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BUILDING ENERGY EFFICIENCY IN NEPAL

Manual for

ENERGY-EFFICIENT BUILDING DESIGN

universität innsbruck
Unit of Energy Efficient Buildings

MinErgy

Greentech Knowledge Solutions Pvt. Ltd.

UNE Normalización Española

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MANUAL FOR ENERGY-EFFICIENT BUILDING DESIGN

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Disclaimer
This publication is funded by the European Union under the SWITCH-Asia Grants Programme. Its contents are the sole responsibility of the BEEN Project and do not necessarily reflect the views of the European Union.

This Manual is intended as a guide for designers to design energy efficient building in Nepal. The methods described in the manual are based on good practices, research findings, and consultations with professional expertise in energy efficiency and sustainable design. While every effort has been made to ensure the accuracy and reliability of the information presented, it is important to acknowledge that building design and construction practices may vary significantly based on local climate conditions, regulations and project-specific requirements. Thus, the authors, publishers, funders or any legal entity or person associated with this design manual disclaim any responsibility (legal, social or financial) for any adverse conditions/ consequences resulting from the suggested procedures, from any undetected errors, or from the readers misunderstanding of the text. Moreover, this Manual is not intended to replace or override any legal or regulatory requirements that may be applicable to the design and construction of buildings in Nepal.

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Preface

Buildings, built inappropriately, can lock in inefficiencies for decades throughout their operational lifespan of 50 years or more. Improved thermal comfort and energy-efficient buildings, along with increased use of renewable energy, are integral to sustainable development and an improved quality of life.

Nepal is one of the least urbanized, yet it ranks among the top ten fastest urbanizing developing nations. However, over the past few decades, market demands for space have led to buildings being designed without consideration of the local climate, resulting in uncomfortable indoor environments or high energy consumption to compensate for this discomfort. Climate-responsive design and energy efficiency are often overlooked in the planning of new buildings. Consequently, energy consumption in buildings is on the rise. Many of these challenges could be mitigated through improvements in building envelope design, including enhanced insulation of walls and roofs, thoughtful window design and shading to optimize daylight and ventilation, and implementation of double-glazed windows.

One of the main constraints is the limited awareness and application of building physics in designing and constructing energy-efficient buildings. This manual is intended for designers, including building consulting firms, individual architects and engineers who wield significant influence over a building or house owner's decision regarding design and construction materials. The aim of this manual is to introduce and explain how a building influences the thermal and visual comfort of its occupants. Additionally, it explains passive design principles tailored to the climate zones in Nepal, which consequently help reduce energy requirements in building.

This manual was developed as part of the "BUILDING Energy Efficiency in Nepal" (BEEN) project, supported by the SWITCH-Asia Grants Programme from the European Union.

The authors welcome ideas and case studies from Nepal to enhance this manual for future versions.

Government of Nepal
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Message

In Nepal, the number of non-engineered buildings far outnumber that of engineered buildings. Even engineered buildings do not take energy perspective into consideration. The owners' efforts in building construction are characterized by a high degree of informality. As the involvement of engineers or professionals in building construction is limited, after obtaining a building permit from the municipality, the owners make their own decisions, supported by advice from friends, neighbors and very rarely from professionals. The need for conducting training on energy-efficient construction technologies could not be overstated.

Energy efficient design and construction are seldom included in the regular curriculum of civil engineering and architecture courses in Nepal. Regulatory agencies, including federal, provincial and local governments, have not yet been able to enforce or implement energy efficiency in design standards and codes due to a lack of sufficient knowledge and capabilities, both in terms of the availability of manpower and technical competence. It is, therefore, imperative to train engineers, professional designers, builders, construction material producers and contractors to acquaint them with the best practices in energy efficiency.

I hope this manual will serve as a harmonized training curriculum acceptable to all major stakeholders. This manual has been prepared after a series of interactive sessions were organized among concerned stakeholders. Though this is essentially a technical manual, I believe that policy makers and even the general public can benefit from this book as a guide towards energy-efficient construction of houses.

I would like to congratulate and express my gratitude to the entire project officials and professionals' team involved in preparing this manual. I am positive that this design manual will serve as a reference material for engineers and all stakeholders involved in building construction in Nepal.

Mr. Kamal Prasad Bhattarai
Acting Secretary
Ministry of Federal Affairs and General Administration
Date: 23rd February, 2024

EUROPEAN UNION
DELEGATION TO NEPAL

Head of Cooperation

Message

Energy efficiency helps reduce overall energy consumption and is therefore central to achieving the European Union’s climate ambition, while enhancing present and future energy security and affordability in Europe. To ensure that the European Union’s 2030 target of reducing greenhouse gas emissions by at least 55% (compared to 1990) can be met, the European Commission has revised the Energy Efficiency Directive, which came into place first in 2012, together with other energy and climate rules in 2023. It establishes ‘energy efficiency first’ as a fundamental principle of EU energy policy, giving it legal-standing for the first time. In practical terms, this means that energy efficiency must be considered by EU countries in all relevant policy and major investment decisions taken in the energy and non-energy sectors. The revised directive also puts a stronger focus on alleviating energy poverty.

Nepal is one of the fastest urbanising developing economies and a lot of energy is used for heating and cooling, leaving a large carbon footprint in the building sector in Nepal and increasing energy costs for consumers. The Building Energy Efficiency in Nepal (BEEN) Project is funded by the European Union under the SWITCH-Asia Programme and developed this “Manual for Energy-Efficient Building Design for Architects and Designers”. It combines local, national and international expertise and practitioners to response to the needs of varied local bio-climatic conditions of Nepal by drawing and improving the baseline practices. This manual will be a crucial tool for architects and designers to incorporate strategies for climate-responsive building design, for reducing demand for space conditioning, and upholding the thermal comfort for users. It should support policy measures for incentivising and regulating the building design trends suitable to Nepal’s bio-climatic variations.

I would like to thank all the partners of the three tiers of Government, the private sector and home owners and of course the entire team of the BEEN project to support this valuable resource. It can be a key milestone to support Nepal’s transition to a circular economy and achieving the Sustainable Development Goals as well as the Nationally Determined Contributions by decoupling economic growth and environmental degradation, the main essence behind the philosophy of the EU’s SWITCH-Asia programme.

