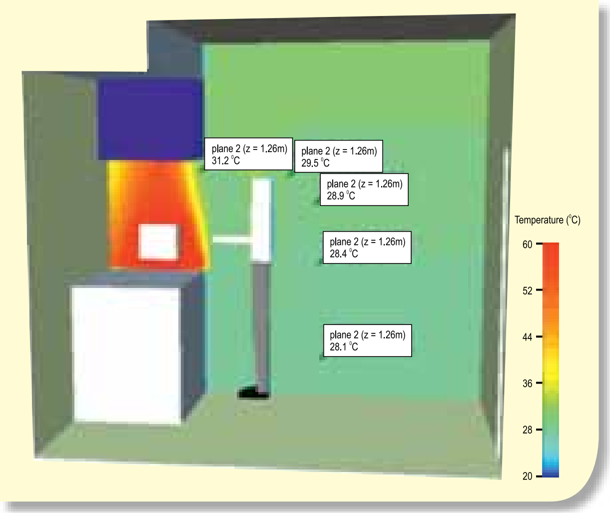

Figure 5.16 *Door between the living room partly opened, hood 1 m above the gas fire, flow rate: 800 m^3/h. Average air temperature of 29 °C between 1 m and 1.6 m above the floor*

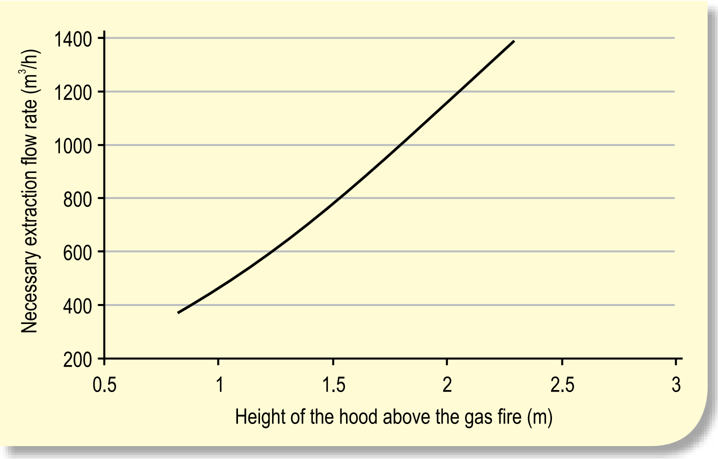

Figure 5.17 *Height of the hood above the gas fire versus necessary extraction rate*

5.5.3 Conclusions on kitchen ventilation

Based on the analysis presented in sections 5.5.1 and 5.5.2, the following conclusions can be drawn about ventilation of the kitchen:

- For effective natural ventilation of the kitchen, in addition to the window, an additional lower opening should be provided.
- When the kitchen is ventilated using an extraction hood, the height of the hood from the gas fire and the flow rate need to be properly selected for efficient ventilation of the kitchen.

RECOMMENDATIONS

Recommendation 6: Design and position windows to improve natural ventilation

- Wherever possible, provision for cross-ventilation at the flat or room level is to be made. Cross-ventilation results in higher air change rates, i.e., better ventilation. In the case of cross-ventilation, openable window area should be at least 10%–15% of the floor area, for both inlet and outlet openings.
- In case of single-sided ventilation, i.e., having window(s) on one wall of the room, tall windows should be designed. These windows should have openings at the bottom (for entry of cold air into the room) and at the top (for the exit of warm air to the outside). The height/width ratio of 2 is practically feasible for such windows for regular bedroom sizes.
- As far as possible, openings should be placed normal to the prevalent wind direction. If the wind direction is >60° from the normal direction of the opening, i.e. parallel to the wall, design features like wing walls; louvres provided on the outside surface of the wall can help in steering the wind inside.
- Casement windows are recommended over sliding windows as they allow more openable window area.

Recommendation 7: Use of efficient ceiling fans

- Use BEE star-rated or super-efficient ceiling fans.

Recommendation 8: Raise the cooling set-point

- Raising the cooling set-point from 24 °C to 28 °C (~adaptive comfort temperature for summer as per ASHRAE 55) can bring ~55%–60% reduction in cooling demand.

Recommendation 9: Use energy-efficient air-conditioning system

- When using conventional air-cooled windows or split units, use the highest star rating possible.
- Incorporate new and innovative ways to improve efficiency of room air-conditioners. For example, an individual water-cooled split unit cooled through a central loop attached to a cooling tower (ultimate potential ~40% savings against air-cooled split).

CHAPTER 6

APPLIANCES

AT A GLANCE

The Bureau of Energy Efficiency (BEE) launched the Standards and Labelling (S&L) Programme in May 2006 to provide consumers with informed choices for energy-saving equipment/appliances and their resultant cost-saving potential. The equipment/appliances are given a star rating of one to five; five stars being the most energy efficient.

Some of the equipment and appliances that are relevant while designing multi-storey residential buildings and are covered under the BEE star rating are listed below.

- Distribution transformer: The star rating of distribution transformers is based on the total losses at 50% and 100% load. Higher the star rating, lower the energy losses through the distribution transformer.
- Air-conditioners (ACs): The star rating of ACs is based on the energy-efficiency ratio (EER). Higher the EER, higher is the star rating.
- Ceiling fans: The star rating of ceiling fans is based on the ‘service value’. Higher the ‘service value’, higher is the star rating.
- Tubular fluorescent lamps (TFLs): The star rating of TFLs is based on ‘lumens per watt’. Higher the ‘lumens per watt’, higher is the star rating.
- Electromagnetic and electronic ballasts: The star rating of ballasts is based on the ‘ballast efficiency class.’
    - Electromagnetic ballasts (one star)
    - Non-dimmable electronic ballasts (two, three, and four stars)
    - Dimmable electronic ballasts (five stars)
- Storage-type electric water heaters/geyser: The star rating of electric water heaters is based on the grade of standing loss. Higher the star rating, lower the energy losses through the geyser.
- Diesel generating sets: The star rating of diesel generating sets is based on the specific fuel consumption (SFC). Higher the star rating, lower the SFC.

In addition, new energy-efficient equipment/appliances such as inverter air-conditioners (ACs), super-efficient fans, and light-emmiting diodes (LEDs) are also listed below for which the star rating is available at present.

- Inverter ACs: Inverter ACs are based on DC compressor with variable speed drive motors and they are one of the most energy-efficient commercially available ACs for residences. It can save 20%–40% of the electricity as compared to a five-star-rated AC.
- Super-efficient fans: These fans are based on efficient brushless DC motor and improved blade designs, which make them more energy efficient. A super-efficient fan can save ~30% of the electricity as compared to a five-star-rated ceiling fan.
- Light-emitting diode (LED): LEDs are one of the most energy-efficient lighting devices commercially available in the market today. As compared to fluorescent lights, LEDs are more energy efficient, mercury free, and have longer life.

RECOMMENDATION FOR APPLIANCES

Recommendation 10: Select higher BEE star-labelled energy-efficient equipment and appliances for common services and space cooling, water heating, and lighting inside flats

- It is recommended that higher BEE star-labelled energy-efficient equipment and appliances should be used for:
  - Common services
  - Distribution transformers
  - TFLs for the lighting of common areas
  - Electronic ballasts for the lighting of common areas
  - Diesel-generating sets

- Space cooling, water heating, and lighting inside flats
  - Air-conditioner
  - Ceiling fan
  - TFLs
  - Electronic ballasts
  - Storage-type electric water heaters/geyser

- Although the star rating is presently not available for inverter ACs, super-efficient fans, and LEDs, they are recommended for cooling and lighting applications, as they are more energy efficient.

6.1 Introduction

In the previous chapters, recommendations were given for minimising heat gains, and utilising daylight so that the energy requirement for end uses (e.g., lighting, cooling) is reduced. This chapter deals with the energy-efficiency aspect of equipment/appliances that are used for these end uses. In order to address the energy efficiency of appliances, the Bureau of Energy Efficiency (BEE) launched the Standards and Labelling (S&L) Programme in May 2006.

The objective of the S&L Programme is to provide consumers with informed choices for energy saving, and thereby, the operational cost-saving potential of equipment/appliances. The equipment/appliances are given a star rating of one to five; five stars being the most energy efficient. BEE has mandatory scheme for eight equipment/appliances, which includes frost-free (no-frost) refrigerators, tubular fluorescent lamps (TFLs), room air-conditioners (ACs) (window and split-type), distribution transformers, storage type electric water heaters, colour television, direct cool refrigerators and room air conditioners (Cassette, Floor Standing Tower, Ceiling, Corner AC). In addition, BEE has a voluntary scheme for equipment/appliances, which includes induction motors, agricultural pump sets, ceiling fans, domestic liquefied petroleum gas (LPG) stoves, ballasts, washing machine, computer (notebook/laptops), ballast (electronic/magnetic), office equipment (printer, copier, scanner, fax machines, and multi-functional devices), diesel engine-driven mono-set pumps for agricultural purposes, solid-state inverter, and diesel generator. Some of the key equipment/appliances that are important for the design of multi-storey residential buildings are covered in this chapter.[1]

6.2 Room air-conditioners

Single-phase split and unitary (window) ACs of the vapour compression-type for household use, up to a rated cooling capacity of 11 kW (3.1 ton), are considered under the S&L programme. The star rating of an AC is based on the energy-efficiency ratio (EER). The EER for the AC is defined as the ratio of output cooling power (watt) to the input electrical energy (watt). ACs are tested as per the code and procedure described in IS1391 Part 1 and Part 2 with all amendments. Table 6.1 and Table 6.2 give the star rating and the corresponding EER for split-type ACs and unitary-type (window) ACs, respectively.

In addition, the star rating has been done for cassette ACs, floor standing tower ACs, ceiling/floor ACs, and corner ACs. Star rating and the corresponding EER for these types of ACs is the same as split-type ACs (Table 6.1).

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[1] *Detailed information on all star-rated products is available on the BEE website <http://beestarlabel.com/>.*

Table 6.1 Star rating for split-type ACs (valid from 1 January 2016 to 31 December 2017)

	Energy-efficiency ratio (watt/watt)	
Star level	**Minimum**	**Maximum**
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	—

Table 6.2 Star rating for unitary type (window) ACs (valid from 1 January 2016 to 31 December 2017)

	Energy efficiency ratio (watt/watt)	
Star level	**Minimum**	**Maximum**
1 star *	2.50	2.69
2 star **	2.70	2.89
3 star ***	2.90	3.09
4 star ****	3.10	3.29
5 star *****	3.30	—

It is recommended to opt for five-star ACs. An indicative electricity consumption graph (Figure 6.1) compares the performances[2] of one-star and five-star rated ACs. Depending on the usage of the ACs, the energy saving (with five-star over one-star) during the year is expected to range from 200 kWh/year to 700 kWh/year.

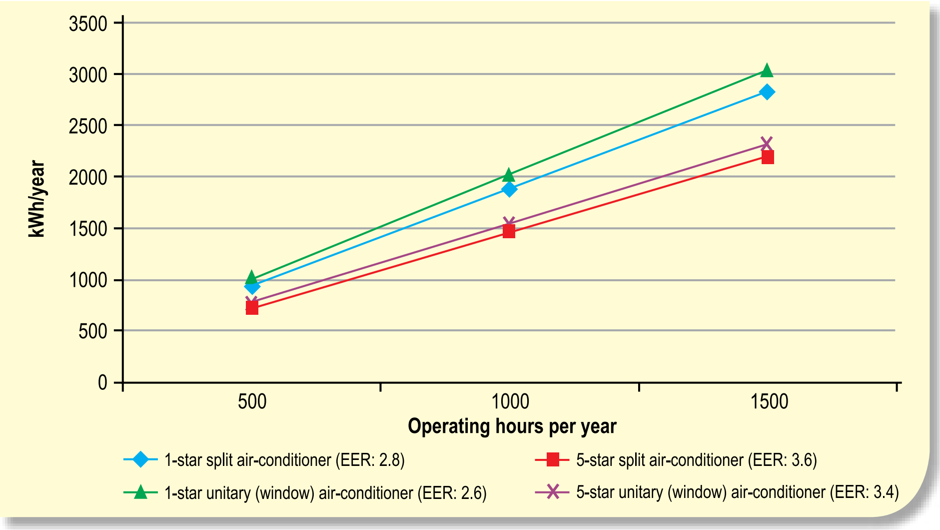

***Figure 6.1** Electricity consumption for air-conditioners of one- and five-star ratings*

6.2.1 Inverter air-conditioners

Inverter ACs are one of the most energy-efficient commercially available ACs for residences. They are similar to split ACs but are equipped with inverter technology with variable speed motor (for compressor and fan). The advantages of inverter ACs are listed below.

- Non-inverter ACs have compressors that go 'On' and 'Off' whereas inverter ACs have compressors that are 'On' all the time. It can save 20%–40% of the electricity as the compressor and fan energy required is lesser due to optimal utilisation through the variable speed motor.

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[2] *The calculation is made for 1.5 ton (5.3 kW) AC, assuming the AC compressor works during the operating hours as shown in Figure 6.1. Average EER for the rating is taken for calculations.*

- It always ensures that the temperatures are very close to the set-point as the compressor is 'On' all the time (Figure 6.2).
- Inverter ACs have variable speed motors that start up gradually needing much lesser current at start-up as compared to regular ACs. Hence, they can work with smaller capacity (~40%) of the power back-up.
- An inverter technology motor will have a power factor close to unity (or 1), which results in lesser electricity consumption.

Till now, inverter ACs have not been rated under the BEE S&L programme.

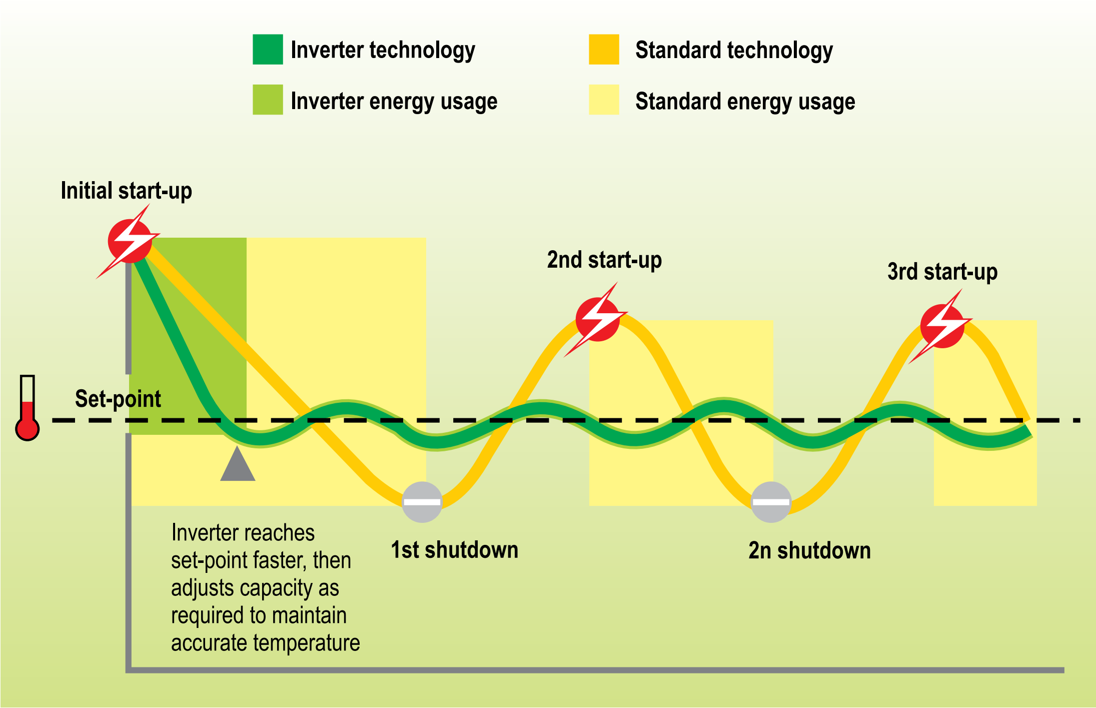

Figure 6.2 *Energy usage and set-point control with Inverter AC*
Source *http://www.so-cool.com.au/#!split-systems/c252x, 8 September, 2015.*

6.3 Ceiling fans

Ceiling fans covering up to 1200 mm sweep[3] are considered under the S&L 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 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 6.3 gives the star rating and the corresponding service values for ceiling fans.

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

It is recommended to opt for five-star ceiling fans. An indicative electricity consumption graph (Figure 6.3) is shown below to compare the performance of one-star and five-star rated ceiling fans. Depending on the usage of the ceiling fan, the energy saving[4] (with five star over one star) during the year, may range from 12 kWh/year to 75 kWh/year.

Table 6.3 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.

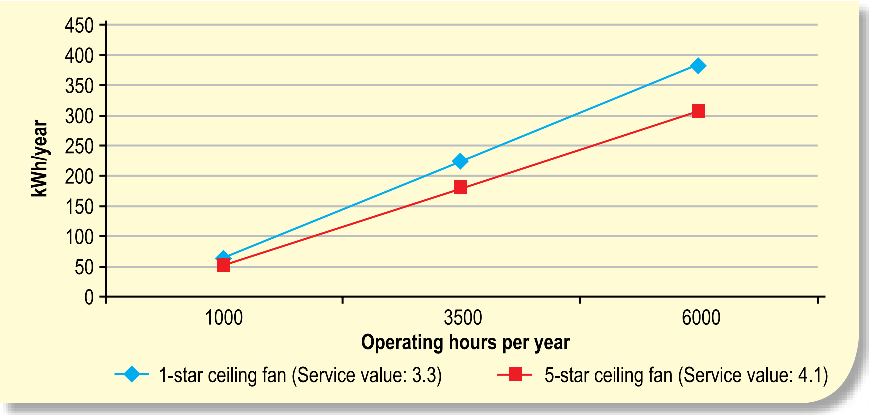

Figure 6.3 *Electricity consumption for ceiling fans of one- and five-star ratings*

6.3.1 Super-efficient fans

There has been significant improvement in the energy efficiency of ceiling fans with the BEE S&L Programme. However, there are super-efficient fans available in the market, which consumes even lesser electricity as compared to five-star rated fans. To achieve energy 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 watt of electricity consumption by a BEE five-star rated ceiling fan, resulting in ~30% of energy saving. Till now, super-efficient fans have not been rated under the BEE S&L Programme.

6.4 Tubular fluorescent lamps

Tubular fluorescent lamps (TFLs) of 4 feet long and up to 40 W rating are considered under the BEE S&L Programme. The star rating of the TFL is based on 'lumens per watt', which is defined as the light output in lumen divided by the electrical power input to the TFL in watts at the voltage and frequency specified for the tests. The testing code and procedure

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[4] *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).*

for TFL for general lighting service is done as per IS 2418 (part I) – 1977 with all amendments. Table 6.4 gives the star rating and the corresponding 'lumen per watt' values for TFL. As the efficiency of the TFL decreases over time, these values are defined for three different hours of usage. It is recommended to the users to opt for five-star TFL. Light distribution can be improved by using suitable reflectors with the lighting lamps.

Table 6.4 Star rating for tubular fluorescent lamps

Star rating	1 star	2 star	3 star	4 star	5 star
Lumens per watt at 0100 hours of use	<61	≥61 and <67	≥67 and <86	≥86 and <92	≥92
Lumens per watt at 2000 hours of use	<52	≥52 and <57	≥57 and <77	≥77 and <83	≥83
Lumens per watt at 3500 hours of use	<49	≥49 and <54	≥54 and <73	≥73 and <78	≥78

TFLs come in three variants: T-12, T-8, and T-5 with diameter 38 mm, 25 mm, and 16 mm, respectively. A T-5 with electronic ballast would be most energy efficient.

6.4.1 Compact fluorescent lamp

Compact fluorescent lamps (CFLs) work on the same principle/technology as TFL; but differ in size and shape. They are made compact by making the tube smaller and folded over so that they can be fitted in the same space designed for incandescent bulbs. They became very popular as they offered energy efficient and economical replacement of incandescent bulbs. Their efficiency is similar to TFL but due to their compactness they can be preferred for smaller areas like puja room, kitchen (if it is small), bathrooms, etc., where the light requirement is less. Till now, CFLs have not been rated under the BEE S&L Programme.

TFL and CFL both contain mercury, which is harmful for the environment. Therefore, it is recommended that burned-out TFL and CFL must be recycled.

6.4.2 Light-emitting diode (LED)

Light-emitting diodes (LEDs) are one of the most energy-efficient lighting devices commercially available in the market today. LED is a semiconductor device that emits light when an electric current passes through it. As compared to fluorescent lights, LEDs are more energy efficient, mercury-free, and have longer life (detailed comparison is given in Chapter 7), and therefore, it is the recommended lighting technology. Till now, LEDs have not been rated under the BEE S&L Programme.

6.5 Ballasts: electromagnetic and electronic ballasts

Electromagnetic ballasts and electronic ballasts for TFLs are considered under the S&L Programme. The applicable Indian Standards are IS 1534 (Part 1): 1977 for electromagnetic

ballasts and IS 13021 (Part 1 and 2): 1991 for electronic ballasts. The star rating of the ballasts is based on the 'ballast efficiency class'.

- Electromagnetic ballasts (one star)
- Non-dimmable electronic ballasts (two, three, and four stars)
- Dimmable electronic ballasts (five stars)

For best energy efficiency, users can opt for four-star non-dimmable electronic ballast or five-star rated dimmable electronic ballast.

6.6 Storage-type electric water heaters

Stationary storage-type electric water heaters (both vertical and horizontal) up to rated capacity of 200 litres are considered under the S&L Programme. The star rating of the electric water heater is based on the grade of standing loss (kWh/24 h/45 °C),[5] which indicates how much energy is lost from the tank. This is defined for different capacities of storage tank varying from 6 litres to 200 litres. The testing code and procedure for stationary storage-type electric water heaters are done as per IS 2082: 1993 and IS 302-2-21 with all amendments. Table 6.5 gives the star rating and the corresponding 'standing loss (kWh/24h/45 °C)' values for storage-type electric water heaters. This star rating has been made mandatory since 1st July 2015. It is recommended to the users to opt for five-star-rated storage-type electric water heater.

Table 6.5 Star rating for storage-type electric water heaters (valid from 1 July 2015 to 30 June 2017)

Rated capacity (litres)	Standing losses (kWh/24 h/45 °C)				
	1 star	2 star	3 star	4 star	5 star
6	≤0.469 and >0.426	≤0.426 and >0.387	≤0.387 and >0.352	≤0.352 and >0.320	≤0.320
10	≤0.587 and >0.534	≤0.534 and >0.485	≤0.485 and >0.441	≤0.441 and >0.401	≤0.401
15	≤0.675 and >0.614	≤0.614 and >0.558	≤0.558 and >0.507	≤0.507 and >0.461	≤0.461
25	≤0.823 and >0.748	≤0.748 and >0.680	≤0.680 and >0.618	≤0.618 and >0.562	≤0.562
35	≤0.940 and >0.855	≤0.855 and >0.777	≤0.777 and >0.706	≤0.706 and >0.642	≤0.642
50	≤1.086 and >0.988	≤0.988 and >0.898	≤0.898 and >0.816	≤0.816 and >0.742	≤0.742
70	≤1.233 and >1.121	≤1.121 and >1.019	≤1.019 and >0.926	≤0.926 and >0.842	≤0.842
100	≤1.408 and >1.280	≤1.280 and >1.164	≤1.164 and >1.058	≤1.058 and >0.962	≤0.962
140	≤1.586 and >1.441	≤1.441 and >1.310	≤1.310 and >1.191	≤1.191 and >1.083	≤1.083
200	≤1.761 and >1.601	≤1.601 and >1.456	≤1.456 and >1.323	≤1.323 and >1.203	≤1.203

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[5] *Standing loss is the energy consumption of a filled water heater, after steady-state conditions have been reached when connected to electrical supply, and when no water is drawn for 24 hours and a temperature difference of 45 °C is maintained between the tank water and ambient temperature.*

6.7 Distribution Transformer

Oil immersed, naturally air-cooled, three-phase, and double-wound non-sealed type outdoor distribution transformers are considered under the S&L Programme. The standard ratings covered under the pilot energy labelling scheme are 16, 25, 63, 100, 160, and 200 kVA and non-standard ratings from 16 kVA to 200 kVA distribution transformers. The referred Indian Standards are IS 1180 (part I) Outdoor-type Three-phase Distribution Transformers up to and including 200 kVA, 11 kV – Specification; IS 2026 (part 2) Specifications of Power Transformers – for temperature-rise; and IS 2500 (part-I) -2000–Sampling Schemes, indexed by Acceptance Quality Limit (AQL) for lot-by-lot inspection.

The star rating of distribution transformers is based on the 'total losses at 50% and 100% load'. Higher the star rating lower is the energy loss through the distribution transformer. Table 6.6 gives the star rating and the corresponding 'total losses at 50% and 100% load' values for different capacities of distribution transformers. It is recommended to the users to opt for a five-star-rated distribution transformer.

Table 6.6 Star rating for distribution transformers

	1 star		2 star		3 star		4 star		5 star	
Rating (kVA)	Max losses at 50% (watts)	Max losses at 100% (watts)	Max losses at 50% (watts)	Max losses at 100% (watts)	Max losses at 50% (watts)	Max losses at 100% (watts)	Max losses at 50% (watts)	Max losses at 100% (watts)	Max losses at 5 0% (watts)	Max losses at 100% (watts)
16	200	555	165	520	150	480	135	440	120	400
25	290	785	235	740	210	695	190	635	175	595
63	490	1415	430	1335	380	1250	340	1140	300	1050
100	700	2020	610	1910	520	1800	475	1650	435	1500
160	1000	2800	880	2550	770	2200	670	1950	570	1700
200	1130	3300	1010	3000	890	2700	780	2300	670	2100

6.8 Diesel generator sets

Single/three-phase diesel-generating (DG) sets consisting of a reciprocating internal combustion (RIC) engine driven by diesel as fuel, alternating current (AC) generator, any associated control gear, switch gear, and auxiliary equipment, are considered under the S&L Programme. New DG sets up to 19 kW ratings are covered under pilot energy labelling scheme for single/three-phase DG sets. The referred Indian Standards are IS 10000, IS 10001, IS 13364, and IS 4889: 1968 (all parts with amendments till date) and 'Scheme for Energy Efficiency Labelling' covered under Standard Labelling Programme, with all applicable amendments.

Table 6.7: Star rating for DG sets

Star rating	Specific fuel consumption (SFC) in g/kWh
1 Star	>302 and ≤336
2 Star	>272 and ≤302
3 Star	>245 and ≤272
4 Star	>220 and ≤245
5 Star	≤220

The star rating of DG sets is based on the specific fuel consumption (SFC)[6] in g/kWh of electricity. Higher the star rating, lower the diesel consumption for electricity generation. Table 6.7 gives the star rating and the corresponding SFC values for different star ratings. It is recommended to users to opt for a five-star rated DG set.

6.9 Other equipment/appliances

In addition to the equipment/appliances mentioned in the previous sections, there are other equipment/appliances that have star ratings. These include:

- Frost-free (No-frost) refrigerators
- Direct cool refrigerators
- Pump sets
- Domestic liquefied petroleum gas (LPG) stoves
- Colour televisions
- Washing machines
- Laptop/Notebook computers
- Office equipment (printers, scanners, copiers, fax machines, and multi-function devices)
- Solid-state inverter

Details about the star rating of these equipment/appliances (e.g., criteria, standards followed, etc.) are available on the BEE website. Users can opt for five-star rated equipment/appliances to have maximum energy savings.

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[6] *For example, if a DG set produces 4 units of electricity by consuming 1 kg (or 1000 g) of diesel, then its SFC would be 250 g/kWh.*

RECOMMENDATION FOR APPLIANCES

Recommendation 10: Select higher BEE star-labelled energy-efficient equipment and appliances for common services and space cooling, water heating, and lighting inside flats

- It is recommended that higher BEE star-labelled energy-efficient equipment and appliances should be used for:
    - Common services
    - Distribution transformers
    - TFLs for the lighting of common areas
    - Electronic ballasts for the lighting of common areas
    - Diesel-generating sets

- Space cooling, water heating, and lighting inside flats
    - Air-conditioner
    - Ceiling fan
    - TFLs
    - Electronic ballasts
    - Storage-type electric water heaters/geyser

- Although the star rating is presently not available for inverter ACs, super-efficient fans, and LEDs, they are recommended for cooling and lighting applications, as they are more energy efficient.

CHAPTER 7

COMMON SERVICES

AT A GLANCE

The three main electricity-consuming common services that are found in almost all multi-storey residential complexes are:

- common area lighting,
- community water pumping, and
- lifts

The common area lighting includes lighting of common areas inside the building, such as corridors, staircases, and basements; and lighting of outdoor areas, such as roads and parks. The electricity consumption for the lighting of common areas depends on the following:

- Extent of utilisation of daylight in common areas inside the building
- Choice of lighting fixtures
- Artificial lighting design

Water supply in a multi-storey residential building is either through pumped gravity water distribution system, or hydro-pneumatic pumping system. The electricity consumption for pumping water depends on the following:

- Sizing and choice of the pump
- Choice of motor and its control
- Piping design

There are two main types of lifts used in residential buildings: (a) hydraulic lifts and (b) traction lifts. Traction lifts can be classified further as geared, gearless, and machine room-less lifts. Electricity is consumed during the operation of lifts and during the stand-by mode. Electricity consumption in lifts depends on the following:

- Type and control of lighting and ventilation systems in the lift car
- Type of lift
- Control system of electric motors
- Type of braking system

RECOMMENDATIONS FOR COMMON SERVICES

Recommendation 11: Incorporate energy-efficiency features in the design of lighting of common areas

- Design for daylighting of corridors, staircases, parking areas
- Minimise the use of basement that would require artificial lighting
- Choose energy-efficient artificial lighting
    - Indoor spaces: Use light-emitting diodes (LEDs), compact fluorescent lamps (CFLs), and higher BEE star-rated tubular fluorescent lamps (TFLs)
    - Outdoor spaces:
        - Use LEDs and metal halide lamps
        - Optimise for height and distance

Recommendation 12: Incorporate energy-efficiency features in the design of community water pumping system

- Pumped gravity system
    - Selecting a pump whose head and flow parameter for the ‘DutyPoint’ matches with that of the ‘Best Efficiency Point’ of the pump
    - Design piping so as to reduce frictional losses
    - Use variable frequency drives (VFDs) on pump motors
- Hydro-pneumatic system
    - Install VFDs for all pumps

Recommendation 13: Incorporate energy-efficiency features in the design of lifts

- Measures to reduce standby electricity consumption
    - Use LED or CFL for the lighting of the lift car
    - Avoid dark interiors in the lift car
    - Use high-efficiency motors for the ventilation of the lift car
    - Provide auto-switch off for lights and ventilation fan
- Measures to reduce running electricity consumption
    - Use of VFDs in motors
    - Opting for lifts with gearless systems as they usually consume less electricity
    - Incorporation of regenerative braking

7.1 Electricity consumption for common services

In a residential complex, electricity is used for many common services, including lighting of common areas, operation of lifts, water pumping systems, effluent treatment plants, and swimming pools. Common services in residential complexes may vary significantly; however, there are three main electricity consuming services that are found in almost all multi-storey residential complexes. These are: (1) lighting of corridors, staircases, and outdoor areas; (2) water pumping; and (3) lifts. The focus of this chapter is to look at energy-efficiency strategies for these three services.

Data collected from a small housing complex (3 towers, G+7 floors, 90 flats) in New Delhi show that the electricity consumed for these three common services was 72,000 kWh/year or around 16% of the total annual electricity consumption of the complex. Further breakdown of the common area electricity consumption data (Table 7.1 and Figure 7.1) shows that the operation of lifts consumed most of the electricity (62%), followed by the lighting of common areas (21%) and pumping of water to overhead tanks (17%).

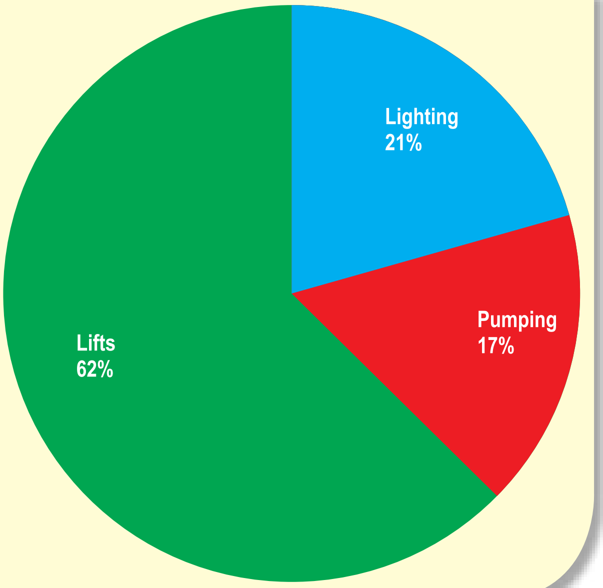

Figure 7.1 *Share of electricity consumption for common services (lighting, pumping, and lifts) in a small multi-storey residential complex*

7.2 Energy-efficient design of common area lighting

Common area lighting can be further sub-divided into two categories: lighting of common areas inside the building, such as corridors, staircases, and basements; and lighting of outdoor areas, such as roads and parks.

Table 7.1 Electricity consumption for common services in a small multi-storey residential complex

Common services	Energy consumption (kWh/year)	Energy consumption (kWh/flat.year)
Lighting of common areas	14,900	165
Water pumping	12,200	135
Lifts	44,900	500
Total	72,000	800

7.2.1 Daylighting of common areas

Common spaces such as corridors, staircases, and basements should have suitable openings/access to ambient light so that the need for artificial lighting during daytime is reduced. A different design approach can be used to provide daylight in common areas than in dwellings or office areas where non-uniformity and glare can be problematic. In common areas, small openings in the façades would facilitate daylight penetration for circulation. Typical recommended values for daylight in common areas are mentioned in Table 7.2. Illuminance level of 50–100 lux is sufficient for standard circulation spaces; higher illuminance of 100–150 lux is needed for staircases or circulation areas with obstacles. Another recognised technique for enhancing daylight in common areas is to use light finishes on the interior surfaces to maximise reflection of daylight in the space.

Table 7.2 Typical recommended values for daylight in common areas

Type of space	Illuminance level required (lux)[1]
Corridors, lobbies, circulation areas	50–100
Staircases	100–150

7.2.2 Lighting technologies

Lighting technologies are broadly of three types: (1) incandescent; (2) gas discharge lamps; and (3) light-emitting diodes (LEDs). Luminous efficacy is a reflection of the efficiency of energy conversion from electricity to light form. Colour rendering index (CRI) is one of the factors that determines the application of the lighting system. Incandescent lamps, LEDs, or compact fluorescent lamps (CFLs) with high CRI are more suitable for indoor lighting, while high pressure sodium vapour (HPSV) and low pressure sodium vapour (LPSV) lamps with low CRI are better for outdoor lighting. Table 7.3 provides a comparison of different lighting technologies.

A couple of useful tips for choosing an energy-efficient lighting system is given below.

- LEDs, CFLs, and fluorescent tube lights (FTLs) with electronic ballast are for lighting indoor spaces such as corridors, staircases, and parking areas.
- LEDs and metal halide lamps are for lighting outdoor areas.

A well-designed reflective luminaire can further increase light distribution.

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[1] *Chuard P and Chuard D. May 1992. Energy Savings in Schools: Publication on Daylighting, Research Project on Rational Use of Energy in Buildings. Switzerland: Federal Ministry for Energy.*

Table 7.3 Comparison of commonly used lighting systems[2]

Type of lamp	Lumens efficacy range (lumens/watt)[3]	Colour rendering index[4]	Life (hours)
1. Incandescent	8–18	Excellent (100)	1000
2. Gas discharge lamps			
a) Fluorescent lamp	46–60	Good w.r.t. coating (67–77)	5000
b) Compact fluorescent lamp (CFL)	40–70	Very good (85)	8000–10000
c) High pressure mercury vapour (HPMV)	44–57	Fair (45)	5000
d) Halogen lamp	18–24	Excellent (100)	2000–4000
e) High pressure sodium vapour (HPSV)	67–121	Fair (22)	6000–12000
f) Low pressure sodium vapour (LPSV)	101–175	Poor (10)	6000–12000
g) Metal halides	75–125	Good (70)	6000–20000
3. Light emitting diode (LED)	60–120	Very good (85)	40000–100000

7.2.3 Lighting design

Efficient lighting technologies will only make an impact if they are designed intelligently. A good lighting design meets the requirements of the space with smart placement of fixtures in order to achieve the desired distribution of light. Control systems can further increase energy savings by operating the lighting system efficiently.

Some useful tips related to lighting design are listed below.

- For corridors and staircases, lighting design depends on the dimensions of the space to be lighted and the luminaire height. Similarly, for outdoor lighting, the distance between poles and their height can be optimised to get the required lighting levels.
- For outdoor lighting, timers can be used that would allow the light to operate within a predefined schedule. There can be one setting (same time) for the whole year or several (seasonal/weekly/daily) settings to align with the changing availability of daylight. Another possibility is to use ON/OFF-type photo sensors to switch ON or OFF the outdoor lights by sensing daylight levels.
- Occupancy sensors can be used in some common areas (e.g., corridors). Sensors are simple controls that turn the light on when someone enters the space and turn off when there is no occupancy.

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[2] *BEE Energy Auditor Exam Book-3 (Energy Efficiency in Electrical Utilities).*

[3] *Luminous efficacy (lm/W) is the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. It is a reflection of efficiency of energy conversion from electricity to light form.*

[4] *Colour rendering index (CRI) is the lamp's ability to accurately show the colours of objects illuminated by the lamp. This attribute is measured in CRI, which peaks at 100.*

7.3 Energy-Efficient Design of Water Pumping

7.3.1 Pumped gravity water distribution system

Typically, in a multi-storey building, water is received from the municipal water supply to a ground-level reservoir (GLR) and is then pumped to an overhead reservoir (OHR) located on the roof. The water is then distributed to individual flats. Measurement in some residential building complexes[5] shows that the overall pumping system efficiency could be as low as 25%–30%, whereas the rated efficiencies of the pumps are much higher. If the design of a pumping system is done carefully, then the energy used can be minimised.

7.3.1.1 Selection of pumps

The first step in the selection of the right pump is to determine the required discharge flow rate. For example, a residential complex having 50 flats will have water demand of around 40 m^3 of water per day.[6] If the water is to be pumped from GLR to OHR in 4 hours (2 hours in the evening and 2 hours in the morning), then the minimum discharge flow rate is 10 m^3/h.

The second step is to calculate the total pressure head to be overcome by the pumping system. Pressure head refers to the sum of the static head and the friction head, and is usually expressed in metres. The static head in the pumping system is the difference in water level between the GLR and the OHR. For example, for a 25-storey building, with each storey having a height of 3 m, the static head would be close to 80 m depending on the levels of GLR at ground/basement and OHR at roof. The friction head is the total pressure head lost due to friction that occurs as water flows through the pipeline. Friction head loss includes the loss in pipe-work and in the fittings, starting from the suction inlet fitting to the discharge pipe outlet. For a given discharge flow rate, this friction loss depends on the material, size, and length of the pipe, and the type and number of fittings. It can be computed once these pipeline specifications are determined. In the previous example of the 25-storey building with a static head of 80 m, if the frictional head is 20 m, then the total pressure head for the pumping system is 100 m.

Pumps are generally selected based on their ability to meet specific requirements of flow rate and system head from a wide range of types and models. Efficiency, duty point, suction inlet conditions, operating life, and maintenance also need to be considered in the selection process. Multi-storey residential buildings, usually have flow rates of <1 m^3/min and heads ranging from 30 m to 150 m. Usually, high-head radial centrifugal pumps are used for the application (Figure 7.2).

