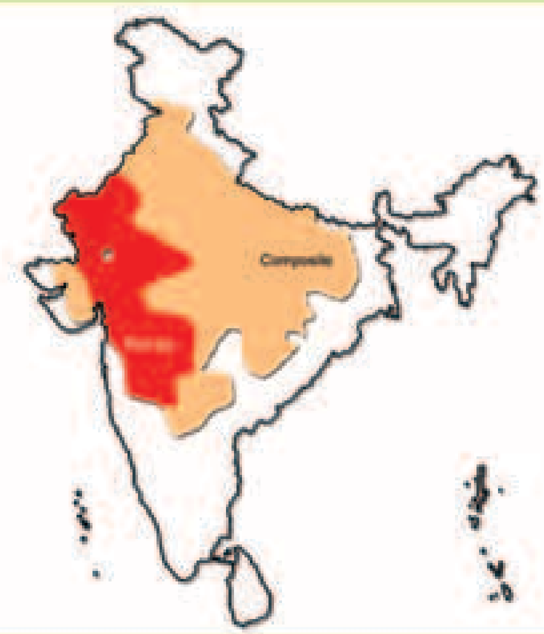
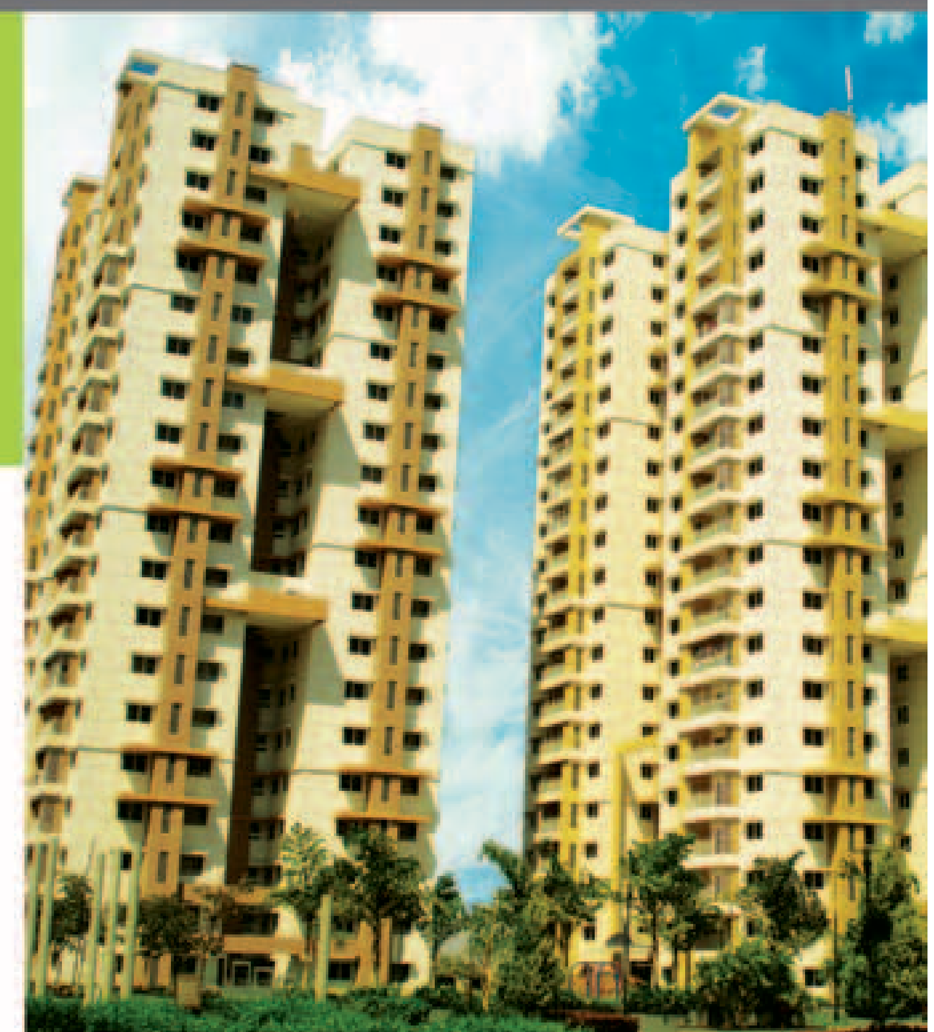
DESIGN GUIDELINES FOR ENERGY-EFFICIENT MULTI-STOREY RESIDENTIAL BUILDINGS

Composite and Hot-Dry Climates

BEEP
BUILDING ENERGY EFFICIENCY PROJECT





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DESIGN GUIDELINES FOR ENERGY-EFFICIENT MULTI-STOREY RESIDENTIAL BUILDINGS

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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. 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. This will lead to large additions to the residential building stock in existing cities as well as creation of several new cities. Due to the scarcity and high cost of land, as well as the desire to curtail suburban sprawl, a large part of this new urban residential construction is likely to be in the form of multi-storey residential buildings. The electricity consumption in residential buildings is expected to increase seven-fold during the period 2012 to 2032.

A large potential exists for reducing electricity consumption in multi-storey residential buildings. 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.

Given these future trends, there is an urgent need to design new 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).

I am glad to see that the first set of guidelines applicable to the composite and hot-dry climatic regions of India have been introduced. The Bureau of Energy Efficiency has plans to bring out similar guidelines for other climatic regions of the country in the future.

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. This will not only help the country in saving energy, but also provide more comfortable housing.

Piyush Goyal
Minister of State (I/C) for Power, Coal, and New & Renewable Energy
Government of India

Integration of energy-efficiency measures in buildings offers profound benefits of energy savings and carbon dioxide mitigation. Switzerland has a long experience in this area. The process started in late seventies with the adoption of a first standard for building insulation. With continuous efforts, the energy efficiency in new buildings has improved dramatically over time. The building energy norms released in 2008 were 60% lower compared to the building energy norms of 1992. The expertise developed in Switzerland over the past 30 years has also been internationally acknowledged.

The rapidly expanding building sector in India offers a large potential for energy-efficiency improvements in terms of design, building material, and the appliances used in buildings. This subject is accorded high importance by the Government of India. The 12th Five-Year Plan has identified 'Faster Adoption of Green Building Codes' as one of the main strategies for low carbon and inclusive growth. Similar ambitions are outlined in India's National Missions on Sustainable Habitat and Enhanced Energy Efficiency. The Energy Conservation Building Code and the Standards and Labelling programme are essential instruments for meeting these ambitions.

Realising the potential for experience-sharing and know-how transfer on these matters, a joint initiative was launched in November 2011 by the Government of India and the Government of Switzerland. The Indo-Swiss Building Energy Efficiency Project (BEEP) is a bilateral cooperation project between India's Ministry of Power (MoP) and Switzerland's Federal Department of Foreign Affairs (FDFA). The Bureau of Energy Efficiency (BEE) is the implementing agency on behalf of the MoP while the Swiss Agency for Development and Cooperation (SDC) is the agency in charge on behalf of the FDFA.

I feel proud in saying that BEEP is an excellent example that leads to strengthening the bilateral cooperation between the governments of our two nations. It is a project that brings some of the best available expertise for improving energy efficiency in buildings from Switzerland to its counterparts in India. I am convinced that this transfer of know-how will go a long way in supporting India's striving for more energy security and energy efficiency.

The guidelines for designing energy-efficient multi-storey residential buildings are a key outcome of this cooperation. I congratulate the entire team of BEEP for this far-reaching product, which has come at the right time. India is poised to achieve fast economic growth through which the building sector is also seen to continue growing at a fast pace. I am sure these guidelines will be a source of knowledge and guidance for the builders, architects, engineers, institutions and all stakeholders of the building sector of India.

Linus von Castelmur
Ambassador of Switzerland to India and Bhutan

MESSAGE

PREFACE

The Indo-Swiss Building Energy Efficiency Project (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. The overall objective of the project is to reduce energy consumption in new commercial buildings and to disseminate best practices for the construction of low-energy residential and public buildings. Development of guidelines for energy-efficient design of new multi-storey residential buildings is an important component of BEEP. It is projected that the residential sector of India will grow many folds in the next two decades hence the share of energy consumption of this sector in the total energy consumption of the country will dramatically increase.

The objective of the design guidelines is to provide comprehensive information on how to design energy-efficient multi-storey residential buildings. The guidelines take into account different climatic conditions prevailing in India, and the first set of guidelines is for the composite and hot-dry climatic regions of India. The methodology followed for the development of the guidelines consisted of (a) background research and collection of design and energy consumption data for sample residential buildings; (b) measurement of electricity consumption, temperature, and humidity in sample flats to collect data for the development and validation of energy simulation models; (c) evaluation and analysis of different energy-efficiency design strategies using energy simulation models; (d) formulation of guidelines based on the results of the simulation studies; and (e) consultation with experienced architects and design professionals to get their feedback in fine-tuning the draft guidelines.

There are 15 main recommendations presented in the guidelines. The recommendations cover building massing and spatial configuration to reduce solar radiation exposure on the building surface through proper orientation and mutual shading; strategies for reducing cooling energy and improving thermal comfort through proper window design, insulation of walls and roof, external movable window shutters, wall finishes, and natural ventilation. The recommendations also include methods to reduce electricity consumption in space cooling, appliances, and in common services such as lighting, lifts, and water pumping.

Recommendations on renewable energy integration include solar water heating and solar photovoltaic.

The project team is now developing similar guidelines for warm-humid climatic zone, which is expected to be finalised early next year. We look forward to receiving comments and suggestions for further improvements in these guidelines.

Daniel Ziegerer
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ACKNOWLEDGEMENTS

The publication, 'Design Guidelines for Energy-Efficient Multi-storey Residential Buildings', has been developed under the Indo-Swiss Building Energy Efficiency Project (BEEP). This publication is a distillation of the learnings from the extensive 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 especially acknowledge the contribution of the teams led by Mr Pierre Jaboyedoff from the Swiss side and Dr Sameer Maithel from the Indian side.

The overall guidance provided by the members of the Joint Apex Committee (JAC) and the Joint Implementing Group (JIG) of the Project is noteworthy. I am grateful to the Co-Chairs of the JAC – Mr Satish Kumar, Joint Secretary, Ministry of Power and Mr Daniel Ziegerer, Director of Cooperation and Counsellor – for their leadership. I also gratefully note the inputs provided in implementation of the project work plan by Mr P T Bhutia, Director, Ministry of Power, and Dr Veena Joshi, Senior Advisor (Energy), Embassy of Switzerland, as Co-Chairs of the JIG. 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, Energy Economist, 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.

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

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Note: See Annexure 1 for the complete list of stakeholders who participated in various consultations.

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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 India would potentially have to build 700–900 million m^2 of residential and commercial spaces in the urban areas every year for the next 20 years.[3] Due to the scarcity and high cost of land, as well as the desire to curtail suburban sprawl, there is movement towards multi-storey buildings.

In 2012, residential buildings accounted for 20.4% of India's total electricity consumption, and the electricity consumption in residential buildings is about 2.3 times more than that for commercial buildings. Projections done by the Planning Commission show that the electricity consumption in residential buildings is expected to increase seven-fold during the period 2012 to 2032, and the residential sector will become the largest consumer of electricity in the country with a 36.5% share of the total electricity consumed in 2032.[4]

To understand 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 732 flats[5] located in multi-storey building complexes in the National Capital Region. The average energy performance index (EPI), based on electricity bill data for the surveyed flats for the year 2009, was found to be 48 kWh/m^2.year[6] and about 16% were found to have a very high EPI of >70 kWh/m^2.year. The study also showed that space cooling and fans is the largest component (33%–65%) of the electricity consumption 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 electricity demand in New Delhi has doubled since 2001 and is estimated to again

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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] *Mckinsey Global Institute. April 2010. India's Urban Awakening: Building Inclusive Cities, Sustaining Economic Growth.*

[4] *Planning Commission. India Energy Security Scenario, 2047. New Delhi: Planning Commission, Government of India.*

[5] *2–3 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.).*

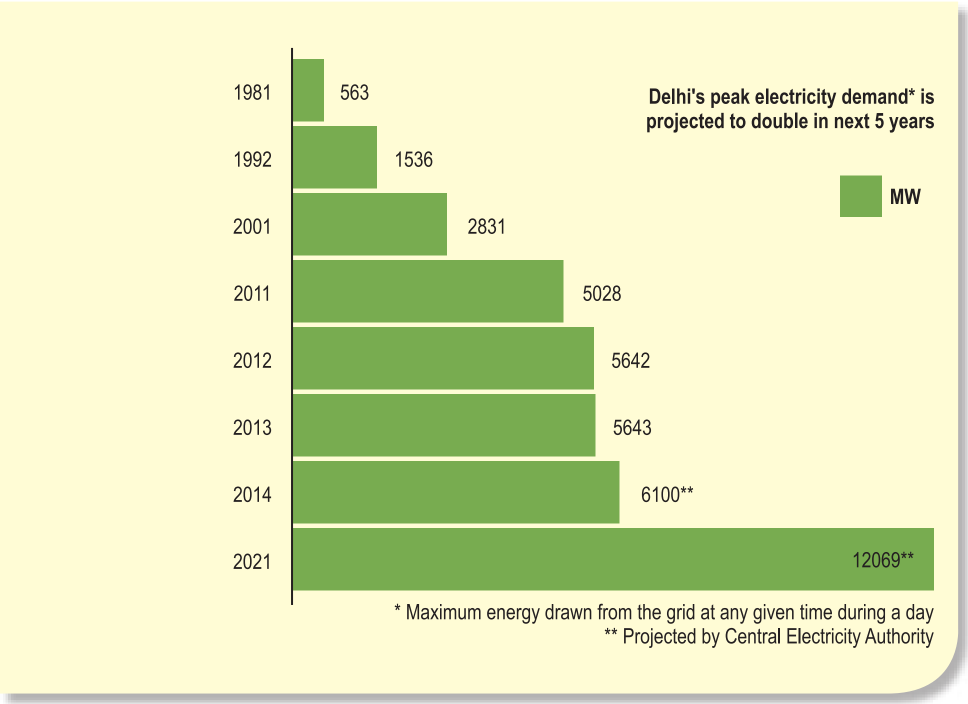

Figure 1.1
Increase in peak electricity demand in New Delhi (1981–2021)

double from current levels by 2021 (Figure 1.1).[7] The recent trends show that the use of air-conditioners in homes is now starting in early April and continues until September. A recent study estimates that the annual sales of room air-conditioners in India has gone up from 1.7 million/year in 2009 to 6.1 million/year, or has trebled over the past five years.[8]

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 the standard.[9]

Electricity savings can be achieved primarily through (a) incorporating energy-efficiency features into the building architecture and design, and (b) the 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 13 household appliances and has been made mandatory for four appliances, namely, frost-free refrigerators, room air-conditioners, tube lights, and transformers. However, currently, there are no design guidelines that cover comprehensively the design of energy-efficient multi-storey residential buildings.

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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[7] *<http://www.downtoearth.org.in/content/city-trapped-solar-oven>*
[8] *Lawrence Berkeley National Laboratory. 2013. Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners. Berkeley, CA: Lawrence Berkeley National Laboratory.*
[9] *<http://www.ee-homes.com/>*

different climatic conditions prevailing in the country, and the first guideline document is applicable to the composite and hot-dry climatic regions of India (Figure 1.2).

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 the consumer

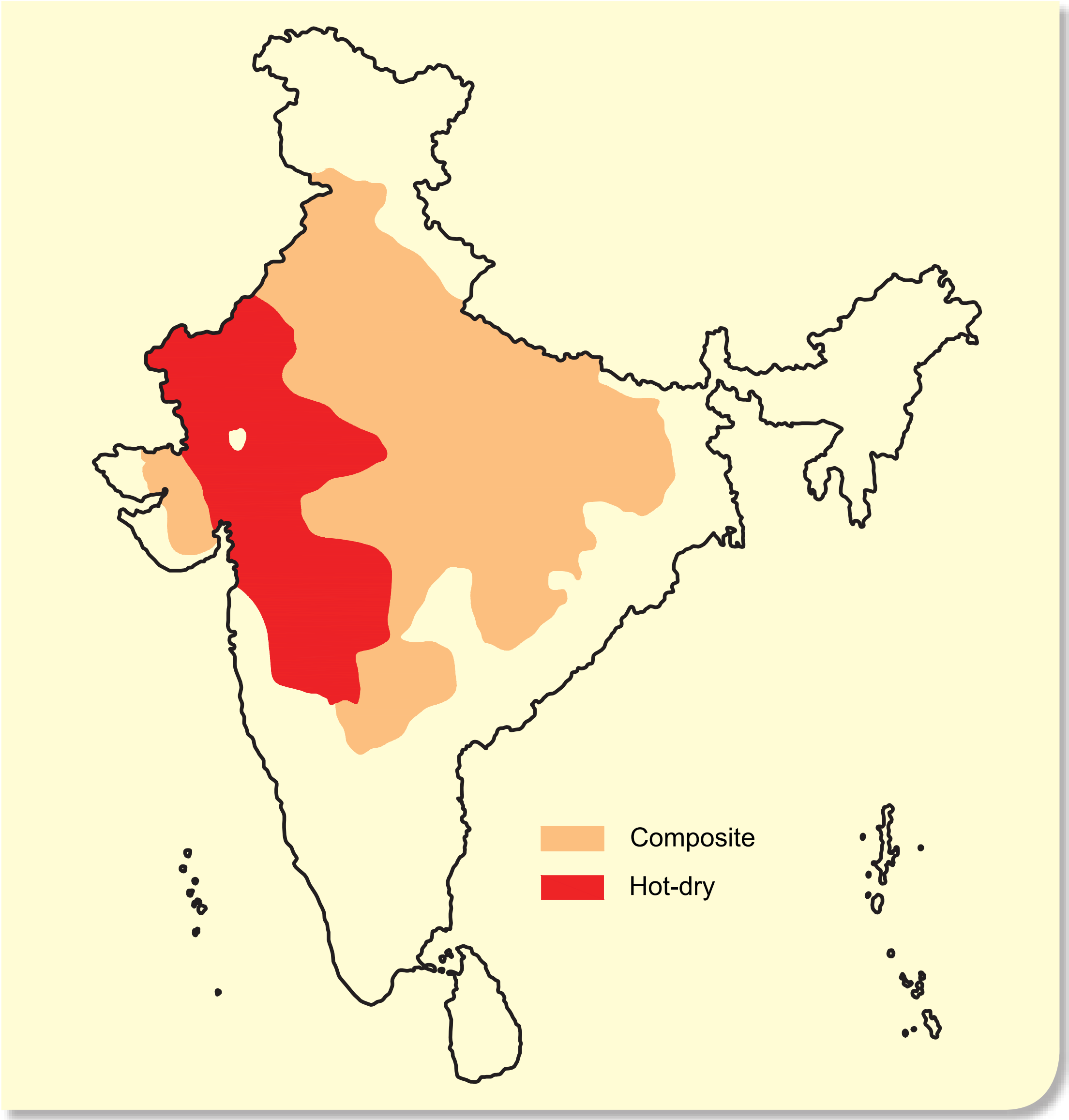


***Figure 1.2** Composite and hot-dry climate zones of India*[10]

[10] *Bureau of Indian Standard (BIS. 2005): National Building Code of India 2005. New Delhi: BIS*

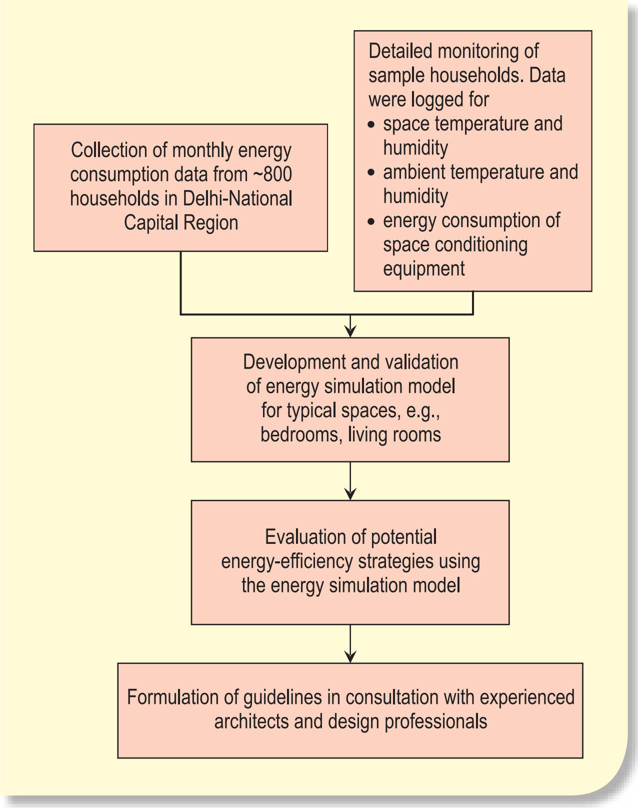


Figure 1.3 *Methodology followed for developing design guidelines*

would be a necessary compliment to these guidelines.

1.3 Methodology

The methodology followed for the development of the guidelines is shown in Figure 1.3. 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 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 the energy simulation models were used to quantify energy savings from the recommended energy-efficiency strategies and are presented in six sections dealing with: building massing and spatial configuration, building envelope, building space cooling, appliances, common services, and integration of renewable energy.

1.4 Organisation of this report

The remainder of this document 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, as well as mutual shading by buildings 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, like window–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 the application of various space-conditioning systems, like evaporative cooling, and 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, provides an overview of the 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.

Several annexures provide supporting information and analysis results.

CHAPTER 2

SURVEY AND MONITORING OF ELECTRICITY CONSUMPTION

2.1 Introduction

Inside residential building flats, electricity is primarily used for operating:

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

Electricity is also required outside a flat for the operation of common services such as water pumping, lifts, and outdoor lighting.

When the development of these design guidelines began, the project team realised that data were unavailable for computing the energy performance index (EPI) of different types of multi-storey residential buildings at the flat or building level. Similarly, there was a shortage of literature that could provide insights into the end-use electricity distribution in urban households and influence of building design on electricity consumption. In 2009, during the preparation phase that preceded BEEP, a survey was conducted to collect monthly electricity consumption data from a sample of residential units located in multi-storey residential complexes in the National Capital Region (NCR). Subsequent to the survey, detailed monitoring of appliance-level electricity consumption, temperature, and humidity in the indoor spaces of two sample flats were carried out in Delhi over a period of about one year. Time-series data on electricity consumption from a residential complex were collected for 2006 to 2013.

The results of that survey and the monitoring exercise are presented in this chapter. As these results are based on a small sample size, they should not be taken as 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 current electricity usage, particularly for space conditioning. This understanding aided the development of these design guidelines.

2.2 Methodology of the survey and monitoring

2.2.1 Survey

Electricity consumption data (in the form of monthly electricity bills) for one-year duration (2009) were collected from 732 residential units from four residential complexes in Delhi–NCR. The selected residential complexes were multi-storey apartment buildings of 3 to 15 storeys, with built-up area of individual flats ranging from 80 m^2 to 130 m^2. The residential units had two or three bedrooms, a living room, and a kitchen. Apart from the electricity consumption data, architectural plans and construction details were collected for the buildings. For sample flats, data on appliance ownership and operation schedules were also collected.

A mathematical model was used to filter monthly electricity consumption data. After data filtering, 89% of the data was selected for further analysis. The data were statistically analysed for EPI distribution, monthly electricity consumption profiles, and share of electricity for space conditioning. Time-series data (for 8 years) from one of the residential complexes in Delhi were used to understand the trend in electricity used 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 Delhi. The monitoring included discrete logging of space and ambient hygro-thermal conditions and electricity consumption monitoring of space-conditioning equipment. The instruments used for monitoring are shown in Figure 2.1. Electricity consumption data for sample flats and monitored temperature, humidity, and data for space-conditioning equipment were used to define inputs and to validate outputs of the energy simulation models (developed in TRNSYS[1]) for bedrooms, living rooms, and other spaces.

Figure 2.1a *Temperature humidity logger assembly for monitoring ambient conditions*

Figure 2.1b *Globe temperature logger assembly for measuring mean radiant temperature in a room*

Figure 2.1c *Energy loggers for monitoring electricity consumption of space-conditioning equipment*

2.3 Survey results

2.3.1 Energy performance index

The mean EPI,[2] based on data collected from 732 residential units for the year 2009 in the composite climate, is calculated as 48 kWh/m^2.year (Figure 2.2). The EPI does not include the electricity consumption for common services. The EPI range distribution

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

[2] *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 built-up area includes the covered area of the flat and does not include balcony areas, 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.*

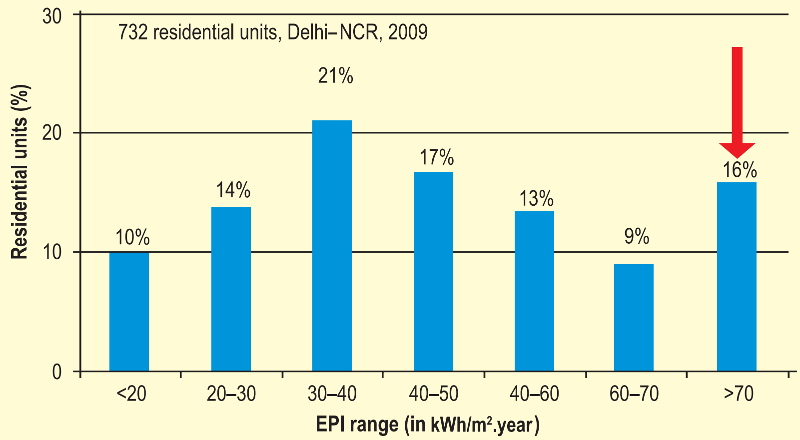


Figure 2.2 *EPI distribution of residential units in the composite climatic region*

(Figure 2.3) shows that almost 16% of the residential units have an EPI value greater than 70 kWh/m^2.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. Figure 2.4 shows that the average EPI of residential units increases when the number of air-conditioners owned increases.

A recent study conducted by CEPT University, Ahmedabad,[3] reported an average EPI of 57 kWh/m^2.year based on the data collected from 201 sample residential units in Delhi for the year 2013.

2.3.2 Seasonal variation and electricity used for space conditioning

For the purpose of analysis, three flats having different EPIs were selected. All these flats were located in a single residential complex in Delhi.

- Flat A has an EPI of 35 kWh/m^2.year (below average)
- Flat B has an EPI of 65 kWh/m^2.year (above average)
- Flat C has an EPI of 117 kWh/m^2.year (high)

An analysis of these flats are provided below (Figures 2.5 and 2.6).

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

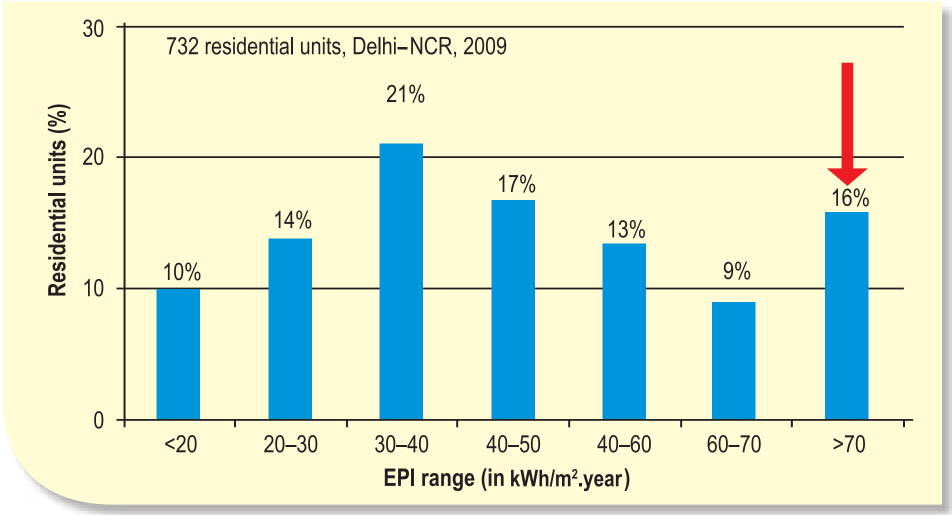


Figure 2.3 EPI range distribution for surveyed residential units

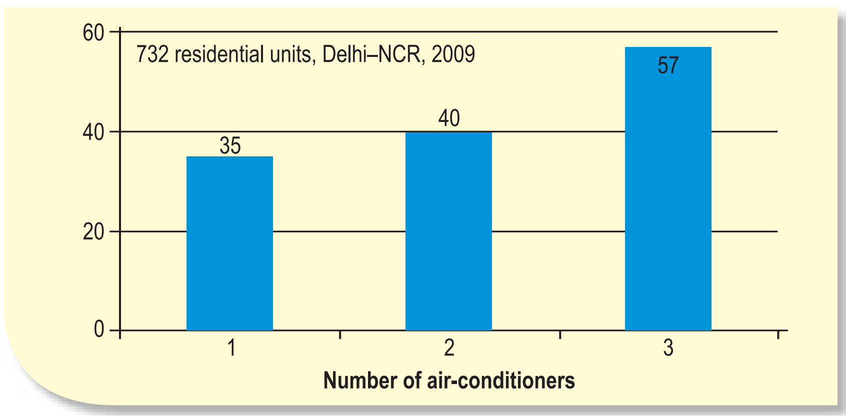


Figure 2.4 Distribution of average EPI with respect to air-conditioner ownership

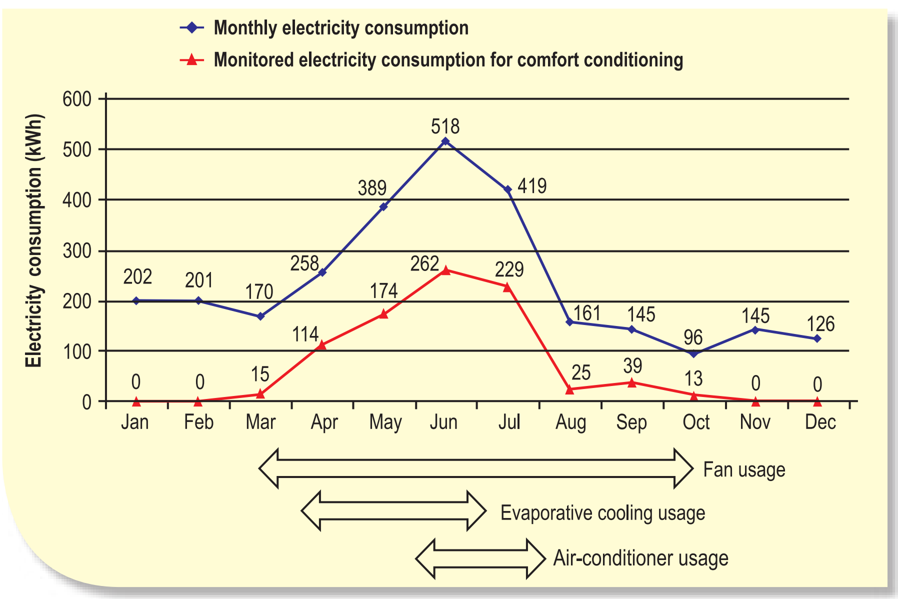


Figure 2.5 Monthly electricity consumption of Flat A (below average EPI)

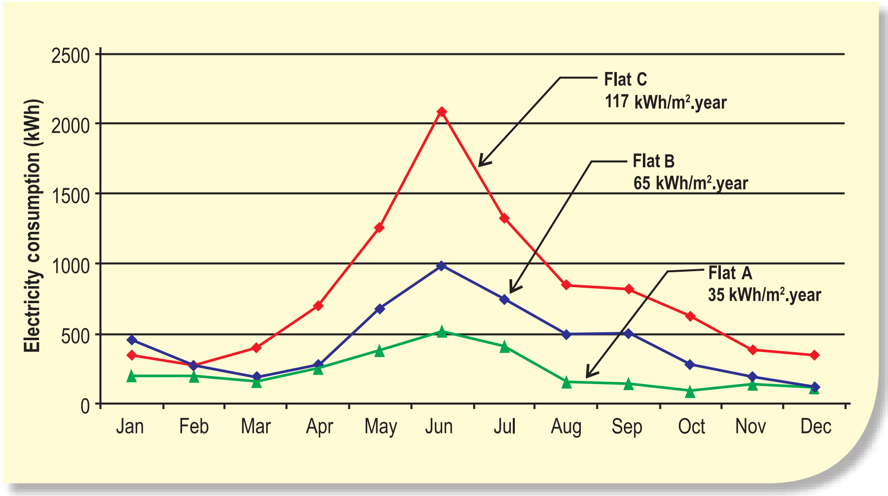


Figure 2.6 *Monthly electricity consumption profiles of three residential units*

Figure 2.5 plots the total monthly electricity consumption and the monthly electricity consumption for space conditioning (space-cooling equipment and fans) for Flat A. It is observed that the highest electricity consumption is for the month of June, and the minimum electricity consumption is for the months of February, March, and October when the requirement for space conditioning is lowest. Further analysis of the monitored data for space conditioning during summer months shows that the occupants of Flat A used ceiling fans (5 fans) from mid-March to mid-October; evaporative desert coolers (2 coolers) from April to June; and room air-conditioners (2 air-conditioners) from June to July. The EPI of this flat was 35 kWh/m^2.year. Monitored data show that almost 33% of the annual electricity consumption is attributed to the operation of equipment for space cooling and fans. The balance 67% of the electricity was used for refrigerator, lighting, washing machine, electric geysers, kitchen appliances, television, computers, etc.

Figure 2.6 shows monthly electricity consumption for Flat B and Flat C. Flat B has two air-conditioners for space cooling and has an EPI of 65 kWh/m^2.year; while Flat C has four air-conditioners and has an EPI of 117 kWh/m^2.year. The contribution of electricity consumption for space cooling and fans is calculated as 38% for Flat B and 65% for Flat C of the total annual electricity consumption.

2.3.3 Time-series data: trend for electricity consumption for space-cooling equipment

Time-series data on electricity consumption from 2006 to 2013 for a 90 residential unit multi-storey complex were analysed. The average electricity consumption data for the occupied residential units in a typical summer month (May) is plotted for 2006 to 2013 (Figure 2.7). The plot provides an important insight into the impact of electricity consumption due to the

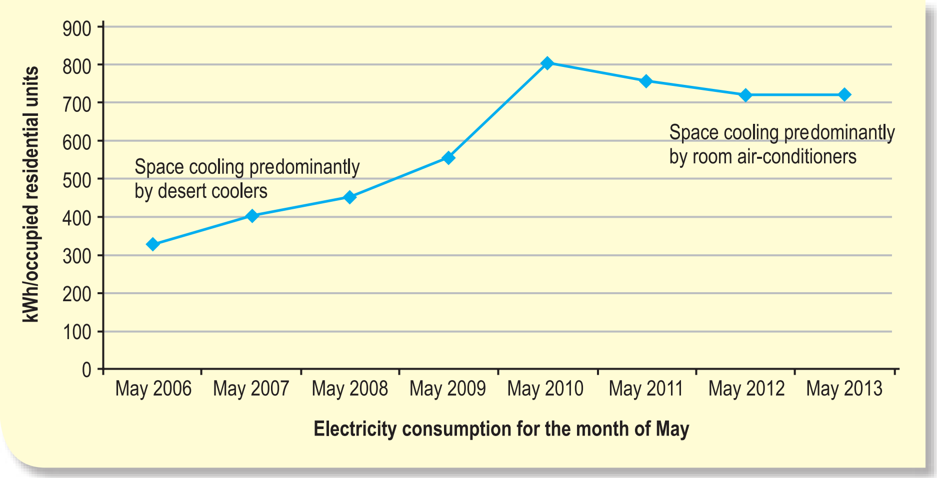


Figure 2.7 *Time-series data of electricity consumption for May for a residential complex in Delhi*

increased use of room air-conditioners. In 2006, the residential units were predominantly using desert coolers and fans for space conditioning. Gradually, a majority of desert coolers were replaced by room air-conditioners. By 2010, room air-conditioners had become the dominant mode of space cooling. It can be observed that the electricity consumption (kWh/occupied residential unit) more than doubled, from around 300 kWh per occupied residential unit in 2006 (with predominantly desert coolers) to 700–800 kWh per occupied residential unit (with predominantly room air-conditioners).

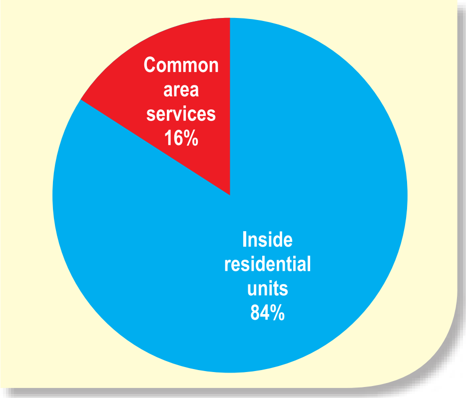


Figure 2.8 *Breakdown of total electricity consumption of a small multi-storey residential complex in Delhi*

2.3.4 Electricity use for common services

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, and water pumping) was around 16% of the total annual electricity consumption of the complex (Figure 2.8). Further breakdown of the common area electricity consumption (Figure 2.9) shows that electricity consumption in lifts was the largest (62%), followed by lighting of common areas (21%) and pumping water to overhead tanks (17%).

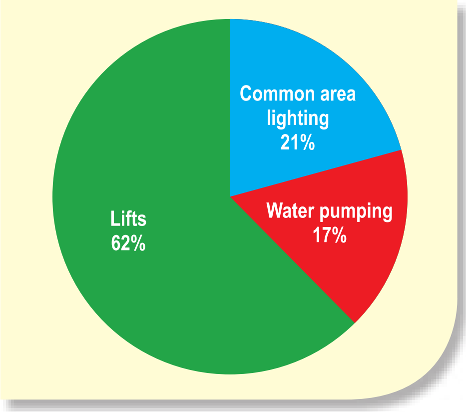


Figure 2.9 *Share of electricity consumption for common services (lighting, pumping, and lifts) in a small multi-storey residential complex in Delhi*

CONCLUSIONS

1. The average EPI for sample 2–3 bedroom residential flats in composite climate (732 flats) for the year 2009 is calculated as 48 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 the contribution of electricity consumption for space cooling and fans increases with the increase in EPI (and increased usage of air-conditioners), and vary from 33% to 65% of the total electricity consumption.
3. Analysis of time-series data (2006–2013) from one of the residential complexes in Delhi indicates that electricity consumption for space-cooling more than doubles when shifting from a situation where space-cooling is predominantly met by desert coolers to a situation where space-cooling is predominantly met by room air-conditioners. 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 resorted to. Savings can also be effected 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, size, and orientation of the building blocks; 'spatial configuration' characterizes how the building blocks are arranged in the given plot of land.

Unlike office buildings, for which cooling loads are often dominated by internal heat gains (computers, lighting, persons, etc.), most of the cooling load in residential buildings originates from solar heat gains through the building envelope. The thermal quality of the building envelope of residential buildings is usually poor (uninsulated walls, single-glazed windows, absence of good external shading for windows), which allows large solar heat gains through windows and walls.

Reducing the solar exposure on vertical surfaces of a multi-storey residential building is the first step towards reducing solar heat gains and internal cooling loads. It is a good practice to conduct a solar exposure analysis before deciding on building massing and spatial configuration.

The layout of a building depends on many factors such as shape and size of site, building bye-laws, and town planning regulations. It is seen that some town planning regulations, such as requirements for floor space index (FSI), set-backs, and distance between buildings come in the way of optimising mutual shading and orientation. It would be worthwhile to review these from the point of view of energy efficiency.

RECOMMENDATIONS FOR BUILDING MASSING AND SPATIAL CONFIGURATION

Recommendation 1: Orient the buildings to minimise solar exposure on vertical surfaces

Orient the buildings to minimise solar exposure on vertical surfaces (e.g., the larger façade faces north and south).

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%–40%. If there is the flexibility of orienting the building correctly (i.e., larger façade in a north and south direction), then the preference of typologies in terms of reduced solar radiation exposure is

- Preference 1: Linear double-loaded corridor typology
- Preference 2: Linear typology
- Preference 3: Tower typology

Recommendation 3: Try to arrange building blocks so as to benefit from mutual shading to minimise solar exposure on vertical surfaces during summer months

Mutual shading is a function of (a) latitude, (b) location with respect to the other buildings, (c) height of the context buildings, and (d) distance between the buildings.

- Benefits of mutual shading in reducing the solar exposure are possible if the buildings are closely placed to the east and west of the reference building.
- Shading from the buildings located south of the reference building is minimal during peak summer (June), though some amount of shading is possible during the months of April and September.
- There is negligible shading from the buildings located north of a reference building.

Note: It is to be noted that recommendations 2 and 3 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 east and west 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.

As shown in Chapter 2, in the composite and hot-dry climate, space cooling and fans account for a large share of the total electricity consumption. Thus one of the primary concerns during building design should be to include strategies that can reduce heat gains inside the living spaces. Solar heat gain through the building envelope (walls, roof, windows) is one of the important sources of heat gains. This chapter deals with appropriate selection of building forms (exposed surface area/built-up area), building orientation (façades orientation), and spatial configuration (building location and spacing) to reduce solar exposure and hence solar heat gains.

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 b).

3.2.2 Linear 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–c).

3.2.3 Linear double-loaded typology

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

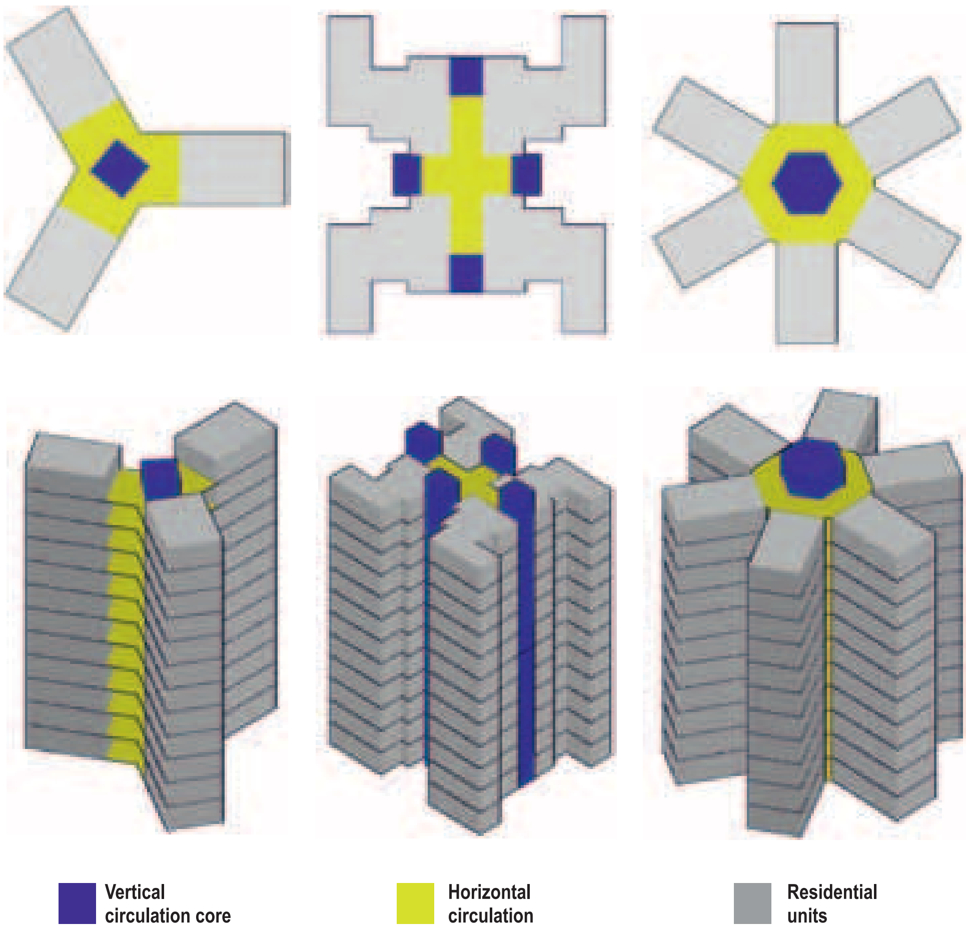


Figure 3.1a Possible configurations for tower typology

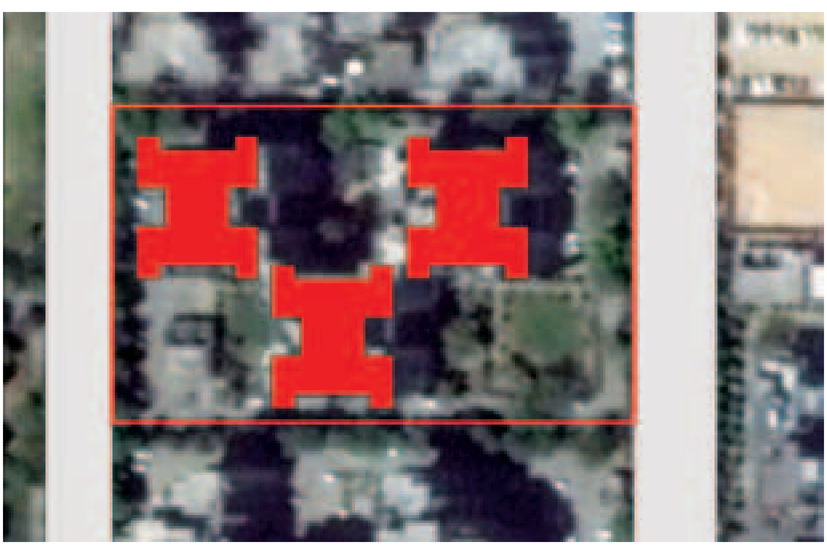
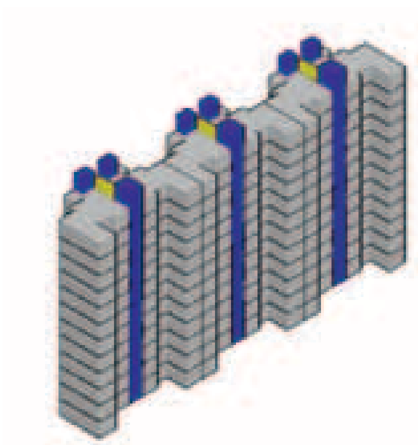


Figure 3.1b
Example layout of a tower typology

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*

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

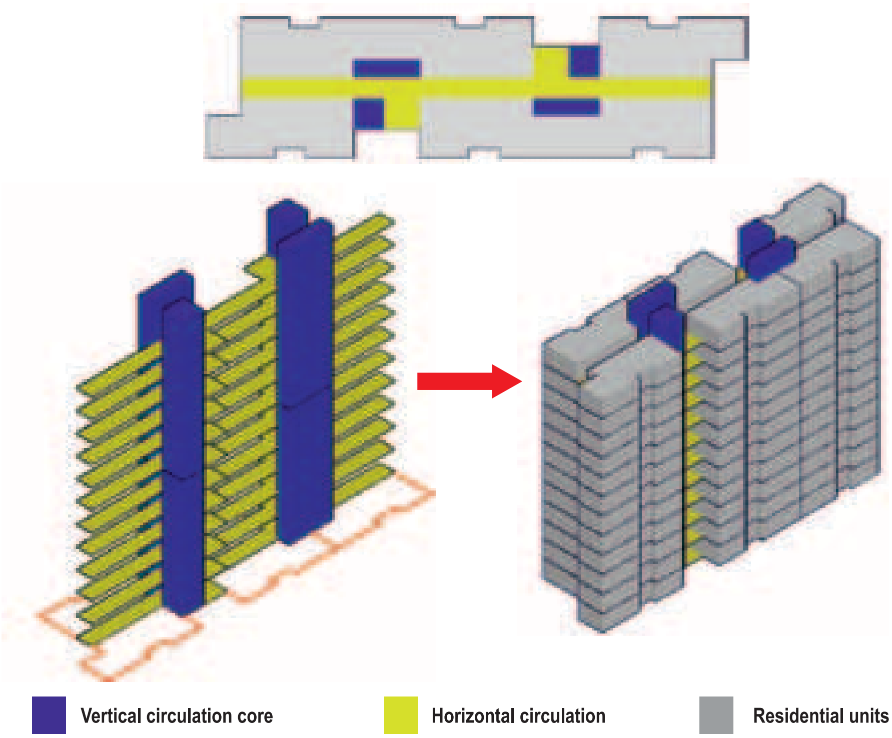


Figure 3.3b
Schematic of typical linear double-loaded corridor typology

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 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 New Delhi (Ground + 11 storey residential blocks).

Figure 3.4 shows the hourly dry-bulb temperature distribution for one full year for New Delhi. The analysis was carried out from 1 April to 30 June, which was considered as overheating period (the area highlighted by the black box in Figure 3.4).

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

[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.*

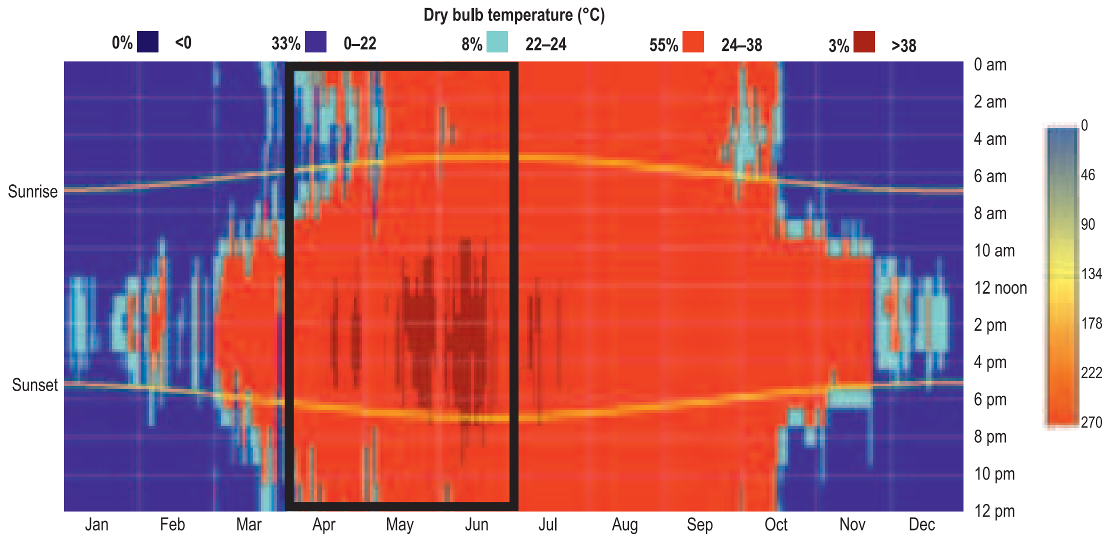


Figure 3.4 *Graph showing overheating period for New Delhi*[2]

3.3.2 Results

The results of the analysis 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.

The analysis shows the following results.

- There is a large difference in solar radiation exposure during peak summer months (April–June) depending on the building typology and orientation. The solar radiation exposure on vertical surfaces increases by 71% from a minimum (128 kWh/m^2 of flat built-up area) for a north–south oriented linear double-loaded corridor to a maximum (219 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 (east–west orientation), the solar radiation exposure on vertical surfaces increases by 46% compared to the tower typology.
- For the tower typology, there is almost no effect of orientation on the solar radiation exposure on the vertical surfaces.

3.4 Mutual shading analysis

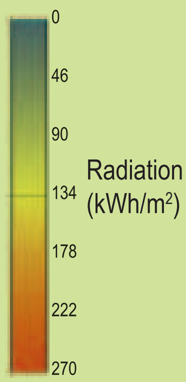
3.4.1 Methodology

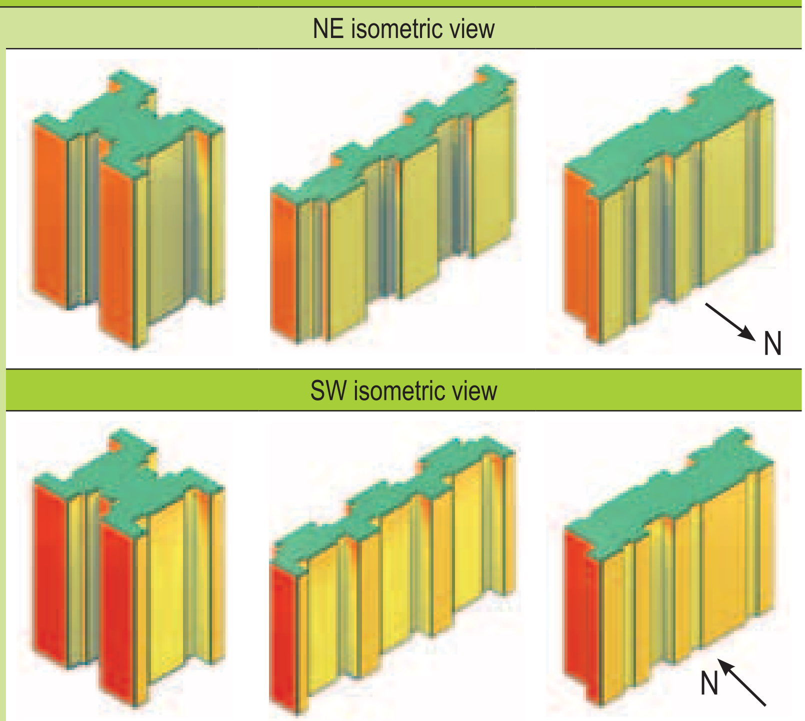
'Mutual shading' is the shading provided by the adjacent building blocks. This is a function of the following parameters: (a) latitude, (b) location with respect to the other building,

[2] *Climate Consultant Tool 5.4, <http://www.energy-design-tools.aud.ucla.edu/climate-consultant/>*

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
Total exposed vertical surface area in m^2/flat built-up area in m^2	1.3	1.3	1.0
Cumulative radiation exposure in kWh/m^2 of flat built-up area (from 1 April–30 June)	178	147	128
Solar radiation map			



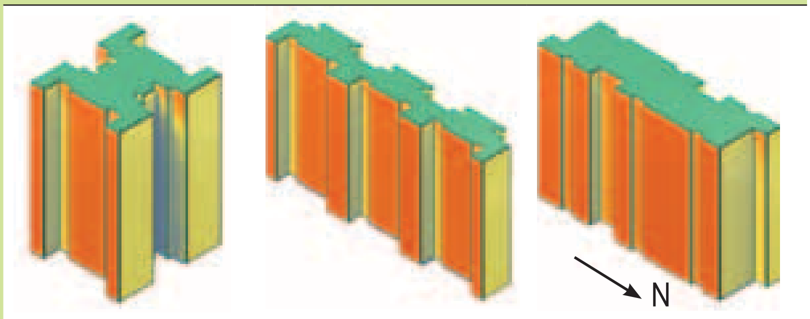
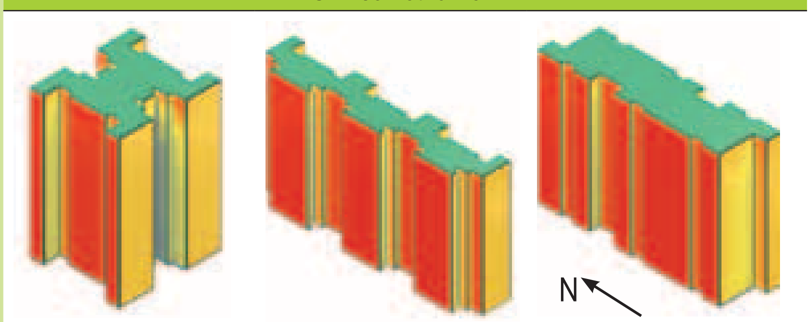


* Roof solar radiation is not included for the analysis

(c) height of the context buildings, and (d) distance between the buildings. These parameters vary between the projects, so the following section uses a case study to discuss the analyses and to inform the understanding of the impact of mutual shading.

For the purpose of analysis (Figure 3.5), Three blocks of 12-storey (36 m height) tower typology were placed 6 m apart from each other. The figure shows the arrangement of the three blocks in plan view, along with 2 m offset rectangles (in green) around the reference building. The red line indicates the recommended distance as per the National Building

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
Total exposed vertical surface area in m^2/flat built-up area in m^2	1.3	1.3	1.0
Cumulative radiation exposure in kWh/m^2 of flat built-up area (from 1 April–30 June)	182	219	187
Solar radiation map	NE isometric view		
			
Radiation (kWh/m^2)	SW isometric view		
			

* Roof solar radiation is not included for the analysis

Code[3] on the front, side, and rear setbacks, if the residential units derive light and ventilation from the respective façades.

For the purpose of shadow range analysis, the Autodesk® Ecotect™ [4] Analysis 2010 tool was used.

[3] *National Building Code 2005, Part 3: Development Control Rules and General Building Requirements, Sections 8.2.3.1 and 8.2.3.2 discuss the open space requirements (front, rear and sides) for buildings with a height above 10 m.*

[4] *Autodesk® Ecotect® Analysis is a sustainable design software used for shadows and reflections analysis, daylight analysis and solar radiation analysis.*

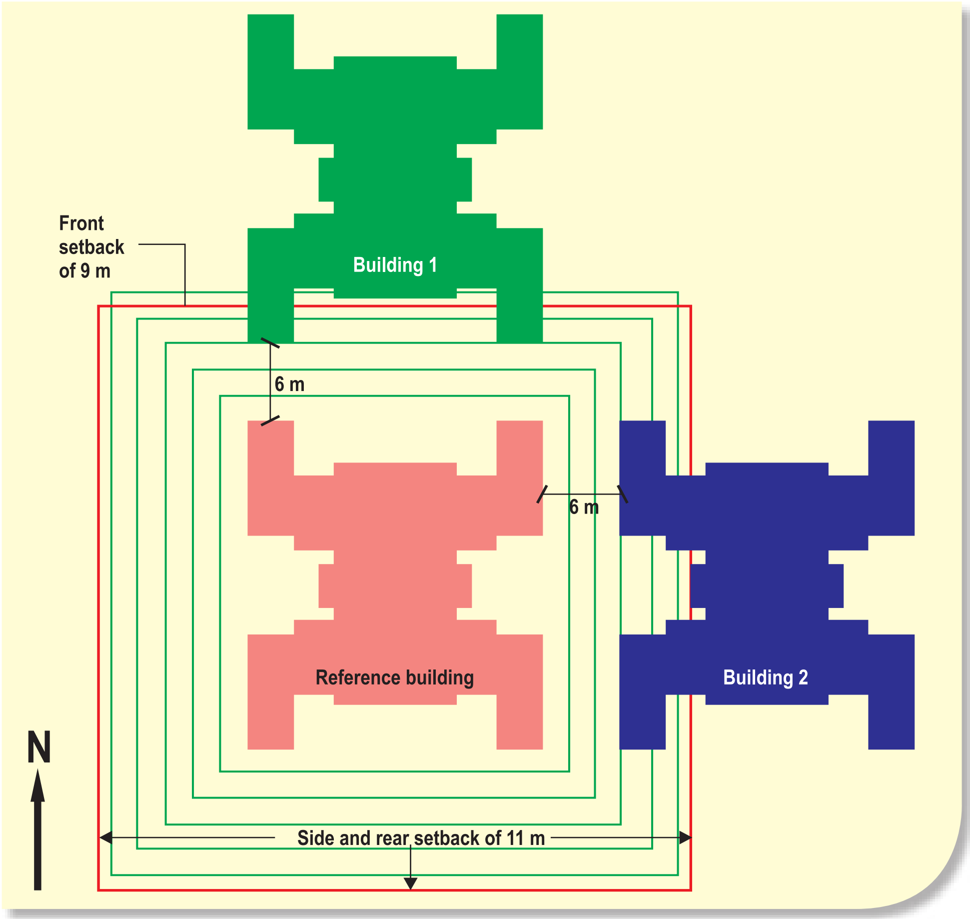


Figure 3.5 Building layout used for the analysis of mutual shading

3.4.2 Results

Figures 3.6a and 3.7a show shadows of the reference building at 1 hour time step (between 09:00 and 16:00 hours) for 1 April and 30 June, respectively. This is useful to understand the horizontal spread of the shadows. Figures 3.6b and 3.7b show qualitatively the mutual shading for 1 April and 30 June, respectively, by adjacent buildings when Building 1 and Building 2 are placed to the north and east of the reference building, respectively.