Dr. Marco GEMMER
Head of Cooperation
Delegation of the European Union to Nepal
Kathmandu, 21 February 2024

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नेपाली वास्तुविद् समाज

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Message

The Society of Nepalese Architects (SONA) extends its heartfelt commendations and support to BEEN Project researchers and contributors involved in the comprehensive study outlined in the provided document "MANUAL FOR ENERGY-EFFICIENT BUILDING DESIGN FOR ARCHITECTS & DESIGNERS".

The exploration of topics ranging from energy use in buildings to various strategies for thermal comfort, climate analysis, heat transfer, passive design, natural ventilation, and visual comfort highlights a significant commitment to advancing sustainable architectural practices.

SONA applauds the thorough effort invested in understanding and disseminating critical insights summarized in the manual. The exploration of diverse climate zones in Nepal, coupled with an in-depth analysis of building envelope strategies tailored to specific zones, reflects a dedication to promoting energy efficiency in architectural design.

While the manual covers essential theoretical aspects, SONA encourages the inclusion of real-life architectural practices and examples to enhance its practical utility. Integrating case studies or showcasing successful projects that have effectively implemented the strategies discussed in the manual would provide valuable insights and inspiration for emerging architects.

Considering the country's diverse climates, which include extreme conditions, there is a request to contemplate whether the mentioned topics adequately address all these climatic variations in Nepal. Ensuring the manual's applicability across a wide range of scenarios will enhance its overall effectiveness.

In closing, the Society of Nepalese Architects expresses its sincere appreciation for the achievements documented in this study. The dedication to unravelling complexities related to energy consumption and comfort in buildings is a testament to the commitment of the architectural community to positively impact our built environment. SONA looks forward to continued collaboration and endeavors that propel the field towards a more sustainable and innovative future, with a keen eye on practical relevance and inclusivity for all climatic challenges in Nepal.

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w w w . s o n a . o r g . n p

Message

I am thrilled to introduce you to this comprehensive design manual, a vital component of the BUILDING Energy Efficiency in Nepal (BEEN) Project. This manual has been meticulously crafted to serve as a valuable resource for building designers, architects, and engineers, aligning with the objectives of our project to promote energy efficiency and sustainability within Nepal's built environment.

At the core of the BEEN Project lie several key objectives, including enhancing capacity, creating markets for energy-efficient products and services, facilitating access to financial resources, and collaborating with government entities to develop and implement supportive policies and initiatives. The development of this design manual aligns perfectly with these objectives by providing practical guidance and resources to support capacity-building efforts among building professionals. Through extensive research and analysis, our team has meticulously crafted this manual to address the pressing need for energy-efficient building practices in Nepal. We have conducted rigorous market research and building simulations across diverse bioclimatic zones and building typologies to ensure that the contents of this manual are well-informed and relevant to practitioners in the field.

The outcome of this manual is multifaceted. Firstly, it serves as a comprehensive reference guide, offering insights into passive design strategies, building envelope optimization techniques, renewable energy integration solutions, and more. Secondly, it is a tool for empowerment, empowering building professionals to create healthier, more comfortable, and more energy-efficient built environments. Finally, it is a catalyst for positive change, inspiring innovation and driving progress towards a brighter, more sustainable future for Nepal. As you navigate through the pages of this manual, I encourage you to approach it not merely as a reference guide, but as a tool for inspiration and innovation. Let the principles outlined herein serve as a springboard for your creativity, enabling you to push the boundaries of what is possible in sustainable building design.

In closing, I would like to express my deepest gratitude to all those who have contributed to the development of this manual, as well as to you, the reader, for your commitment to advancing energy efficiency in Nepal's built environment. Together, we can build a brighter, more sustainable future for all.

Warm regards,

DI Dr. techn. Daniel Neyer
Project Leader (BEEN)

Acknowledgement

Development of this manual has been possible with contributions of wider networks of people, institutions and stakeholders. Every effort was made to include the knowledge and perspectives of practitioners, national and international experts as well as stakeholders associated with the designing of buildings. We would like to acknowledge the support of various individuals and institutions who have contributed in various ways during the process of developing this manual.

Publication of this manual, led by the BUILDING Energy Efficiency in Nepal (BEEN) Project, has been possible because of the financial support by the European Union under the SWITCH-Asia Grants Programme. We would like to express our gratitude to Dr Ranjan Prakash Shrestha, Senior Programme Manager, Delegation of the European Union to Nepal , for his continuous guidance and support. His strategic support has been valuable to align the manual to needs and commitments of Government of Nepal.

We extend our heartfelt gratitude to the Department of Urban Development and Building Construction (DUDBC). Special thanks are to Ar. Sudha Ghimire, Architect, DUDBC, Er. Ukesh Dawadi, Engineer, DUDBC, Ar. Diksha Panta, DUDBC and Ar. Kabita Pandey, Nepal Academy of Science and Technology-NAST for their strategic inputs to make the manual valuable for the practitioners and to make it responsive to needs of different levels of Governments of Nepal as well as enriching the content.

The contributions of Society of Nepalese Architects (SONA) have been invaluable to develop this manual. Special recognition is to the experts Ar. Bibhuti Man Singh, Ar. Ujjwal Man Shakya, Ar. Prabal Thapa, Ar. Anju Malla Pradhan, Ar. Gyanendra Shakya and Ar. Arjun Basnet and Ar. Sameer Ratna Bajracharya for their invaluable suggestion and feedback to enrich the content and contextualize the manual.