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[5] *Study conducted by International Institute for Energy Conservation (IIEC) for Maharashtra Electricity Regulatory Commission (MERC) in Mumbai.*

[6] *Assuming 4 persons per flat or a total population of 200 persons. Water demand taken as 200 litres per person per day.*

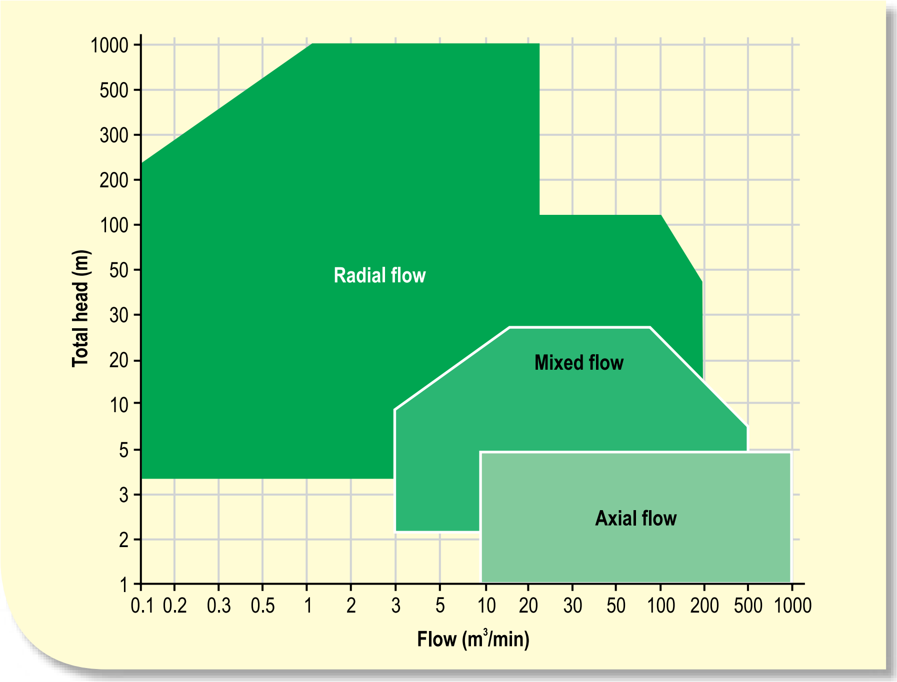

Figure 7.2 *Centrifugal pump types and ranges*[7]

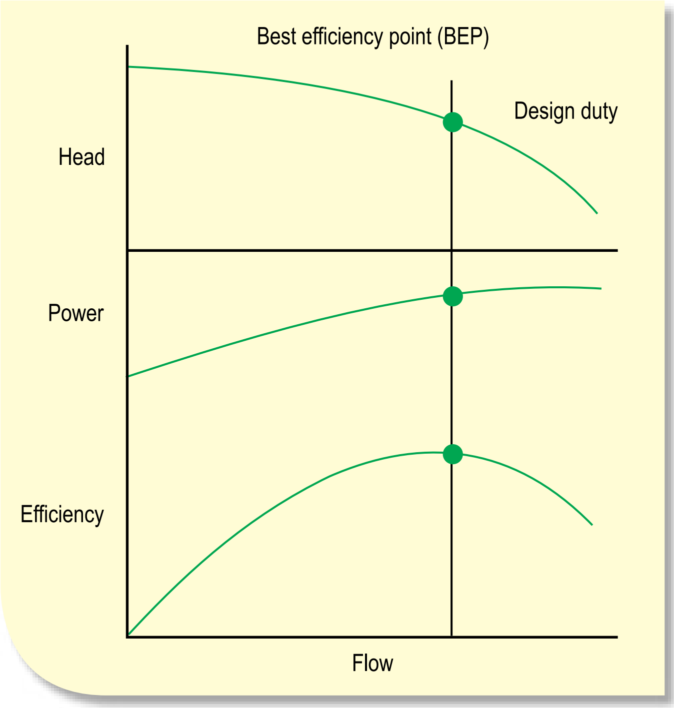

Figure 7.3 *Simplified characteristic curve for centrifugal pump*

It is very important to understand the characteristic curve of a pump to select a suitable one to meet the requirement. A pump's characteristic curve is a graphical representation of how a pump's operating parameters, head, power, and efficiency vary with the flow of water (Figure 7.3). Pump manufacturers provide a chart that indicates the range of flow rate and system head for a particular pump and this can be a good resource when selecting a pump. The most important detail to read from this curve is the best efficiency point (BEP) of the pump when the

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[7] *Sustainability Victoria. 2009. Energy Efficiency Best Practice Guide Pumping Systems. Melbourne: Sustainability Victoria.*

pump operates at its maximum efficiency. Another important thing is to identify the duty point. The duty point of a pump is identified by the intersection of the system resistance curve[8] and the pump curve as shown in Figure 7.4.

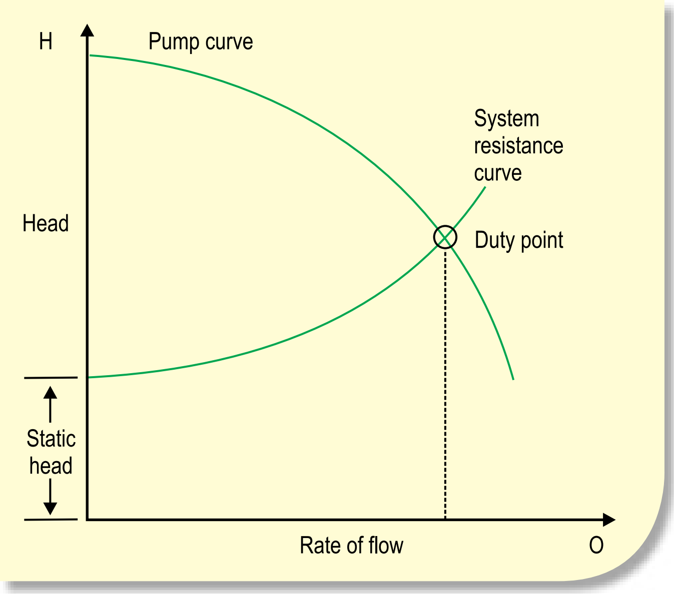

Figure 7.4 *The duty point of a pump*

7.3.2 Hydro-pneumatic Pumping System

Sometimes, instead of a pumped gravity water distribution system, a hydro-pneumatic system is used. Hydro-pneumatic systems generally eliminate the need for an overhead tank and may supply water at a much higher pressure than that available from overhead tanks, particularly on the upper floors, resulting in even distribution of water for all floors (Figure 7.5).

In hydro-pneumatic system,[9] an air-tight pressure vessel is installed on the line to regulate the operation of the pumps. The vessel is arranged to consist of approximately half the capacity of water. As the pumps operate, the incoming water in the vessel compresses the air on top. When a predetermined pressure is reached in the vessel, a pressure switch installed on the vessel switches the pumps off. As water is drawn into the system, pressure falls in the vessel starting the pumps at a preset pressure. The air in the pressure tank slowly reduces in volume due to dissolution in water and leakages from pipelines. An air compressor is also necessary to feed air into the vessel so as to maintain the required air–water ratio. It is recommended to use variable frequency drives (VFDs) for optimal operation of pumps.

7.3.3 Useful tips for designing a pumping system

- Pumped gravity system
    - Pump selection should be such that the head and flow parameter for the duty point matches with that of the BEP of the pump. Energy audits of residential complexes show that the pumps are often oversized. This should be avoided.
    - The aim of the piping design should be to reduce frictional losses by
        - maximising pipe diameter,

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[8] *The system resistance curve is the variation in head with respect to the change in the flow.*

[9] *Bureau of Indian Standards (BIS). Indian Standard (IS : 12183 Part 1 Water Supply): 1987. Reaffirmed in 2004. Code of Practice for Plumbing in Multi-Storeyed Buildings. New Delhi: BIS.*

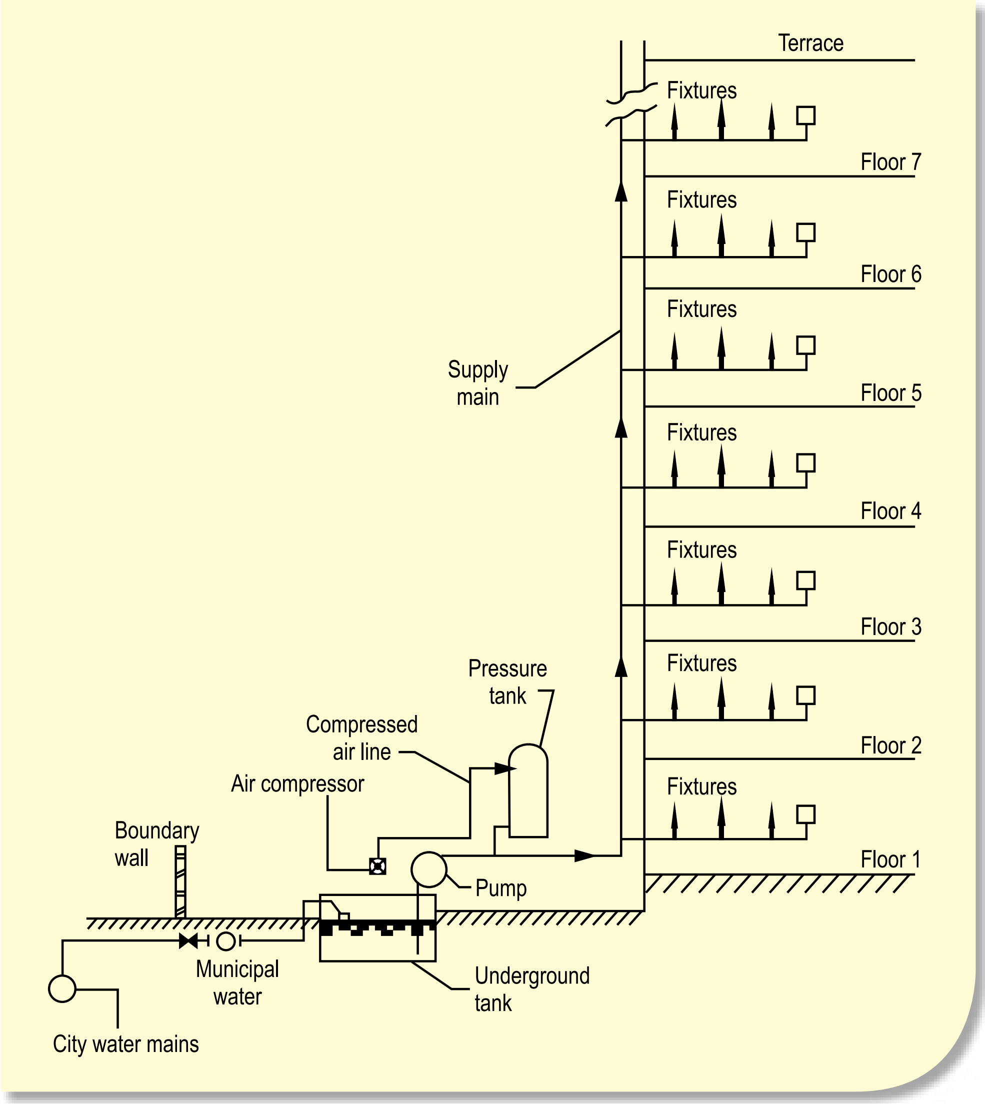

Figure 7.5 *Schematic of hydro-pneumatic pumping system*[10]

  - optimising pipe layout to minimise pressure loss,
  - minimising pressure losses through valves and fittings, and
  - selecting a piping having a low friction factor.
- Use VFDs on pump motors.

- Hydro-pneumatic system
  - Proper design (pressure tanks, pumps, and controls) and operation of a hydro-pneumatic pumping system is essential in order to be energy efficient.
  - Installation of VFDs for all pumps in a hydro-pneumatic pumping system is recommended.

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[10] *Bureau of Indian Standards (BIS). Indian Standard (IS : 12183 Part 1 Water Supply): 1987. Reaffirmed in 2004. Code of Practice for Plumbing in Multi-Storeyed Buildings. New Delhi: BIS.*

7.4 Energy-efficiency in lifts[11]

7.4.1 Types of lifts

Lifts are broadly classified into hydraulic lifts and traction lifts.

- Hydraulic lifts: are commonly used where the lift travel is less than 20 m (up to 6 or 7 floors).
- Traction lifts: is further divided into three types.
  - Geared: These are typically used in mid-rise applications (7 to 20 floors) where high speed is not a major concern (typical speeds range from 0.1 m/s to 2.5 m/s).
  - Gearless: In these lifts, the sheave is driven directly by the motor, thus eliminating losses in the gear train. These are normally used in high-rise applications with nominal speeds between 2.5 m/s and 10 m/s.
  - Machine-roomless: In these lifts, the motor and gears are fitted directly on to the lift shaft, thus eliminating the need for a separate lift room.

7.4.2 Electricity consumption in lifts

Electricity consumption in lifts can be classified under two heads:

- Running electricity consumption, which refers to electricity consumed by the motors during lift operation
- Standby electricity consumption, which includes electricity consumed for lighting inside lifts, operation of control panels, displays, fans, etc.

An extensive 2010 European study on energy-efficiency possibilities in lifts shows that approximately 70% of the overall electricity consumed by lifts in residential buildings (Figure 7.6) is used during the standby mode. This is because the amount of time spent in standby mode in residential buildings is much more than in lifts installed in offices and industries, where the utilisation of lifts is higher.

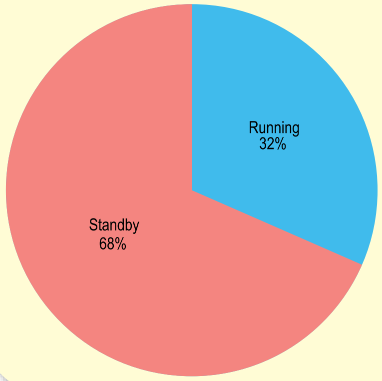

Figure 7.6 *Proportion of standby and running mode to overall energy consumption of lifts in residential buildings*[12]

The results of monitoring electricity consumption in residential lifts in Europe are shown in Table 7.4. It can be observed that hydraulic lifts have the highest average energy used per cycle.

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[11] *This section on lifts is based on the report: 'E4 Project – European Union (March 2010): Energy Efficient Elevators and Escalators'. <http://www.e4project.eu/>, last accessed in July 2015.*

[12] *E4 Project – European Union (March 2010): Energy Efficient Elevators and Escalators.*

Table 7.4 Results of monitoring of residential lifts in Europe[13]

Parameter	Hydraulic	Geared	Gearless
Average energy used per cycle (Wh)	63.8	50.4	33.07
Average standby power (W)	180.4	163.8	249.0

7.4.3 Regeneration

In conventional traction lifts, braking energy is dissipated by a braking resistor. A regenerative system allows energy to be recovered and fed back either into the building or into the electrical grid, depending on the configuration and on local regulations. A study estimates that the degree of energy recovery (as the relation of recovered energy to overall energy demand for travelling up and down) for small lifts (630 kg, 1.6 m/s) is below 30%, while for large installations (2200 kg, 2.5 m/second), it can be up to 40%.[14] Recovery is possible during a period of stable running, thus decreasing the recovery potential for lifts with shorter shafts.

7.4.4 Useful tips for the design of lifts

- While selecting a lift, the designer should consider the electricity consumed for running the lift, as well as during its standby mode.
- Energy efficiency in standby mode:
  - Use energy-efficient lighting fixtures having higher lumens/watt (e.g. CFLs or LEDs).
  - Use occupancy sensors with auto switch-off option.
  - Avoid dark surface materials and textures in the interiors of the lift car.
  - Use high-efficiency motors for ventilation, along with an auto switch-off option or a manual switch, which can help in reducing electricity consumption for ventilation.
- Energy efficiency in the running of the lift system:
  - Choose an energy-efficient drive option. Usually gearless lifts have the lowest electricity consumption.
  - Use VFDs on electric motors.
  - Check whether there is a possibility of incorporating a regenerative system.

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[13] *E4 Project – European Union (March 2010): Energy Efficient Elevators and Escalators.*

[14] *Ibid.*

RECOMMENDATIONS

Recommendation 11: Incorporate energy-efficiency features in the design of lighting of common areas

- Design for daylighting of corridors, staircases, parking areas
- Choose energy-efficient artificial lighting
  - Indoor spaces
    - Use LEDs, CFLs, and higher BEE star-rated TFLs
  - Outdoor spaces:
    - Use LEDs and metal halide lamps
    - Optimise for height and distance

Recommendation 12: Incorporate energy-efficiency features in the design of community water pumping system

- Pumped gravity system
  - Select a pump whose head and flow parameters for the ‘Duty Point’ matches with that of the ‘Best Efficiency Point’ of the pump.
  - Design piping so as to reduce frictional losses.
  - Use variable frequency drives (VFDs) on pump motors.
- Hydro-pneumatic system
  - Install VFDs for all pumps.

Recommendation 13: Incorporate energy-efficiency features in the design of lifts

- Measures to reduce standby electricity consumption
  - Use LED or CFL for the lighting of the lift car
  - Avoid dark interiors in the lift car
  - Use high-efficiency motors for the ventilation of the lift car
  - Provide auto switch-off for lights and ventilation fan
- Measures to reduce running electricity consumption
  - Use of VFDs in motors
  - Opting for lifts with gearless systems
  - Incorporation of regenerative braking

CHAPTER 8

RENEWABLE ENERGY INTEGRATION

AT A GLANCE

Most parts of warm-humid regions (except parts of north-eastern states) of India receive high-intensity solar radiation. Most of the urban centres located in these regions receive annual global solar irradiation >5 kWh/m^2.day (OR >1700 kWh/m^2.year). The available solar radiation can be used for either heating water (solar water heating technology) or for generating electricity (solar photovoltaic [PV] technology).

Though solar panels can be installed on the building façade, the roof is the best place for installation of solar systems. In multi-storey residential buildings, the available roof area for harnessing solar energy per flat decreases from about 13–18 m^2 of the roof area per flat for a 4-storey building to 2–3 m^2 roof area per flat in case of a 24-storey building.

Solar water heating

In the warm-humid climates, the requirement for hot water varies from 6 to 12 months. In cities, people like to take bath with warm water for almost round the year, and hence,the demand for hot water remains throughout the year. The average daily demand for hot water (at 40 °C) per flat is around 300 litres.

Solar water heater (SWH) systems can be of two configurations—smaller individual systems for each flat or larger community system, which supplies hot water through a common pipe network to a group of flats. Design of proper hot water distribution system and back-up heating system is essential for the success of community SWH systems.

Solar photovoltaic

Listed below are the three main configurations that are possible for rooftop solar PV.

1. Stand-alone (off-grid) solar PV system with dedicated loads
2. Grid-connected solar PV system with net metering
3. Hybrid system (system with grid back-up power)

RECOMMENDATION FOR RENEWABLE ENERGY INTEGRATION

Recommendation 14: Utilise rooftops of multi-storey residential buildings for the generation of hot water and/or electricity using solar energy

For highly energy-efficient residential buildings (overall EPI <30 kWh/m^2.year) of up to four storeys, it is possible to generate enough electricity through rooftop solar PV (assuming utilisation of 60% of the roof area) to meet the annual electricity consumption.

As a general rule, in most multi-storey residential buildings, the electricity generated from rooftop solar PV systems (assuming utilisation of 60% of the roof area) in a year is sufficient to meet either full or a substantial portion of the electricity consumption for common services during the year.

As a general rule, for multi-storey residential buildings up to 18 storeys, community SWH systems on the roof (assuming utilisation of 60% of the roof area) can meet 60%–70% of the annual electricity requirement for heating water. Beyond 18 storeys, there are diminishing returns due to lower energy replacement, increased complexity in distribution, and heat losses.

Unlike individual and low-rise housing where the roof area is sufficient to install both SWH and solar PV systems, in most multi-storey residential buildings only one of the technologies can be used due to the limitations in the roof area. The choice of technology should be based on the priority of the requirements and a cost–benefit analysis.

8.1 Introduction

Most parts of warm-humid regions (except parts of the north-eastern states) of India receive high-intensity solar radiation. Most of the urban centres located in these regions receive annual global solar irradiation >5 kWh/m^2.day (Figure 8.1). The main requirement for harnessing solar energy is the availability of shadow-free space. Figure 8.2 shows that typically the annual solar radiation per square metre on a roof is almost three times the average solar radiation falling on the walls. This chapter deals with the utilisation of solar energy falling on the roof of a multi-storey residential building to produce hot water (using solar water heater [SWH] technology) and electricity (using solar photovoltaic [PV] technology).

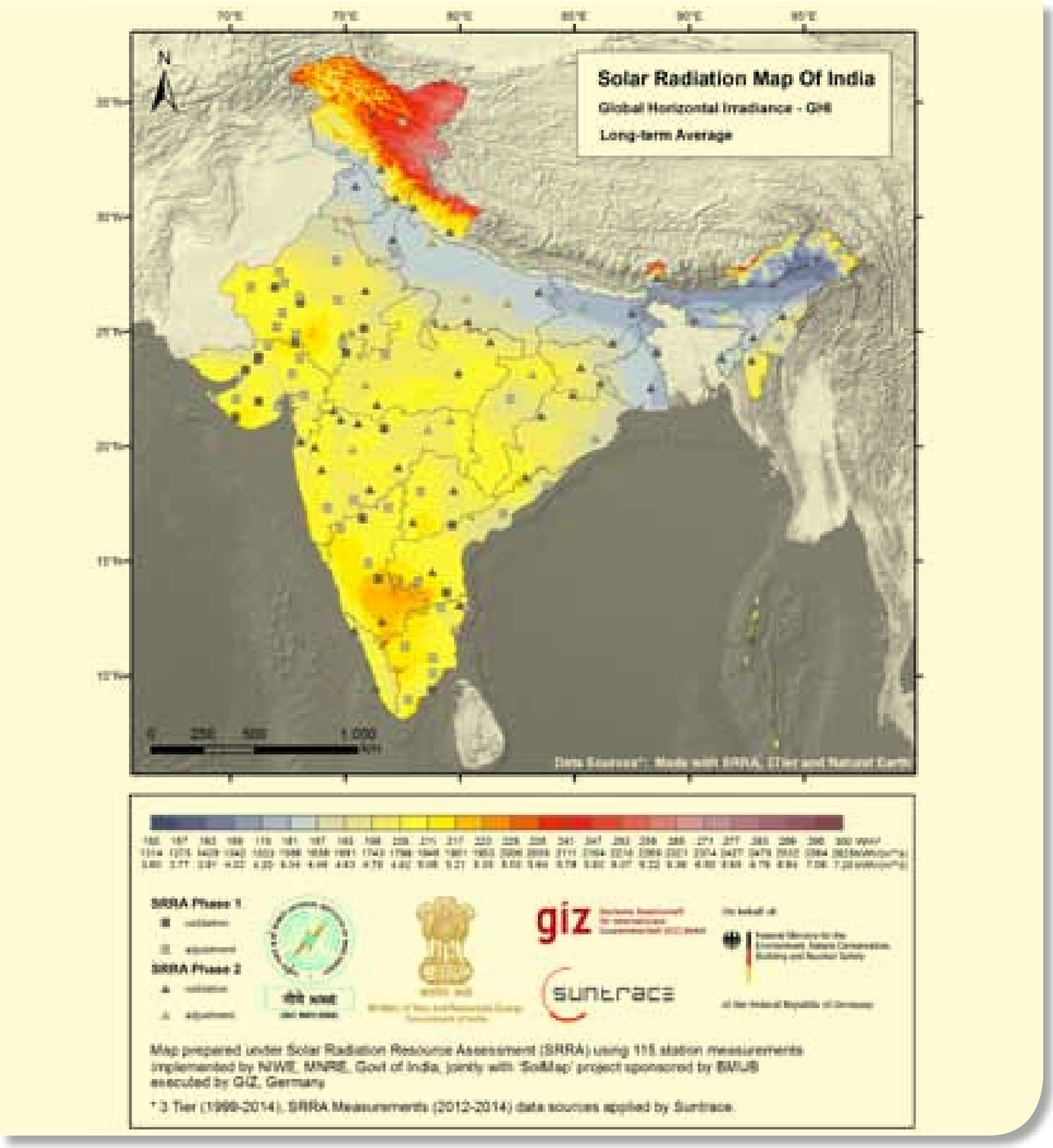

Figure 8.1 *Global horizontal irradiation of India*
(Source: 'Indian Solar Radiation Atlas' prepared by NIWE, MNRE, and GIZ)

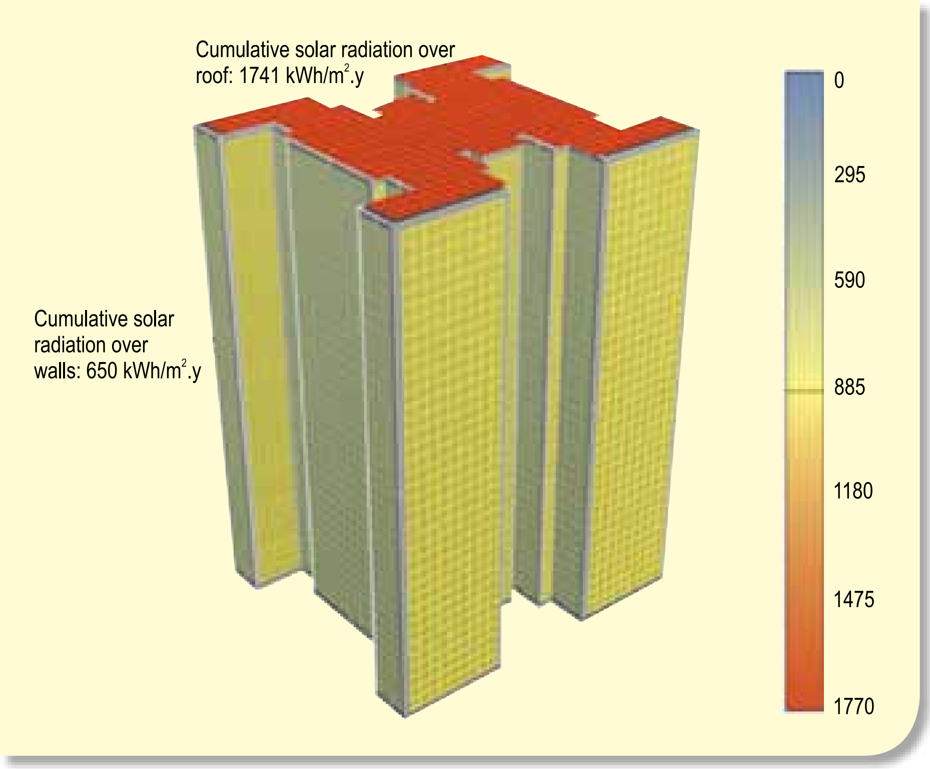

Figure 8.2 *Average annual solar irradiation at roof and walls for a tower typology 12-storey building in Chennai*

8.2 Availability of rooftop area

Usually, only a fraction of the roof area of a multi-storey residential building can be utilised for harnessing solar energy. Water tanks, lift rooms, dish antennas, and other common services are located on the roof and can occupy a significant area. Shadow from the parapet walls further reduces the shadow-free roof area available for harnessing solar energy on the roof.

For example, in a typical building block comprising towers (Figure 8.2), with four flats on each floor of a tower, the total roof area is 355 m^2. The available shadow-free area for harnessing solar energy, assuming that 60% of the total roof area is shadow-free and is available for harnessing solar energy, is 213 m^2 (Table 8.1).

It is important to note that for multi-storey residential buildings, the available roof area for harnessing solar energy per flat decreases as the height (number of storeys) increases. This is shown in Figure 8.3, in which variation in the available roof area for solar energy

Table 8.1 Example showing available roof area for solar energy technologies for a multi-storey building

Building typology	Tower
Flat/floor	4
Roof area of the building (m^2)	355
Available shadow-free roof area for solar (%)	60
Available shadow-free roof area for solar (m^2)	213

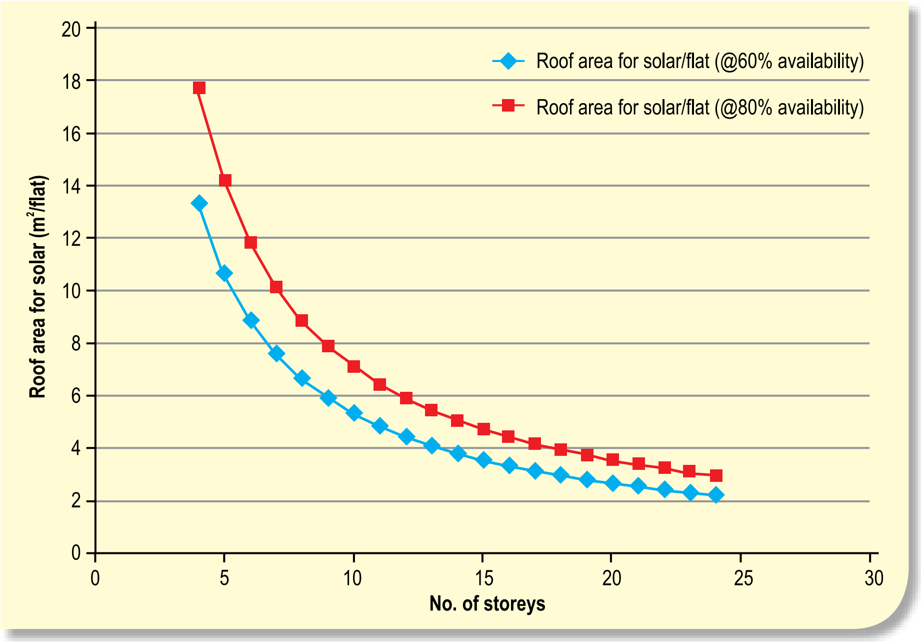

Figure 8.3 *Variation in available roof area for solar/flat with the number of storeys*

per flat is plotted against the variation in height for the building specified in Table 8.1. The plot is for two conditions:

- 60% of the roof area is assumed to be available for solar energy technologies, and
- 80% of the roof area is assumed to be available for solar energy technologies.

The graph shows that while for a 4-storey building, 13–18 m^2 roof area is available per flat for harnessing solar energy, this area decreases to 2–3 m^2 roof area per flat for a 24-storey building. The practical implication of this observation is that for low-rise buildings (around five storeys), a larger fraction of the total energy requirements can be met by solar energy. This aspect will be discussed in detail later in the chapter. The analysis presented in this chapter does not consider the installation of solar collectors on the walls.

Solar energy can be harnessed through two distinct technologies: SWH technology, which can be used for heating water to meet hot water requirements of the residents; and/or solar PV technology, which can be used to generate electricity (Figures 8.4 and 8.5).

8.3 Solar Water Heaters

8.3.1 Hot water requirement

In residential buildings located in the warm-humid climate, the requirement for hot water varies from six months to round the year. In cities, people like to take bath with warm water for almost round the year. The hot water requirement for a typical flat is estimated to be around 300 litres of hot water (at 40 °C) per day (Table 8.2). The requirement of hot water is the highest for bathing.

Figure 8.4 *Solar water heater systems installed on rooftop*

Figure 8.5 *Solar PV system on a rooftop*

Table 8.2 Hot water requirement for a typical flat

Hot water norms (for winter months) @ 40 °C[1]	
Bathing per person per day	40 litres
Wash basin per person per day	10 litres
Kitchen use per person per day	15 litres
Total per person per day	65 litres
Heat loss and hot water wastage factor	20%
Total hot water requirement per person per day	78 litres
Number of persons in each flat	4
Total hot water requirement per flat per day	312 litres @ 40 °C

To illustrate the sizing of SWH system and the potential electricity savings, three cases for typical residential building (6, 12, and 24 storeys), as described in Table 8.1, were analysed using RETScreen[2] software. The analysis was done for Mumbai and Chennai considering the requirement of hot water round the year. The results of the analysis are presented in the following sections.

8.3.2 Electricity required for water heating with electric geysers

Generally, individual electric geysers are used for heating water. The annual electricity consumption for the generation of hot water using electric geysers is estimated to be 1843 kWh/flat/year in Mumbai and 1656 kWh/flat/year in Chennai (Table 8.3).

8.3.3 Solar water heating system (SWHS) sizing and output

The general strategy for designing SWHs is to size it for the peak winter season. Using the RETScreen software, the size and output of the SWH system for the three cases (6, 12, and 24 storeys) were calculated for Mumbai and Chennai. The results presented in Table 8.4 are summarised below.

- An optimally sized SWH system can meet 60%–70% of the annual energy required for heating water (or solar fraction[3]) for 6- and 12-storey buildings located in Mumbai and

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[1] *Kumar A and Goswami N. 2010. User's Handbook on Solar Water Heaters. MNRE-UNDP-GEF Global Solar Water Heater Project.*

[2] *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 website <www.retscreen.net>.*

[3] *Solar fraction is defined as the ratio of the amount of input energy contributed by a solar energy system to the total input energy required for a specific application.*

Table 8.3 Electricity consumption for hot water generation for a typical flat in Mumbai and Chennai

	Useful energy required for hot water generation	
Parameter	**Mumbai**	**Chennai**
Minimum temperature of cold water[4] (°C)	23.0	22.0
Mean temperature of cold water (October–March) (°C)	27.5	28.8
Useful energy required for heating (kWh/year.flat)	1659	1491
Electric energy consumed in water heating (kWh/year.flat)*	1843	1656
Hot water requirement @60 °C for minimum cold water temperature (litres/day)	120	112

*Assuming storage-type geysers with 90% efficiency

Table 8.4 Size and output of SWHs for a typical building in Mumbai and Chennai

SWH technology	**Flat-plate collector**					
Typical size of solar collector	2 m^2					
Roof area required for one solar collector	4 m^2					
Maximum solar collectors possible on roof	53 collectors					
Location	Mumbai			Chennai		
Number of storeys	6	12	24	6	12	24
Flats	24	48	96	24	48	96
Number of SWH collectors as calculated from RETScreen (winter optimised[5])	18	36	71	18	35	70
Whether sufficient roof area available	Yes	Yes	No	Yes	Yes	No
Number of SWH panels after considering roof area constraint	18	36	53	18	36	53
Heating delivered from SWH (kWh/year)	23,800	47,600	75,000	24,600	48,200	77,600
Solar fraction (%)	60	60	47	69	67	54
Electricity saved (kWh/year)	26,500	52,900	83,300	27,300	53,500	86,200
Electricity saved per flat (kWh/year)	1104	1102	868	1138	1115	898

Chennai. As can be observed in Figure 8.6, the solar fraction decreases for buildings higher than 12 storeys due to roof area constraints; hence, for a 24-storey building, only 47% of the energy demand in Mumbai and 54% of the energy demand in Chennai can be met.

- For a 6-storey building, only 34% of the roof area available for solar system is utilised, while in a 12-storey building, 67% of the roof area available for solar system is utilised.

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[4] *Kumar A and Goswami N. 2010.User's Handbook on Solar Water Heaters. MNRE-UNDP-GEF Global Solar Water Heater Project.*

[5] *In winter optimisation, system is sized in a manner that it can provide the required hot water even for minimum cold water temperature.*

The analysis suggests that for a building of up to 18 storeys, an SWH system of optimum size can be installed by utilising 100% available roof area for solar system. For buildings higher than 18 storeys, sufficient roof area is not available to install SWHs of optimum size.

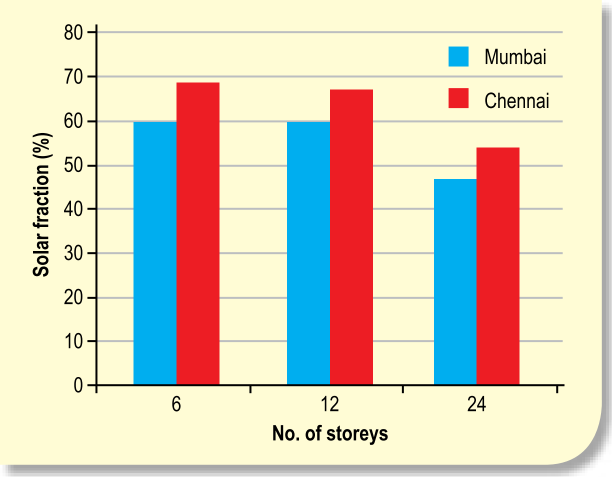

Figure 8.6 Variation in annual solar fraction with the height of building

In Figure 8.7, the solar fraction for Mumbai and Chennai is shown to vary significantly over different months. In Mumbai, while the SWH system will be able to meet only 38% of the energy requirement for heating water in July, it can meet 74% of the energy requirement in April. The variation for Chennai is relatively less, varying from 51% in December to 82% in April.

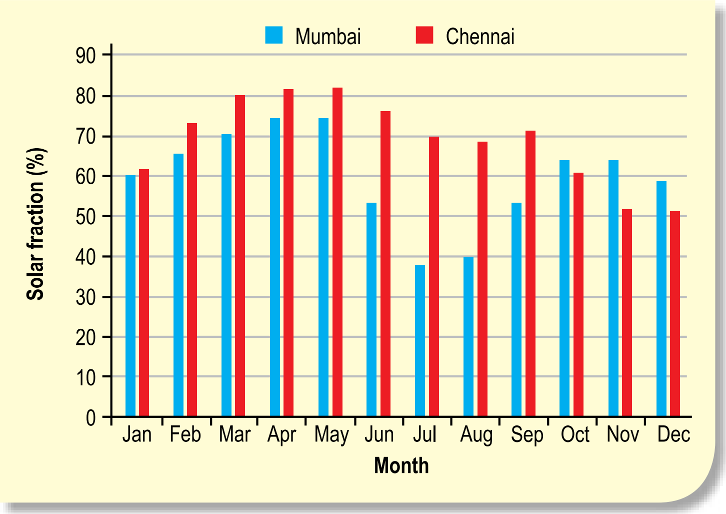

Figure 8.7 Monthly solar fraction for a six-storey residential building in Mumbai and Chennai

8.3.4 Solar water heating system configurations

In a multi-storey building, there could be two configurations of SWH system.

- **Individual system for each flat:** In this configuration (Figure 8.8), a separate SWH system for each flat is installed on the roof of the building. A hot water pipeline is individually drawn for each flat. The advantage of this configuration is that (a) it ensures equal distribution of hot water to each of the flats, and (b) each flat bears the maintenance and service cost of the individual system. However, this configuration requires more space on the terrace because some circulation area needs to be left between two SWH systems. Also, the length and cost of the hot water piping are relatively high. Owing to the long hot water pipes needed and the related heat loss caused thereof, it is difficult to provide water to the flats situated on the lower floors at the required temperatures. This system is usually used only for buildings up to four storeys.
- **Community-type system:** In this configuration (Figure 8.9), a large SWH system that is capable of providing hot water to the entire building is installed on the roof. The hot

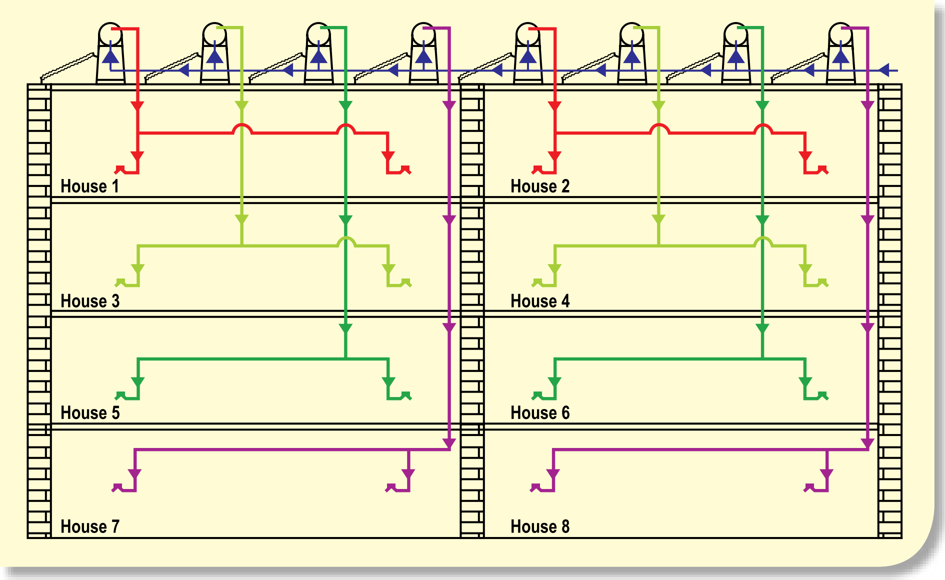

Figure 8.8 *Schematic for individual system for each flat*[6]

water from the system is supplied through a common pipe network. This configuration occupies less area of the roof than the individual-type configuration, and it is generally used for buildings with three or more storeys. However, in the community-type configuration, proper arrangements need to be made to ensure (a) efficient back-up heating, (b) equal hot water sharing among the flats, and (c) instant hot water supply for the lower floors.