To understand the impact of mutual shading quantitatively (in terms of kWh/m^2 of flat built-up area, radiation map analysis was performed for both unshaded tower typology and shaded tower typology (Figure 3.8). The result shows a reduction of 35% (from 178 to 116 kWh/m^2 of flat built-up area) in solar radiation exposure on the vertical surfaces for the shaded tower typology compared to the unshaded tower typology.

3.5 Remarks

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

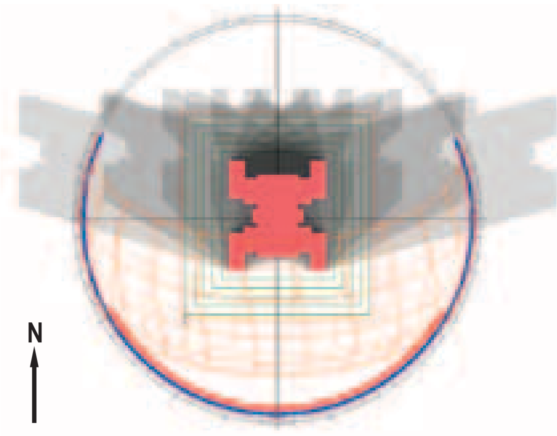


Figure 3.6a
Hourly shadow range for 1 April (09:00–16:00)

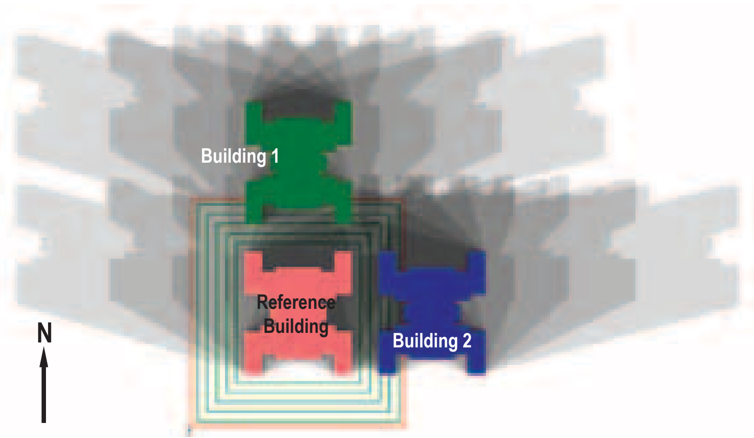


Figure 3.6b
Mutual shading by adjacent building blocks for 1 April (09:00–16:00)

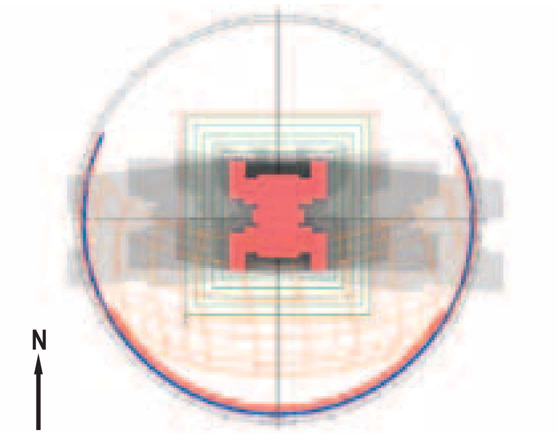


Figure 3.7a
Hourly shadow range for 30 June (09:00–16:00)

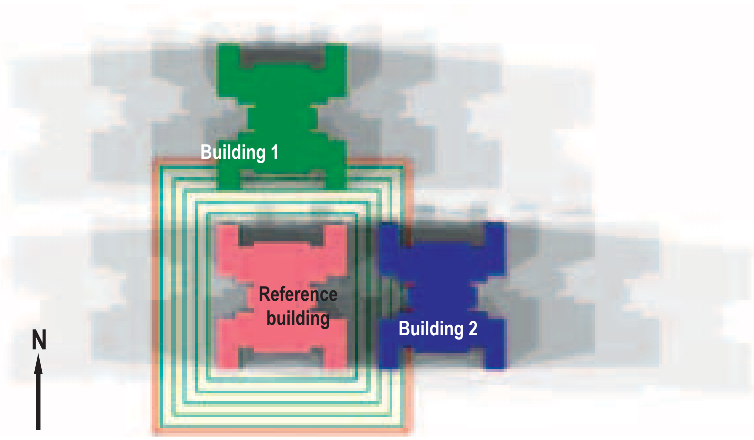


Figure 3.7b
Mutual shading by adjacent building blocks for 30 June (09:00–16:00)

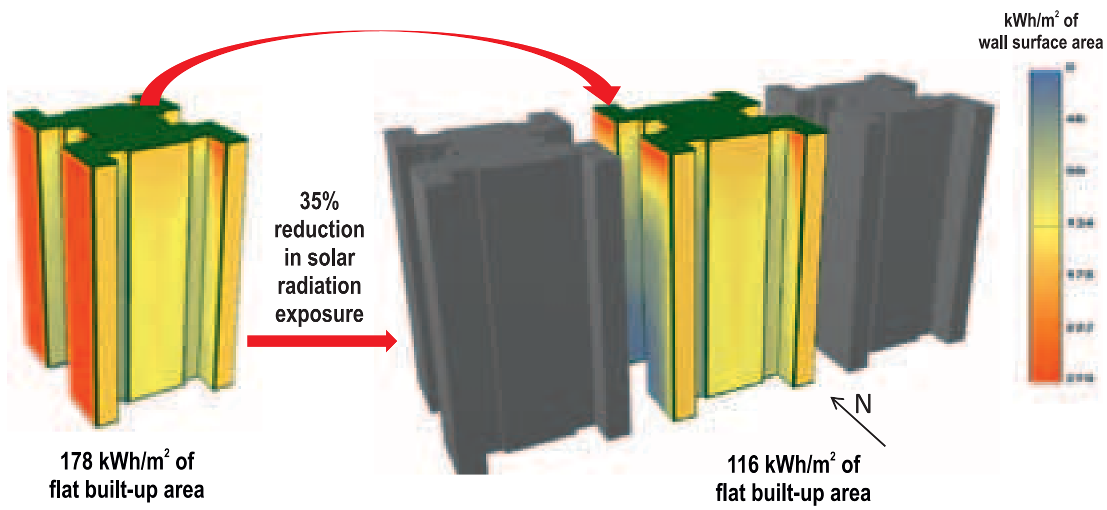


Figure 3.8 *Comparison of incident solar radiation for unshaded tower typology and shaded tower typology*

storey residential building design and construction practices. The present stock of residential building 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 decisions on building massing and spatial configuration for residential complexes are influenced by several parameters, including 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 before deciding on building massing and spatial configuration.

RECOMMENDATIONS

Recommendation 1: Orient the buildings to minimise solar exposure on vertical surfaces

Orient the buildings to minimise solar exposure on vertical surfaces (e.g., the larger façade faces north and south).

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%–40%. If there is the flexibility of orienting the building correctly (i.e., larger façade in a north and south direction), then the preference of typologies in terms of reduced solar radiation exposure is

- Preference 1: Linear double-loaded corridor typology
- Preference 2: Linear typology
- Preference 3: Tower typology

Recommendation 3: Try to arrange building blocks so as to benefit from mutual shading to minimise solar exposure on vertical surfaces during summer months

Mutual shading is a function of (a) latitude, (b) location with respect to the other buildings, (c) height of the context buildings, and (d) distance between the buildings.

- Benefits of mutual shading in reducing the solar exposure are possible if the buildings are closely placed to the east and west of the reference building.

contd...

contd...

- Shading from the buildings located south of the reference building is minimal during peak summer (June), though some amount of shading is possible during the months of April and September.
- There is negligible shading from the buildings located north of a reference building.

Note: It is to be noted that recommendations 2 and 3 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 east and west faces, then it becomes necessary to insulate them well.

CHAPTER 4

BUILDING ENVELOPE

AT A GLANCE

Most of the cooling load in the residential buildings originates from solar heat gains and heat transmissions through the envelope (through windows, walls, and roof). Thus, special attention should be paid to reduce solar heat gains and heat transmission through the building envelope.

The main building envelope features that influence the cooling thermal energy demand 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 wall
- Insulation properties of roof
- Colour and finish of exterior surfaces (walls and roofs)
- Natural ventilation
- Building air-tightness

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.

AT A GLANCE

RECOMMENDATIONS FOR BUILDING ENVELOPE

Recommendation 4: Take suitable passive design measures for walls and windows to reduce the cooling thermal energy demand and improve thermal comfort

- **Package of Measures I** that can bring about 15%–20% reduction in cooling thermal energy demand: Use of light colours on wall (absorptivity ≤0.4) + window shades with extended overhangs to intercept direct solar radiation on the window + insulated walls (U-value: 0.7 W/m^2.K) + optimised natural ventilation.
- **Package of Measures II** that can bring about 40%–45% reduction in cooling thermal energy demand: Package of Measures I + external movable shutters on windows.
- **Package of Measures III** that can bring about 50%–60% reduction in cooling thermal energy: 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.

Recommendation 5: Design for adequate daylighting

- Usually 10%–15% window-to-wall ratio (WWR) in bedrooms and 30% WWR in living room are needed to provide adequate daylighting. However, when building blocks in a residential complex are located near to each other, daylighting in bedrooms and living room located on lower floors is substantially reduced. The daylight on the lower floors can be improved by increasing the window area, using light colour with smooth finishes on the wall opposite to the window and using light colour interiors.

Recommendation 6: Design the roof to reduce the cooling thermal energy demand and improve thermal comfort

- Provide overdeck insulation and high reflective surface on roof to minimise heat gain through roof.

4.1 Introduction

The building envelope is the interface between the indoor spaces of the building and the outdoor environment. The opaque components of the envelope consist of walls, roofs, slab on grade (in contact with the ground), basement walls, and opaque doors; the fenestration component consists mainly of windows and ventilators. The building envelope acts as a thermal barrier and plays an important role in regulating interior temperatures and in influencing the amount of electricity required to maintain thermal comfort. In hot climates, a properly designed building envelope can help improve thermal comfort and reduce the energy required for cooling. During the monitoring of sample flats, it was observed that most of the electricity used for space cooling is consumed in bedrooms (occupied during the night) and living rooms (occupied during the day and evening). This chapter discusses the envelope design with special focus on bedrooms and living rooms.

Unlike office buildings, for which cooling loads are often dominated by the internal heat gains (computers, lighting, persons, etc.), most of the cooling load in residential buildings originate from the heat gains through the envelope (solar heat gain through windows, heat ingress across the walls, and uncontrolled air infiltration). Reducing cooling loads thus requires a reduction in the heat gains in the building from the outside.

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 intermediate floor with ceiling and floor modelled as adiabatic (i.e., no heat flux occurs across these components). During research, it was found that bedrooms having two exterior walls are the most common typology. Thus the base case was made with a bedroom having two external walls and 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.

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, such as cooling thermal energy demand (hourly, monthly, and yearly); air and mean radiant temperatures; specific surface temperatures; air change by infiltration; natural ventilation air change; air mass flow rate; air change cooling power.

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

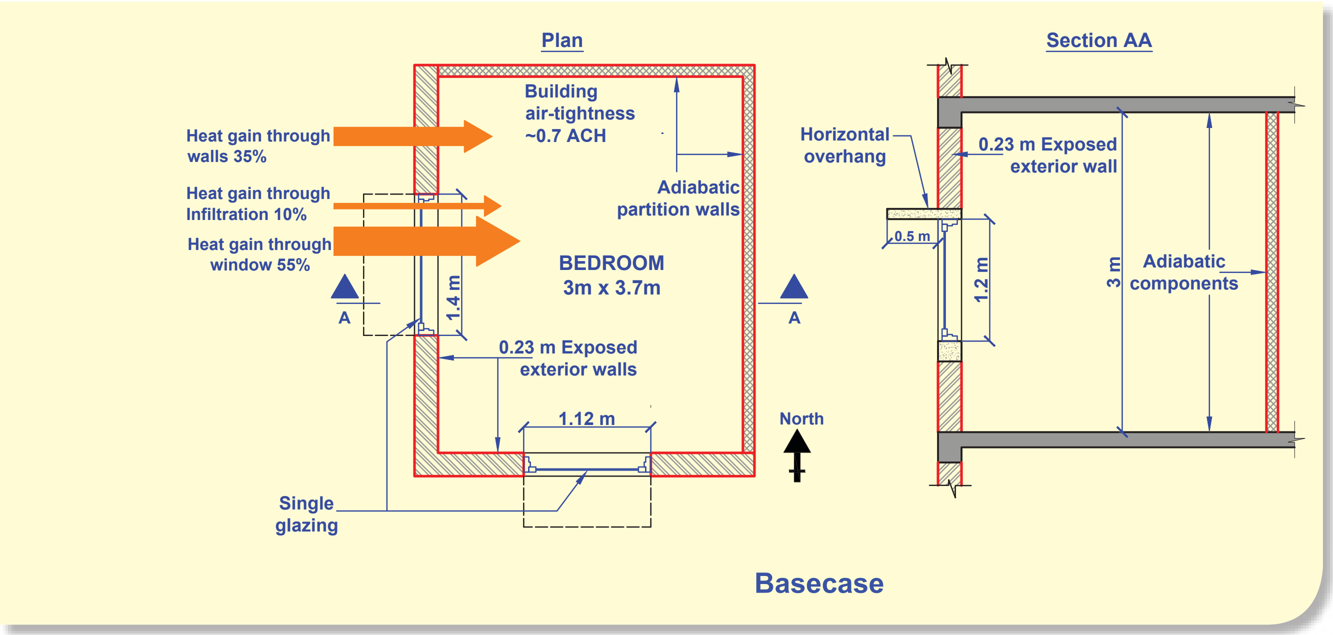


Figure 4.1 Schematic of base case model for bedroom developed in TRNSYS

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	26 °C
Location	Delhi

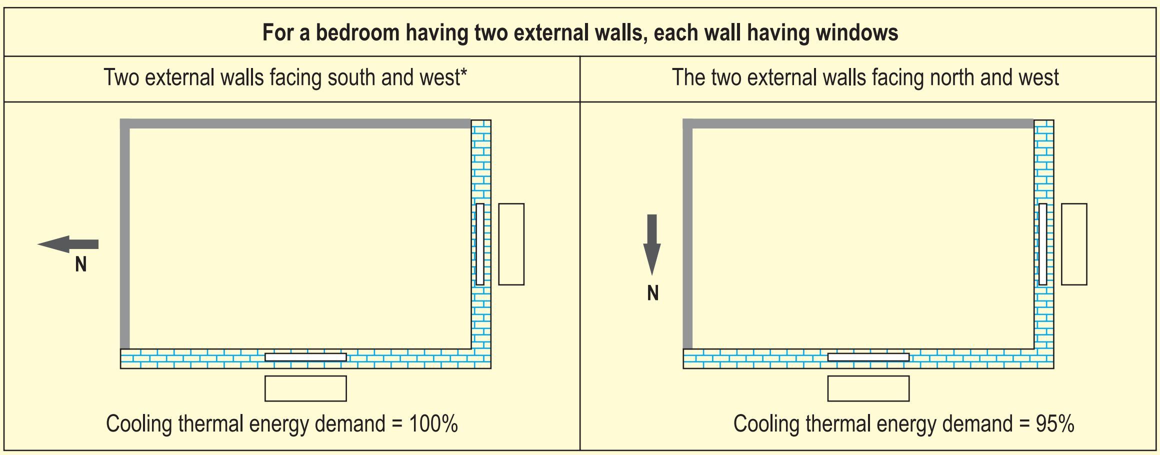
[a] U-value is the heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side.
[b] Solar heat gain coefficient (SHGC) is the ratio of the solar heat gain entering the space through 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.

4.2.1.2 Effect of orientation on cooling thermal energy demand

Orientation of bedrooms has an impact on both cooling thermal energy demand as well as thermal comfort. The impact on cooling thermal energy demand is illustrated through a case in Figure 4.2. It shows that for a bedroom having two external walls with each wall having windows, the cooling thermal energy demand decreases by 5% when the external walls are facing north and west, compared to when they are facing south and west.

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

Figure 4.3 shows the effect of number of external walls on cooling thermal energy demand. It shows that for the bedroom having only one south facing wall exposed to the ambient air, the cooling thermal energy demand is 18% lower compared to the base case with two external walls facing south and west.



* 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*

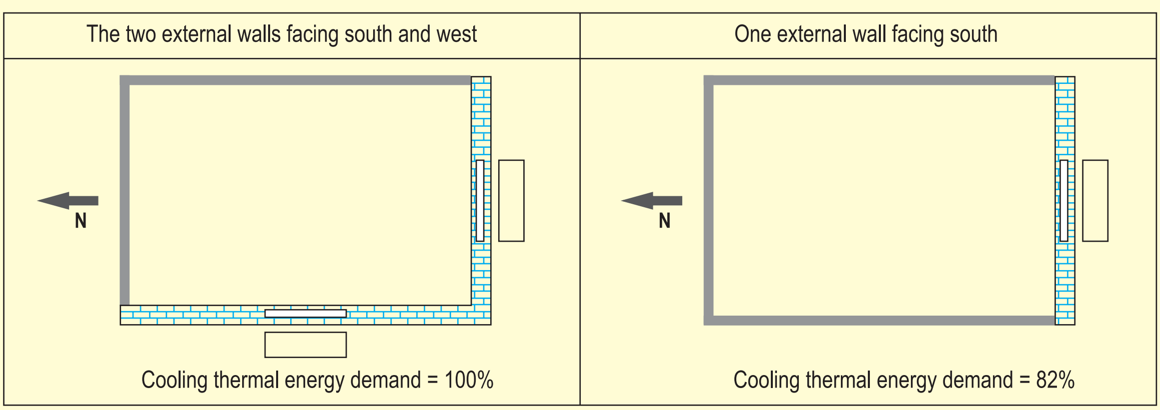


Figure 4.3 *Effect of number of external walls on cooling thermal energy demand*

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 from the building envelope in the bedrooms.

Package I

Package I consists of solutions that are commercially available and are already 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 4.4). This extension helps in cutting the solar radiation falling on the window.[2]
- *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

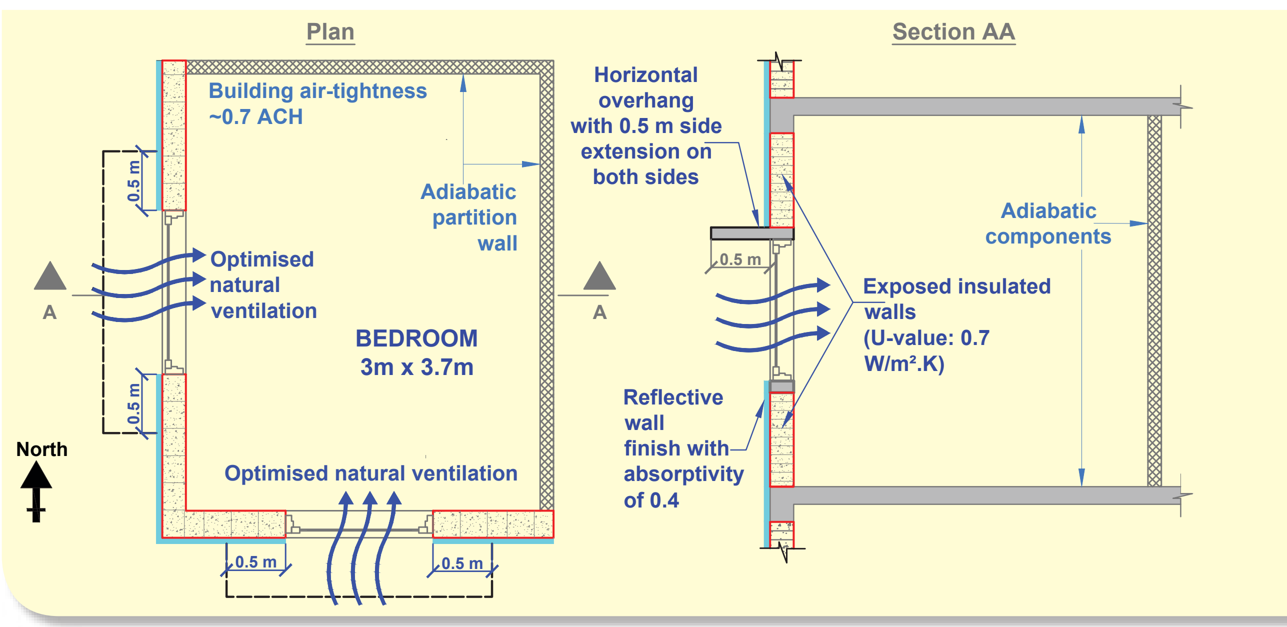


Figure 4.4 *Schematic of Package I measures*

[2] *In practice, similar shading effect is achieved through suitably designed recessed windows or windows shaded by balconies.*

transmission due to conduction through external walls can be reduced. A U-value of around 0.7 W/m².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 of cooling thermal energy by 23% over the base case, as shown in Figure 4.7. A large number of simulation runs showed that different bedroom configurations (as depicted in Figures A.4-1 to A.4-32 in Annexure 2) result in 18%–23% savings in cooling thermal energy demand compared to the base case.

Package II

Package II consists of measures suggested in Package I, along with the addition of external movable window shutters as shown in Figure 4.5.

Figure 4.1 shows that on a typical hot day, for the base case, the solar heat gains 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

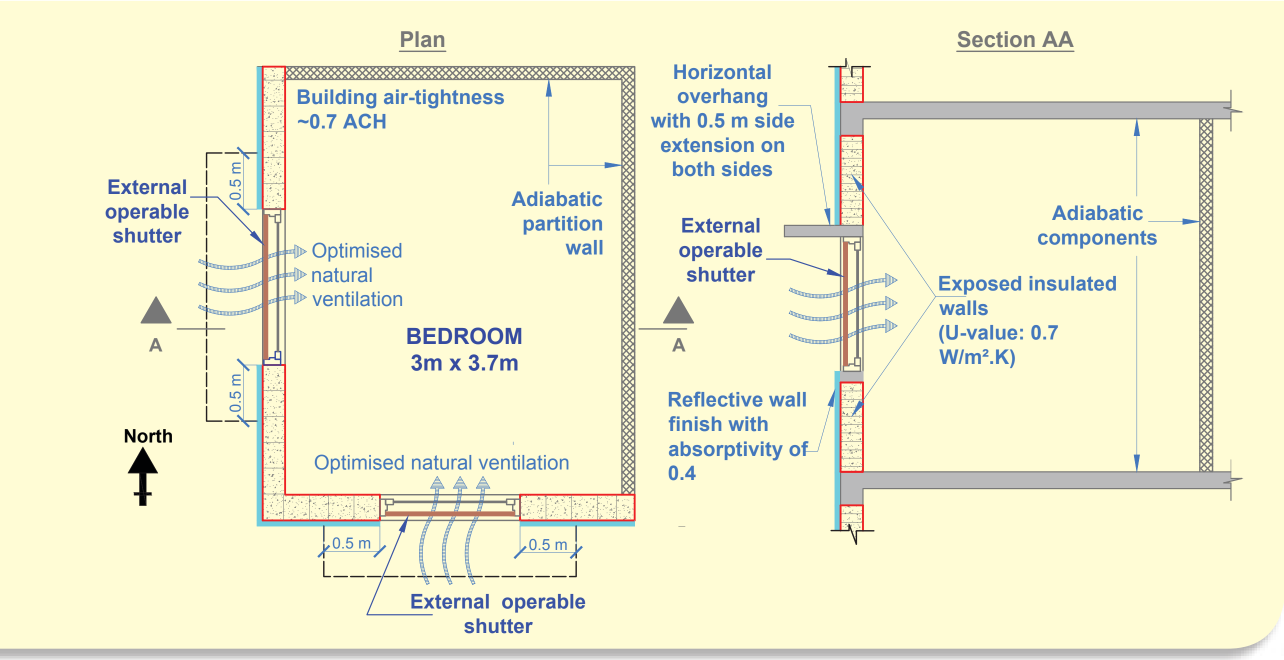


***Figure 4.5** Schematic of Package II measures*

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 4.6a and b. 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 the availability of modern external movable shutters is rather limited.

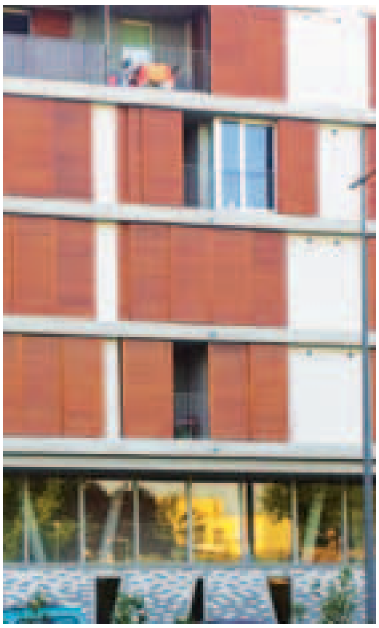


Figure 4.6a *Sliding shutters*

Figure 4.6b *Hinged shutters and top rolling shutters*

For the purpose of the simulation, a 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.

Application of the measures suggested in Package II can reduce the demand of cooling thermal energy by 46% over the base case as shown in Figure 4.7. A large number of simulation runs showed that different bedroom configurations (as depicted in Figures A.4-1 to A.4-32 in Annexure 2) result in 40%–46% savings in cooling thermal energy demand compared to the base case.

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

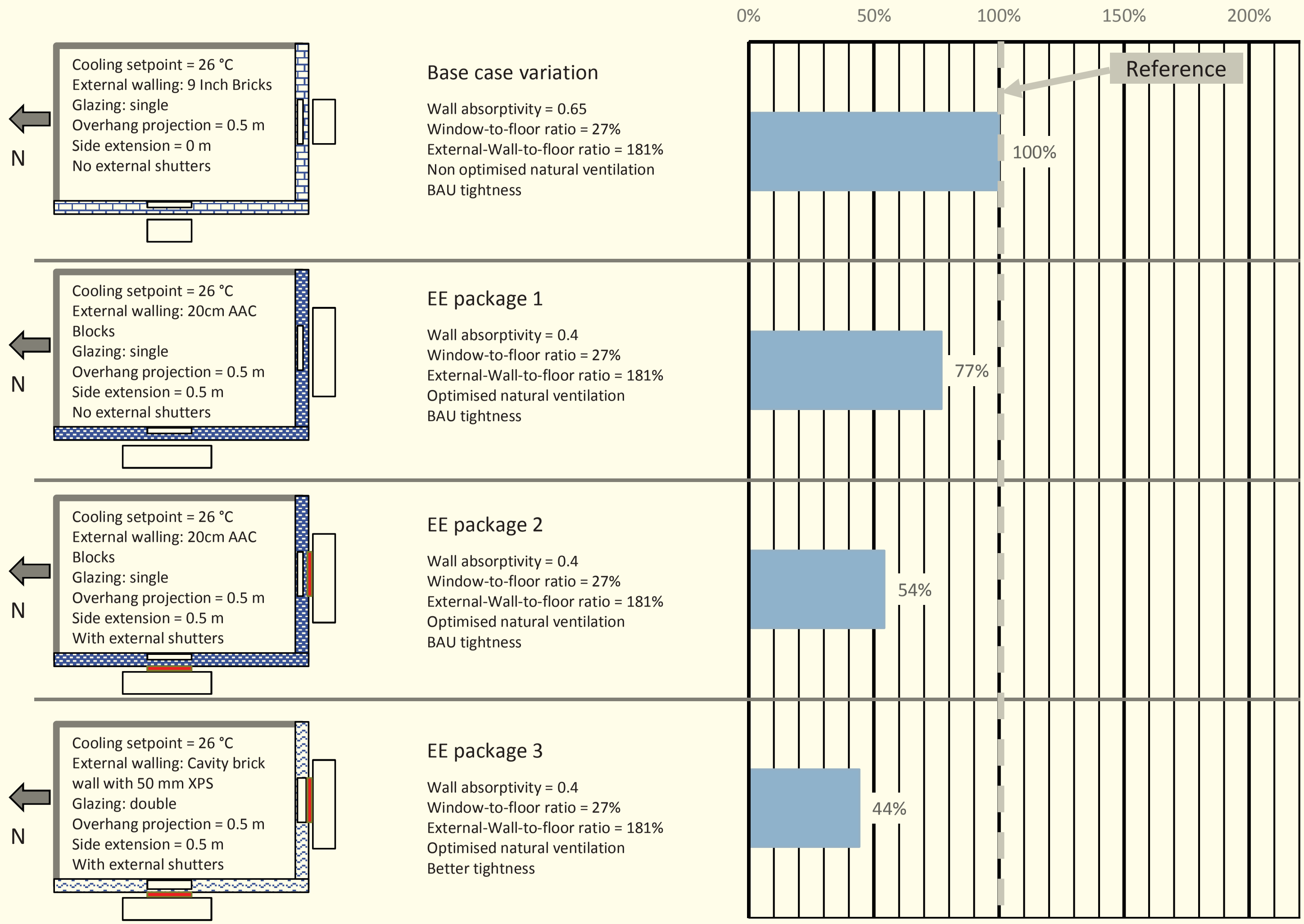


Figure 4.7 *Effect of energy-efficiency measures on the cooling thermal energy demand for the base case of the bedroom*

Package III

Package III is an improvement over Package II. In addition to the measures described in Packages I and II, the configuration shown in Figure 4.8 has the following:

- *Insulated walls (U-value: 0.5 W/m².K):* Use of better insulated walls[4] to achieve U-value 0.5 W/m².K. This can be achieved by 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/m².K, SHGC: 0.75).
- *Better building 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 components by using caulks, gaskets, and weather strips.

Application of the measures suggested in Package III can reduce the demand of cooling thermal energy by 56% over the base case, as shown in Figure 4.7. A large number of simulation runs showed that for different bedroom configurations (as depicted in Figures A.4-1 to A.4-32 in Annexure 2), 55%–60% savings in cooling thermal energy demand can be achieved compared to the base case.

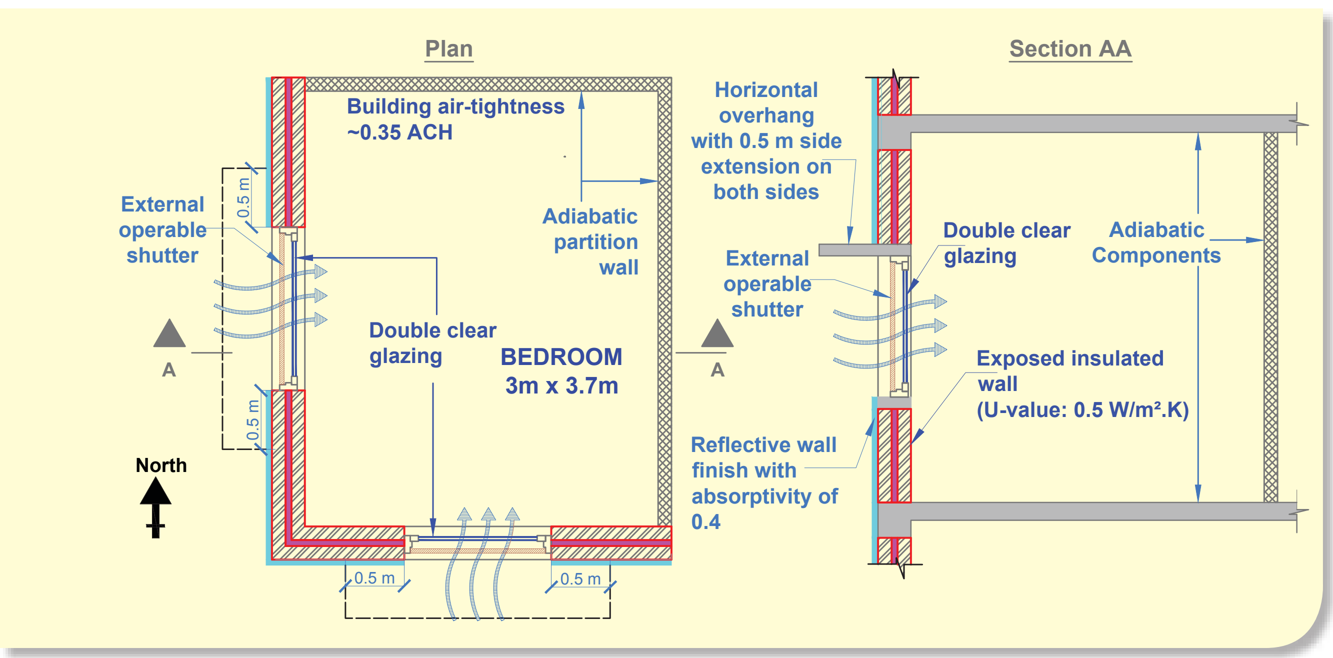


Figure 4.8 Schematic for Package III

[4] *For composite and hot-dry climates, it is recommended to use insulation on the outside surface of the wall or inside the cavity, in a cavity wall configuration. As far as possible, insulation should not be applied on the internal surface of the walls, as this does not allow the thermal inertia of the masonry wall to participate in the space thermal performance.*

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

Figure 4.9 shows the comparison of thermal performance of typical bedroom (3 x 3.7 x 3 m) configurations for the following four cases.

- **Two exposed walls**
  - *Case 1 (lower window-to-floor ratio):* Two exposed walls on the south and west with windows on both the exposed walls; window-to-floor area ratio of 0.27.
  - *Case 2 (higher window-to-floor ratio):* Similar to Case 1 with 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 has been doubled as compared to Case 1.
- **One exposed wall**
  - *Case 3 (lower window-to-floor ratio):* One exposed wall on the south side with window; window-to-floor area ratio of 0.27.
  - *Case 4 (higher window-to-floor ratio):* One exposed wall on the south side with window; window-to-floor area ratio of 0.54.

The interpretation of the results is as follows:

- Cases 2 and 4 have higher glazed area [higher window-to-wall ratio (WWR)] and, as expected, have higher cooling thermal energy demand.
- Case 3, the bedroom with one external wall and low window-to-floor ratio, has the lowest cooling thermal energy demand both for the base case as well as after the implementation of Package III.

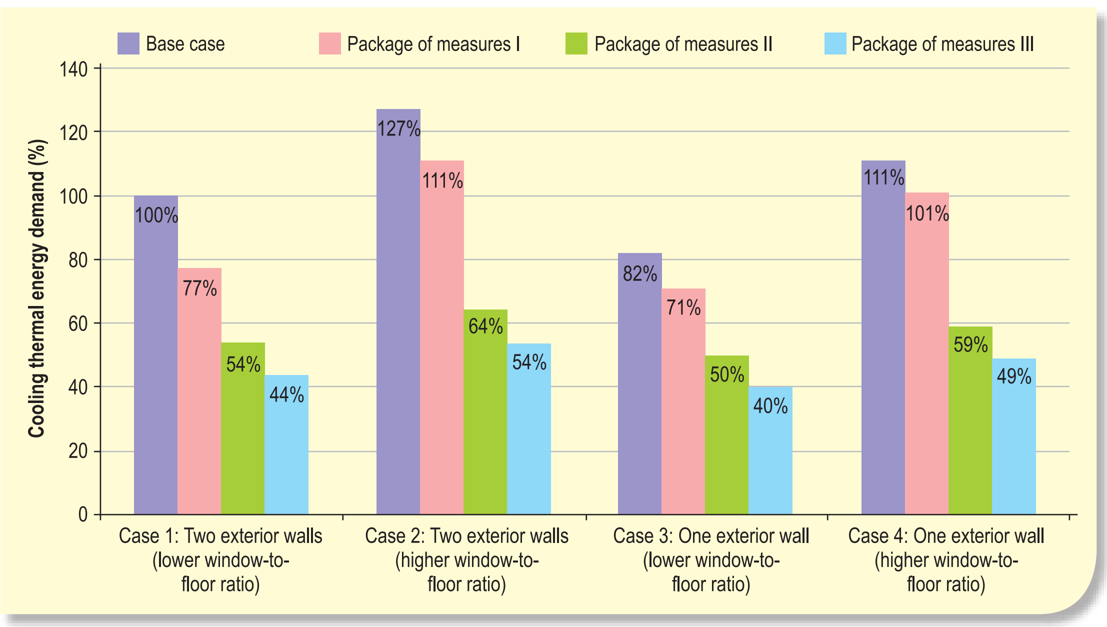


Figure 4.9 *Comparison of cooling thermal energy demand of typical bedroom configurations*

- It can be observed that in all the cases, the highest reduction in cooling thermal energy demand occurs due to the introduction of external movable shutters (Package II).
- The ratio of cooling thermal energy demand in the base case for Case 2 (127%) to that of the base case for Case 3 (82%) is 1.54. However, the ratio of cooling thermal energy demand after the implementation of Package III for Case 2 (54%) to implementation of Package III for Case 3 (40%) is 1.35. This shows that once the walls are well insulated (U-value of 0.5 W/m^2.K), windows are double glazed and well protected by the use of external movable shades, and the natural ventilation is optimised, the impact of factors such as the number of external walls, orientation, and glazing area on the cooling thermal energy demand is much lower.

Annexure 2 provides more details and results of the simulations.

4.2.2 Daylighting analysis for bedrooms

4.2.2.1 Methodology

The analysis was performed using ReluxPro Professional[5] software, with a clear sky without sun, at 12.30 pm on 21 January for a window oriented east (as shown in Figure 4.10). The analysis was performed to check whether a target of 0.9 average daylight factor (DF)[6] is achieved at middle of the room. Sky condition, represented by 'clear sky without sun' was selected to perform studies in the composite climate (New Delhi) because the worst situation with regard to daylight in buildings is found during the winter months when the lux levels are lowest.

4.2.2.2 Results

The analysis performed has shown that for a typical bedroom of size 3 x 3.7 x 3m, availability of daylight is not a major concern. Analysis showed that 10% WWR is sufficient for achieving the desired DF of 0.9 in a standard bedroom (Figure 4.11).

In practice, the blocks of multi-storey buildings are often located very close to each other in a residential complex. In such cases, daylight in lower floors is expected to be less. The analysis was performed for a bedroom on the second floor of a 12-floor tower situated 6 m apart from a similar tower. The results for WWR of 10% show that in such a case, daylight is very critical (Figure 4.12).[7]

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[5] *ReluxPro is a software for daylighting and artificial lighting analysis. <http://www.relux.biz/>*

[6] *German DIN Norm 5034.*
Daylight factor (DF) is the ratio of internal light level to external light level and is defined as follows:
DF = (Ei / Eo) x 100%
where, Ei = illuminance due to daylight at a point on the indoors working plane, Eo = simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.

[7] *This study was performed for the following time: 21 January, 9 am.*

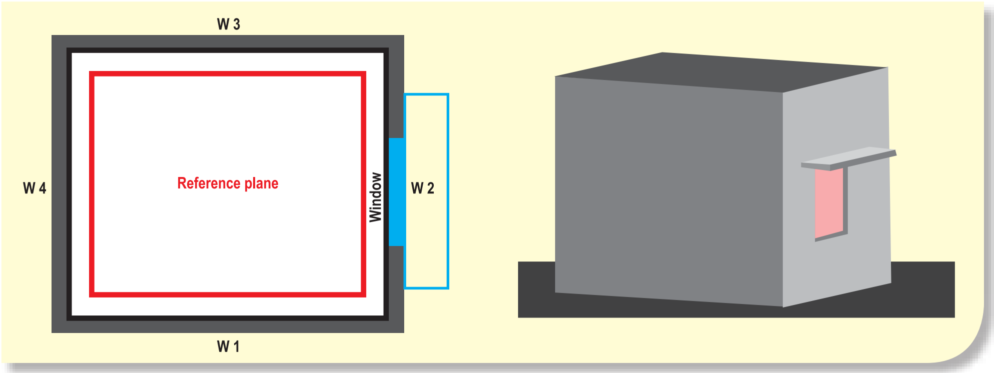

Figure 4.10 *Model for daylight analysis in the bedroom*

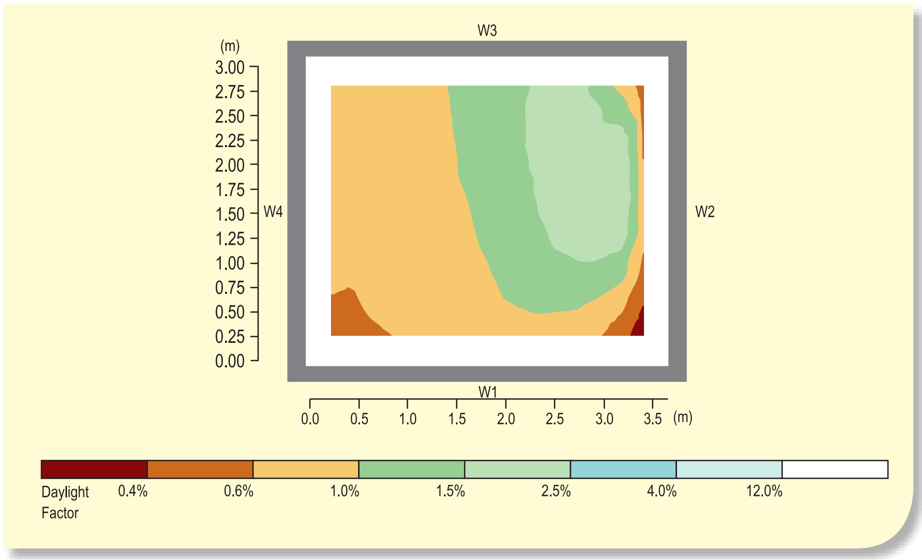

Figure 4.11 *Results of daylight analysis for a bedroom (WWR =10%), 21 January, 12.30 pm*

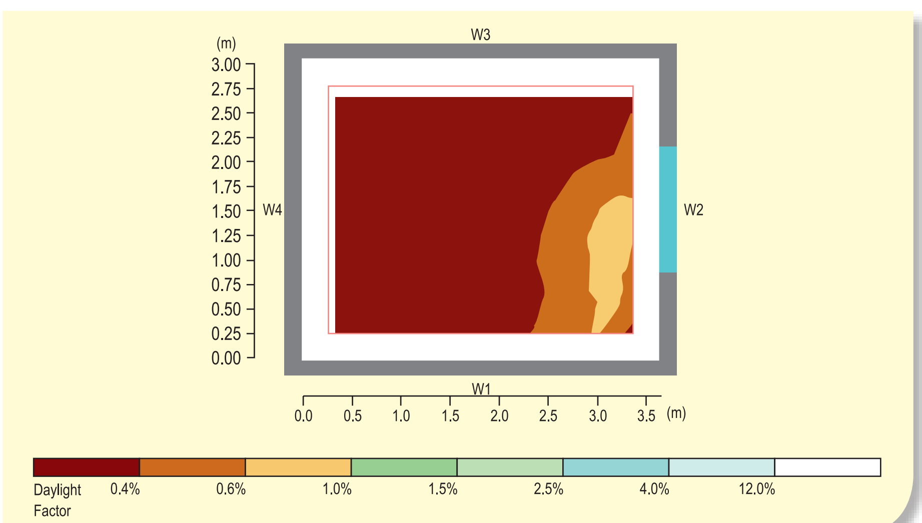

Figure 4.12 *Daylight analysis for a bedroom located on the 2nd floor of a 12-storey tower located at a distance of 6 m from another tower, 21 January, 9 am*

The daylight on the lower floors can be improved by increasing the distance between the blocks, increasing the window area, using light colours with smooth finishes on the wall opposite to the window, and using light colour interiors. Simulation for this particular case showed that the daylight was improved to satisfactory levels for WWR of 30%.

To analyse the daylighting in the multi-storey apartments, it is recommended to perform daylight analysis for the rooms that have critical daylight access (e.g., rooms on the lower floors may have lower daylight access, while some of the top-floor rooms may have too much daylight exposure). The designer should give due importance at the flat level for improving the daylighting in critical spaces.

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 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 4.13). The input parameters for simulating the base case are given in Table 4.2 The main difference between the bedroom and the living room is the difference in the occupancy schedule, while the

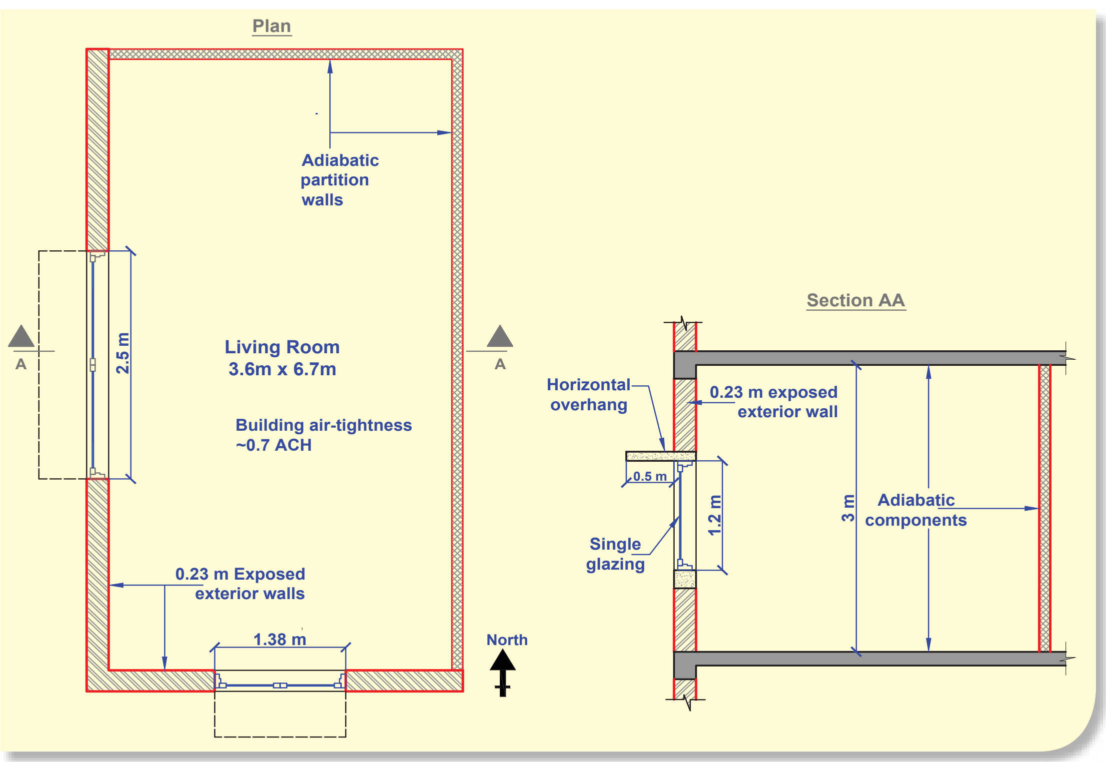

Figure 4.13 *Schematic of base-case model for living room developed in TRNSYS*

Table 4.2 Base-case simulation inputs for a living room

Building component/schedule types/parameters	Living room
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%
Set point	26 °C
Occupancy schedule	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

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 Figure 4.14. The results are quite similar to the results of the bedroom. The cooling thermal energy demand is expected to reduce by 16% for the Package I measures; while it is expected to reduce by 40% for Package II and 47% for Package III. Once again, the largest reduction in cooling thermal energy demand is attributed to the introduction of external movable shutters.

Annexure 2 (Figures A.4-33 to A.4-64) provides more details and results of the simulations.

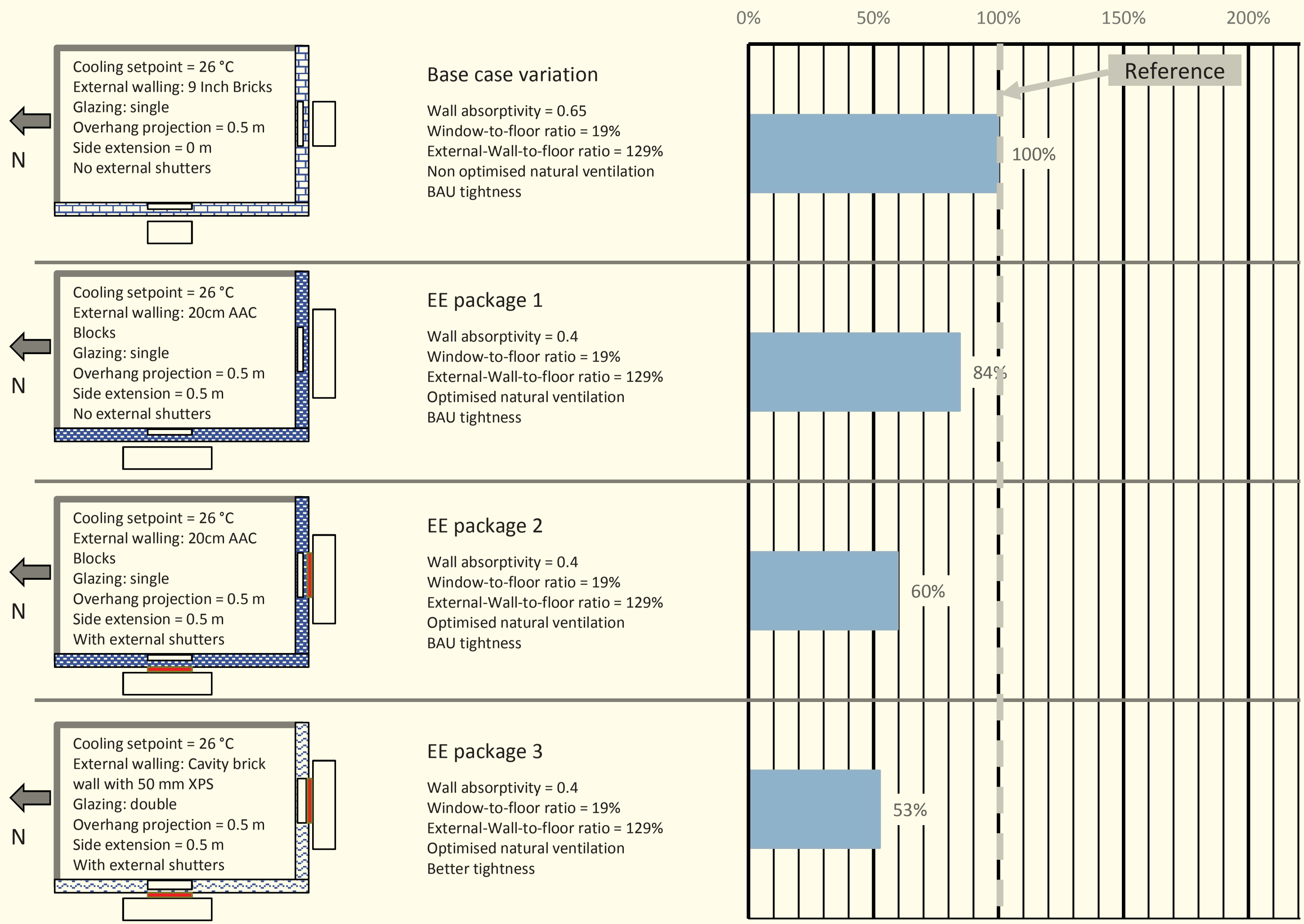

Figure 4.14 Effect of energy-efficiency measures on the cooling thermal energy demand for the base case of the living room

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. A typical living room of size 3.65 x 6.7 x 3 m was simulated (floor area: 24.5 m^2). The base case has 20% WWR, with a window onto the balcony (2.0 by 2.2 m). The second case has an additional window of 1.2 by 1.6 m (Figure 4.15). Figure 4.16 shows the daylight factor distribution with a 20% and then a 30% WWR.

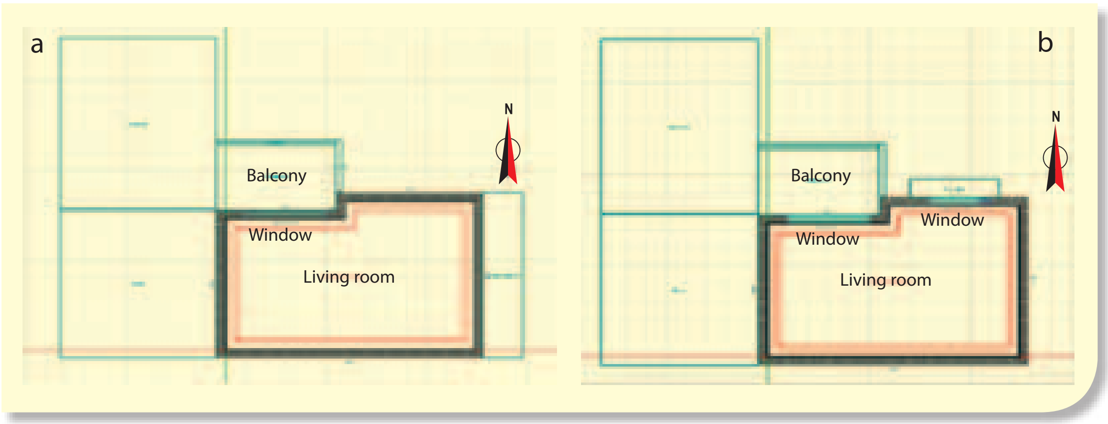

Figure 4.15 *(a) Living room layout with 20% WWR (b) Living room layout with 30% WWR*

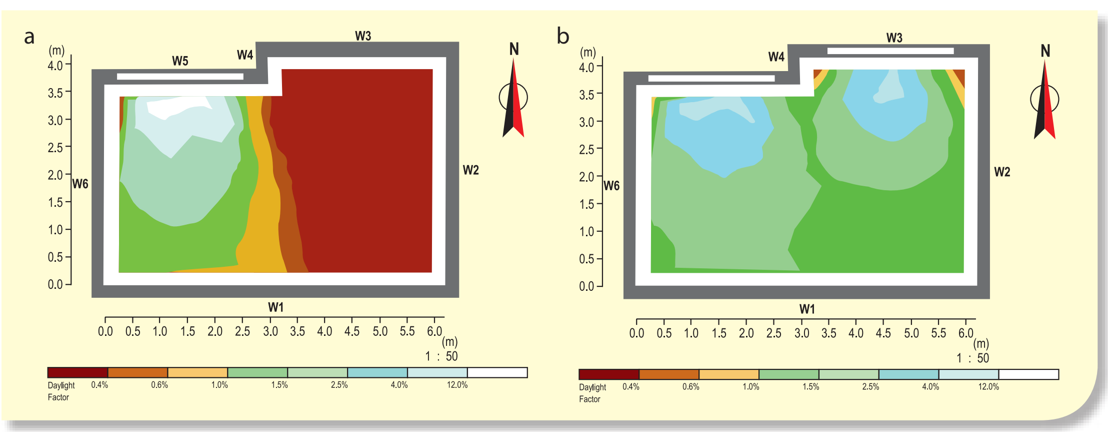

Figure 4.16 *(a) Daylight distribution for 20% WWR*
(b) Daylight distribution for 30% WWR

This analysis highlights the fact that a 30% WWR is required to ensure sufficient daylight, i.e., to meet the target of 1.1 average DF[8] along the middle of the room. However, if the living room is situated in a large multi-residential complex with 12 floors or more and buildings located close to each other, then the available daylight is substantially reduced.

[8] *Daylight factor norm based on the German DIN Norm 5034, slightly adapted for living rooms in the composite climate of India.*

4.4 Roofs

Roofs receive approximately four times more solar radiation (kWh/m^2) than walls during the summer months. For the flats located on the top 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 overdeck insulation[9] (insulation placed above the structural slab) and by using high reflective (absorptivity <0.4) finishes/paints (Figure 4.17). Periodic maintenance of the roof is required to retain the reflective characteristics of the surface.

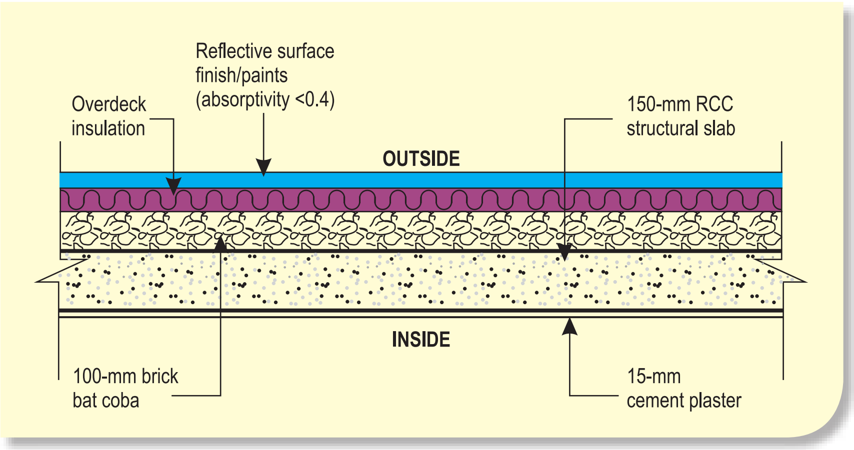

***Figure 4.17** Typical section of the roof showing overdeck insulation and reflective surface finish*

RECOMMENDATIONS

Recommendation 4: Take suitable passive design measures for walls and windows to reduce the cooling thermal energy demand and improve thermal comfort

- **Package of Measures I** that can bring about 15%–20% reduction in cooling thermal energy demand: Use of light colours on wall (absorptivity ≤0.4) + window shades with extended overhangs to intercept direct solar radiation on the window + insulated walls (U-value: 0.7 W/m^2.K) + optimised natural ventilation.
- **Package of Measures II** that can bring about 40%–45% reduction in cooling thermal energy demand: Package of Measures I + external movable shutters on windows.

contd...

[9] *The base-case uninsulated roof (inside to outside: 15-mm cement plaster +150-mm RCC + 100-mm brick bat coba + 20-mm tile finish) has U-value of ~2.5 W/m^2.K. By using 75 mm and 100 mm of extruded polystyrene insulation, the U-value of roof assembly can be reduced to 0.39 W/m^2.K and 0.31 W/m^2.K, respectively.*

contd...

- **Package of Measures III** that can bring about 50%–60% reduction in cooling thermal energy: Package of Measures II + improved wall insulation (U-value: 0.5 W/m^2.K) + use of double glazing in windows + better envelope tightness.

Recommendation 5: Design for adequate daylighting

- Usually 10%–15% window-to-wall ratio (WWR) in bedrooms and 30% WWR in living room are needed to provide adequate daylighting. However, when building blocks in a residential complex are located near to each other, daylighting in bedrooms and living room located on lower floors is substantially reduced. The daylight on the lower floors can be improved by increasing the window area, using light colour with smooth finishes on the wall opposite to the window and using light colour interiors.

Recommendation 6: Design the roof to reduce the cooling thermal energy demand and improve thermal comfort

- Provide overdeck insulation and high reflective surface on roof to minimise heat ingress through roof.

CHAPTER 5

SPACE COOLING

AT A GLANCE

Electricity consumption for space cooling and fans forms a significant part 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 33% to 65% of the total electricity consumption.

In the composite and hot-dry climates, direct evaporative cooling (desert cooler) is an effective technological option for space cooling particularly during the March–June period. Recent technological advances in evaporative cooling, such as indirect two-stage evaporative cooling, have made them perform better and are highly energy efficient. The integration of evaporative cooling in multi-storey residential buildings requires due considerations for water supply and provision of suitable space and window opening for installing the evaporative cooling system at the time of building design.