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Abbreviations

AAC	Autoclaved Aerated Cement Blocks
ACH	Air Changes Per Hour
ASE	Annual Solar Exposure
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEE	Bureau of Energy Efficiency
CAD	Computer-Aided Design and drafting
CBE	Centre for the Built Environment
CFL	Compact Fluorescent Lamp
CIBSE	Chartered Institution of Building Services Engineers
CSEB	Compressed Stabilized Earth Block
DA	Daylight Autonomy
DBT	Dry Bulb Temperature
DDH	Discomfort Degree Hours
DEF	Daylight Extension Factor
DF	Daylight Factor
DGU	Double-Glazed Units
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
ECBC	Energy Conservation Building Code
EIA	Environmental Impact Assessment
EMSyS	External Moveable Shading Systems
EPI	Energy Performance Index
ESF	External Shading Factor
GHI	Global Horizontal Radiation
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IGBC	Indian Green Building Council
LED	Light Emitting Diode.
LPD	Lighting Power Density
MET	Metabolic Equivalent
MRT	Mean Radiant Temperature
PF	Projection Factor

PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied occupants
PVC	Polyvinyl Chloride
RCC	Reinforced Cement Concrete
RH	Relative Humidity
SC	Shading Coefficient
SHGC	Solar Reflective Index
SRI	Solar Reflective Index
SRR	Skylight-to-Roof Ratio
UDI	Useful Daylight Illuminance
VLT	Visible Light Transmission
WBT	Wet-Bulb Temperature
WECS	Water and Energy Commission Secretariat
WWR	Window-to-Wall Ratio
XPS	Extruded Polystyrene

1
INTRODUCTION

What's in this section?

Introduction

Buildings account for 30% of global final energy consumption and 26% of global energy-related CO_2 emissions (IEA, 2023). It is estimated that by 2030, the global building stock will increase by 15% (IEA, 2023). The rise in construction, along with increased urbanization and living standards, especially in developing countries, will continue to drive energy consumption in buildings. The primary sources of energy consumption in buildings encompass the energy used for construction, space heating/cooling, lighting, and the appliances and equipment installed in them.

Nepal is one of the top ten fastest-urbanizing countries (Bakrania, 2015). In 2022, the urban percentage of the country was 22%, and an annual urban population growth of 3.8% (World Bank). Many policies on access to clean, reliable, and appropriate energy in rural areas and the development of the renewable energy sector have been implemented in the country. It has resulted in 94 % of the total population having access to electricity today, whereas only 19% in the year 2000 (IEA, 2023). In Nepal, 70% of the total energy consumption is in the residential and commercial building sectors (WECS, Water and Energy Commission Secretariat (WECS), Energy Sector Synopsis Report 2021/2022., 2022).

Most buildings in Nepal are designed without consideration for local and changing climatic conditions, leading to low thermal comfort and an increased demand for energy to achieve it. The rising heating and cooling needs, driven by an improved living standard and the growing affordability of space conditioning, result in increased energy use when building designs are not appropriate. Passive design strategies during the early phases of the design can enhance thermal comfort and significantly reduce energy consumption.

1.1 Energy use in Buildings

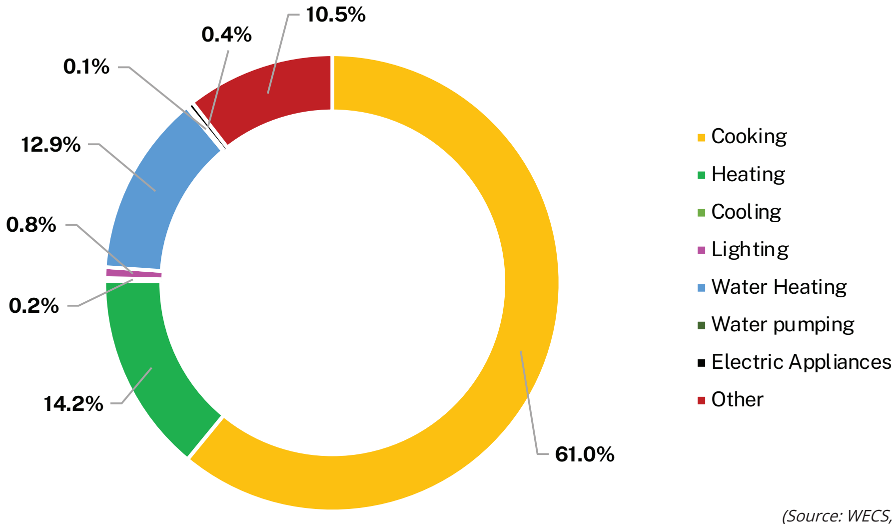
Globally, around 40% of the energy consumed in buildings is attributed to Heating, Cooling, and Ventilation (HVAC) systems. In developed regions such as the United States and the European Union, the share of HVAC in building energy usage is notably higher, accounting for around 53% (U.S.(EIA), 2019) and approximately 58% (Odyssee, 2021). In India, HVAC systems contribute to 40% - 60%[1] of the electricity consumption in commercial buildings, while in urban residential buildings, cooling consumes 30% - 40% of the electricity used.

Nepal generates electricity mostly from hydropower, with surpluses exported to India in wet seasons and minor deficits imported from India during the dry seasons. Most of the energy supply is from bio-fuels and waste as 21 million people still rely on traditional biomass for cooking (IEA, 2023).

1 Building Innovation: A Guide for High-Performance Energy Efficient Buildings in India Reshma Singh, Baptiste Ravache, Dale Sartor Lawrence Berkeley National Laboratory May, 2018

The residential energy consumption in Nepal has been increasing at the rate of 2.23% per annum in the last two years, which is higher than the population growth rate of Nepal (WECS, 2022). Around 14% of the building energy is used for space cooling and space heating in residential sectors (WECS, 2014), and the same amount of energy is consumed for water heating and lighting purposes (WECS, 2014). The energy consumption by end-use for residential buildings in Nepal is shown in Figure 1.

FIGURE 1: ENERGY CONSUMPTION FOR END USE IN RESIDENTIAL BUILDING IN NEPAL, 2014



(Source: WECS, 2014)

However, the share of space heating and cooling energy is high in new and urban buildings in Nepal. Contemporary buildings in Kathmandu use 60% of their total energy for heating and cooling (Bajracharya, 2014). If buildings are not designed with energy-efficient strategies, this demand will keep increasing at the same pace. In this regard, designers, architects, and civil engineers can play a critical role in designing such buildings in the early phase of the design. This manual is for Nepal's architects and civil engineering community to design energy-efficient and thermally comfortable buildings through passive measures.