Back-up heating arrangement can be provided in two ways.

1. **Centralised back-up heating:** An electrical heater is installed in the main hot water storage tank or in a smaller auxiliary tank of the SWH system on the roof. In this case, the main or the auxiliary tank would always be maintained at a specified temperature and heat losses could be significantly higher.
2. **Individual back-up heating:** Individual electric geysers (either storage or instant) are installed in each of the flats. Another option is to provide an insulated hot water tank at each flat that receives hot water from the central hot water tank at a specified time during the day.

To ensure instant hot water supply at the lower floors, one possible option is to provide a solenoid valve in the hot water supply line to each flat. The solenoid valve operates at a pre-set temperature and diverts water from the SWH system to the cold water line if the water temperature in the SWH line is below the pre-set temperature. In this way, it avoids wastage of water. To deal with issues related to the equal distribution of hot water in a community-type system, the following options may be considered: (a) system

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[6] *School of Energy Studies, University of Pune. August 2012. 'Guidelines on Installation of Solar Water Heating Systems in High Rise Buildings, MNRE-UNDP-GEF Global Solar Water Heater Project.*

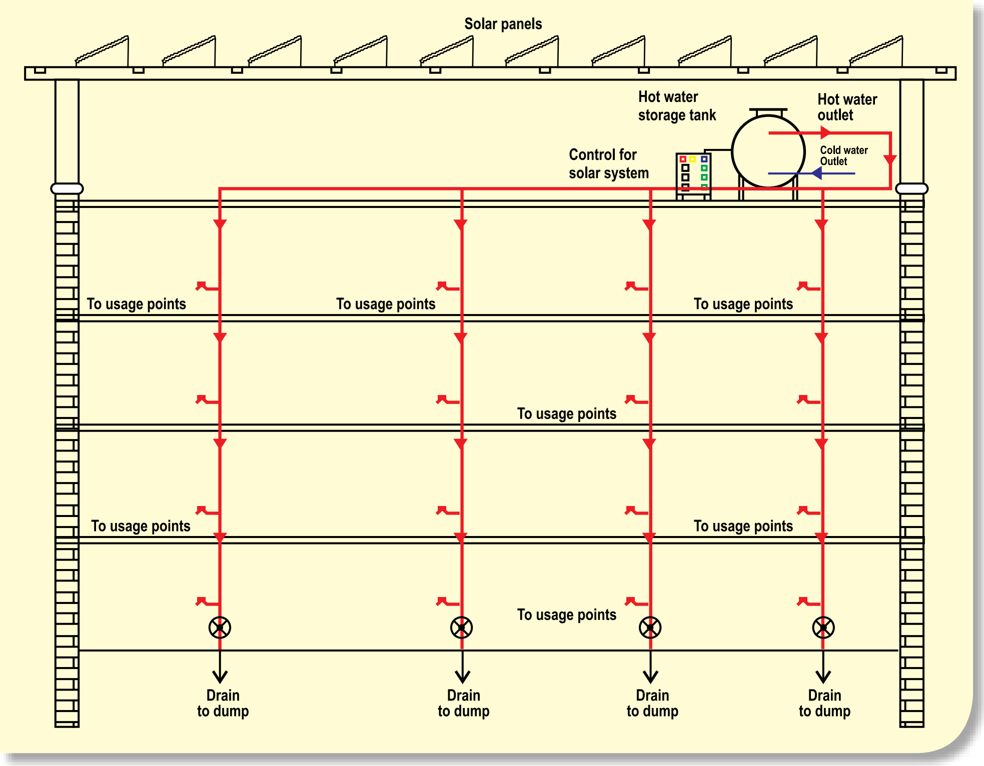

Figure 8.9 *Schematic for community type system*[7]

split into number of units, with each unit supplying hot water to a separate wing of the building, (b) an individual hot water storage tank system, in which through a centralised control panel, a metered amount of hot water is transferred from the main hot water tank to individual hot water storage tanks.

8.3.5 Useful tips for solar water heaters

- For up to 18-storey buildings, there is usually sufficient roof space to install an SWH system that can meet around 60%–70% of the annual energy required for heating water in the warm-humid climate regions.
- For buildings which are more than 18 storeys, the amount of hot water generated through solar energy decreases, and for a 24-storey building 47%–54% of the annual hot water requirement can be met. There are diminishing returns due to increased complexity in distribution and heat losses.
- To be effective, the design of SWH systems should be done carefully to incorporate suitable provisions to deal with equal distribution of hot water, back-up heating, and instant supply of hot water on lower floors.

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[7] *School of Energy Studies, University of Pune. August 2012. 'Guidelines on Installation of Solar Water Heating Systems in High Rise Buildings, MNRE-UNDP-GEF Global Solar Water Heater Project.*

8.4 Solar Photovoltaic

A solar PV system can be installed on the roof or on any other available shadow-free space within the residential complex to generate electricity that can be used either to meet the electricity demands of the building or to export to the grid. To illustrate the benefits of solar PV, a similar exercise as performed for the SWH system was conducted for the available roof area of typical building units (described in Table 8.1) for two locations, Mumbai and Chennai.

8.4.1 Electricity Generation from Solar photovoltaic technology

RETScreen was used to estimate the electricity generation from 1 kW_p of solar PV system in Mumbai and Chennai. Table 8.5 and Figure 8.10 show the annual electricity generation and variation in the monthly average daily output of the solar PV system.

Table 8.5 Annual electricity generation from 1 kW_p solar PV system at Mumbai and Chennai

	Mumbai	Chennai
Annual electricity generation (kWh/kW_p.year)	1435	1473

8.4.2 Sizing of solar PV system

The size of a solar PV system for a residential building is determined by the building's available roof area. For the building considered in Figure 8.2, there is only sufficient space to install 21 kW_p of solar PV panels (when 60% of the roof area is available for solar PV), which will generate around 30,100 kWh in Mumbai and 30,900 kWh in Chennai annually (Table 8.6).

8.4.3 Net zero-energy 4-storey residential building concept

The output from a rooftop solar PV system installed on a 4-storey residential building in Chennai, as shown in Table 8.6, is around 31,000 kWh/year. In Figure 8.11, this is shown by a thick black line. The two bars shown in the figure represent the total annual electricity consumption for an energy

Table 8.6 Sizing and output of the proposed solar PV solution in a typical building

Solar PV technology	Polycrystalline 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)	355	
Available shadow-free roof area for solar (%)	60	
Available shadow-free roof area for solar (m^2)	213	
Maximum size of photovoltaic system possible on roof (kW_p)	21	
Location	**Mumbai**	**Chennai**
Annual electricity generation (kWh/year)	30,100	30,900

*Efficiency of the polycrystalline solar panel lies between 11 % and 14 %[8]

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[8] *Singapore, Building and Construction Authority. undated. Handbook for Solar Photovoltaic Systems. Singapore: Singapore Building and Construction Authority.*

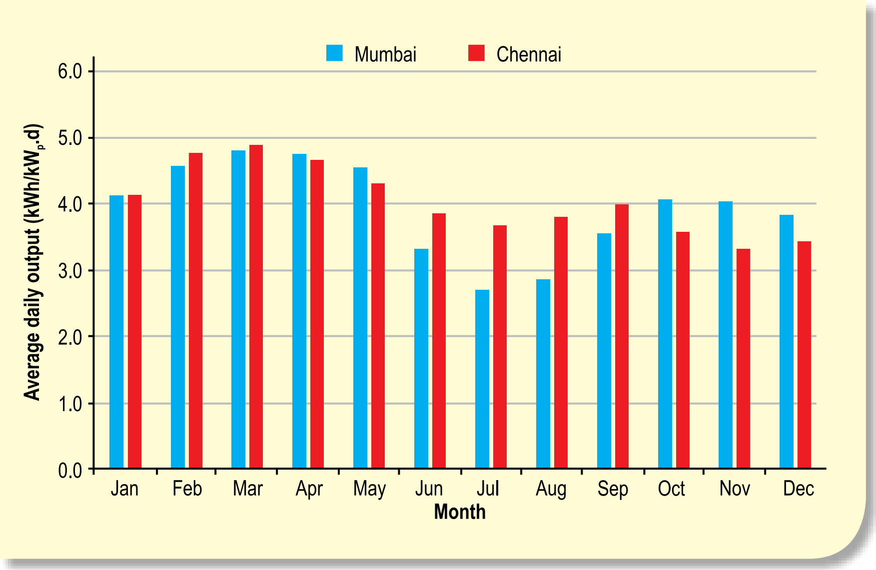

Figure 8.10 *Average daily output for solar PV system at Mumbai and Chennai*

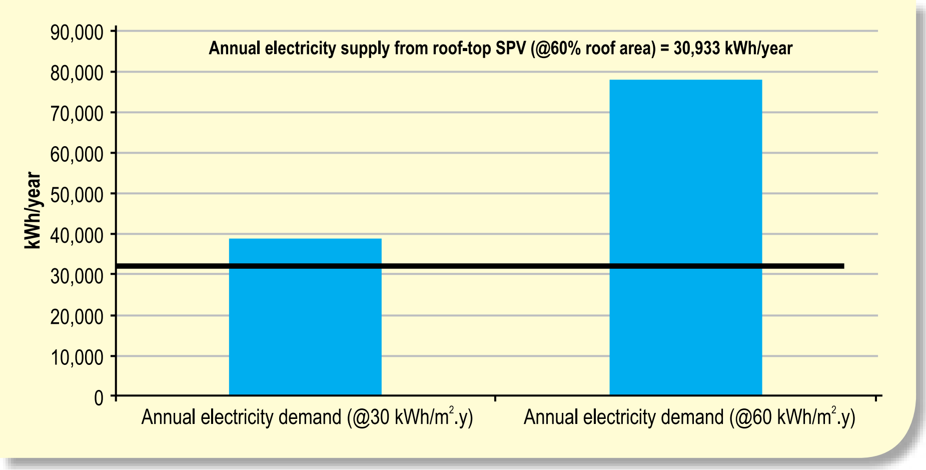

Figure 8.11 *Electricity generation from rooftop solar PV on a 4-storey building vs. annual electricity demand*

performance index (EPI) of 60 kWh/m^2.year and 30 kWh/ m^2.year. It can be observed that if the total EPI (including that for common services), through the energy-efficiency measures described in Chapters 3–7, is brought down to 30 kWh/m^2.year, the rooftop solar PV system will be able to meet almost the entire amount of electricity requirement of a 4-storey residential complex. This indicates the possibility of developing net zero-energy in multi-storey building complexes.

8.4.4 Meeting electricity requirements for common services through solar PV

Annual electricity demand for common services for different building heights is plotted in Figure 8.12. It shows that for very efficient common services (5 kWh/m^2.year), the electricity generated from the rooftop solar PV system is sufficient to meet electricity requirements for all common services in buildings up to 20 storeys. When the electricity consumption for

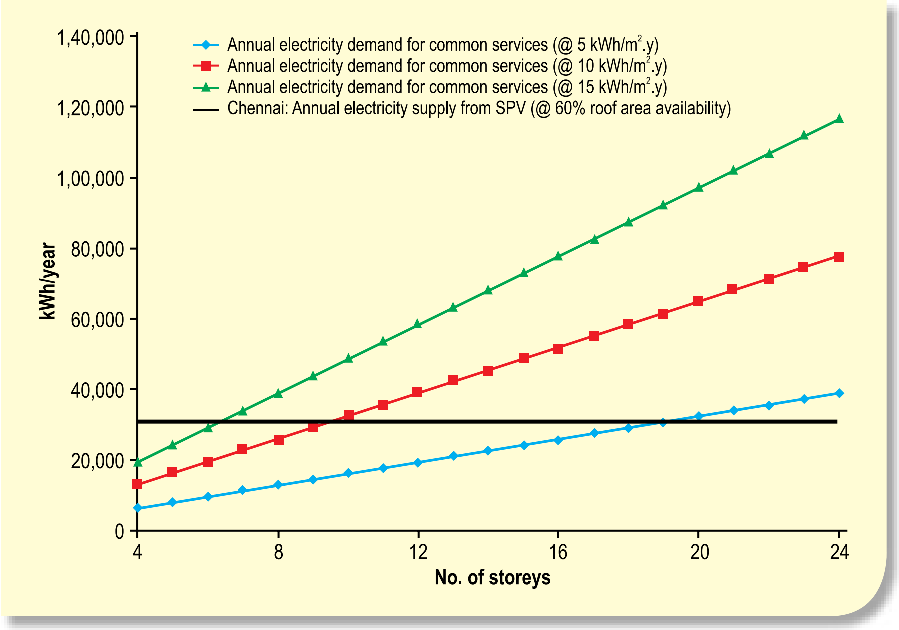

Figure 8.12 *Potential solar PV generation from rooftop solar PV system versus annual electricity consumption for common services*

common services is high (10 kWh/m^2.year and 15 kWh/m^2.year), rooftop solar PV can meet the electricity requirement for buildings up to 10 and 6 storeys, respectively.

8.4.5 Configuration of solar PV system[9]

Solar PV system output can be utilised in three configurations.

1. **Stand-alone (off-grid) solar PV system with dedicated loads:** In this configuration, the solar PV system is not connected with the grid. Electricity generated from the solar PV system is used for either meeting certain dedicated loads in the daytime or storing the energy by charging the batteries for night-time loads. Electricity for pumping water and for operating lifts during daytime can be directly supplied by the solar PV system. The energy stored in the batteries can be used to meet the requirements of lighting and lifts during the night. This configuration requires a substantial battery bank to store the electricity for night-time. The schematic of this system is shown in Figure 8.13.
2. **Grid-connected solar PV system with net metering:** In this system, the building has two meters. One meter measures the electricity generated from the solar PV 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 solar PV-generated electricity and its tariff, and the electricity consumed from the grid and its tariff, the electricity bill is calculated. The schematic is shown in Figure 8.14.

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[9] *Energy Informative <http://energyinformative.org/grid-tied-off-grid-and-hybrid-solar-systems/> accessed on 8 September 2015.*

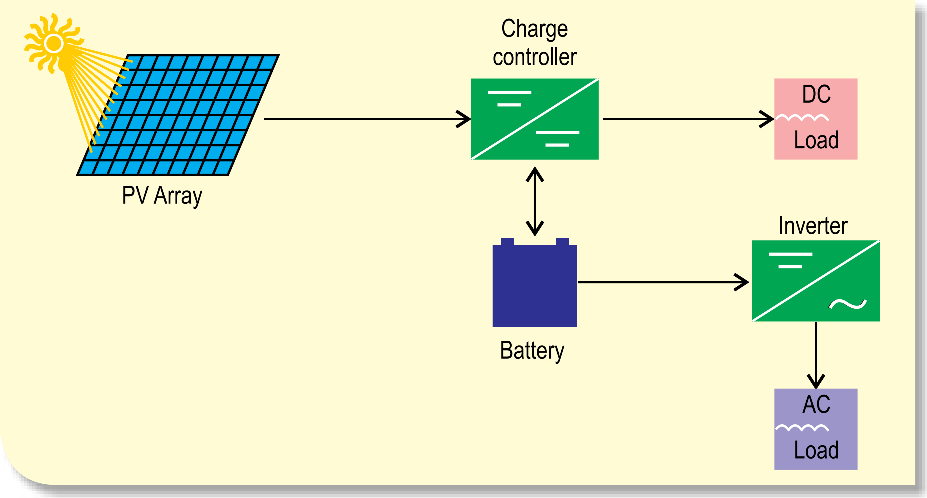

Figure 8.13 Schematic for solar PV system for stand-alone off-grid configuration

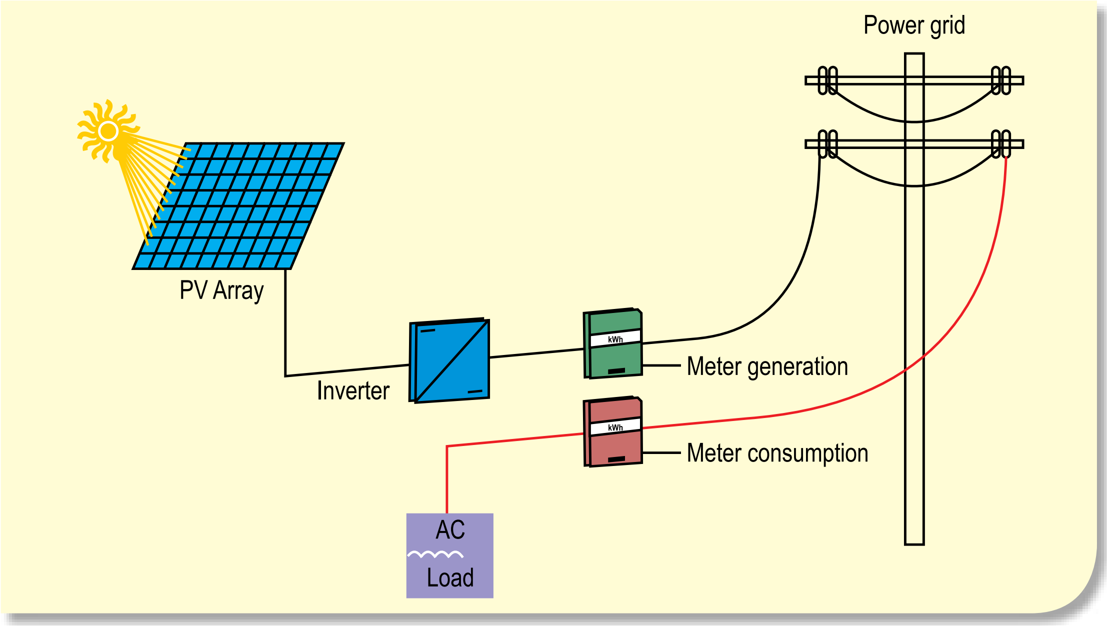

Figure 8.14 Schematic for solar PV system for grid-tied configuration[10]

3. **Hybrid system (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 solar PV 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 only acts 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 solar PV system. There is an option to switch to grid-connected configuration with minimal cost. The schematic of the configuration is presented in Figure 8.15.

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

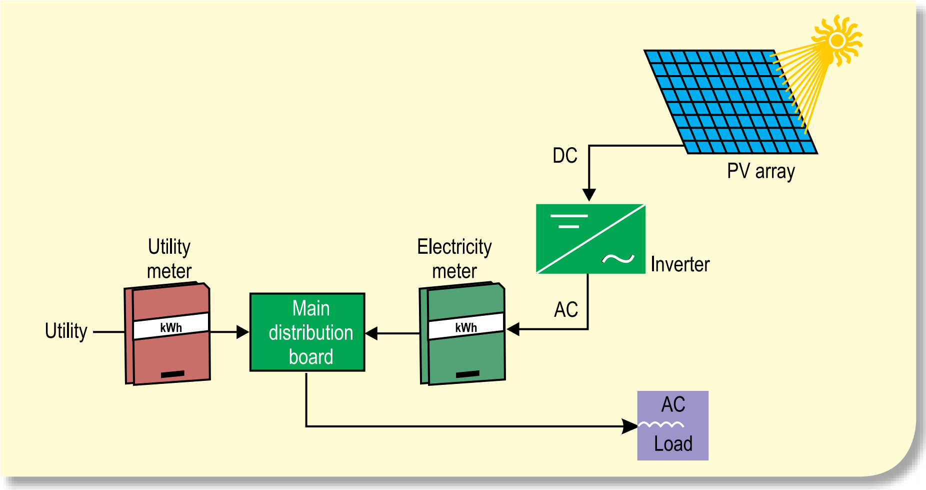

Figure 8.15
Schematic for solar PV system for hybrid system configuration[11]

8.4.6 Emerging technologies (DC-to-home[12])

Presently, all the houses are supplied with AC power. However, there are many appliances (e.g., laptops, mobile chargers) that require DC and need an adapter to convert AC to DC to power these appliances. The conversion loss could be as high as 30%, which means for all the DC appliances, one has to pay 30% more on energy bills. Therefore, parallel supply of AC and DC power can help in energy saving.

Also, there are many DC-based appliances (e.g., lights, fans, pumps) available in the market that can substitute for similar AC-powered appliances. These DC-based appliances are more energy efficient than AC-powered appliances and the price difference is small:

- 30 W DC fan: Rs 1500 (a 70 W AC fan is Rs 1300)
- 18 W, 1.2 m LED lighting equivalent to 36 W fluorescent: Rs 1100

Another advantage of DC appliances is that they can be operated efficiently at part load (e.g., a 30 W DC-powered fan would take only 11 W at lowest speed; an 18 W DC-powered LED light can be operated at 5 W also with lower light output).

Solar PV systems can directly interface with the 48 V DC line that can power all the DC appliances. A battery bank can be integrated to store energy and power appliances at night-time. Thus, clean DC power can be utilised without the DC–AC conversion losses. A schematic of such a system is shown in Figure 8.16.

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[11] *HK RE Net <http://re.emsd.gov.hk/english/solar/solar_ph/solar_ph_to.html> accessed on 8 September 2015.*

[12] *IIT-Madras press conference: Professor Ashok Jhunjhunwala makes the case for taking DC power to home, 3 February 2014.*

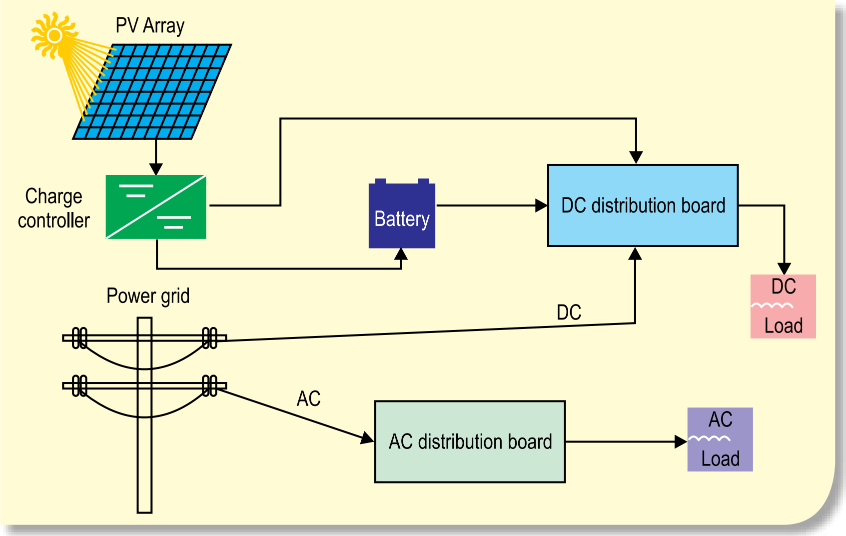


Figure 8.16 *Parallel DC and AC supply with solar PV integration*

RECOMMENDATIONS

Recommendation 14: Utilise rooftops of multi-storey residential buildings for the generation of hot water and/or electricity using solar energy

For buildings and neighbourhoods, which are 4-storey high and are designed with energy-efficiency principles, it is possible to meet the annual requirement for electricity and hot water using rooftop solar PV and SWH systems. Such a building can become a net zero-energy consumer.

As a general rule, in most multi-storey residential buildings, the electricity generated from rooftop solar PV systems (assuming utilisation of 60% of the roof area) in a year is sufficient to meet either full or a substantial portion of the electricity consumption for common services during the year.

As a general rule, for multi-storey residential buildings up to 18 storeys, community SWH systems on the roof (assuming utilisation of 60% of the roof area) can meet 60%–70% of the annual electricity requirement for heating water. Beyond 18 storeys, there are diminishing returns due to lower energy replacement, increased complexity in distribution, and heat losses.

Unlike individual and low-rise housing where the roof area is sufficient to install both SWH and solar PV systems, in most multi-storey residential buildings only one of the technologies can be used due to the limitations in the roof area. The choice of the technology should be based on the priority of the requirements and a cost–benefit analysis.

ANNEXURES

ANNEXURE 1: THERMAL PERFORMANCE ANALYSIS (CHAPTER 4)

Thermal performance analysis of bedroom

To understand the thermal performance of a bedroom, an energy simulation model was developed in TRNSYS. The bedroom has a dimension of 3 x 3.7 x 3 m. It is located on an intermediate floor and hence no heat transfer is considered across the ceiling and floor.

The simulation was first carried out for the base case. The bedroom in the base case has two external walls (exposed to ambient) and two internal walls, which it shares with other spaces. The other inputs for the base case, as given in Table 4.1 in Chapter 4, is reproduced here as Table A.1.1 for the convenience of the reader.

Table A.1.1 Important inputs for the simulation of the base case for bedrooms

Parameter	Values
Wall External wall: 230-mm brick wall Internal wall: 115-mm brick wall	 U-value[a]: 2.0 W/m^2.K; surface absorptivity: 0.65 U-value: 3.2 W/m^2.K; adiabatic
Glazing 6-mm single clear glass	U-value: 6.1 W/m^2.K SHGC[b]: 0.85 VLT[c]: 0.9
Shading on the window	500-mm horizontal static overhang at lintel level
Intermediate floor 150-mm RCC slab	U-value: 3.0 W/m^2.K Adiabatic
Window-to-floor area ratio	27%
External wall-to-floor area ratio	181%
Window-to-wall area ratio	15%
Occupancy load and schedule	*Schedule for weekdays:* 2 persons, (21:00–07:00 hours) *Schedule for weekend:* 2 persons, (23:00–07:00 hours) and (14:00–17:00 hours)
Set-point	26 °C
Location	Mumbai and Chennai

[a] U-value is the heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side.

[b] Solar heat gain coefficient (SHGC) is the ratio of the solar heat gain entering the space through fenestration area to the incident solar radiation.

[c] Visible light transmittance (VLT) is the amount of visible light that passes through a glazing system and is expressed as a percent.

Please refer to Figure A.1-1 (page 130 for Mumbai) and Figure A. 1-9 (page 138 for Chennai).

- The top-most bar shows the result for the base case. The cooling thermal energy demand for the base case calculated by the simulation model is shown as 100%. The other three bars in Figure A.1-1 and A.1-9 show the effect of energy-efficiency measures on the cooling thermal energy demand.

- The second bar corresponds to Package I measures, i.e., use of light colours on wall (absorptivity ≤0.4) + window shades with extended overhangs to intercept direct solar radiations on the window + insulated walls (U-value: 0.7 $W/m^2.K$) + optimised natural ventilation. It shows that by adopting Package 1 measures, the cooling thermal energy demand becomes 80%, i.e., reduces by 20% compared to the base case, in Mumbai. In Chennai, these measures result in a reduction by 18% in cooling thermal energy compared to the base case.
- The third bar corresponds to Package II measures, i.e., Package of measures I + external movable shutters on windows. It shows that by adopting Package II measures, the cooling thermal energy demand, in Mumbai, becomes 47%, i.e., reduces by 53% compared to the base case. In Chennai the cooling thermal energy is reduced by 44%.
- The fourth or the lower-most bar corresponds to Package III measures, i.e., Package of measures II + improved wall insulation (U-value: 0.5 $W/m^2.K$) + use of double glazing in windows + better envelope air-tightness. Package III measures are not very effective in both the cities.

Figures A.1-2 to A.1-8 (for Mumbai) and Figures A.1-10 to A.1-16 (for Chennai) show results of parametric simulation runs obtained by varying the number of exposed walls (1 or 2), and window-to-floor ratio (27% or 54%). The set-point temperature is kept 26 °C. The details of the cases for the simulation runs are given in Table A.1.2 and A.1.3.

Table A.1.2 Details of simulation runs for the bedroom (Mumbai)

Figure no.	No. of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Setpoint temperature (°C)	Window-to-floor ratio (%)
A.1-1	2	South	West	26	27
A.1-2	1	South	Internal	26	27
A.1-3	2	South	West	26	54
A.1-4	1	South	Internal	26	54
A.1-5	2	West	North	26	27
A.1-6	1	West	Internal	26	27
A.1-7	2	West	North	26	54
A.1-8	1	West	Internal	26	54

Thermal performance analysis of living room

The living room has a dimension of 3.6 x 6.7 x 3 m with a floor area of 24.5 m^2. It is located on an intermediate floor with ceiling and floor modelled as adiabatic (i.e., no heat flux occurs across these components). The base-case model has two external walls on the south and west direction and the other two walls are modelled as adiabatic surfaces.

The other inputs for the base case are provided in Table A.1.4, which is a reproduction of Table 4.4 from Chapter 4.

Table A.1.3 Details of simulation runs for the bedroom (Chennai)

Figure no.	No. of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Setpoint temperature (°C)	Window-to-floor ratio (%)
A.1-9	2	South	West	26	27
A.1-10	1	South	Internal	26	27
A.1-11	2	South	West	26	54
A.1-12	1	South	Internal	26	54
A.1-13	2	West	North	26	27
A.1-14	1	West	Internal	26	27
A.1-15	2	West	North	26	54
A.1-16	1	West	Internal	26	54

Table A.1.4 Important inputs for the simulation of the base case for living rooms

Parameters	Values
Wall External wall: 230-mm brick wall Internal wall: 115-mm brick wall	 U-value[a]: 2.0 W/m^2.K; Surface absorptivity: 0.65 U-value: 3.2 W/m^2.K; Adiabatic
Glazing 6-mm single clear glass	U-value: 6.1 W/m^2.K SHGC[b]: 0.85 VLT[c]: 0.9
Shading on the window	500-mm horizontal static overhang at lintel level
Intermediate floor 150-mm RCC slab	U-value: 3.0 W/m^2.K Adiabatic
Window-to-floor area ratio	19%
External wall-to-floor area ratio	129%
Infiltration	~0.7 ACH
Occupancy load and schedule	*Schedule for weekdays:* (4 persons, 7:00–08:00 hours; 1 person, 8:00–14:00 hours; 4 persons, 18:00–21:00 hours) TV: 7:00–8:00 hours, 17:00–21:00 hours *Schedule for weekend:* (4 persons, 8:00–14:00 hours; 1 person, 14:00–18:00 hours, 4 persons, 18:00–23:00 hours) TV: 7:00–8:00 hours, 17:00–23:00 hours
Set point	26 °C
Location	Mumbai and Chennai

Figures A.1-17 to A.1-24 (for Mumbai) and Figures A.1-25 to A.1-32 (for Chennai) show results of parametric simulation runs. The details of the cases for the simulation runs are given in Table A.1.5 and A.1.6.

Table A.1.5 Details of simulation runs for the living room (Mumbai)

Figure no.	No. of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Setpoint temperature (°C)	Window-to-floor ratio (%)
A.1-17	2	South	West	26	19
A.1-18	1	South	Internal	26	15
A.1-19	2	South	West	26	39
A.1-20	1	South	Internal	26	30
A.1-21	2	West	North	26	19
A.1-22	1	West	Internal	26	15
A.1-23	2	West	North	26	39
A.1-24	1	West	Internal	26	30

Table A.1.6 Details of simulation runs for the living room (Chennai)

Figure no.	No. of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Setpoint temperature (°C)	Window-to-floor ratio (%)
A.1-25	2	South	West	26	19
A.1-26	1	South	Internal	26	15
A.1-27	2	South	West	26	39
A.1-28	1	South	Internal	26	30
A.1-29	2	West	North	26	19
A.1-30	1	West	Internal	26	15
A.1-31	2	West	North	26	39
A.1-32	1	West	Internal	26	30

An example to illustrate how to read/use the figures

Compare the annual cooling thermal energy demand for the following three cases for bedroom in Mumbai.

- Case 1: Base case with two exposed walls on south and west orientations, with set-point temperature of 26°C, window-to-floor ratio of 27%
- Case 2: Base-case variation with one exposed wall on the south, with set-point temperature of 26°C, window-to-floor ratio of 27%
- Case 3: Package 3 with one exposed wall on the south, with set-point temperature of 26°C, window-to-floor ratio of 27%

Step 1: Select the figure number of the configurations representing the cases to be evaluated from the Table A.1.2 and A.1.3 for bedrooms; and Table A.1.5 and A.1.6 for living rooms. In our example, the cases belong to configurations of bedroom, so we need to select the figure number from Table A.1.2.

Case 1

Case 2

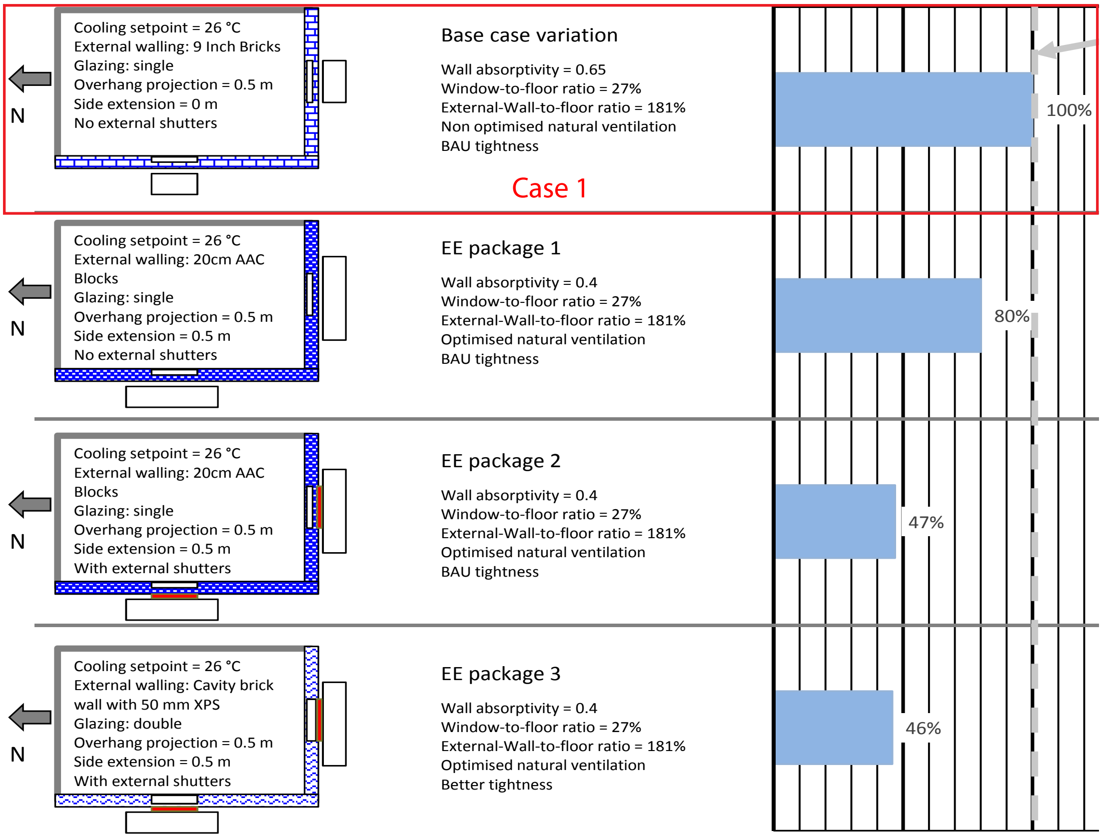
Table A.1.2 Details of simulation runs for the bedroom (Mumbai)

Figure no.	No. of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Setpoint temperature (°C)	Window-to-floor ratio (%)
A.1-1	2	South	West	26	27
A.1-2	1	South	Internal	26	27
A.1-3	2	South	West	26	54
A.1-4	1	South	Internal	26	54
A.1-5	2	West	North	26	27

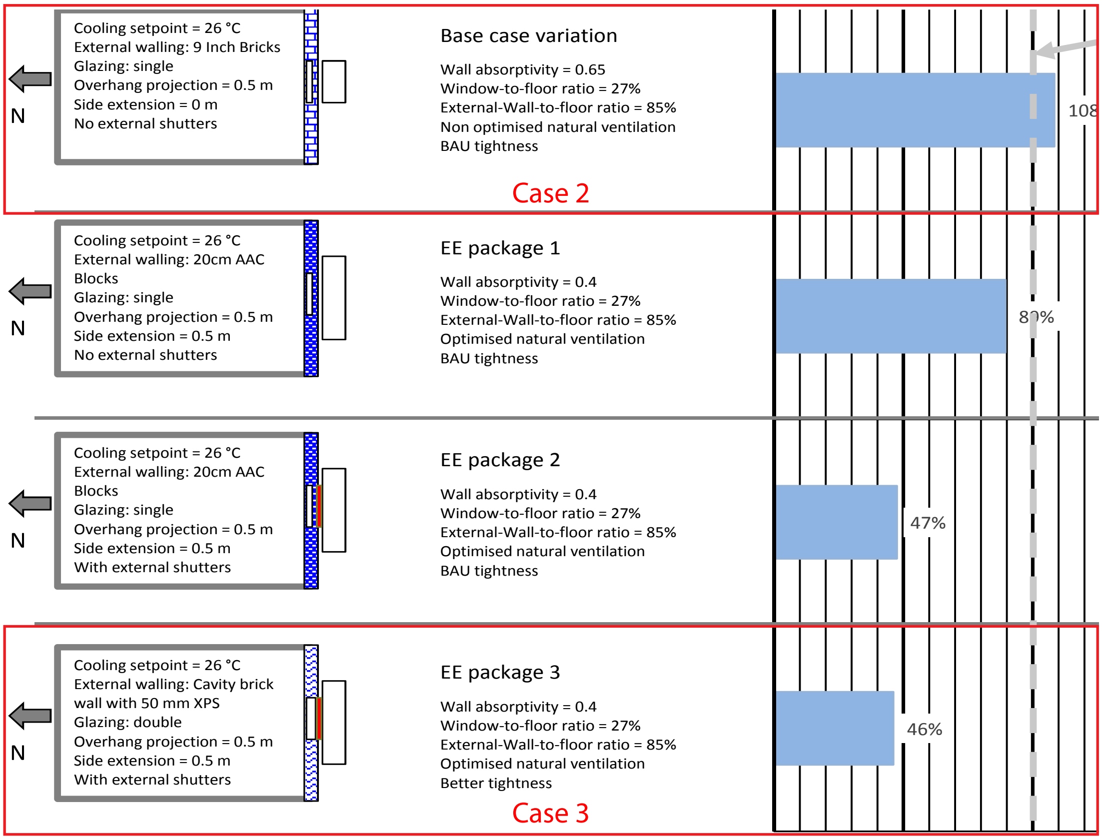
Step 2: Read the respective figures.

In the example given above from Figures A.1-1 and A.1-2, the cases to be evaluated are highlighted in red boxes.