The use of room air-conditioners is increasing rapidly in multi-storey residential buildings. The annual sale of room air-conditioners in India has trebled over the past five years. Analysis of time-series data (2006–2013) from one of the residential complexes in Delhi indicates that electricity consumption for space cooling more than doubles when shifting from a situation where space cooling is predominantly met by desert coolers to a situation where space cooling is predominantly met by room air-conditioners.

The electricity consumption in the space-cooling system primarily depends upon:

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

RECOMMENDATIONS FOR SPACE COOLING

Recommendation 7: Design for raised 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 thermal energy demand. Design the cooling system for the raised cooling set-point.

Recommendation 8: Design the space-cooling system so as to utilise the full potential of evaporative cooling

Cooling system design should favour utilisation of full potential of evaporative cooling in order to reduce the duration of air-conditioning. Incorporation of evaporative cooling can result in 30%–70% electricity savings annually for space cooling (at 28 °C design set-point), depending on the evaporative cooling technology – two-stage indirect evaporative being more efficient compared to direct evaporative cooling systems.

Provide dedicated space and water supply connections for the installation of evaporative cooling equipment.

Recommendation 9: Incorporate measures to increase energy efficiency of the air-conditioning system

When using conventional air-cooled window or split air-conditioning units, use the highest BEE star rating possible.

Incorporate new and innovative ways to improve efficiency of room air-conditioners. For example, incorporate a central water loop with cooling tower to water cool the condensers of split air-conditioners. Such a system has the potential of ~40% savings in energy against air-cooled split air-conditioners. Some such systems have already been installed in India.

Recommendation 10: Design for quick and efficient evacuation of hot air generated in the kitchen

The hot air generated in kitchen while cooking should be evacuated quickly and efficiently.

Sufficient natural ventilation should be provided so that the heat can be partly extracted by natural means. For effective natural ventilation of the kitchen, in addition to the window, an additional lower opening should be provided.

For better comfort in hot season, well-located and efficient mechanical extraction system above the cookstove can take most of the hot air directly out.

5.1 Introduction

After having reduced the cooling thermal energy demand by applying passive measures as described in Chapter 4, the active cooling required in composite and hot-dry climates has to be met efficiently. Chapter 4 shows that a reduction of more than 50% in the cooling thermal energy demand is possible by application of available passive measures.

In the business-as-usual design, window or split room air-conditioner units are used for space cooling. One can use higher BEE star labelled air-conditioners to reduce the electricity consumption. However, apart from the use of BEE star labelled air-conditioners, there are other technological solutions for reducing the electricity consumption for cooling. Some of these are already available in the market, while others have been demonstrated but are still not available in the market for application in residential buildings, e.g., indirect evaporative cooling and central water cooling loop for the split units.

As seen in Figure 2.7, the electricity consumption more than doubled in the surveyed flats with a transition from the desert cooler fan system to room air-conditioners. Hence, the cooling system design approach should be aimed at reducing the usage of air-conditioners, and should look into the possibility of optimising the use of natural ventilation, fans, and evaporative cooling.

5.2 Possible strategies to reduce the electrical energy for space cooling

5.2.1 Raising the cooling set-point temperature

As per the recent adaptive comfort standards (ASHRAE 55[1]), a case has been made to increase the set-point for cooling to 28 °C in peak summer for New Delhi.[2] Based on a parametric study carried out on the base-case model for bedrooms described in Section 4.2.1.1, 36% savings in cooling thermal energy is possible when set-point temperature is increased to 28 °C from 26 °C. The savings will be 55% when set-point temperature is increased to 28 °C from 24 °C (Figure 5.1).

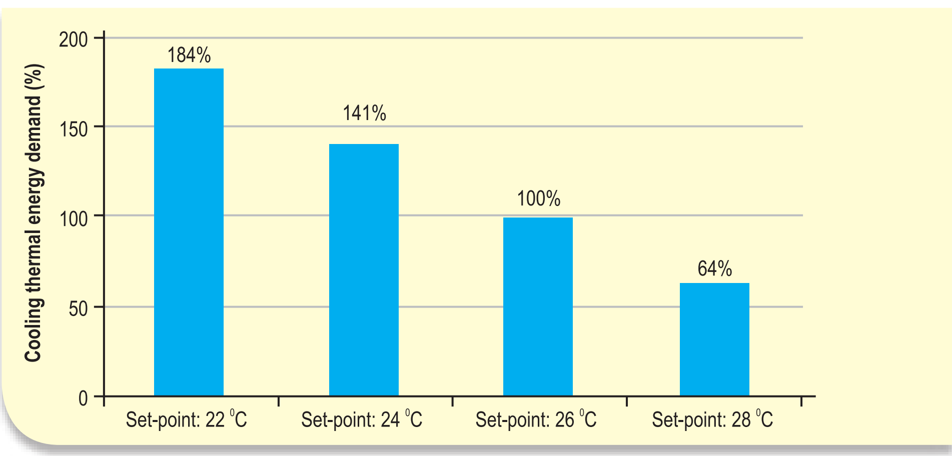

Figure 5.1 *Cooling thermal energy demand for bedrooms at different cooling temperature set-points*

[1] *ASHRAE Standard 55-2013. Thermal Environmental Conditions for Human Occupancy.*

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

5.2.2 Energy efficiency of the cooling systems

5.2.2.1 Energy-efficient window 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. The higher the BEE start rating, the higher the energy savings.

5.2.2.2 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 very 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 5.2 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

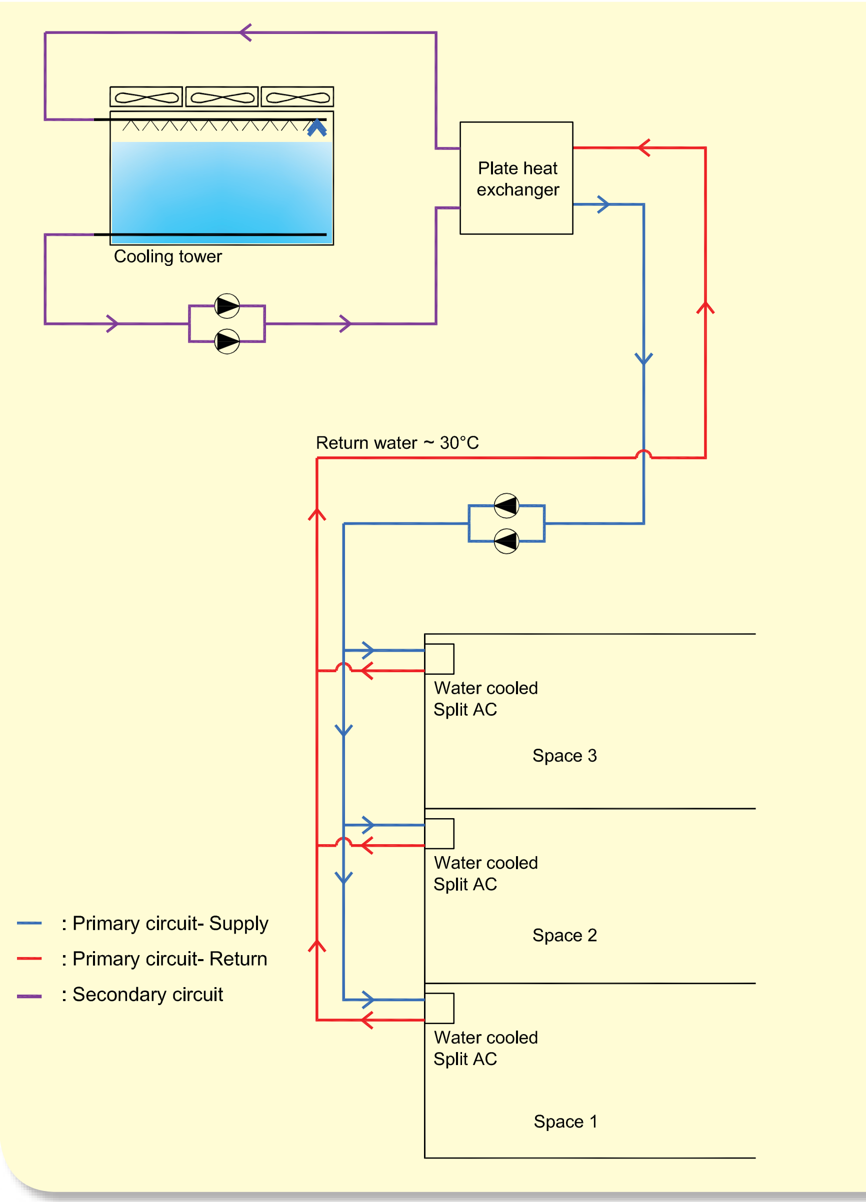

Figure 5.2 Schematic diagram of split air-conditioners cooled by a central water loop

drastically the demand for fresh water for operating the system. Some air-conditioning companies are currently offering these systems in India.

The practical energy-saving potential of 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 require access to outside air, so the cooling units can be installed inside. For the developer, 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 could 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.

5.2.2.3 Evaporative cooling

The use of conventional single-stage evaporative coolers ('desert coolers') is declining in multi-storey residential buildings. Some factors that contribute to the decline include shortage of water, absence of water supply connections near the location of the desert cooler, higher upkeep and maintenance requirements, and absence of a suitable window opening. Where water availability is not an issue, multi-storey residential buildings should be designed so that they facilitate the use of desert coolers.

Emerging technologies like indirect two-stage evaporative cooling, which have better performance and are highly energy efficient, are applied in the commercial sector and should be seen as a possible option for residential apartments; however, commercialisation of the technology must be in place so the products are easily available on a large scale. The energy-saving potential of this technology is approximately 70% when applied with a cooling set-point of 28 °C compared to conventional room air-conditioners.

Figure 5.3 shows the product that was developed and tested in the United States.[3] The data for the system are shown in Table 5.1. The measured performance data are promising and efforts should be made to commercialise such technologies.

5.2.2.4 Future cooling technologies

Some new ultra-efficient cooling technologies are under development. For example, the combination of desiccant and evaporative cooling with new technologies may come on the market in the future.[4] As per available information, these technologies are not yet available commercially.

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[3] *Davis Energy Group. March 2004. Development of an Improved Two-Stage Evaporative Cooling System. Report prepared for the Public Interest Energy Research Program of the California Energy Commission.*

[4] *Kozubal E, Woods J, Burch J, Boranian A, and Merrigan T. January 2011. Desiccant Enhanced Evaporative Air Conditioning (DEVap): Evaluation of a New Concept in Ultra Efficient Air Conditioning. National Renewable Energy Lab, USA. Prepared under Task No. ARRB2206.*

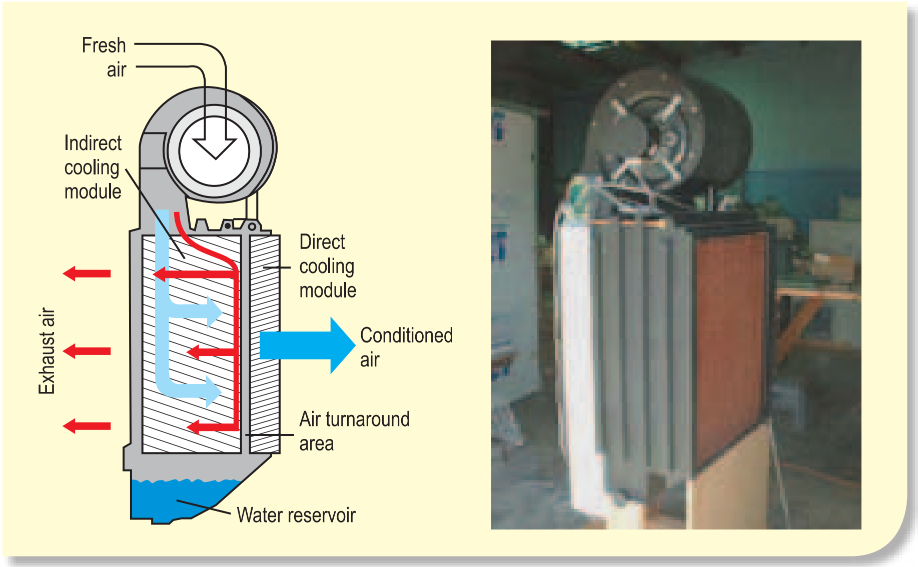

Figure 5.3 *Improved two-stage evaporative cooling system*

Table 5.1 Data for an improved two-stage evaporative cooling system

Parameter	High speed	Middle speed	Low speed
Fan power (W)	498	266	58
Total power (W)	521	289	81
Supply air (m^3/h)	2635	2125	1274
Secondary air (m^3/h)	1057	812	425
Entering air - dry bulb (°C)	40.4	39.8	40.2
Entering air - wet bulb (°C)	21.6	21.7	22.8
Between stage - dry bulb (°C)	30.6	29.4	29.2
Leaving air - dry bulb (°C)	19.9	19.9	20.4
Leaving air - wet bulb (°C)	18.3	18.5	19.6
Indirect effectiveness (%)	52	57	63
Direct effectiveness (%)	87	87	91
Total effectiveness (%)	109	110	113
Capacity (kW cooling)	6.0	5.0	3.3
Coefficient of performance	11.6	17.4	40.3

5.3 Ventilation for kitchen

Kitchen is often the most uncomfortable thermal space in an apartment because of the large amount of heat generated during cooking. The provision of 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 3.

5.3.1 Strategies of natural ventilation in winter and mid-season

During winters and mid-season months, i.e., from October to March in the composite and hot-dry climates, the outside conditions are suitable for natural ventilation. Figure 5.4a 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 5.4b 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.

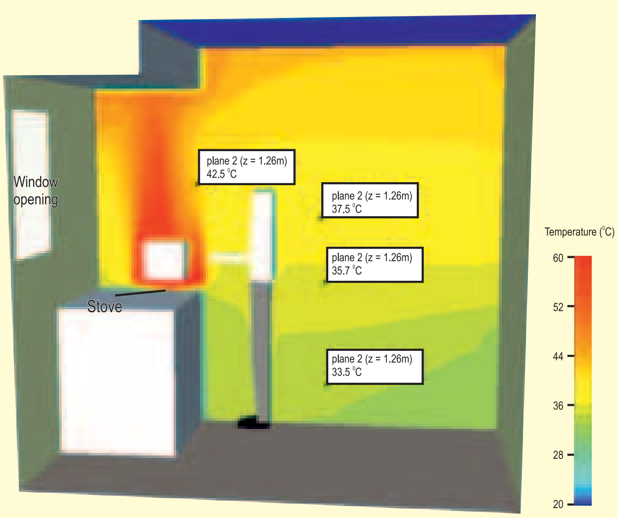

Figure 5.4a Natural ventilation with a conventional window opening. Average air temperature of 36 °C between 1 and 1.6 m above the floor

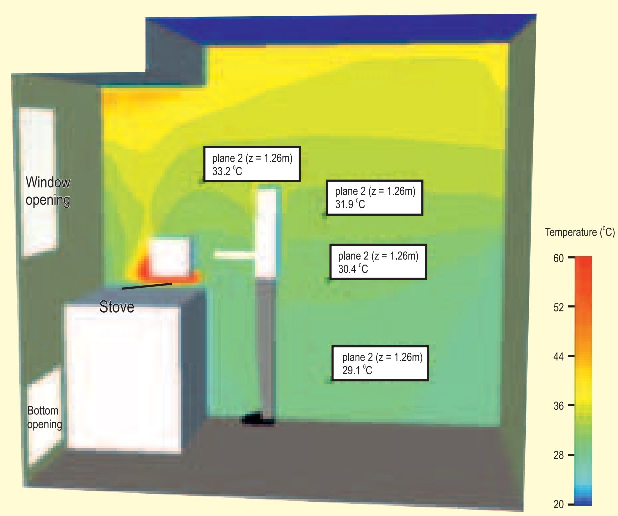

Figure 5.4b Natural ventilation with a conventional window and an additional bottom opening. Average air temperature of 31 °C between 1 and 1.6 m above the floor

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[5] *Mentor Graphics Flovent version 9.3, computational fluid dynamics (CFD) software that predicts 3D airflow, heat transfer, contamination distribution and comfort indices in and around buildings of all types and sizes.*

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

Figure 5.5a 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 5.5b, 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.

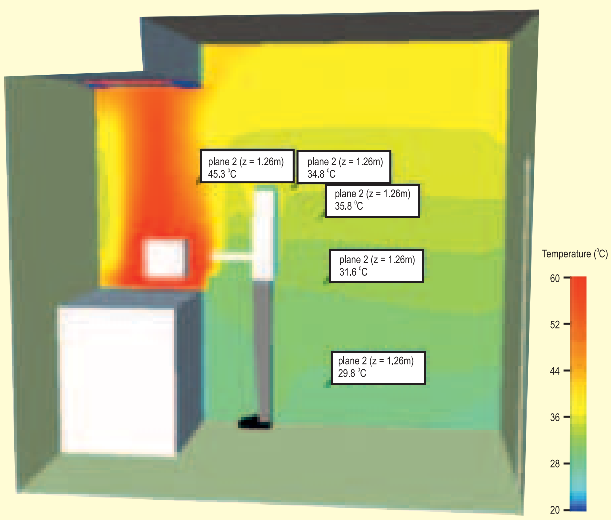

Figure 5.5a *Door between the kitchen and the living room partly opened, hood 1.5 m above the gas fire, flow rate: 500 m^3/h. Average air temperature of 33 °C between 1 and 1.6 m above the floor*

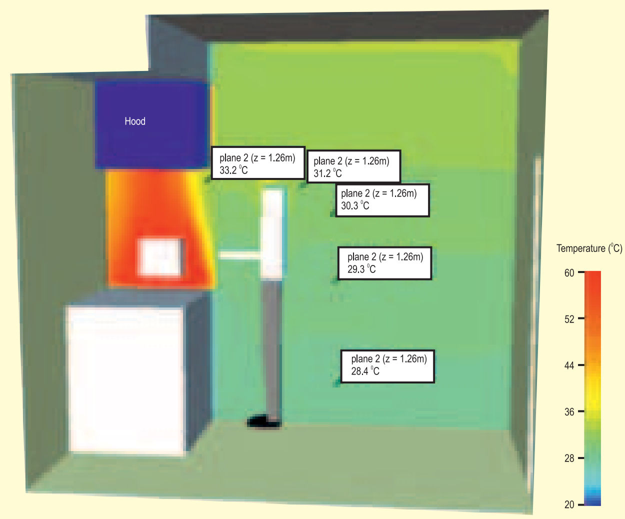

Figure 5.5b *Door between the kitchen and the living room partly opened, hood 1 m above the gas fire, flow rate: 500 m^3/h. Average air temperature of 30 °C between 1 and 1.6 m above the floor*

In Figure 5.6, 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 5.7 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). The lower the hood, the better the efficiency and the 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.

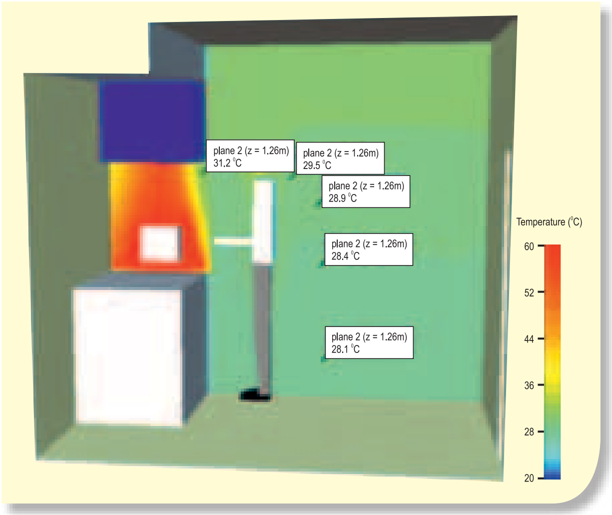

***Figure 5.6** Door between the living room partly opened, hood 1 m above the gas fire, flow rate: 800 m³/h. Average air temperature of 29 °C between 1 and 1.6 m above the floor*

5.3.3 Conclusions on kitchen ventilation

Based on the analysis presented in sections 5.3.1 and 5.3.2, 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.

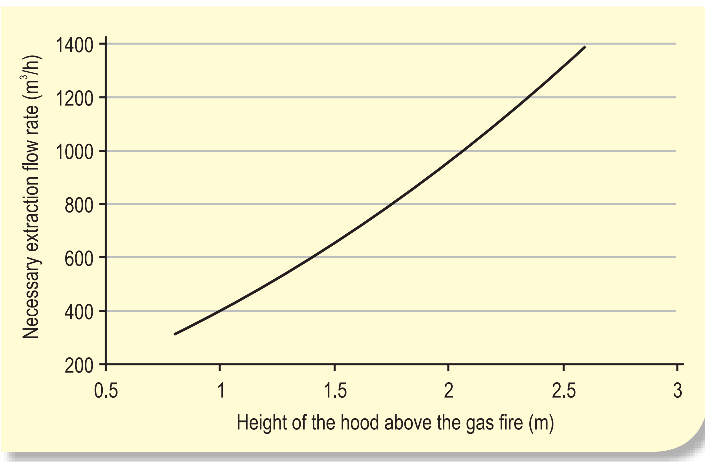

***Figure 5.7** Height of the hood above the gas fire versus necessary extraction rate*

RECOMMENDATIONS

Recommendation 7: Design for raised 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 thermal energy demand. Design the cooling system for the raised cooling set-point.
- Ceiling fans should always be provided and should be used with evaporative cooling or air-conditioning systems.

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Recommendation 8: Design the space-cooling system so as to utilise the full potential of evaporative cooling

- Cooling system design should favour utilisation of full potential of evaporative cooling in order to reduce the duration of air-conditioning. Incorporation of evaporative cooling can result in 30%–70% electricity savings annually for space cooling (at 28 °C design set-point), depending on the choice of the evaporative cooling technology. Two-stage indirect evaporative being more efficient compared to direct evaporative cooling systems.
- Provide dedicated space and water supply connections for the installation of evaporative cooling equipment.

Recommendation 9: Incorporate measures to increase energy efficiency of the air-conditioning system

- When using conventional air-cooled window or split air-conditioning units, use the highest BEE star rating possible.
- Incorporate new and innovative ways to improve efficiency of room air-conditioners. For example, incorporate a central water loop with cooling tower to water cool the condensers of split air-conditioners. Such a system has the potential of ~40% savings in energy against air-cooled split air-conditioners. Some such systems have already been installed in India.

Recommendation 10: Design for quick and efficient evacuation of hot air generated in kitchen

- The hot air generated in kitchen while cooking should be evacuated quickly and efficiently.
- Sufficient natural ventilation should be provided so that the heat can be partly extracted by natural means. For effective natural ventilation of the kitchen, in addition to the window, an additional lower opening should be provided.
- For better comfort in hot season, well-located and efficient mechanical extraction system above the cookstove can take most of the hot air directly out.

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 and thereby the 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.

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. The higher the star rating, the lower the energy losses through the distribution transformer.
- Air-conditioners: The star rating of air-conditioners is based on the energy-efficiency ratio (EER). The higher the EER, the higher is the star rating.
- Ceiling fans: The star rating of ceiling fans is based on the 'service value'. The higher the 'service value', the higher is the star rating.
- Tubular fluorescent lamps (TFLs): The star rating of TFLs is based on 'lumens per watt'. The higher the 'lumens per watt', the 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. The higher the star rating, the lower the energy losses through the geyser.

RECOMMENDATION FOR APPLIANCES

Recommendation 11: 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
    - Tubular fluorescent lamps (TFLs) for the lighting of common areas
    - Electronic ballasts for the lighting of common areas
  - Space cooling, water heating, and lighting inside flats
    - Air-conditioner
    - Ceiling fan
    - Tubular fluorescent lamps (TFLs)
    - Electronic ballasts
    - Storage type electric water heaters/geyser

AT A GLANCE

6.1 Introduction

In the previous chapters, recommendations were given for minimising heat gains, and utilising daylighting 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. The equipment/appliances covered under this programme include frost free (no-frost) refrigerators, tubular fluorescent lamps (TFLs), room air-conditioners, direct cool refrigerators, distribution transformers, induction motors, pump sets, ceiling fans, liquefied petroleum gas (LPG) stoves, electric geysers, ballasts, computers, office equipment, and colour televisions. 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) air-conditioners of the vapour compression type for household use up to a rated cooling capacity of 11 kW (3.1 ton) is considered under the S&L Programme. The star rating of the air-conditioner is based on the energy-efficiency ratio (EER). The EER for the air-conditioner is defined as the ratio of output cooling power (watt) to the input electrical energy (watt). The testing of air-conditioners is done as per the code and procedure described in IS 1391 Part 1 and Part 2 with all amendments. Tables 6.1 and 6.2 give the star rating and the corresponding EER for split air-conditioners and unitary type (window) air-conditioners, respectively.

Table 6.1 Star rating for split air-conditioners (valid from 1 January 2014 to 31 December 2015)

	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) air-conditioners (valid from 1 January 2014 to 31 December 2015)

	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	—

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

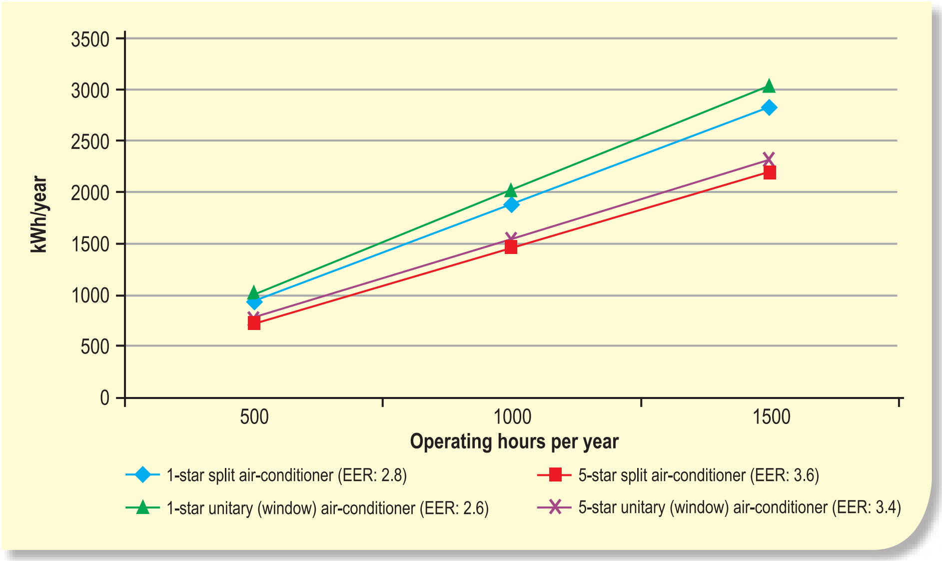

Figure 6.1 *Electricity consumption for air-conditioners of one and five star ratings*

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

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 value for ceiling fans.

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/minute.

It is recommended to opt for five star ceiling fans. An indicative electricity consumption graph (Figure 6.2) is shown below to compare the performance of one star and five star

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

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

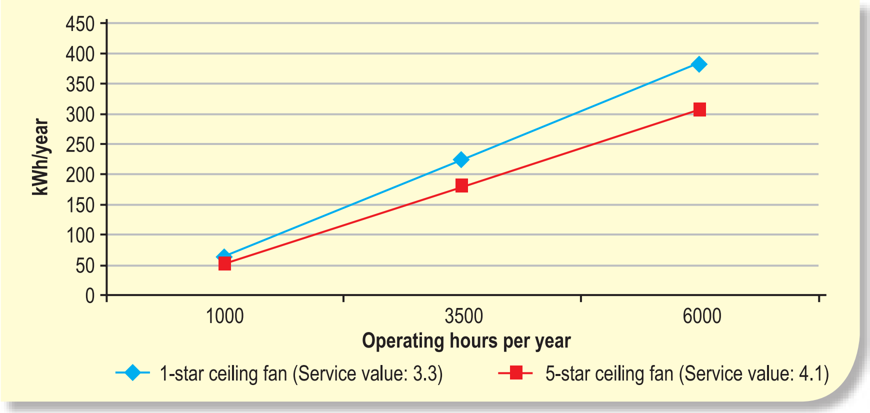

Figure 6.2 *Electricity consumption for ceiling fans of one and five star ratings*

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.

6.4 Tubular fluorescent lamps

Tubular fluorescent lamps (TFLs) of 4 feet long and up to 40 W rating are considered under the S&L Programme. The star rating of the TFL is based on the 'lumens per watt,' which is defined as the light output in lumen divided by electrical power input to the TFL in watts at the voltage and frequency specified for the tests. The testing code and procedure for TFLs for general lighting service is done as per IS 2418 (Part 1): 1977 with all amendments. Table 6.4 gives the star rating and the corresponding lumens per watt values for TFLs. 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 TFLs. 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 100 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

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.'

[4] *For calculations, a flow of 210 m^3/min has been taken and the average value of service value is taken for the range (e.g., for one star rated fan, service value of 3.3 is taken.)*

- 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 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/24 h/45 °C) values for storage-type electric water heaters. It is recommended to users to opt for a five star rated storage-type electric water heater.

Table 6.5 Star rating for storage-type electric water heaters (valid from 1 July 2014 to 30 June 2015)

Rated capacity (litres)	Standing losses (kWh/24 h/45 °C)				
	1 star	2 star	3 star	4 star	5 star
6	≤0.521 and >0.474	≤0.474 and >0.431	≤0.431 and >0.392	≤0.392 and >0.356	≤0.356
10	≤0.654 and >0.594	≤0.594 and >0.540	≤0.540 and >0.491	≤0.491 and >0.446	≤0.446
15	≤0.750 and >0.681	≤0.681 and >0.620	≤0.620 and >0.563	≤0.563 and >0.512	≤0.512
25	≤0.914 and >0.831	≤0.831 and >0.755	≤0.755 and >0.686	≤0.686 and >0.624	≤0.624
35	≤1.044 and >0.949	≤0.949 and >0.864	≤0.863 and >0.784	≤0.784 and >0.713	≤0.713
50	≤1.206 and >1.097	≤1.097 and >0.997	≤0.997 and >0.906	≤0.906 and >0.824	≤0.824
70	≤1.37 and >1.246	≤1.246 and >1.133	≤1.133 and >1.030	≤1.030 and >0.936	≤0.936
100	≤1.565 and >1.423	≤1.423 and >1.239	≤1.293 and >1.176	≤1.176 and >1.069	≤1.069
140	≤1.761 and >1.601	≤1.601 and >1.456	≤1.456 and >1.323	≤1.323 and >1.203	≤1.203
200	≤1.958 and >1.780	≤1.780 and >1.618	≤1.618 and >1.471	≤1.471 and >1.337	≤1.337

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

[5] *Standing loss is the electricity 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.*

ratings covered under the pilot energy labelling scheme is 16, 25, 63, 100, 160, and 200 kVA and non-standard ratings from 16 kVA to 200 kVA distribution transformers.

The star rating of distribution transformers is based on the total losses at 50% and 100% load. The higher the star rating, the lower the energy losses 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

Rating (kVA)	1 star		2 star		3 star		4 star		5 star	
	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 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 LPG stoves
- Color televisions
- Washing machines
- Laptop/notebook computers
- Office equipment (printers, scanners, copiers, fax machines, and multifunction devices)

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.

RECOMMENDATION

Recommendation 11: 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
  - Space cooling, water heating, and lighting inside flats
    - Air-conditioner
    - Ceiling fan
    - TFLs
    - Electronic ballasts
    - Storage-type electric water heaters/geyser

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 in lighting of common areas depends upon the following:

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

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

- The type and control of lighting and ventilation systems in the lift car
- The choice of type of lift
- The control system of electric motors
- The type of braking system

RECOMMENDATIONS FOR COMMON SERVICES

Recommendation 12: 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 13: Incorporate energy-efficiency features in the design of community water pumping system

- Pumped gravity system
  - Select pump so that the head and flow parameter 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 14: 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
  - Lifts with gearless systems usually consumes less electricity
  - Incorporation of regenerative braking

AT A GLANCE

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.

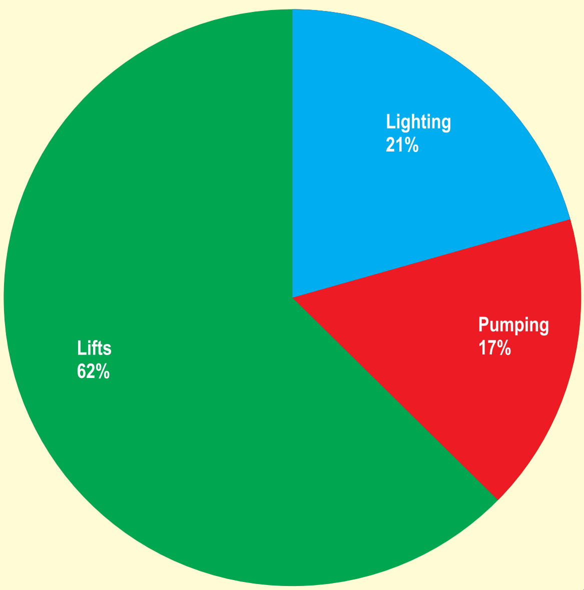

Figure 7.1 Share of electricity consumption for common services (lighting, pumping, and lifts) in a small multi-storey residential complex

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 (Table 7.1 and Figure 7.1) shows that electricity consumption in lifts was the largest (62%), followed by lighting of common areas (21%) and pumping water to overhead tanks (17%).

7.2 Energy-efficient design of common area lighting

Common area lighting can be further subdivided 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	Electricity consumption (kWh/year)	Electricity 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 facilitates daylight penetration for circulation. Typical recommended values for daylight in common areas are given in Table 7.2. Illuminance levels between 50 and 100 lux are sufficient for standard circulation spaces; staircases or circulation areas with obstacles require higher illuminance levels of 100–150 lux. 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]	Minimum daylight factor based on New Delhi climate data (%)
Corridors, lobbies, circulation areas	50–100	0.3–0.5
Staircases	100–150	0.7–1.0

7.2.2 Lighting technologies

The 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) having high CRI are more suitable for indoor lighting, while high pressure sodium vapour (HPSV) and low pressure sodium vapour (LPSV) lamps having lower CRI are better for outdoor lighting. Table 7.3 provides a comparison of different lighting technologies.

Useful tips for choosing an energy-efficient lighting system are as follows:

- 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 the light distribution.

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 and have smart placement of

[1] *Chuard P, 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

fixtures in order to achieve the desired distribution of light in the adjacent space. Control systems can further increase energy savings by operating the lighting system efficiently.

Some useful tips related to lighting design are given below.

- For corridors and staircases, the lighting design depends on the space dimension and 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 allow the light to operate in a predefined ON/OFF schedule. These can have one setting (same time) for the whole year or several (seasonal/weekly/daily) settings to align with the changing daylight availability. Another possibility is to use ON/OFF type photo sensors to switch ON or OFF the outdoor lights by sensing the daylight levels.
- Occupancy sensors can be used in some common areas (e.g., corridors). Sensors are simple controls that turn ON when someone enters the space and turns OFF when there is no occupancy.

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)

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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 that lamp. This attribute is measured in CRI, which peaks at 100.

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 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. The pressure head is usually expressed in metres of water and it is the sum of the static head and the friction head. The static head in the pumping system is the water level difference between the GLR and the OHR. For example, for a 25-storey building with 3 m floor-to-floor-height, 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 the water friction that occurs as water flows through the pipeline. Friction head loss includes that in pipe-work and fittings starting from the suction inlet fitting, through to the discharge pipe outlet. For a given discharge flow rate, this friction loss depends on the pipe material, size, length, and the type and number of fittings. It can be computed once these pipeline specifications are determined. For example, 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 are also elements to be considered in the selection process. Multi-storey residential buildings being considered in these guidelines 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).

It is very important to understand the pump characteristic curve to select a suitable pump to meet the requirement. A pump characteristic curve is a graphical representation of how the pump's operating parameters, head, power, and efficiency vary with flow (Figure 7.3). Pump manufacturers provide a chart that indicates the range flow rate and system head

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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 capita per day.

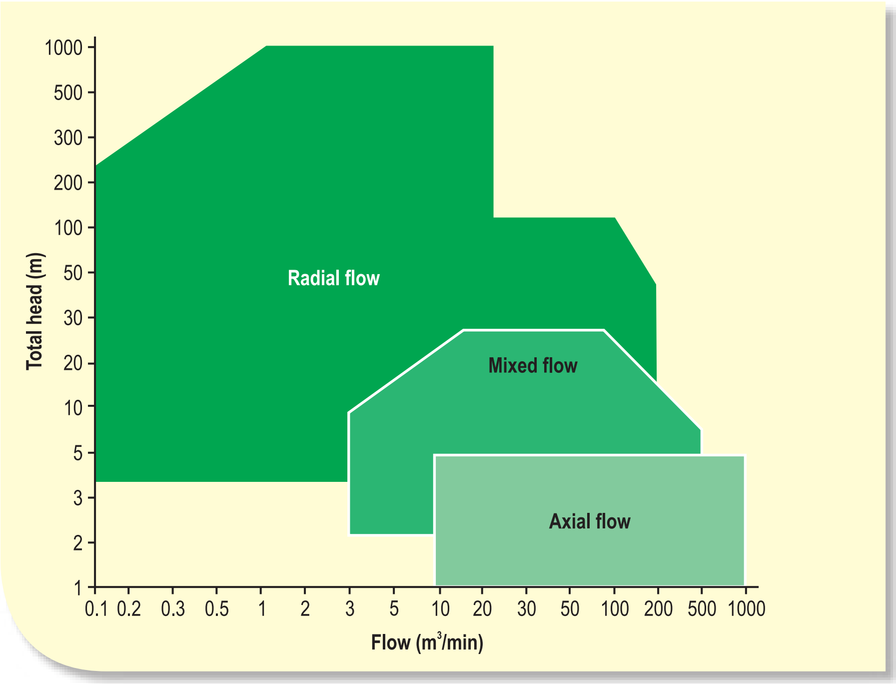

Figure 7.2 Centrifugal pump types and ranges[7]

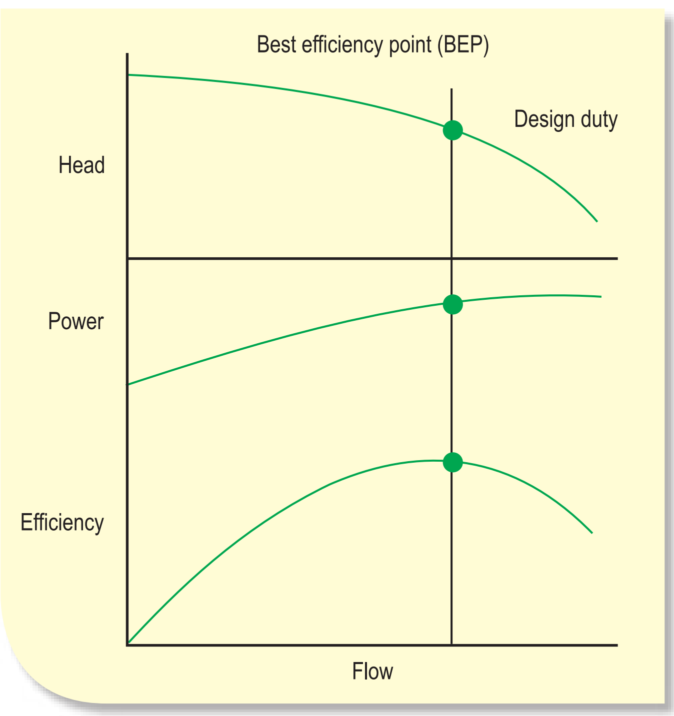

Figure 7.3 Simplified characteristic curve for centrifugal pump

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

for a particular pump and they 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 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.

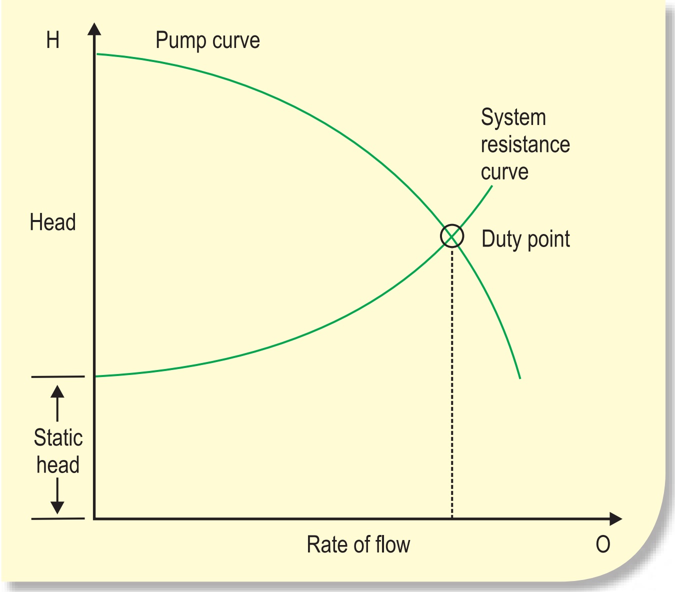

Figure 7.4 *The duty point of a pump*

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 available from overhead tanks, particularly on the upper floors, resulting in even distribution of water for all floors (Figure 7.5).

In hydro-pneumatic systems,[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 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 off the pumps. As water is drawn into the system, pressure falls into the vessel starting the pump 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 design of pumping system

- Pumped gravity system
  - Pump selection should be such that the head and flow parameter for the duty point matches that of the BEP of the pump. Energy audits of residential complexes

[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) Code of Practice for Plumbing in Multi-Storeyed Buildings. New Delhi: BIS*

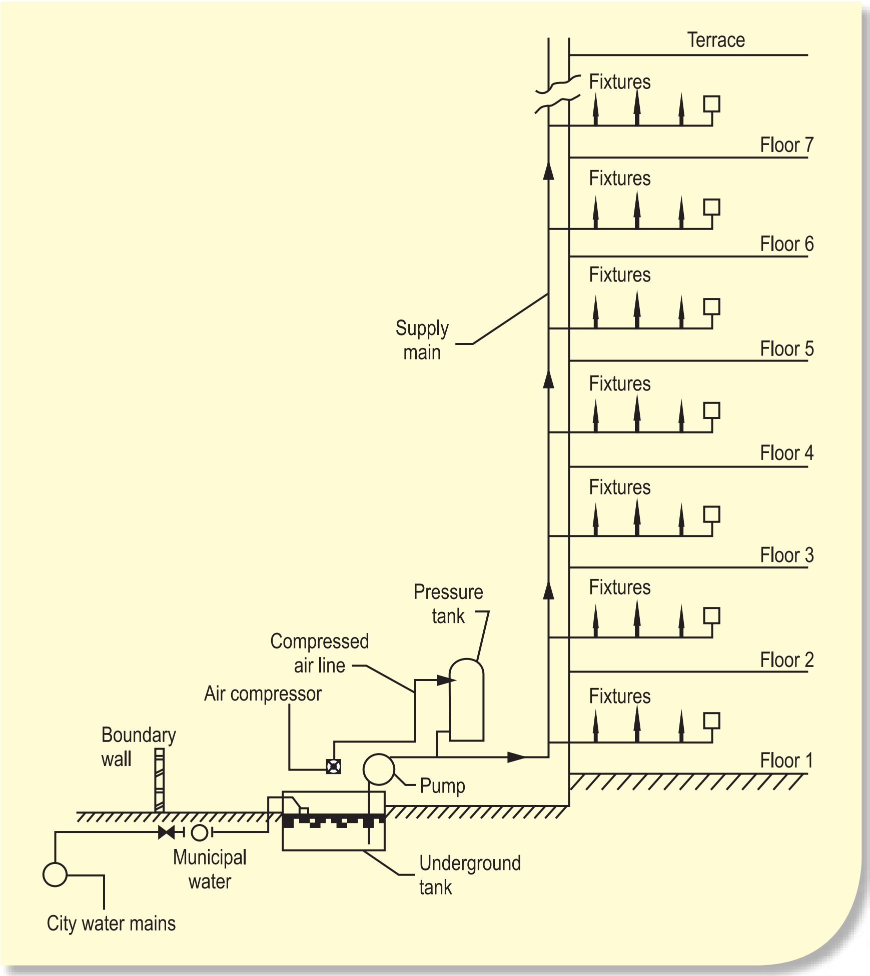

Figure 7.5 *Schematic of hydro-pneumatic pumping system*

show that the pumps are often oversized, thus oversizing of the pumps should be avoided.

- The aim of the piping design should be to reduce frictional losses by
  - maximising pipe diameter,
  - optimising pipe layout to minimise pressure loss,
  - minimising pressure losses through valves and fittings, and
  - selecting the 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.
- It is strongly recommended to install VFDs for all pumps in a hydro-pneumatic pumping system.

7.4 Energy-efficiency in lifts[10]

7.4.1 Types of lifts

The lifts are broadly classified as:

- Hydraulic lifts: These are commonly used where the lift travel is less than 20 m (up to 6 or 7 floors).
- Traction lifts: This is further divided in 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

The electricity consumption in lifts can be classified under two heads:

1. Running electricity consumption, which is mainly the electricity consumption in the motors for lift operation
2. Standby electricity consumption, which is the electricity consumption 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 consumption in the lifts installed in residential buildings is for standby electricity consumption (Figure 7.6). This is due to the amount of time spent in standby mode in residential buildings, where the utilisation of lifts is much lower than in lifts installed in offices and industries.

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.

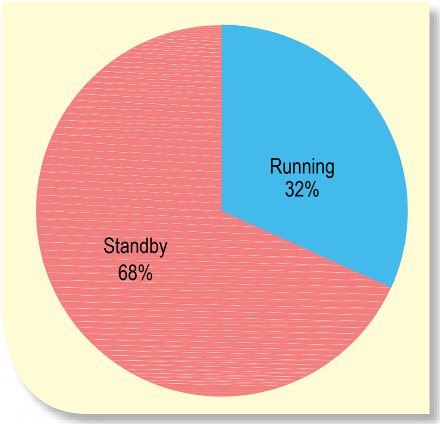

Figure 7.6 *Proportion of standby and running mode to overall energy consumption of lifts in residential buildings*[11]

[10] *This section on lifts is based on the report: E4 Project – European Union (March 2010): Energy Efficient Elevators and Escalators. <http://www.e4project.eu/>*

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

Table 7.4 Results of monitoring of residential lifts in Europe[12]

	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%.[13] 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 both the electricity consumption for running the lift, as well as for the time it spends in 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 lift car interior.
  - 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 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.

[12] *Ibid.*
[13] *Ibid.*

RECOMMENDATIONS

Recommendation 12: 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 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 13: Incorporate energy-efficiency features in the design of community water pumping system

- Pumped gravity system
  - Select pump so that the head and flow parameter 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 14: 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
  - Lifts with gearless systems
  - Incorporation of regenerative braking

CHAPTER 8

RENEWABLE ENERGY INTEGRATION

AT A GLANCE

Composite and hot-dry regions of India receive high intensity solar radiation. Most of the urban centres located in these regions receive annual global solar irradiation >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, 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 roof area per flat for a 4-storey building to 2–3 m^2 roof area per flat for a 24-storey building.

Solar water heating

In the composite and hot-dry climates, the demand for hot water is usually limited for 6 months in a year (October to March), with peak demand occurring in the month of December and January. The average daily demand for hot water per flat is around 300 litres at 40 °C.

Solar water heater 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 solar water heating systems.

Solar photovoltaic

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

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

AT A GLANCE

RECOMMENDATIONS FOR RENEWABLE ENERGY INTEGRATION

Recommendation 15: 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 12 storeys, community solar water heating systems on the roof (assuming utilisation of 60% of the roof area) can meet around 70% of the annual electricity requirement for heating water. Beyond 12 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 solar water heating and solar PV systems, in most of the 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.

8.1 Introduction

Composite and hot-dry regions of India receive high-intensity solar radiation. Most of the urban centres located in these regions receive annual global solar irradiation >1700 kWh/m^2.year (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 four 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 technology) and electricity (using solar photovoltaic [PV] technology).

Figure 8.1 *Global horizontal irradiation of India*[1]

[1] *Ministry of New and Renewable Energy, Government of India*

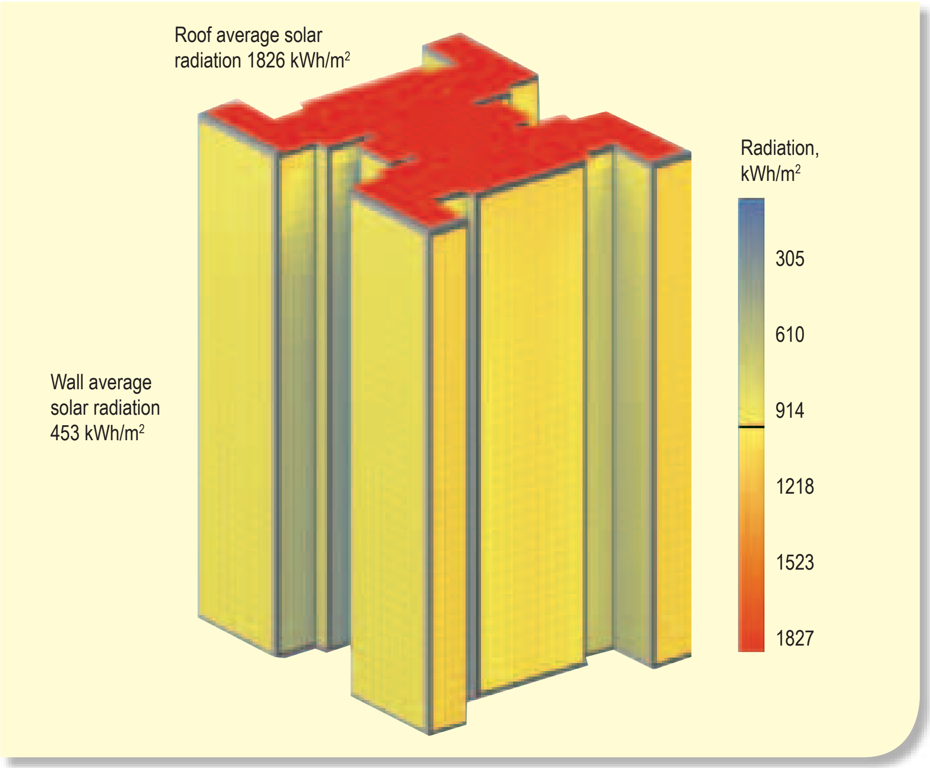

Figure 8.2 *Average annual solar irradiation on roof and walls for a tower typology 12-storey building in New Delhi*

8.2 Availability of roof-top 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.

As an example, for a typical building block of tower type (Figure 8.2), having four flats on each floor, 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 per

Table 8.1 Example showing roof area available 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

flat is plotted against the variation in height for the building specified in Table 8.1. The plot is for two conditions: (a) 60% of the roof area is assumed to be available for solar energy technologies, and (b) 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. One, solar water heater technology can be used for heating water to meet the hot water requirements of the residents, and/or two, solar PV technology can be used to generate electricity (Figures 8.4 and 8.5).

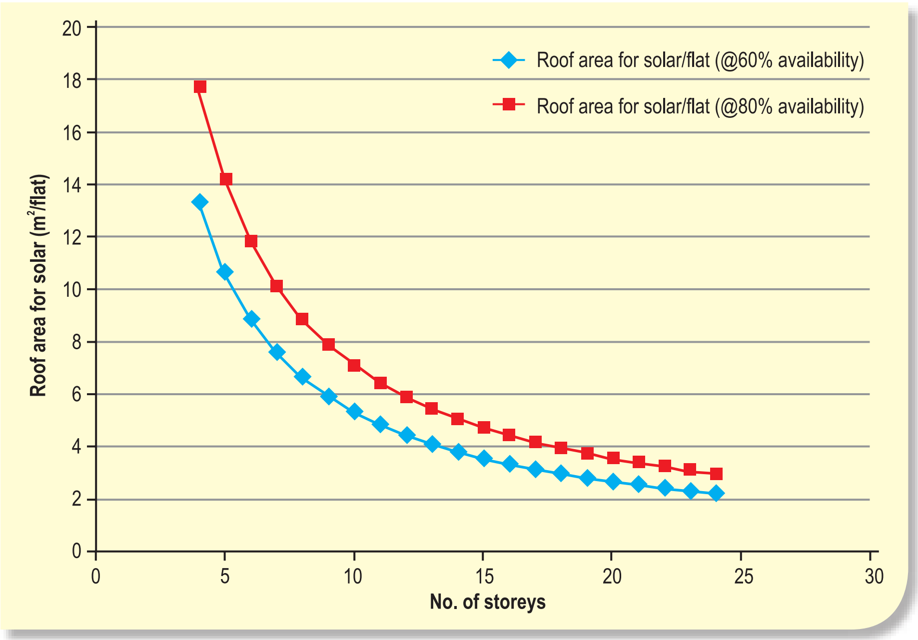

Figure 8.3 *Variation in available roof area for solar/flat with the number of storeys*

8.3 Solar water heaters

8.3.1 Hot water requirement

In residential buildings located in the composite and hot-dry climates, the hot water requirement is generally limited to six months (October to March). The hot water requirement for a typical flat during this period is estimated to be around 300 litres of hot water (at 40 °C) per day (Table 8.2). The hot water requirement for bathing is the highest.

Figure 8.4 *Solar water heater system*[2]

Figure 8.5 *Solar PV system*[3]

Table 8.2 Hot water requirement for a typical flat

Hot water norms (for winter months) @ 40 °C[4]	
Bathing per person per day	40 litres
Washbasin 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 system sizing of solar water heaters 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[5] software. The analysis was done for New Delhi and Nagpur. The results of the analysis are presented in the following sections.

8.3.2 Electricity required for water heating with electric geysers

In the business-as-usual case, individual electric geysers are used for heating water. The annual electricity consumption for hot water generation using electric geysers is estimated to be 1210 kWh/flat.year in New Delhi and 1045 kWh/flat.year in Nagpur (Table 8.3).

8.3.3 Solar water heating system sizing and output

The general strategy for designing solar water heaters is to size it for the peak winter season. Using the RETScreen software, the size and output of the solar water heating system for the three cases (6, 12, and 24 storeys) was calculated for New Delhi and Nagpur. The results presented in Table 8.4 are summarised below.

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[2] *<http://mnre.gov.in/file-manager/UserFiles/Photogalary_swh.pdf>*

[3] *<http://firstgreenconsulting.wordpress.com/2012/06/18/innovative-rooftop-solar-pv-installations-worldwide/>*

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

[5] *RETScreen is an Excel-based clean energy decision-making software program developed by the Government of Canada. It is widely used for renewable energy project analysis. Details are available on their website: <www.retscreen.net>*

Table 8.3 Electricity consumption for hot water generation for a typical flat in New Delhi and Nagpur

Parameter	Useful energy required for hot water generation	
	New Delhi	Nagpur
Minimum temperature of cold water (°C)	10	16
Mean temperature of cold water (October–March) (°C)	23.3	25.5
Useful energy required for heating (kWh/year.flat)	1089	941
Electric energy consumed in water heating (kWh/year.flat)*	1210	1045
Hot water requirement @60 °C for minimum cold water temperature (litres/day)	187	172

*Assuming storage-type geysers with 90% efficiency

Table 8.4 Size and output of solar water heaters (SWH) for typical buildings in New Delhi and Nagpur

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	New Delhi			Nagpur		
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[6])	26	51	101	23	45	89
Sufficient roof area available	Yes	Yes	No	Yes	Yes	No
Number of SWH panels after considering roof area constraint	26	51	53	23	45	53
Heating delivered from SWH (kWh/year)	19,200	37,800	44,700	17,500	34,400	45,500
Solar fraction (%)	74	72	43	77	76	50
Electricity saved (kWh/year)	21,333	42,000	49,667	19,444	38,222	50,556
Electricity saved per flat (kWh/year)	889	875	517	810	796	527

- An optimally sized solar water heating system can meet 72%–77% of the annual energy required for heating water (or solar fraction[7]) for 6- and 12-storey buildings located in New Delhi and Nagpur. As can be observed in Figure 8.6, the solar fraction decreases for buildings higher than 12 storeys due to roof area constraints; for a 24-storey building, only 43% of the energy demand in New Delhi and 50% of the energy demand in Nagpur can be met.

[6] *For winter optimisation, the system is sized so that it can provide the required hot water even for minimum cold water temperatures.*

[7] *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.*

- For a 6-storey building, only 50% of the roof area available for solar systems is utilised, while in a 12-storey building, almost 100% of the roof area available for solar system is utilised. For buildings higher than 12 storeys, there is not sufficient roof area available to install optimum size solar water heaters.

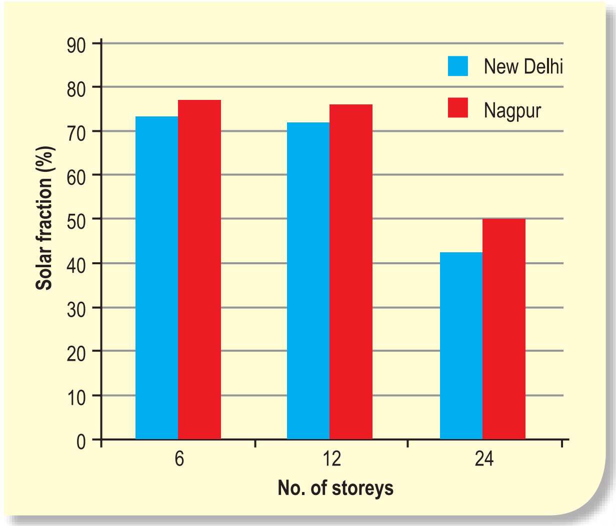

Figure 8.6 Variation in annual solar fraction with the height of building

In Figure 8.7, the solar fraction for New Delhi and Nagpur is shown to vary significantly over different months. In New Delhi, while the SWH system will be able to meet only 61% of the energy requirement for heating water in January, it can meet 93% of the energy requirement in October. The variation for Nagpur is relatively less, varying from 71% in January to 83% in October.

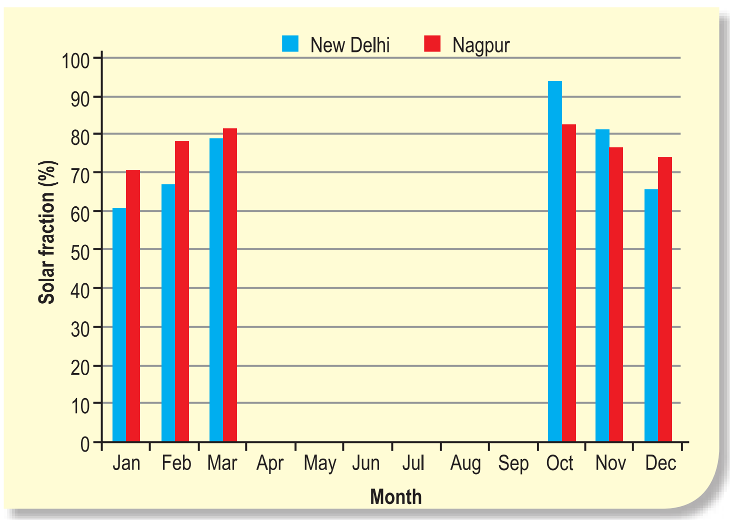

Figure 8.7 Monthly solar fraction for a 6-storey residential building in New Delhi and Nagpur

8.3.4 Solar water heating system configurations

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

1. **Individual system for each flat:**
   In this configuration (Figure 8.8), a separate solar water heating 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) maintenance and service of the individual system is borne by each flat. However, this configuration requires more space on the terrace because a circulation area needs to be left between two solar systems. Also, the length and cost of the hot water piping are relatively high, and providing hot water at requisite temperatures to the flats situated on the lower floors is also difficult due to longer hot water pipe length and related higher pipe heat losses. This system is usually used only for buildings up to four storeys.