1.2 Objective of the Manual

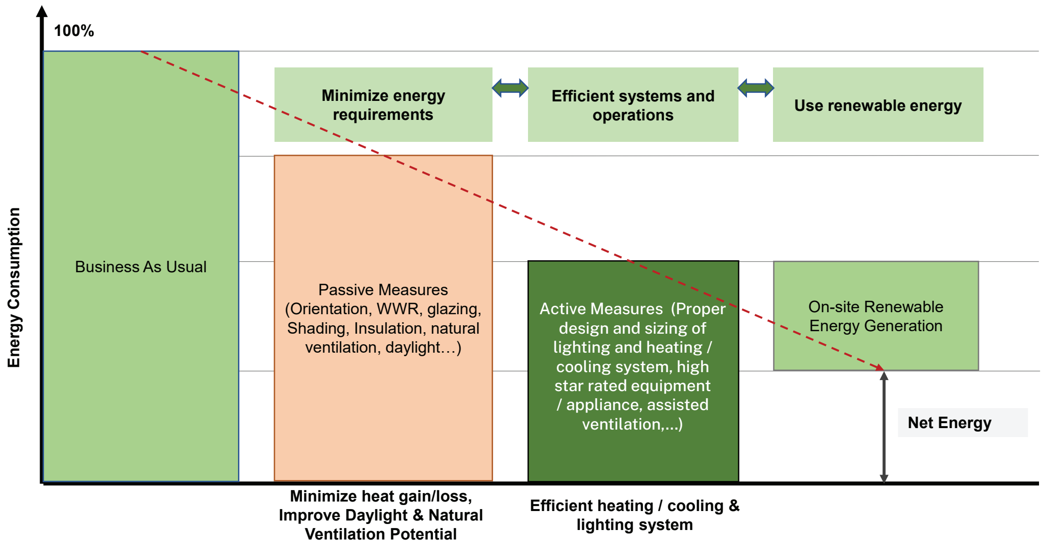
An energy-efficient building is designed based on three guiding principles. An overview of the principles is shown in Figure 2.

- First, minimize energy demand through climate-responsive and passive strategies to reduce the cooling and heating demand and lighting loads.
- Second, efficiently meet the reduced energy demand, which relies on the efficiency of the cooling, heating, and lighting systems.
- Third, utilize renewable energy sources to meet the final required energy.

This manual is intended for designers (architects and civil engineers) engaged in building design, specifically considering the first principle of energy-efficient building design. It emphasizes aspects such as building orientation, building envelope, and other design features aimed at minimizing the building's cooling, heating, and lighting loads.

Notably, this manual does not delve into the second and third principles of energy-efficient building design, namely the HVAC systems, artificial lighting systems, and renewable energy systems.

FIGURE 2: PRINCIPLES OF ENERGY EFFICIENT BUILDING DESIGN



(Source: Reproduced image from Indo-Swiss BEEP)

1.3 Outline of the Manual

The manual has seven chapters as follows:

- Chapter 1 introduces the manual with objectives and the outline of the manual.
- Chapter 2 covers the understanding of thermal comfort, the factors influencing it, and the thermal comfort standards as an energy-efficient building is primarily focused on thermal comfort and visual comfort with minimal energy.
- Chapter 3 explains how climate influences thermal comfort, covering climate variables, sun-path diagrams, and the climate zones in Nepal.
- Chapter 4 explains the heat sources in a building and how heat transfer happens through the building envelope and its components.
- Chapter 5 describes the passive strategies that would be most applicable and impactful in the climate zones in Nepal.
- Chapter 6 describes principles of improving natural ventilation.
- Chapter 7 describes passive strategies for improving visual comfort, i.e., strategies for daylighting.

2
THERMAL COMFORT

What's in this section?

Thermal Comfort

2.1 What is thermal comfort?

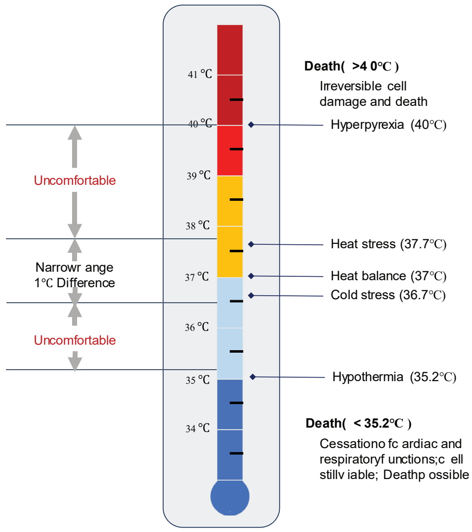
ASHRAE defines thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation."

Thermal comfort is a subjective feeling of satisfaction with the thermal environment and is experienced through bodily sensation. It varies from person to person, as what one person finds comfortable might be too warm or cold for another. Therefore, when designing indoor spaces, architects and designers often aim to create an environment that are acceptable to at least 80% of occupants.

2.2 Factors affecting thermal comfort

Thermal comfort is a subjective feeling of satisfaction with the thermal environment and is experienced through body sensation. Our body temperature needs to be controlled within a narrow range of 1°C from 36.7°C to 37.7°C for proper functioning. Figure 3 shows the comfort band of the human body and how the change in temperature of the human body affects health conditions.

FIGURE 3: COMFORT BAND OF THE HUMAN BODY



Our body always tries to achieve thermal equilibrium with the surroundings by losing excess heat to the surroundings or generating heat by increasing activity. The prominent modes of heat exchange from the human body are radiation, convection, and evaporation. However, very little quantity is lost by conduction and is dominant in heat exchange with clothing. Thus, the overall heat exchange and thermal comfort are influenced by the following:

- Environmental factors, and
- Personal factors.

2.2.1 Environmental Factors

The environmental factors affecting the thermal comfort of occupants are as follows:

2.2.1.1 Dry Bulb Temperature (DBT) or Air Temperature

The Dry Bulb Temperature (DBT) is the temperature of air measured by a thermometer which is freely exposed to the air but shielded from radiation. DBT is usually thought of as air temperature and does not indicate the amount of moisture in the air. It is usually expressed in °C or °F. It determines whether heat loss can occur through evaporation and convection.