A.1-1



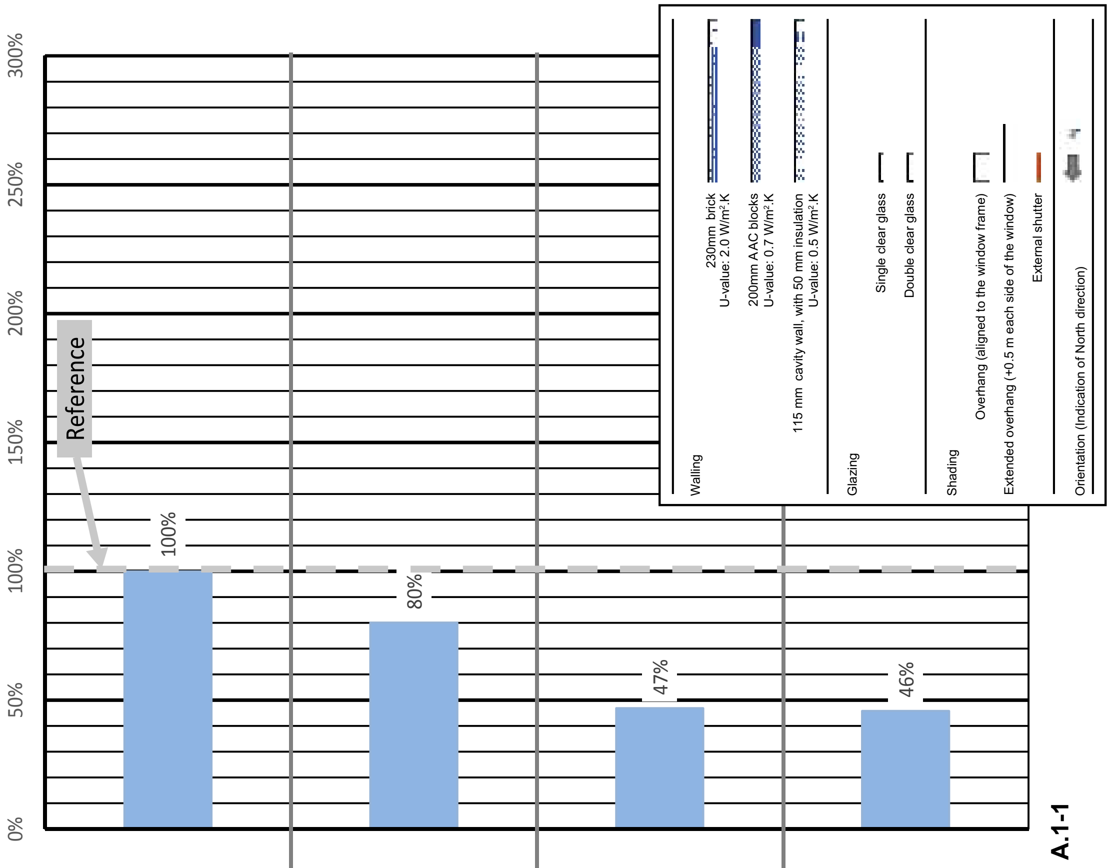
A.1-2



Step 3: The interpretation of percentage annual cooling thermal energy demand of the cases to be evaluated

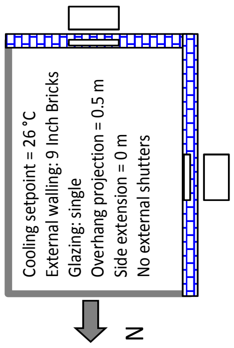
- Case 2 has 8% higher annual cooling thermal energy demand compared to Case 1
- Case 3 has 54% lower annual cooling thermal energy demand compared to Case 1
- Case 3 has 57.4% lower annual cooling thermal energy demand compared to Case 2

Results of parametric simulation runs for the bedroom (Mumbai)



Base case variation

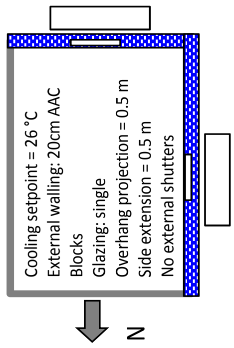
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

EE package 1

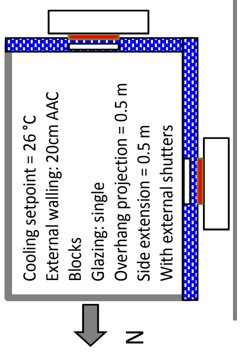
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness



Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 2

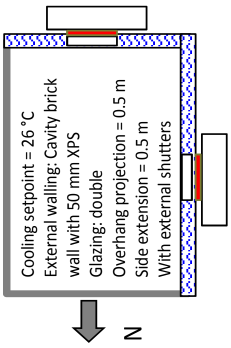
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness



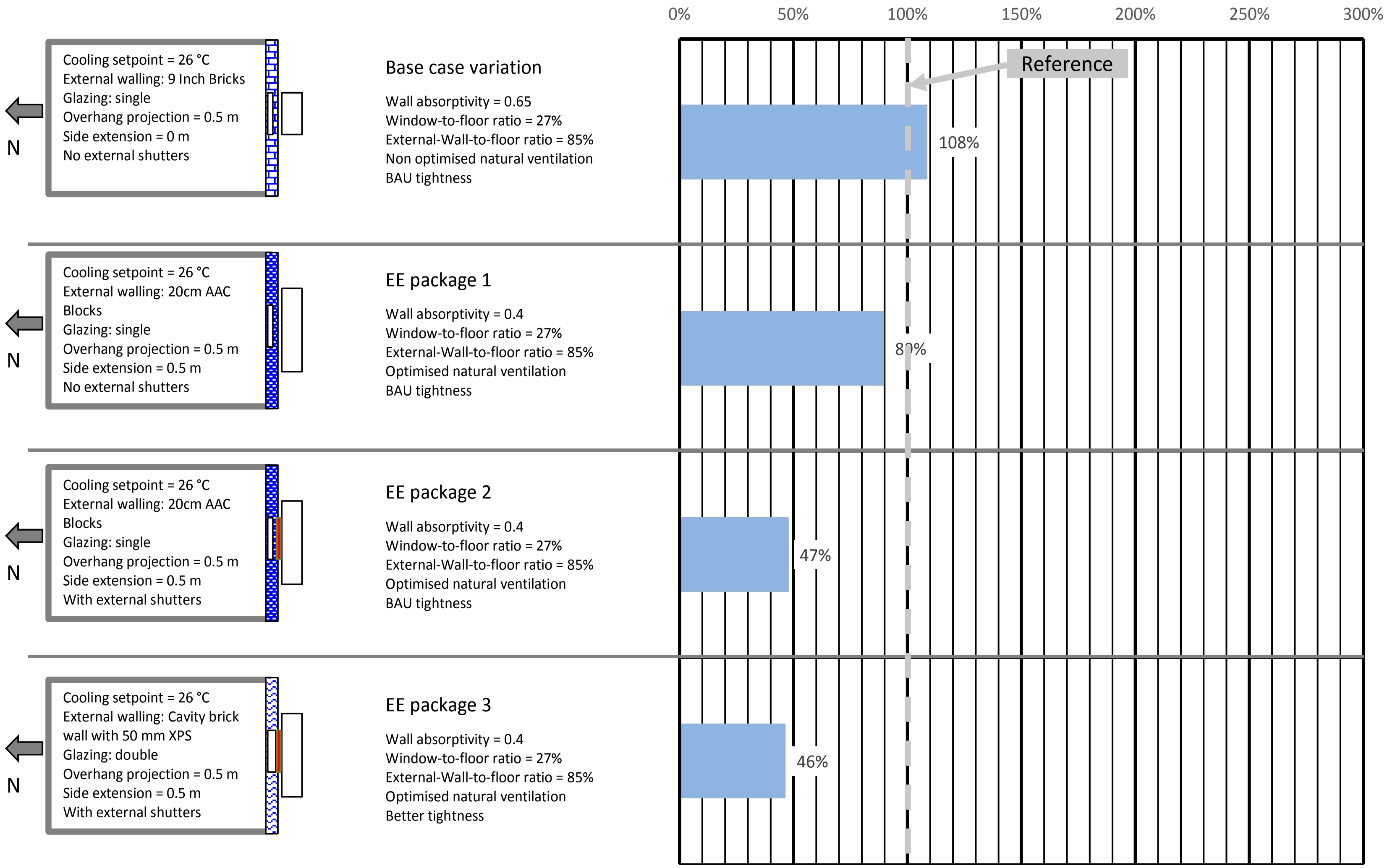
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness



Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

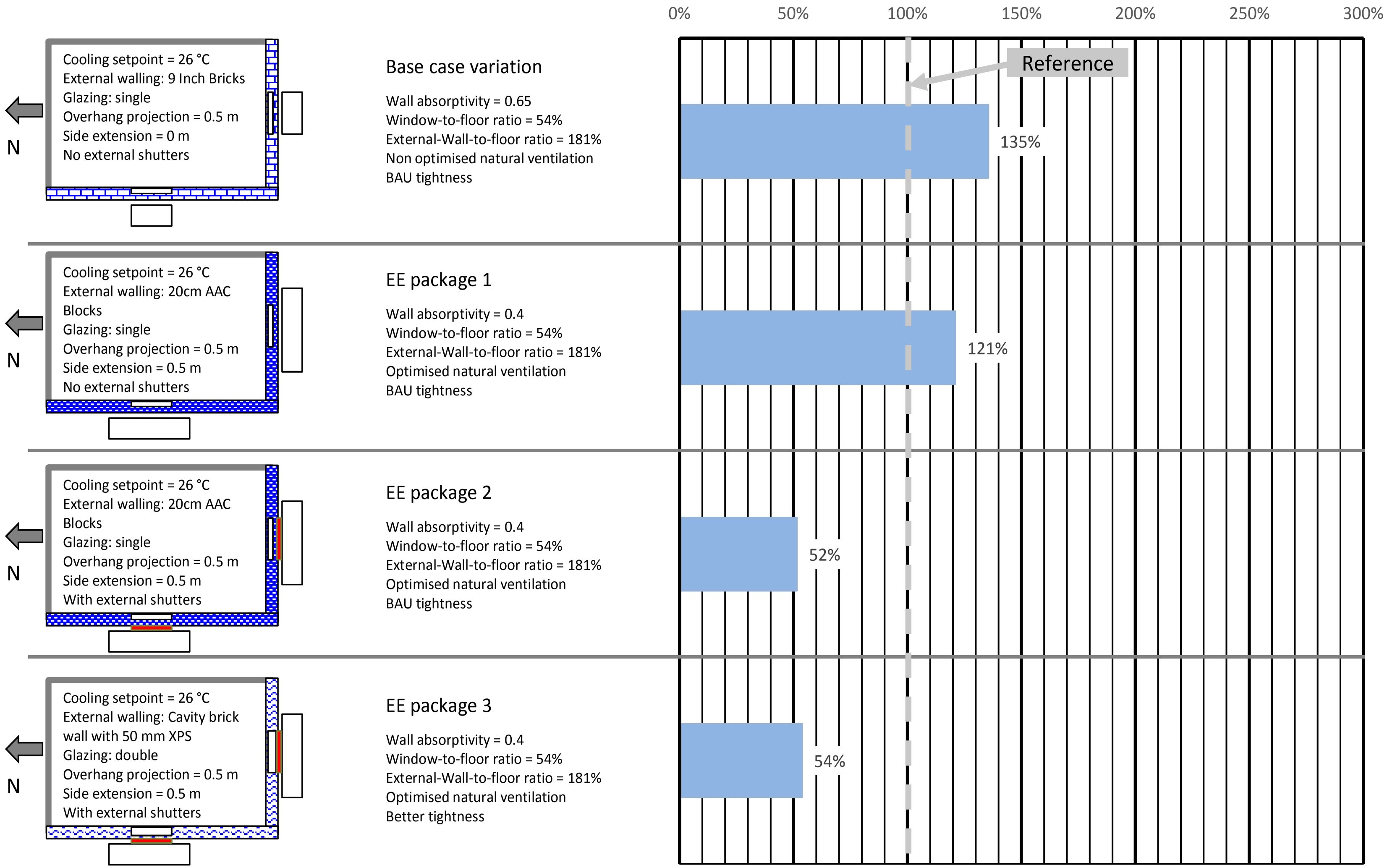
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

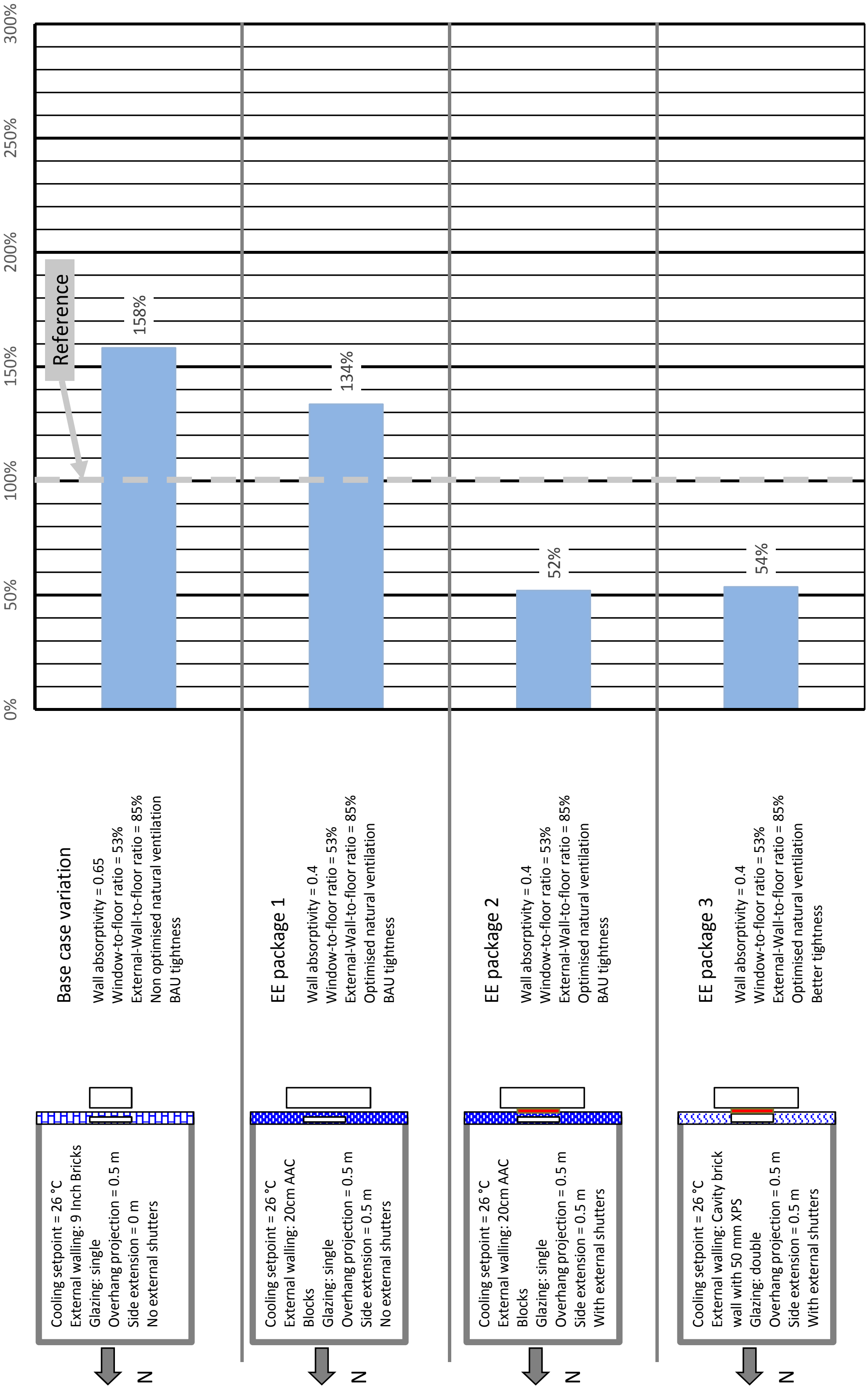
EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness

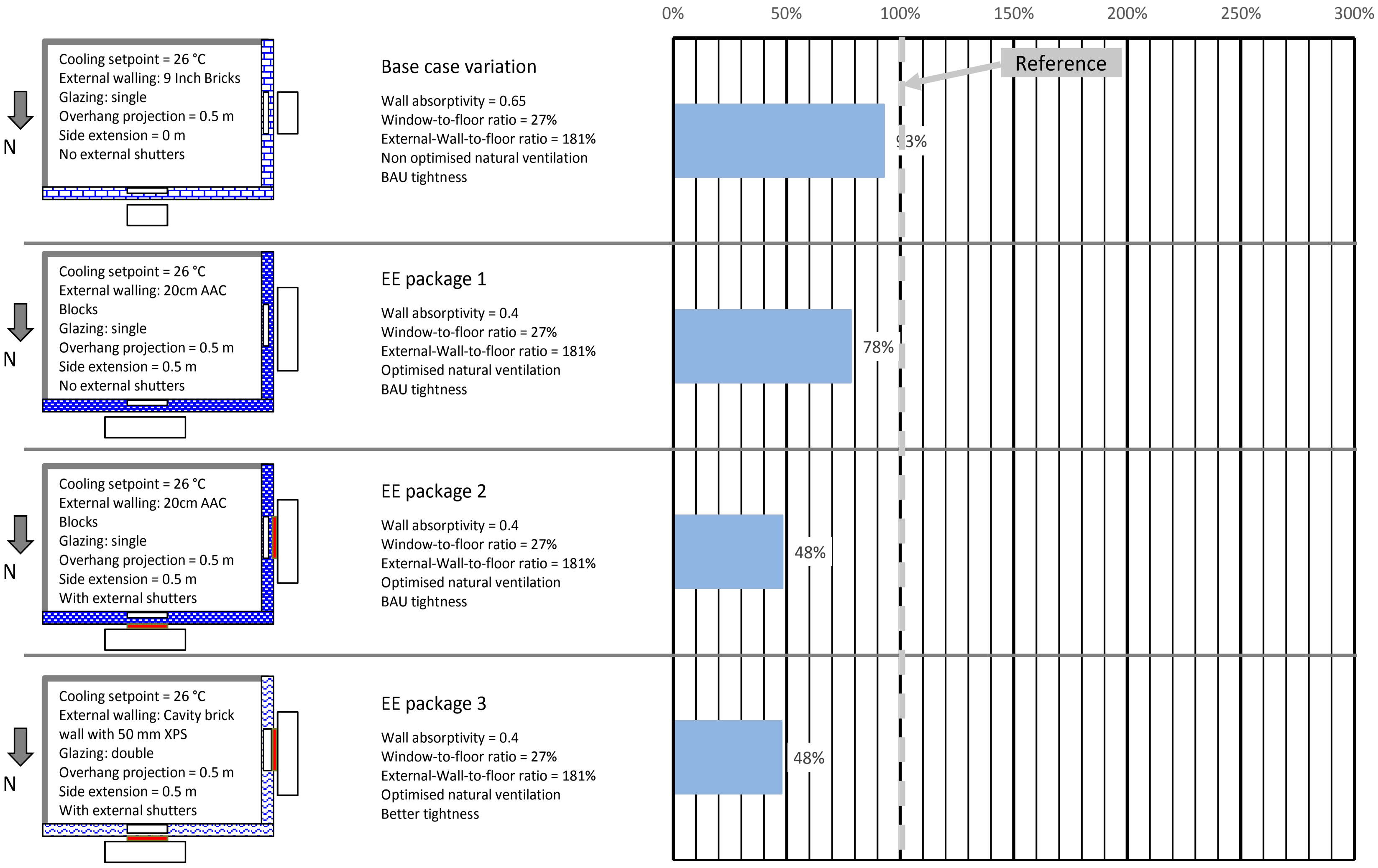
A.1-2


0%
50%
100%
150%
200%
250%
300%
Reference
N
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
135%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
121%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
52%
N
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
54%

A.1-3


0%
50%
100%
150%
200%
250%
300%
Reference
158%
134%
52%
54%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N

A.1-4



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

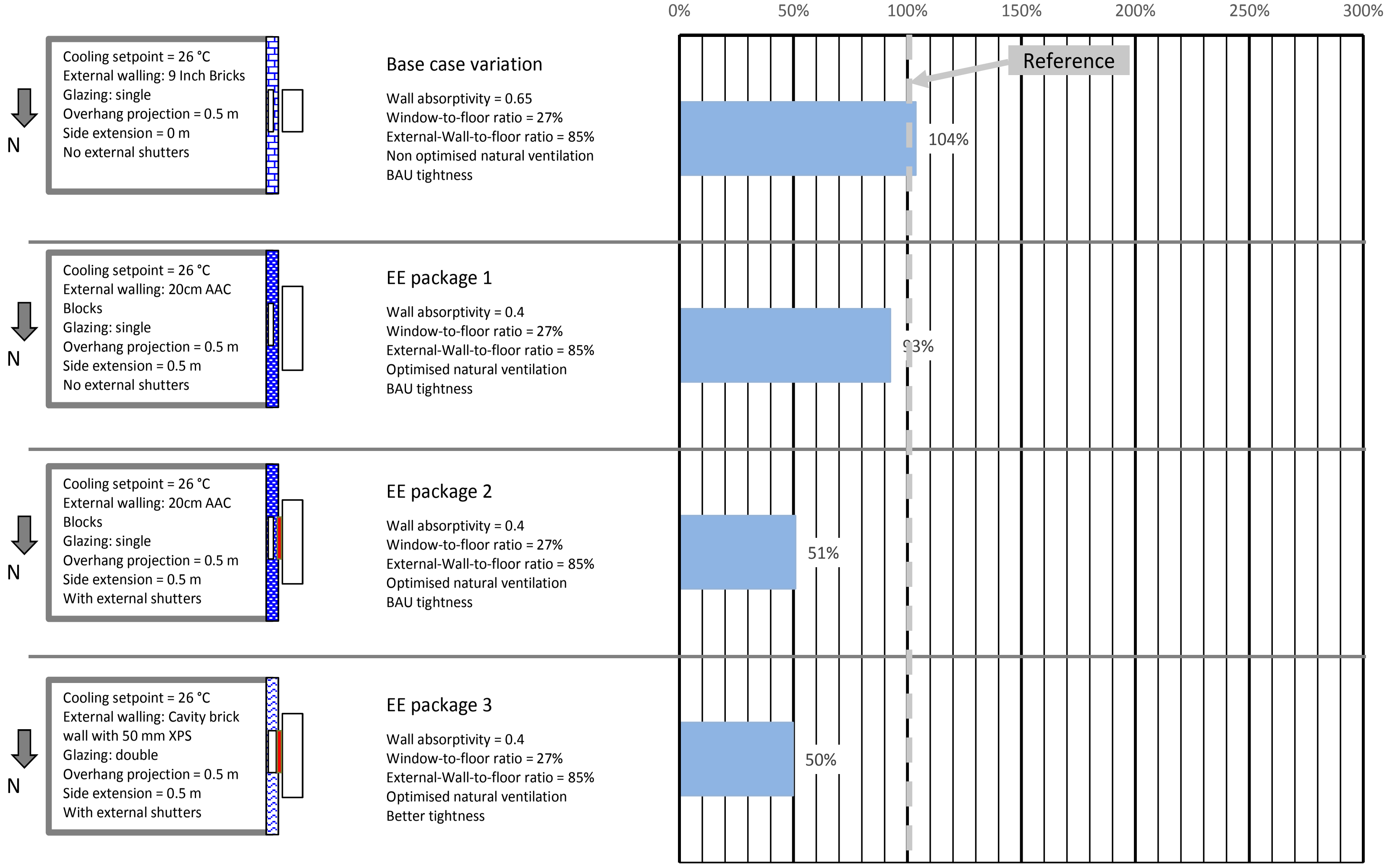
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

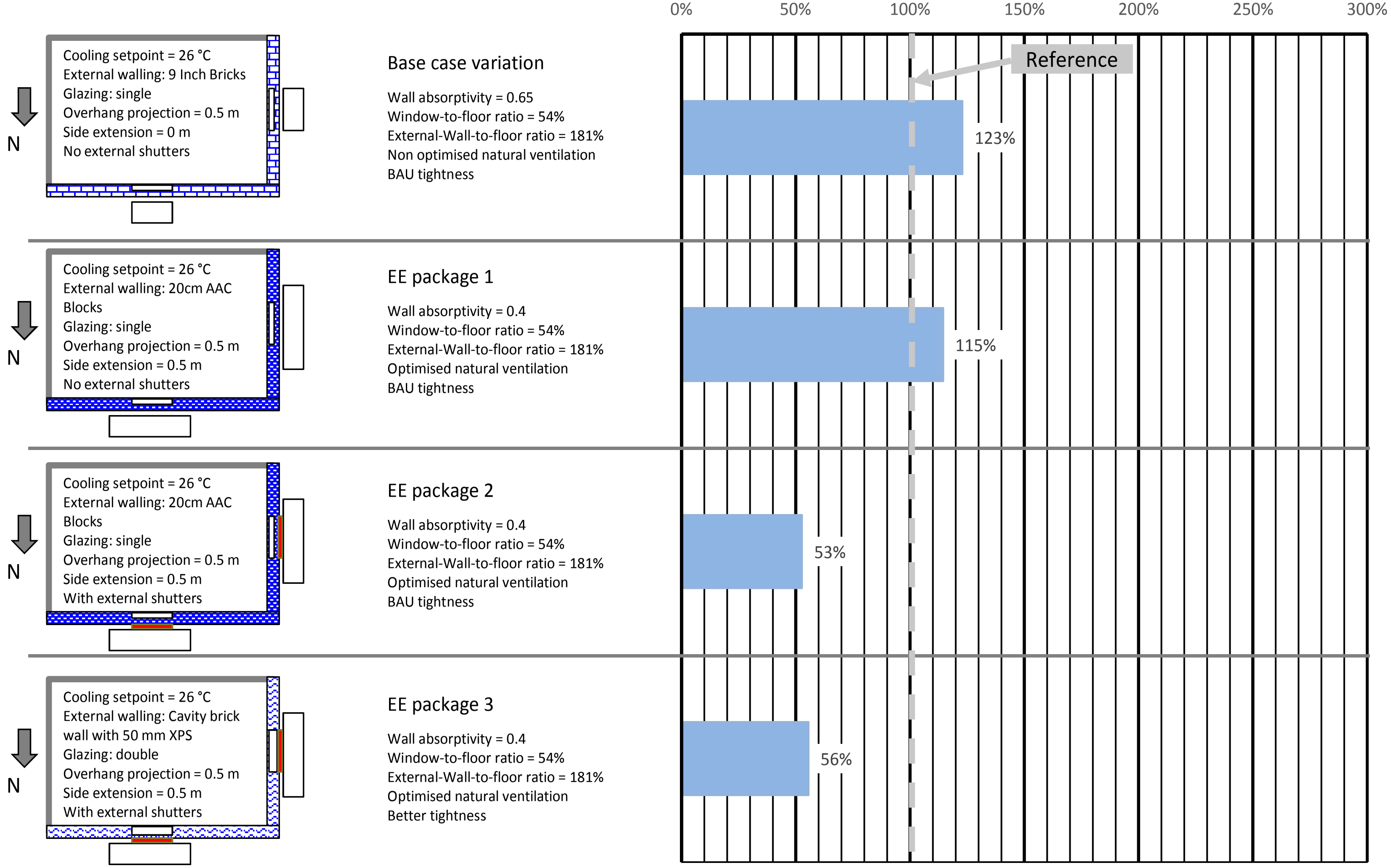
EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness

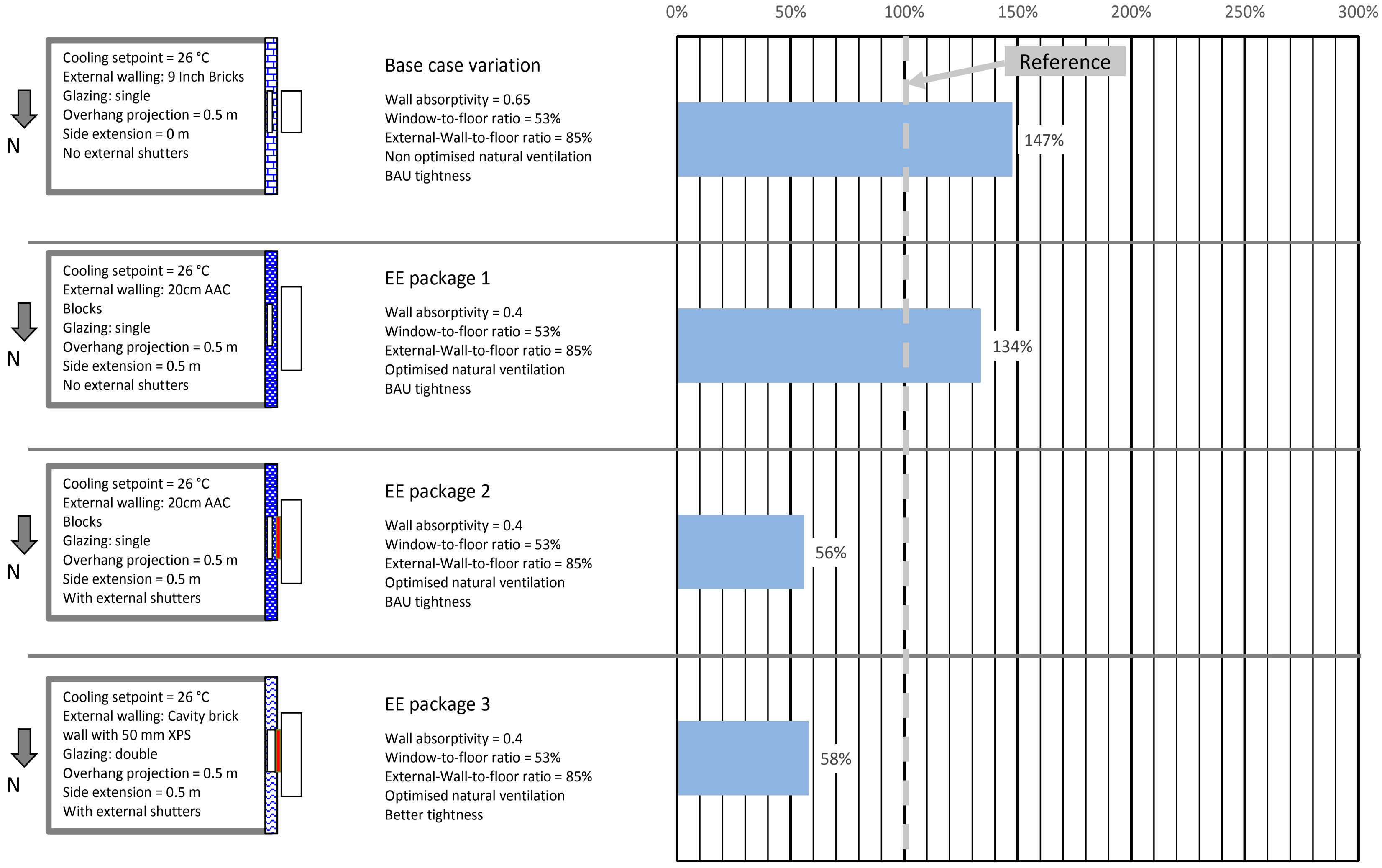
A.1-5


Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness
0%
50%
100%
150%
200%
250%
300%
Reference
104%
93%
51%
50%

A.1-6

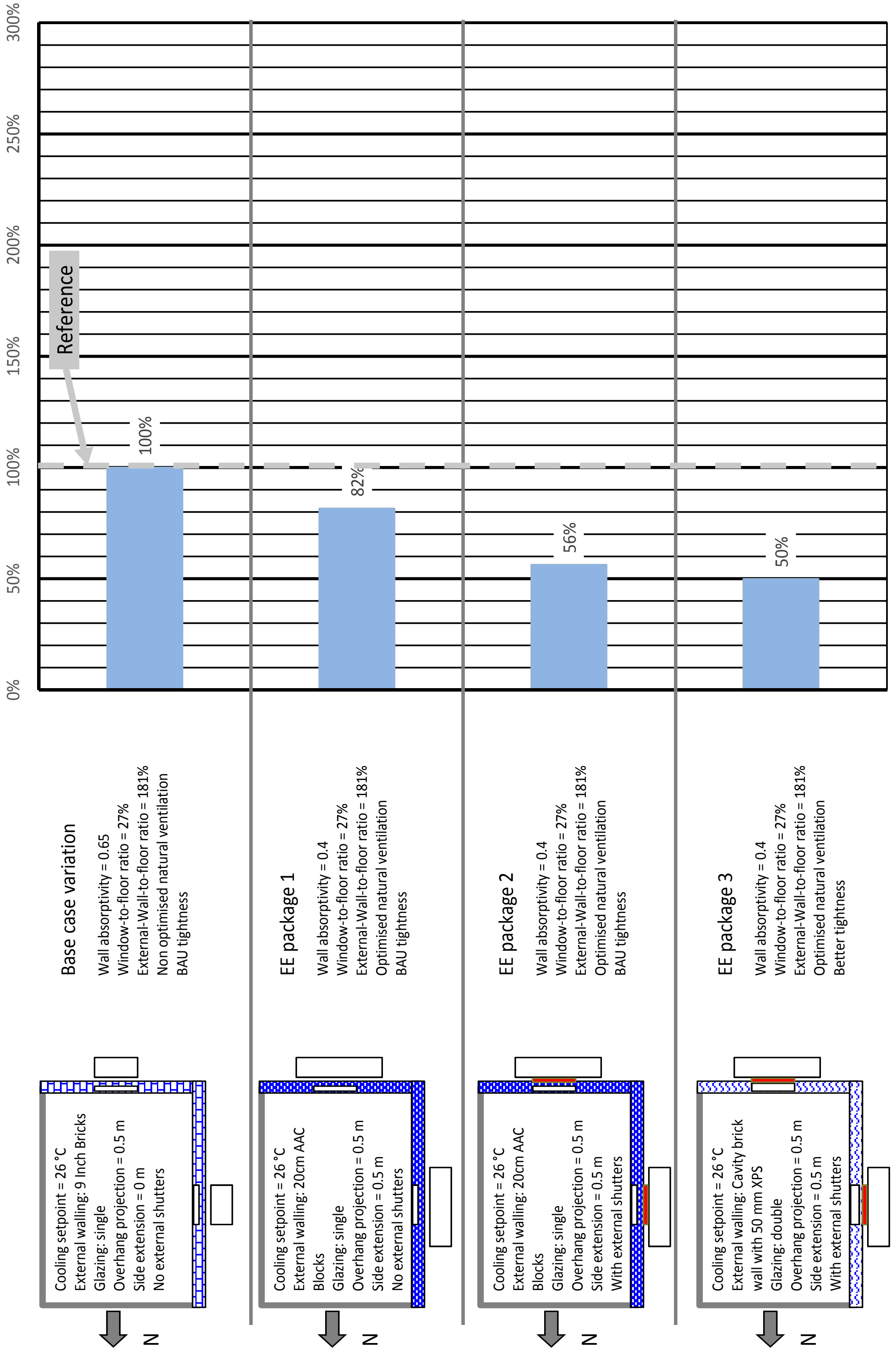

N
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
123%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
115%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
53%
N
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
56%
Reference
0%
50%
100%
150%
200%
250%
300%

A.1-7

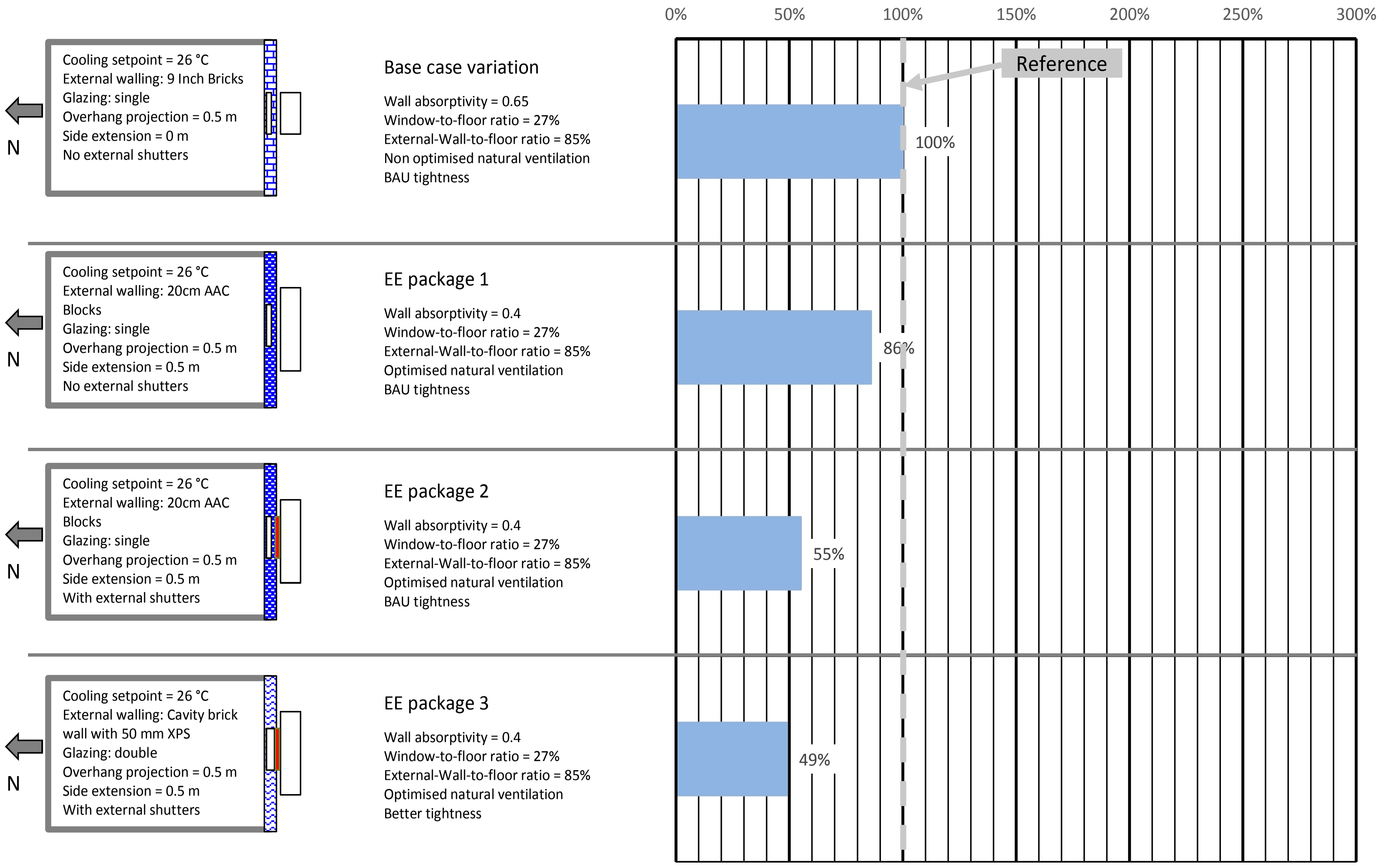

N
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
N
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness
0%
50%
100%
150%
200%
250%
300%
Reference
147%
134%
56%
58%

A.1-8

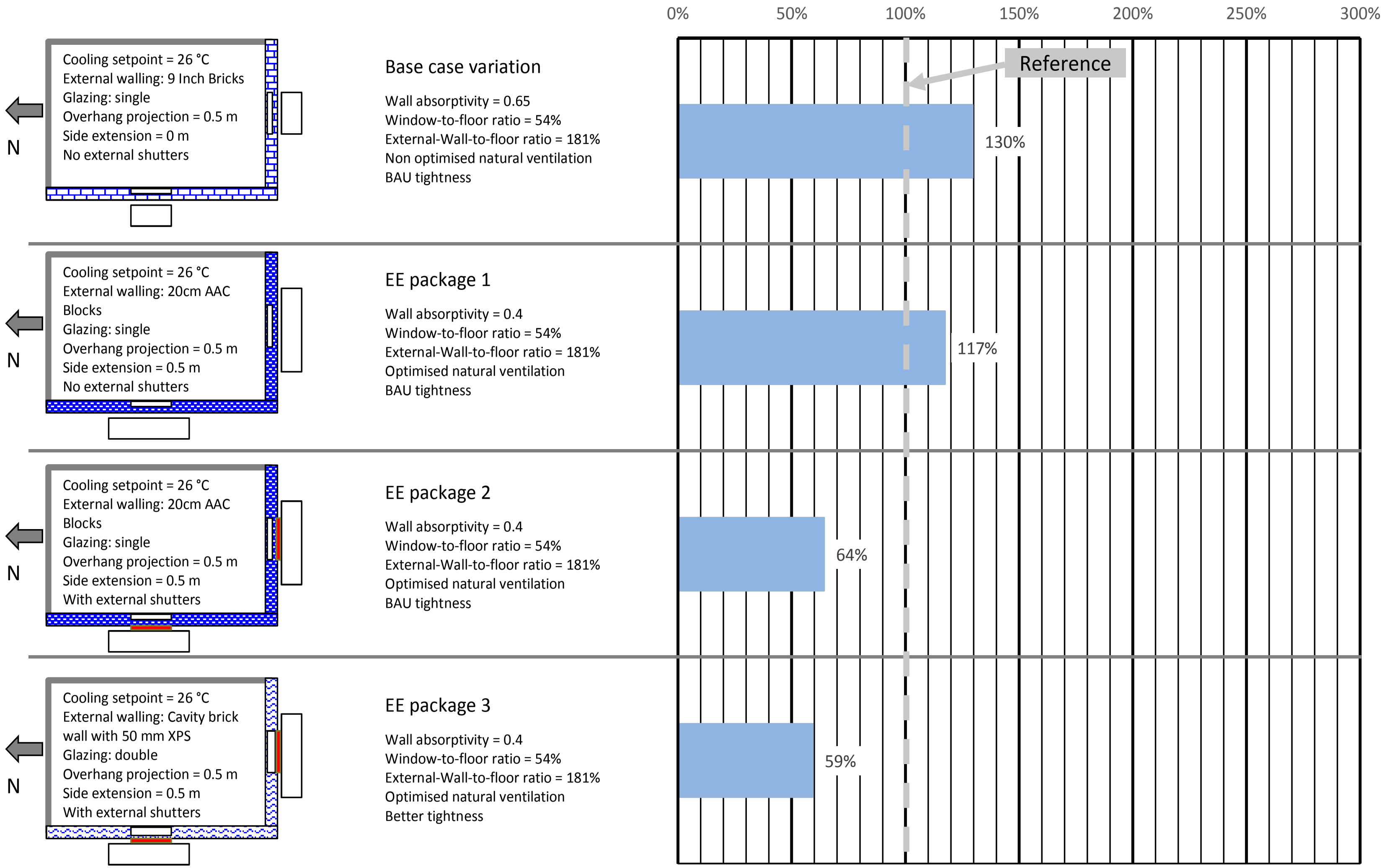
Results of parametric simulation runs for the bedroom (Chennai)