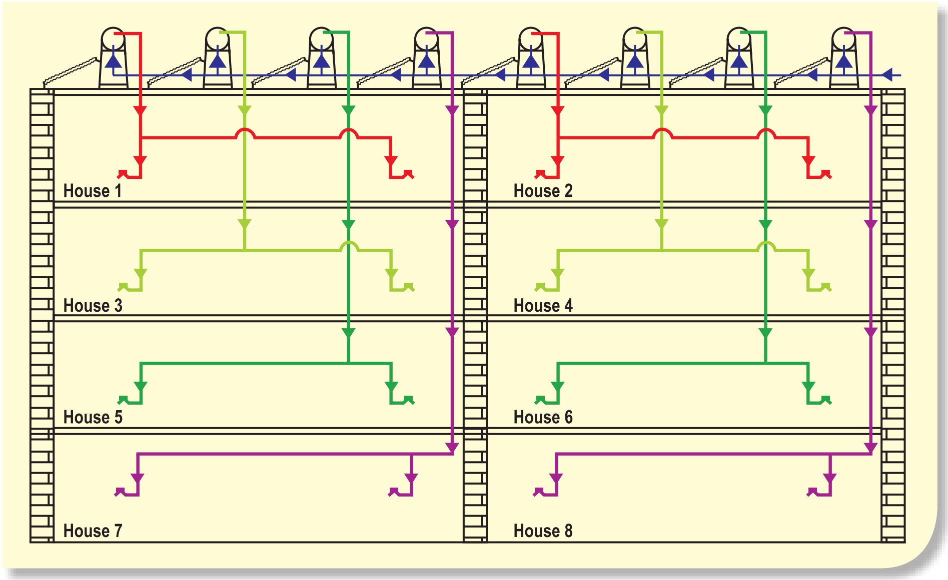

Figure 8.8 *Schematic for individual system for each flat*[8]

2. **Community type system**: In this configuration (Figure 8.9), a large solar water heating system that is capable of providing hot water to the entire building is installed on the roof. The hot 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 for (a) efficient back-up heating, (b) ensuring equal hot water sharing among the flats, and (c) ensuring 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 solar water heater 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 in 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

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

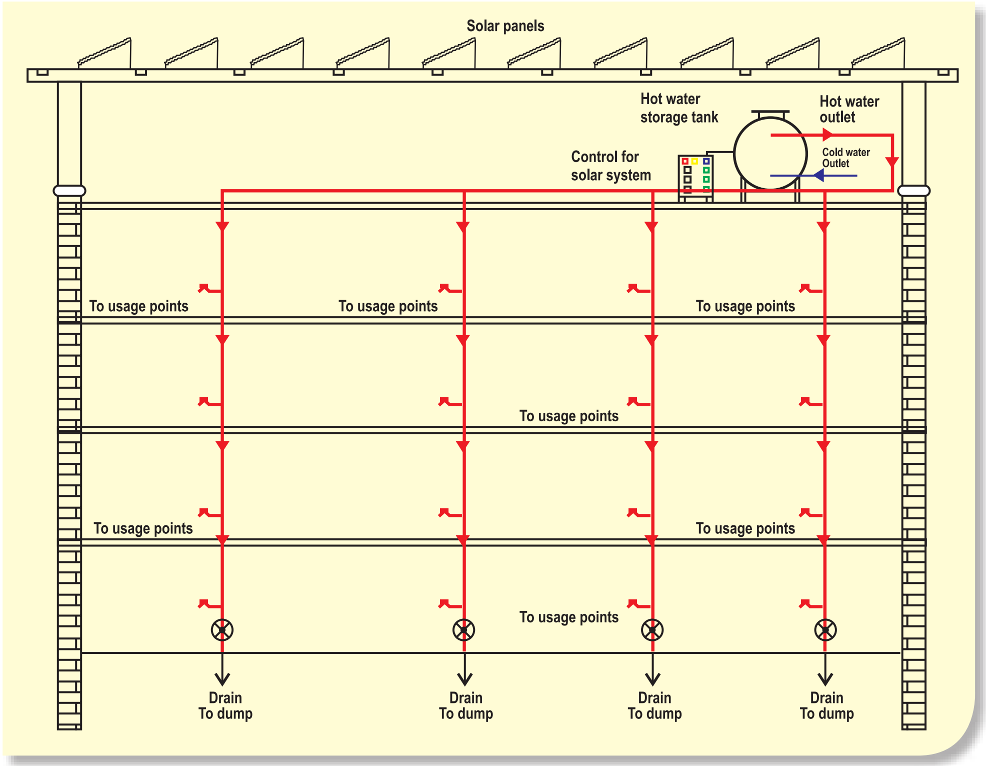

Figure 8.9 *Schematic for community type system*[9]

pre-set temperature and diverts water from the solar water heating 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 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 12-storey buildings, there is usually sufficient roof space to install a solar water heating system that can meet around 75% of the annual energy required for heating water in the composite and hot-dry climate regions.
- For buildings that are more than 12 storeys, the amount of hot water generated through solar energy decreases, and for a 24-storey building 40%–50% of the annual hot water requirement could be met. There are diminishing returns due to increased complexity in distribution and heat losses.

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

- To be effective, the design of solar water heating 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.

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 solar water heating system was conducted for the available roof area of typical building units (described in Table 8.1) for two locations, New Delhi and Nagpur.

8.4.1 Electricity generation from solar PV technology

The System Advisory Model (SAM[10]) was used to estimate the electricity generation from 1 kW_p of solar PV system at New Delhi and Nagpur. Table 8.5 and Figure 8.10 show the annual electricity generation and variation in the monthly average daily output of the solar system.

Table 8.5 Annual electricity generation from 1 kW^p solar PV system at New Delhi and Nagpur

	New Delhi	Nagpur
Annual electricity generation (kWh/kW_p.year)	1472	1535

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 the 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 annually around 31,000 kWh in New Delhi and 32,000 kWh in Nagpur (Table 8.6).

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	**New Delhi**	**Nagpur**
Annual electricity generation (kWh/year)	30,904	32,232

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

[10] *The System Advisor Model was developed by the National Renewable Energy Laboratory.*

[11] *Energy Market Authority and Building and Construction Authority. (undated) Handbook for Solar Photovoltaic Systems. Singapore: Energy Market Authority and Building and Construction Authority.*

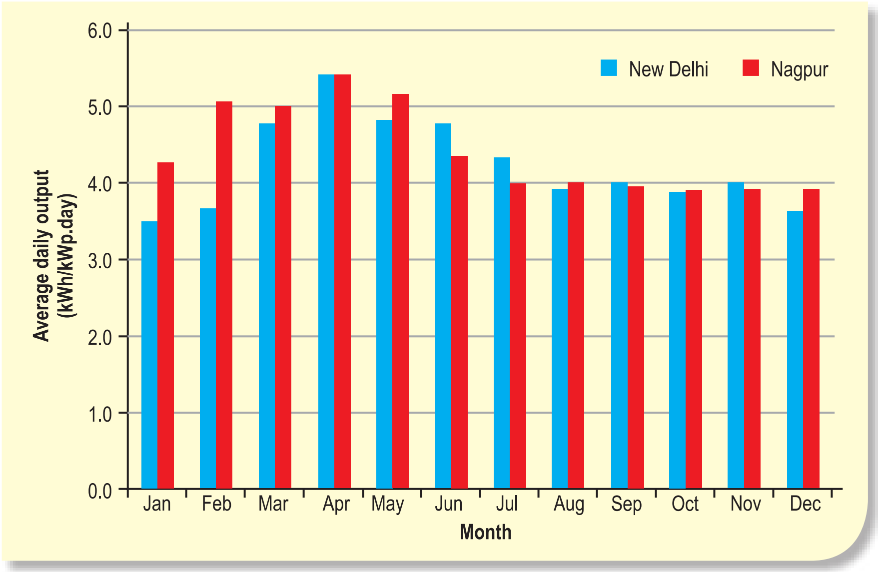

Figure 8.10 Average daily output for solar PV system at New Delhi and Nagpur

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 Delhi, 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 performance index (EPI) of 60 kWh/m^2.year and 30 kWh/m^2.year. It can be observed that if, through the energy-efficiency measures described in Chapters 3 to 7, the total EPI (including that for common services) 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 multi-storey building complexes.

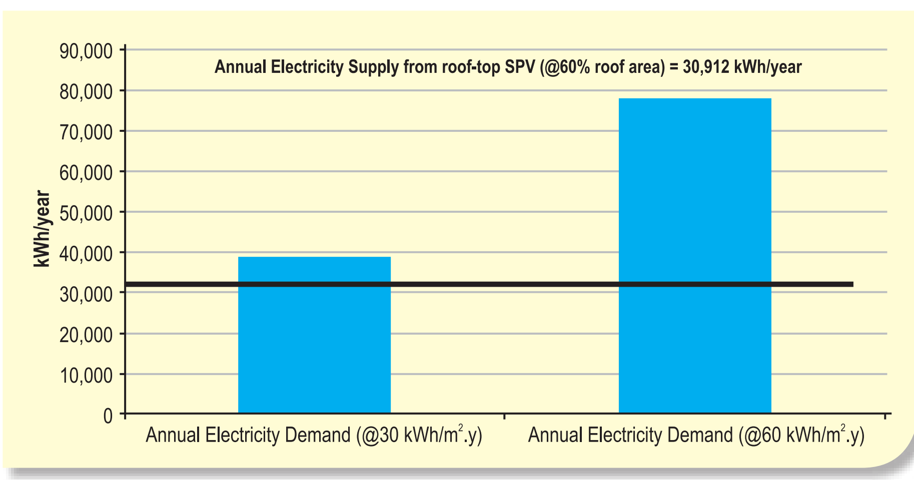

Figure 8.11 Electricity generation from rooftop solar PV on a 4-storey building vs. annual electricity demand

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/m².year), the electricity generated from the rooftop solar PV system is sufficient to meet the electricity requirements for all the common services in buildings up to 20 storeys high. When the electricity consumption for common services is higher (10 kWh/m².year and 15 kWh/m².year), rooftop solar PV can meet the electricity requirement for buildings up to 10 and 6 storeys, respectively.

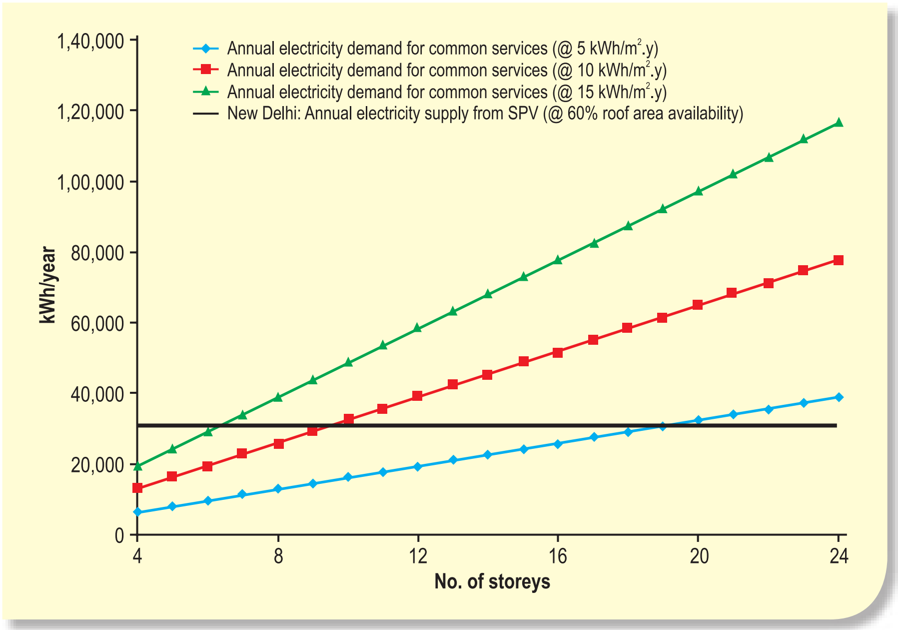

***Figure 8.12** Potential solar PV generation from rooftop solar PV system vs. annual electricity consumption for common services*

8.4.5 Configuration of solar PV system[12]

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 nighttime loads. Electricity for water pumping and lifts during daytime can be directly supplied by the solar PV system. The energy stored in the batteries can be used to meet the requirement of lighting and lifts during the night. This configuration requires a substantial battery bank to store the electricity for nighttime. The schematic of this system is shown in Figure 8.13.

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[12] *Energy Informative <http://energyinformative.org/grid-tied-off-grid-and-hybrid-solar-systems/>*

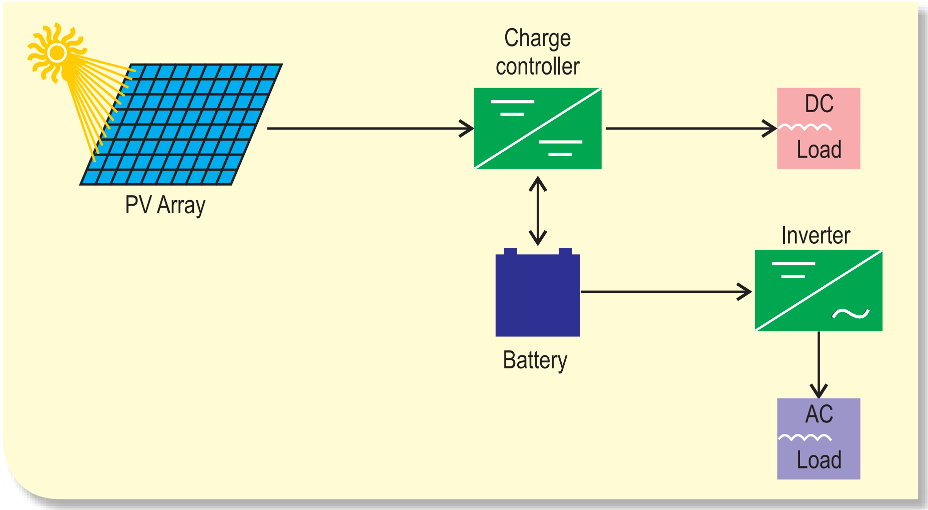

Figure 8.13 Schematic for solar PV system for stand-alone off-grid configuration

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.
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

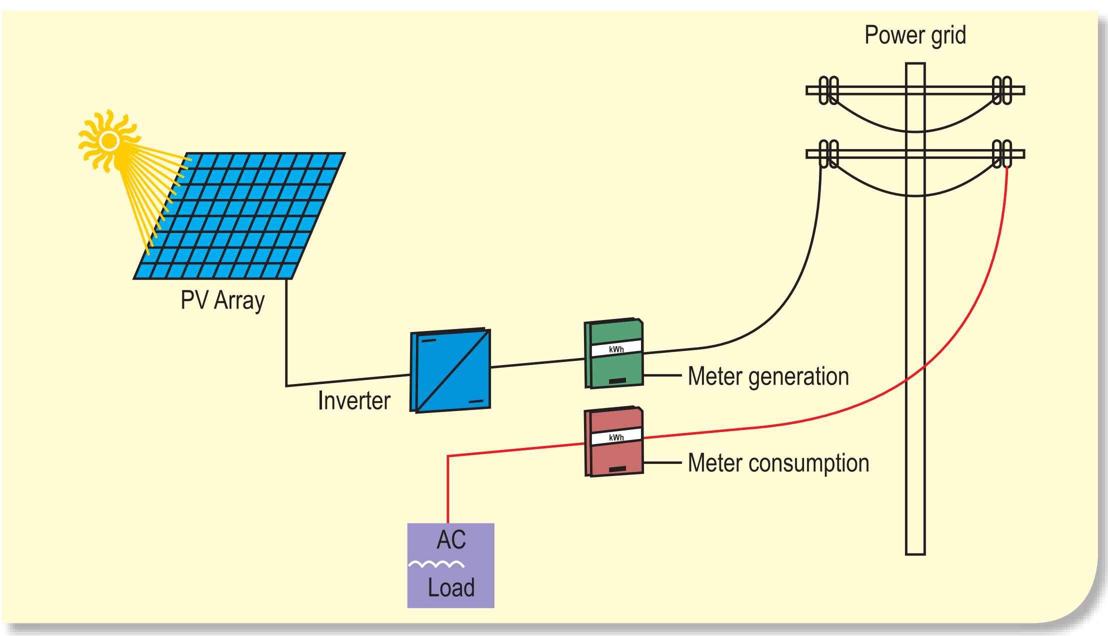

Figure 8.14 Schematic for solar PV system for grid-tied configuration[13]

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

solar PV system and another 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.

8.4.6 Emerging technologies (DC-to-home[14])

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 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 to 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).

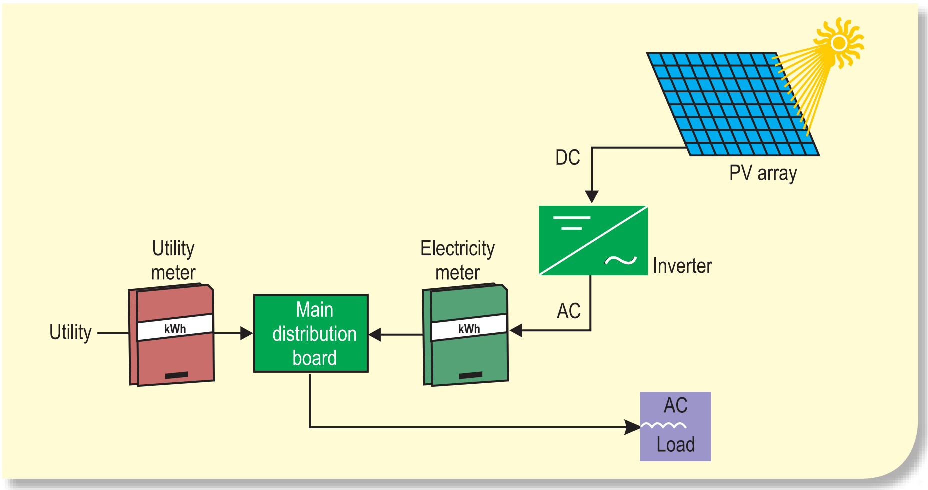

Figure 8.15 *Schematic for solar PV system for hybrid system configuration*[15]

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

[15] *HK RE Net <http://re.emsd.gov.hk/english/solar/solar_ph/solar_ph_to.html>*

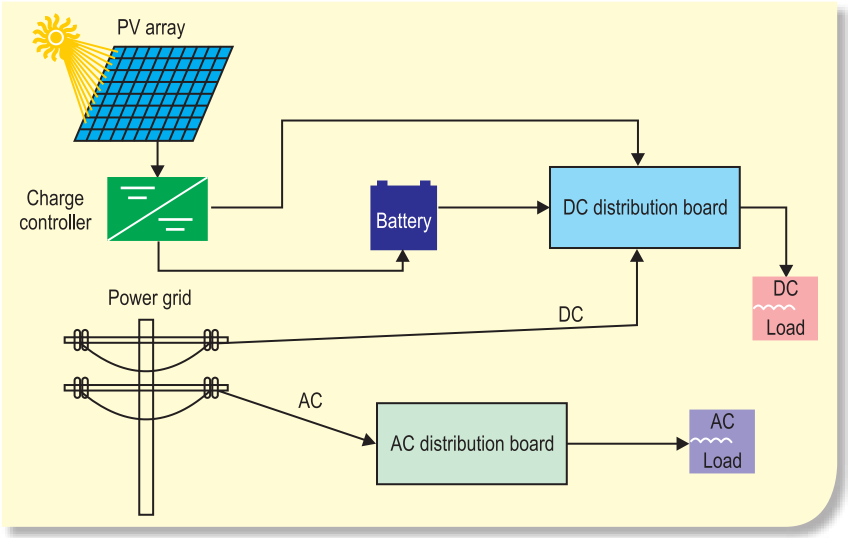

Figure 8.16 *Parallel DC and AC supply with solar PV integration*

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 in the nighttime. 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.

RECOMMENDATIONS

Recommendation 15: 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 solar water heating 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 12 storeys, community solar water heating systems on the roof (assuming utilisation of 60% of the roof area) can meet around 70% of the annual electricity requirement for heating water. Beyond 12 storeys, there are diminishing returns due to lower energy replacement, increased complexity in distribution, and heat losses.

contd...

Unlike individual and low-rise housing where the roof area is sufficient to install both solar water heating and solar PV systems, in most of the 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: LIST OF STAKEHOLDERS WHO PARTICIPATED IN VARIOUS CONSULTATIONS

Participants of Stakeholder Workshop (28 July 2014)

Smita Chandiwala
Shakti Sustainable Energy Foundation

Aalok Deshmukh
Schneider Electric India

Vishal Garg
International Institute of Information Technology, Hyderabad

Vishal Goyal
National Housing Bank

Veena Joshi
Climate Change and Development Division, Embassy of Switzerland

Radhika Khosla
Centre for Policy Research

Priyanka Kochhar
Association for Development and Research of Sustainable Habitats

Satish Kumar
Schneider Electric India

Ashok B Lall
Ashok B Lall Architects

Sharad Maithel
Maithel & Associates Architects Pvt. Ltd

Mili Majumdar
The Energy and Resources Institute

Rajat Malhotra
Jones Lang LaSalle

Sanyogita Manu
Centre for Environmental Planning and Technology (CEPT) University

Gyan Chand Modgil
Sterling India

Usha K Rao
KfW

Rajan Rawal
Centre for Environmental Planning and Technology (CEPT) University

Sanjay Seth
Bureau of Energy Efficiency

Anand Shukla
Climate Change and Development Division, Embassy of Switzerland

Tanmay Tataghat
Environmental Design Solutions

Julius Weisner
KfW

Hina Zia
The Energy and Resources Institute

Daniel Ziegerer
Climate Change and Development Division, Embassy of Switzerland

Expert Consultation (May–July 2014)

Sharad Maithel
Maithel & Associates Architects Pvt. Ltd

Gyan Chand Modgil
Sterling India

Tanmay Tathagat
Environmental Design Solutions

Participants of Experts Workshop (15 November 2013)

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Tanmay Tataghat
Environmental Design Solutions

Assistance in Collection of Survey Data

Management and residents of:

- Abhiyan Apartments, Dwarka, New Delhi
- HEWO Towers, Gurgaon
- DDA Flats (D-4, D-3, and B-10 sectors), Vasant Kunj, New Delhi

ANNEXURE 2: ANNEXURES TO 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.4.1 for the convenience of the reader.

Table A.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	26 °C
Location	Delhi

[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.4-1 (page 114).

- 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.4-1 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 77%, i.e., reduces by 23% 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 becomes 54%, i.e., reduces by 46% compared to the base case.
- 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. It shows that by adopting Package III measures, the cooling thermal energy demand becomes 44%, i.e., reduces by 56% compared to the base case.

Figures A.4-2 to A.4-32 show results of parametric simulation runs obtained by varying the number of exposed walls (1 or 2), set-point temperature (22, 24, 26, and 28 °C) and window-to-floor ratio (27% or 54%). The details of the cases for the simulation runs are given in Table A.4.2.

Table A.4.2 Details of simulation runs for the bedroom

Figure number	Number of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Set-point temperature (°C)	Window-to-floor ratio (%)
A.4-1	2	South	West	26	27
A.4-2	1	South	Internal	26	27
A.4-3	2	South	West	26	54
A.4-4	1	South	Internal	26	54
A.4-5	2	South	West	28	27
A.4-6	1	South	Internal	28	27
A.4-7	2	South	West	28	54
A.4-8	1	South	Internal	28	54
A.4-9	2	West	North	26	27
A.4-10	1	West	Internal	26	27
A.4-11	2	West	North	26	54
A.4-12	1	West	Internal	26	54
A.4-13	2	West	North	28	27
A.4-14	1	West	Internal	28	27
A.4-15	2	West	North	28	54
A.4-16	1	West	Internal	28	54

Contd...

Table A.4.2 contd....					
Figure number	Number of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Set-point temperature (°C)	Window-to-floor ratio (%)
A.4-17	2	South	West	24	27
A.4-18	1	South	Internal	24	27
A.4-19	2	South	West	24	54
A.4-20	1	South	Internal	24	54
A.4-21	2	South	West	22	27
A.4-22	1	South	Internal	22	27
A.4-23	2	South	West	22	54
A.4-24	1	South	Internal	22	54
A.4-25	2	West	North	24	27
A.4-26	1	West	Internal	24	27
A.4-27	2	West	North	24	54
A.4-28	1	West	Internal	24	54
A.4-29	2	West	North	22	27
A.4-30	1	West	Internal	22	27
A.4-31	2	West	North	22	54
A.4-32	1	West	Internal	22	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.4.3, which is a reproduction of Table A.4.2 from Chapter 4.

Table A.4.3 Base-case simulation inputs for a living room	
Building component/schedule types/parameters	Living room
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

contd...

Table A.4.3 contd...	
Building component/schedule types/parameters	**Living room**
Intermediate floor 150-mm RCC slab	U-value: 3.0 W/m².K Adiabatic
Infiltration	~0.7 ACH
Window-to-floor area ratio	19%
External wall-to-floor area ratio	129%
Set point	26 °C
Occupancy schedule	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

Figures A.4-33 to A.4-64 show results of parametric simulation runs. The details of the cases for the simulation runs are given in Table A.4.4.

Table A.4.4 Details of simulation runs for the living room

Figure number	Number of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Set-point temperature (°C)	Window-to-floor ratio (%)
A.4-33	2	South	West	26	19
A.4-34	1	South	Internal	26	15
A.4-35	2	South	West	26	39
A.4-36	1	South	Internal	26	30
A.4-37	2	South	West	28	19
A.4-38	1	South	Internal	28	15
A.4-39	2	South	West	28	39
A.4-40	1	South	Internal	28	30
A.4-41	2	South	West	24	19
A.4-42	1	South	Internal	24	15
A.4-43	2	South	West	24	39
A.4-44	1	South	Internal	24	30
A.4-45	2	South	West	22	19
A.4-46	1	South	Internal	22	15
A.4-47	2	South	West	22	39
A.4-48	1	South	Internal	22	30

Contd...

Table A.4.4 contd...					
Figure number	Number of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Set-point temperature (°C)	Window-to-floor ratio (%)
A.4-49	2	West	North	26	19
A.4-50	1	West	Internal	26	15
A.4-51	2	West	North	26	39
A.4-52	1	West	Internal	26	30
A.4-53	2	West	North	28	19
A.4-54	1	West	Internal	28	15
A.4-55	2	West	North	28	39
A.4-56	1	West	Internal	28	30
A.4-57	2	West	North	24	19
A.4-58	1	West	Internal	24	15
A.4-59	2	West	North	24	39
A.4-60	1	West	Internal	24	3
A.4-61	2	West	North	22	19
A.4-62	1	West	Internal	22	15
A.4-63	2	West	North	22	39
A.4-64	1	West	Internal	22	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.

- Case 1: Base case with two exposed walls on south and west orientations, with set-point temperature of 26 ^{0}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 ^{0}C, window-to-floor ratio of 27%
- Case 3: Package 3 with one exposed wall on the south, with set-point temperature of 26 ^{0}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.4.2 for bedrooms and Table A.4.4 for living rooms. In our example, the cases belong to configurations of bedroom, so we need to select the figure number from Table A.4.2.

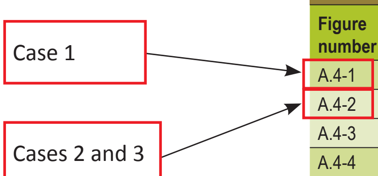
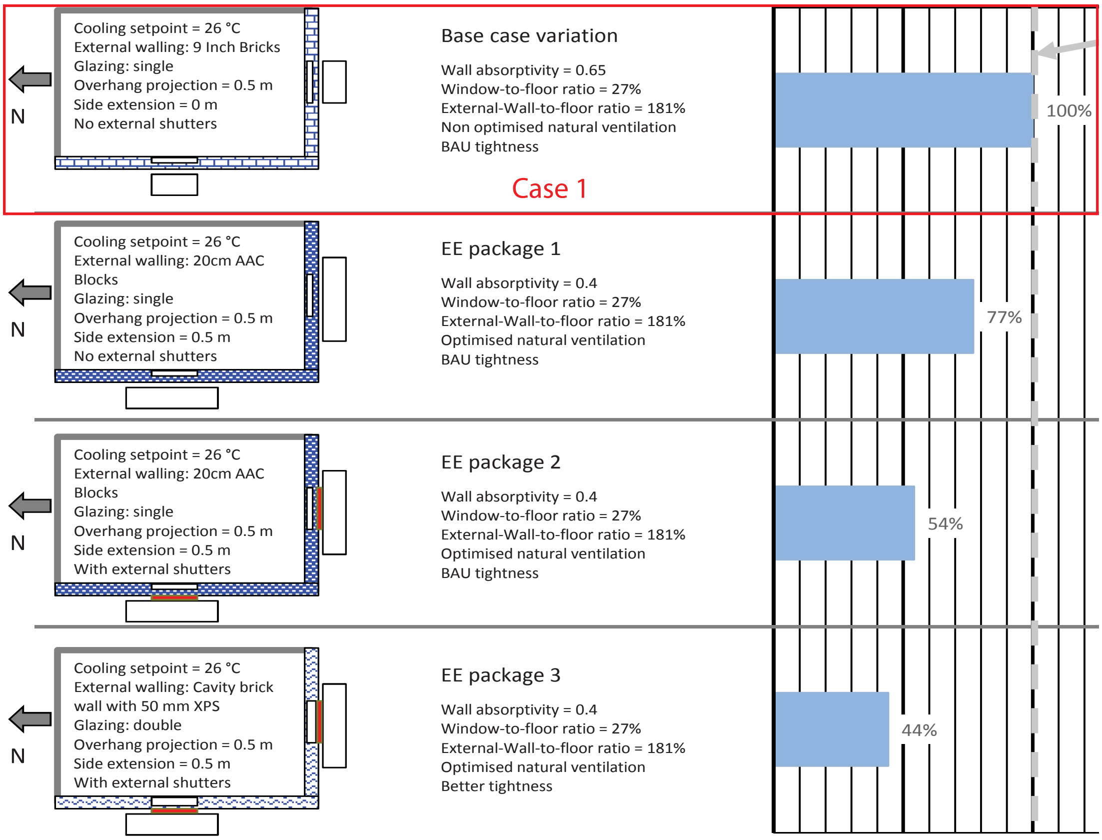


Table A.4.2 Details of simulation runs for the bedroom					
Figure number	Number of exposed walls	Orientation of 1st wall	Orientation of 2nd wall	Set-point temperature (°C)	Window-to-floor ratio (%)
A.4-1	2	South	West	26	27
A.4-2	1	South	Internal	26	27
A.4-3	2	South	West	26	54
A.4-4	1	South	Internal	26	54
A.4-5	2	South	West	28	27

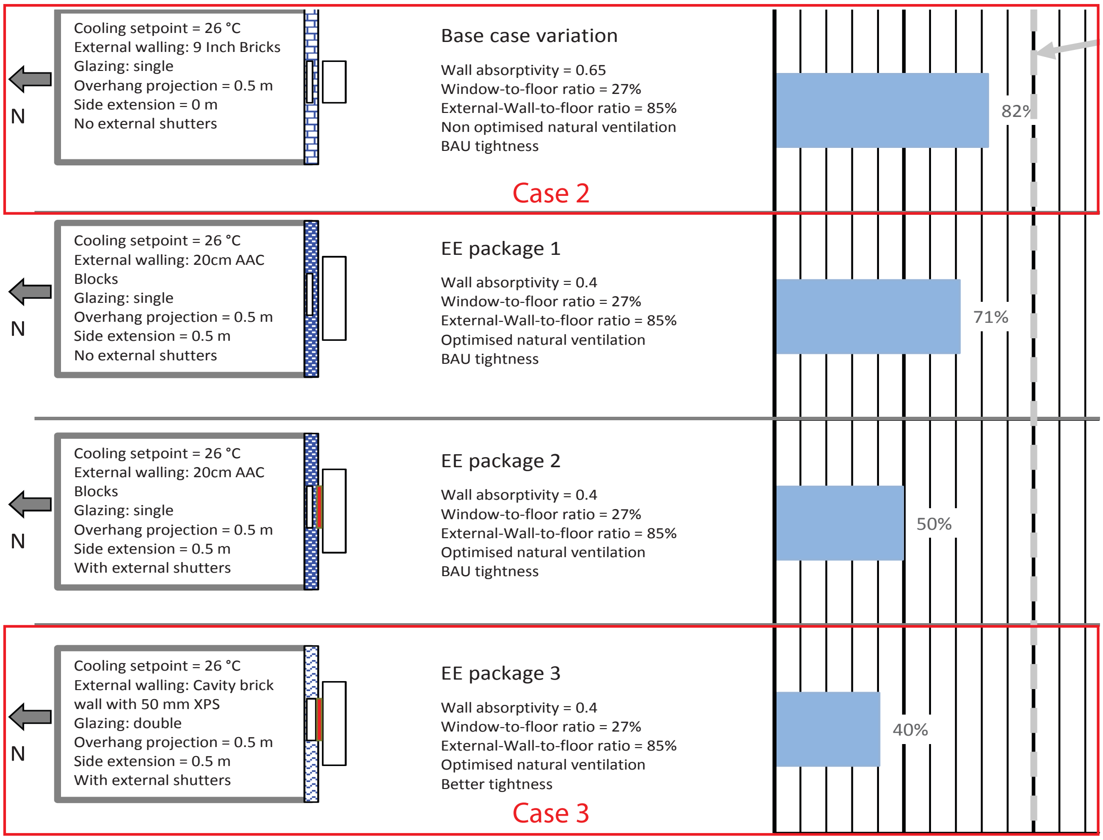
Step 2: Read the respective figures.

In the example given above from Figures A.4-1 and A.4-2, the cases to be evaluated are highlighted in red boxes.

A.4-1

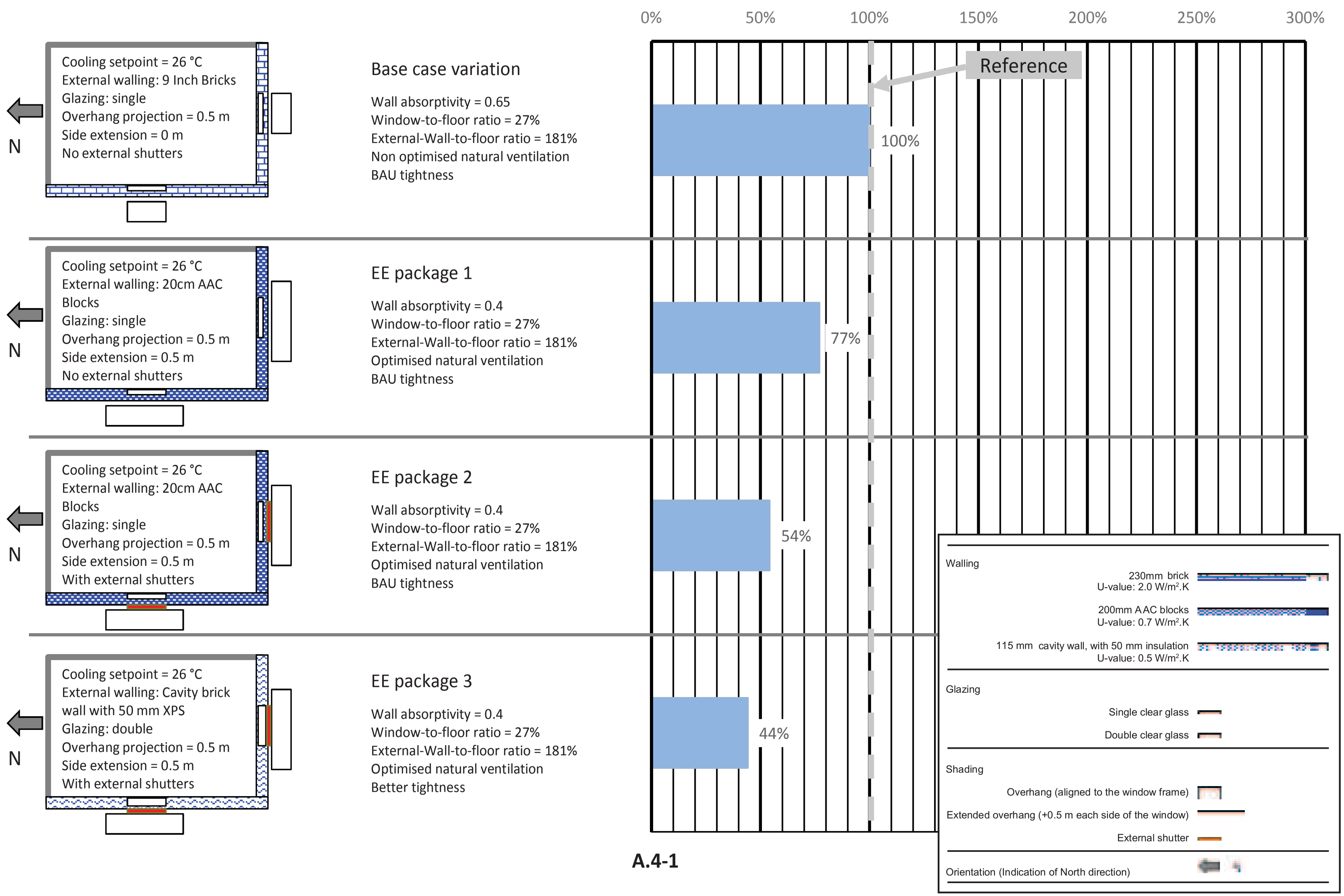


A.4-2

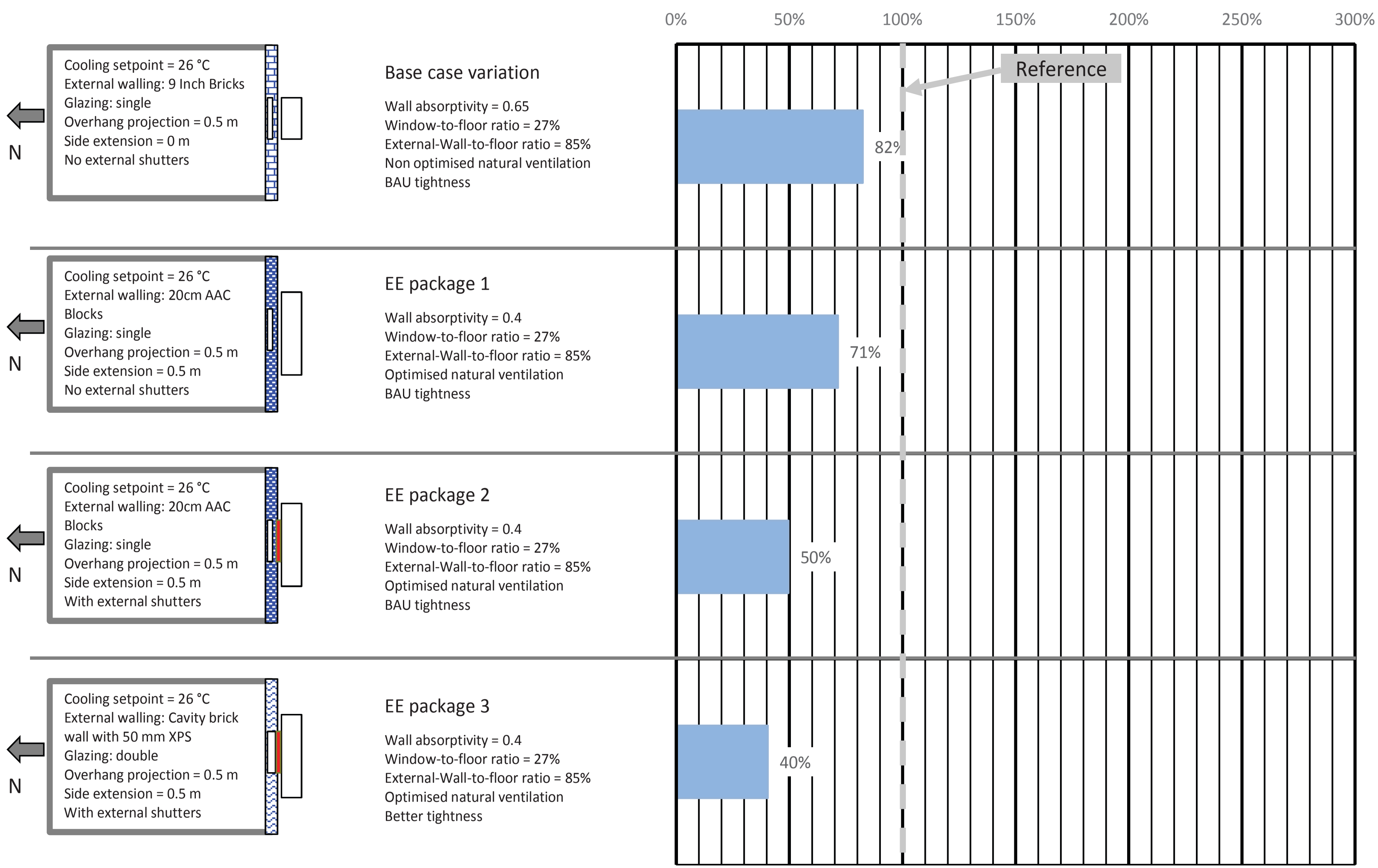


Step 3: The interpretation of percentage annual cooling thermal energy demand of the cases to be evaluated

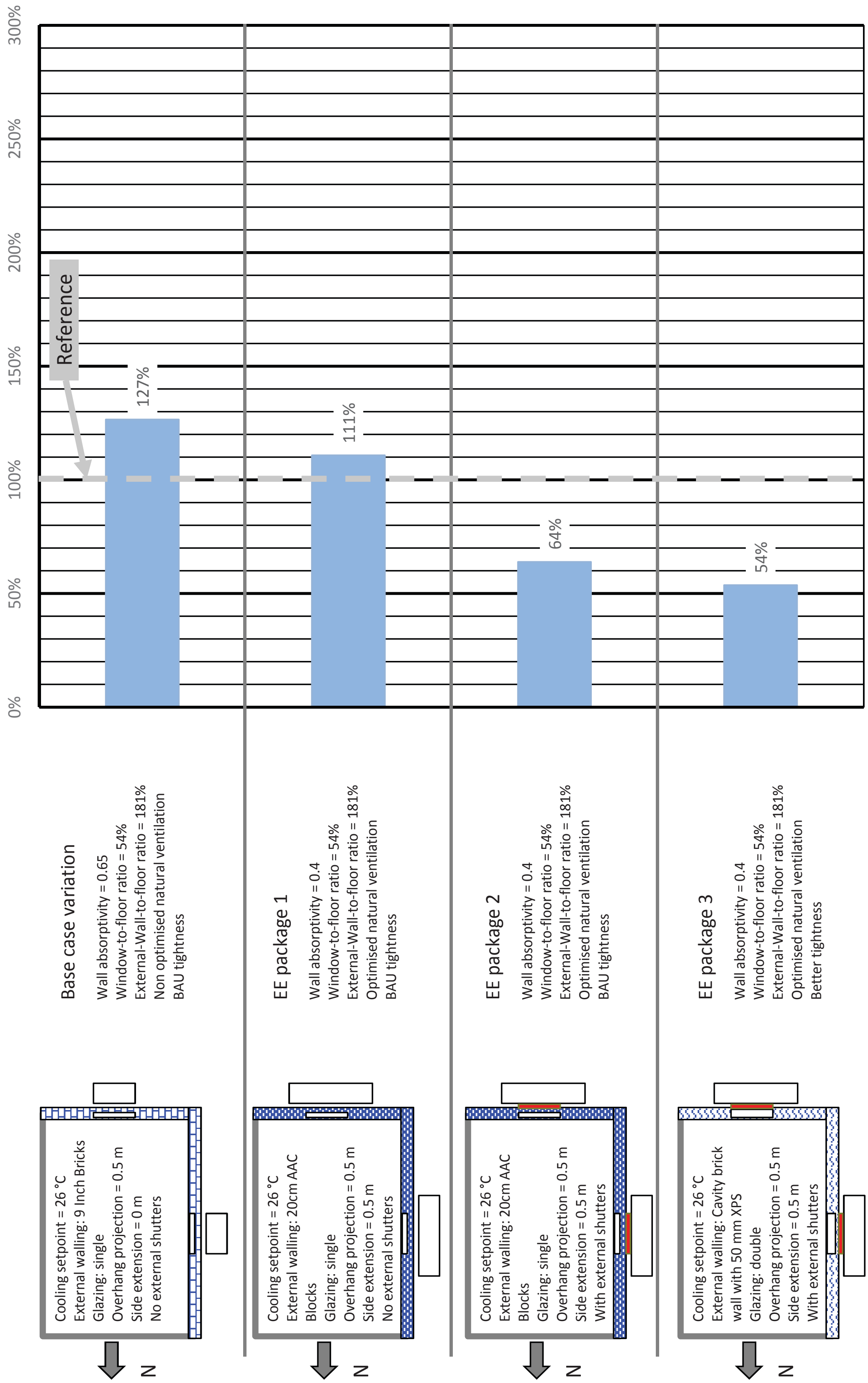
- Case 2 has 18% lower annual cooling thermal energy demand compared to Case 1
- Case 3 has 60% lower annual cooling thermal energy demand compared to Case 1
- Case 3 has 51.2% lower annual cooling thermal energy demand compared to Case 2


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 = 181%
Non optimised natural ventilation
BAU tightness
100%
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 = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
77%
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 = 181%
Optimised natural ventilation
BAU tightness
54%
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 = 181%
Optimised natural ventilation
Better tightness
44%
0%
50%
100%
150%
200%
250%
300%
Walling
230mm brick U-value: 2.0 W/m².K
200mm AAC blocks U-value: 0.7 W/m².K
115 mm cavity wall, with 50 mm insulation U-value: 0.5 W/m².K
Glazing
Single clear glass
Double clear glass
Shading
Overhang (aligned to the window frame)
Extended overhang (+0.5 m each side of the window)
External shutter
Orientation (Indication of North direction)

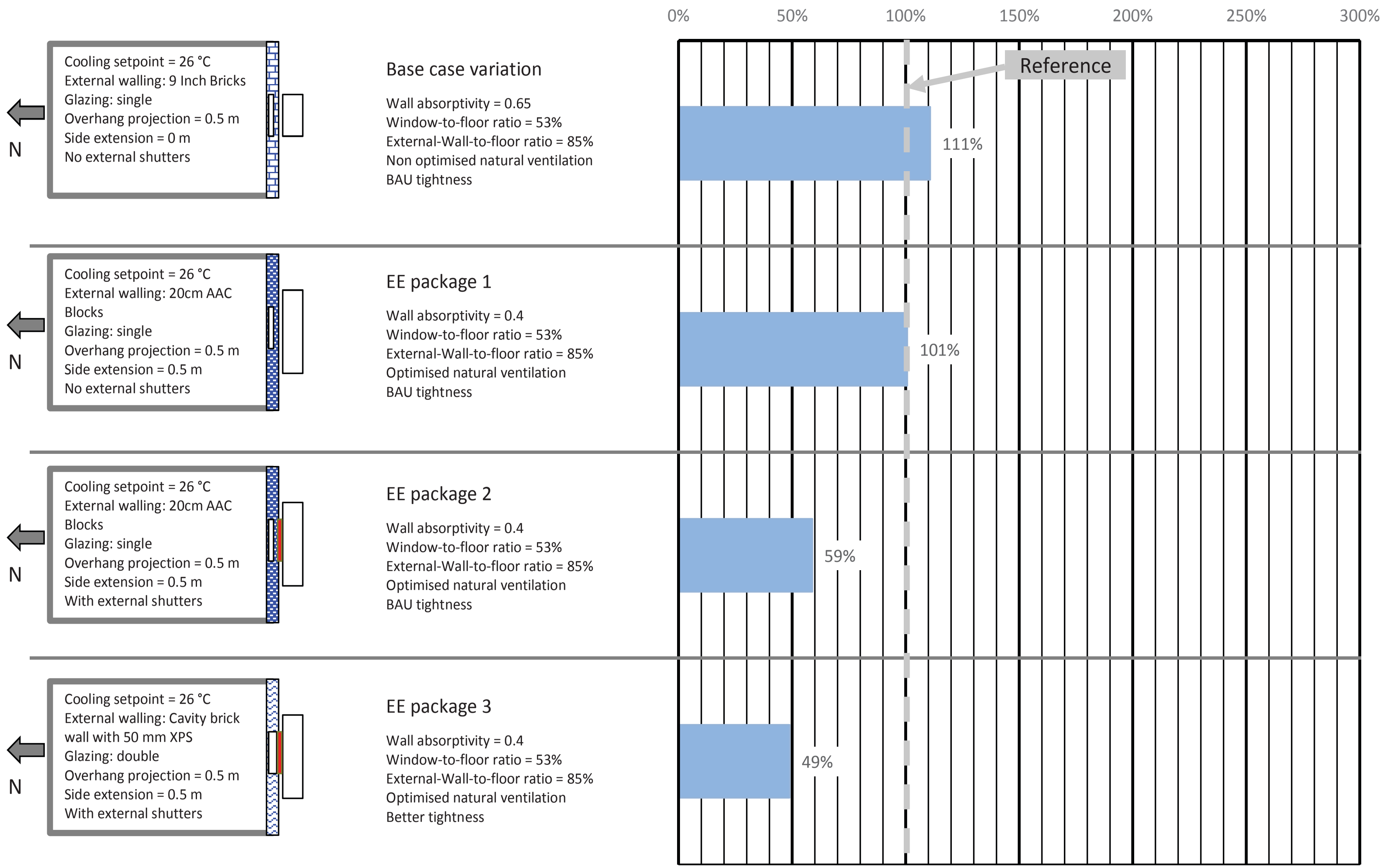
A.4-1


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
82%
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 = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
71%
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
50%
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
40%
0%
50%
100%
150%
200%
250%
300%

A.4-2

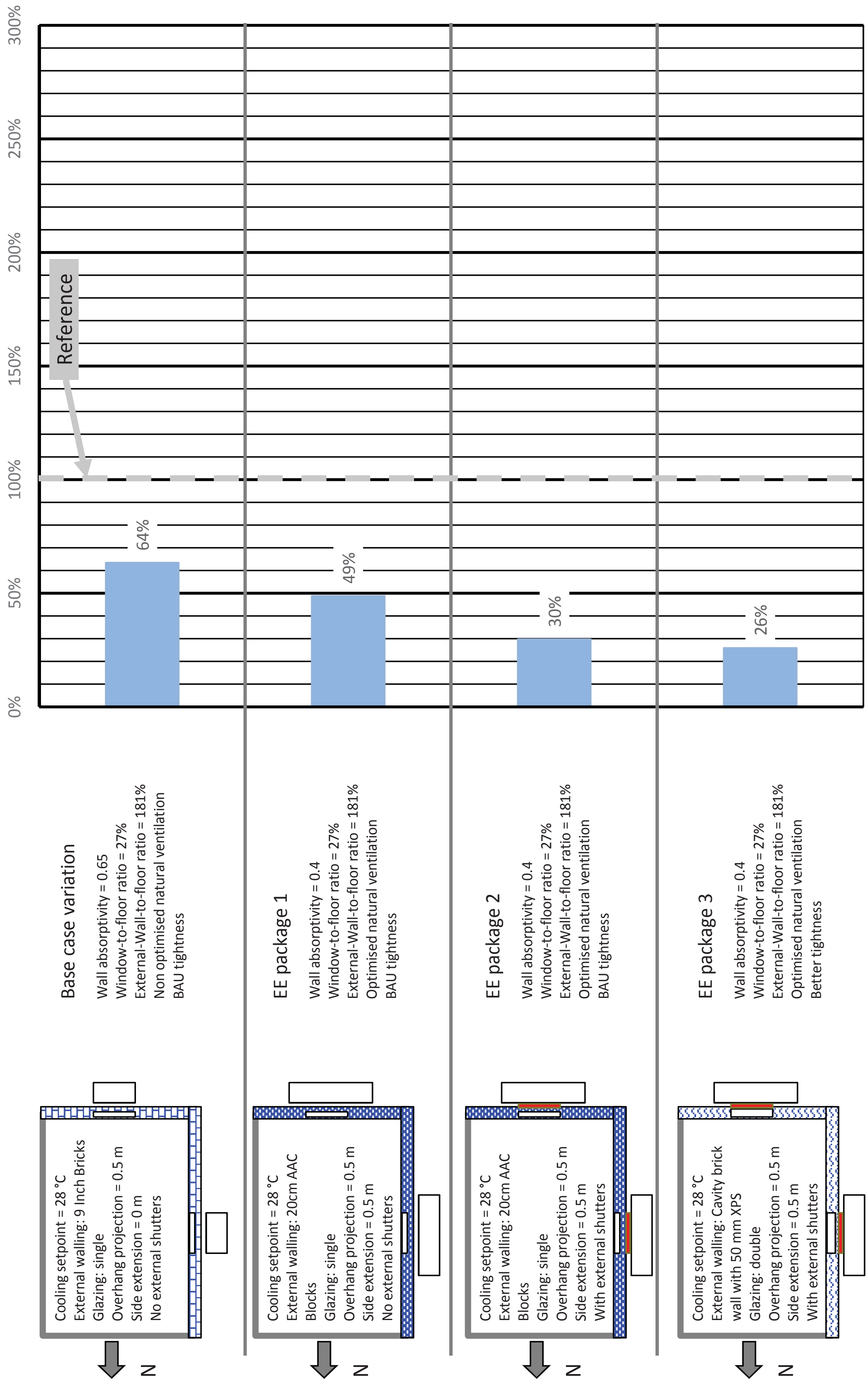

0%
50%
100%
150%
200%
250%
300%
Reference
127%
111%
64%
54%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
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.4-3

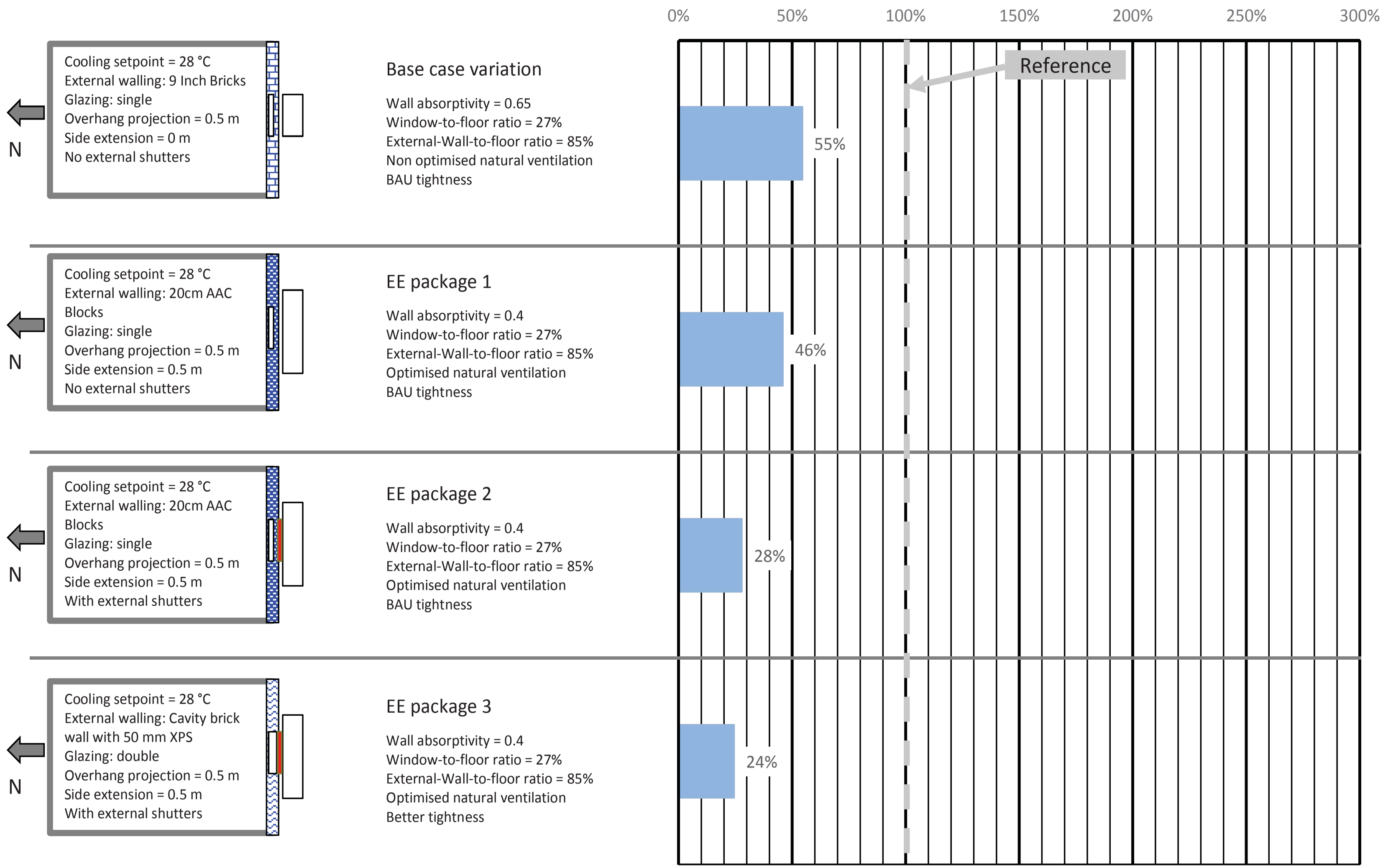


Cooling setpoint = 26 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
111%
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 = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
101%
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
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 = 53%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness
49%
0%
50%
100%
150%
200%
250%
300%

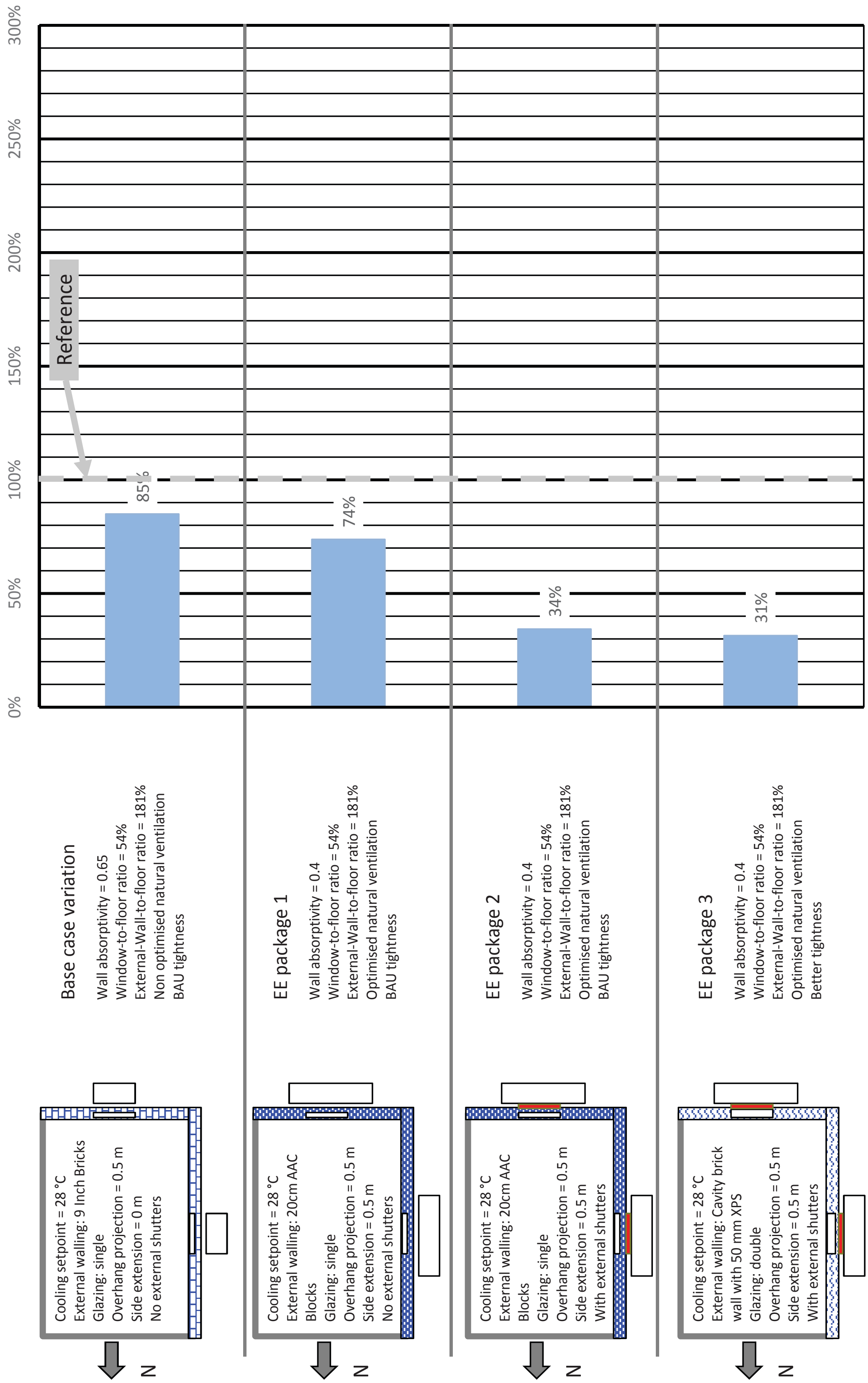
A.4-4


0%
50%
100%
150%
200%
250%
300%
Reference
64%
49%
30%
26%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
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 = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 28 °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