2.2.1.2 Relative Humidity (RH)

Relative Humidity (RH) is the ratio of the amount of water present in the air to the maximum amount that the same volume of air can hold at the same temperature. It signifies the moisture content of the air. The values of both RH and DBT of the surrounding air collectively influence the potential for heat loss through evaporation. In conditions of high RH (indicating high moisture in the air), the likelihood of evaporation to the surrounding air decreases, resulting in less heat released through sweating. Conversely, in low RH conditions (indicating low moisture in the air), the potential for evaporation increases, allowing water vapour to more readily evaporate into the air.

2.2.1.3 Mean Radiant Temperature (MRT)

The Mean Radiant Temperature (MRT) is a measure of the average temperature of all surfaces surrounding us, with which the human body exchanges thermal radiation. It represents the radiant heat emitted by all the surfaces within the vicinity of a point or a person in space, including walls, floors, and ceilings. Radiation heat loss or gain is driven by the temperature difference ($T_1^4 - T_2^4$, T in Kelvin: °C + 273) of the outer surface of a body (such as exposed skin or the exterior of clothing) and inner surface temperatures of the surrounding surfaces. Since radiation is the dominant form of heat transfer from the human body, MRT becomes a crucial factor in determining thermal comfort.

When MRT is too low, individuals may feel cold even in warm temperatures, and conversely, when MRT is too high, they may experience discomfort due to excessive warmth.

2.2.1.4 Air speed/air movement

Air speed is the average speed of air, indicating its movement within a space. It is usually expressed in terms of m/s. It is averaged over time intervals between one to three minutes due to the continuous variation in air speed.

Elevated air speed influences thermal comfort in several ways. When air moves faster across the skin, it enhances heat transfer from the body to the environment through convection. Additionally, air that has absorbed sweat from the skin in the form of water vapour is carried away, and drier air takes its place, capable of absorbing water vapour through evaporation. This increased heat loss creates a cooling effect, making individuals feel cooler than in still air. However, if the air speed is too high, it can cause discomfort and make individuals feel cold, especially if the air temperature is already low.

Air Movement and Comfort

- Air speed doesn't cool the air itself.
- It creates a "cooling" effect by moving air around the body, increasing heat loss through convection and evaporation.
- Higher air speed increases the rate of heat loss from the skin, making individuals feel cooler.
- In warm temperatures, air movement is comfortable, while low airspeed can lead to a stagnant, stuffy feeling.
- In cold temperatures, airspeed can reduce skin temperature further, potentially causing discomfort by making the body feel colder.

2.2.2 Personal factors

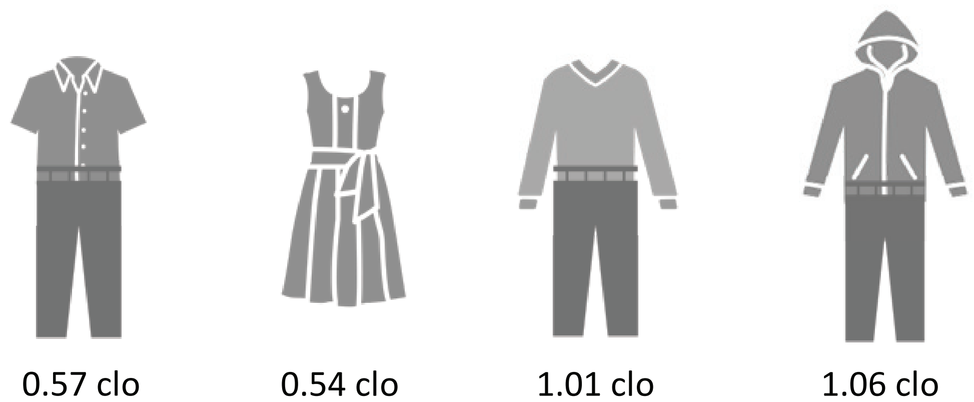
The personal factors affecting the thermal comfort of occupants are the following:

2.2.2.1 Clothing (Clo) value

Clothing value, or Clo, is a measure of the thermal resistance of clothing and is another crucial factor in determining thermal comfort. Clothing interferes with our ability to lose heat. A resistance of 0.155 m^2K/W is considered a 1 Clo.

The Clo value of clothing is important in determining how much heat is lost from the body to the environment, and it can be used to help determine the appropriate temperature and humidity levels in a space to achieve optimal thermal comfort. In a cold environment, higher Clo values may help retain body heat and increase comfort. However, in a hot environment, a high Clo value can hinder heat dissipation from the body and lead to discomfort. Figure 4 illustrates the change in Clo value based on the clothing type providing thermal resistance.

FIGURE 4: THE CHANGE IN CLO VALUE BASED ON THE CLOTHING TYPE PROVIDING THERMAL RESISTANCE



(Source: ASHRAE, 2010)

2.2.2.2 Metabolic rate

The metabolic rate is the amount of heat released by the human body, depending on the activities individuals are engaged in. An average person seated at rest typically produces 60 W/m² of surface heat and about 100 W/person, which is termed as 1 met. The more strenuous the activity, the more heat is generated.

Higher metabolic rates, such as those experienced during physical activities, can increase heat production, causing individuals to feel warmer and less comfortable. Conversely, lower metabolic rates, such as those during sedentary activities, may require less heat dissipation, allowing individuals to feel cooler and more comfortable. Metabolic rates (met Rate) for different activities are shown in Figure 5.

FIGURE 5: METABOLIC RATES (MET RATE) FOR DIFFERENT ACTIVITIES

Seating	Sleeping	Walking	Running
58.2 W/m²	40 W/m²	115W /m²	220W /m²
1.0 MET	0.7 MET	2.0 MET	3.8 MET

(Source: ASHRAE, 2010)

2.2.3 Operative temperature

As mentioned earlier, thermal comfort depends on various personal and environmental factors. Due to the complexity of empirically fitting all these variables, a simple measure can be more practical. Operative temperature, derived from air temperature, mean radiant temperature, and air speed, is the simplified measure of human thermal comfort. When designing a building, achieving a comfortable operative temperature is a key focus.

Operative temperature can be defined as the average of the mean radiant and ambient air temperatures, weighted by their respective heat transfer coefficients. In simpler terms, it is the mean value of the radiant and the air temperature. (ASHRAE, Handbook on Fundamentals, 2009)

2.3 Thermal comfort models and indices

The desired range of thermal comfort can be defined for a building based on the comfort expectation of the users of the building and the degree of personal control offered within the indoor environment. The range of desired comfort is based on either of the following two thermal comfort models: the heat balance model and the adaptive comfort model.