A.1-9


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
100%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
86%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
55%
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness
49%

A.1-10



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

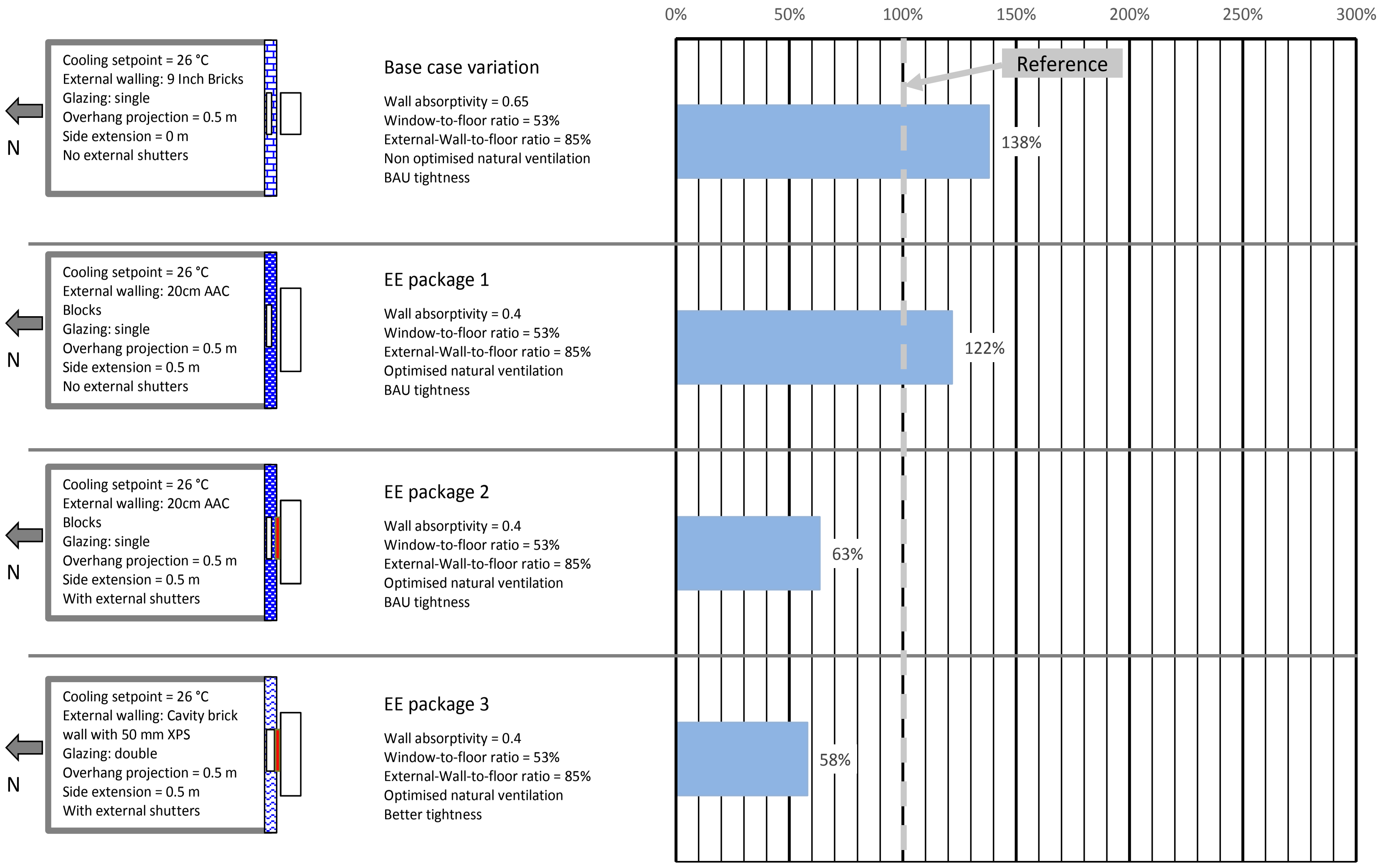
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness

A.1-11



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

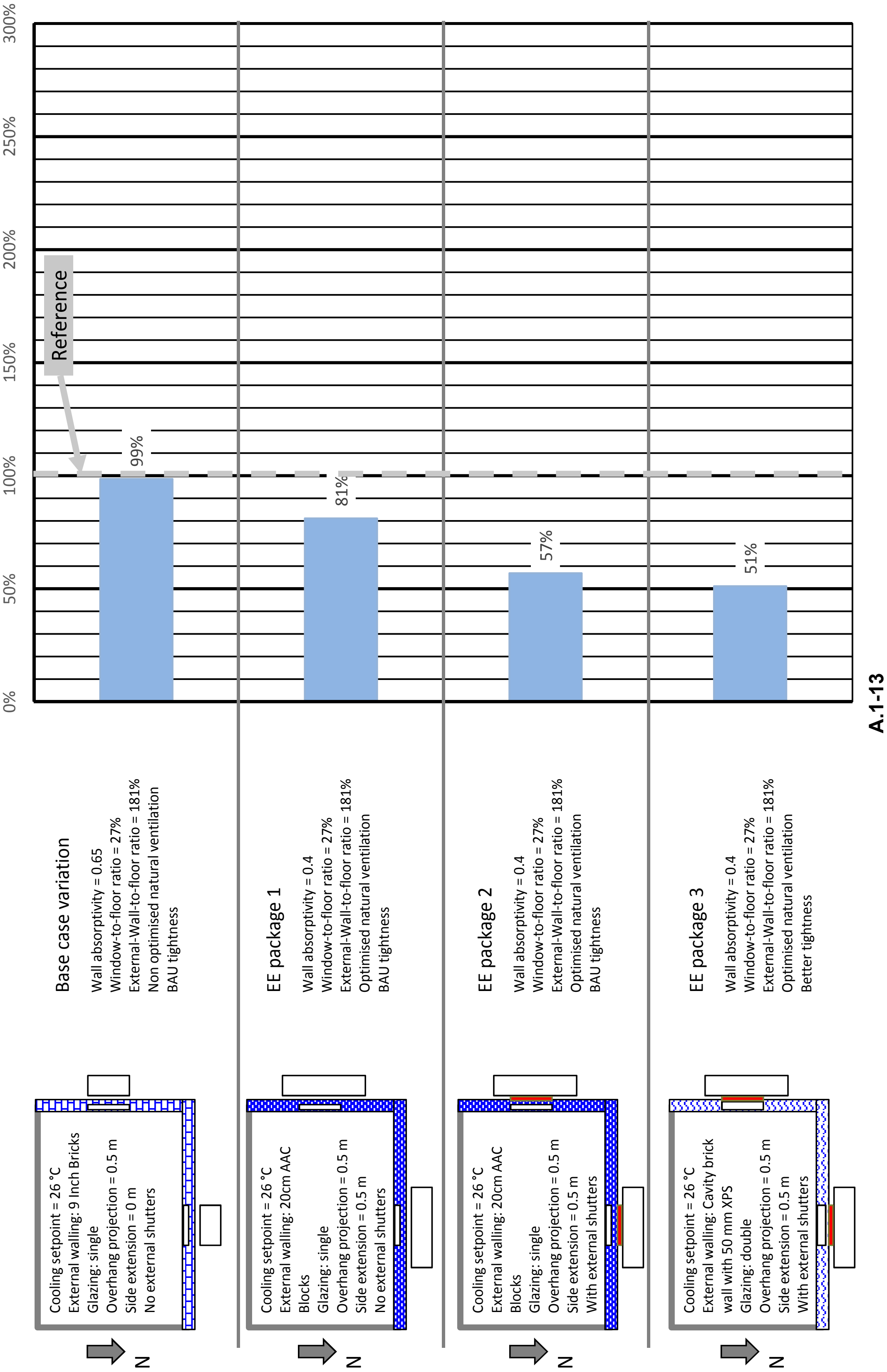
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness

A.1-12



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness

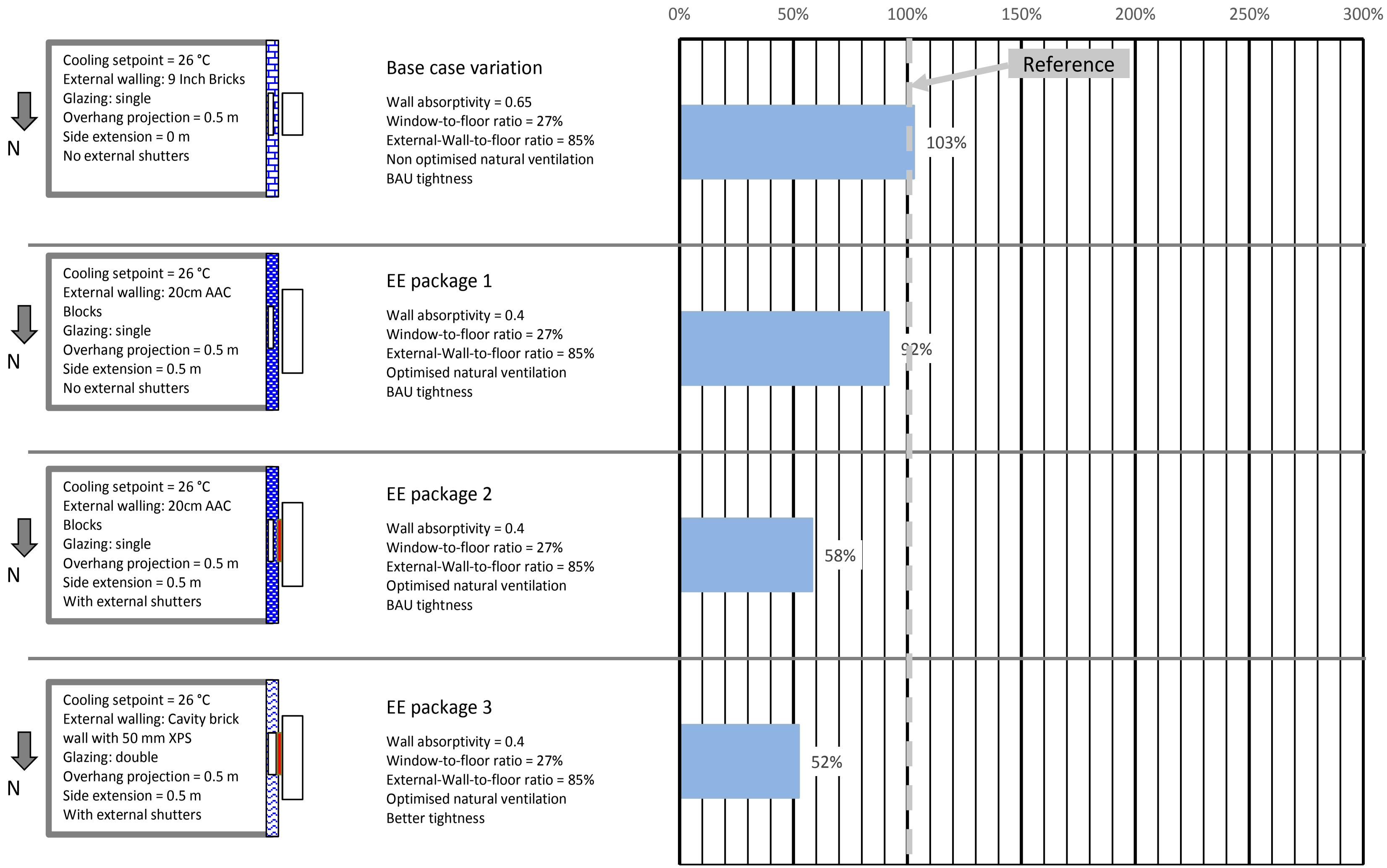
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness

A.1-13



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

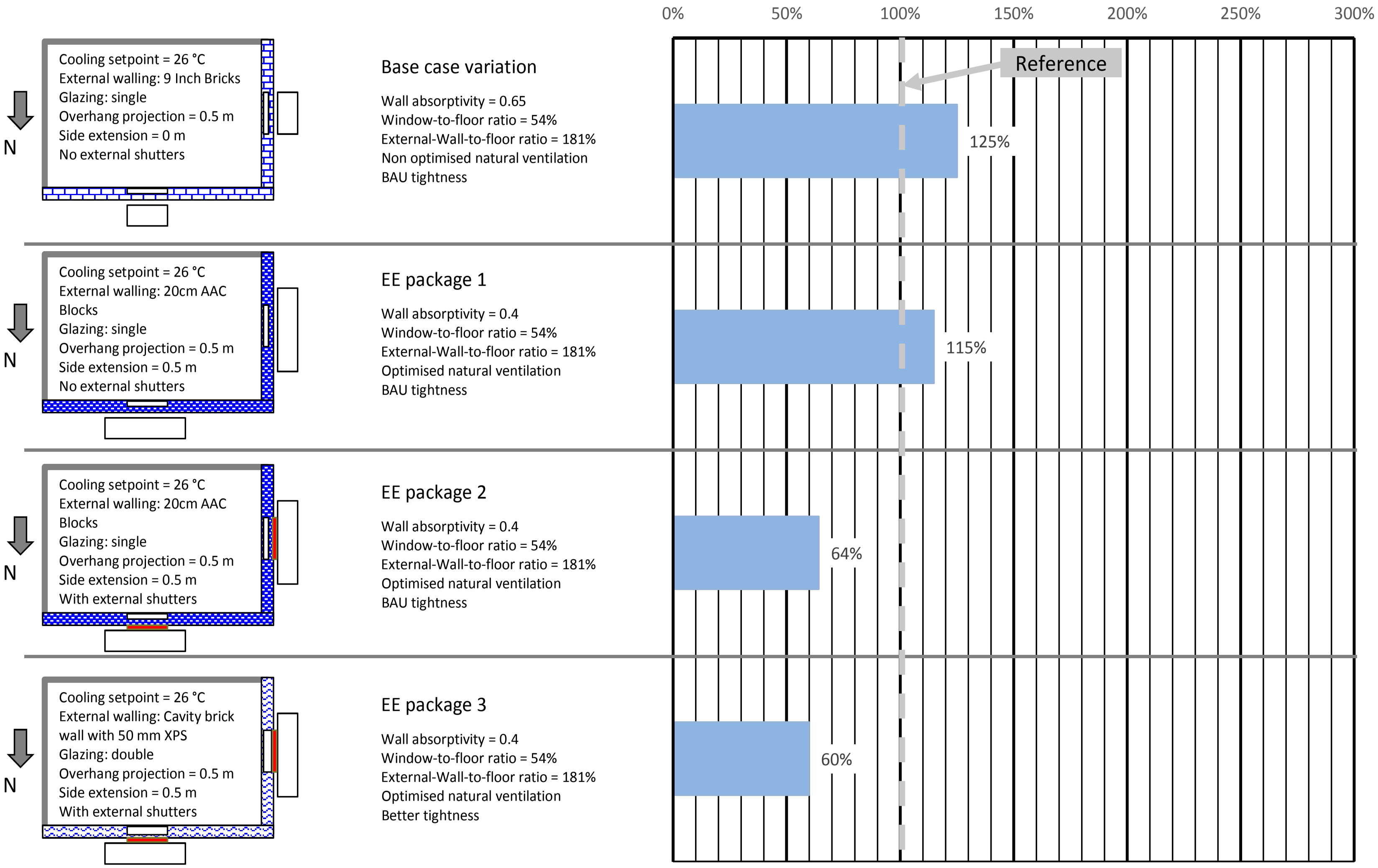
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

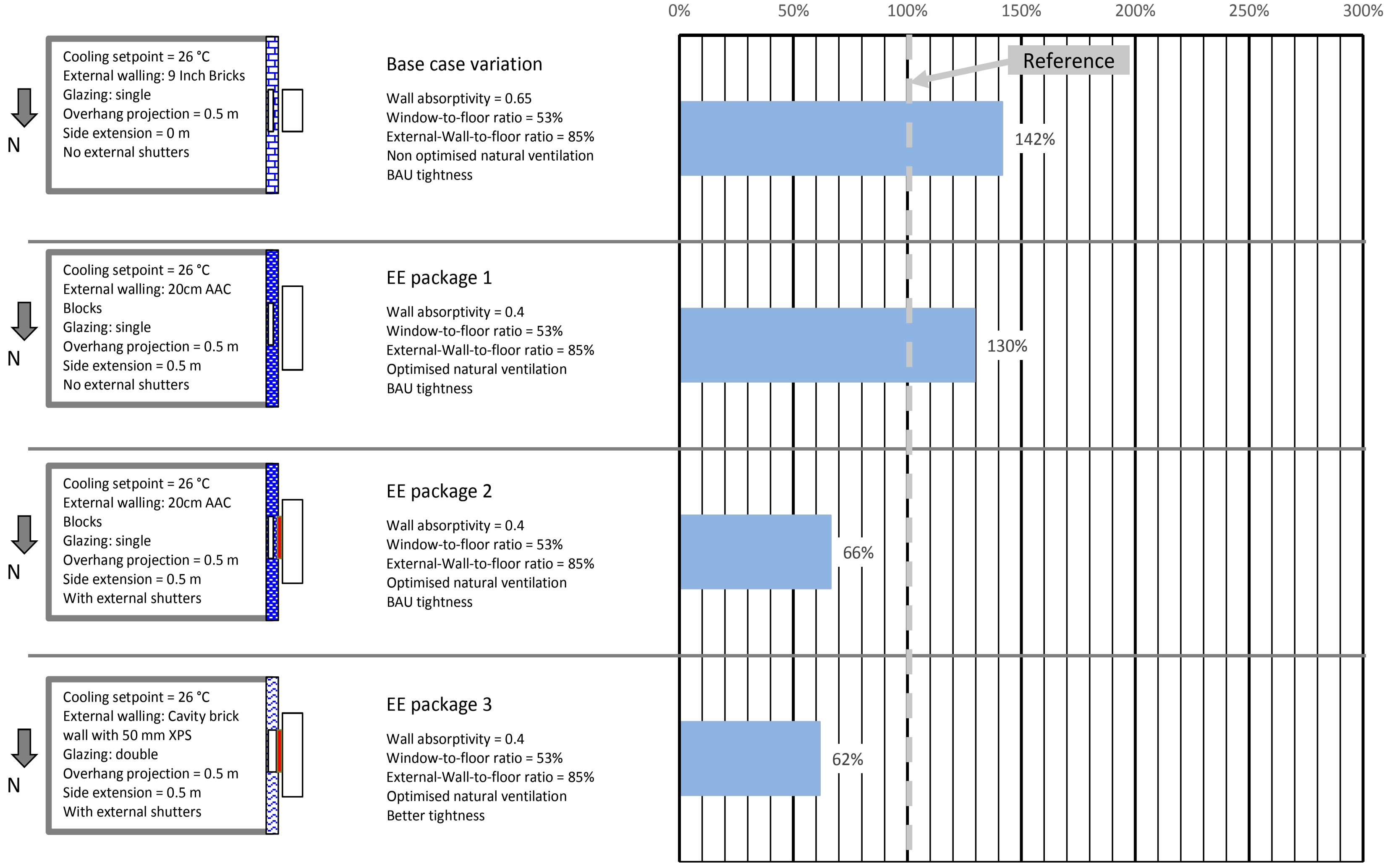
EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness

A.1-14

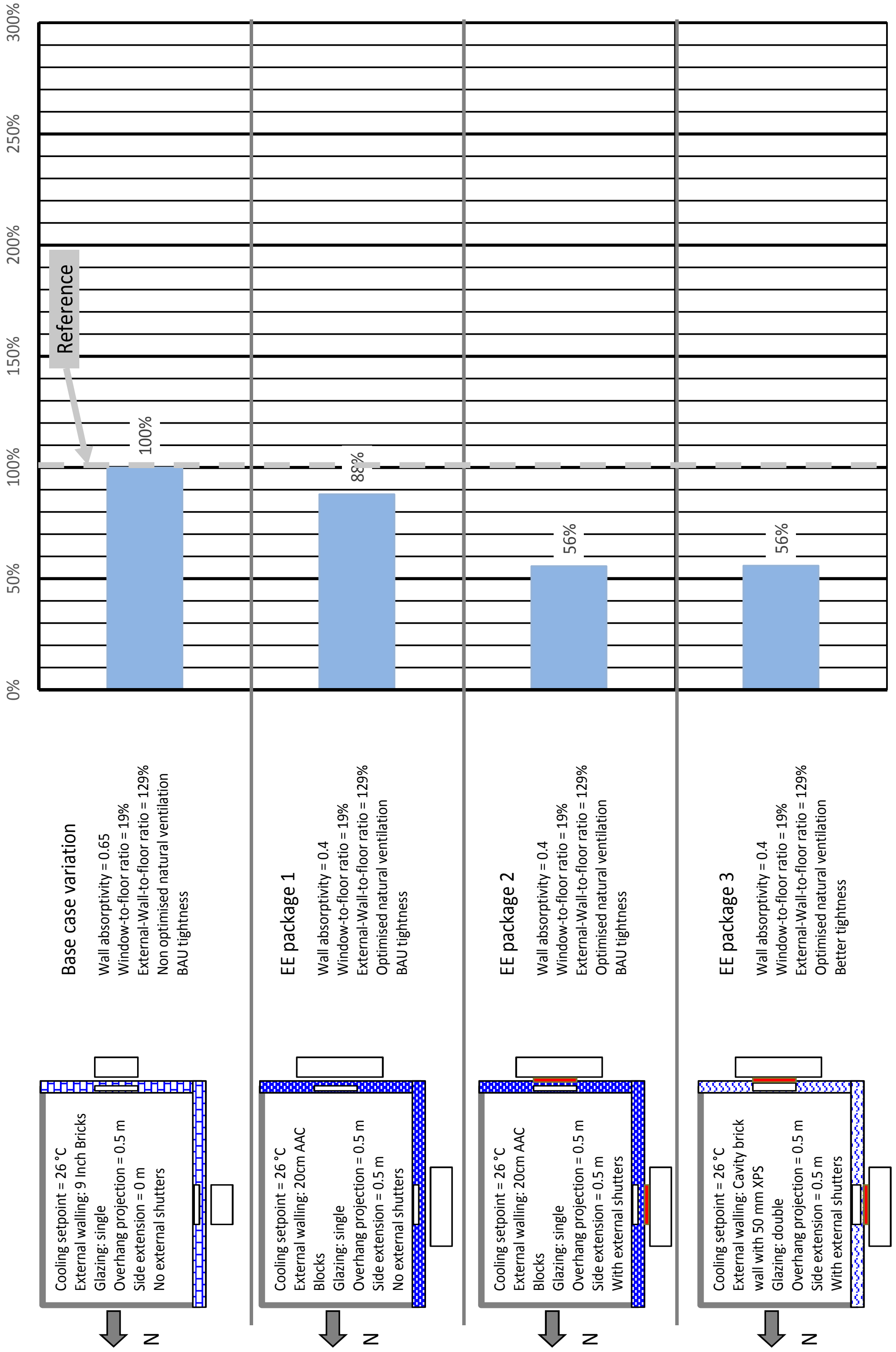

0%
50%
100%
150%
200%
250%
300%
Reference
N
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
125%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
115%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
64%
N
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
60%

A.1-15

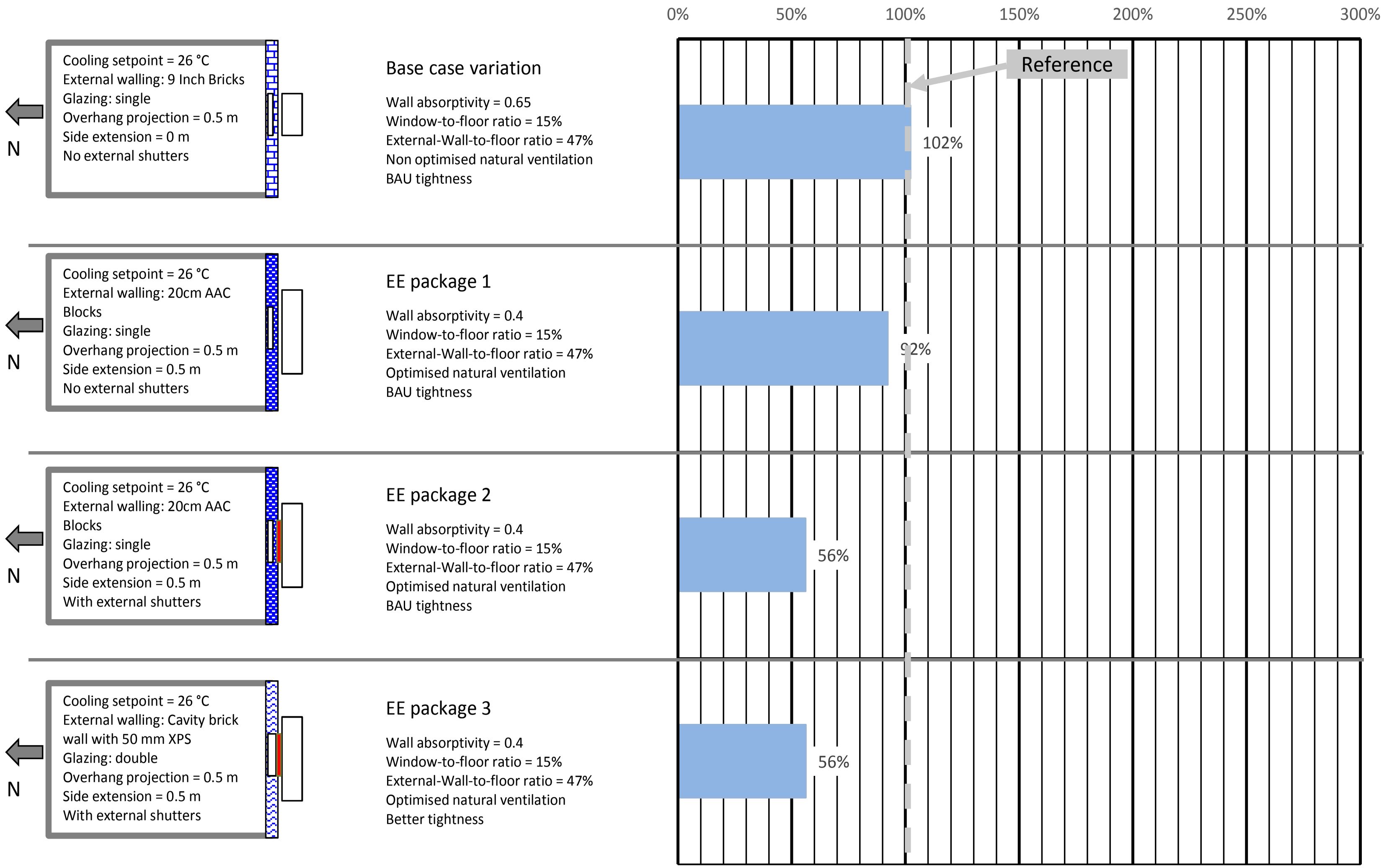

Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness
0%
50%
100%
150%
200%
250%
300%
Reference
142%
130%
66%
62%

A.1-16

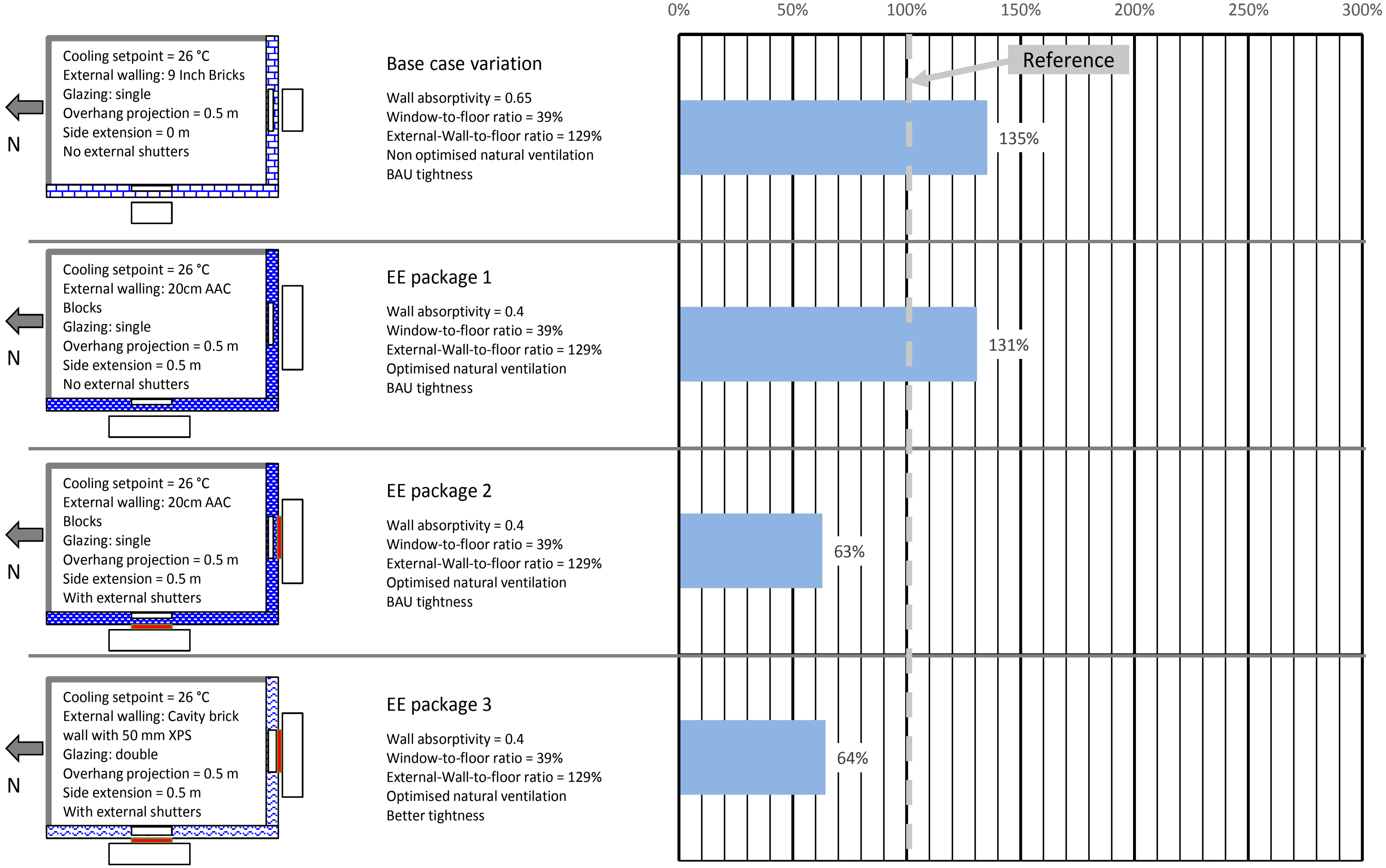
Results of parametric simulation runs for the living room (Mumbai)



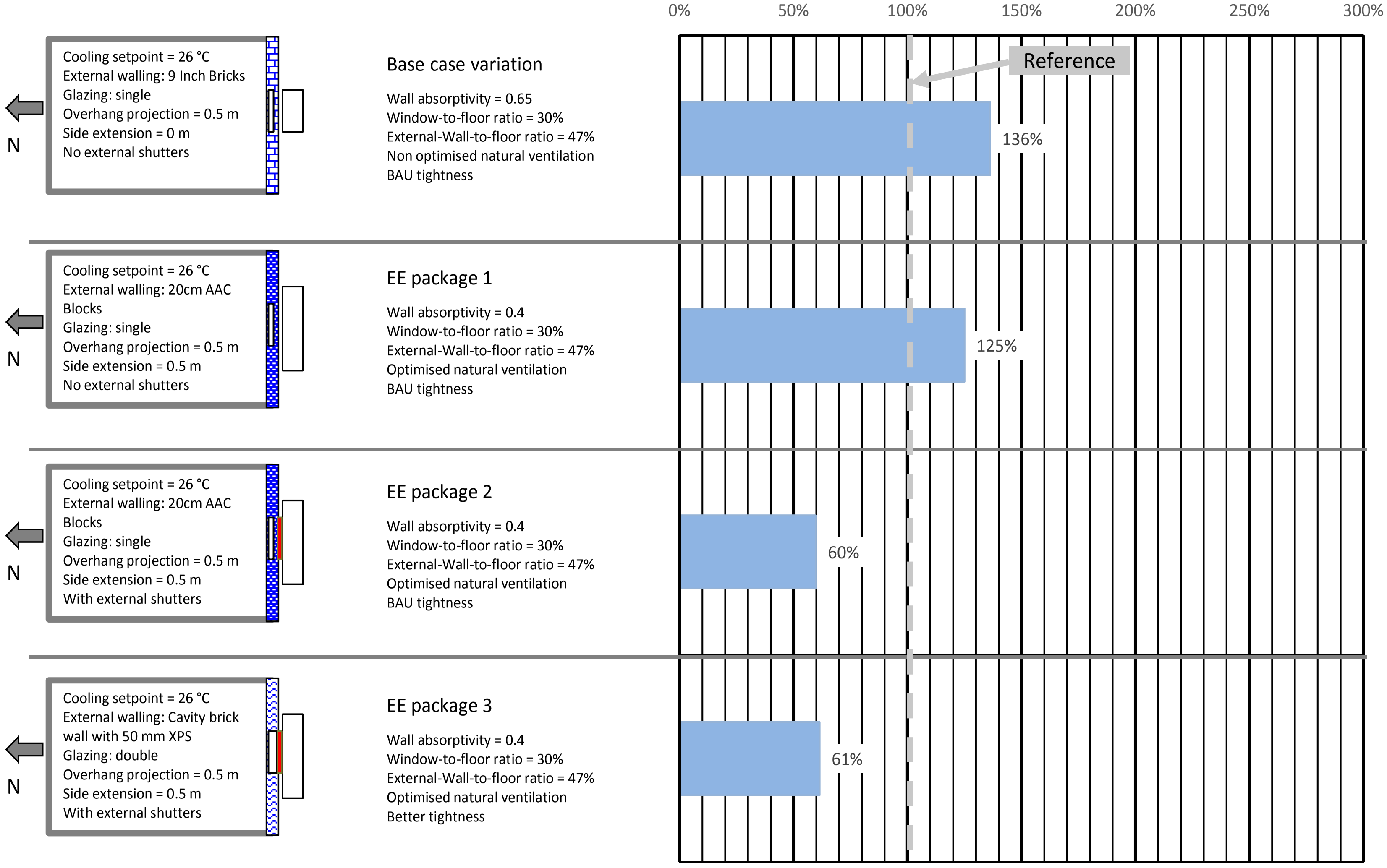
A.1-17


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
102%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
92%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
56%
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness
56%

A.1-18


Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
135%
Reference
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
131%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
63%
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
64%
0%
50%
100%
150%
200%
250%
300%

A.1-19



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

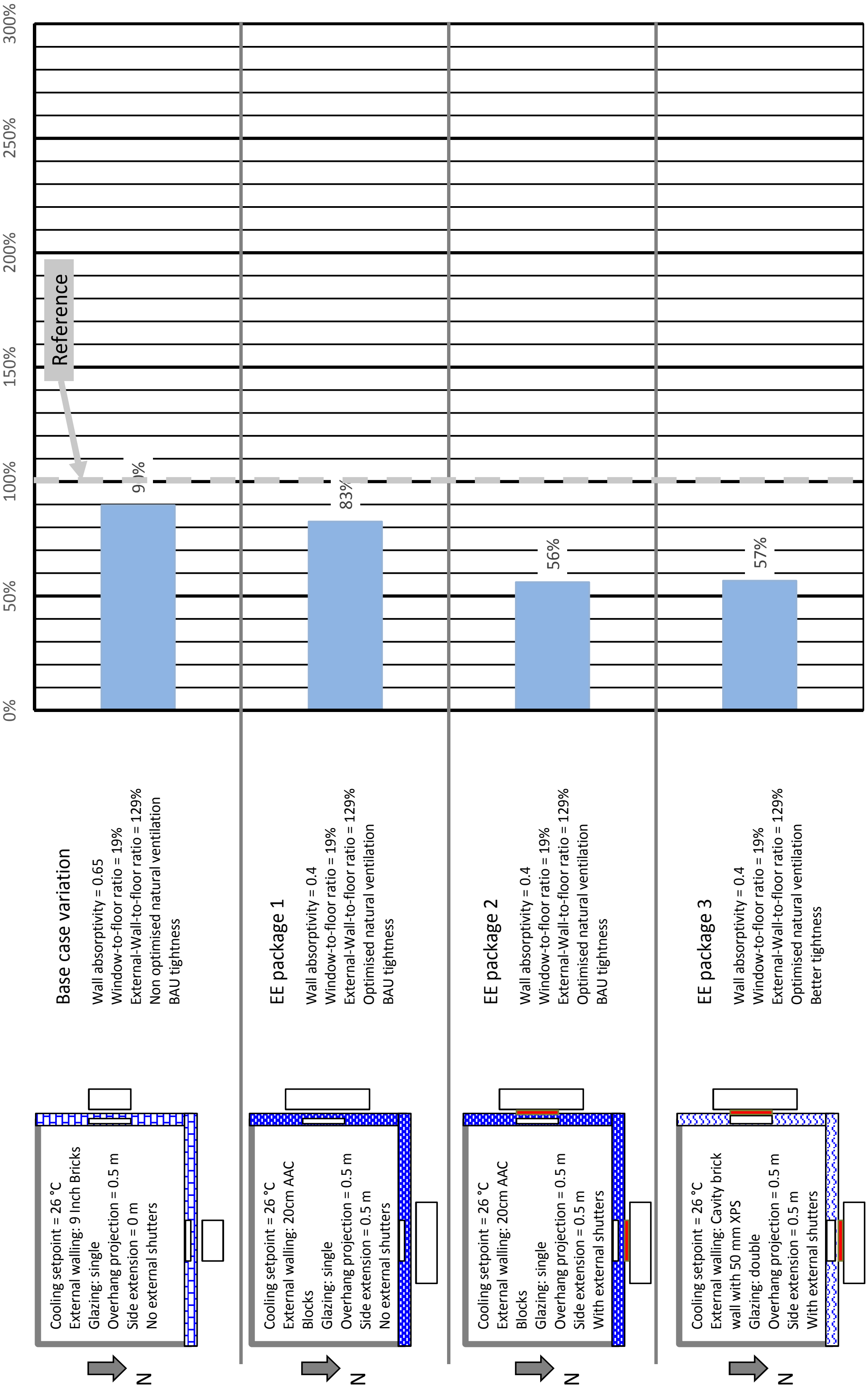
Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