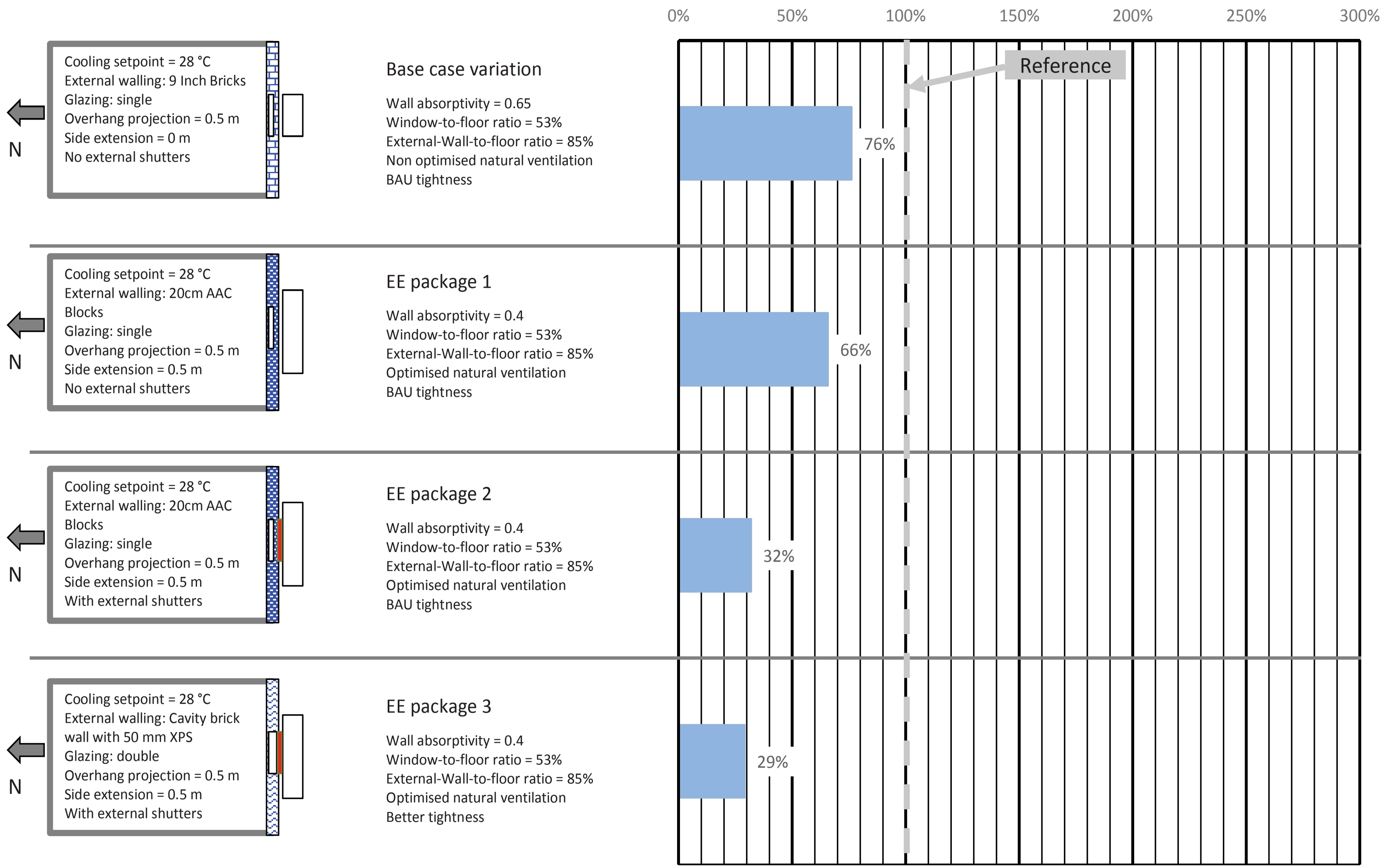
A.4-5


Cooling setpoint = 28 °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
55%
Cooling setpoint = 28 °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
46%
Cooling setpoint = 28 °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
28%
Cooling setpoint = 28 °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
24%
0%
50%
100%
150%
200%
250%
300%
Reference

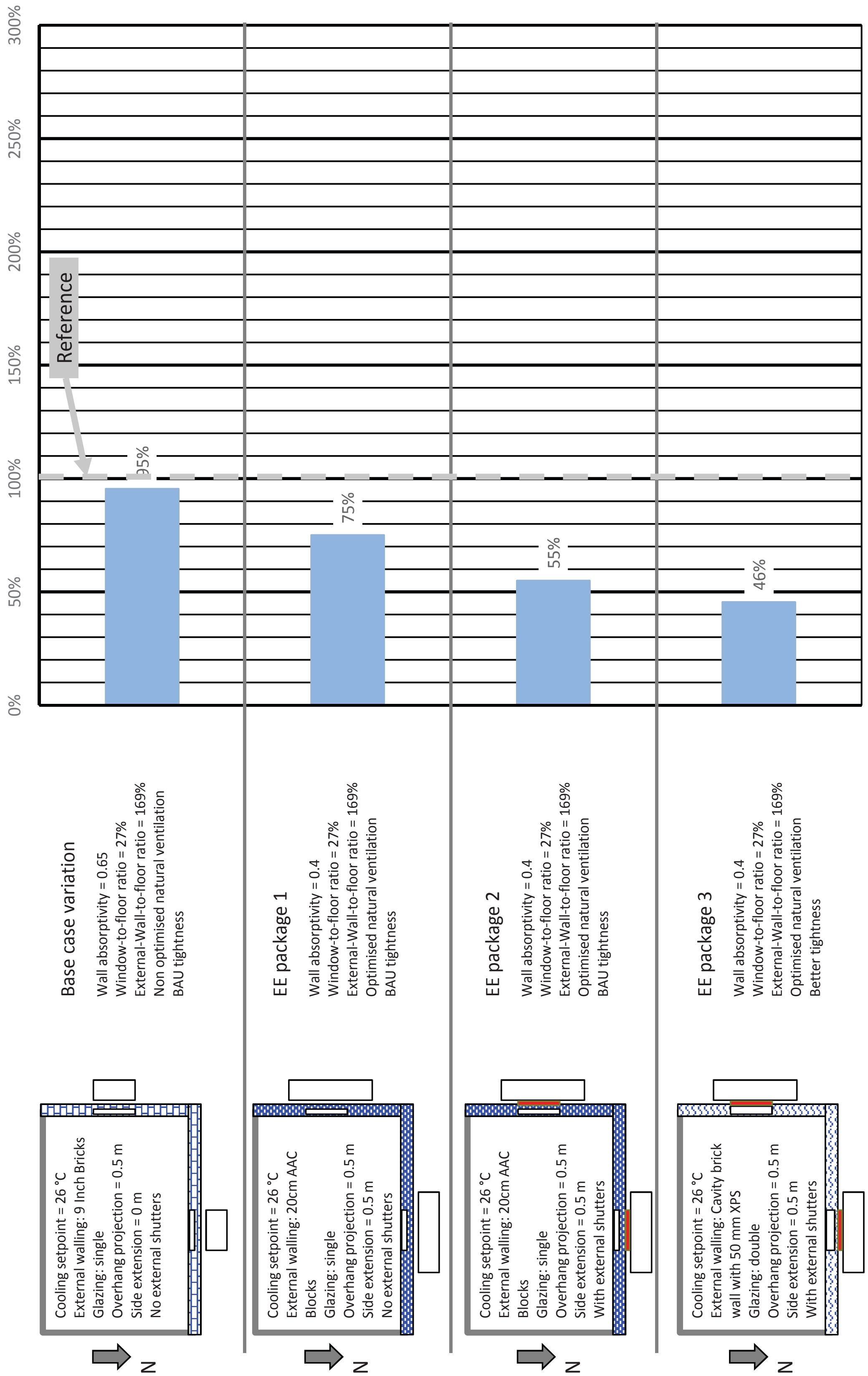
A.4-6


0%
50%
100%
150%
200%
250%
300%
Reference
85%
74%
34%
31%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 28 °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.4-7

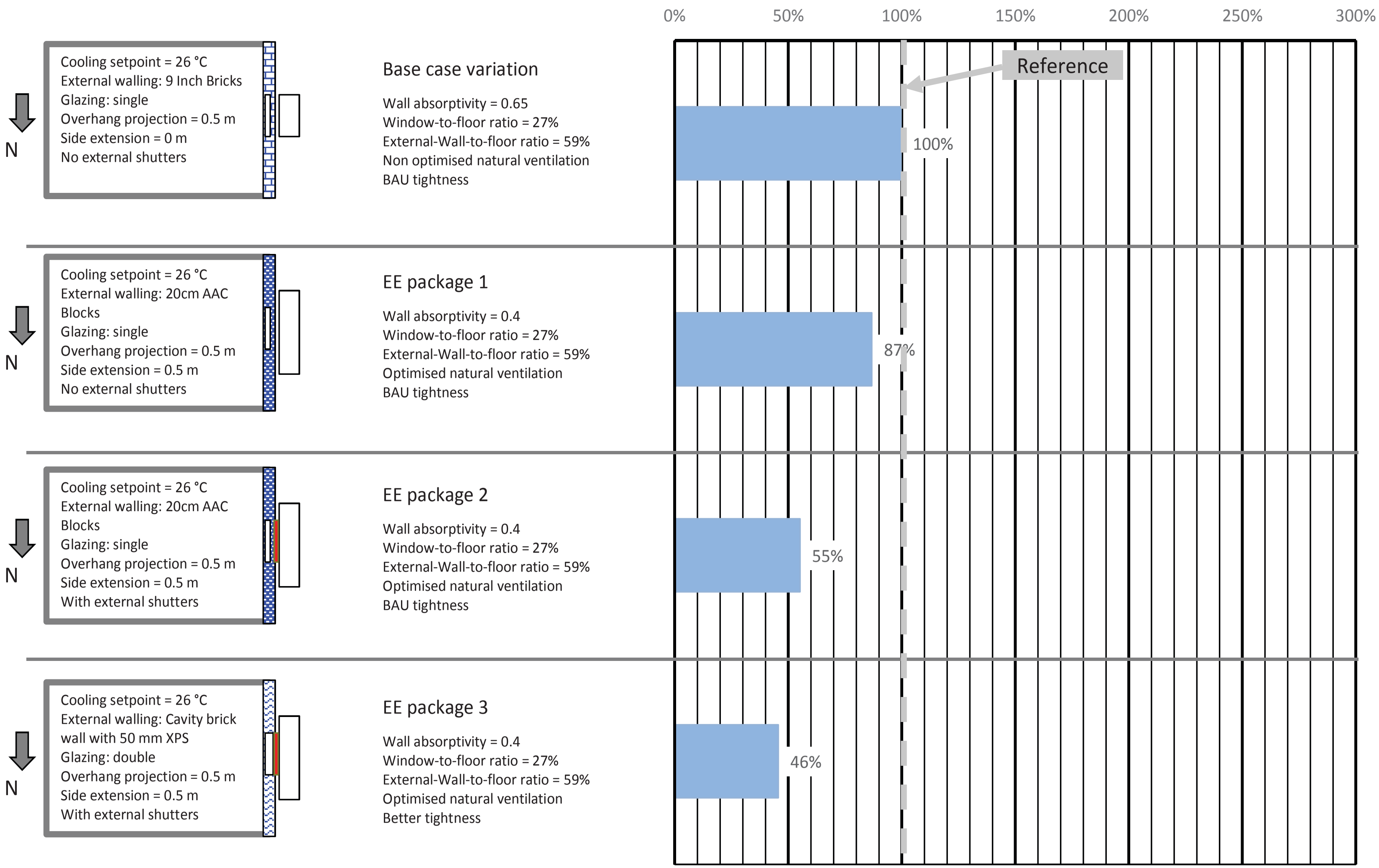

0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
76%
Cooling setpoint = 28 °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
66%
Cooling setpoint = 28 °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
32%
Cooling setpoint = 28 °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
29%

A.4-8

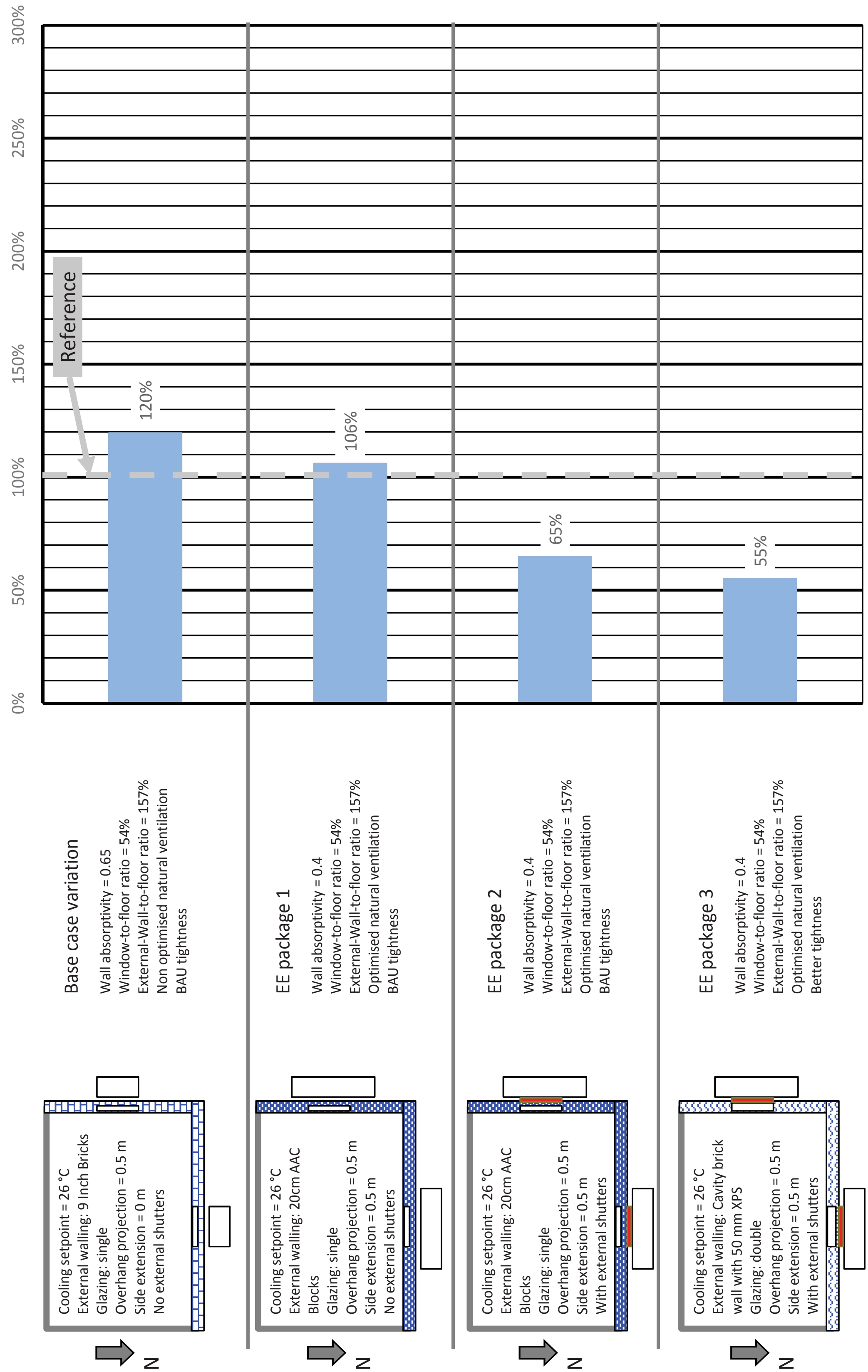


0%
50%
100%
150%
200%
250%
300%
Reference
95%
75%
55%
46%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 169%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 169%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 169%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 169%
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

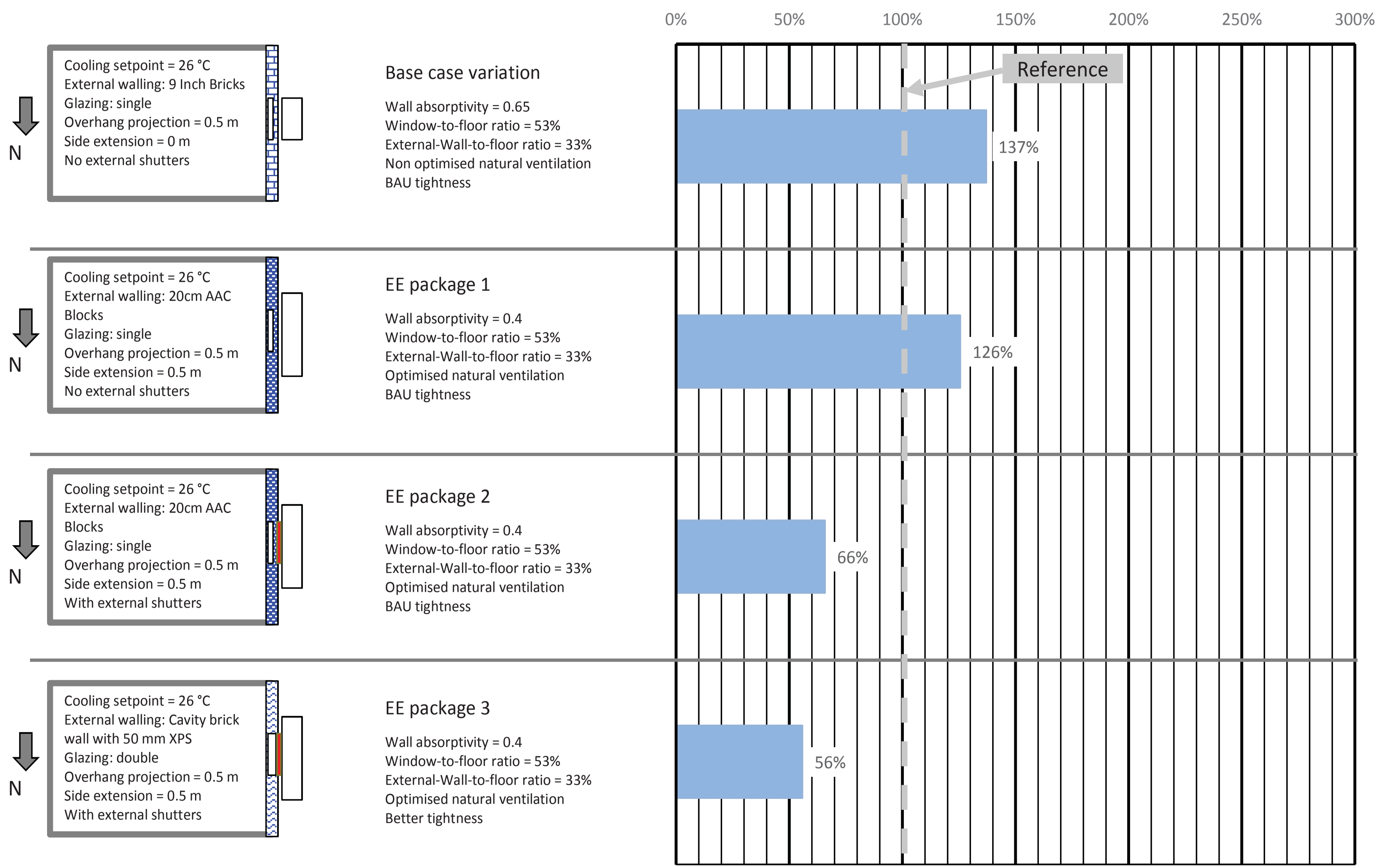
A.4-9


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 = 59%
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 = 59%
Optimised natural ventilation
BAU tightness
87%
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 = 59%
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 = 59%
Optimised natural ventilation
Better tightness
46%

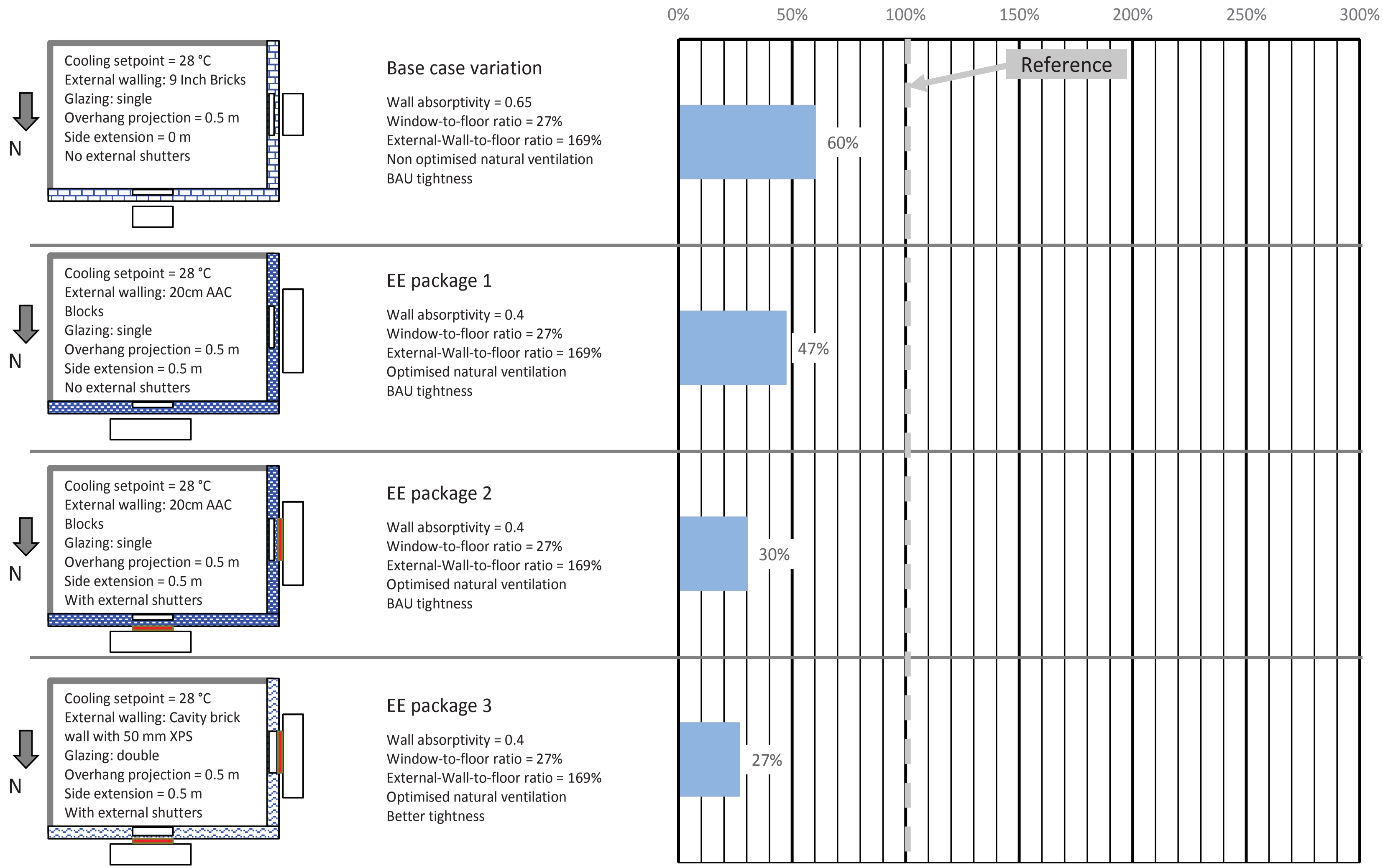
A.4-10


0%
50%
100%
150%
200%
250%
300%
Reference
120%
106%
65%
55%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 157%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 157%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 157%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 157%
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

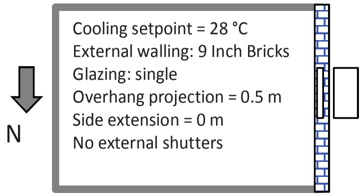
A.4-11


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 = 33%
Non optimised natural ventilation
BAU tightness
137%
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 = 53%
External-Wall-to-floor ratio = 33%
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
With external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 33%
Optimised natural ventilation
BAU tightness
66%
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 = 33%
Optimised natural ventilation
Better tightness
56%
0%
50%
100%
150%
200%
250%
300%

A.4-12

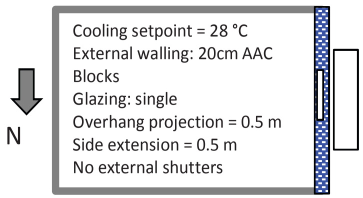

Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 169%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 169%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 169%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 169%
Optimised natural ventilation
Better tightness
0%
50%
100%
150%
200%
250%
300%
Reference
60%
47%
30%
27%

A.4-13



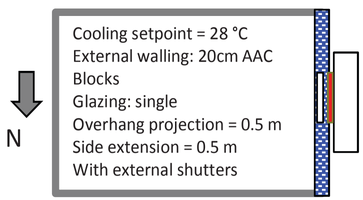
Base case variation

Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 59%
Non optimised natural ventilation
BAU tightness



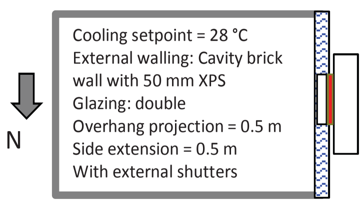
EE package 1

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 59%
Optimised natural ventilation
BAU tightness



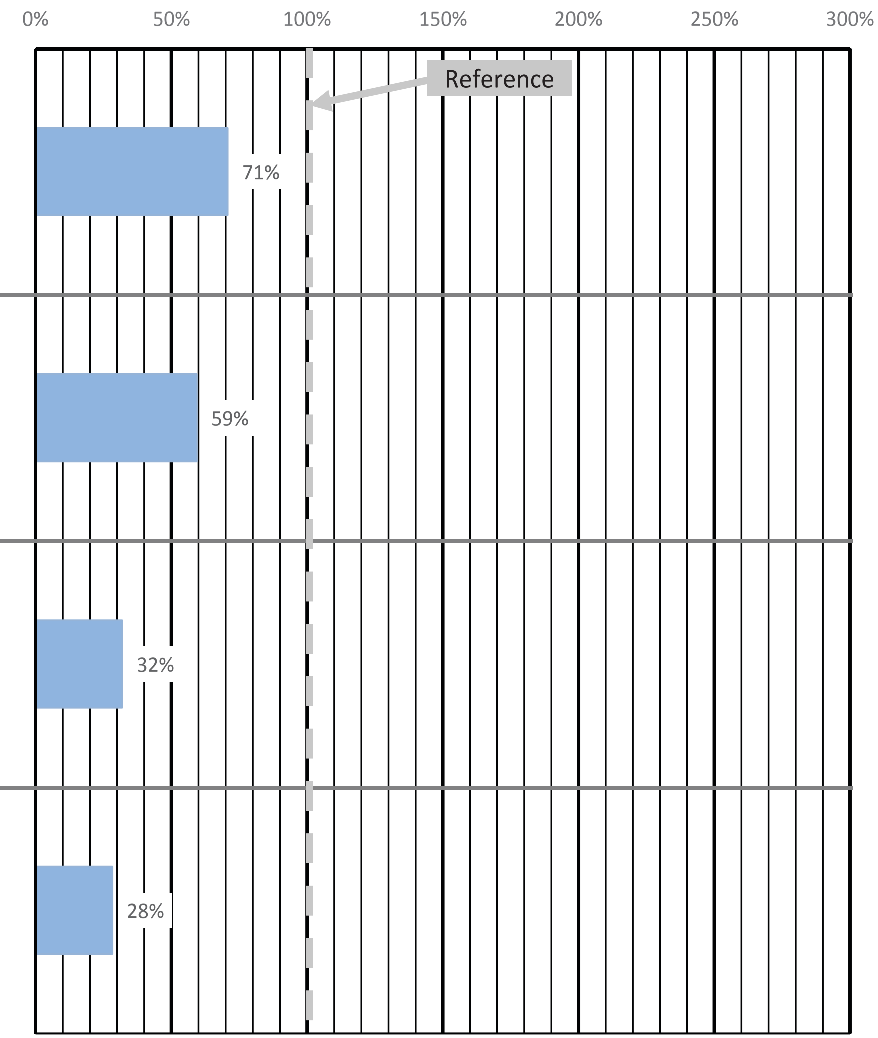
EE package 2

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 59%
Optimised natural ventilation
BAU tightness

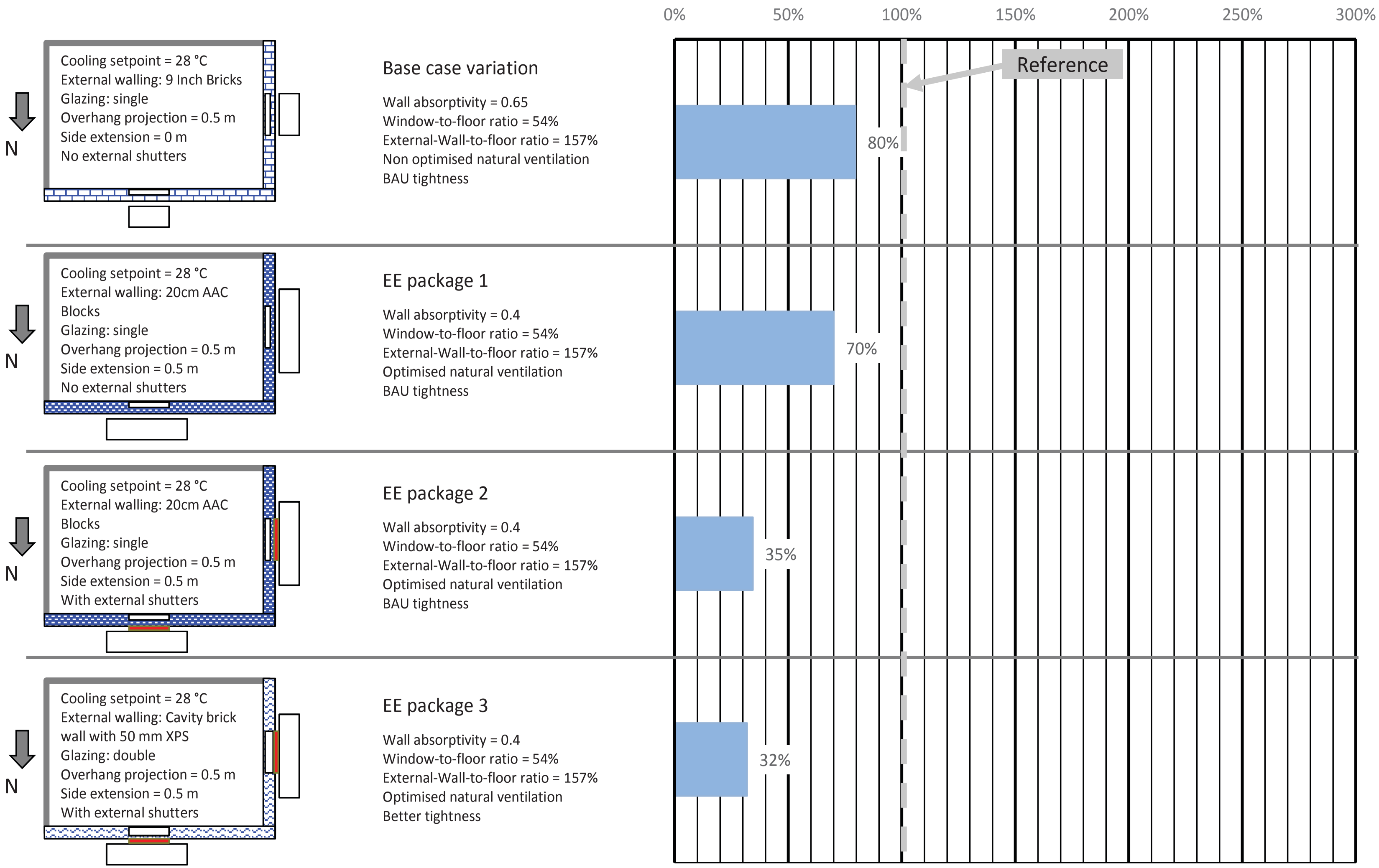


EE package 3

Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 59%
Optimised natural ventilation
Better tightness

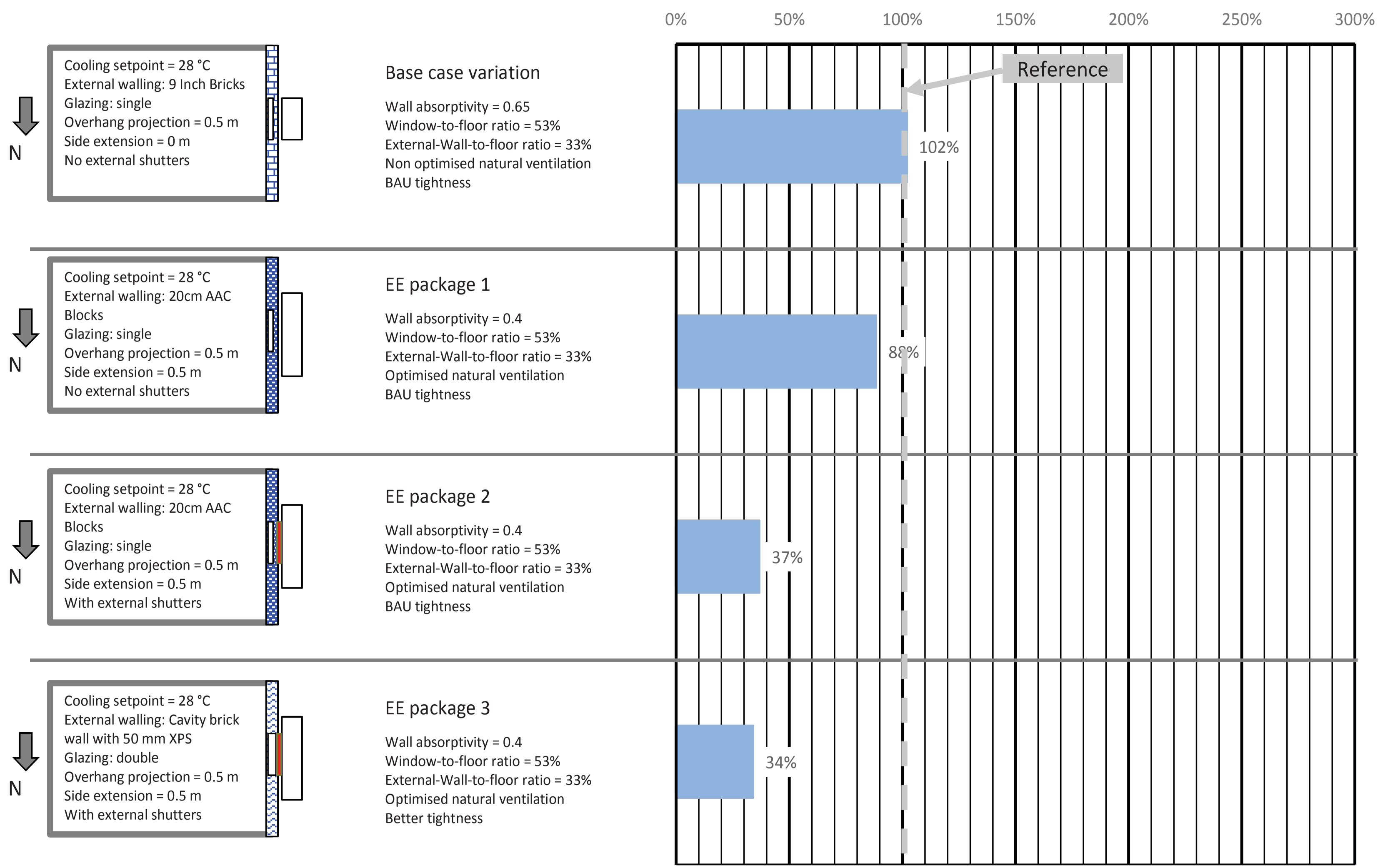


A.4-14

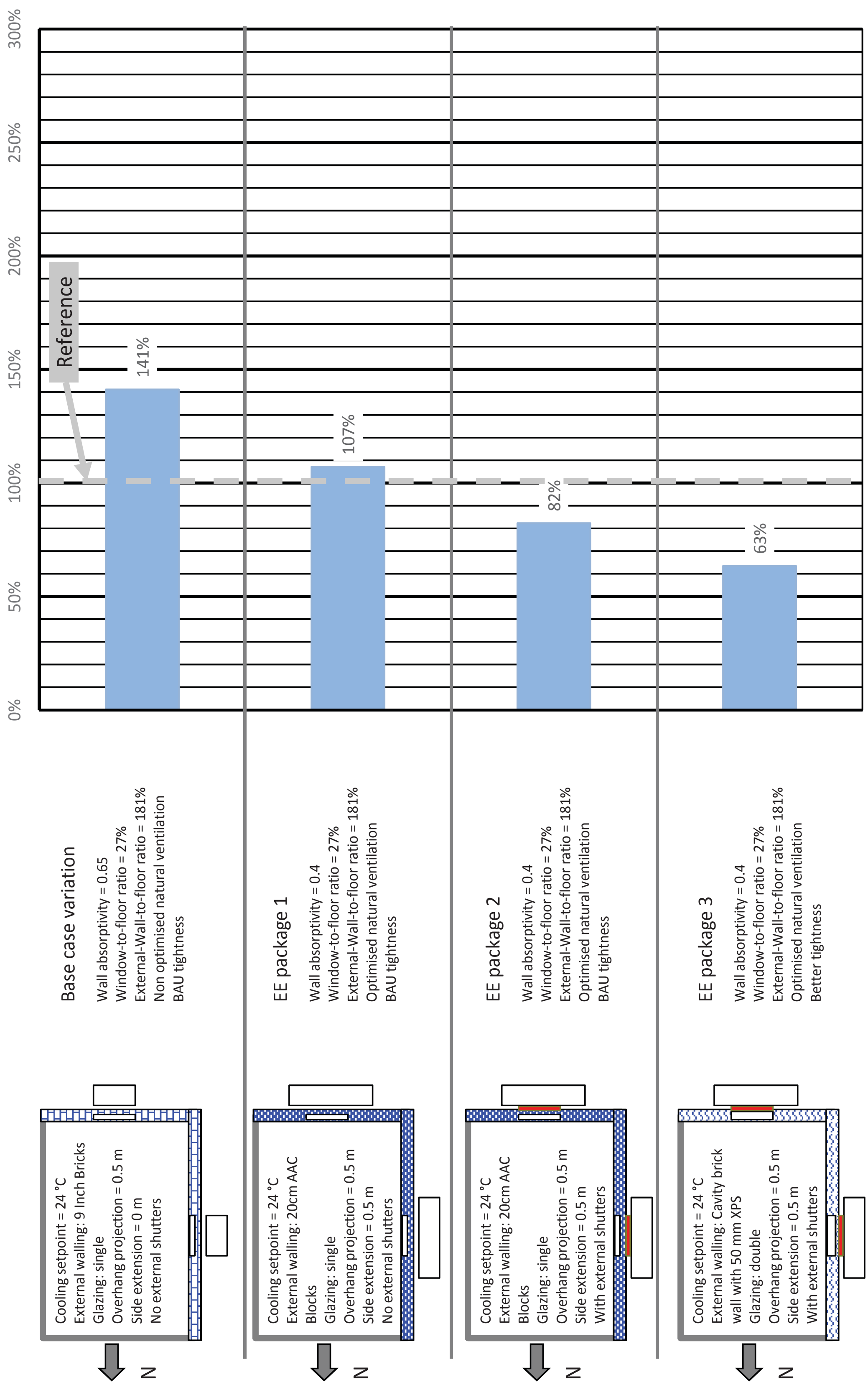


Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 157%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 54%
External-Wall-to-floor ratio = 157%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 54%
External-Wall-to-floor ratio = 157%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 54%
External-Wall-to-floor ratio = 157%
Optimised natural ventilation
Better tightness
0%
50%
100%
150%
200%
250%
300%
Reference
80%
70%
35%
32%

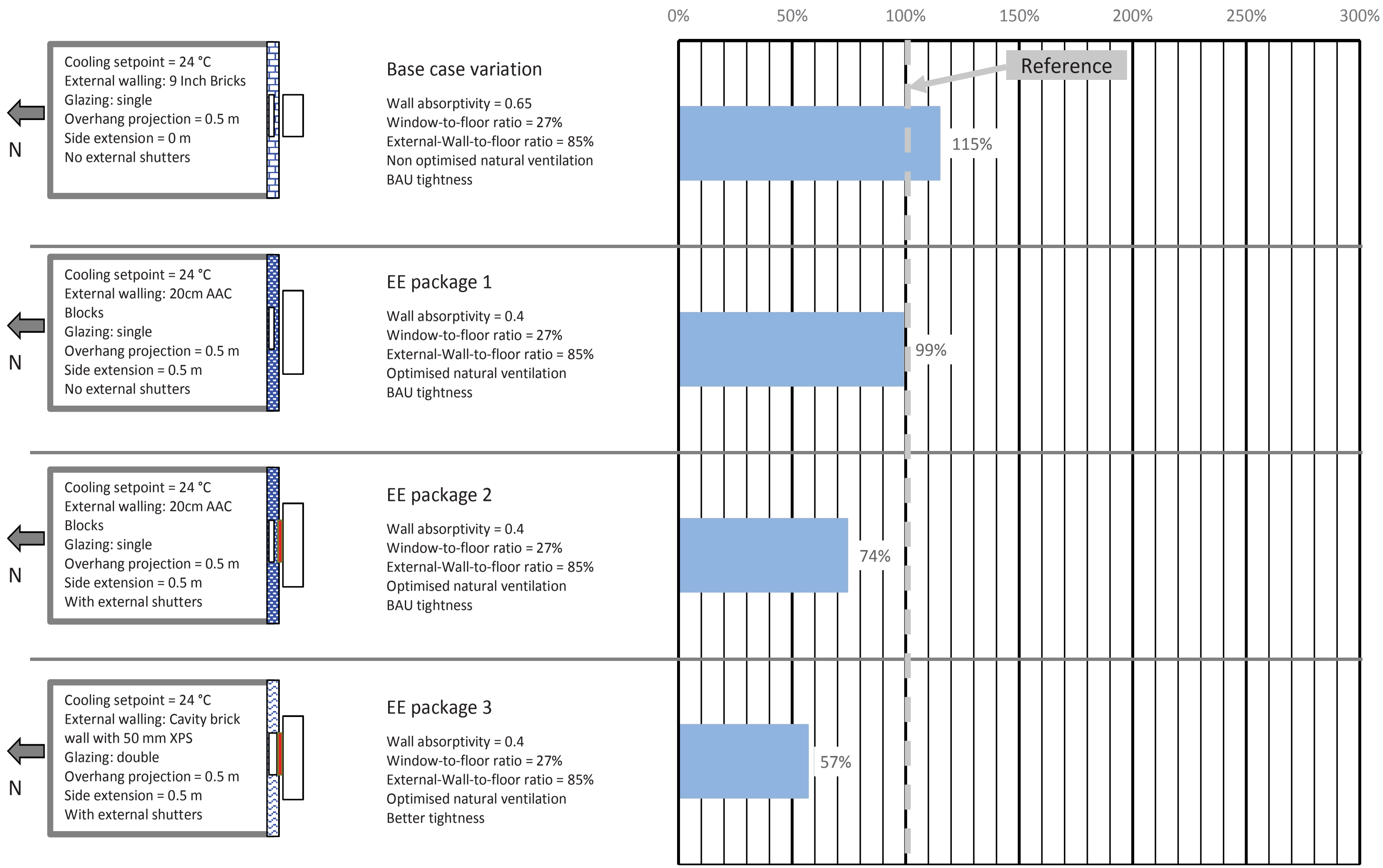
A.4-15


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 28 °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 = 33%
Non optimised natural ventilation
BAU tightness
102%
Cooling setpoint = 28 °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 = 33%
Optimised natural ventilation
BAU tightness
88%
Cooling setpoint = 28 °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 = 33%
Optimised natural ventilation
BAU tightness
37%
Cooling setpoint = 28 °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 = 33%
Optimised natural ventilation
Better tightness
34%

A.4-16

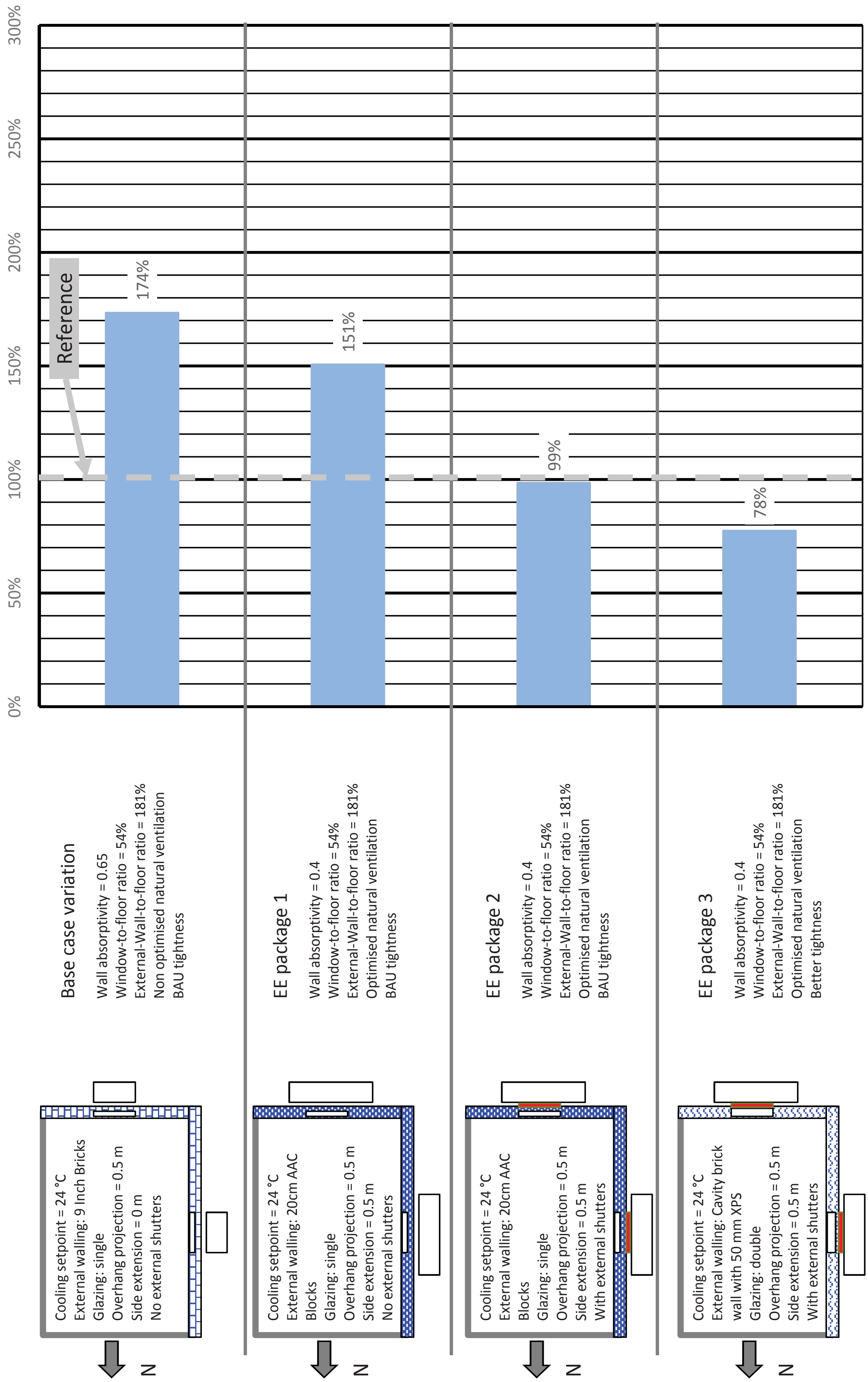

0%
50%
100%
150%
200%
250%
300%
Reference
141%
107%
82%
63%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
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 = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 24 °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.4-17

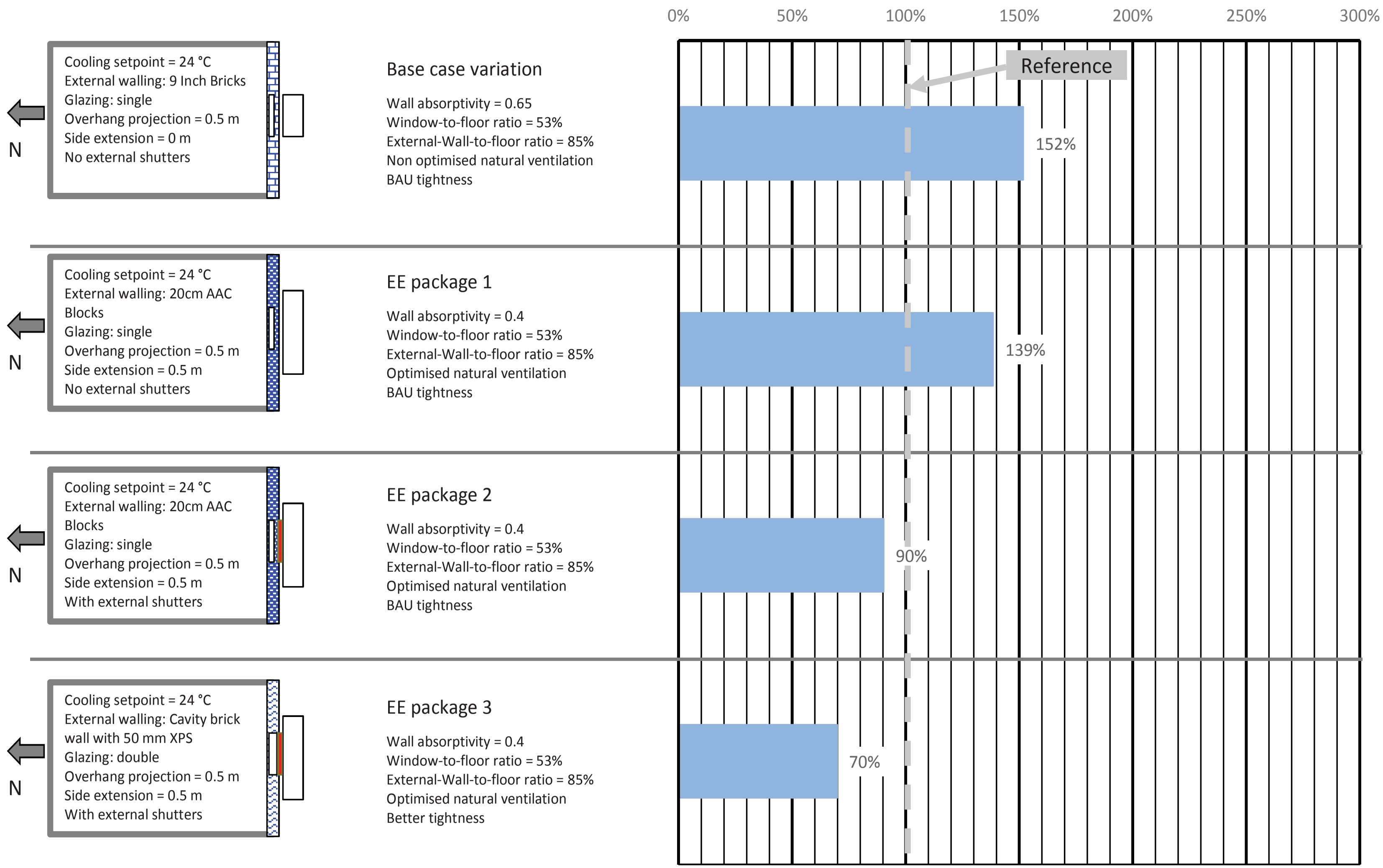


Cooling setpoint = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 24 °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 = 24 °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 = 24 °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
115%
99%
74%
57%

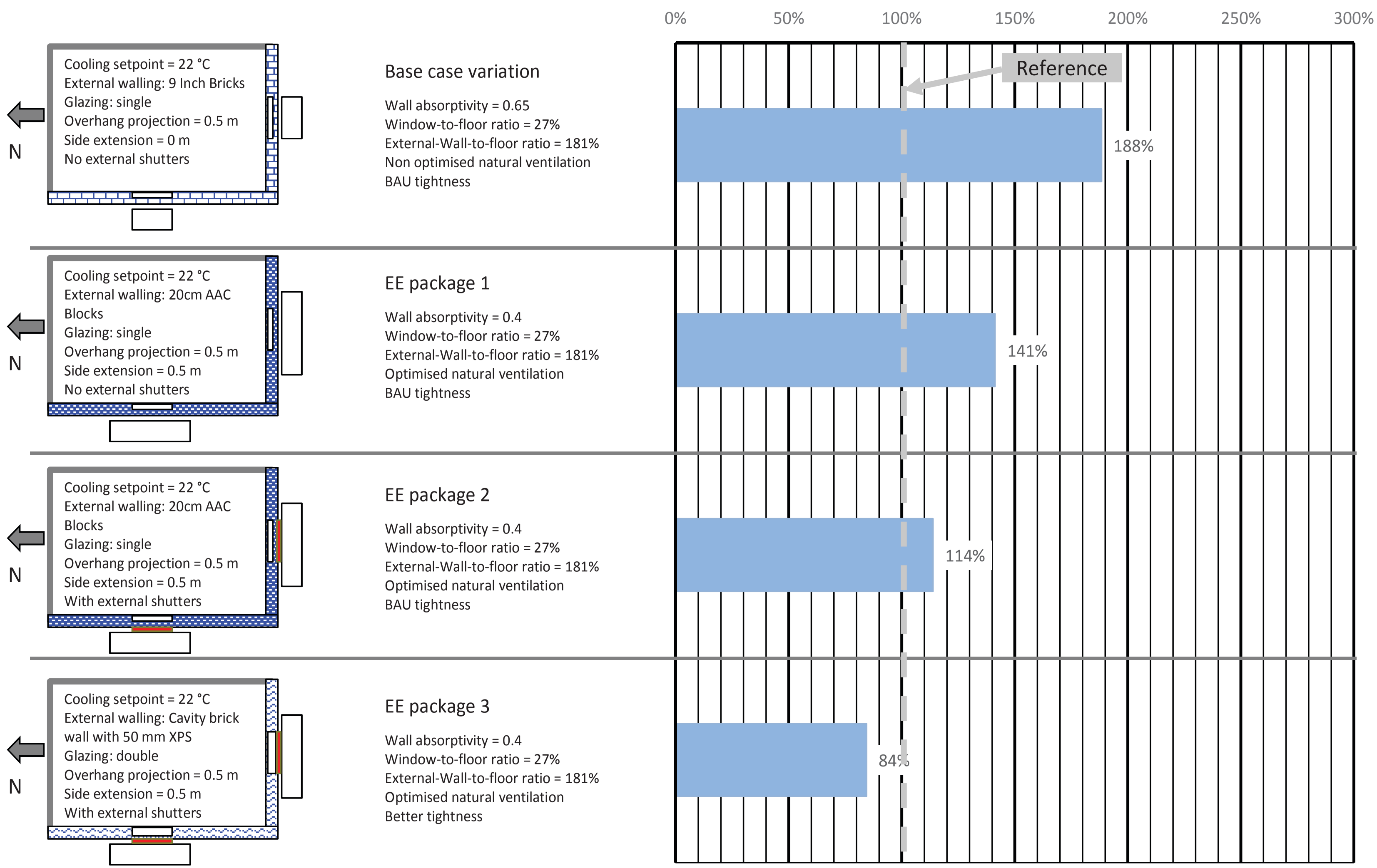
A.4-18


0%
50%
100%
150%
200%
250%
300%
Reference
174%
151%
99%
78%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
Cooling setpoint = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 24 °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

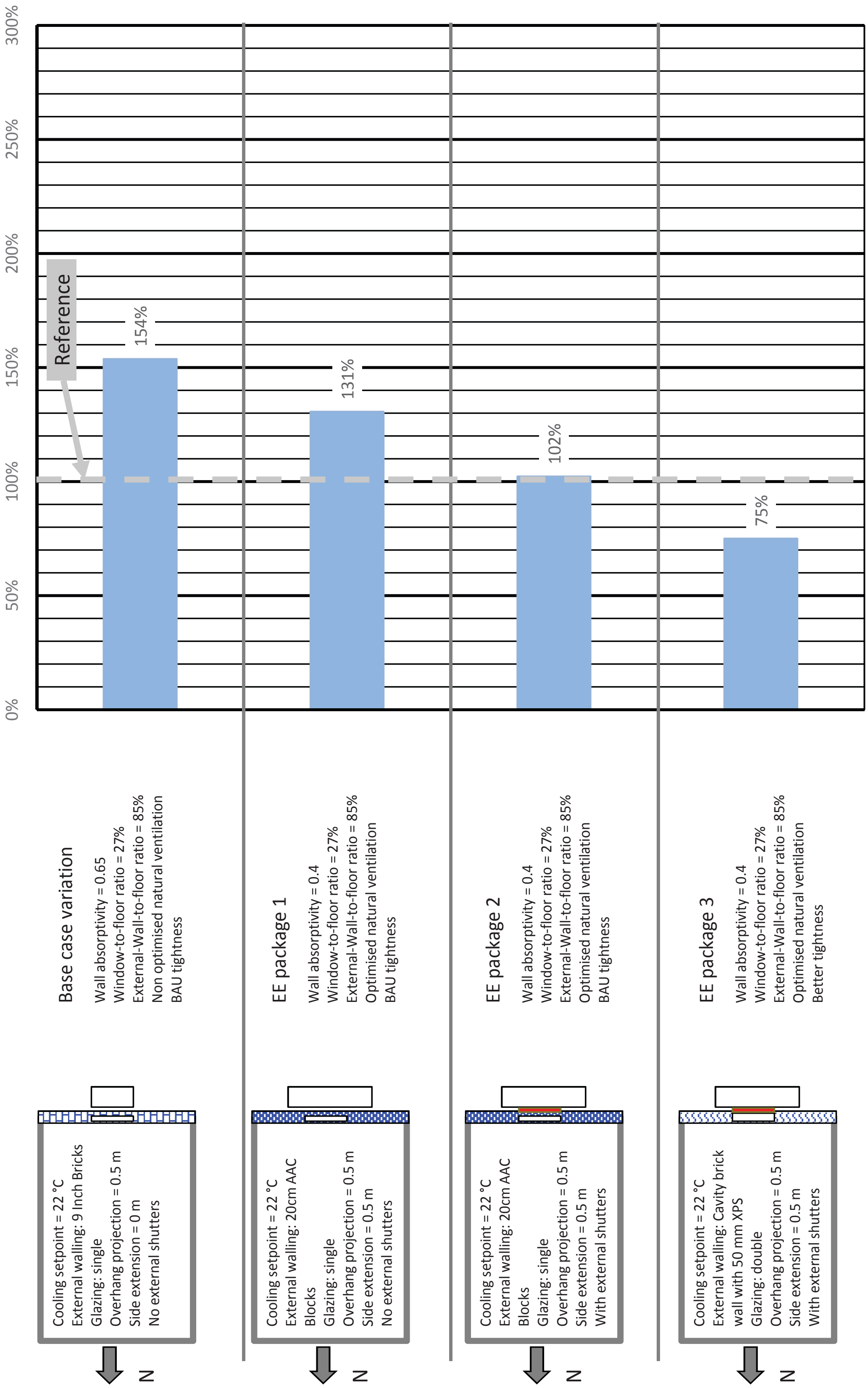
A.4-19


Cooling setpoint = 24 °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 = 24 °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 = 24 °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 = 24 °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
152%
139%
90%
70%