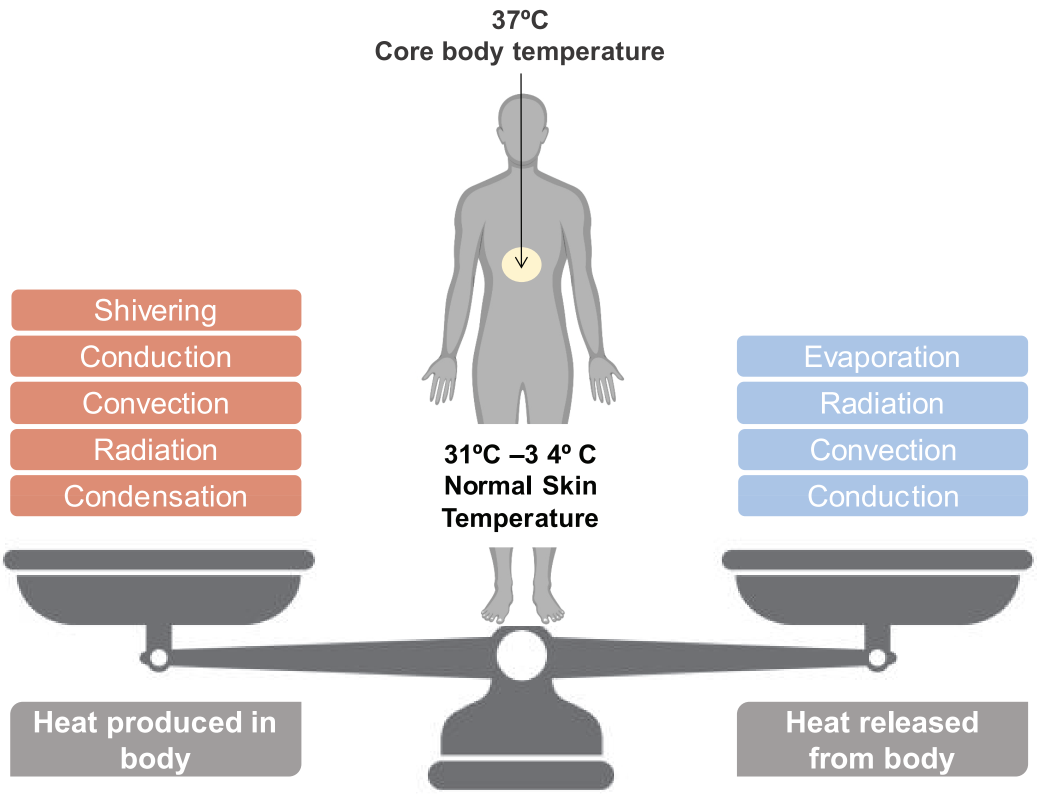
2.3.1 The heat balance model

The heat balance method presents a physics based mathematical model. It establishes thermal comfort when heat loss from the body is exactly equal to the heat produced within the body. The heat balance model is illustrated in Figure 6.

The heat balance method approaches thermal comfort from a biological perspective:

- If heat generation rate > heat loss rate, the individual will feel warm/hot
- If heat generation rate < heat loss rate, the individual will feel cool/cold
- If heat generation rate = heat loss rate, the individual will experience thermal comfort

FIGURE 6: HEAT BALANCE MODEL



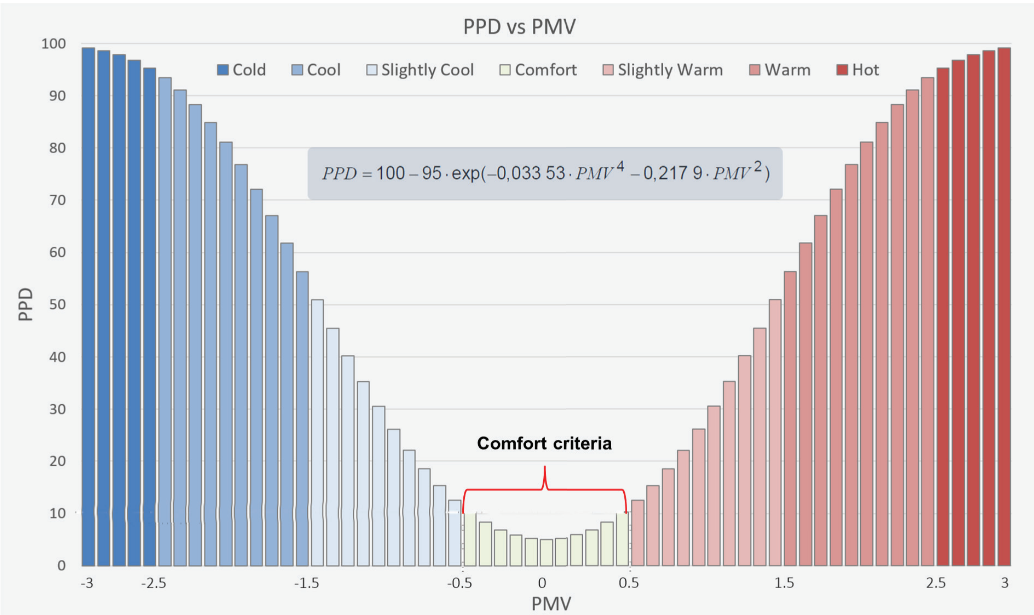
The acceptable thermal comfort range in the heat balance method is defined by Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD).

PMV & PPD

The Predicted Mean Vote (PMV) is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale based on the heat balance of the human body. The sensation scale is expressed from –3 to +3 corresponding to the categories "cold," "cool," "slightly cool," "neutral," "slightly warm," "warm," and "hot." Thermal balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment. PMV can be calculated for different combinations of metabolic rate, clothing insulation, air temperature, mean radiant temperature, air velocity, and air humidity (ISO:7730, 2005).

Once the PMV is calculated, the PPD or Predicted Percentage of Dissatisfied (PPD) can be determined. PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. Thermally dissatisfied people are those who will vote hot, warm, cool, or cold on the 7-point thermal sensation scale. Figure 7 shows the PMV and PPD scale and the comfort criteria.