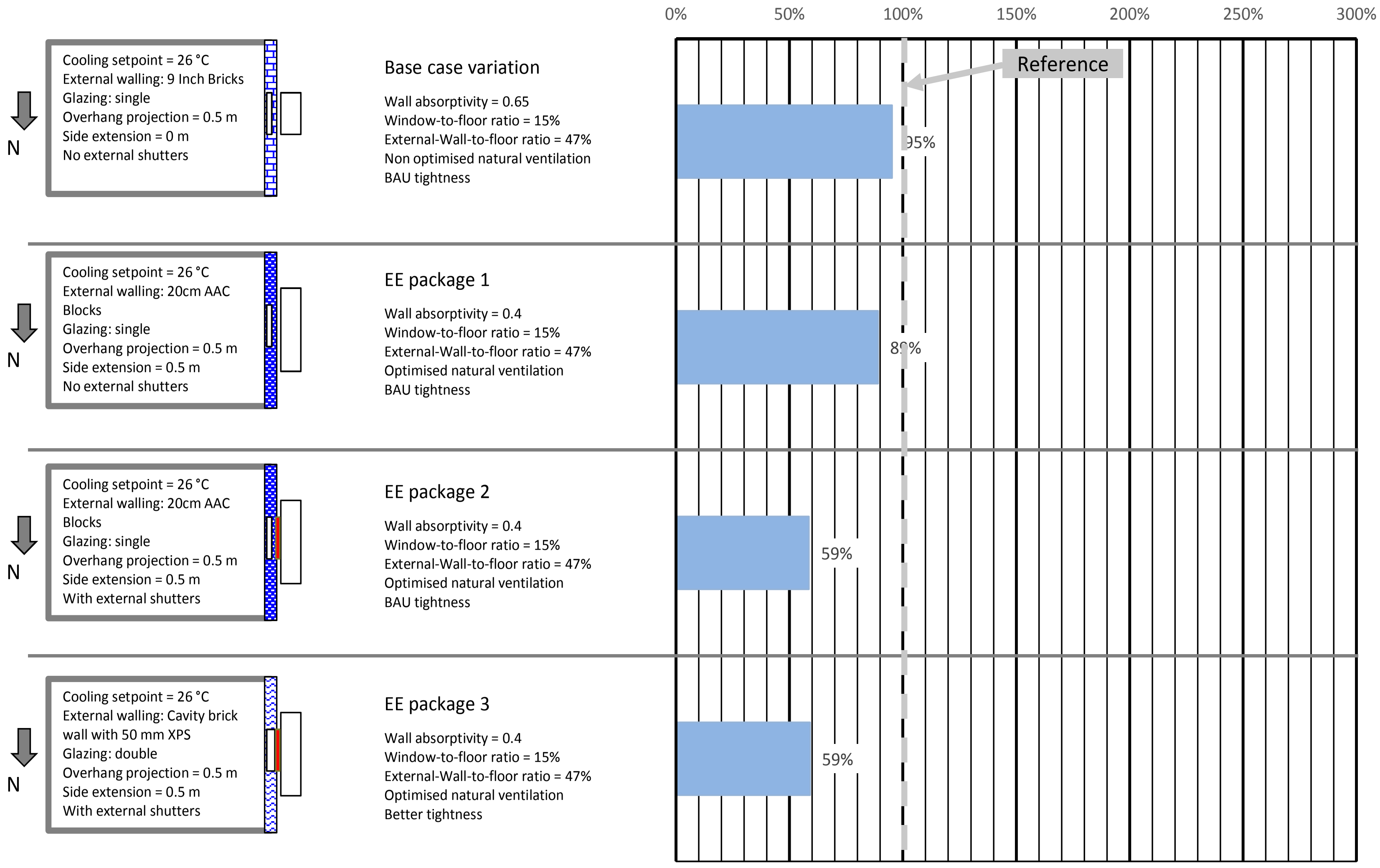
EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness

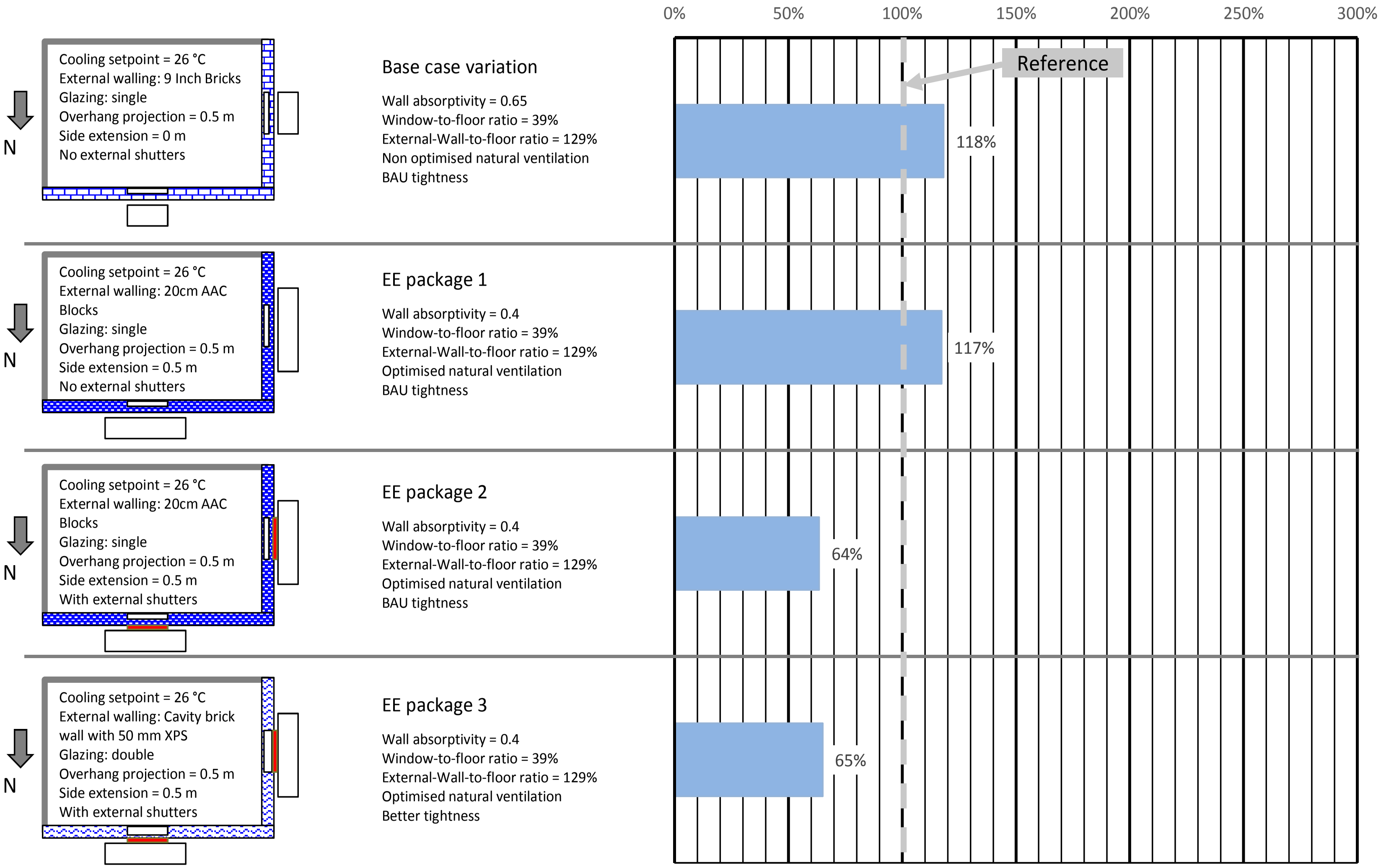
A.1-20


Reference
0%
50%
100%
150%
200%
250%
300%
90%
83%
56%
57%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
N
N
N

A.1-21


0%
50%
100%
150%
200%
250%
300%
Reference
N
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
95%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
89%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
59%
N
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness
59%

A.1-22



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

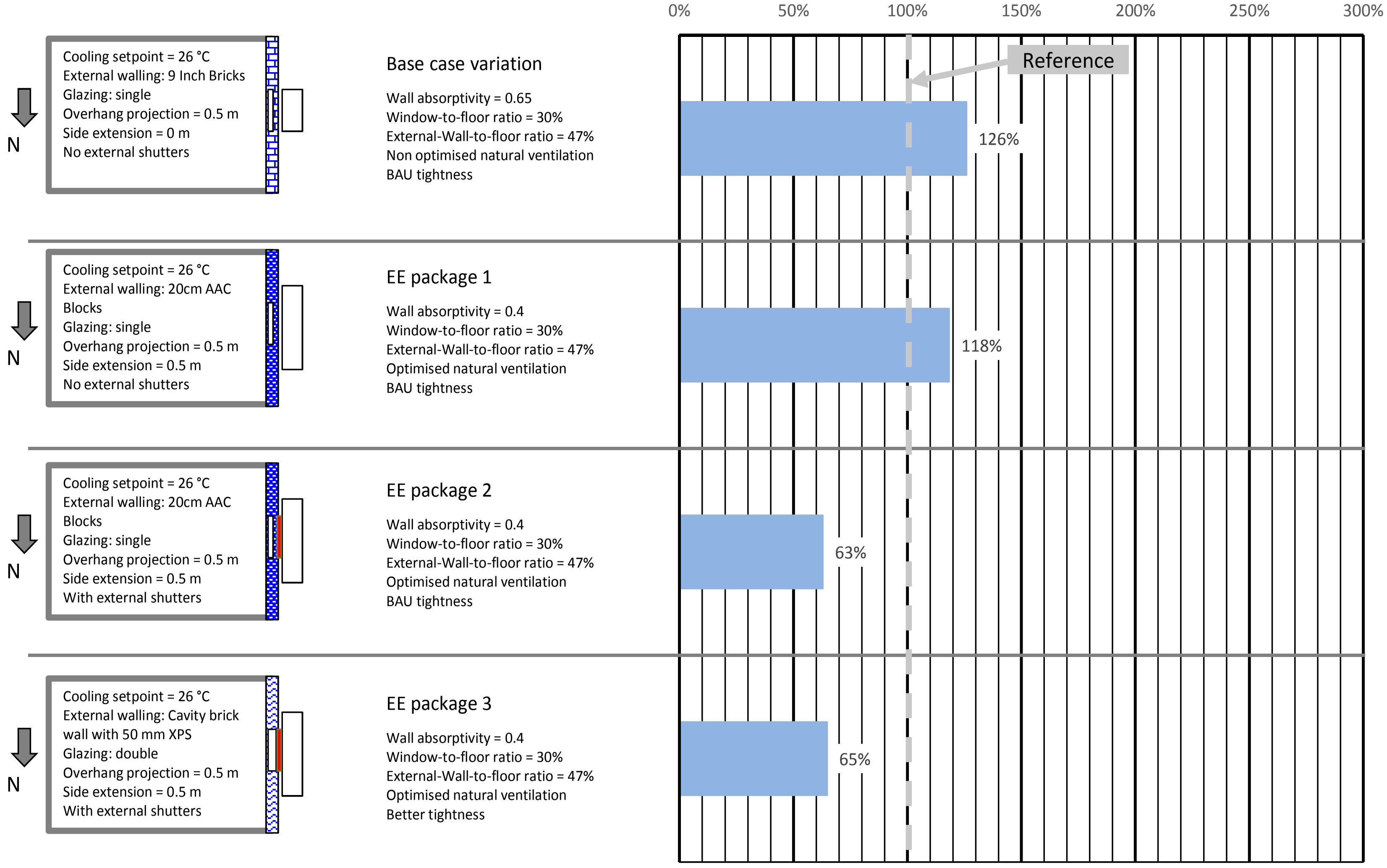
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

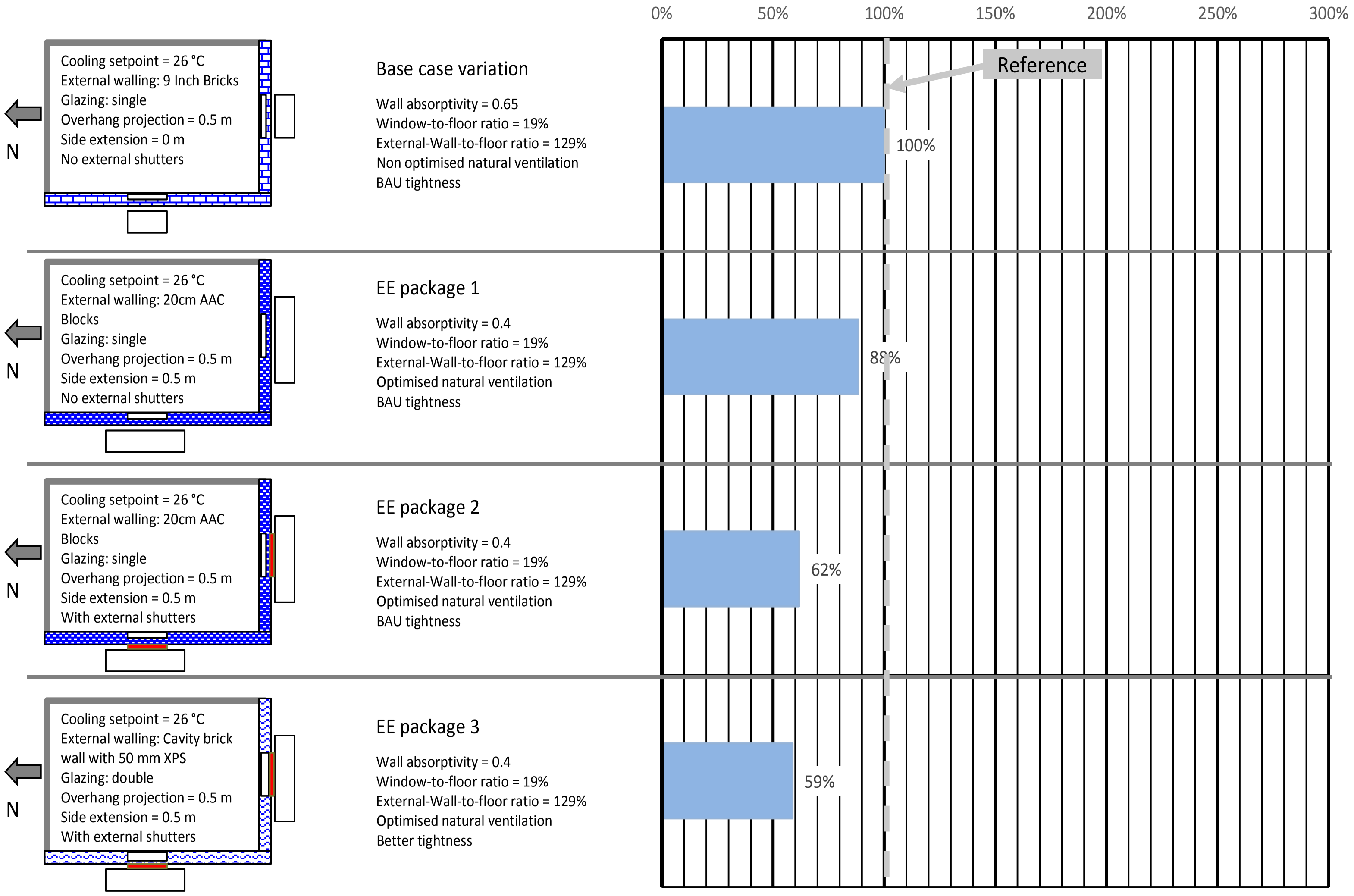
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness

A.1-23

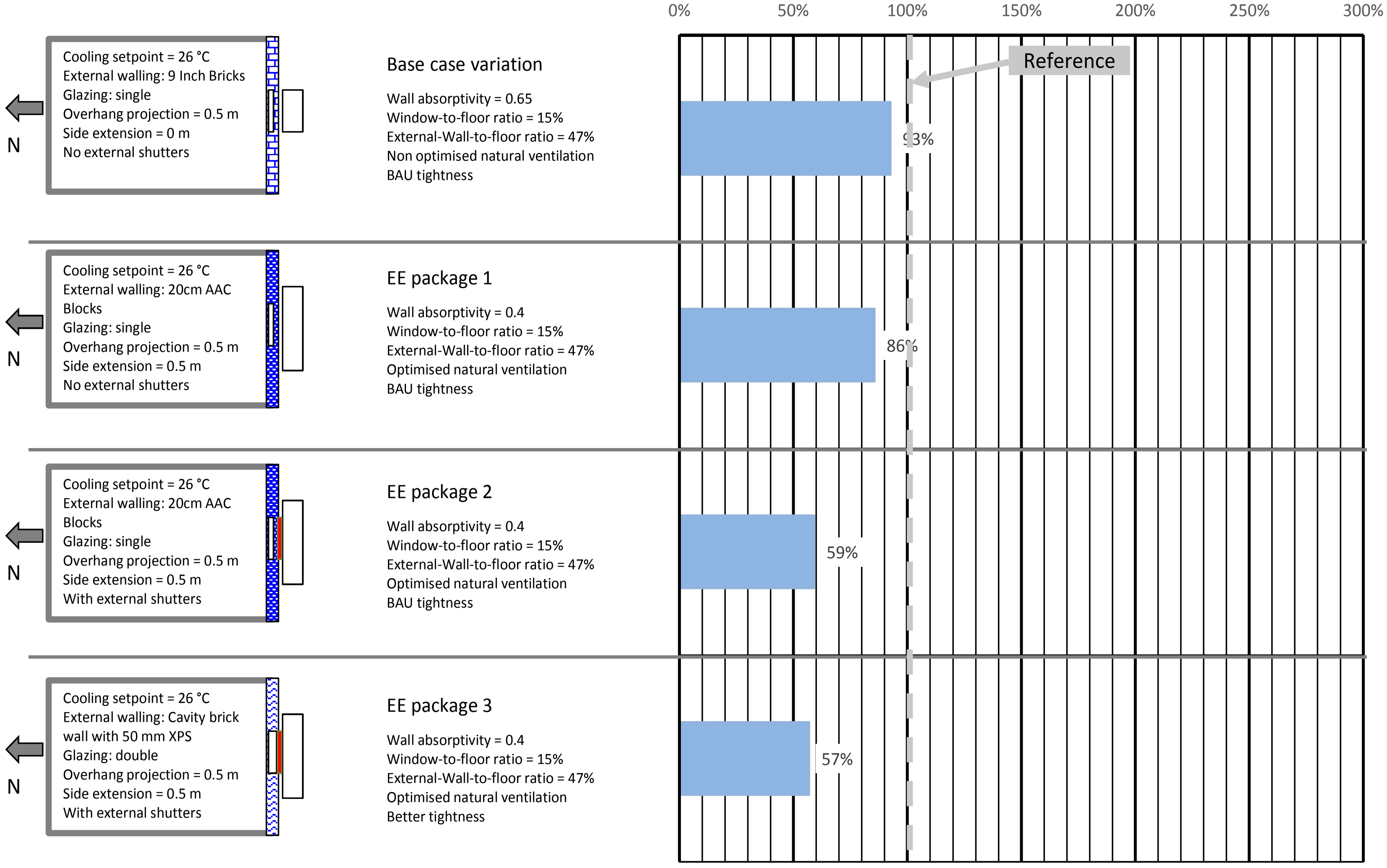

0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
126%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
118%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
63%
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness
65%

A.1-24

Results of parametric simulation runs for the living room (Chennai)



A.1-25


0%
50%
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200%
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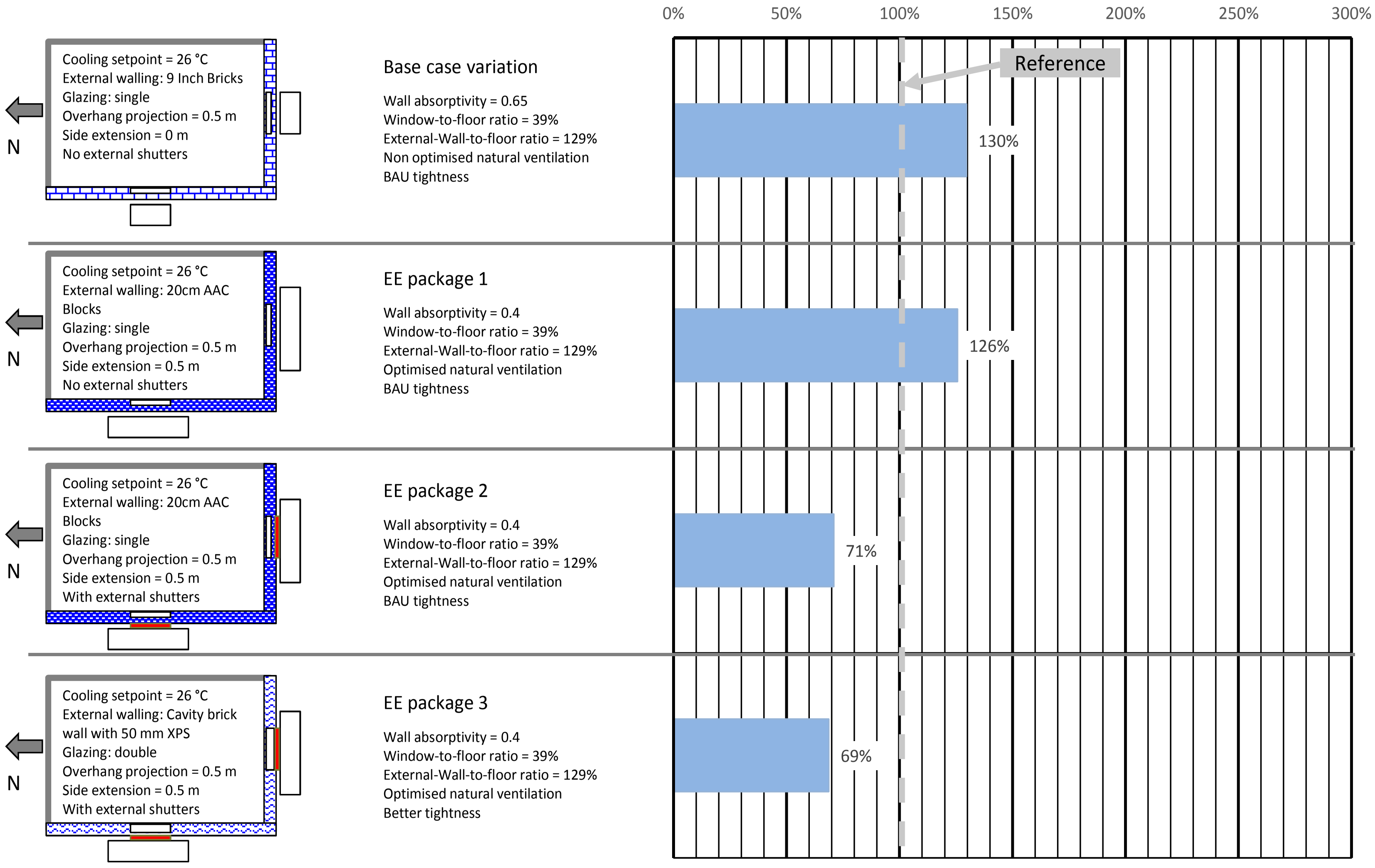
300%
Reference
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
93%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
86%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
59%
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness
57%

A.1-26



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

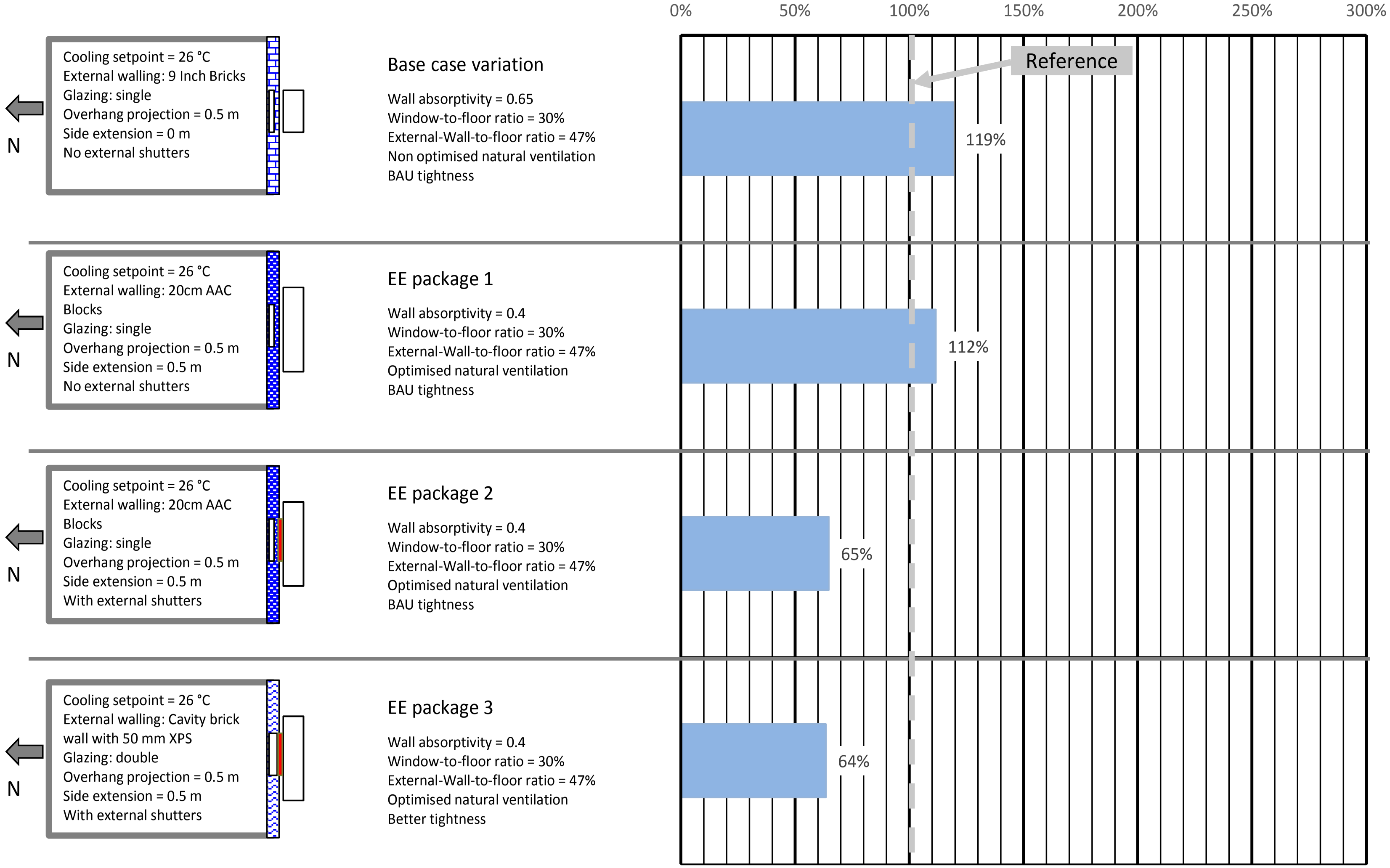
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness

A.1-27



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

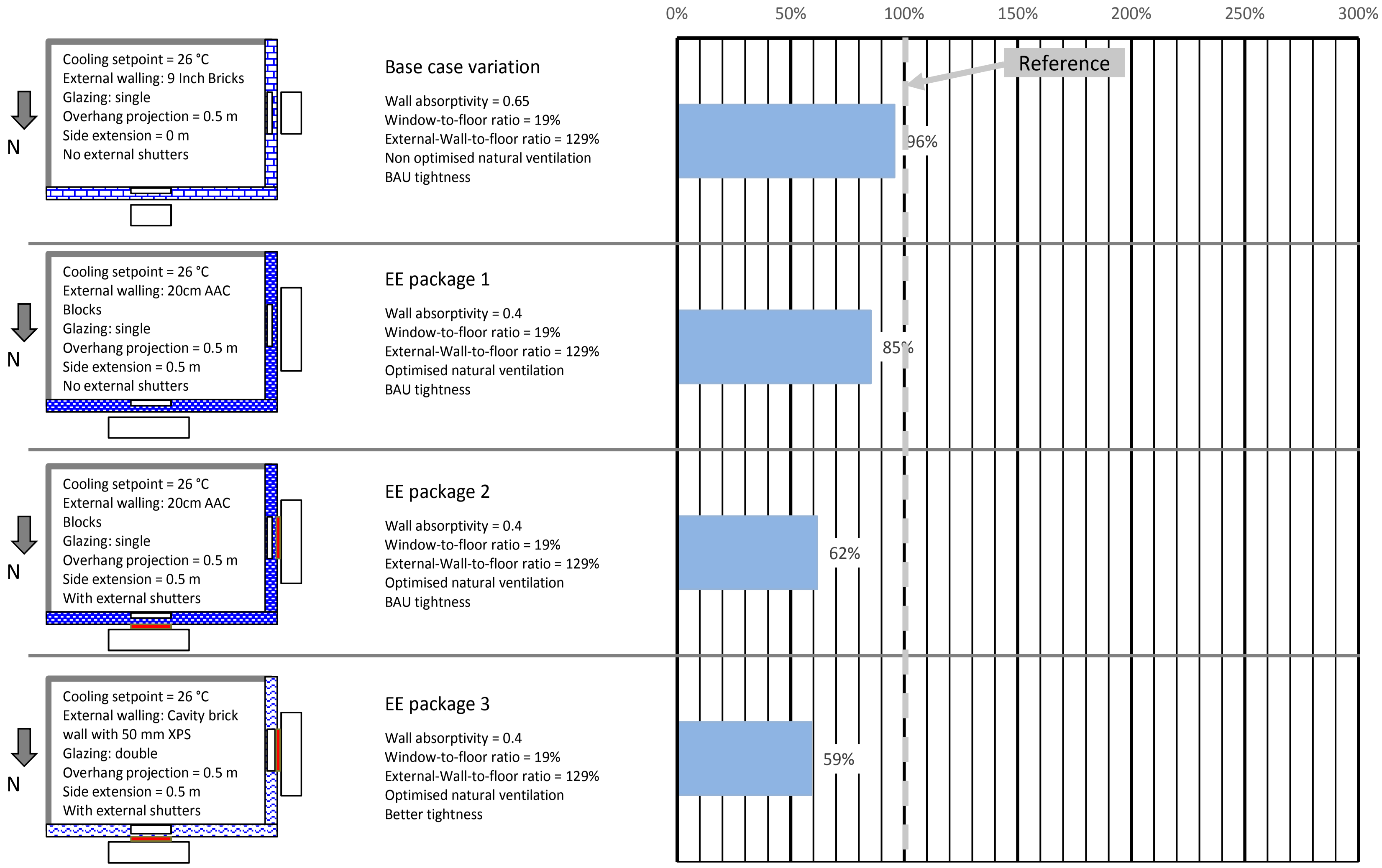
Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness

A.1-28



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

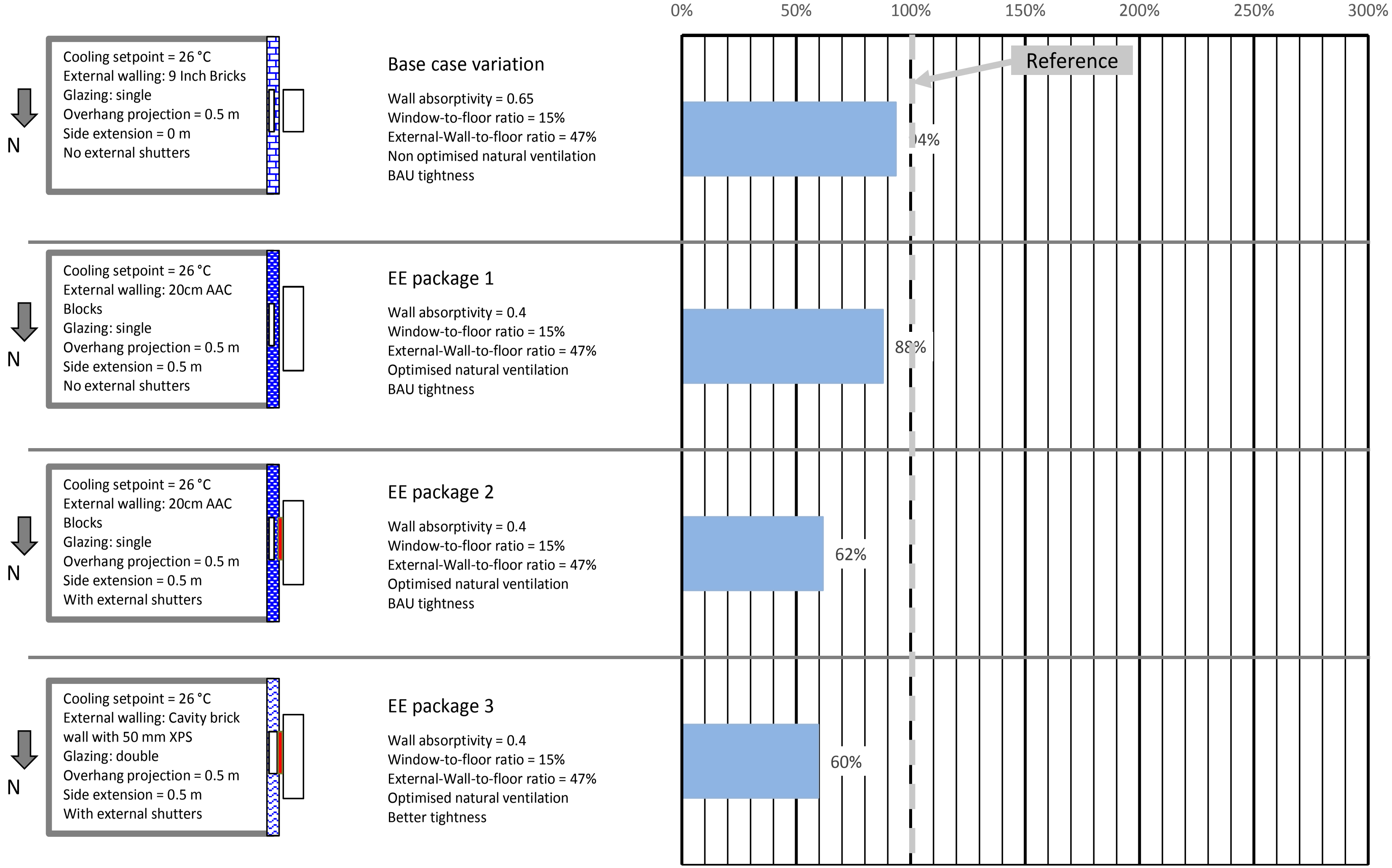
Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness

A.1-29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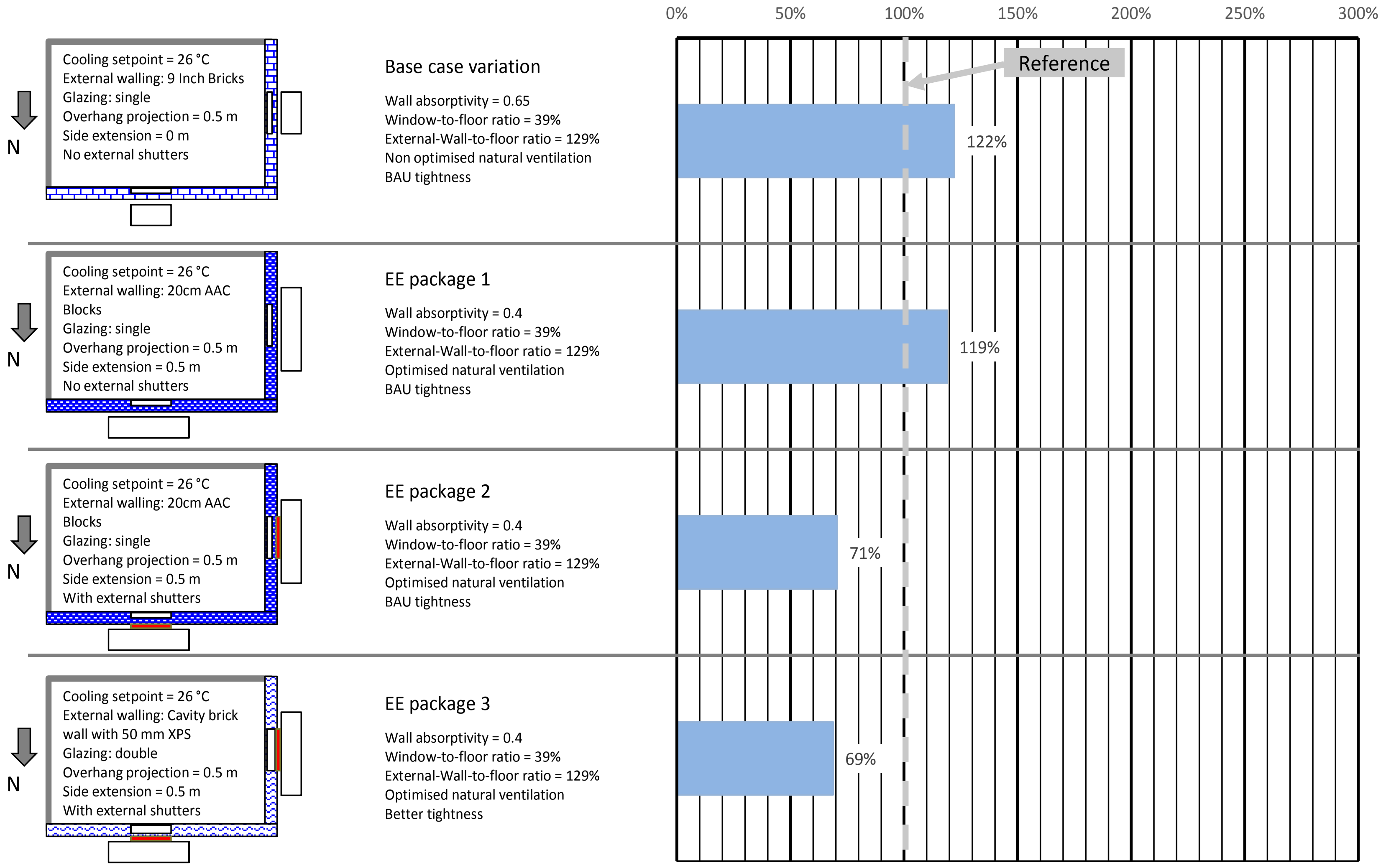
Reference
N
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
94%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
88%
N
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness
62%
N
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness
60%

A.1-30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50%
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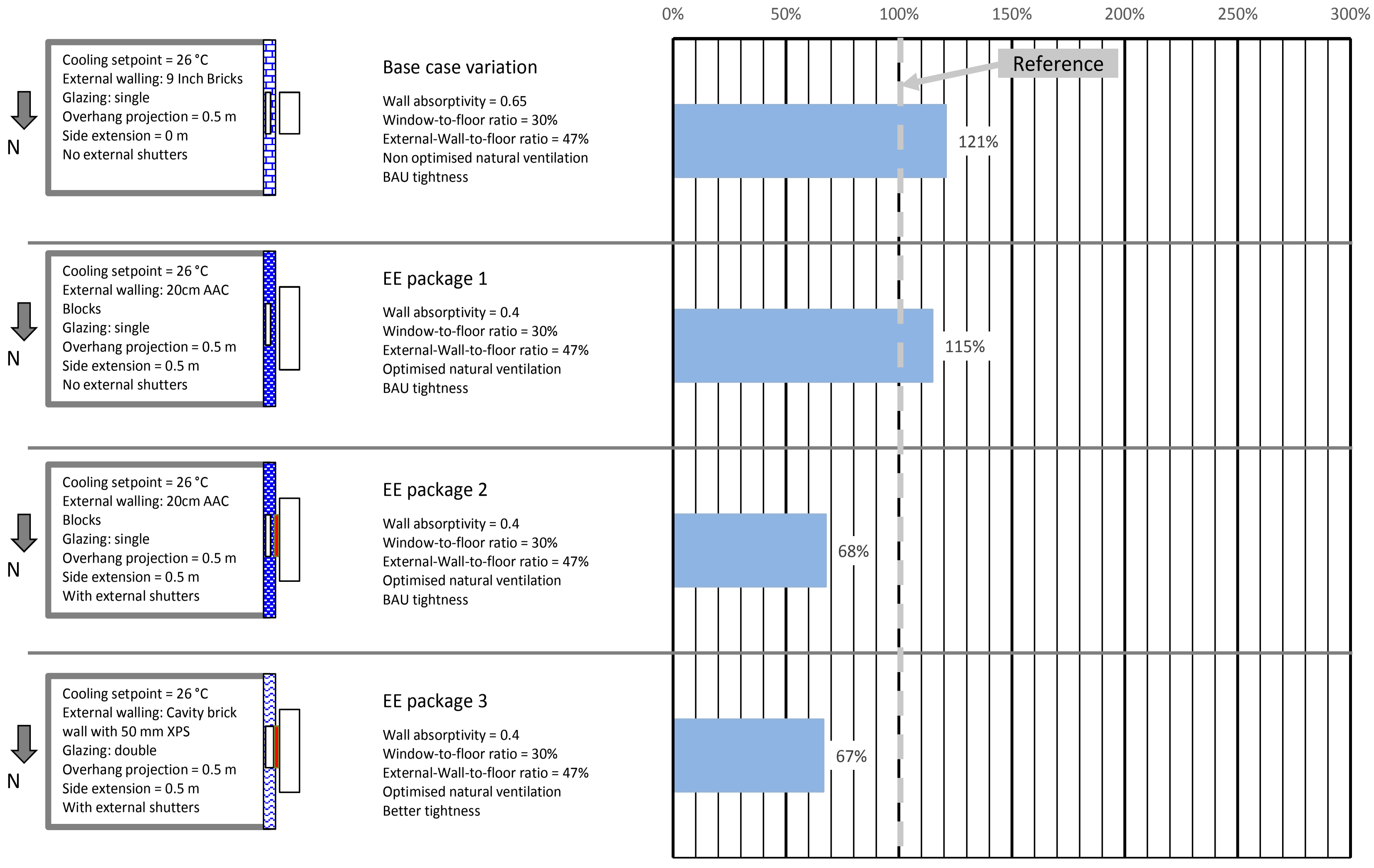
150%
200%
250%
300%
Reference
Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
122%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
119%
Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
71%
Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
69%

A.1-31



Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters

Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters

EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 2

Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
BAU tightness

Cooling setpoint = 26 °C
External walling: Cavity brick wall with 50 mm XPS
Glazing: double
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters

EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Optimised natural ventilation
Better tightness

A.1-32

ANNEXURE 2: PARAMETRIC STUDY TO IDENTIFY THE OPTIMUM DAYLIGHT FACTOR IN DWELLINGS, TAKING INTO ACCOUNT BOTH AVAILABLE DAYLIGHT AND COOLING DEMAND (CHAPTER 4)

Introduction & Context

The above study was carried out to identify adapted objectives for daylight in dwellings in the warm humid climate of India.