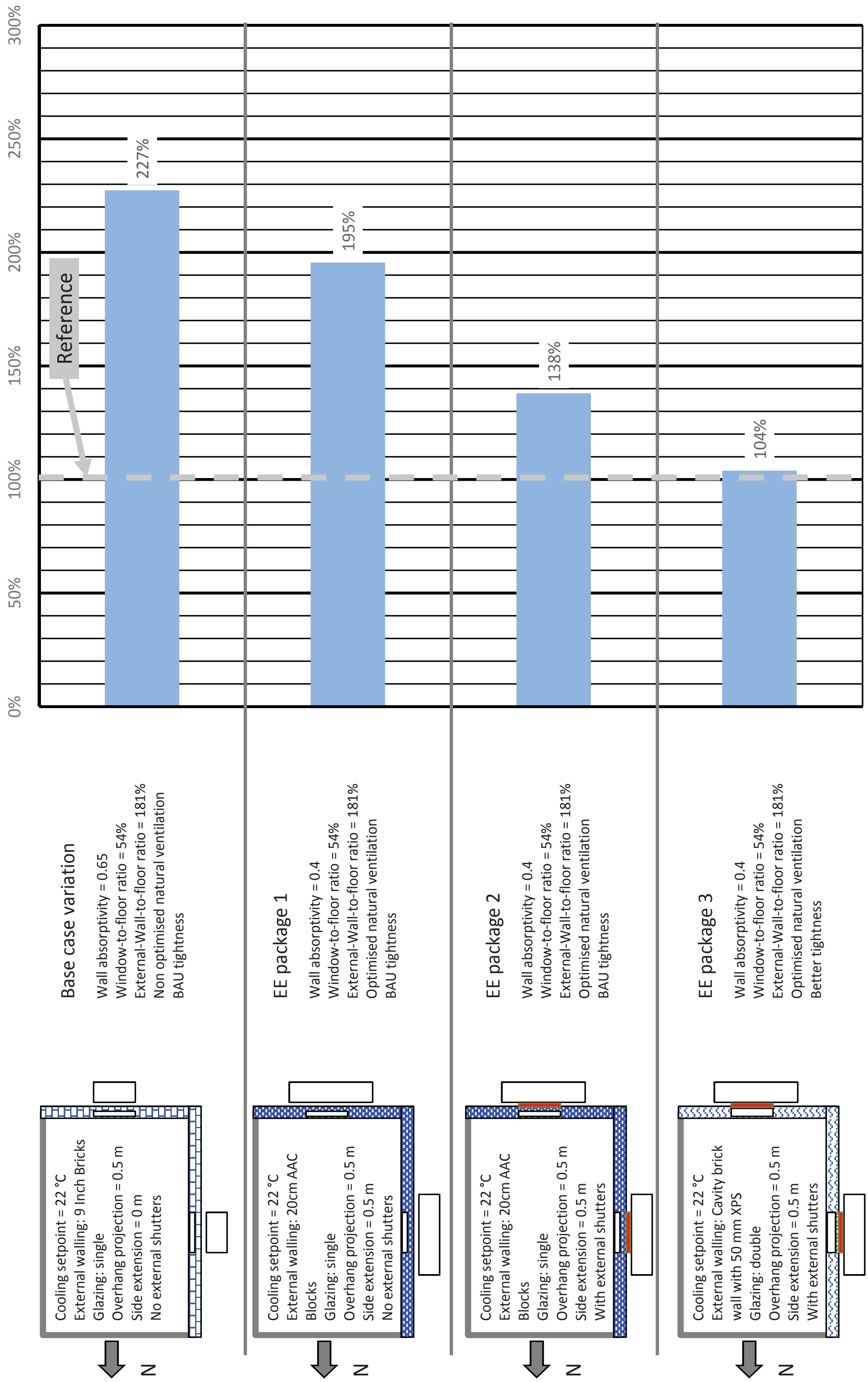
A.4-20


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 22 °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 = 181%
Non optimised natural ventilation
BAU tightness
188%
Cooling setpoint = 22 °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 = 181%
Optimised natural ventilation
BAU tightness
141%
Cooling setpoint = 22 °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 = 181%
Optimised natural ventilation
BAU tightness
114%
Cooling setpoint = 22 °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 = 181%
Optimised natural ventilation
Better tightness
84%

A.4-21

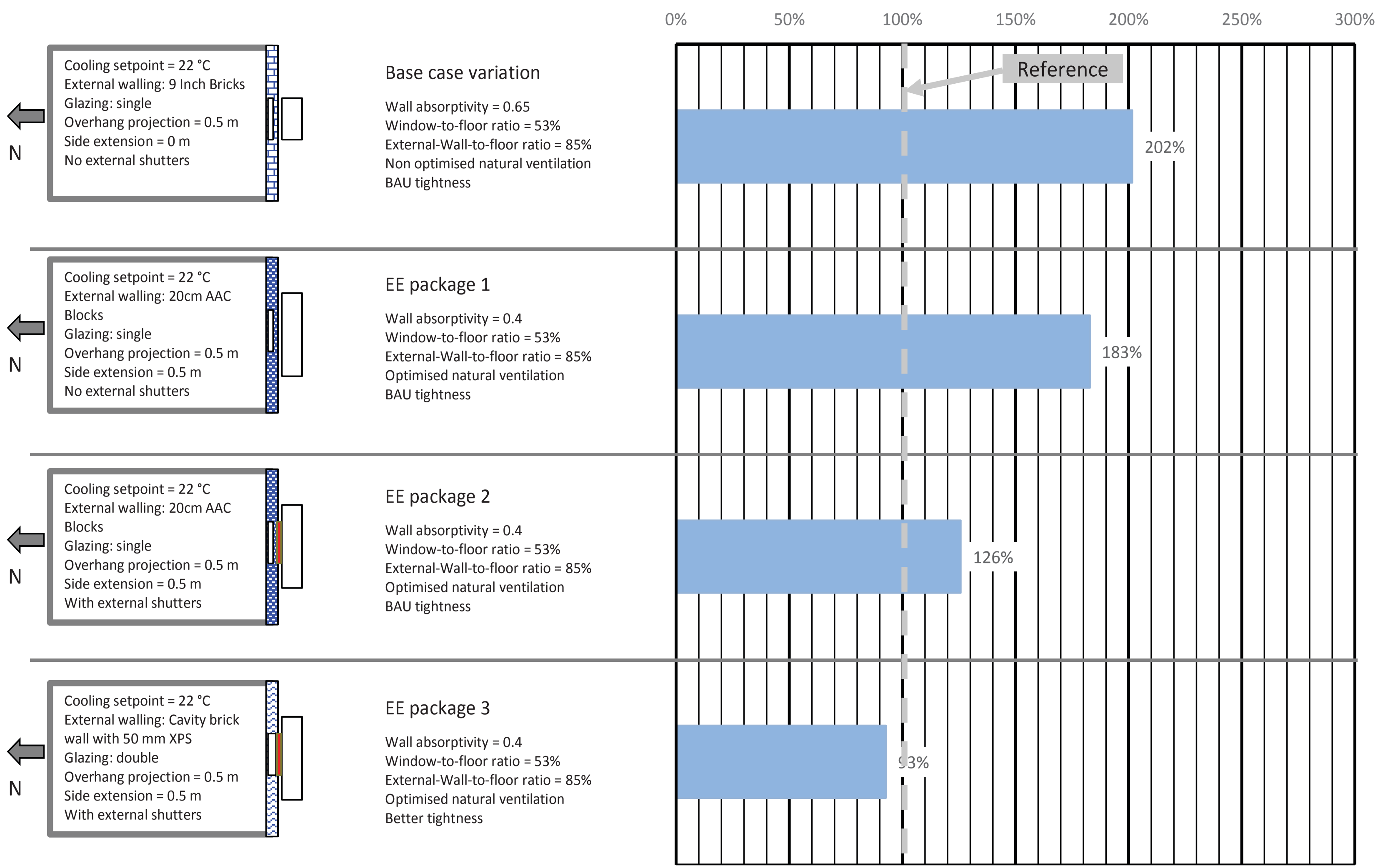

0%
50%
100%
150%
200%
250%
300%
Reference
154%
131%
102%
75%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Optimised natural ventilation
Better tightness
Cooling setpoint = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 22 °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.4-22

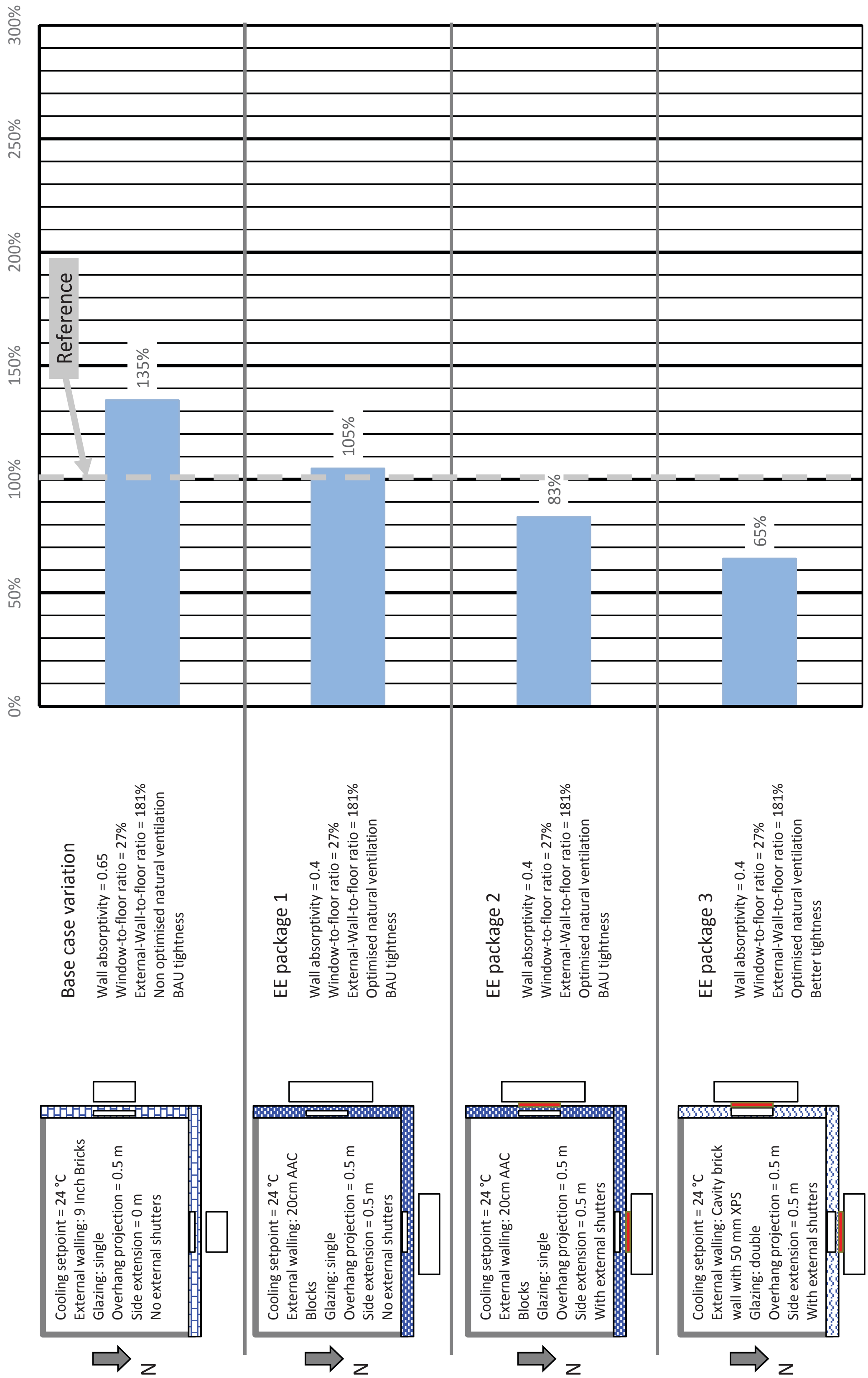


0%
50%
100%
150%
200%
250%
300%
Reference
227%
195%
138%
104%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
Cooling setpoint = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 22 °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

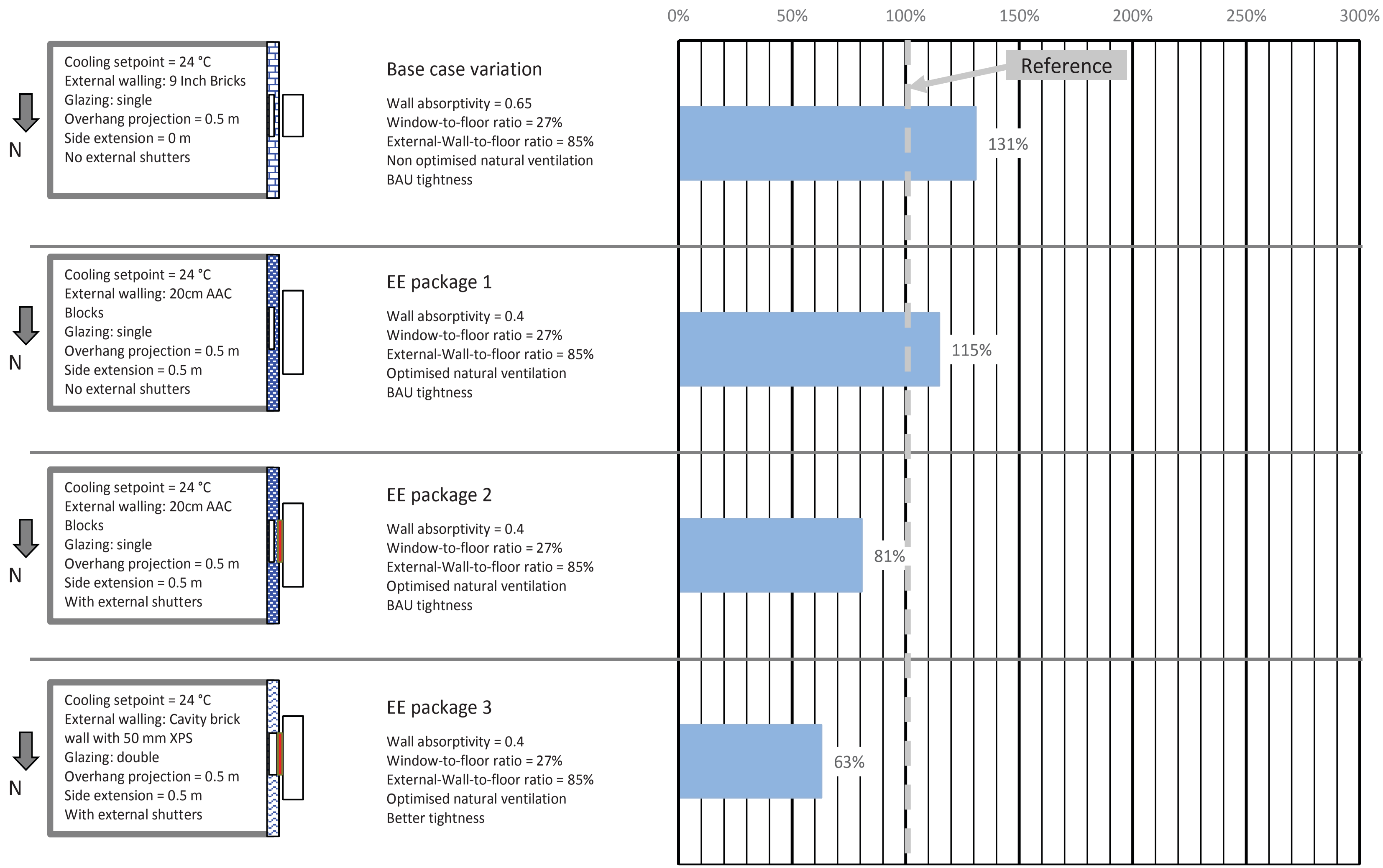
A.4-23


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 22 °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
202%
Cooling setpoint = 22 °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
183%
Cooling setpoint = 22 °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
126%
Cooling setpoint = 22 °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

A.4-24

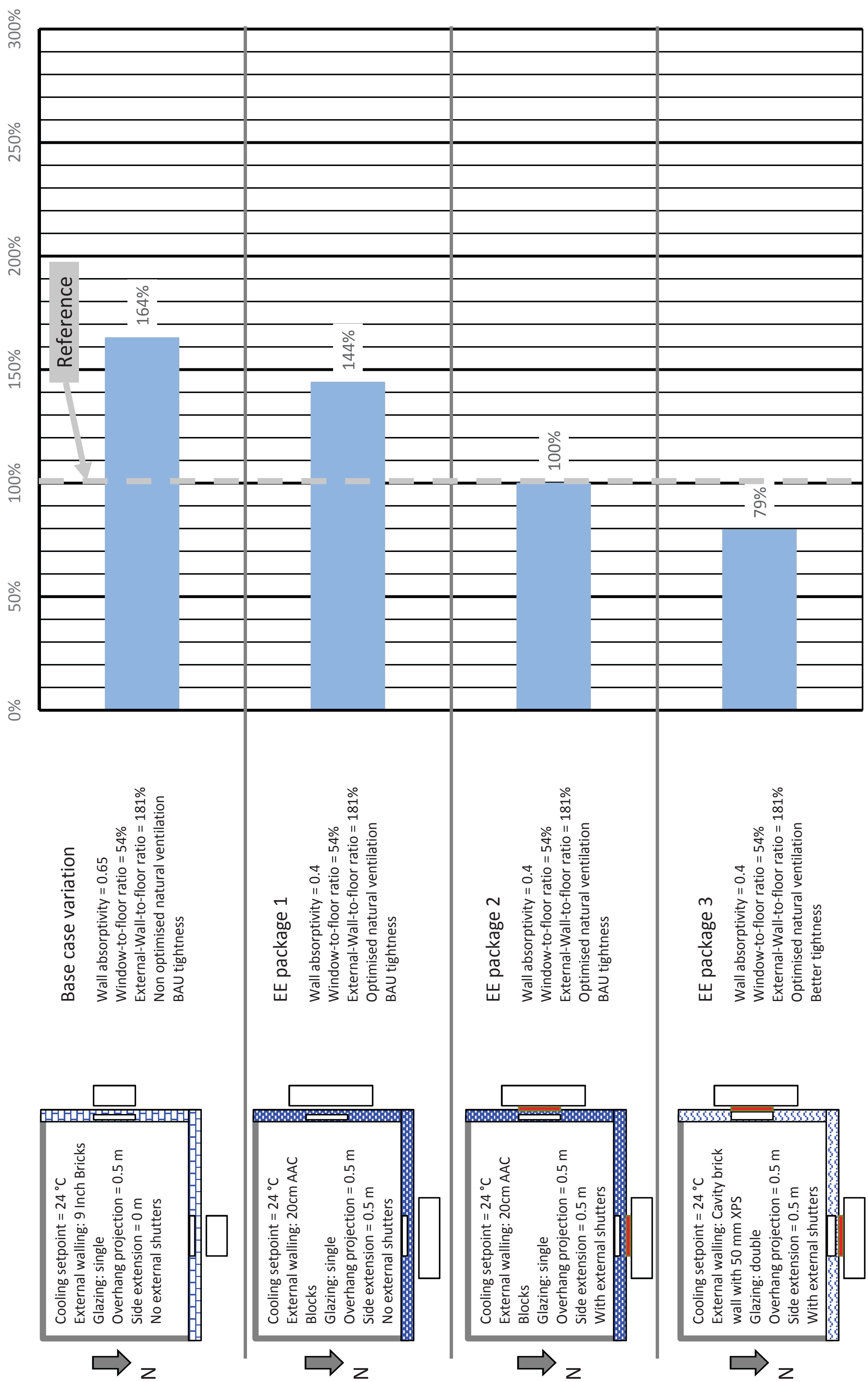

0%
50%
100%
150%
200%
250%
300%
Reference
135%
105%
83%
65%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
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 = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 24 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 24 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 24 °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.4-25

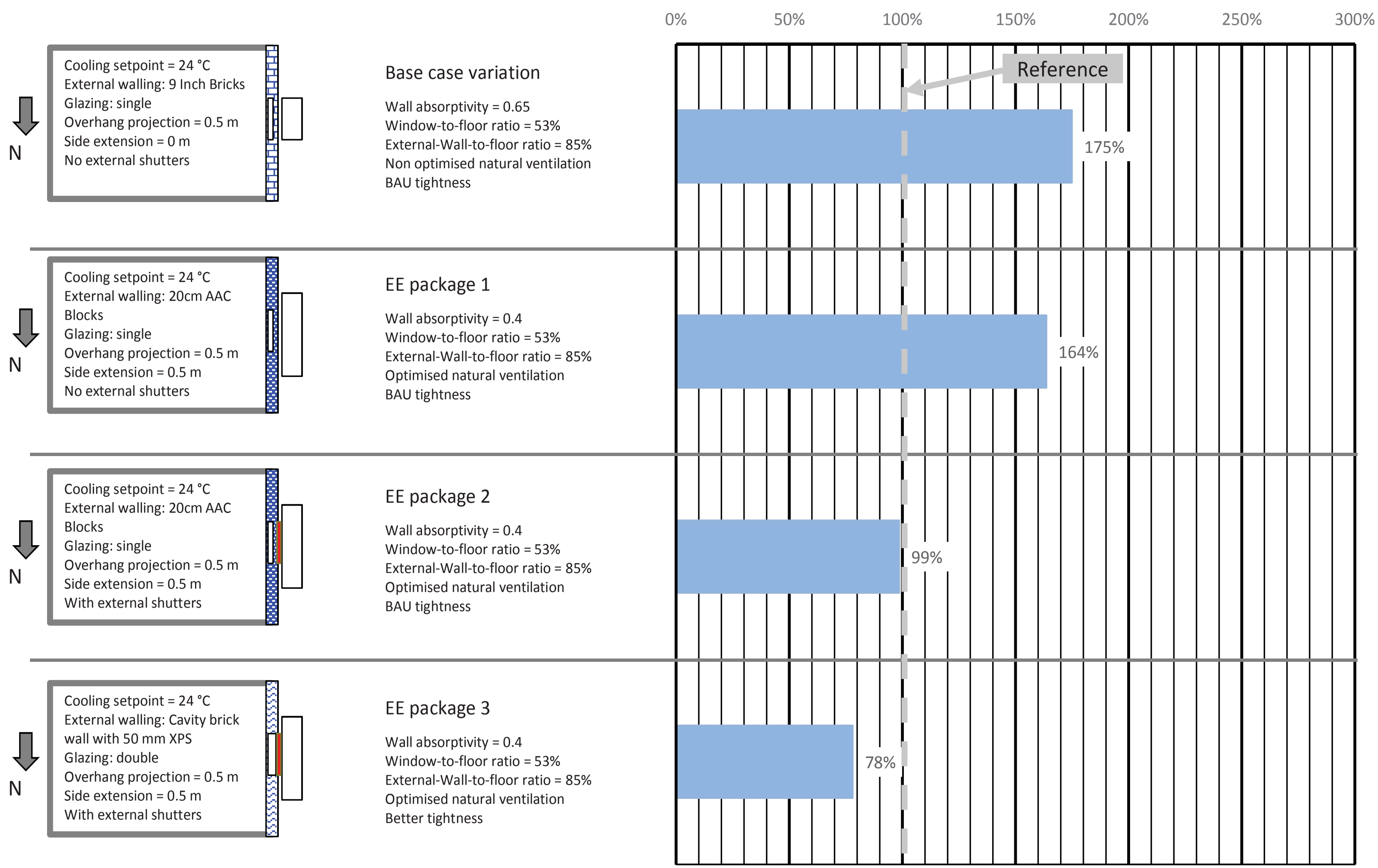


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
131%
Cooling setpoint = 24 °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
115%
Cooling setpoint = 24 °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
81%
Cooling setpoint = 24 °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
63%

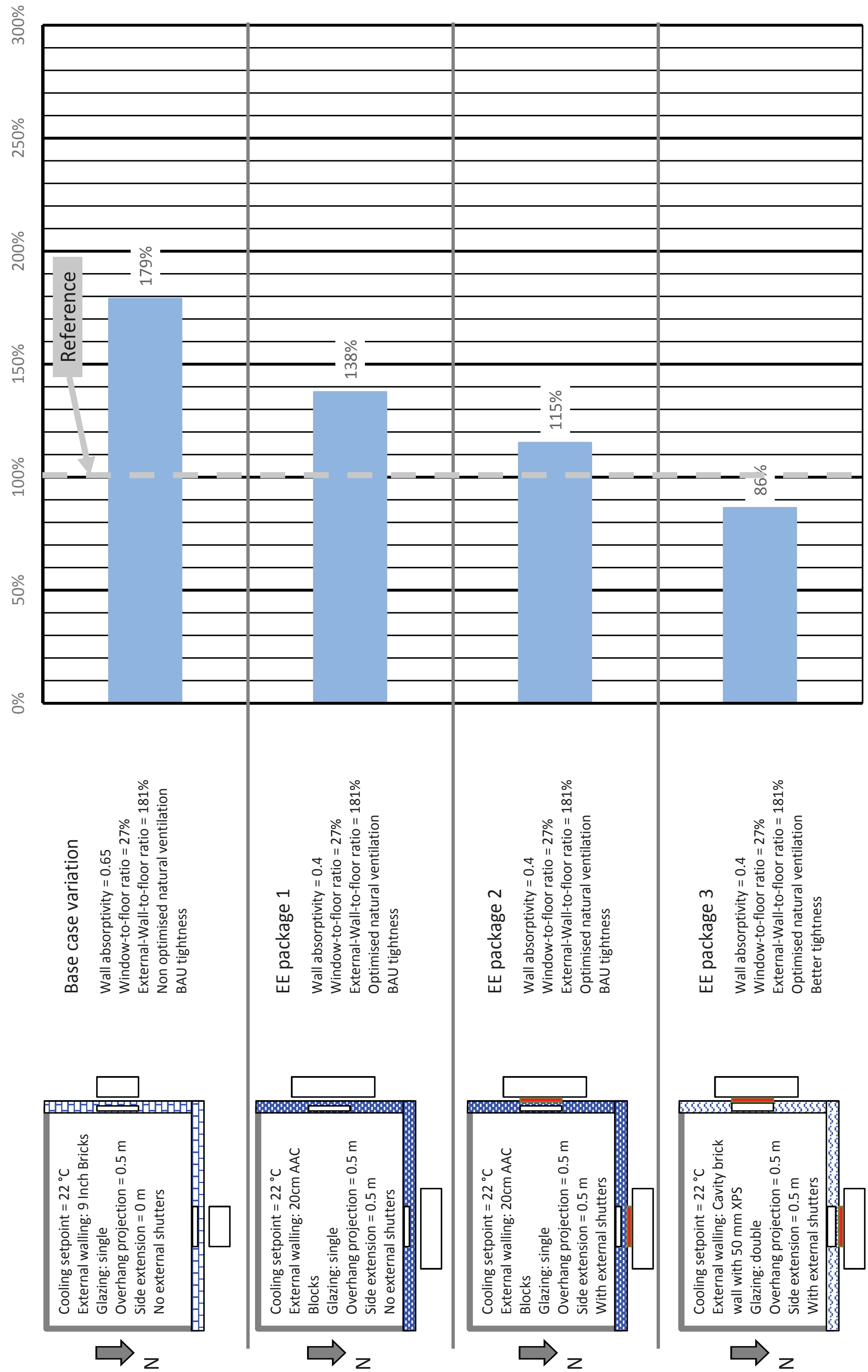
A.4-26


0%
50%
100%
150%
200%
250%
300%
Reference
164%
144%
100%
79%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
Cooling setpoint = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 24 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 24 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 24 °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

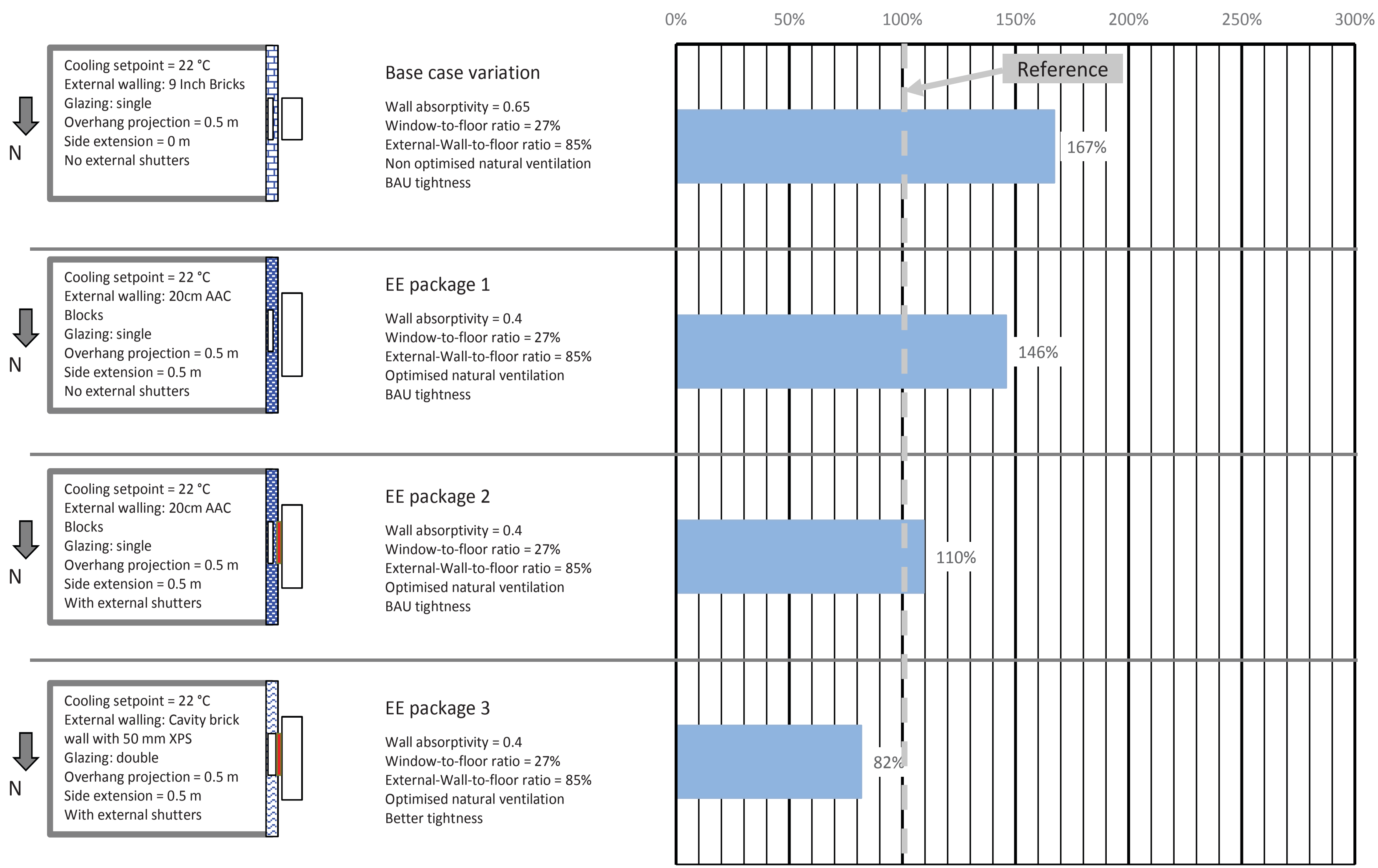
A.4-27


Cooling setpoint = 24 °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 = 24 °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 = 24 °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 = 24 °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
175%
164%
99%
78%

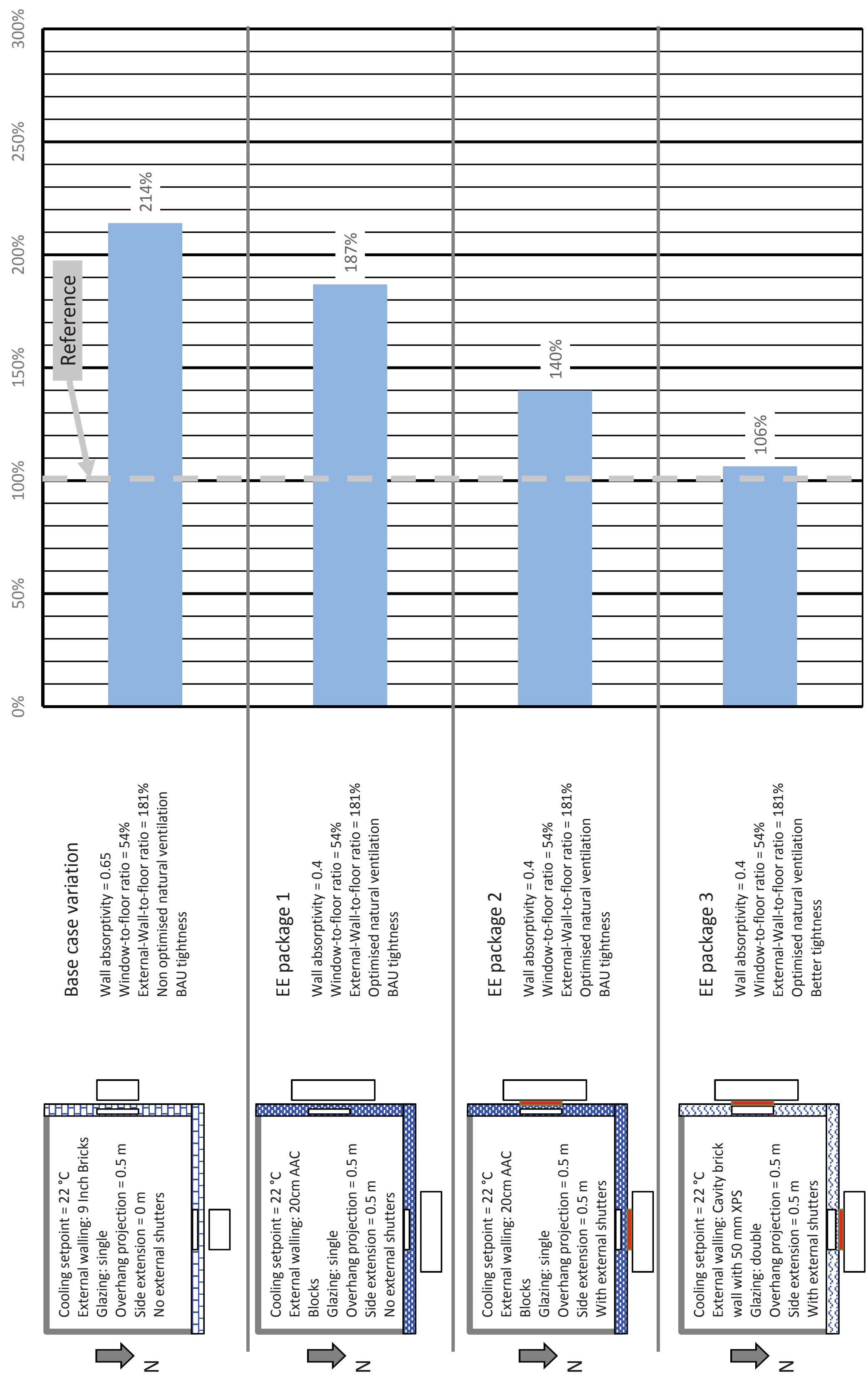
A.4-28


0%
50%
100%
150%
200%
250%
300%
Reference
179%
138%
115%
86%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 27%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
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 = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 22 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 22 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 22 °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

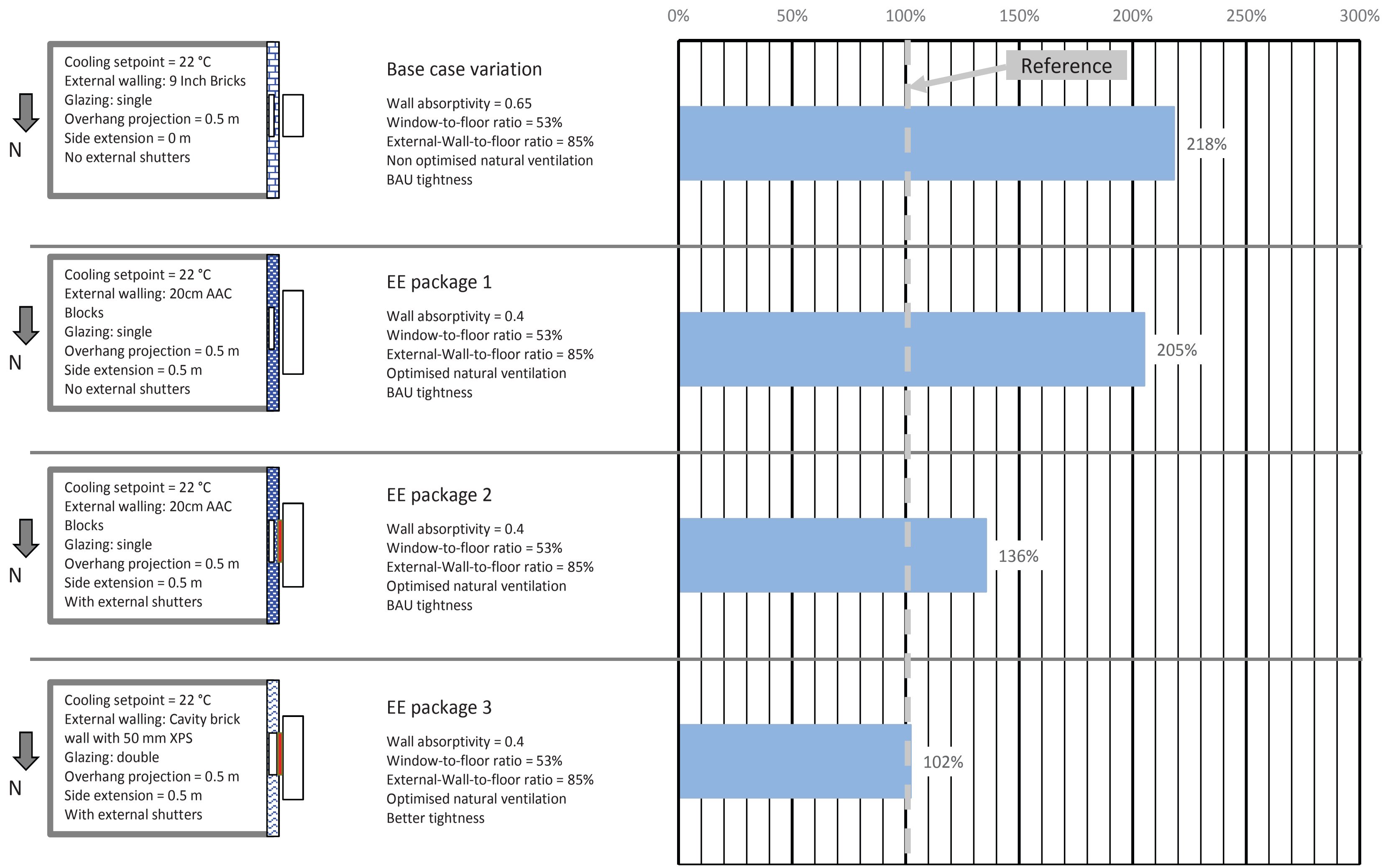
A.4-29


Cooling setpoint = 22 °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 = 22 °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 = 22 °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 = 22 °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
167%
146%
110%
82%

A.4-30

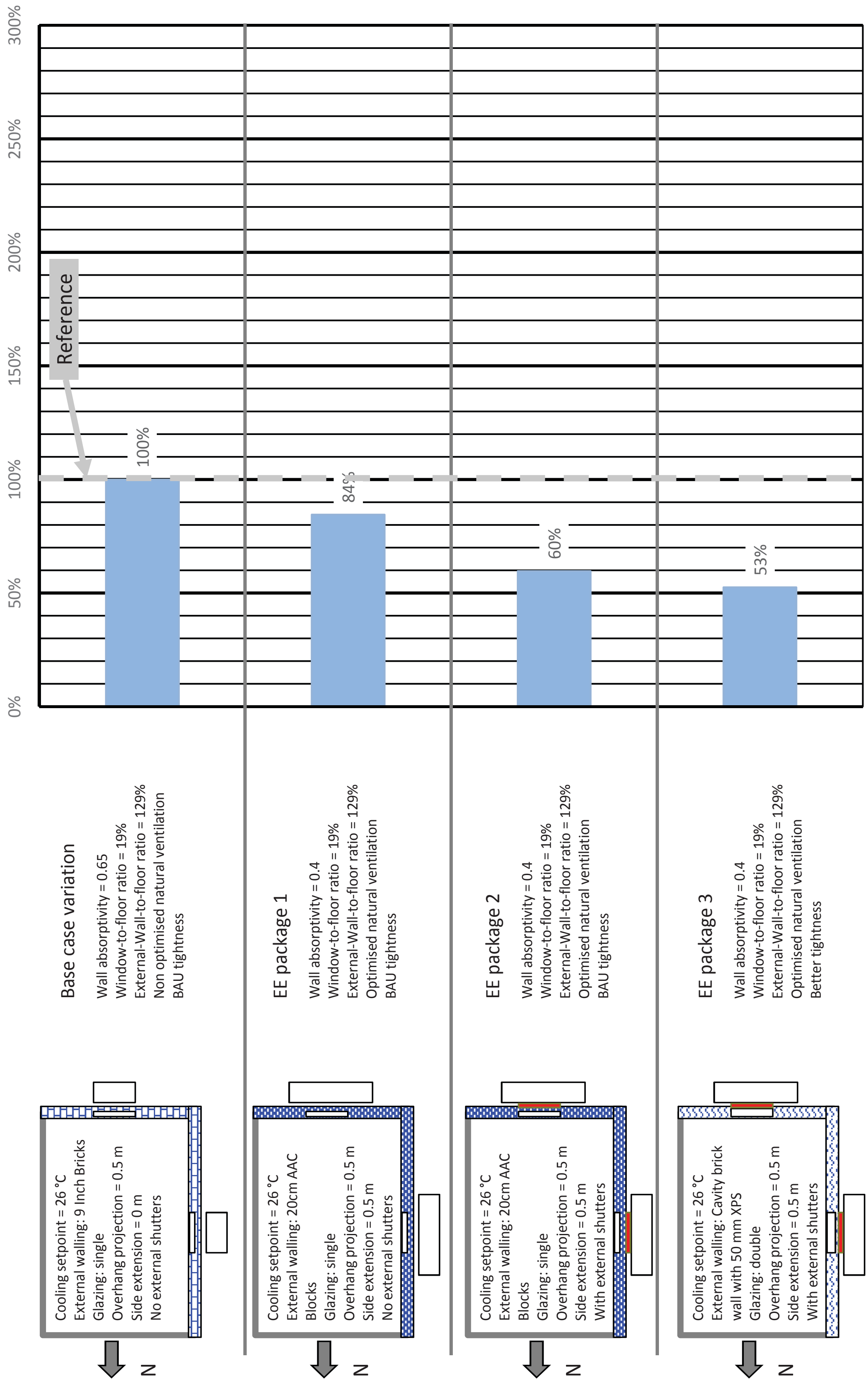

0%
50%
100%
150%
200%
250%
300%
Reference
214%
187%
140%
106%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 54%
External-Wall-to-floor ratio = 181%
Optimised natural ventilation
Better tightness
Cooling setpoint = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 22 °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.4-31



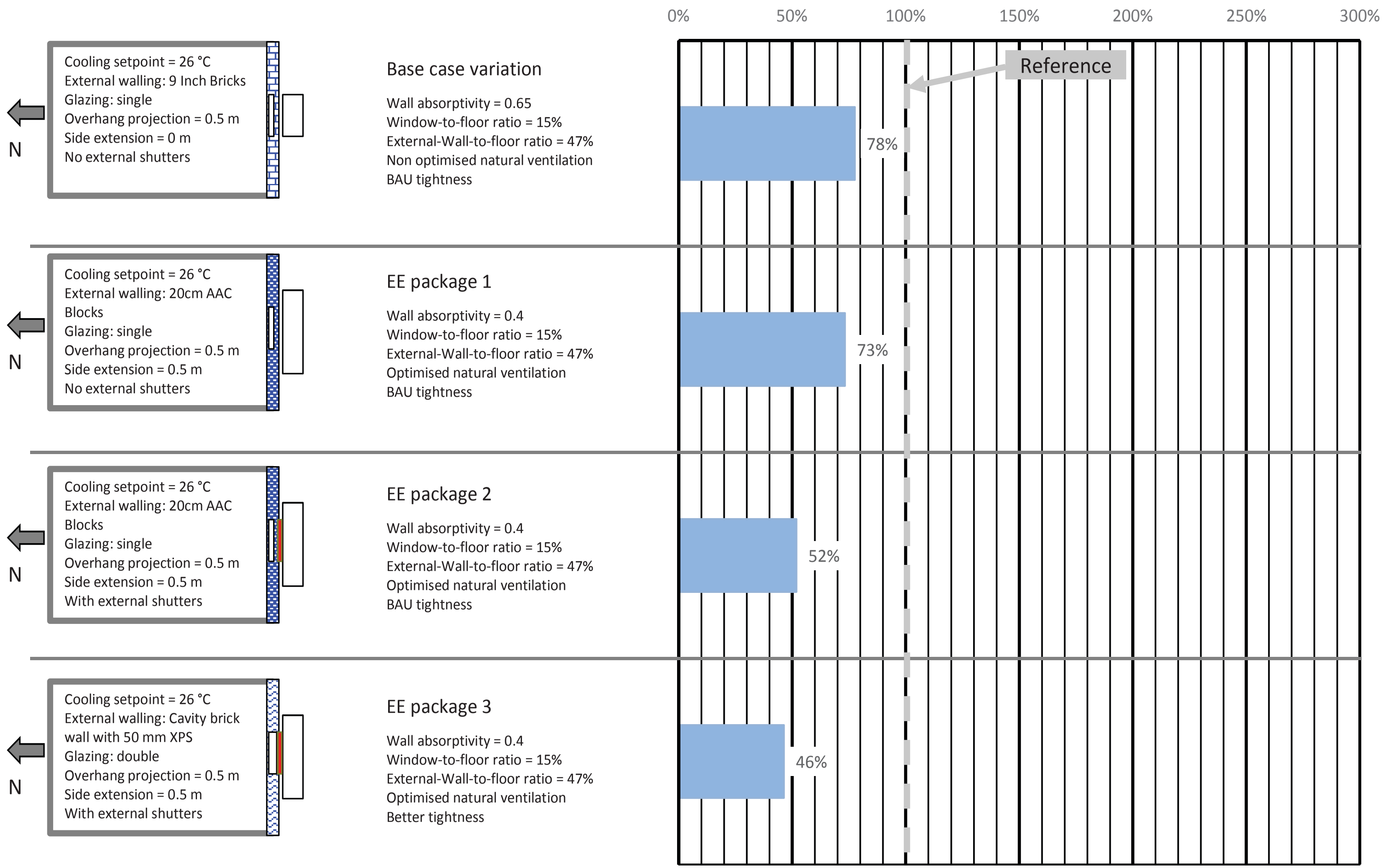
0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 53%
External-Wall-to-floor ratio = 85%
Non optimised natural ventilation
BAU tightness
218%
Cooling setpoint = 22 °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
205%
Cooling setpoint = 22 °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
136%
Cooling setpoint = 22 °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
102%

A.4-32

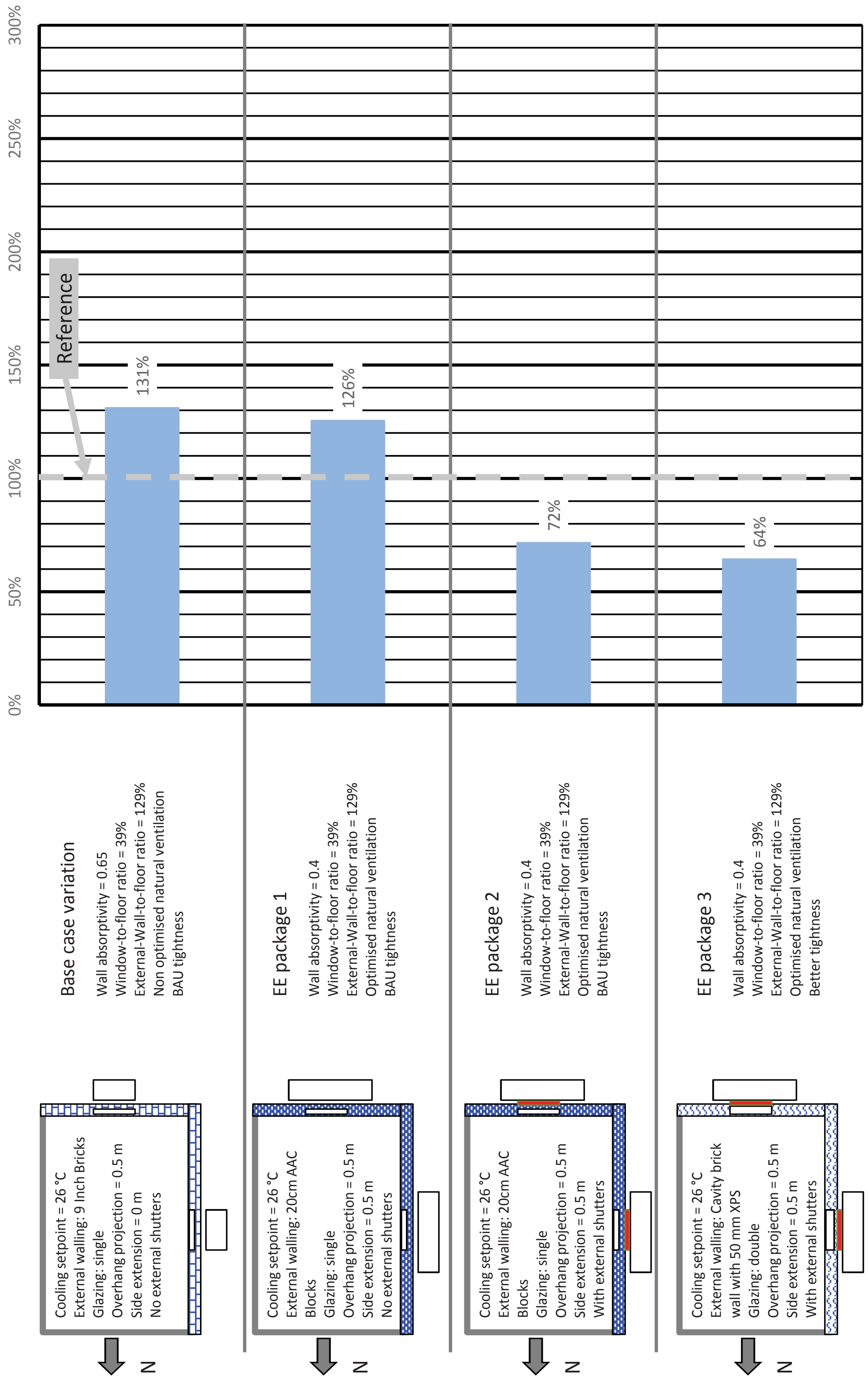


0%
50%
100%
150%
200%
250%
300%
Reference
100%
84%
60%
53%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor 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

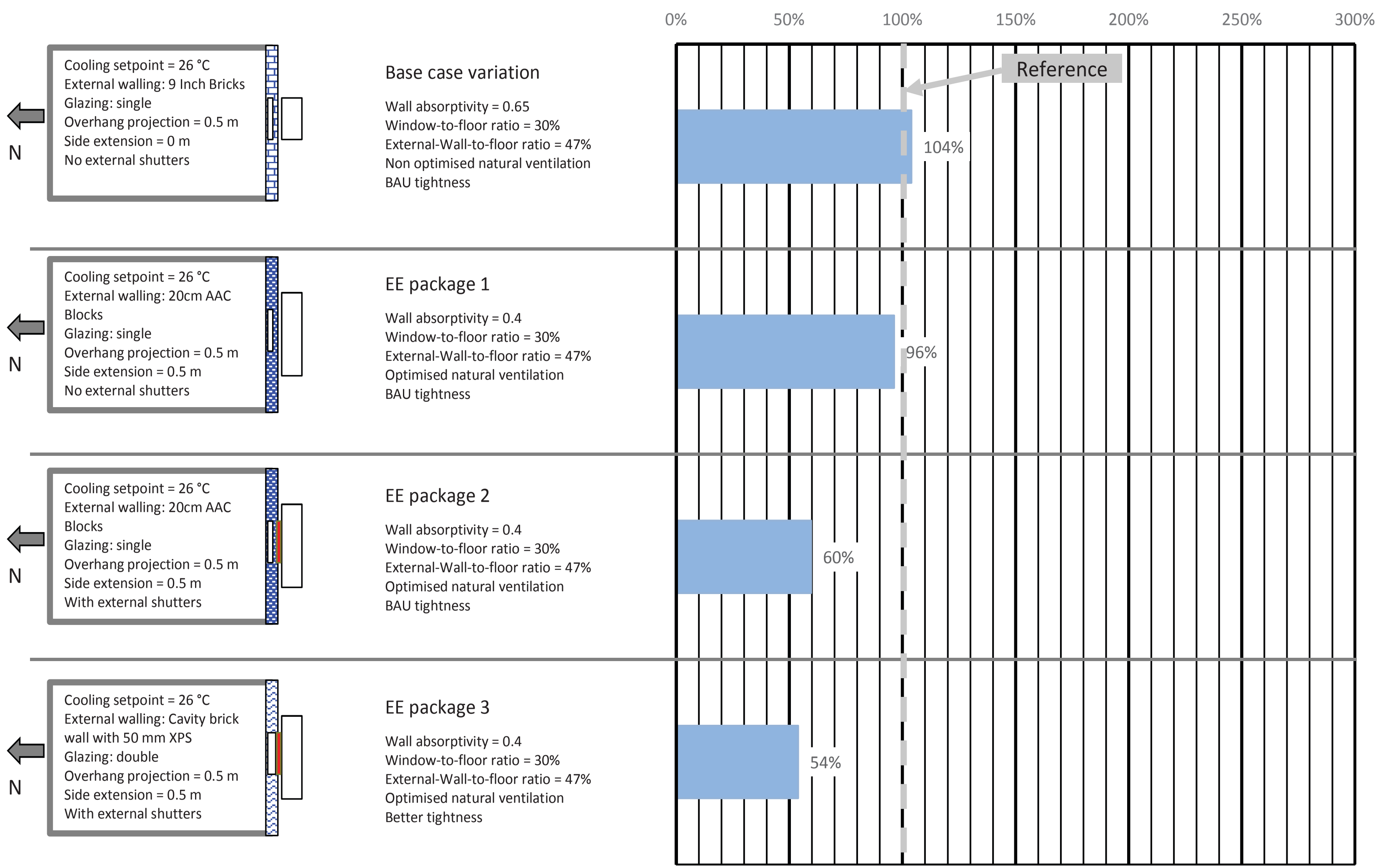
A.4-33


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
78%
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
73%
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
52%
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
46%

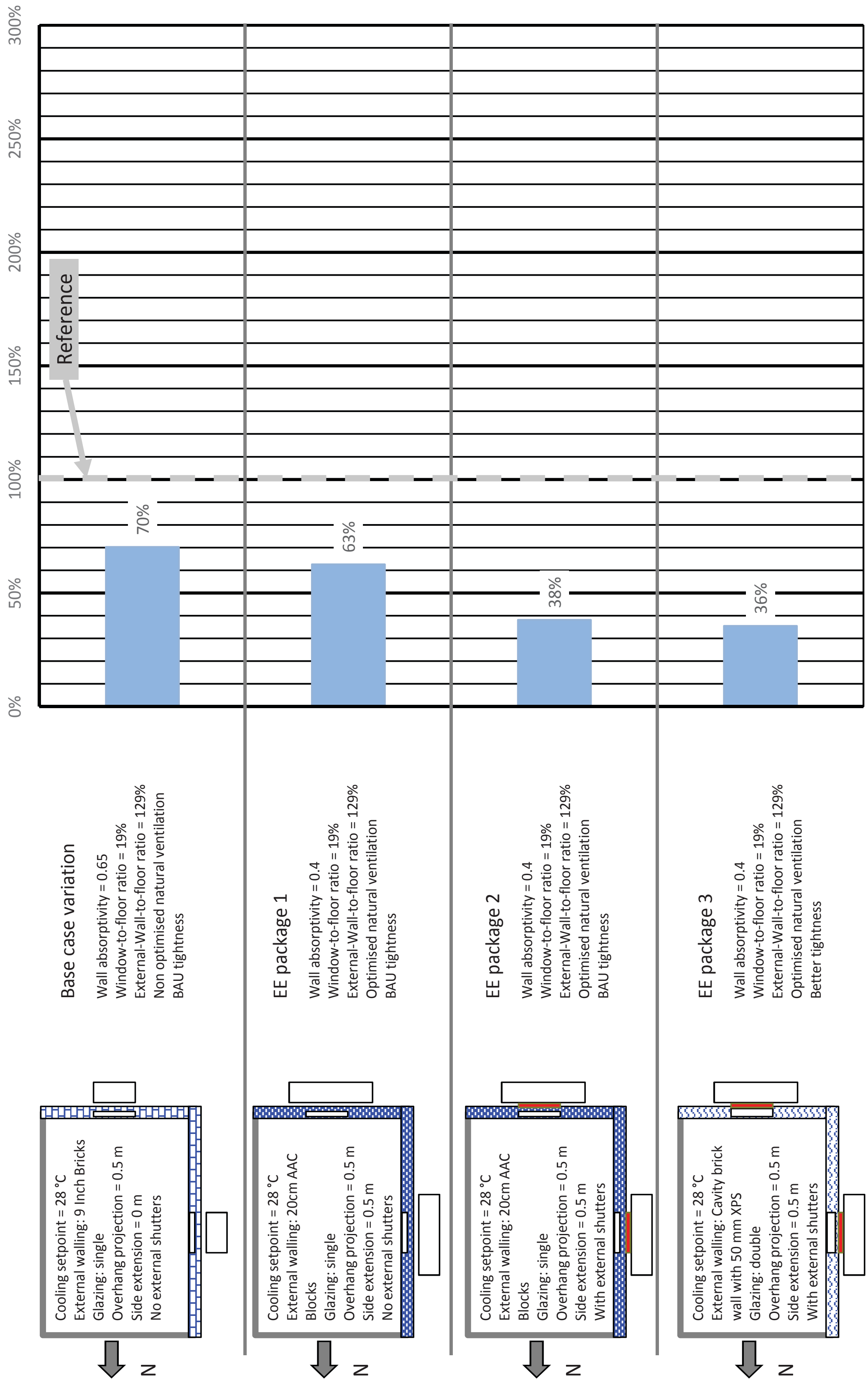
A.4-34


0%
50%
100%
150%
200%
250%
300%
Reference
131%
126%
72%
64%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
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