FIGURE 7: PMV AND PPD SCALE AND THE COMFORT CRITERIA



(Source: Modified image from https://www.simulationhub.com/blog/role-of-cfd-in-evaluating-occupant-thermal-comfort)

For example, the desired operative temperature in offices, as per PMV/PPD, is shown in Table 1. The considered metabolic rate is 1.2 MET, and clothing value is considered 0.5 Clo during summer ('cooling season') and 1.0 Clo during winter ('heating season').

The heat balance method quantifies the heat exchange between the human body and the immediate surrounding environment. It signifies that occupants' perception of thermal comfort relies solely on human psychology and heat transfer mechanisms between the environment and the body. However, research has indicated that thermal comfort perception is also influenced by social factors and the occupants' psychological responses to the environment.

TABLE 1: DESIGN CRITERIA FOR THE OPERATIVE TEMPERATURE IN OFFICE BUILDING

Activity	Category	Operative temperature (°C)	
		Summer (Cooling Season)	Winter (Heating Season)
70 W/m^2	**A** PMV – 0.2 < PMV < + 0.2 PPD <6%	24.5 ± 1.0	22.0 ± 1.0
	B PMV – 0.5< PMV < + 0.5 PPD <10%	24.5 ± 1.5	22.0 ± 2.0
	C PMV – 0.7< PMV < + 0.7 PPD <15%	24.5 ± 2.5	22.0 ± 3.0

2.3.2 Adaptive thermal comfort model

Human beings naturally adjust and adapt to outside weather conditions, minimizing discomfort through changes in activity, posture, clothing, and the manipulation of windows (opening or closing). Furthermore, individuals tend to find comfort in a broader range of temperatures within a space, influenced by the prevailing outside weather conditions.

The adaptive thermal comfort model was developed to acknowledge the influence of behavioural and psychological adaptations on the human body. The adaptive thermal comfort model takes the physiological, psychological, and behavioural aspects of the occupants and their influence on perception on thermal comfort.

Acceptable thermal conditions in occupant-controlled naturally conditioned spaces: ASHRAE 55

ASHRAE 55 uses an adaptive comfort model to recommend acceptable thermal conditions for naturally ventilated spaces. This method defines acceptable thermal environments only for occupant-controlled naturally conditioned spaces that meet all the following criteria:

- No mechanical cooling system (e.g., refrigerated air conditioning, radiant cooling, or desiccant cooling) was installed. No heating system is in operation.
- Representative occupants have metabolic rates ranging from 1.0 to 1.3 met. They are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5 to 1.0 Clo.
- The prevailing mean outdoor temperature is greater than 10°C and less than 33.5°C.

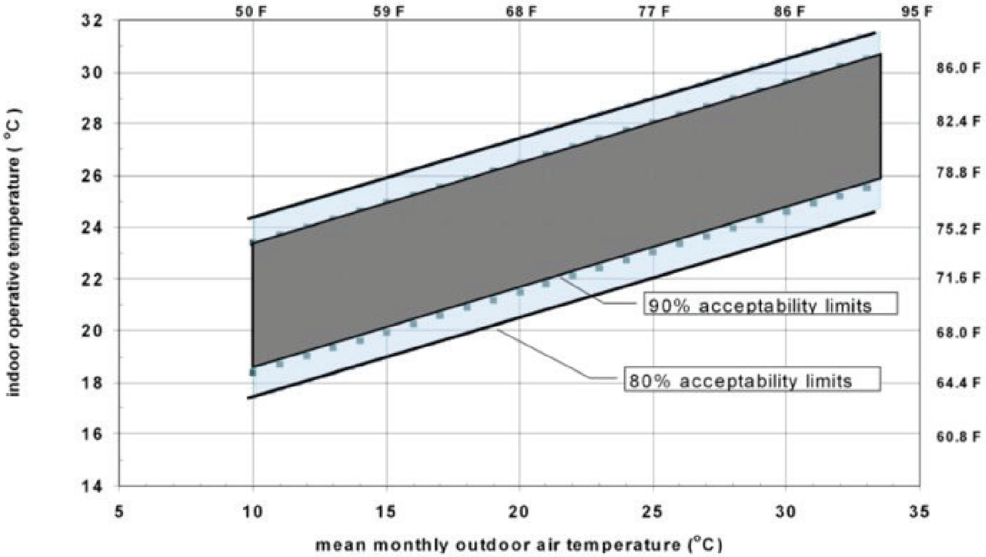
The allowable indoor operative temperatures, t_o, shall be determined from the graph in Figure 8 using the 80% acceptability limits. Alternatively, the following Equation 1 and Equation 2 may be used:

Upper 80% acceptability limit (°C) = 0.31 $t_{pma(out)}$ + 21.3 (1)

Lower 80% acceptability limit (°C) = 0.31 $t_{pma(out)}$ + 14.3 (2)

Where, $t_{pma(out)}$ is the arithmetic average of the mean daily outdoor temperatures over no fewer than seven and no more than thirty sequential days before the day in question.

FIGURE 8: ACCEPTABLE OPERATIVE TEMPER ATURE TO RANGES FOR NATURALLY CONDITIONED SPACES



(Source: ASHRAE 55)

2.4 Roles of the Designers

Two decisions need to be taken at the beginning for determination of thermal comfort, which will also impact energy efficiency strategies:

- The comfort expectation of the users of a building depends on the user preference as well as the mode of operation of the building.
- The degree of personal control offered over the indoor environment.

Suppose users expect a narrow range of comfort with a high degree of control. In that case, the expectation is that of an air-conditioned building where the indoor temperature is always controlled within the comfort range. In this case, the comfort range, as per the PMV/PPD model, must be considered. This is usually the case with hospitals, several types of office/commercial buildings, high-end hotels, and even certain high-end residences.

For most residential buildings, schools, institutional buildings, etc., the expectation of comfort and the degree of control is less strict compared to buildings like hotels or office buildings. In these buildings, the adaptive comfort range can be determined. It must be reiterated here that thermal comfort is very subjective, and the comfort ranges given by the models are only guidelines to enable design, where 80% of the users may be thermally comfortable.