A benchmarking study was carried out to compare the requirements in international labels, standards and norms with regard to daylight in dwellings. The German DIN norm DIN 5034 (interior spaces) fixes an objective of minimum 0.9% for the points situated in the middle of the room, one meter from the wall, whereas the French Habitat and Environment Certification fixes minimum requirements of 2% in the first part of the room, and 1.5% in the further part of the room, for bedrooms, and 3% and 1.5% for living rooms respectively (See Figure A.2.1 and A.2.2)

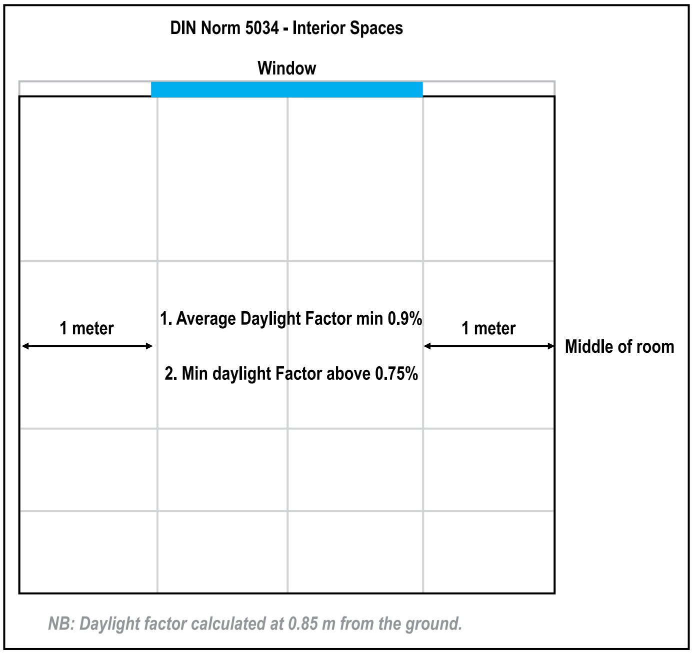


Figure A.2.1
Minimum daylight factor as per German DIN norm

BREEAM[1] and the Littlefair Guide to Good Practice (BR 209) fix requirements of 1.5% average daylight factor in the room. British Standard (BS 8206-2:2008) Lighting for Buildings fixes objectives of minimum 1% average daylight factor in bedrooms, 1.5% in living rooms and

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[1] *BREEAM is a British Standard for best practice in sustainable building design, construction and operation, http://www.breeam.org/about.jsp?id=66.*

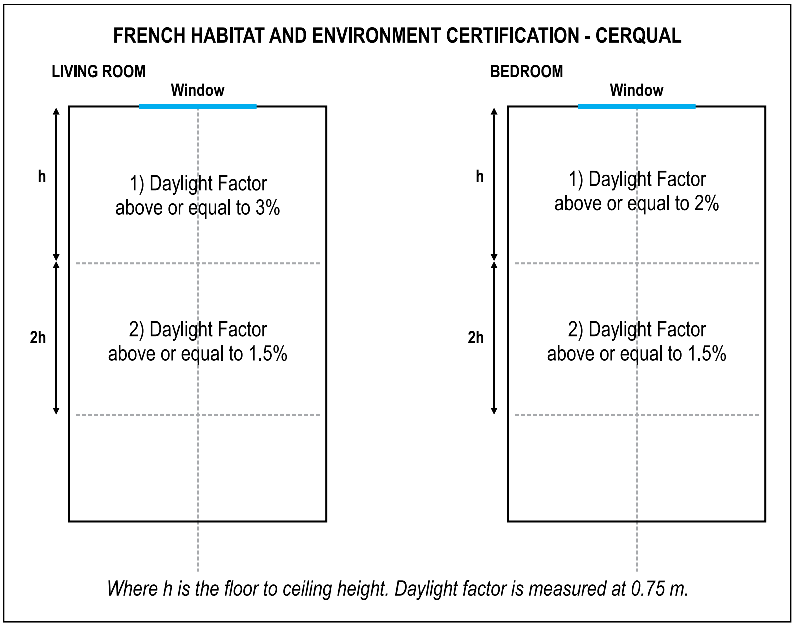

Figure A.2.2
Minimum daylight factor as per French Habitat and Environment Certification

2% in kitchens. Best practice would rather recommend daylight factors above 5% "to ensure that an interior looks substantially daylit".[2]

The targets mentioned above are fixed for CIE overcast skies, and correspond to climates where available daylight is much scarcer than in Indian climates. The BEEP team therefore estimated that it was necessary to assess what would be a reasonable target for Indian climates, while taking into consideration the cooling demand as well as the daylight autonomy in typical dwellings.

The study compared electrical consumption for lighting and cooling, in relation to the Window to Wall Ratio (WWR), in a typical living room occupied from 8 AM to 9 PM. The resulting daylight factor in the middle of the room was calculated on RADIANCE, and then used to control the lighting in a TRNSYS thermo-dynamic model. The lighting set point is 300 lux and the cooling set point is 26 °C. Figure A.2.3 gives an overview of the cases used for daylight as well as thermal dynamic simulation and the details of the characteristics used for modelling.

The results are summarised in Figure A.2.4.

The study showed that a **WWR in the range of 7% to 15%** corresponds to an optimum where daylight is sufficient and cooling demand is relatively low. Above 15% WWR, the cooling demand starts increasing very sharply. Below 7% WWR, the room will lack sufficient views to the outside.

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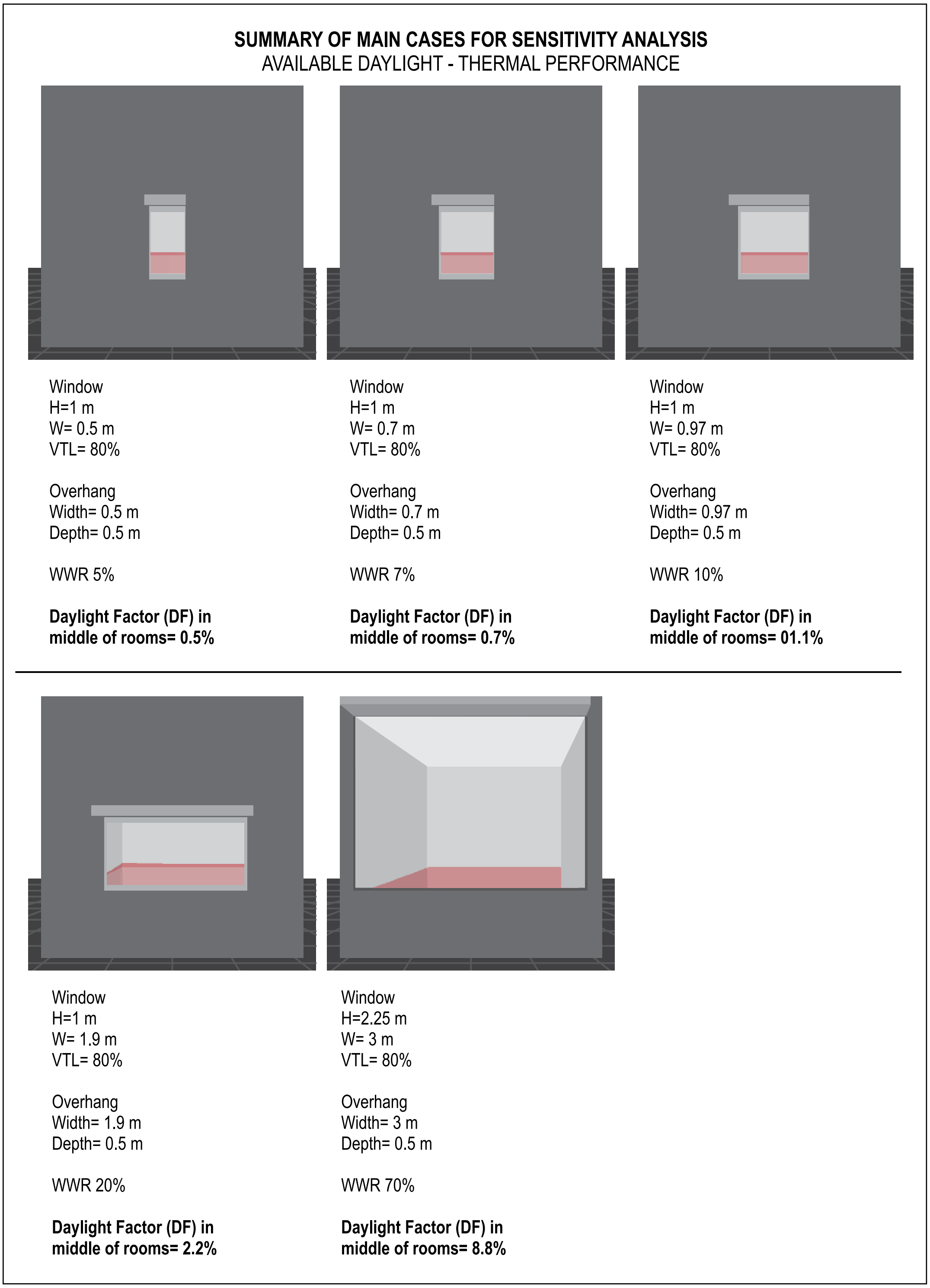
[2] *CIBSE Lighting Guide 10.*



SUMMARY OF MAIN CASES FOR SENSITIVITY ANALYSIS
AVAILABLE DAYLIGHT - THERMAL PERFORMANCE

Window
H=1 m
W= 0.5 m
VTL= 80%

Overhang
Width= 0.5 m
Depth= 0.5 m

WWR 5%

Daylight Factor (DF) in middle of rooms= 0.5%

Window
H=1 m
W= 0.7 m
VTL= 80%

Overhang
Width= 0.7 m
Depth= 0.5 m

WWR 7%

Daylight Factor (DF) in middle of rooms= 0.7%

Window
H=1 m
W= 0.97 m
VTL= 80%

Overhang
Width= 0.97 m
Depth= 0.5 m

WWR 10%

Daylight Factor (DF) in middle of rooms= 01.1%

Window
H=1 m
W= 1.9 m
VTL= 80%

Overhang
Width= 1.9 m
Depth= 0.5 m

WWR 20%

Daylight Factor (DF) in middle of rooms= 2.2%

Window
H=2.25 m
W= 3 m
VTL= 80%

Overhang
Width= 3 m
Depth= 0.5 m

WWR 70%

Daylight Factor (DF) in middle of rooms= 8.8%

Figure A.2.3 *Cases cases used for daylight as well as thermal dynamic simulation*

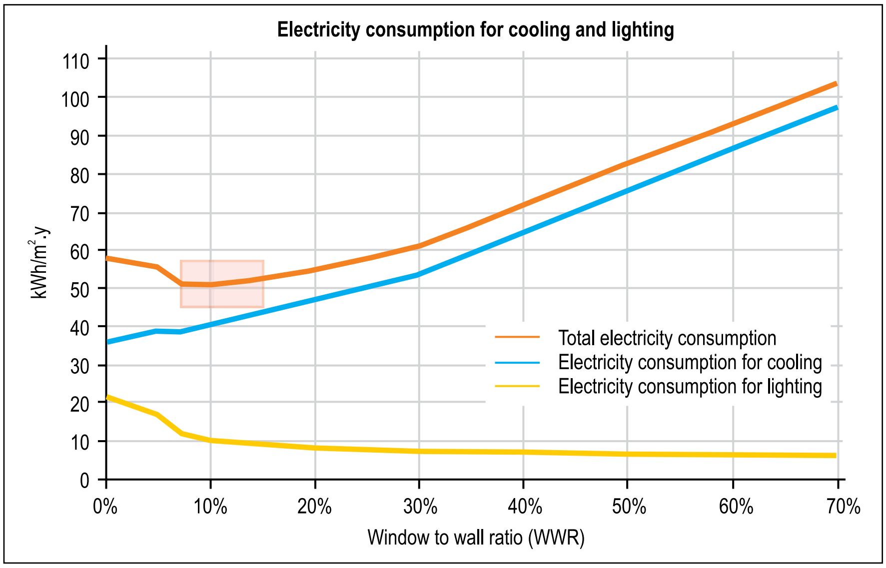
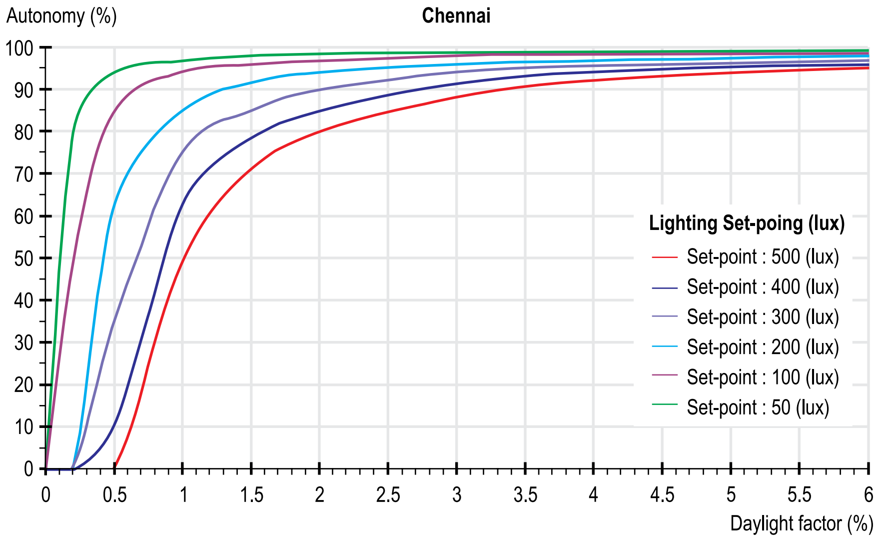
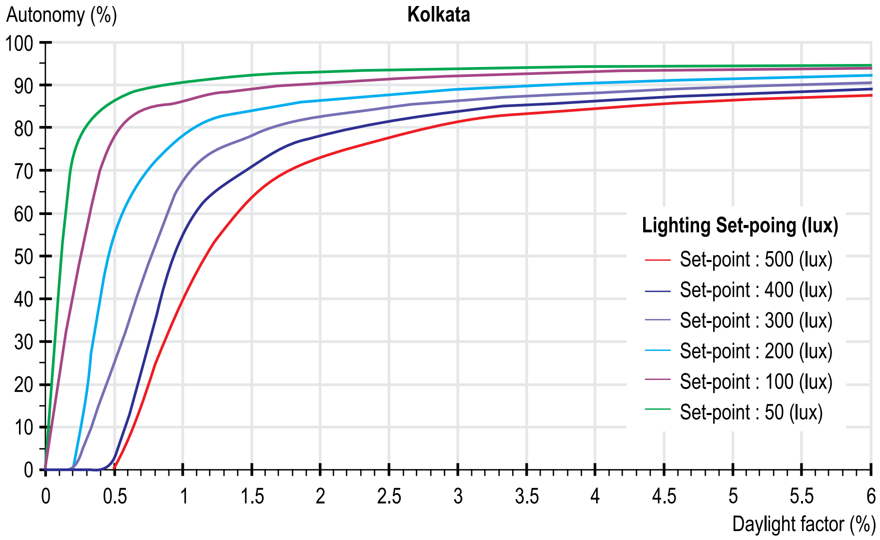


Figure A.2.4 *Results from sensitivity study on optimum WWR in relation to cooling and lighting demand*

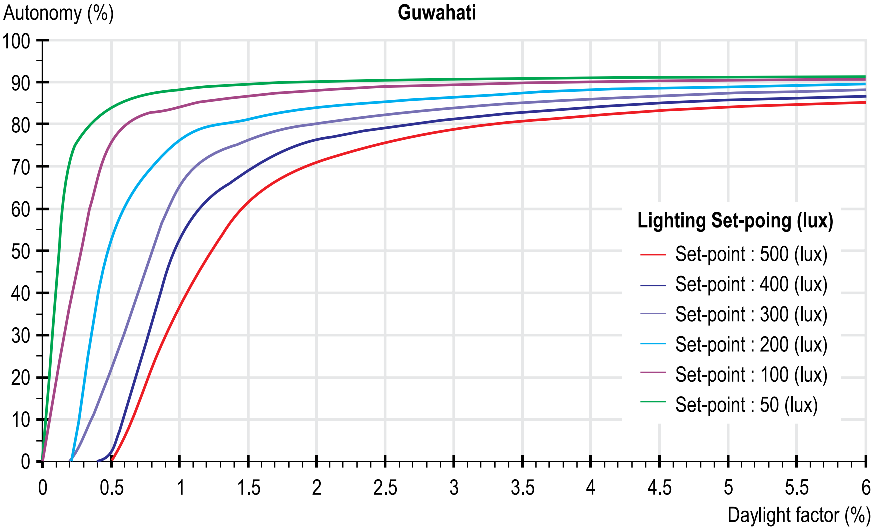
ANNEXURE 3: DAYLIGHT POTENTIAL IN DIFFERENT CITIES OF THE WARM HUMID CLIMATE ZONE (CHAPTER 4)



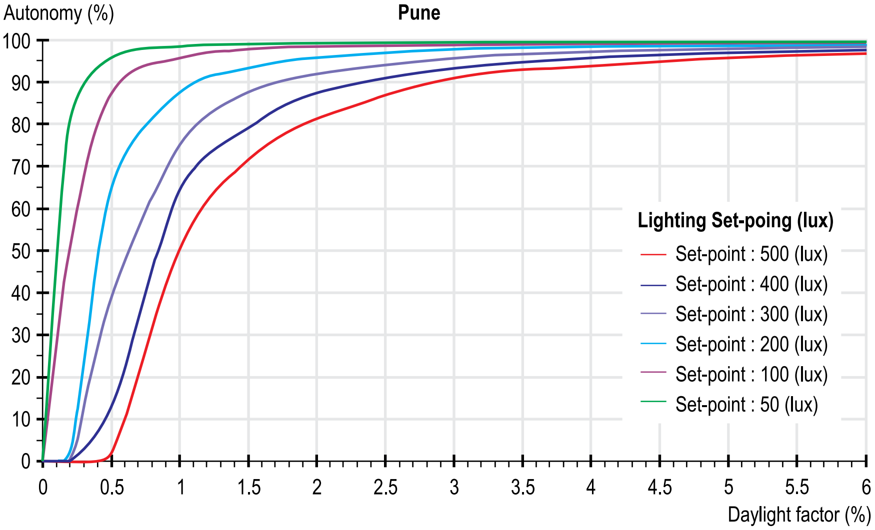
Annual daylight autonomy (in %) in Chennai, considering time period between 9 am and 6 pm.



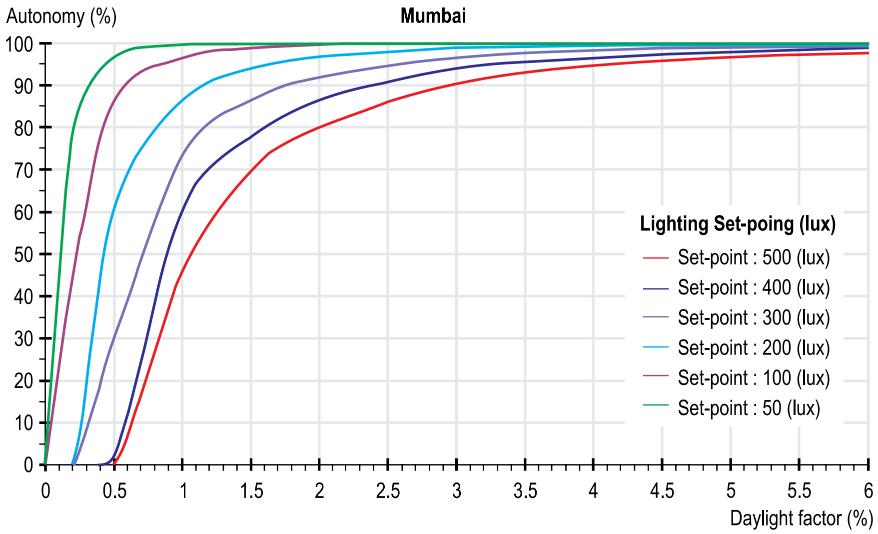
Annual daylight autonomy (in %) in Kolkata, considering time period between 9 am and 6 pm.



Annual daylight autonomy (in %) in Guwahati, considering time period between 9 am and 6 pm.



Annual daylight autonomy (in %) in Pune, considering time period between 9 am and 6 pm.

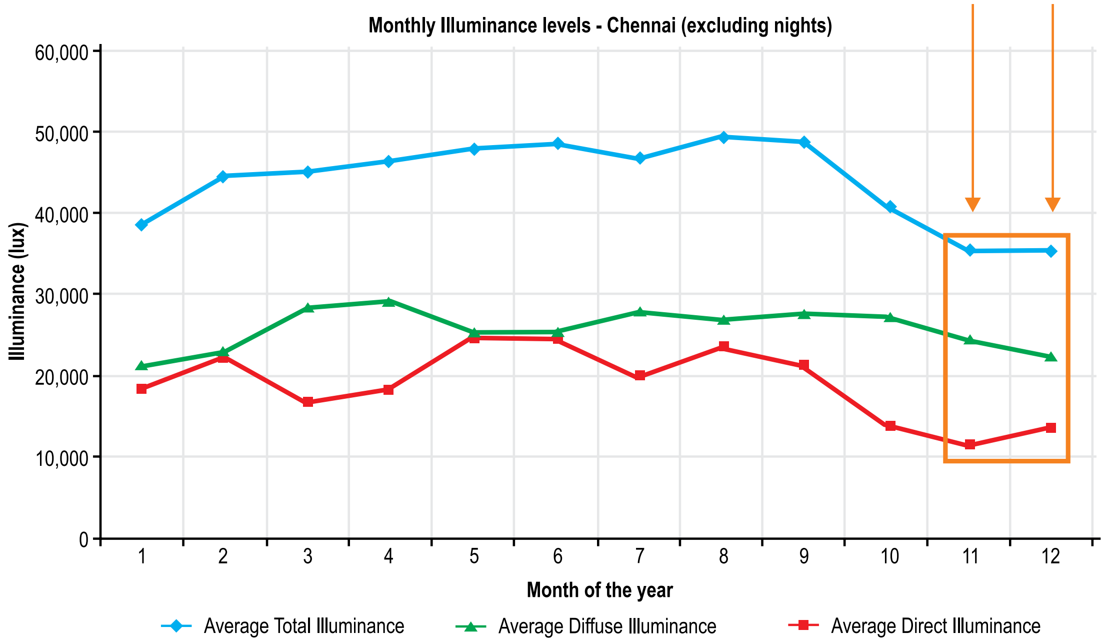


Annual daylight autonomy (in %) in Mumbai, considering time period between 9 am and 6 pm.

ANNEXURE 4: COMPARATIVE ANALYSIS FOR SELECTION OF TYPICAL SKY FOR DAYLIGHT ANALYSIS IN 5 CITIES OF THE WARM HUMID CLIMATIC ZONE (CHAPTER 4)

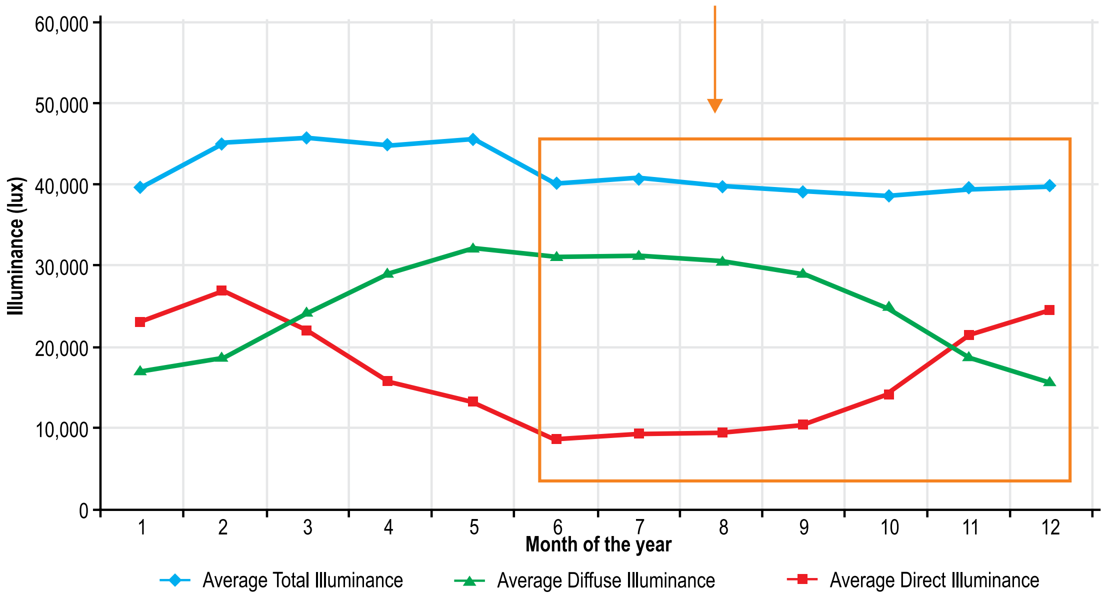
In order to select the most suited sky for performing daylight simulations in the warm humid climatic zone of India, a comparative analysis was carried out.

The monthly average illuminance levels in the 5 different cities of the warm humid climate were compared. The figures below give an overview of the illuminance throughout the year in the 5 cities.


Monthly Illuminance levels - Chennai (excluding nights)

Lowest Illuminance: 35,000 lux (monthly average excluding nights) in November and December
Diffuse Illuminance is 1.5 to 2 times higher than the direct illuminance

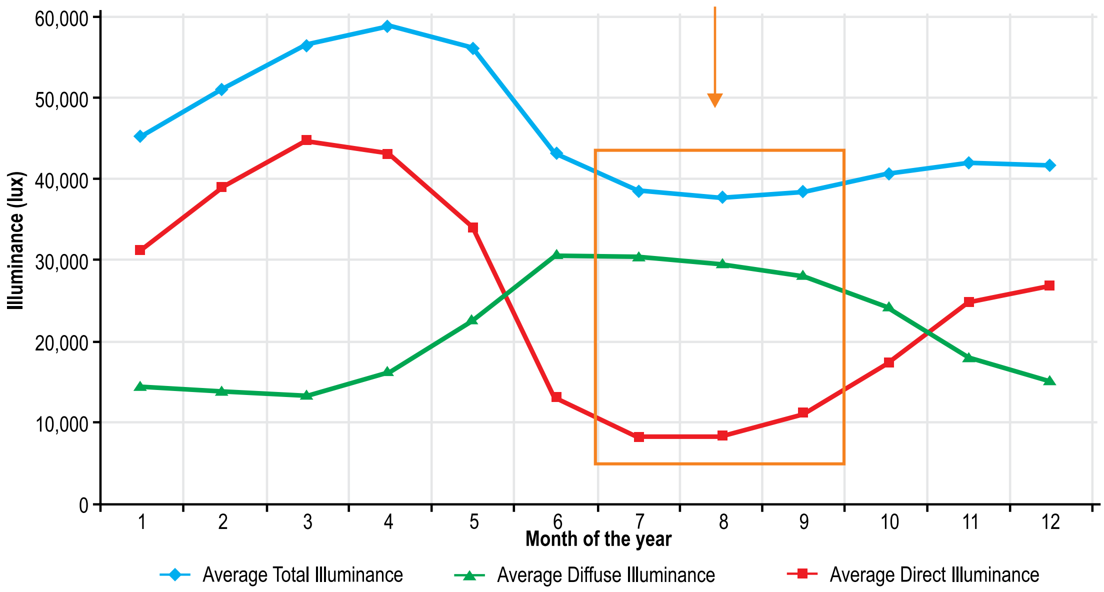
Monthly Illuminance levels - Mumbai (excluding nights)



Lowest Illuminance: 40,000 lux (monthly average) from June to January

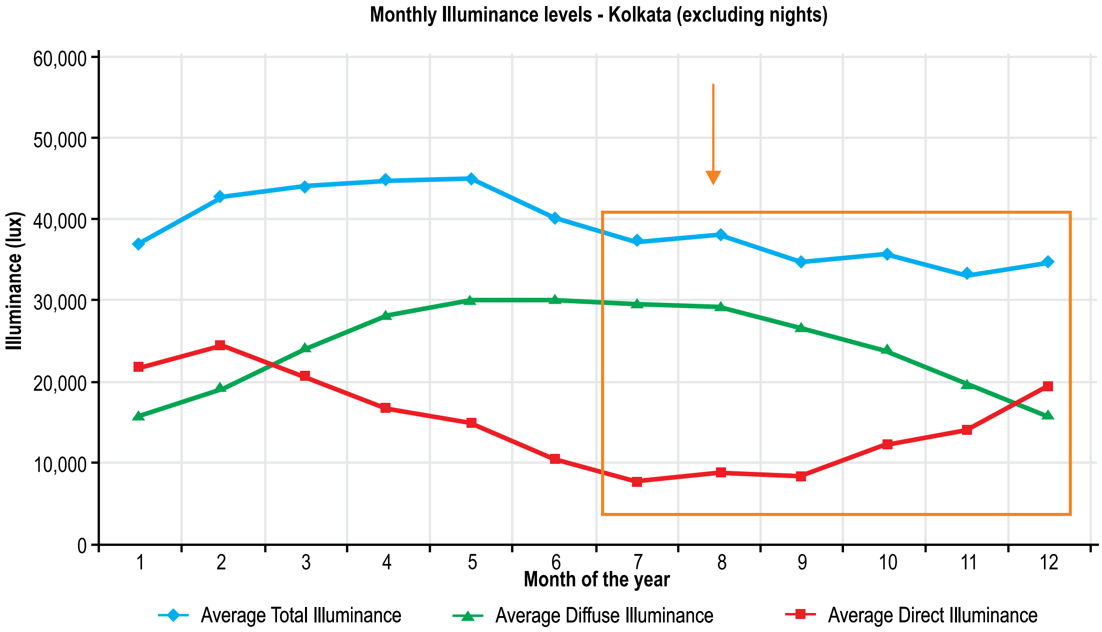
Diffuse Illuminance is up to 3 times higher than the direct illuminance

Monthly Illuminance levels - Pune (excluding nights)

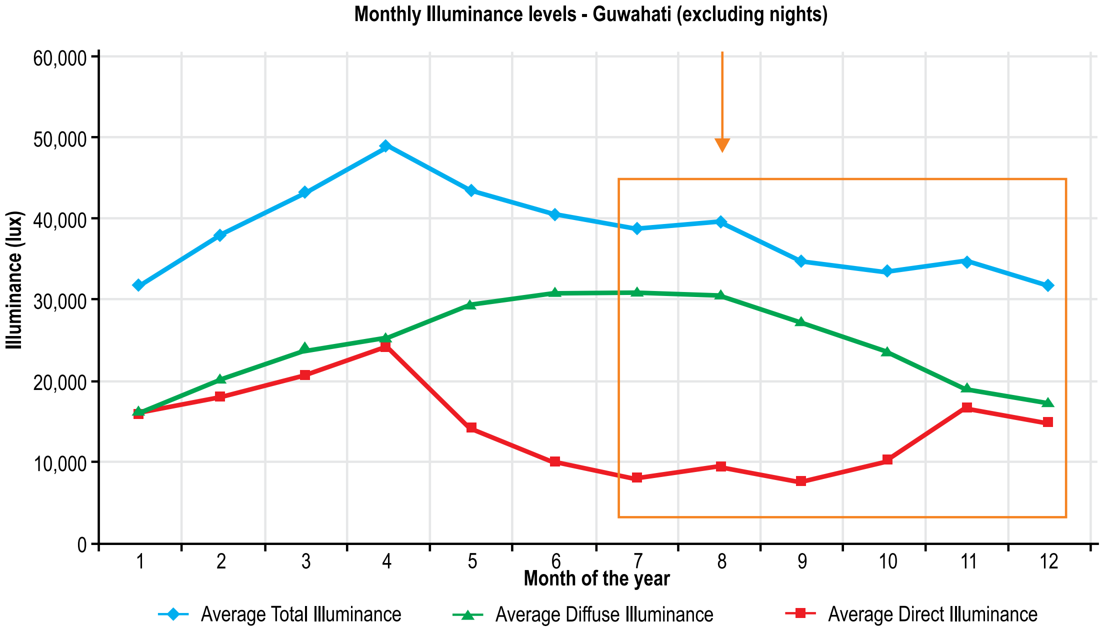


Lowest Illuminance: 37,000 lux (monthly average) from July to September

Diffuse Illuminance is up to 3 times higher than the direct illuminance



Lowest Illuminance: 34-37,000 lux (monthly average) from July to December
Diffuse Illuminance is up to 4 times higher than the direct illuminance



Lowest Illuminance: 32-40,000 lux (monthly average) from July to December
Diffuse Illuminance is up to 4 times higher than the direct illuminance

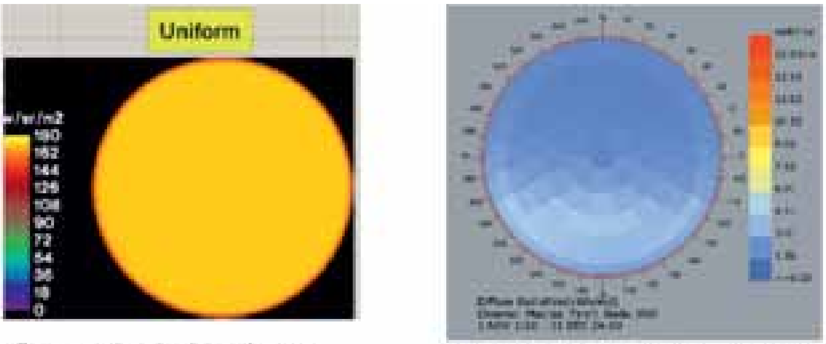
Analysis & Conclusions

The graphs of Illuminance in the 5 cities Chennai, Mumbai, Pune, Kolkata and Guwahati show that the lowest levels of Illuminance, - where daylight availability will be most critical in buildings - are found in the second half of the year, June to December.

During this period, daylight is most scarce. Design and dimensioning should ensure that daylight is sufficient during that period. If daylight is excessive during other periods, then shading can be applied.

This period corresponds to the times of the year when the diffuse illuminance is 2 to 4 times higher than the direct illuminance. For several cities, this corresponds to the extended monsoon period.

To reflect this situation in the daylight analysis for residential buildings in the warm humid climatic zone, the uniform sky type will be used. The uniform sky corresponds to an overcast sky where daylight is evenly spread out in the sky dome (see figure below).



Representation of typical uniform sky

Representation of cumulative generated sky (Rheinhart) with diffuse radiation for November - December in Chenna

Source: Rhino Grasshopper - Watch the sky - Standard Uniform sky & Cumulated Sky with Diffuse Radiation for Chennai (based on epw wheather file)

ANNEXURE 5: ANNEXURE TO CHAPTER 5

Thermal comfort design for typical Indian kitchen

This annexure presents the study of different strategies to maintain thermally comfortable conditions in a kitchen. The study has been performed using a CFD (computational fluid dynamics) software. Figure A.5.1 shows a sketch of the kitchen. The dimensions are given in Table A.5.1. Some of the important design features of/input to the model are listed below.

- The window can be opened by 50% (sliding window, free opening of 0.6 m width).
- An additional natural ventilation opening can be opened at the bottom of the kitchen.
- A door between the living room and the kitchen can be opened to 10% of its width to allow fresh air to enter the kitchen (the windows of the living room must be partly opened during the operation of the exhaust in summer conditions).
- The kitchen working plane is located at a height of 1.1 m.
- A person is standing near the vessel.

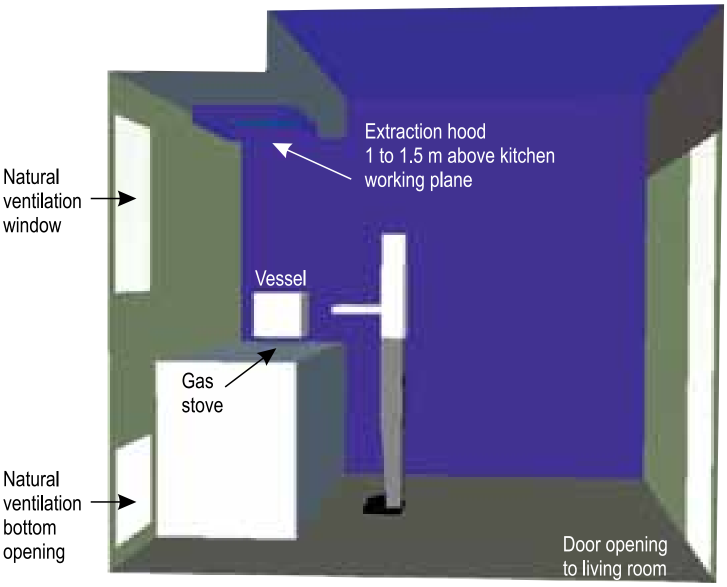


***Figure A.5.1** Sketch of the kitchen used for the CFD study*

Table A.5.1 Main dimensions of the kitchen	
Kitchen	**Dimension / Unit**
Length	3 m
Width	3 m
Height	2.8 m
Window location and size	
Vertical position	1.4 m above the floor
Height	1.4 m
Clear opening width	0.6 m

Table contd...

Table A.5.1 Contd...

Kitchen	Dimension / Unit
Natural ventilation bottom opening	
Vertical position	0.1 m above the floor
Height	0.5 m
Clear opening width	0.6 m
Door between living room and kitchen	
Vertical position	0 m above the floor
Height	2 m
Clear opening width	0.8 m
Cooking stove	2 kW thermal
Extraction hood	
Length	1 m
Width	0.7 m
Height	1 to 1.5 m above the gas fire

Strategies of natural ventilation for winter and mid-season

Figure A.5.2 presents the base case (Case 1).

The main assumptions are as follows:

- The window is open with a width of 0.6 m.
- The outdoor temperature is 28 °C.
- Bottom additional natural ventilation opening is closed.
- No extraction hood.

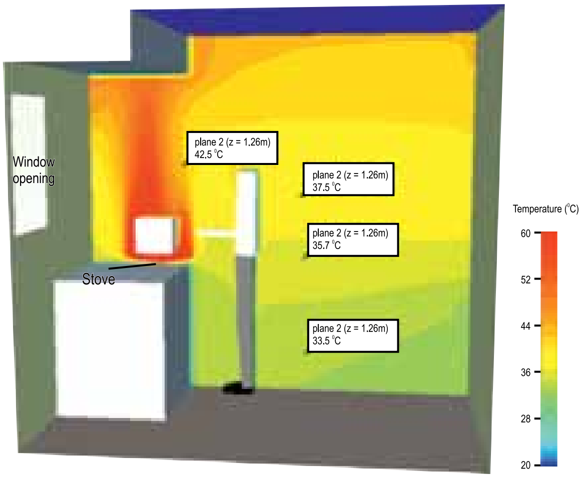


Figure A.5.2
Case 1

In Case 1, very uncomfortable thermal conditions are obtained. The average temperature in the occupation zone is around 36 °C, which is very high.