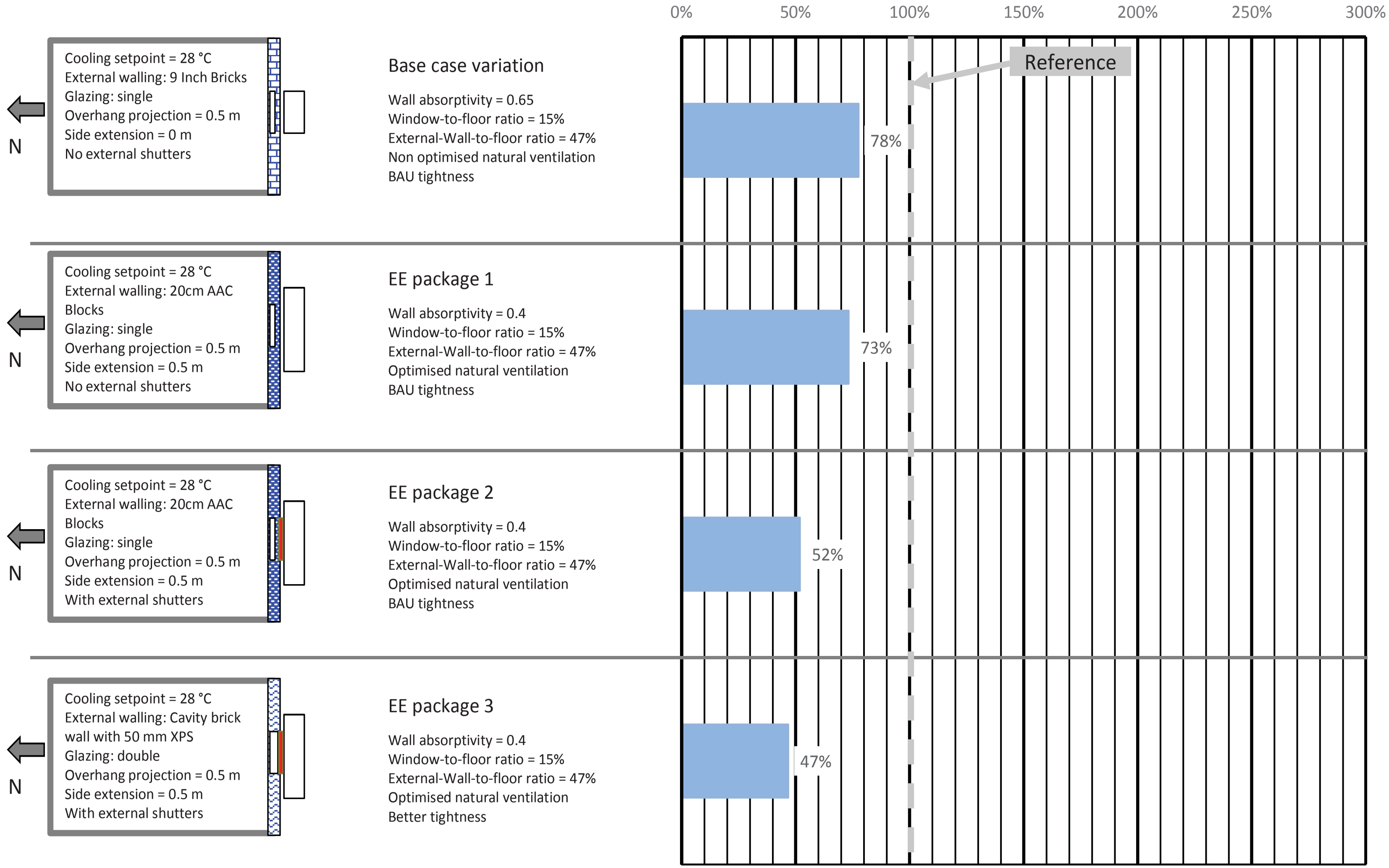
A.4-35


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
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
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
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
0%
50%
100%
150%
200%
250%
300%
Reference
104%
96%
60%
54%

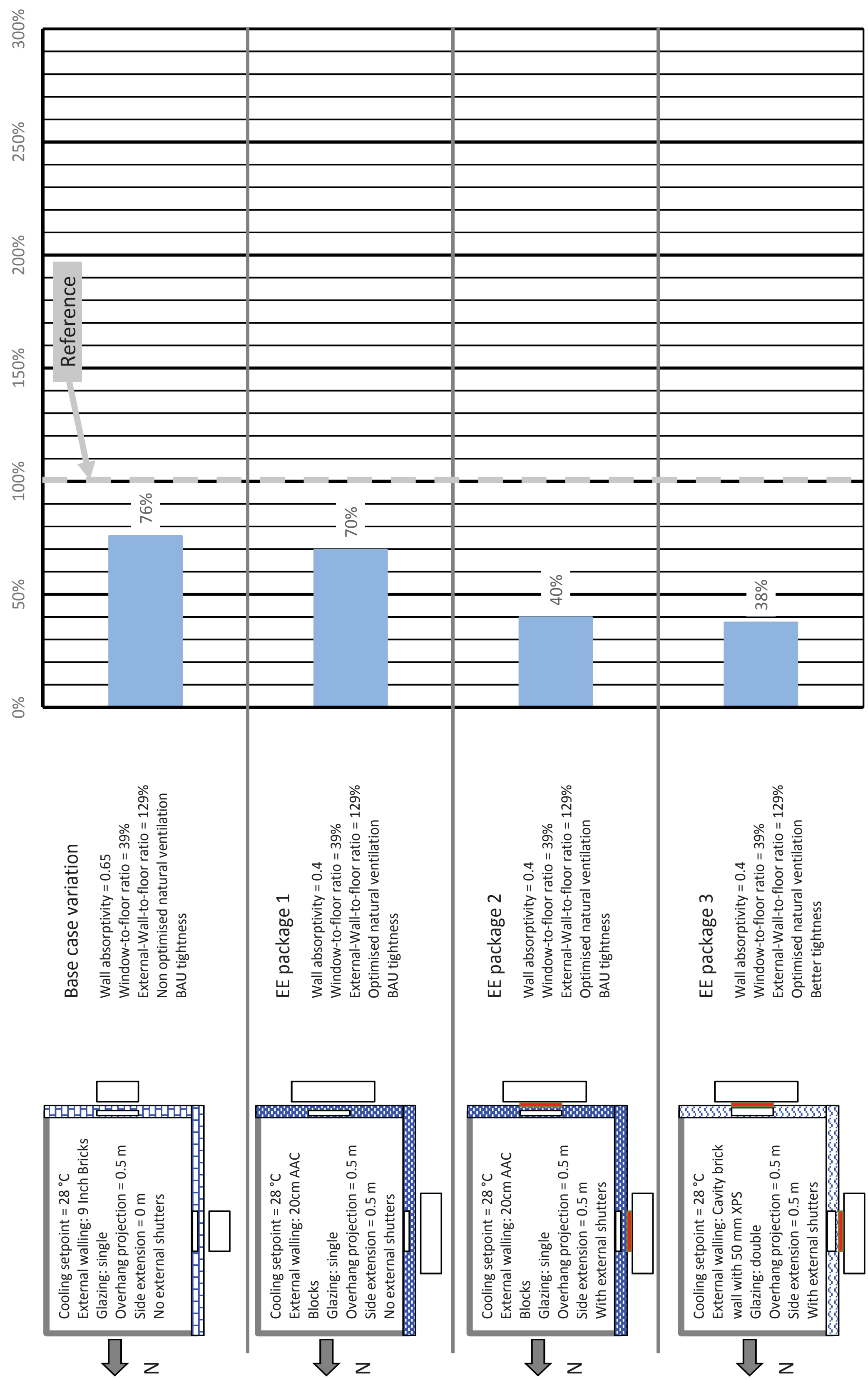
A.4-36


0%
50%
100%
150%
200%
250%
300%
Reference
70%
63%
38%
36%
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 = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 28 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 28 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 28 °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

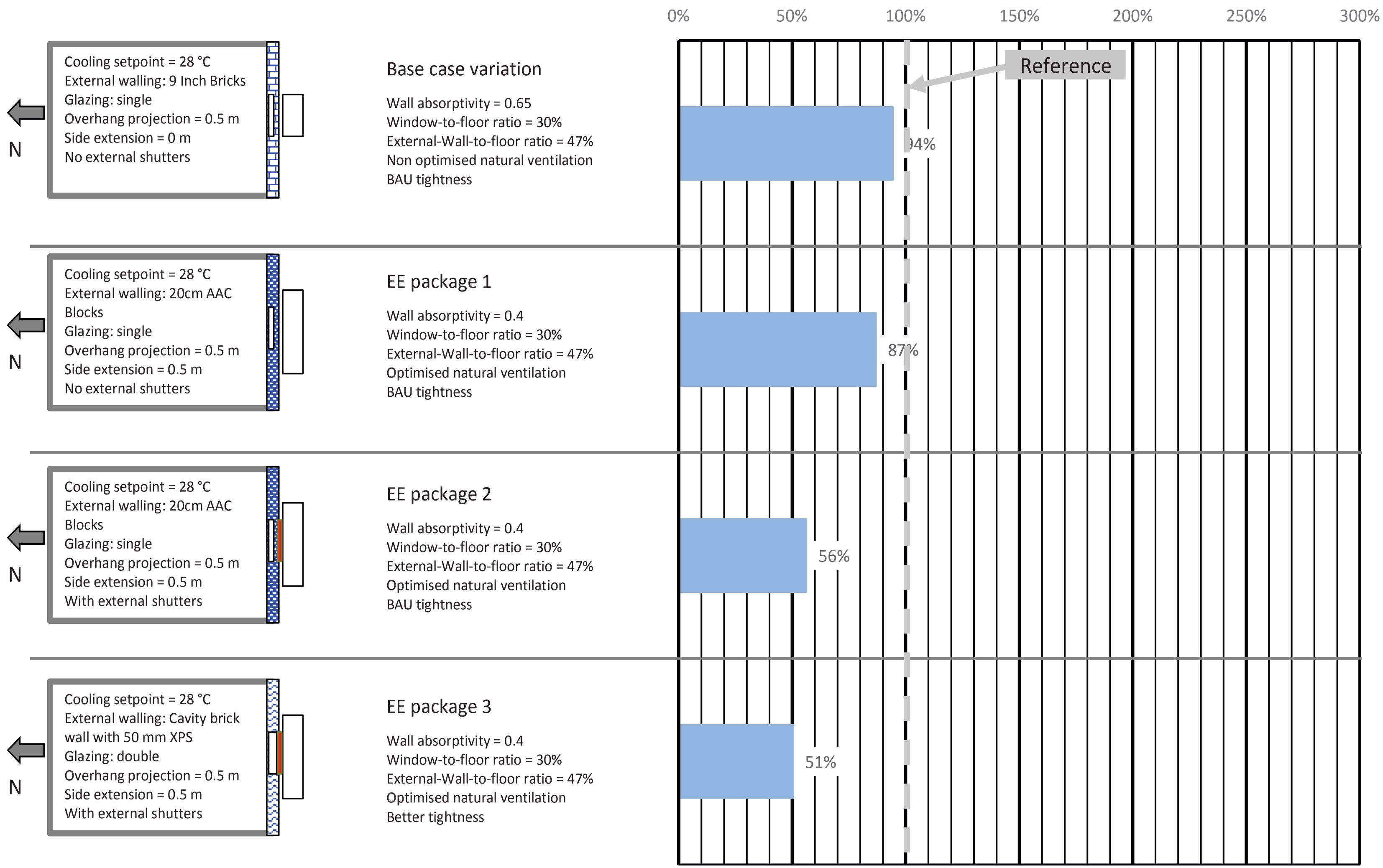
A.4-37


Cooling setpoint = 28 °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
Cooling setpoint = 28 °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
Cooling setpoint = 28 °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
Cooling setpoint = 28 °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
0%
50%
100%
150%
200%
250%
300%
Reference
78%
73%
52%
47%

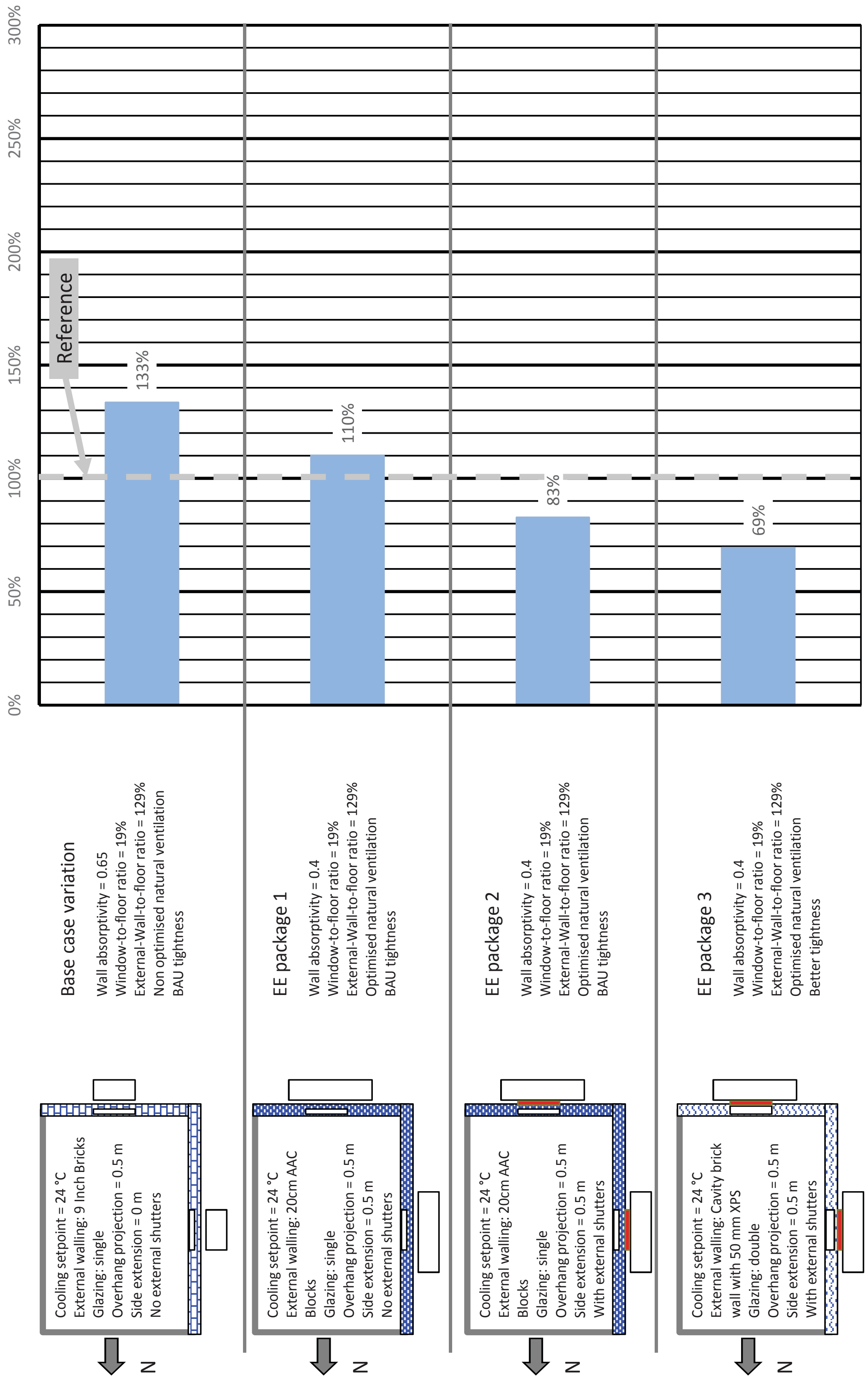
A.4-38


0%
50%
100%
150%
200%
250%
300%
Reference
76%
70%
40%
38%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 28 °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

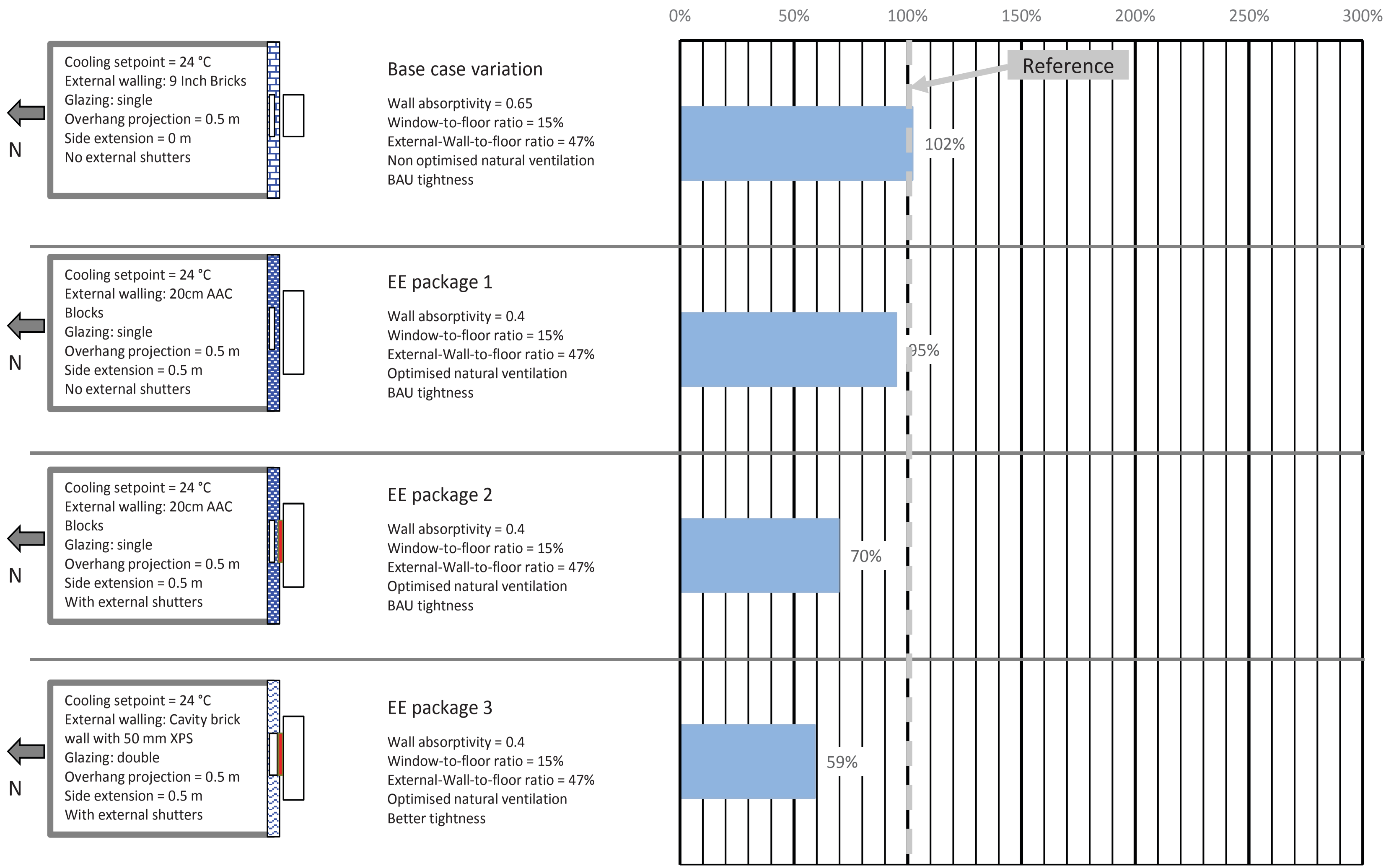
A.4-39


Cooling setpoint = 28 °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
Cooling setpoint = 28 °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
Cooling setpoint = 28 °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
Cooling setpoint = 28 °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
0%
50%
100%
150%
200%
250%
300%
Reference
94%
87%
56%
51%

A.4-40

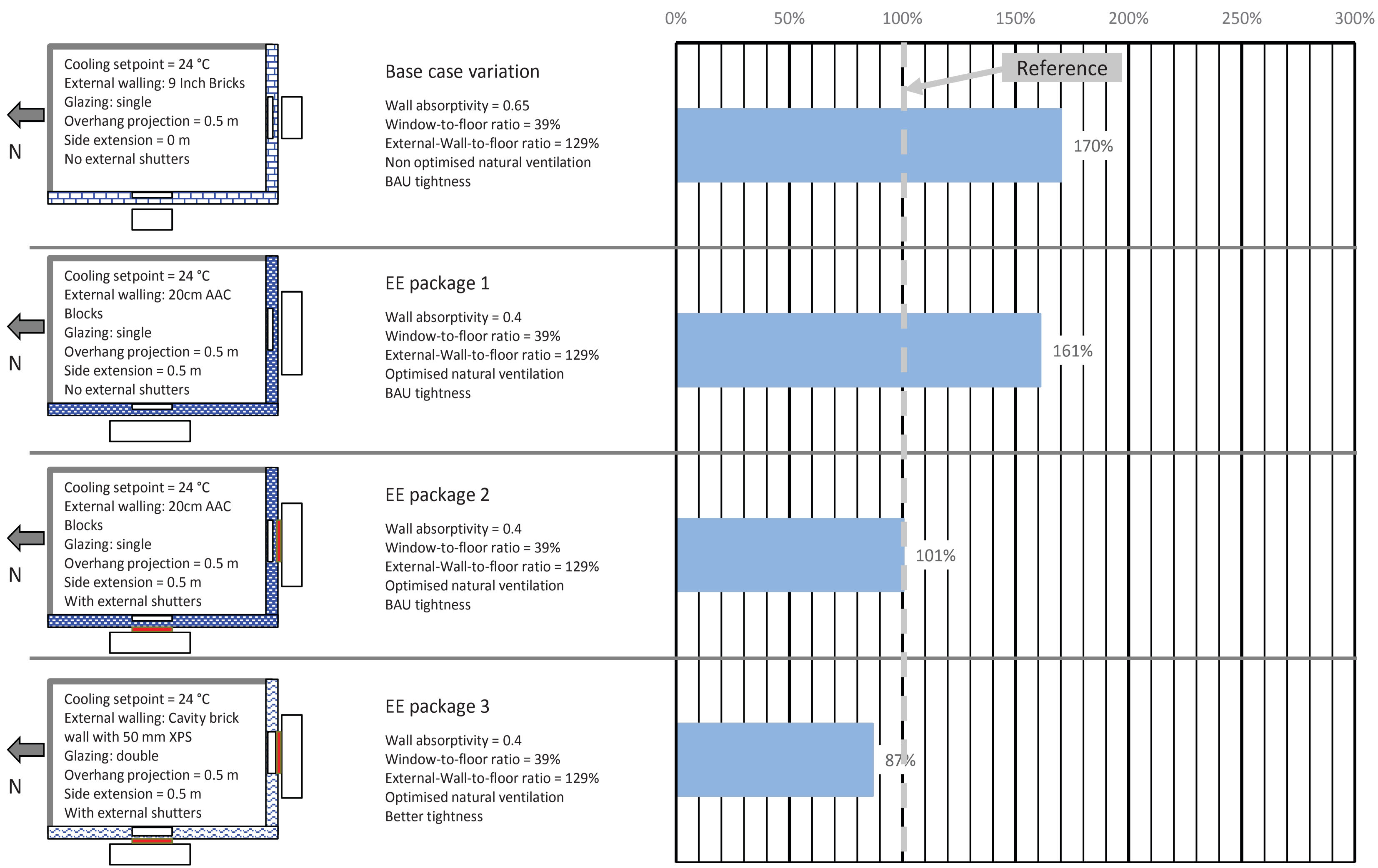

0%
50%
100%
150%
200%
250%
300%
Reference
133%
110%
83%
69%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor 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 = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 24 °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.4-41

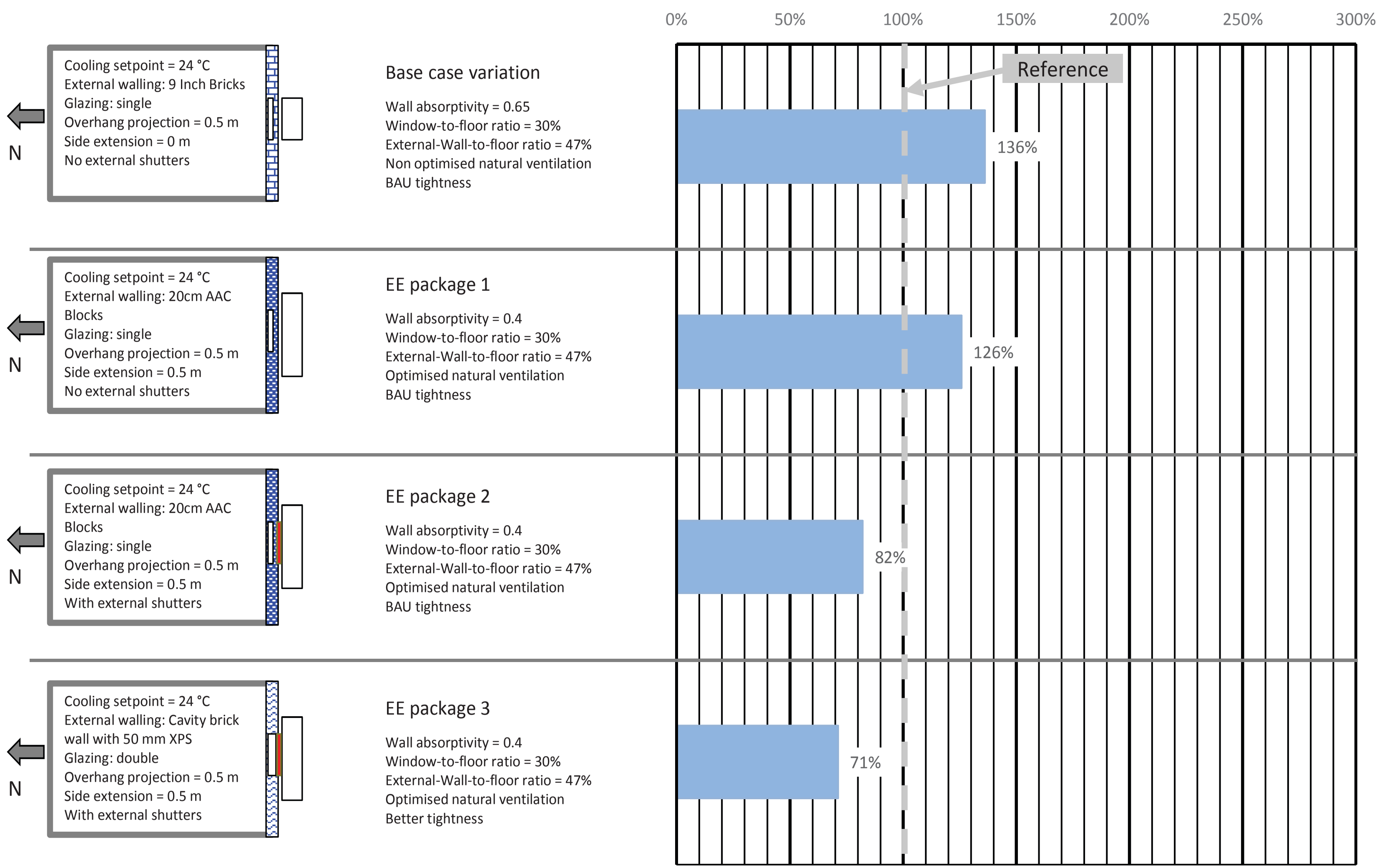


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
102%
Cooling setpoint = 24 °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
95%
Cooling setpoint = 24 °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
70%
Cooling setpoint = 24 °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
59%

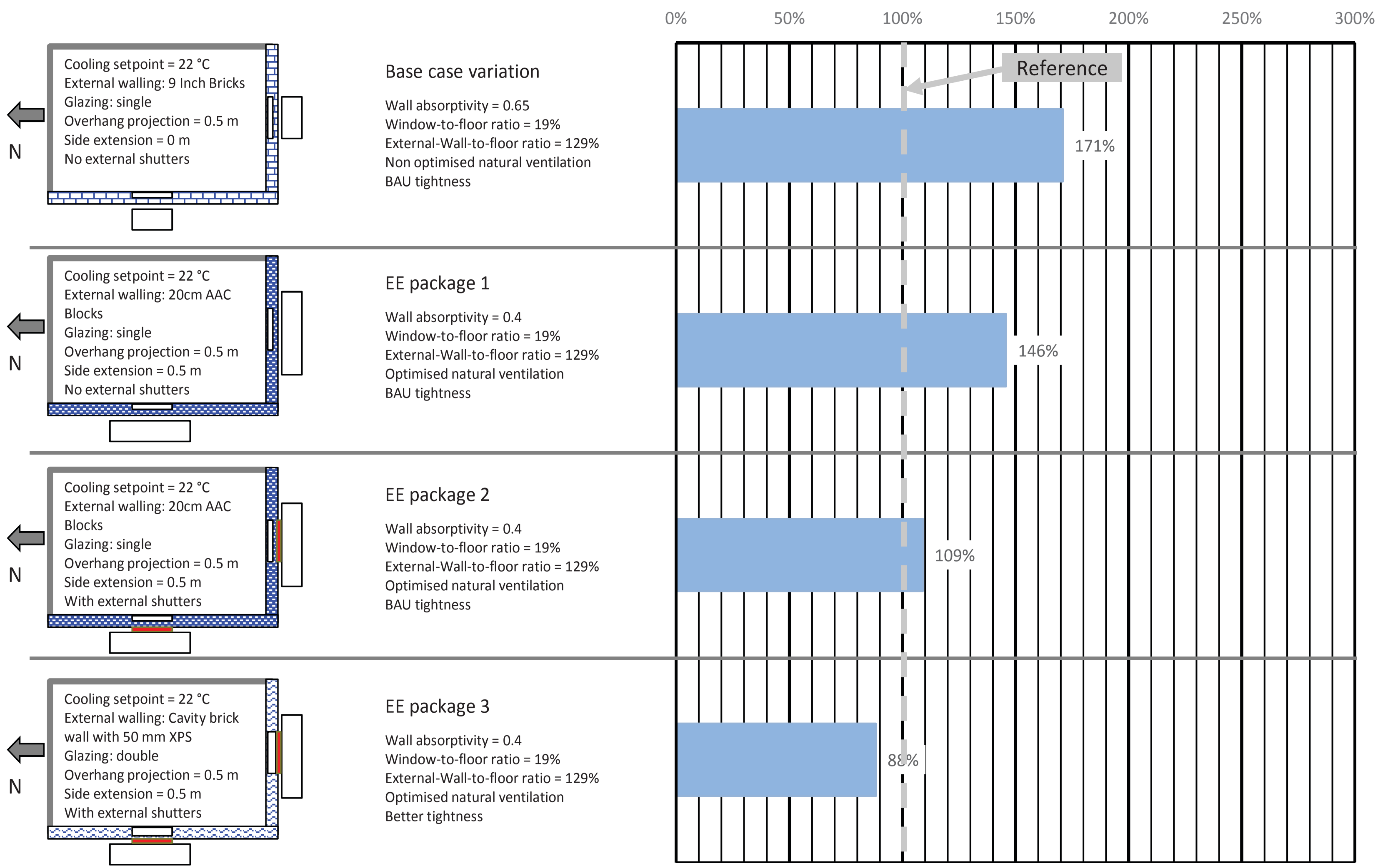
A.4-42


Cooling setpoint = 24 °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
Cooling setpoint = 24 °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
Cooling setpoint = 24 °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
Cooling setpoint = 24 °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
0%
50%
100%
150%
200%
250%
300%
Reference
170%
161%
101%
87%

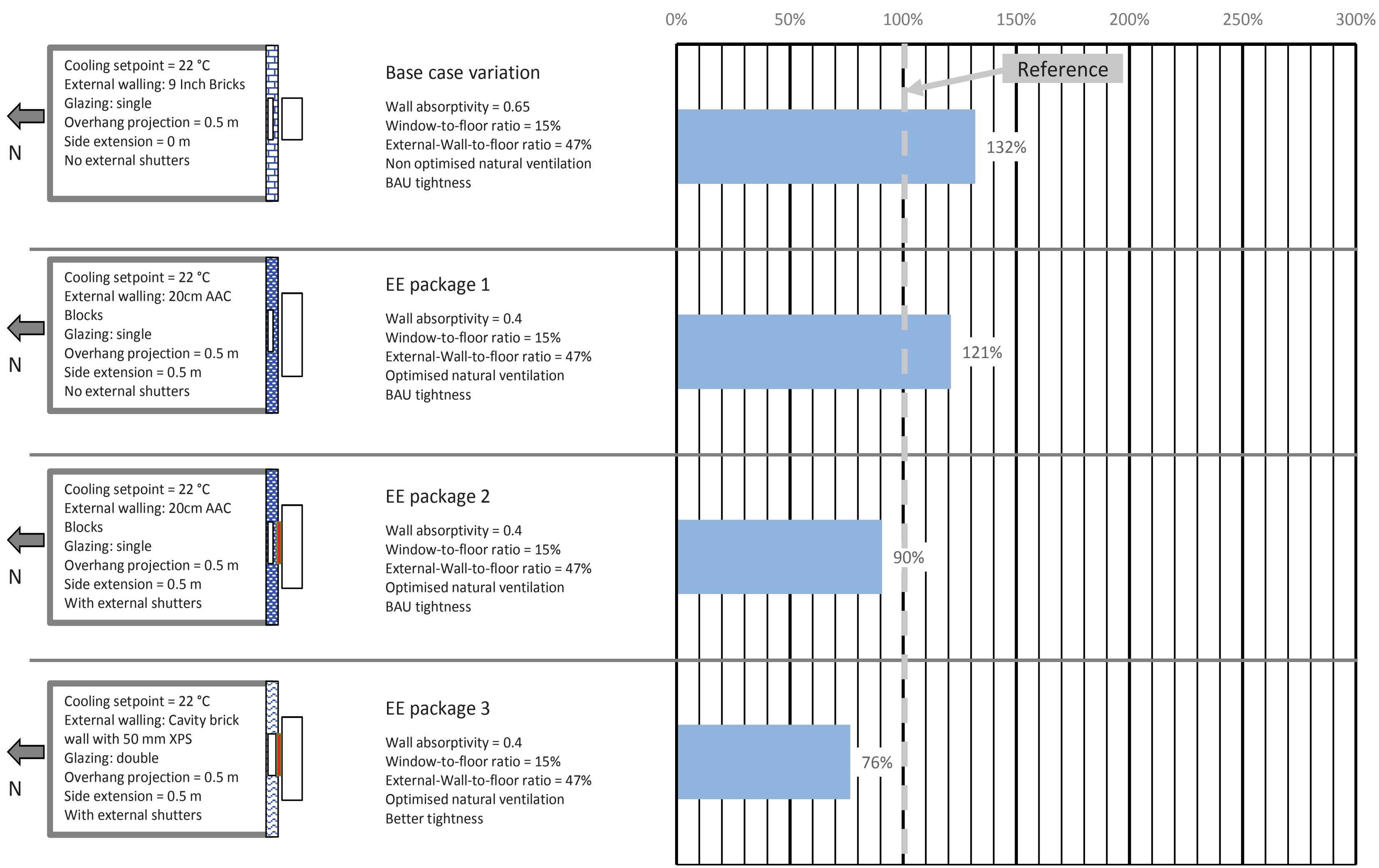
A.4-43


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 24 °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
136%
Cooling setpoint = 24 °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
126%
Cooling setpoint = 24 °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
82%
Cooling setpoint = 24 °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
71%

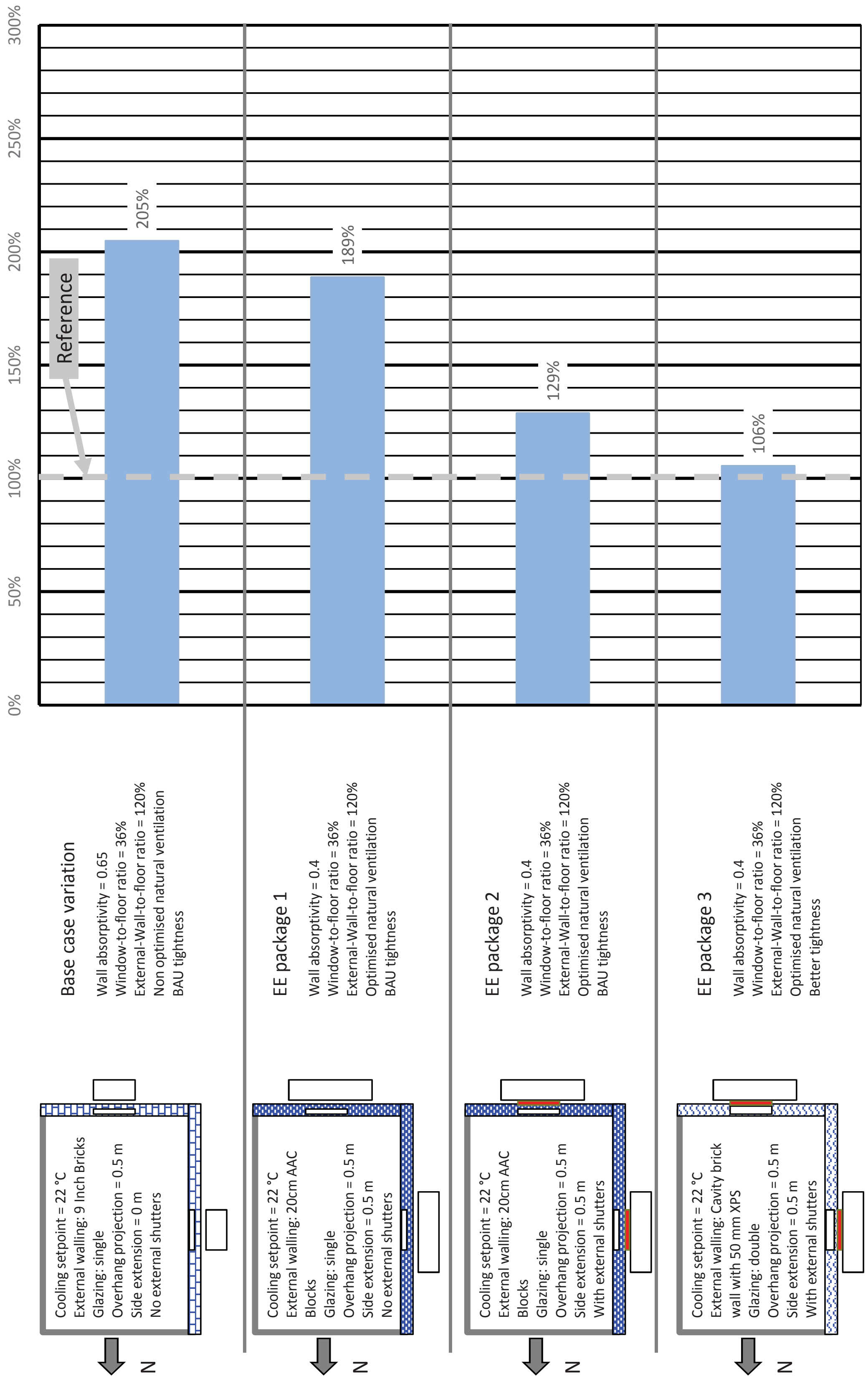
A.4-44


Cooling setpoint = 22 °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 = 19%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °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 = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °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 = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °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 = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
0%
50%
100%
150%
200%
250%
300%
Reference
171%
146%
109%
88%

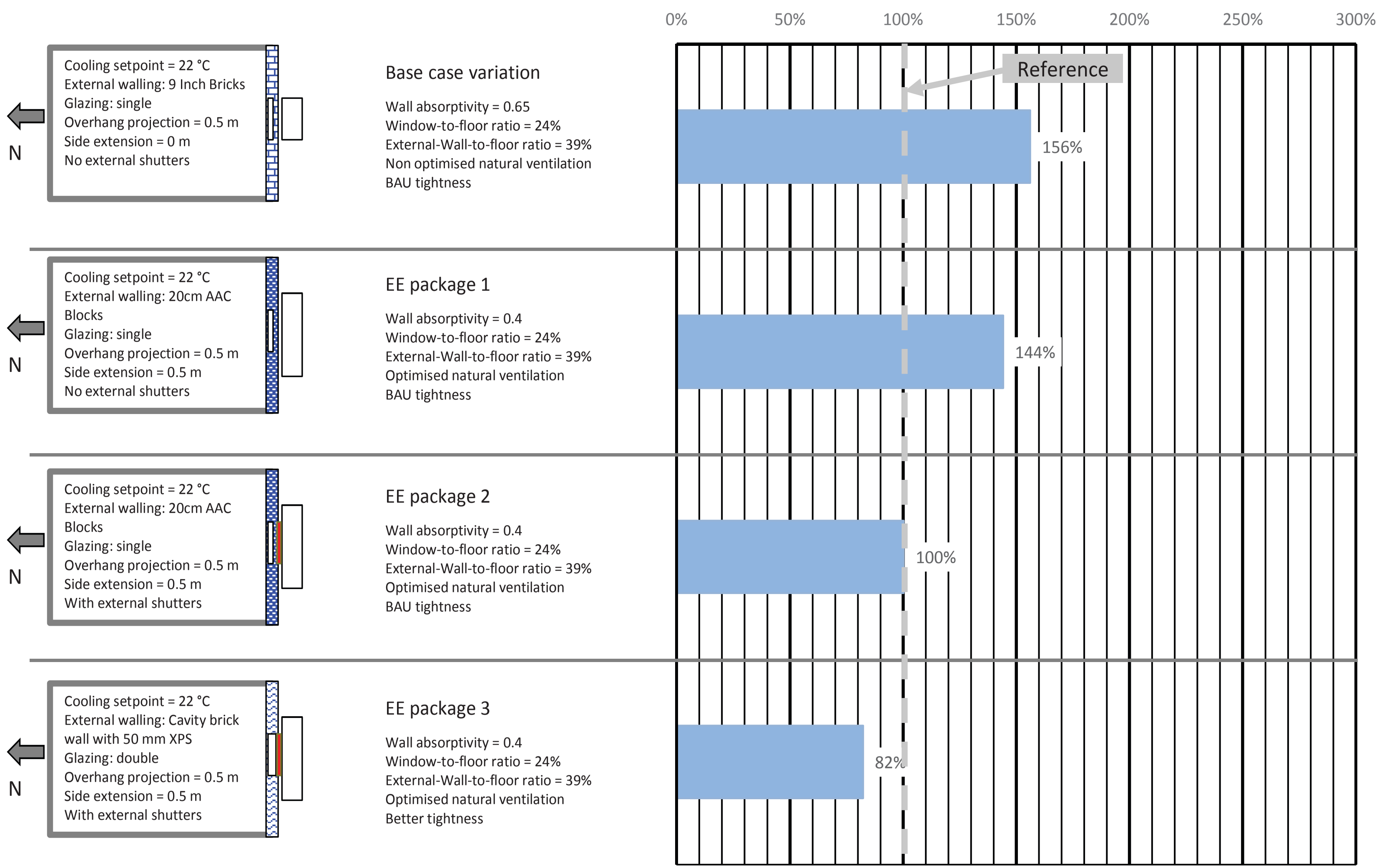
A.4-45


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 22 °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
132%
Cooling setpoint = 22 °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
121%
Cooling setpoint = 22 °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
90%
Cooling setpoint = 22 °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
76%

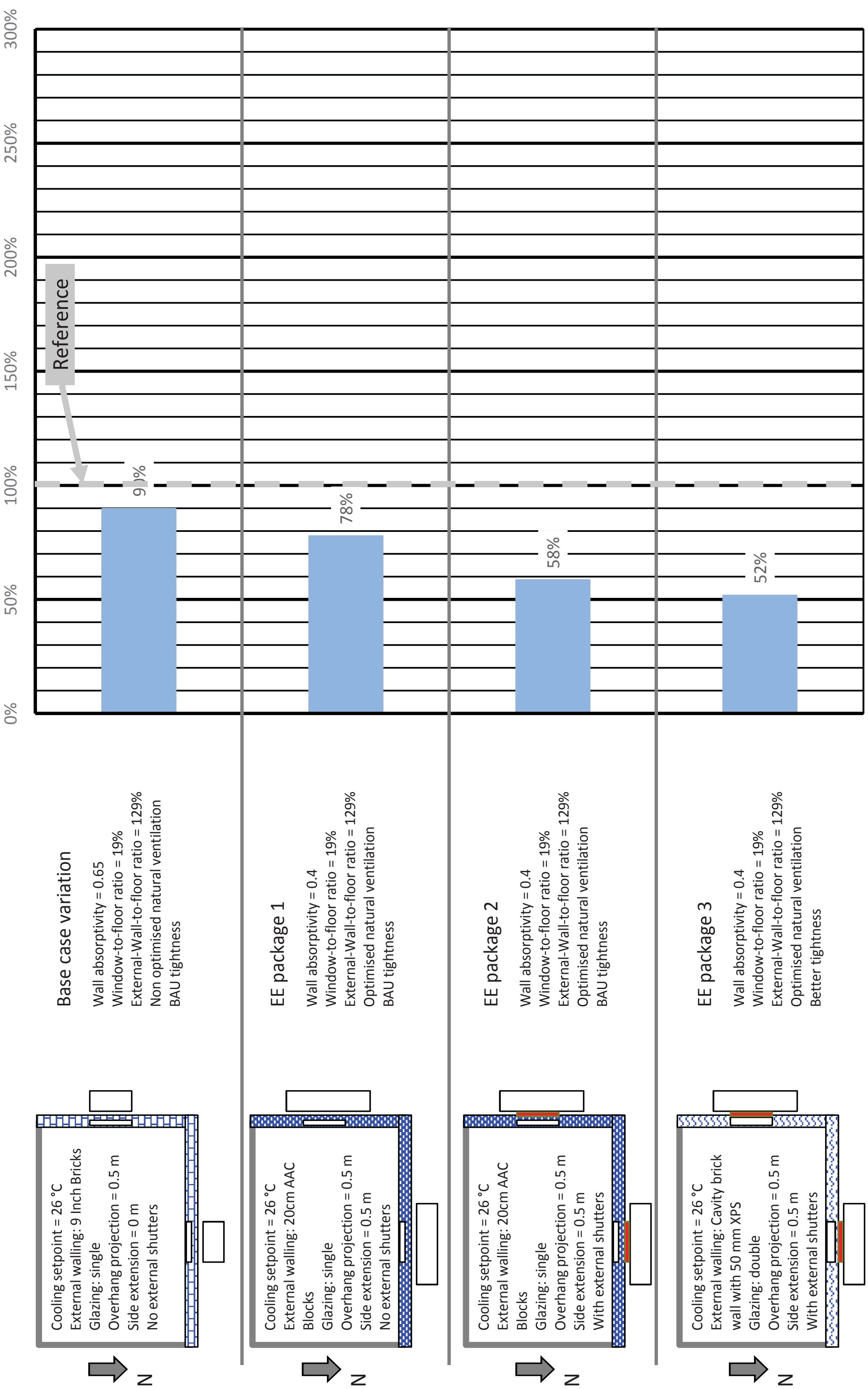
A.4-46


0%
50%
100%
150%
200%
250%
300%
Reference
205%
189%
129%
106%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 36%
External-Wall-to-floor ratio = 120%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 36%
External-Wall-to-floor ratio = 120%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 36%
External-Wall-to-floor ratio = 120%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °C
External walling: 20cm AAC Blocks
Glazing: single
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 = 36%
External-Wall-to-floor ratio = 120%
Optimised natural ventilation
Better tightness
Cooling setpoint = 22 °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

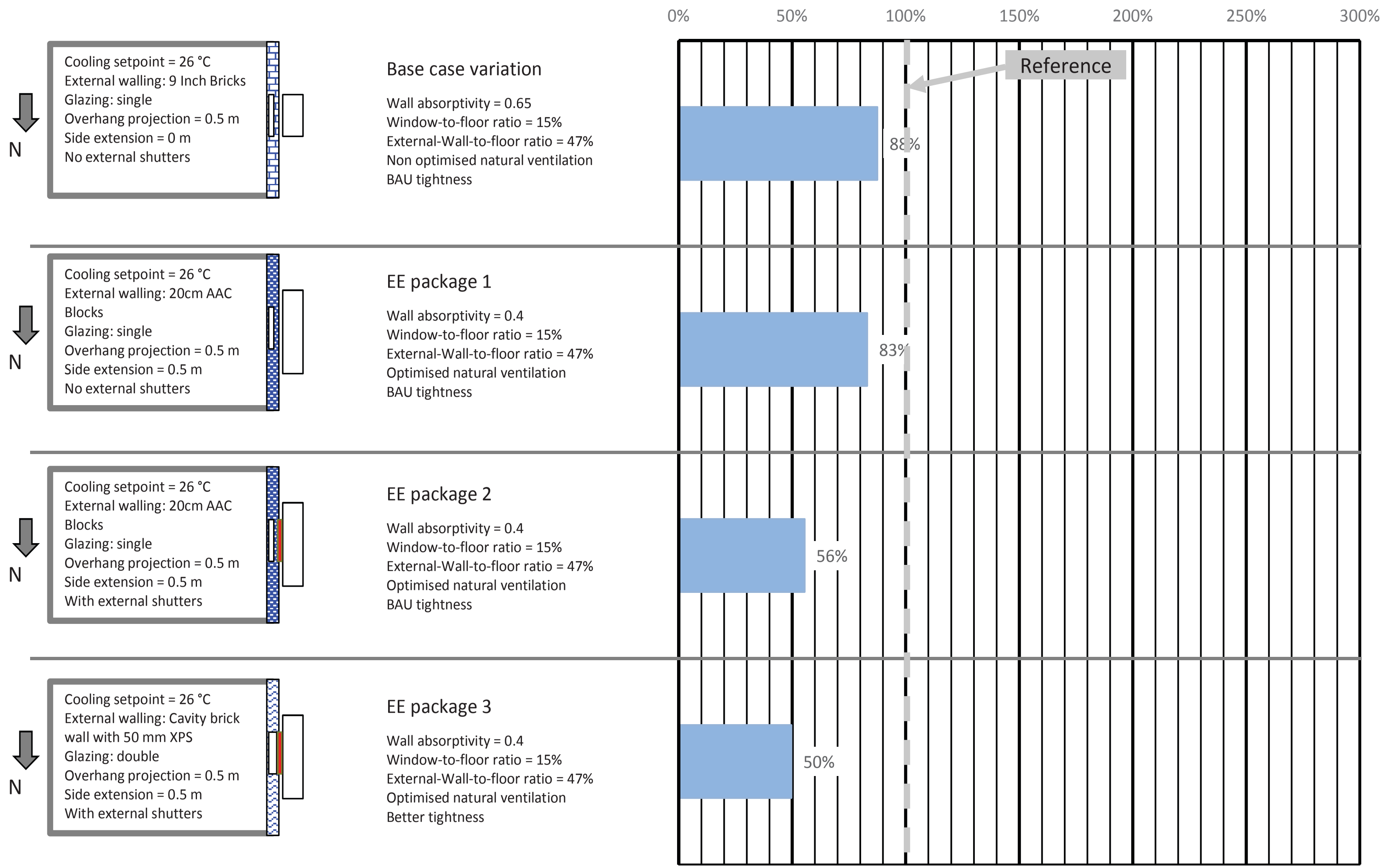
A.4-47


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 22 °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 = 24%
External-Wall-to-floor ratio = 39%
Non optimised natural ventilation
BAU tightness
156%
Cooling setpoint = 22 °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 = 24%
External-Wall-to-floor ratio = 39%
Optimised natural ventilation
BAU tightness
144%
Cooling setpoint = 22 °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 = 24%
External-Wall-to-floor ratio = 39%
Optimised natural ventilation
BAU tightness
100%
Cooling setpoint = 22 °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 = 24%
External-Wall-to-floor ratio = 39%
Optimised natural ventilation
Better tightness
82%

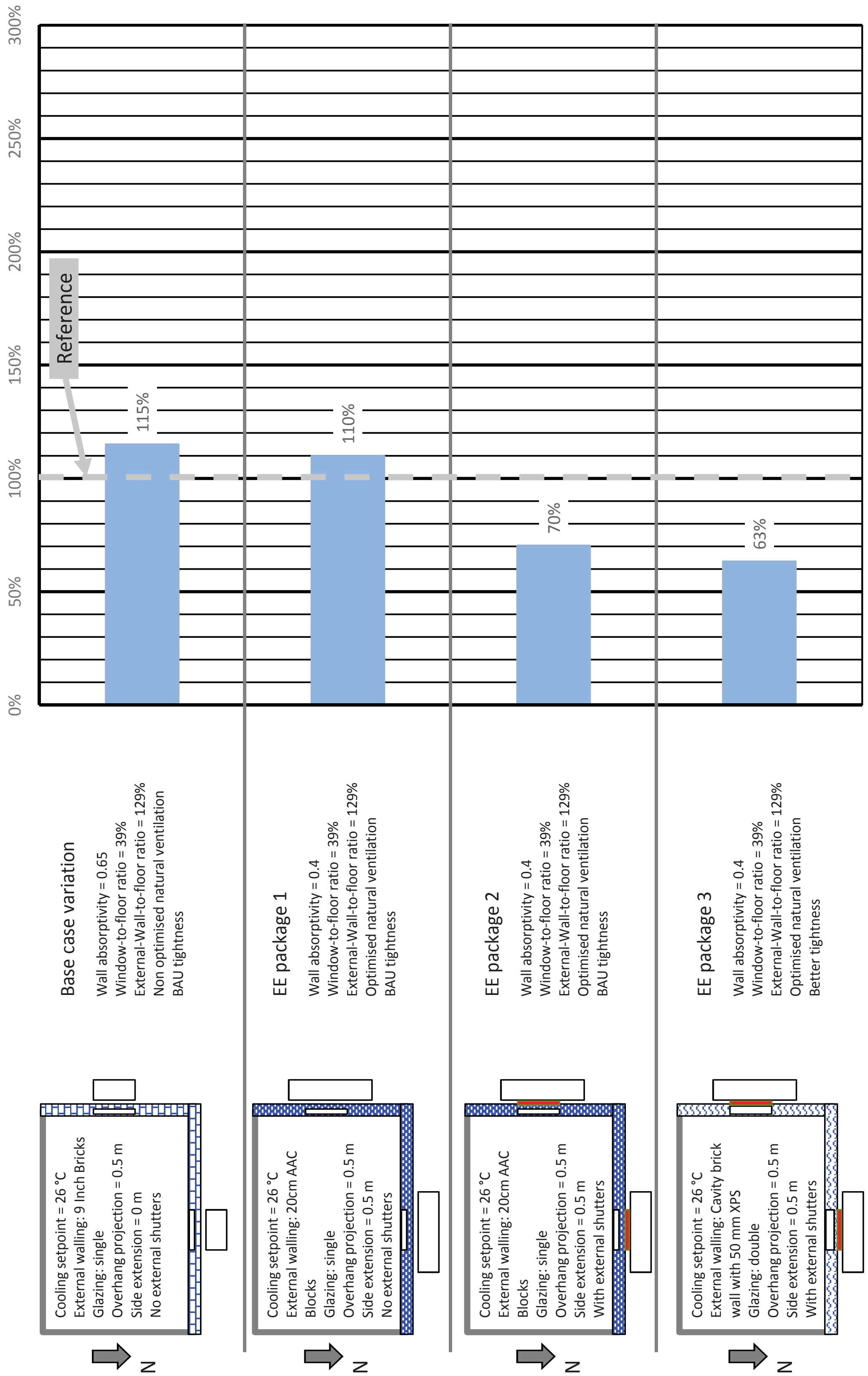
A.4-48


Reference
0%
50%
100%
150%
200%
250%
300%
78%
58%
52%
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

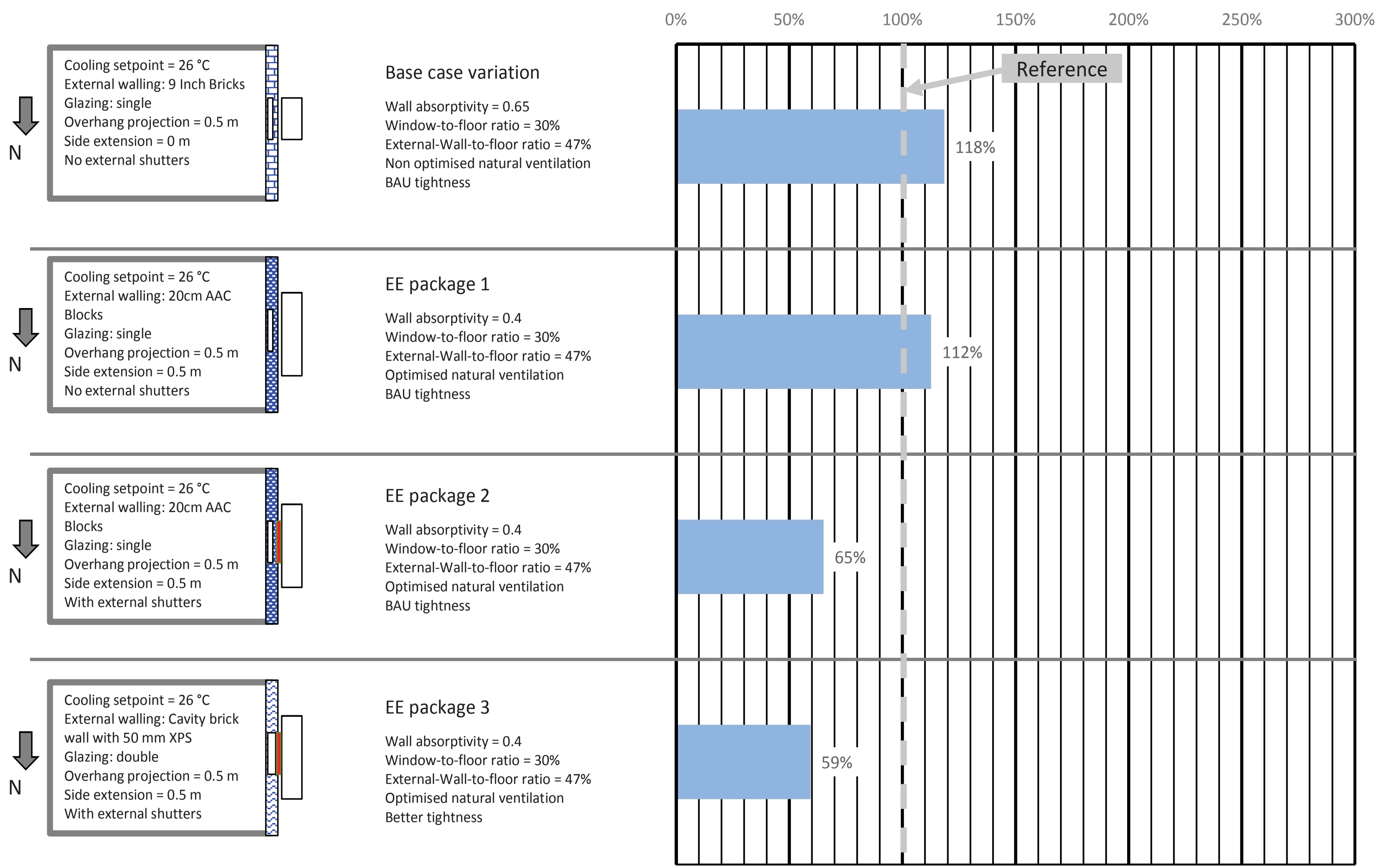
A.4-49


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
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
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
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
0%
50%
100%
150%
200%
250%
300%
Reference
83%
56%
50%