In Case 2, the same conditions are applied but the lower natural ventilation opening is also opened (Figure A.5.3).

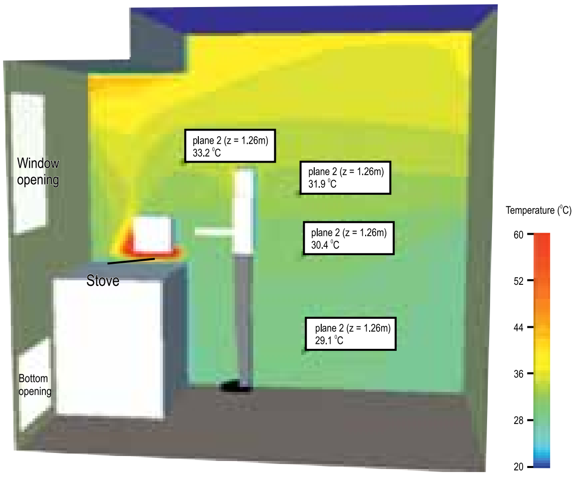


Figure A.5.3 *Case 2*

In mid-season, the positive impact of a bottom opening on natural ventilation is very important. The temperature in the occupied zone (1.2–1.7 m height) is about 5 °C lower in Case 2 than in Case 1. This simple measure allows improving significantly the condition of comfort in the kitchen. The improvement in natural ventilation takes place as the height difference between the bottom opening (from where outside air enters the kitchen) and the window opening (from which the hot air exits the kitchen) is much larger and this allows for a higher air flow rate. In these conditions, provision of a fan located near the person and blowing air in the direction of the living room can bring acceptable thermal comfort conditions.

Case 3 (Figure A.5.4) consists of simulation with a kitchen hood, but without the bottom natural ventilation opening. The main inputs are as follows:

- Outdoor temperature 28 °C.
- Window opened, bottom natural ventilation closed.
- Extraction hood located 1.5 m above the working plane with extraction flow rate of 300 m^3/h.

In this case, even with an extraction hood, but without lower natural ventilation opening, the thermal comfort level in the kitchen is not as good as in Case 2 (natural ventilation).

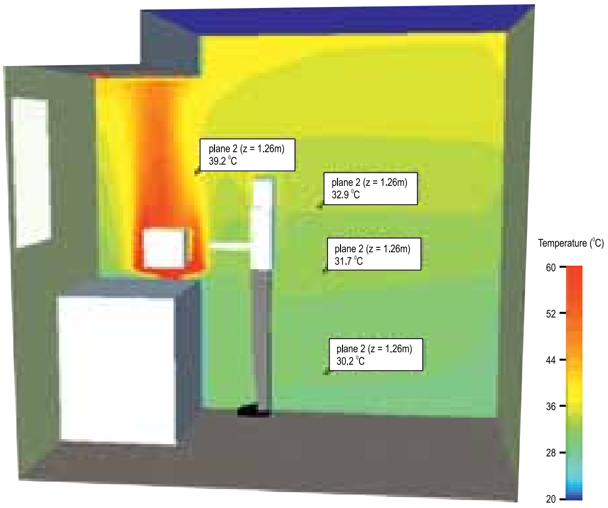


Figure A.5.4 *Case 3*

Case 4 (Figure A.5.5) is similar to Case 3, but now the lower opening for natural ventilation is also open. The main inputs are as follows:

- Outdoor temperature 28 °C.
- Window and bottom natural ventilation opened.
- Extraction hood located 1.5 m above the working plane with extraction flow rate of 300 m³/h.

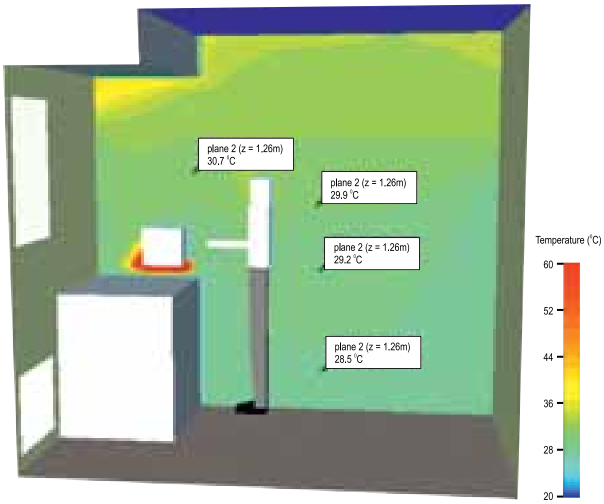


Figure A.5.5 *Case 4*

The thermal comfort situation improves in the kitchen because the temperature is about 3 °C lower as compared to Case 3 and about 2 °C lower as compared to Case 2. In this condition, the provision of a fan located near the person and blowing air in the direction of the living room helps achieve quite acceptable thermal comfort conditions.

In Case 5 (Figure A.5.6), the hood entrance is further lowered by 0.5 m. The main inputs are as follows:

- Outdoor temperature 28 °C.
- Window opened, bottom natural ventilation opened.
- Extraction hood located 1 m above the working plane with extraction flow rate of 300 m³/h.

Figure A.5.6 *Case 5*

By reducing the height of the hood to 1 m above the working plan, the thermal comfort improves further and the temperature in the kitchen comes down by about 0.5 to 1 °C as compared to Case 4.

In Case 6, the flow rate is increased from 300 to 500 m³/h (Figure A.5.7). The main inputs are as follows:

- Outdoor temperature 28 °C.
- Window opened.

- Bottom natural ventilation opened.
- Extraction hood located 1 m above the working plan with 500 m³/h.

By increasing the flow rate from 300 to 500 m³/h, the temperature in the kitchen is reduced by about 0.5 °C reaching a temperature very near to the outside temperature (28 °C). This is the best achievable comfort conditions in mid-season. It is important to note that 100% natural solution (Case 2) is almost as good.

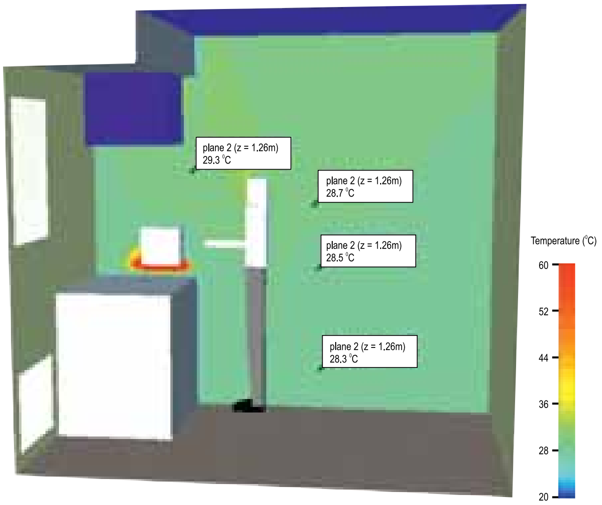


Figure A.5.7 *Case 6*

Strategies for heat extraction by ventilation during hot summer

When the outdoor temperature is high (>40 °C), natural ventilation without cooling cannot provide comfortable temperature conditions in the kitchen. In Case 7 (Figure A.5.8), natural ventilation is not used. The main inputs are as follows:

- Outdoor temperature 42 °C.
- Temperature in the living room 28 °C.
- Window closed, bottom natural ventilation closed.
- Living room door partly opened (10% in width), extraction hood located 1.5 m above the working plane with 500 m³/h extraction.

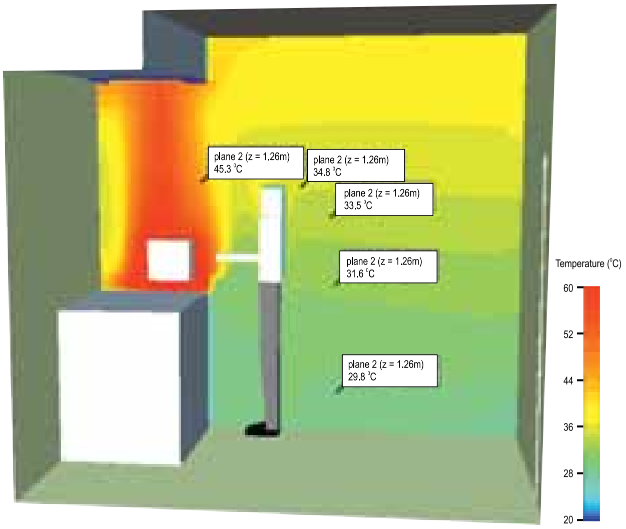


Figure A.5.8 *Case 7*

In this case, as the hood is located far from the heat source, a good part of the hot gases bypasses the hood. The temperature in the occupied zone is in the range of 30 °C to 35°C. In the next case (Case 8) Figure A.5.9, the entrance of the hood is lowered by 0.5 m. The main inputs are listed below.

- Outdoor temperature 42 °C.
- Temperature in the living room 28 °C.
- Window closed, bottom natural ventilation closed.

- Living room door partly opened (10% in width).
- Extraction hood located 1 m above the working plane with 500 m^3/h extraction.

The temperature in the occupied zone is reduced by about 3 °C. The comfort conditions can be considered as acceptable.

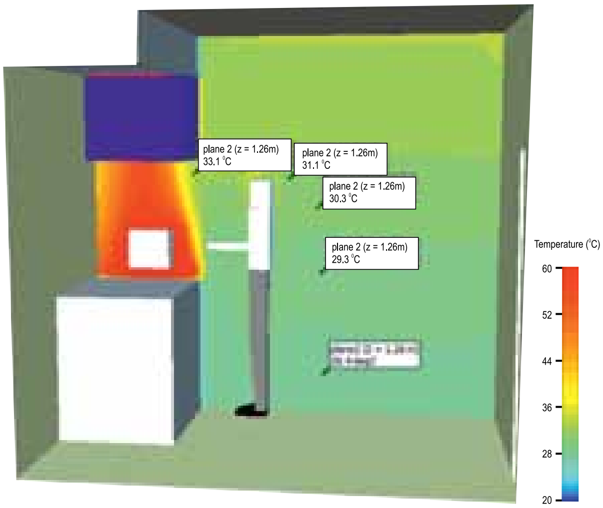


Figure A.5.9 *Case 8*

In Case 9 (Figure A.5.10), the extraction flow rate is increased to 800 m^3/h.

The main inputs are as follows:

- Outdoor temperature 42 °C.
- Temperature in the living room 28 °C.
- Window closed, bottom natural ventilation closed, living room door partly opened (10% in width), extraction hood located 1 m above the working plan with 800 m^3/h extraction.

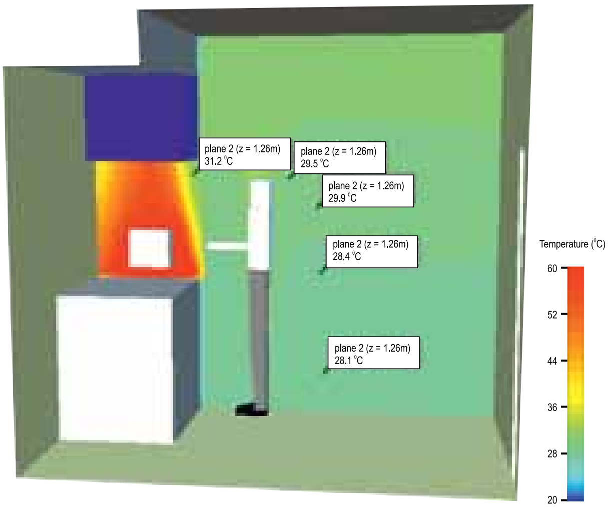
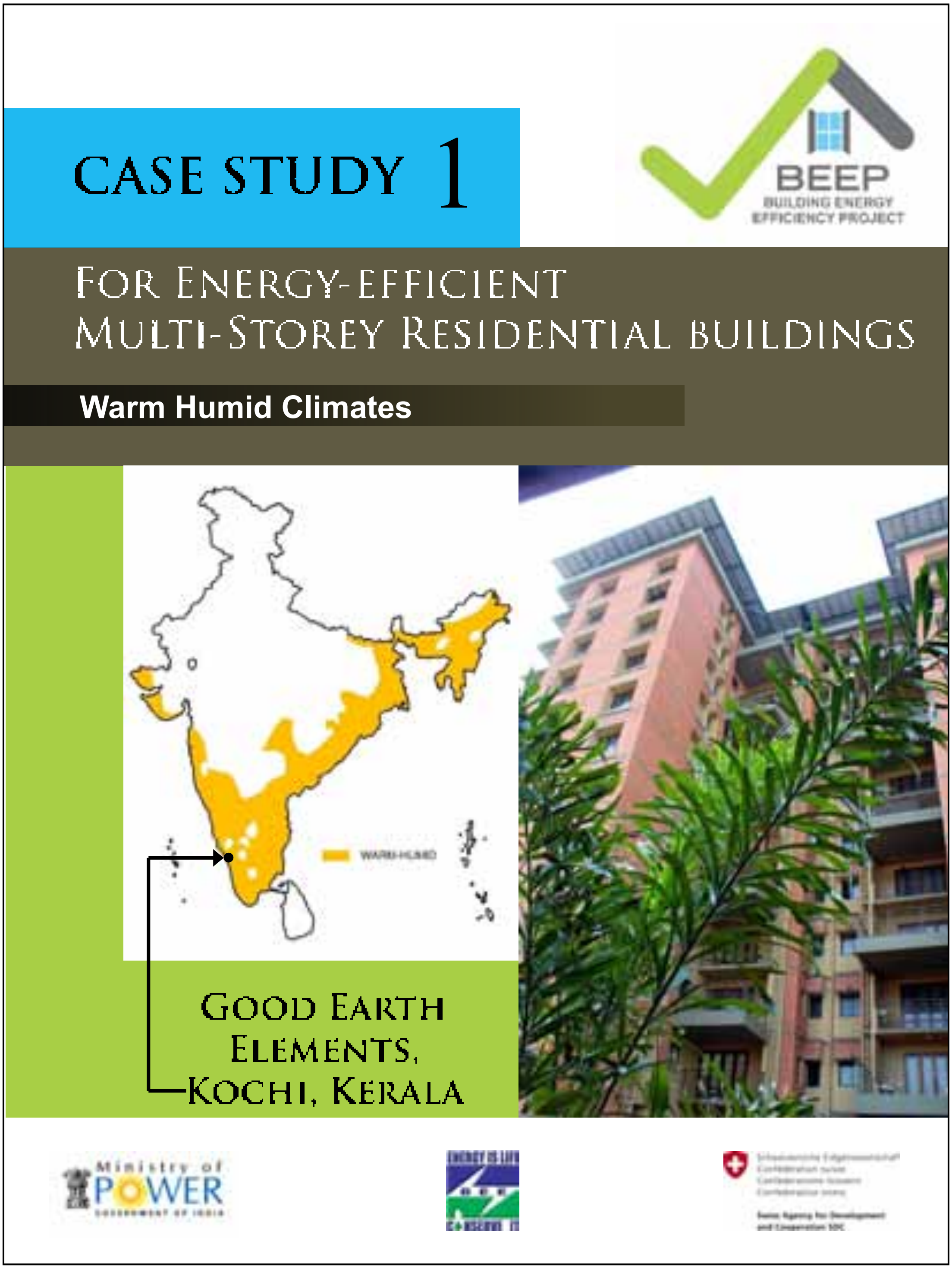


Figure A.5.10 *Case 9*

With this additional flow rate, the temperature is again lowered by about 1 °C. In this condition, the provision of a fan located near the person and blowing air in the direction of the living room brings acceptable thermal comfort conditions.



CASE STUDY 1

BEEP
BUILDING ENERGY EFFICIENCY PROJECT

FOR ENERGY-EFFICIENT MULTI-STOREY RESIDENTIAL BUILDINGS

Warm Humid Climates

GOOD EARTH
ELEMENTS,
KOCHI, KERALA

Ministry of
POWER
GOVERNMENT OF INDIA

PROJECT INFORMATION

Good Earth Elements is a multi-storey apartment building consisting of 50 premium nature apartments, located in Thrikkakara, Kochi.

Project Developer:	Good Earth India Infra Pvt. Ltd.
Project Architect:	Jayakumar & Associates, Bangalore

Project features:	
Site area	1.05 acres
Project built-up area	10,030 m^2 Footprint < 35%
Number of floors	Stilt floor + 11
F.A.R.	1.99

Flat type	**Flat area**	**No. of bedrooms**	**No. of units**
Type A	200 m^2	3	11
Type B	208 m^2	3	11
Type C1	132 m^2	2	1
Type C2	266 m^2	4 (duplex)	5
Type D	157 m^2	3	11
Type E	179 m^2	3	11

Good Earth Elements was completed and handed over in January 2015. It was designed and constructed over a period of 3 years.

Good Earth have pioneered alternative architecture and environment friendly development. They are intensely involved from design to delivery of any project. Their projects are designed to be low-energy while providing better occupant comfort. The broader objective is to create a sustainable society, promote community living.

CLIMATE

Located on the south-west coast of India, Kochi shows little seasonal variation due to its proximity to the equator as well as the sea.

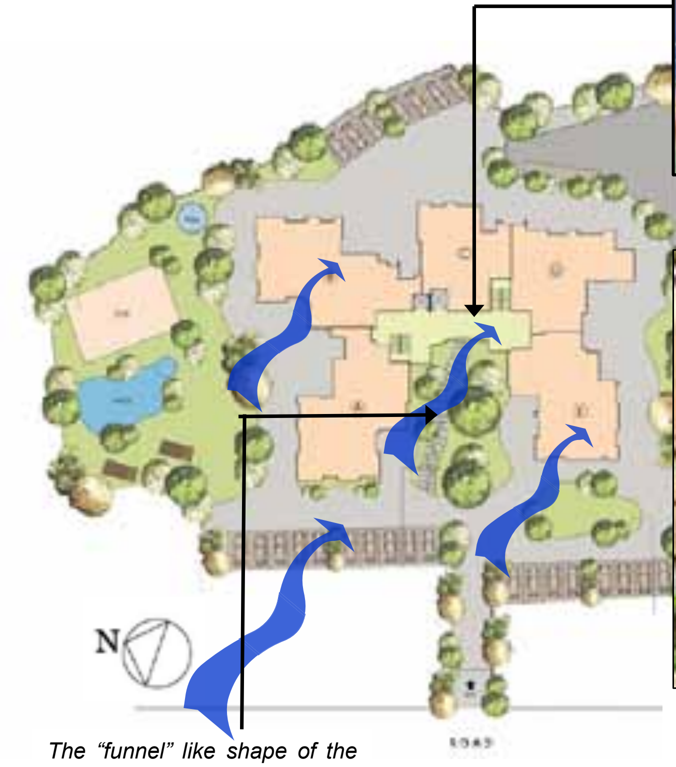
- Temperatures in Kochi are not very harsh. Average annual temperature ranges from 23 - 31°C
- High humidity throughout the year: 75 – 90%.
- Good wind velocities with average velocity of 3 – 4 m/s. The wind direction is predominantly from the west and south-west for most of the year. From October to December, the wind direction is from the north-east.
- Very high rainfall. Average annual rainfall of about 3000 mm.

BUILDING MASSING & ORIENTATION

The building massing and orientation of the building has been done to harness the natural wind direction and speed, improving ventilation within the flats. This is important for occupant comfort in this climate.

Good Earth Elements consists of a single tower. The longer sides of the tower face north-east and south-west. This provides very good natural ventilation potential as the predominant summer wind direction, in Kochi, is from the west and south-west.

The tower design includes the “sky court”- a landscaped terrace designed in the transition areas around staircases and lifts, at intermediate levels. The sky court facilitates natural ventilation and daylight in all units. *(See section on “Space Cooling”).* Every flat also has a double height individual sky garden, staggered on alternate floors. The projections and indentations in the building shape provide mutual shading, thus reducing solar exposure.



The “funnel” like shape of the central space and the sky court improves wind flow

The Sky Court

The sky court and the open corridors ensures good natural ventilation and improved daylight in the units

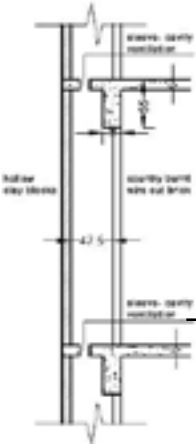
Building Envelope

WALLS:

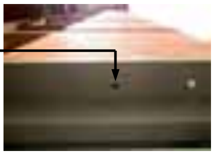
The external double walls has an insulating effect and protect the interior from moisture.

The external walls are double walls- an outer skin of hollow clay blocks and inner skin of solid clay bricks. The cavity in between is ventilated.

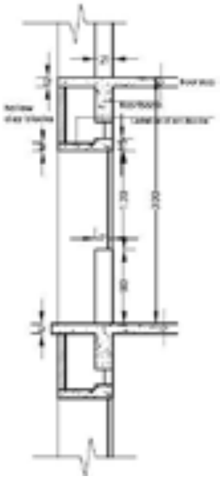
These walls are also an important aesthetic element giving the tower its "signature" look. The exposed brick walls are low-maintenance and reduce embodied energy and cost by avoiding cement plaster.




External cavity walls


Ventilation sleeve for the cavity


Recessed (and shaded) windows



WINDOWS:

The large openable windows provide ample natural ventilation and daylight. They are also windows are recessed and hence well shaded.

The windows are single glazed with aluminium frame and are openable. Due to the double wall design, all windows are recessed by 600 mm and hence well shaded. Window sizes are optimised to provide good natural ventilation and daylight.

ROOF:

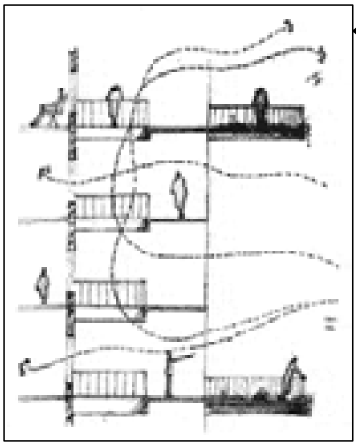
The roof is covered, protecting it from solar radiation and enabling utilisation of the roof for community purposes.

The roof is covered with galvanised aluminum sheets. This shades the terrace from direct solar radiation and also provides rain protection. The shaded roof allows the use of the space for other activities. In this building, laundry cubicles for every apartment are located on the shaded roof.


Shaded roof


Laundry cubicles for individual flats

Good Earth Elements is designed to provide ample cross ventilation through the individual flats. The kitchens are also well ventilated to dissipate the heat generated.



SKY COURT & OPEN CORRIDORS

The 'funnel' like shape of the sky courtacts as a wind scoop, drawing cool fresh air which enters the units through the open corridor. (*See section on "Building Massing & Orientation")*

UNIT DESIGN

The individual units are planned and their windows placed to allow good cross ventilation through the unit. The individual sky-gardens in all flats provide sun & rain protection and improve ventilation, besides creating green break-out spaces.

The individual sky garden

DAYIGHTING & REMOVING HEAT FROM THE KITCHEN

The openable window in the kitchen allows good daylight and ventilates it.

In addition, a pipe and cover provision is made through the double wall to install exhaust fans in the kitchen. This allows air to exhaust out without damaging the building aesthetic. This is also provided in the toilets.

Well day-lit kitchen

Exhaust fan cover for kitchens

Appliances

Design provision to incorporate AC installation. High user awareness

- The lintel of the recessed windows in bedrooms have a ‘sleeve’ to allow piping for split AC and ensures better installation.
- The residents of Good Earth Elements are aware of energy efficiency appliances. Most of them use BEE star rated equipment.
- There are examples of people using energy intensive appliances like dishwashers after 10 pm. This is the non-peak time when electricity tariffs are also low.

Common Services

Common areas day lit. Energy efficient artificial lights and equipment used for the common areas.

- Louvred openings in the stairwells and light colours ensure that the common areas areas are well day lit.

- LED lights used in common areas: 14W in lobby & 6W in outdoor
- Timer controlled systems installed for lighting in common area & outdoor lights.

- 5hp water pumps with sensors for automatic pumping
- Lift with VVVF (Variable Velocity Variable Frequency) System

Renewable Energy

Roof top solar PV system installed with grid-tie inverter

- 5 kWp roof top solar photovoltaic system.
- Smart grid-tie inverter: 5 kW rated, 3 phase. This inverter enables use of solar energy first before using grid power for the common services in the building.
- Estimated annual electricity generation from the installed PV system is approximately 6000 kWh.

Other Features

A high degree of user-developer interaction exists in the Good Earth Projects. The developers often stay at their own properties educating their clients about the building, its design philosophy and its energy efficient and ecological features.

WASTE WATER MANAGEMENT & RAINWATER HARVESTING

An on campus sewage treatment plant treats and recycles all waste water from kitchens and bathrooms. The wastewater is treated in many stages viz., chemical flocculation, primary settlement, equalisation, Moving Bed Biofilm Reactor (MBBR), secondary settlement, disinfection, filtration, UV filtration and aeration. The treated water is used for gardening and toilet flushing.

Rain water is harvested and used for domestic purpose after filtration using charcoal and sand bed. Excess rainwater is recharged to ground through open wells and percolation pits.

Waste water treatment system

WASTE MANAGEMENT

Occupants segregate solid and non biodegradable waste from the organic waste at the source. The organic waste is collected and composted, and the compost reused as manure. Some of the non biodegradable waste are burnt in the on site incinerator. Metals and plastic are recycled. This system is managed by CREDAI.

On-site waste management

MODERN DESIGN WITH RECYCLED MATERIALS

The innovative design and construction techniques used encourages an environment friendly design and local craftsmanship. The double walls of the building exemplify this. Walls along the swimming pool and club house area are constructed with used glass bottles along with brick and mud plaster.

Boundary wall of club house

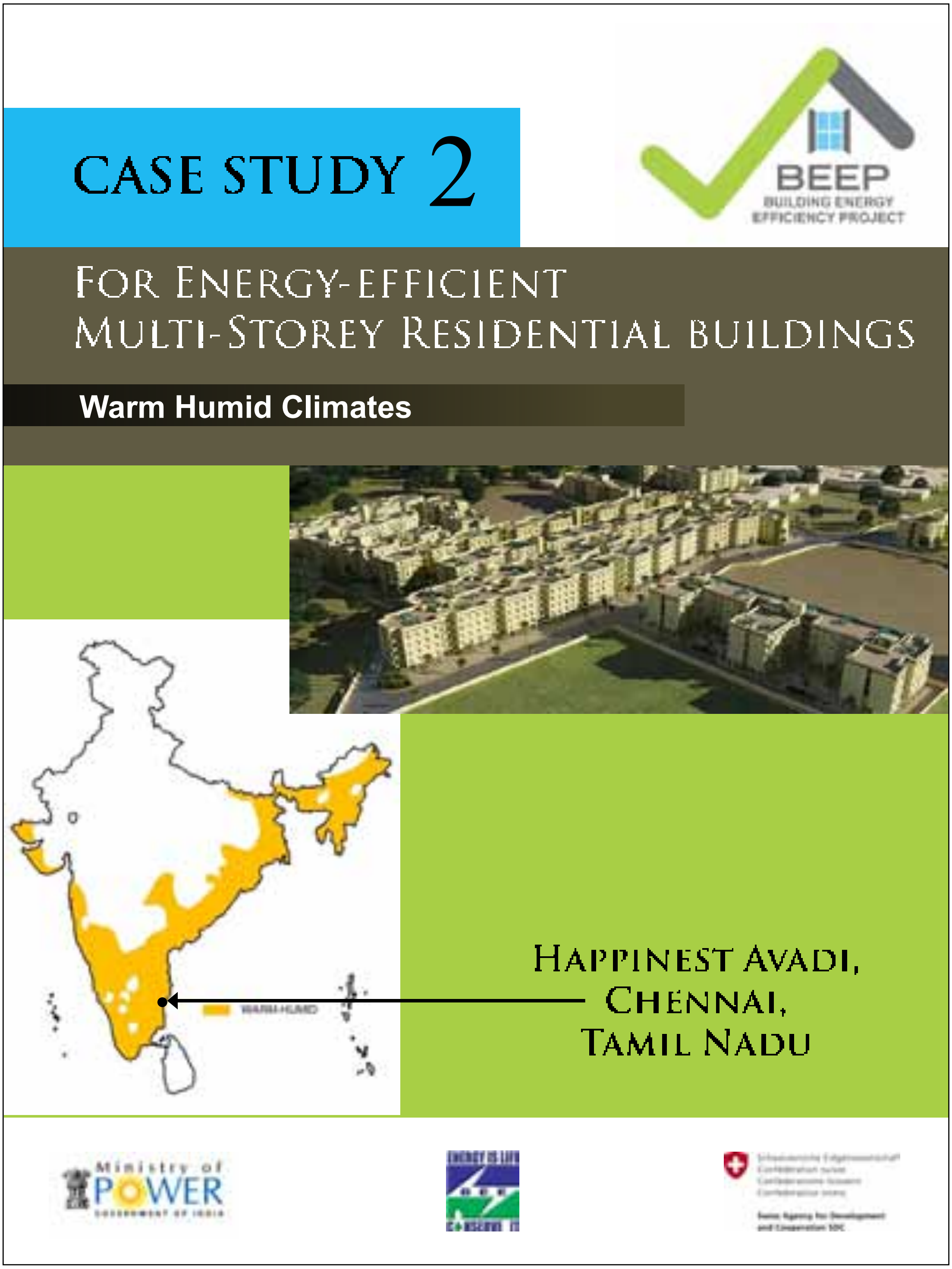
RECAP OF PASSIVE AND ENERGY EFFICIENCY FEATURES

BUILDING MASSING & ORIENTATION	Longer facades face north-east & south-west, taking advantage of the predominant wind direction The shape of the “sky court” and the open corridors ensure natural ventilation in all units The building shape affords mutual shading
BUILDING ENVELOPE	The external walls are double walls built with hollow clay blocks. The cavity between the two walls is ventilated. All windows are shaded by recessing them by 600 mm. Windows are operable to allow natural ventilation. The entire terrace is shaded with GA sheets.
SPACE COOLING	Building and all units designed for good natural ventilation. All bedroom windows have a “sleeve” in the lintel to allow easy installation of split ACs if required. Exhaust pipes and covers provided for in kitchens and toilets.
APPLIANCES	High use of BEE rated appliances and high user awareness.
COMMON SERVICES	Common areas day lit. LED lights and timer controlled systems used for lighting in common areas & outdoor lights. Automatic pumping system with sensors used. Lift with VVVF (Variable Velocity Variable Frequency) System
RENEWABLE ENERGY	5 kWp solar photovoltaic system installed with grid-tied inverter

For more information, please visit:

www.goodearth.org.in

www.beepindia.org



CASE STUDY 2

BEEP
BUILDING ENERGY EFFICIENCY PROJECT

FOR ENERGY-EFFICIENT MULTI-STOREY RESIDENTIAL BUILDINGS

Warm Humid Climates

HAPPINEST AVADI,
CHENNAI,
TAMIL NADU

PROJECT INFORMATION

Happinest is the affordable housing initiative by Mahindra Lifespaces (MLDL), consisting of 1260 apartments with 8 commercial establishments to service the residents.

Project Developer:	Happinest, Mahindra Lifespaces
Project Architect:	Ashok B. Lall Architects, New Delhi
Location:	Off Poonamallee Avadi High Road, Chennai

MLDL espouses green design and healthy living through all its projects.

Ashok B. Lall Architects specializes in low-energy sustainable architecture.

Project features:	
Site area	13.22 acres
Project built-up area	84,126 m^2
Number of floors	G+3 & Stilt + 4 floors
FAR	1.35 (1.5 allowed)

Flat type	Flat area	No. of units
1 BHK compact	36.79 m^2	192
1 BHK	50 m^2	480
2 BHK	62.89 m^2	596

Phase I of Happinest Avadi (604 units) will be completed by December 2015, construction time being 1 year 4 months. Phase II, with the remaining units is expected to be completed by end of 2016.

Housing is made affordable at Happinest projects by reducing cost, without compromising on the quality, by good sustainable value engineering initiatives and use of technology to have control on construction timelines as well.

CLIMATE

Located on the east coast of India, Chennai shows little seasonal variation due to its proximity to the equator as well as the sea.

- Summer in Chennai is very hot, with average maximum temperature between 35 - 40°C. Average minimum temperature in winter remains between 15 - 22°C.
- High humidity throughout the year: 70 – 90%.
- Average wind velocity in Chennai is 2.5 – 4 m/s. The wind direction is predominantly from the south-east and north-west for most of the year. From June to September, the wind direction is from the west.
- Rainy season is from October to December. Average annual rainfall of about 1400 mm.

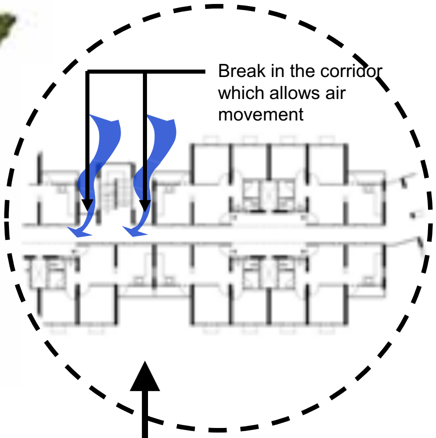
BUILDING MASSING & ORIENTATION

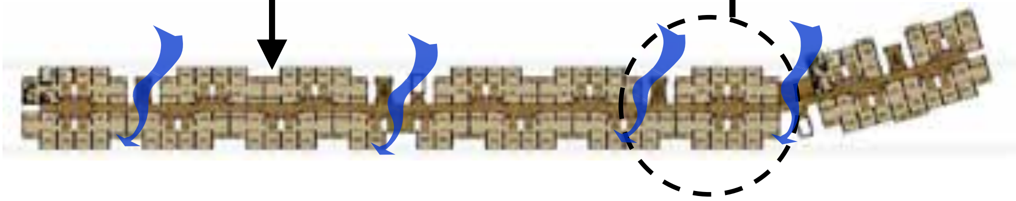
The blocks are oriented and configured in a way to reduce solar heat gains from the building envelope to the best extent possible. The double-loaded corridor planning of the individual units also reduces solar exposure; the corridor is open at the ends and at regular intervals to allow air movement.

Happinest Avadi consists of 12 blocks. The massing is done so that most of the units would face north-south. This reduces heat gains from the critical east-west directions.

All the blocks follow a linear double-loaded corridor typology, i.e., individual units are placed on two sides of a linear corridor. This reduces the exposed surfaces of the building, in turn reducing, heat gains into the building.

The blocks are designed to be "porous", i.e. allowing ample wind movement. The corridor is open at both ends and breaks are provided in between (with the staircase) through which air movement can take place in the corridor and the units.





BUILDING ENVELOPE

WALL:

The building envelope at Happinest Avadi is designed to provide thermal comfort in two ways:

- **The structure consisting of 200 mm thick shear walls and flat slab provide thermal mass**
- **Infill walls of Cellular Lightweight Concrete (CLC) and Autoclaved Aerated Concrete (AAC) blocks provide insulation.**

The building structural system consists of monolithic 200 mm thick shear walls and flat slabs. Infill walls are constructed of CLC and AAC blocks. These shear walls are mostly in the interior of the building. The exterior walls are mostly the CLC or AAC walls.

Chennai has good wind speed providing very good natural ventilation potential. The thermal mass provided by the shear walls and the slab, interacting with the moving ambient air, helps move the inside temperature to the cooler ambient evening temperature.

The exterior infill walls constructed with Cellular Lightweight Concrete (CLC) blocks and Autoclaved Aerated Concrete (AAC) blocks insulate, reducing heat ingress.

ROOF:

The roof has a reflective finish and its inner surface is painted with low-e paint.

The roof slab has a reflective finish to reflect incident solar radiation. In addition, the inner surface of the roof slab is coated with low-emissivity paint so that re-radiation of heat inside the building is reduced.

SOLAR PROTECTION OF WINDOWS

WINDOWS:

The window shading system and balconies are pre-fabricated and designed to give the occupant the opportunity to install further shading of their own or use it for other purposes.

All windows are well-designed with an innovative low-cost shading which allows for additional shading by the occupants. All exterior windows are shaded-

- with a pre-fabricated Mild Steel (MS) shading frame with light coloured cement board overhang, or
- the windows open onto a balcony with MS frame and ferrocement jaali

The frames offer the opportunity to the occupants to install other shading devices like chiks, blinds etc. It could also be used to keep planters and dry clothes.

The shading provided, window-to-wall ratio (WWR) of about 15% and the uPVC frames help control solar heat gain further even though the windows are single glazed.

Rendered image of possible installation of chiks and blinds on the MS frames of the balcony and window shading. The frame is also used to support planters.

Space Cooling

Happinest Avadi is designed to ensure cross ventilation in individual units and take advantage of the good wind to passively cool the building.

CROSS VENTILATION

Windows are located at opposite faces of walls, which enhances cross ventilation throughout the house. Doors have ventilators above them to ensure cross ventilation even when the door is closed for privacy.

The thermal mass provided by the shear walls and the flat slab ensure that the building cools down faster in the evening with good wind flow through the openable windows.

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OPENINGS FOR VENTILATION… OR AC

The window is designed as a system-one that brings in daylight, has a shading fixture, can be opened to bring in cool air and can also accommodate an AC if required.

The top panel is louvred for better ventilation but can also be used to fit in an AC.

.

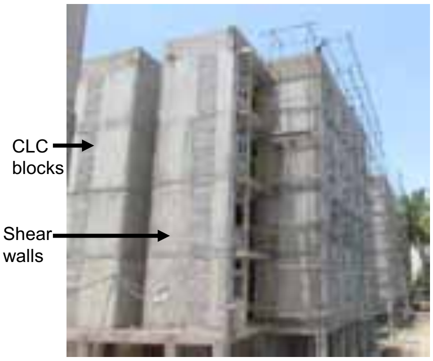
Other Features

Happinest Avadi uses innovative construction practices to reduce its construction cost and time while keeping its embodied energy low.

STRUCTURAL SYSTEM

The structure system consists of 200 mm thick shear walls and 150 mm thick flat slabs cast monolithic instead of the conventional column-beam structure. Mivan aluminium formwork was used to cast the structure. Smart dynamic concrete (SDC), which requires less vibration, was used for the structure.

This system reduced construction time by about 25%. The formwork is also reusable up to 110 times. This structural design also minimises the amount of concrete and steel used, thus reducing the embodied energy.




Mivan aluminium formwork

CLC AND AAC BLOCKS

The Cellular Lightweight Concrete (CLC) blocks for the infill walls were produced on-site. The AAC blocks used were procured from a 60 km radius from the site.

Both the blocks as well as the concrete contains fly-ash obtained from Ennore thermal power station, 35 kms away.


CLC blocks produced on-site

PRE – FABRICATED ELEMENTS

Construction time was also reduced by using pre-fabricated elements like the window shading system, balcony railing feature, kitchen slabs etc.

RECAP OF PASSIVE AND ENERGY EFFICIENCY FEATURES

BUILDING MASSING & ORIENTATION	Longer facades of most blocks face north & south, reducing solar exposure of the walls.
	Linear double-loaded corridor typology reduces solar heat gains further as less walls are exposed to the sun.
	Breaks provided in the corridor to facilitate air movement and cross ventilation.
BUILDING ENVELOPE	The external envelope consists of shear walls, that provide thermal mass, and CLC / AAC blocks that provide insulation.
	All windows are shaded by a pre-fabricated MS shading system and cement board overhang.
	The roof has a reflective finish and the inner surface is painted with low-e paint.
SPACE COOLING	Building and all units designed for good cross ventilation.
	Windows designed to be operated for ventilation and accommodate AC if required.
	With good wind flow, the building thermal mass also helps in cooling the building faster at night.
COMMON SERVICES	LED lights to be used for the common areas.
	Hydro-pneumatic water pumping system implemented. This has health benefits and the operational costs are low.
MATERIALS & CONSTRUCTION	The monolithic shear wall and flat slab structure ensures speedy economic construction which is also low-embodied energy
	CLC blocks are also low-embodied energy and were produced on site

For more information, please visit:

happinest

www.happinest.co.in

BEEP

www.beepindia.org

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