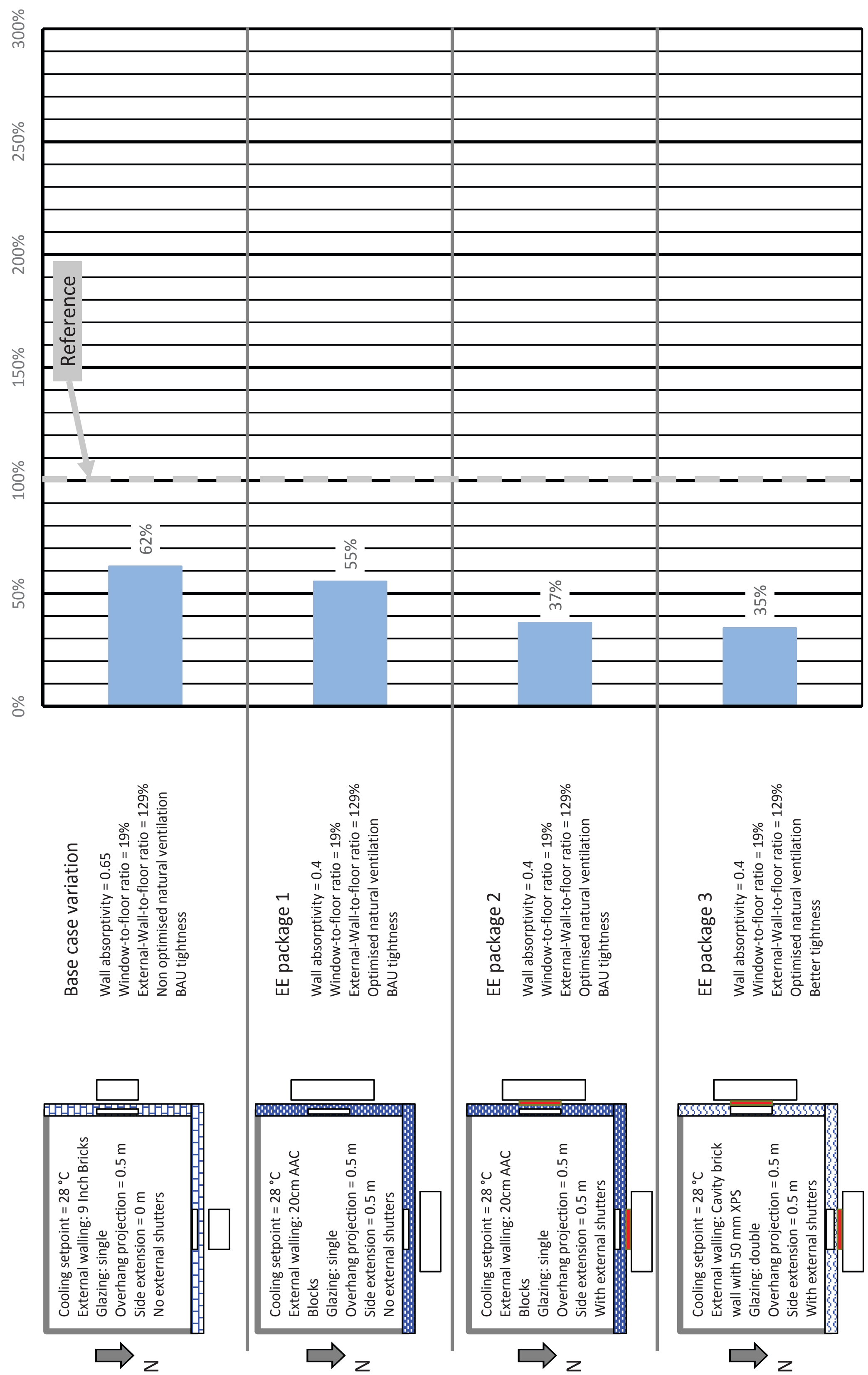
A.4-50


0%
50%
100%
150%
200%
250%
300%
Reference
115%
110%
70%
63%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
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
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

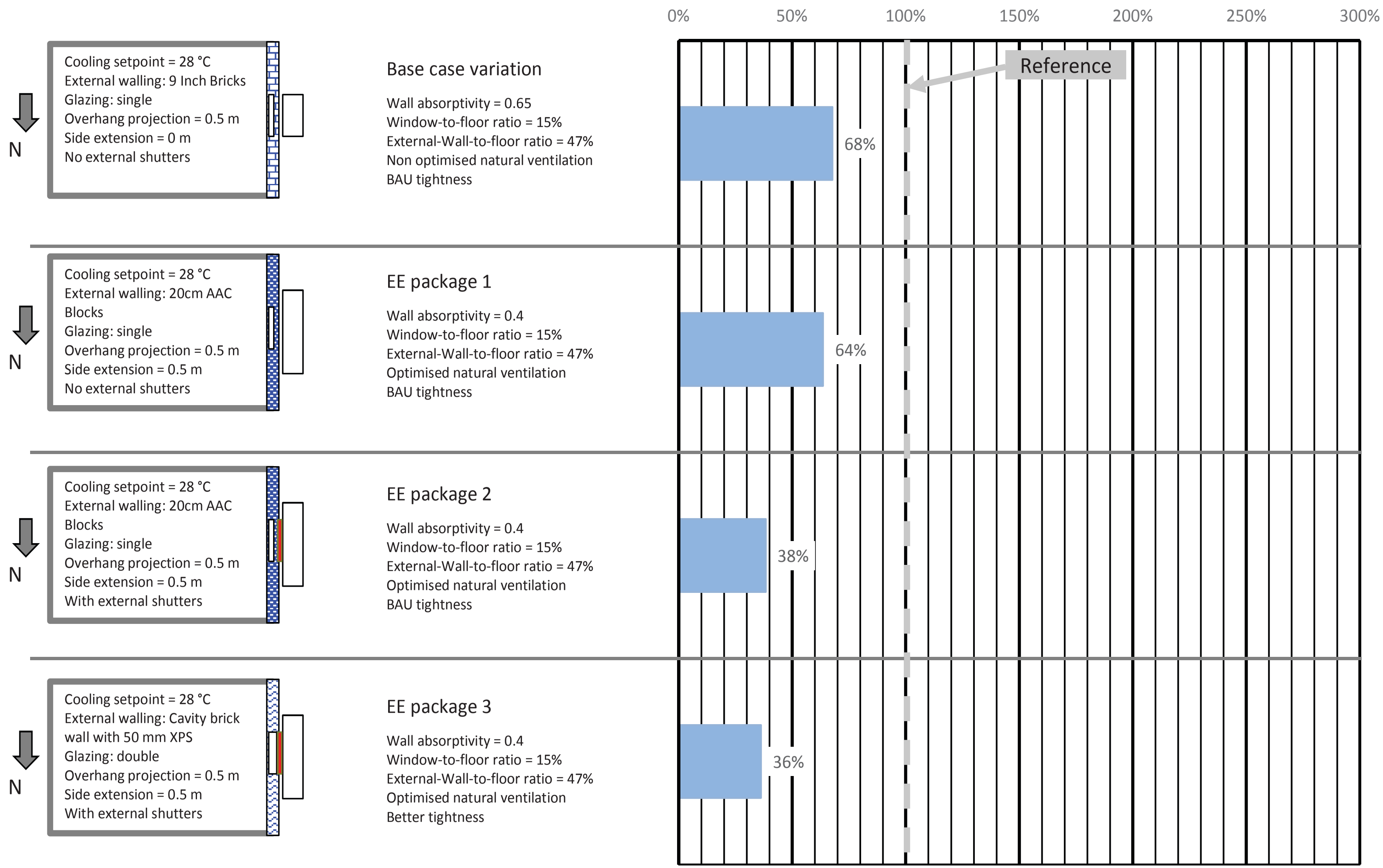
A.4-51


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
118%
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
112%
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
65%
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
59%

A.4-52

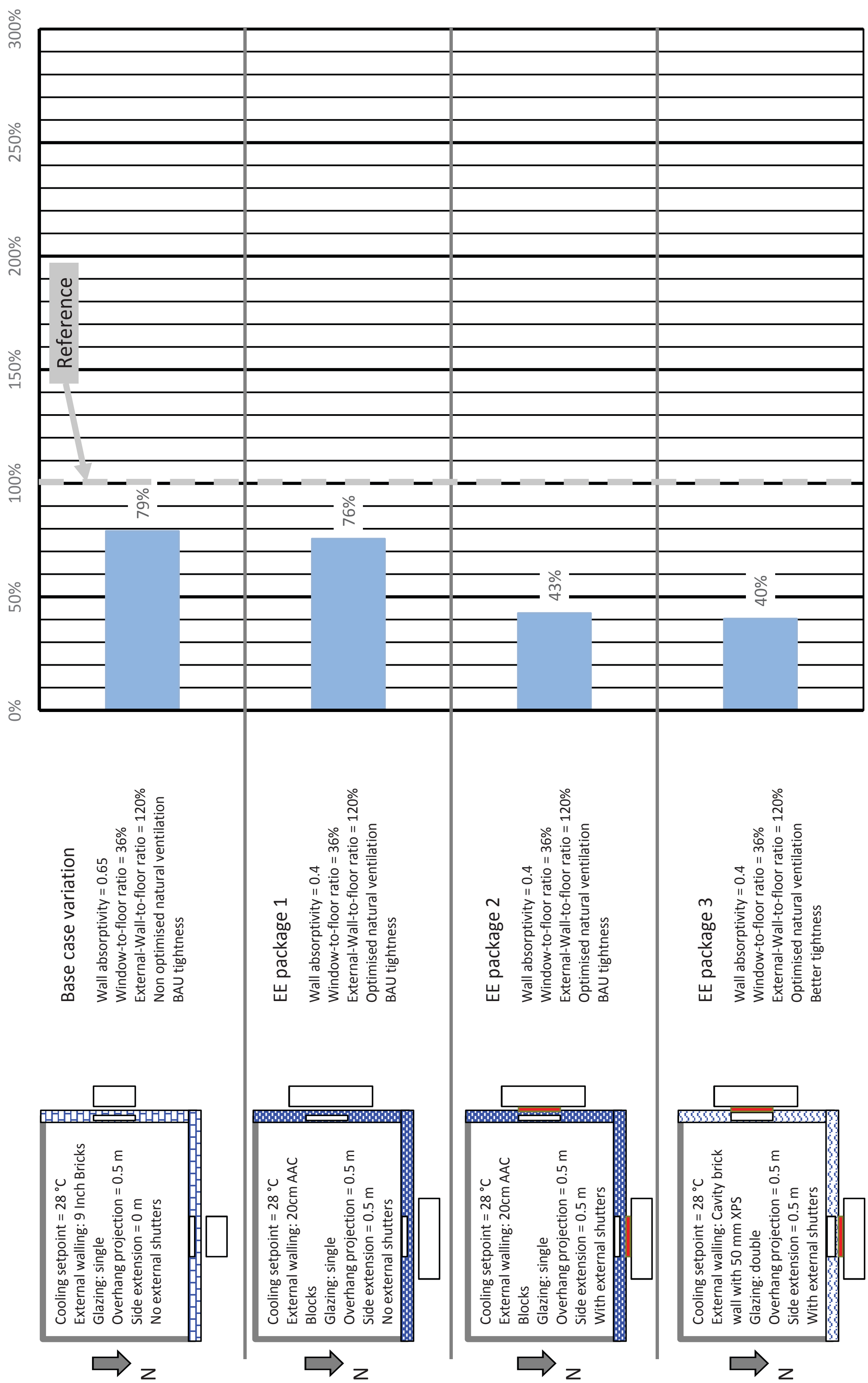

0%
50%
100%
150%
200%
250%
300%
Reference
62%
55%
37%
35%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
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 = 28 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
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 = 28 °C
External walling: 20cm AAC
Blocks
Glazing: single
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 = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
Cooling setpoint = 28 °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.4-53

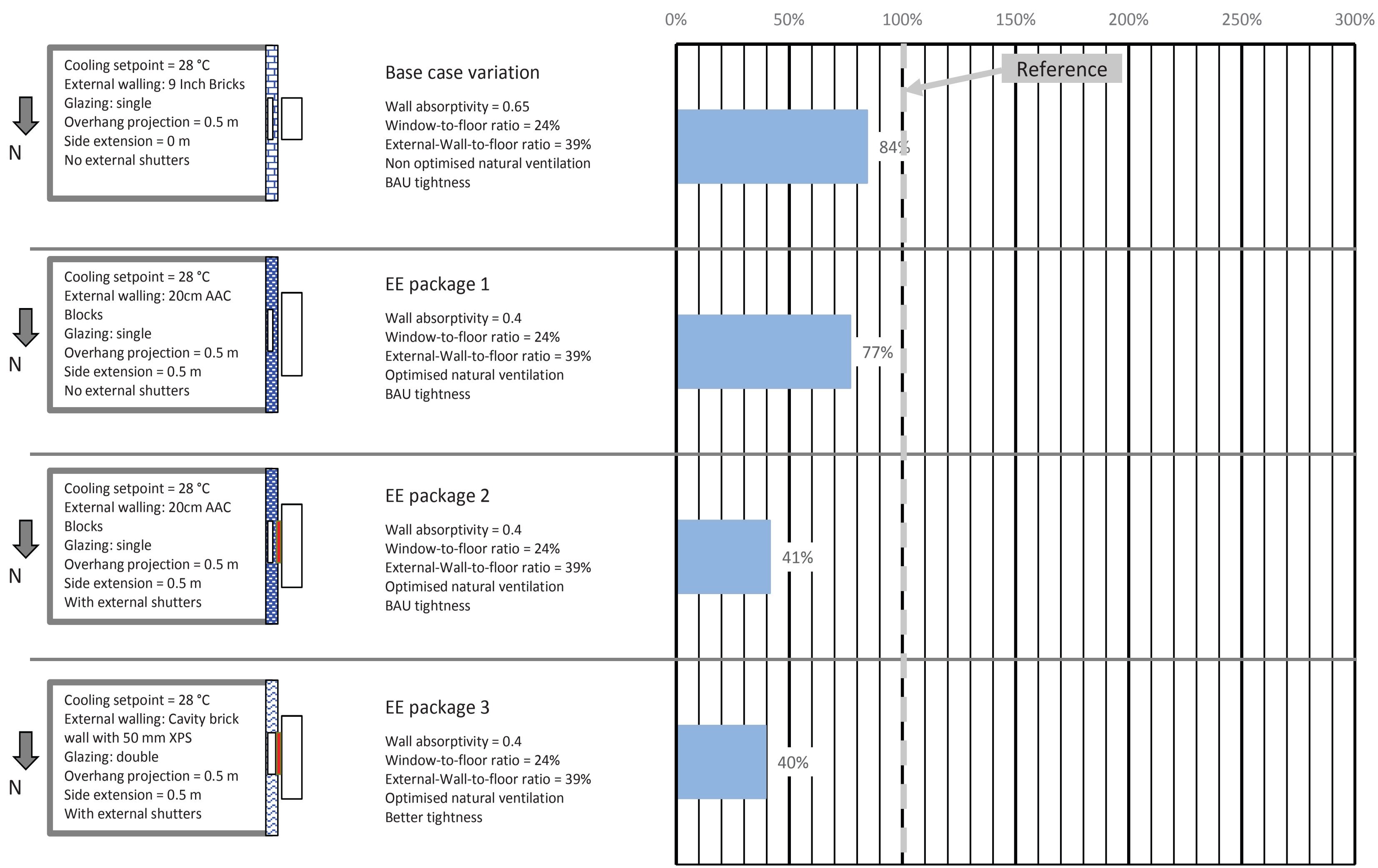


N
Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
N
Cooling setpoint = 28 °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
N
Cooling setpoint = 28 °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
N
Cooling setpoint = 28 °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
0%
50%
100%
150%
200%
250%
300%
Reference
68%
64%
38%
36%

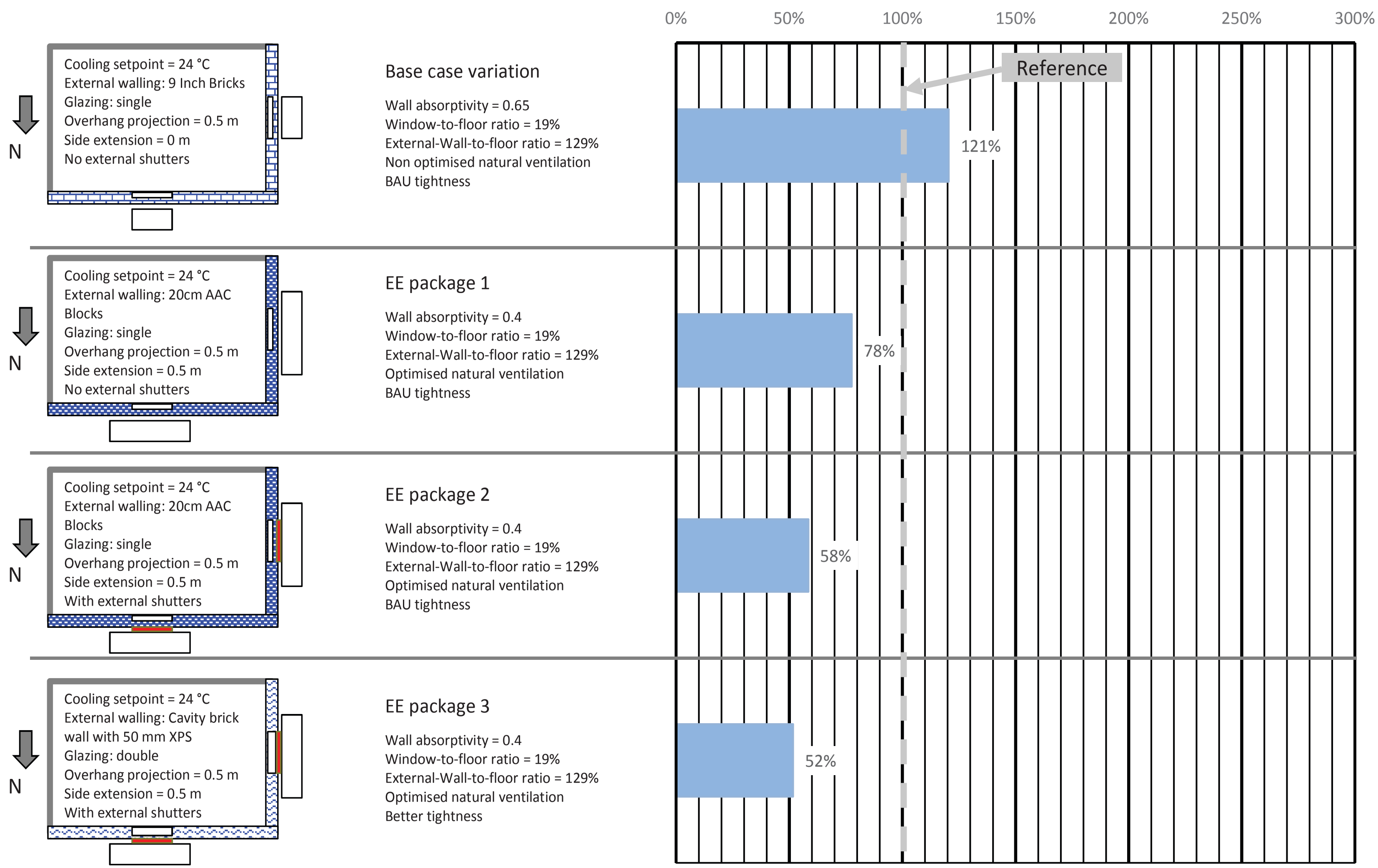
A.4-54


0%
50%
100%
150%
200%
250%
300%
Reference
79%
76%
43%
40%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 36%
External-Wall-to-floor ratio = 120%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 36%
External-Wall-to-floor ratio = 120%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 36%
External-Wall-to-floor ratio = 120%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 36%
External-Wall-to-floor ratio = 120%
Optimised natural ventilation
Better tightness
Cooling setpoint = 28 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
Cooling setpoint = 28 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
Cooling setpoint = 28 °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

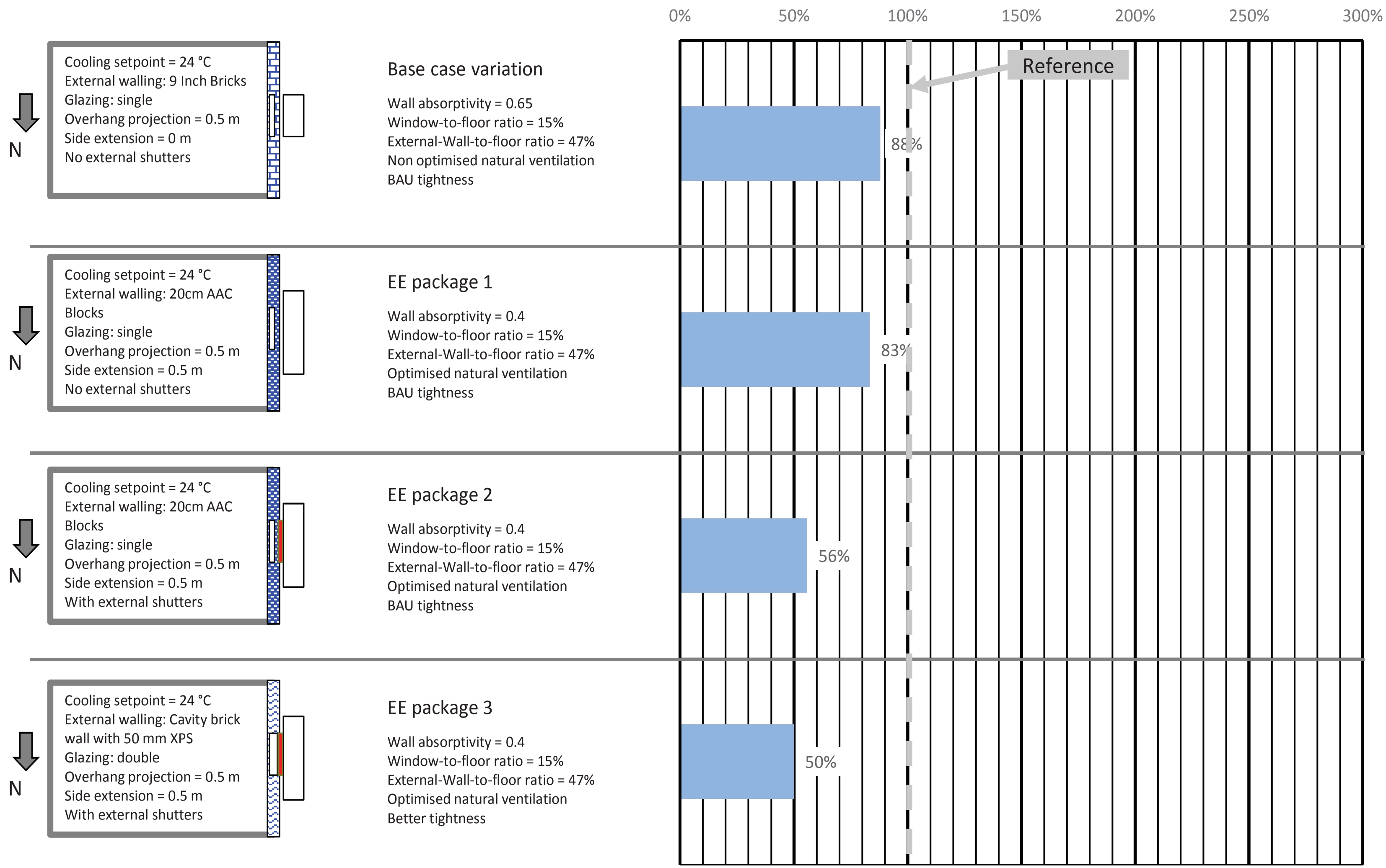
A.4-55


Cooling setpoint = 28 °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 = 24%
External-Wall-to-floor ratio = 39%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 24%
External-Wall-to-floor ratio = 39%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 24%
External-Wall-to-floor ratio = 39%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 28 °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 = 24%
External-Wall-to-floor ratio = 39%
Optimised natural ventilation
Better tightness
0%
50%
100%
150%
200%
250%
300%
Reference
84%
77%
41%
40%

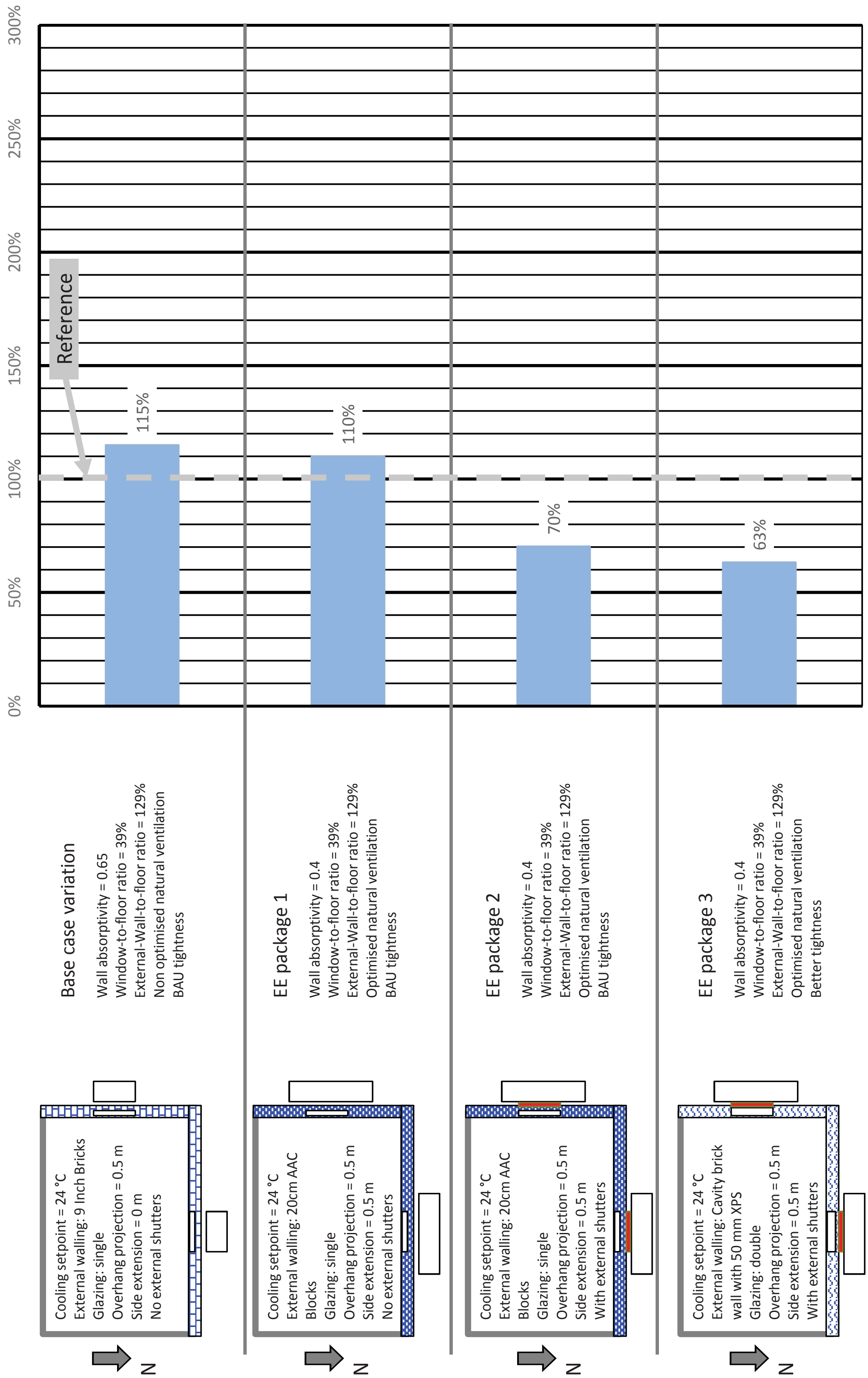
A.4-56


0%
50%
100%
150%
200%
250%
300%
Reference
N
Cooling setpoint = 24 °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
121%
N
Cooling setpoint = 24 °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
78%
N
Cooling setpoint = 24 °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
58%
N
Cooling setpoint = 24 °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
52%

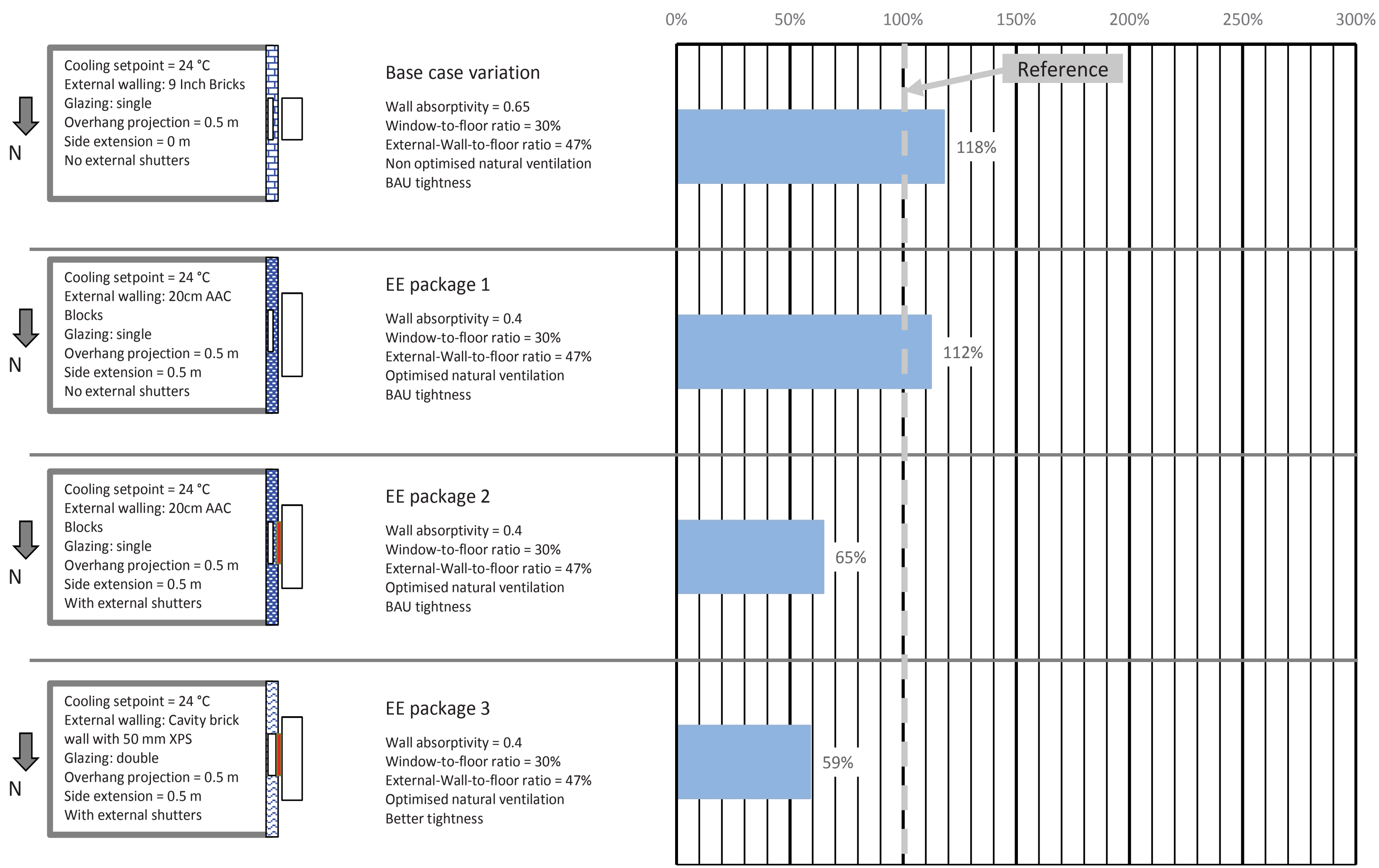
A.4-57


Cooling setpoint = 24 °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
88%
Cooling setpoint = 24 °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
83%
Cooling setpoint = 24 °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 = 24 °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
50%
Reference
0%
50%
100%
150%
200%
250%
300%

A.4-58

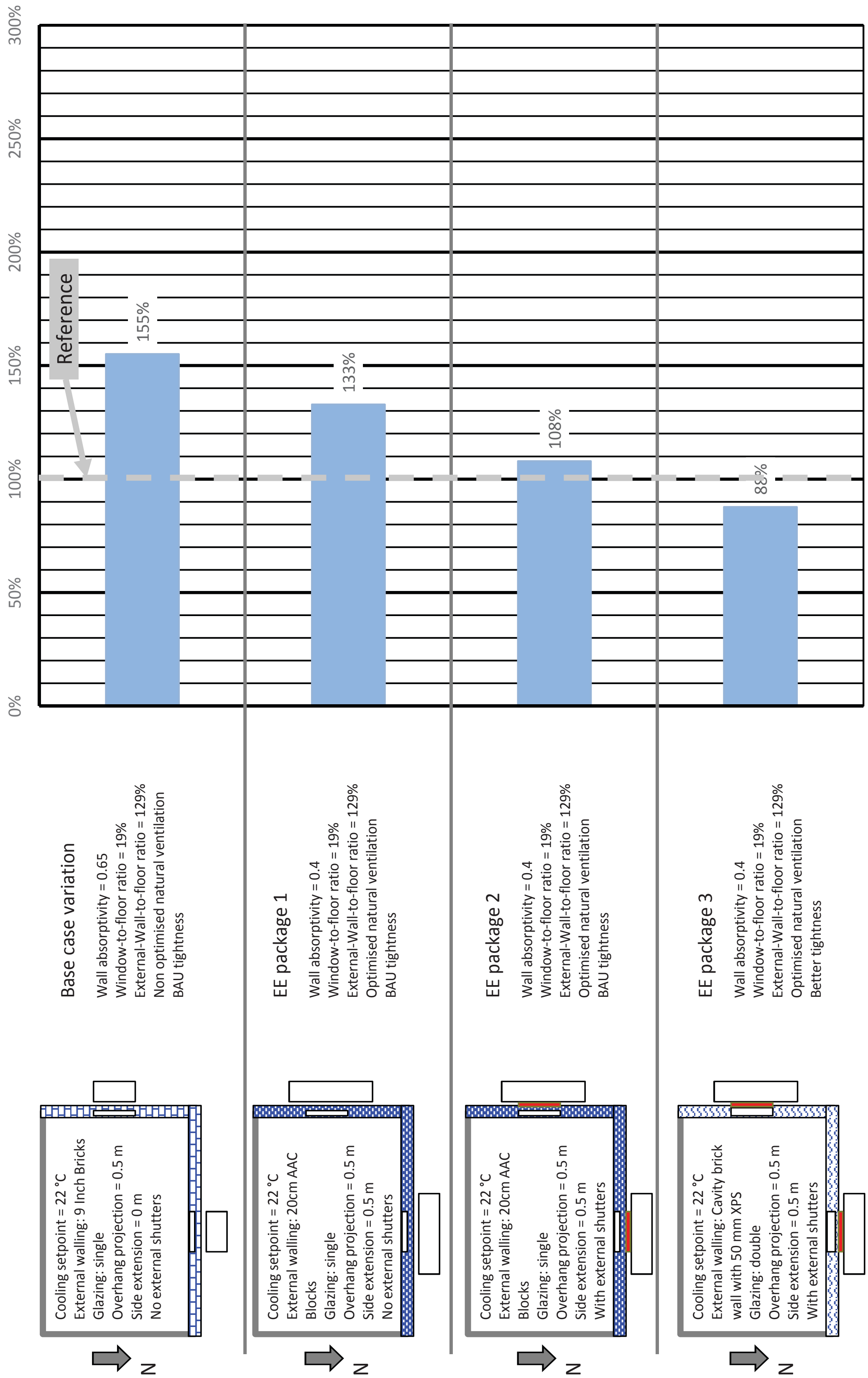

0%
50%
100%
150%
200%
250%
300%
Reference
115%
110%
70%
63%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 2
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
EE package 3
Wall absorptivity = 0.4
Window-to-floor ratio = 39%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
Cooling setpoint = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
No external shutters
N
Cooling setpoint = 24 °C
External walling: 20cm AAC
Blocks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0.5 m
With external shutters
N
Cooling setpoint = 24 °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.4-59

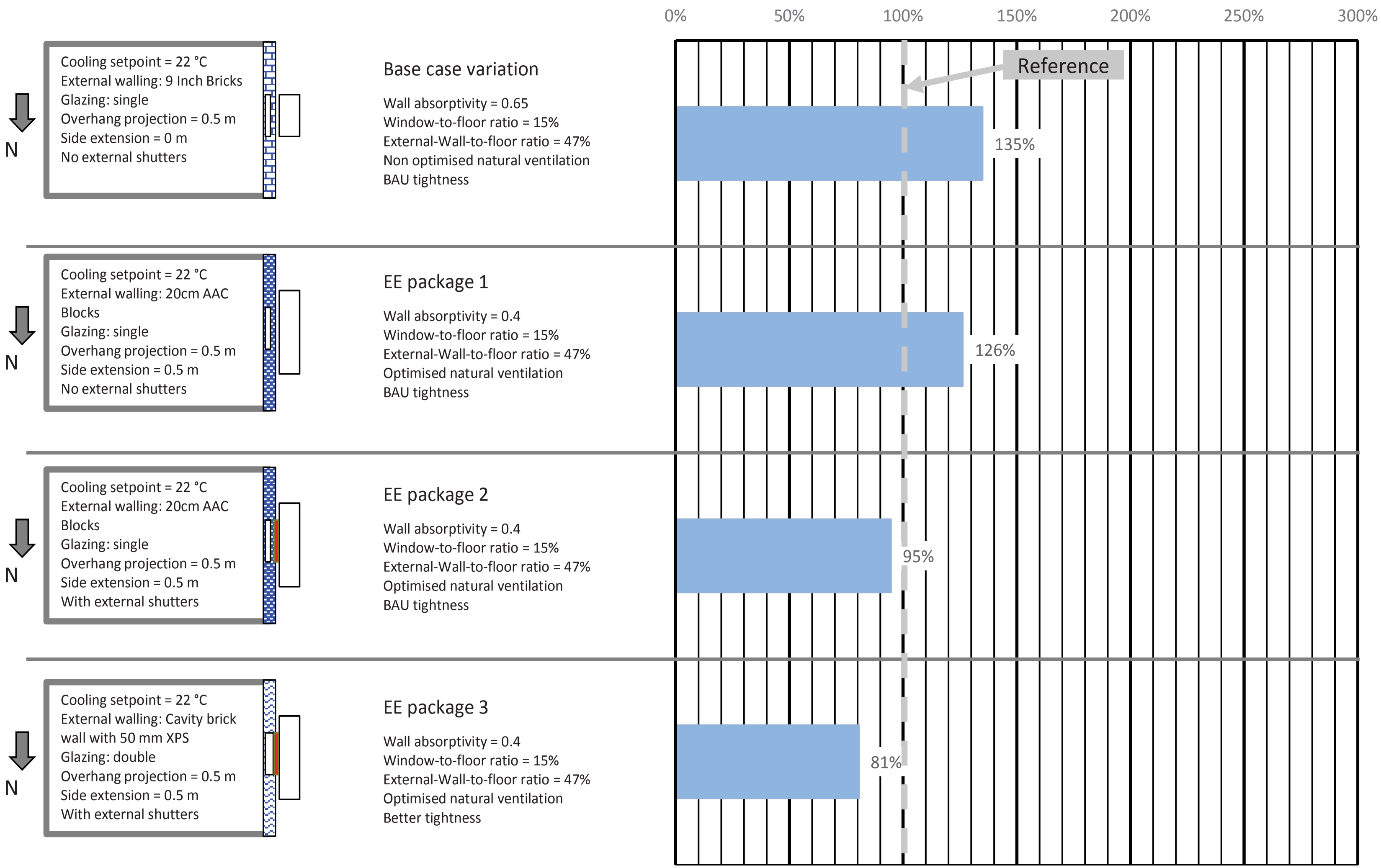


0%
50%
100%
150%
200%
250%
300%
Reference
Cooling setpoint = 24 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 30%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
118%
Cooling setpoint = 24 °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
112%
Cooling setpoint = 24 °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
65%
Cooling setpoint = 24 °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
59%

A.4-60

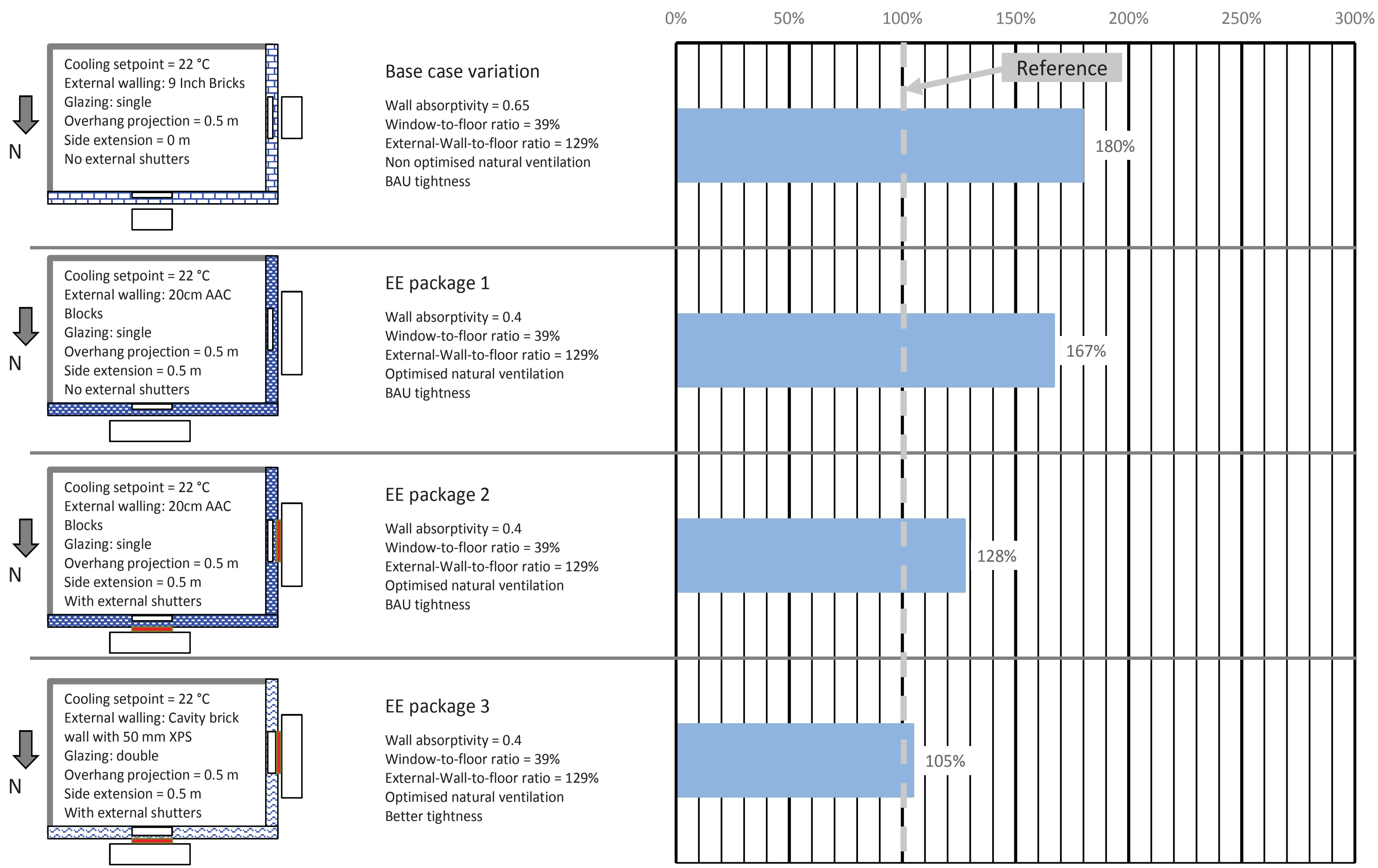

Reference
155%
133%
108%
88%
0%
50%
100%
150%
200%
250%
300%
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
EE package 1
Wall absorptivity = 0.4
Window-to-floor ratio = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °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 = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °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 = 19%
External-Wall-to-floor ratio = 129%
Optimised natural ventilation
Better tightness
Cooling setpoint = 22 °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.4-61



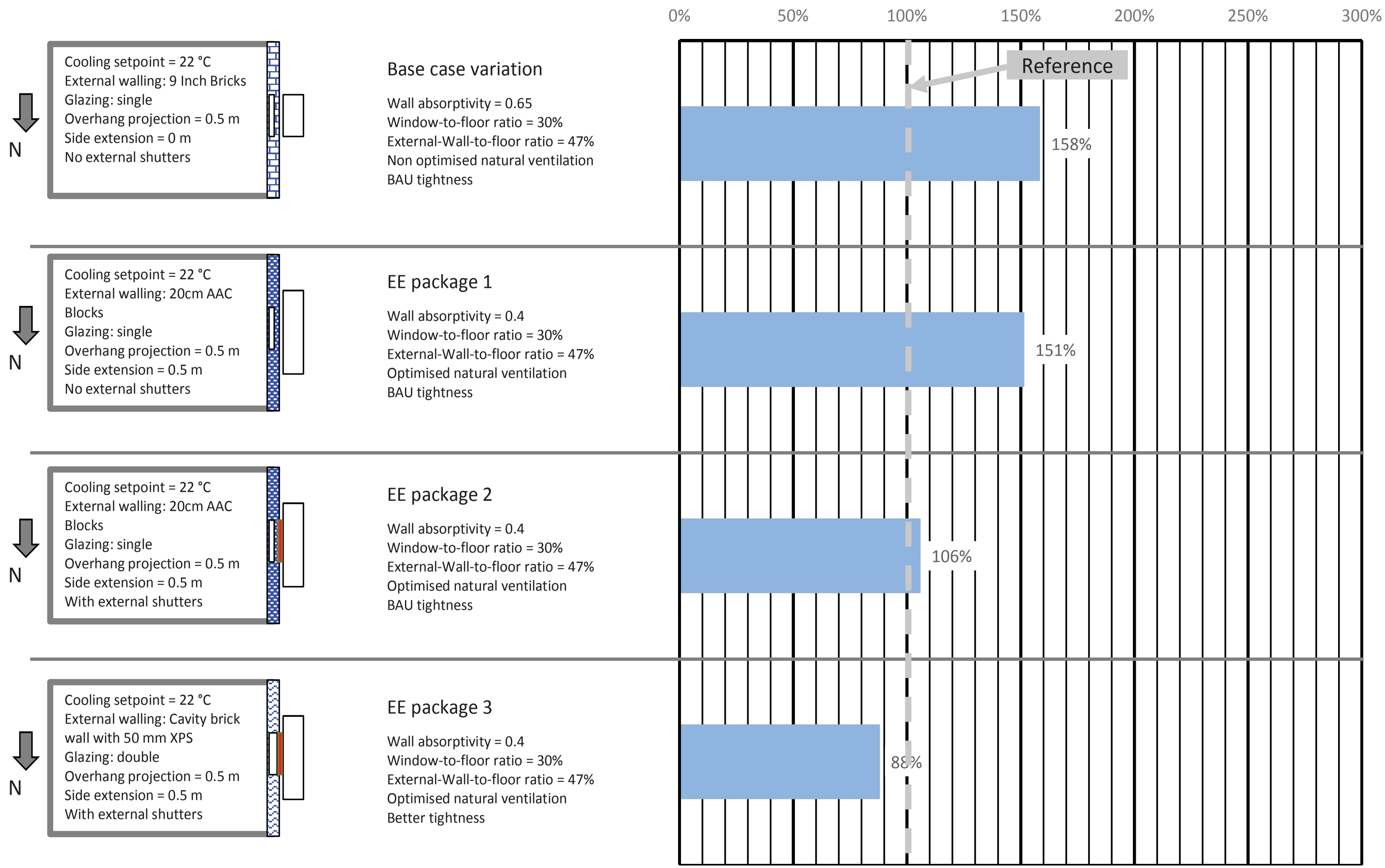
Cooling setpoint = 22 °C
External walling: 9 Inch Bricks
Glazing: single
Overhang projection = 0.5 m
Side extension = 0 m
No external shutters
N
Base case variation
Wall absorptivity = 0.65
Window-to-floor ratio = 15%
External-Wall-to-floor ratio = 47%
Non optimised natural ventilation
BAU tightness
Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
0%
50%
100%
150%
200%
250%
300%
Reference
135%
126%
95%
81%

A.4-62



Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
0%
50%
100%
150%
200%
250%
300%
Reference
180%
167%
128%
105%

A.4-63


Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
Cooling setpoint = 22 °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
0%
50%
100%
150%
200%
250%
300%
Reference
158%
151%
106%
88%

A.4-64

ANNEXURE 3: 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.

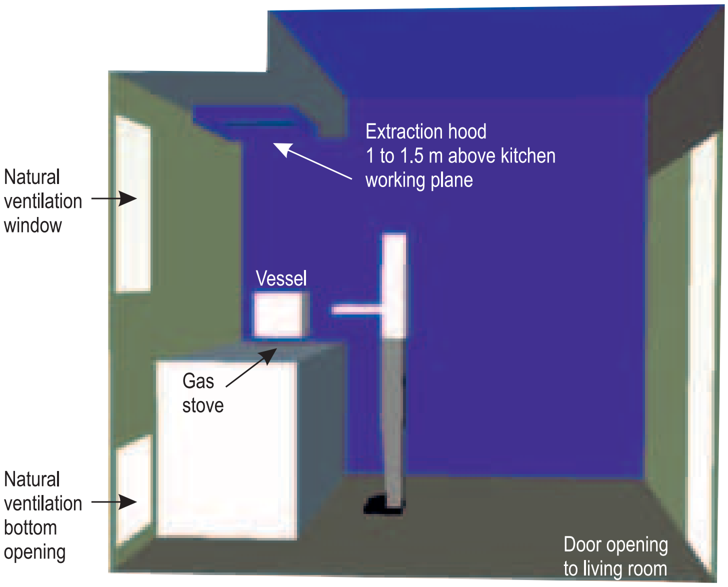


Figure A.5.1 *Sketch of the kitchen used for the CFD study*

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
Natural ventilation bottom opening	
Vertical position	0.1 m above the floor

Table contd...

Table A.5.1 Contd...	
Kitchen	**Dimension / Unit**
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.

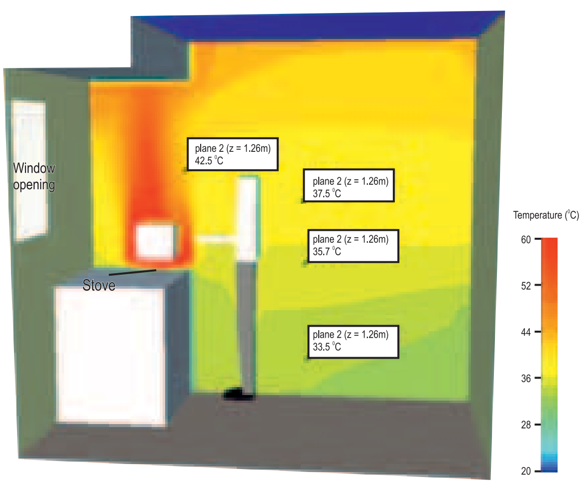


Figure A.5.2
Case 1

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).

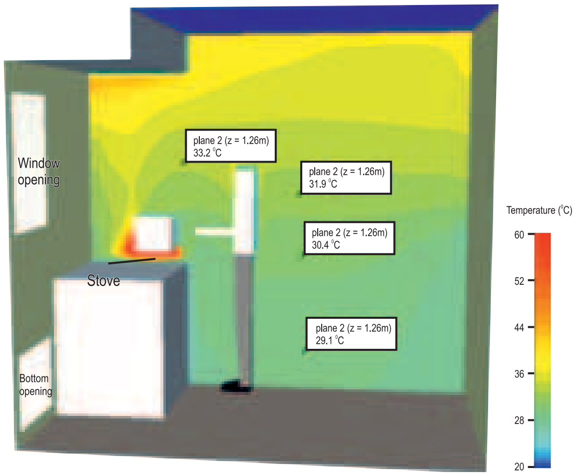


Figure A.5.3 *Case 2*

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).

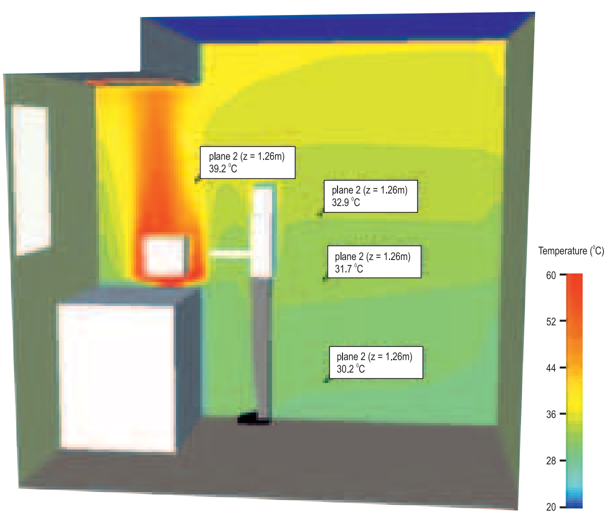


Figure A.5.4 *Case 3*

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.

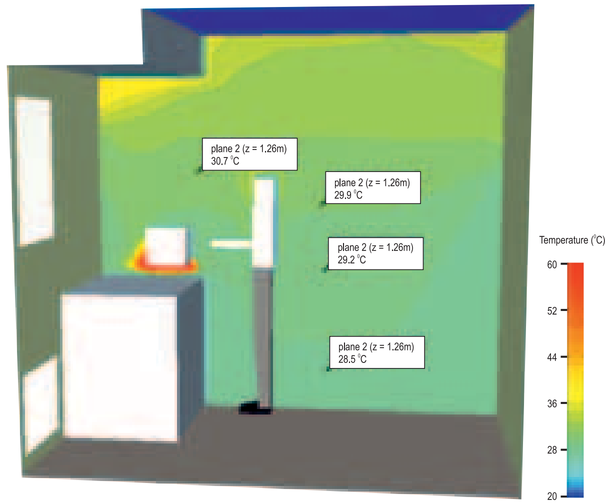


Figure A.5.5 *Case 4*

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.

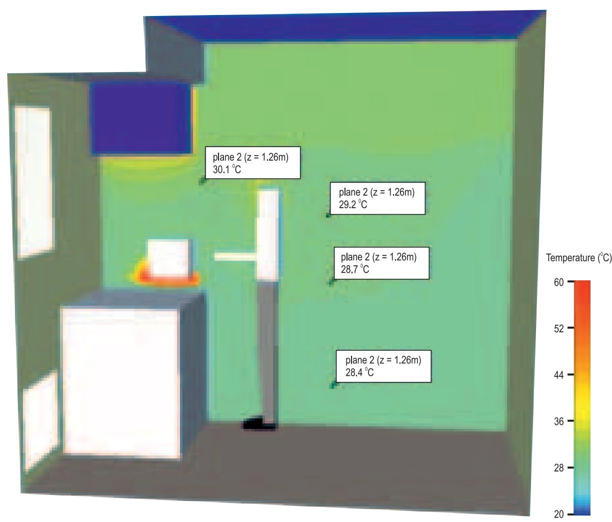


Figure A.5.6 *Case 5*

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 m^3/h.

By increasing the flow rate from 300 to 500 m^3/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.

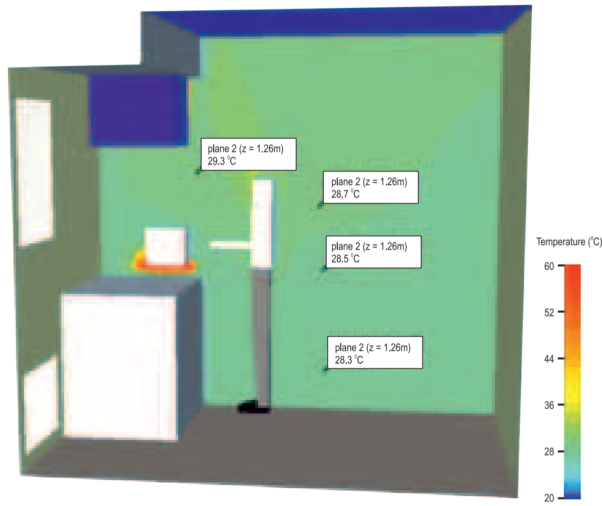


Figure A.5.7 *Case 6*

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 m^3/h extraction.

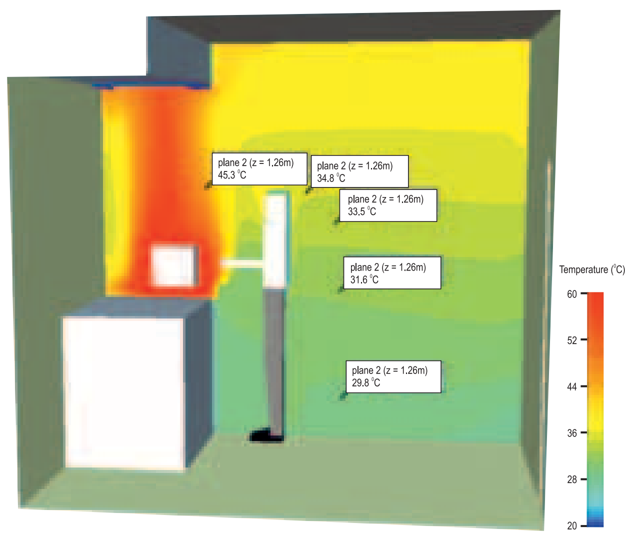


Figure A.5.8 *Case 7*

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.

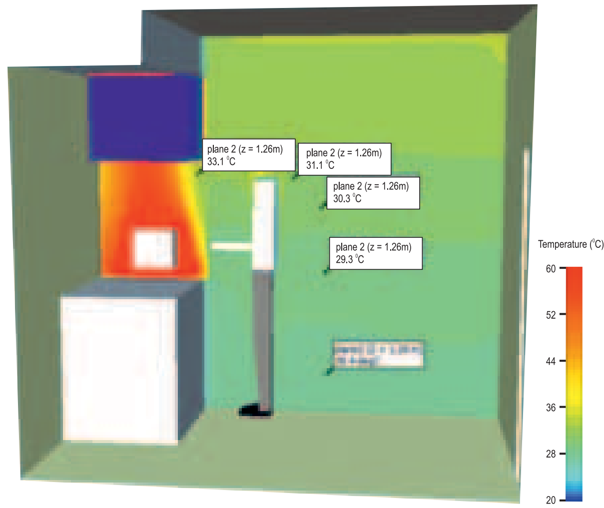


Figure A.5.9 *Case 8*

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.

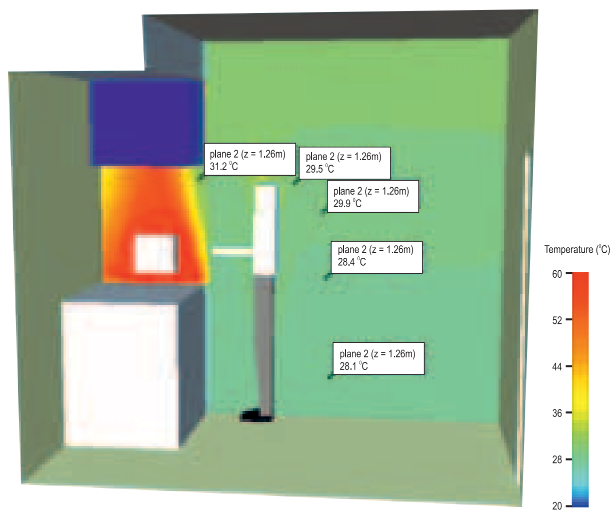


Figure A.5.10 *Case 9*

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.