The more stringent the user's expectations, the longer the time required for heating or cooling, resulting in increased investment for air conditioning and operational expenses.

Once the desired thermal comfort range is determined, thermal comfort at different design iterations can be predicted through simulations. Simulations can show how many hours in a year the indoor operative temperature of the building will be within the determined thermal comfort range. Alternatively, it can show the difference between the achieved operative temperature and the desired operative temperature, and the duration (measured in hours) for which the difference persists. This is denoted by a term called Discomfort Degree Hours (DDH). It has a unit of °C.h.

It is calculated using Equation 3.

$$\text{DDH (annual)} = (T_{\text{operative}} - T_{\text{acceptable}}) \times \text{Time} \qquad (3)$$

Where,

$T_{operative}$: indicates the measured or achieved operative temperature,

$T_{acceptable}$: indicates the targeted operative temperature based on comfort models,

Time: refers to the duration in hours, for which the difference persists.

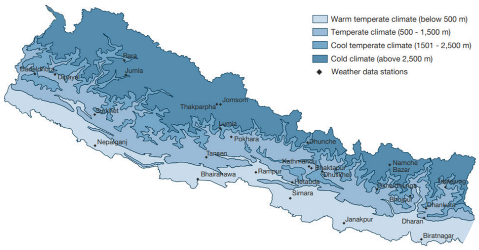
The duration usually considered for DDH calculation is one year. DDH may be used to interpret the following:

- Thermal comfort is achieved within a building. Lower DDH indicates a higher amount of thermal comfort provision within the building throughout the year.
- An indicator of the degree of heating or cooling needed. If less DDH is achieved without any mechanical heating or cooling, less energy will be required.

Summary

- ASHRAE defines thermal comfort as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.”
- Thermal comfort is influenced by environmental factors (DBT, RH, MRT and airspeed) and personal factors (Clo value and MET).
- Operative temperature is a simplified measure of human thermal comfort derived from air temperature, mean radiant temperature and air speed.
- Based on the comfort expectation of the users of a building and the degree of personal control offered over the indoor environment, the desired range of thermal comfort may be defined for the building based on the heat balance model or the adaptive comfort model.
- The purpose of these models and indices is to try to provide an acceptable indoor thermal environment for 80% of occupants in each space while mitigating factors that cause overwhelming discomfort.
- Once the desired thermal comfort range is determined, thermal comfort for different design iterations can be predicted through simulations. Simulations can show the Discomfort Degree Hours (DDH) of a design, which shows the difference between the achieved operative temperature and the desired operative temperature, and the duration (measured in hours) for which the difference persists.
- The more stringent the expectation of the user, the longer the time is required for heating or cooling, resulting in increased investment and operational expenses.

3
CLIMATE



What's in this section?

3.1 Climate zones in Nepal

3.2 Climate analysis

3.3 Sun path analysis

Climate

Climate is the long-term pattern of weather in a particular area. Weather can change from hour-to-hour, day-to-day, month-to-month, or even year-to-year. A region's weather pattern, usually tracked for at least 30 years, is considered its climate.

The climate is influenced by various factors some of which are:

- Location of the place on the Earth, i.e., latitude and longitude
- Height of the location from the sea level, i.e., altitude
- Physical features (land mass and water mass) of the area.
- Atmospheric condition.

3.1 Climate zones in Nepal

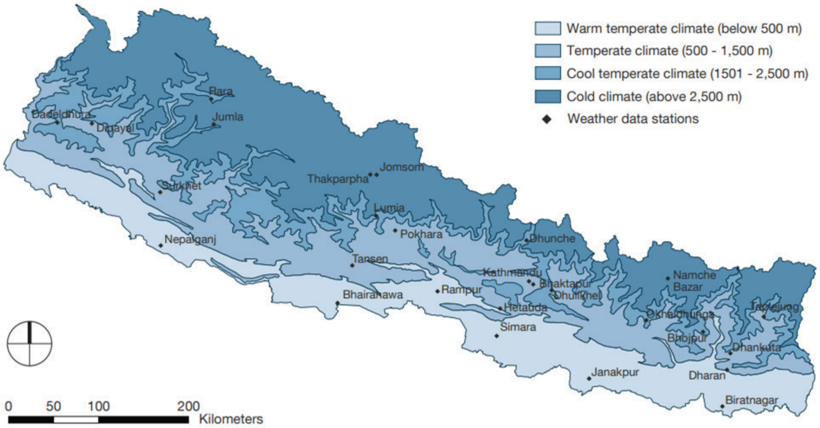
Climate zones are regions that share similar climatic conditions. They are typically divided based on several variables that affect the region's climate, including temperature, precipitation, humidity, and other climate variables.

Susanne Bodach (Bodach, 2016) has proposed climate zone classification based on elevation, as shown in Figure 9. This classification is followed in this manual because it was carried out according to the bio-climatic zoning focusing on the building construction sector. This is relevant to our context and necessary to introduce it in building energy conservation guidelines and standards, as well as in building energy codes. Table 2 shows the climate characteristics of four climate zones with the maximum and minimum DBT & RH for each climatic zone.

This classification of climate zone will be helpful for the designer/architect to broadly understand the outdoor condition of their project location. The climate analysis can indicate:

- The comfort and discomfort months of the years.
- At which time of the year, can indoor comfort be achieved for the building occupants with very little or no effort.
- What passive strategies are required, and will they be effective or not?

FIGURE 9: CLIMATE ZONES OF NEPAL



(Source: Bodach, 2016)

TABLE 2: CLIMATE ZONES OF NEPAL WITH ITS CHARACTERISTICS, MAXIMUM AND MINIMUM DBT&RH

S. N	Climate Zone	Climate Characteristics	Temperature		Avg. Relative Humidity range (%)
			Avg. Max. (°C)	Avg. Min. (°C)	
1	Warm Temperate (Elevation < 500m)	• **Dec-Feb:** Cold & dry season with clear skies • **Mar:** Moderately cold & dry season • **Apr-Jun:** Hot & dry season with clear skies • **Jul-Sep:** Warm & humid season • **Oct-Nov:** Moderately warm & moderately humid season	33 - 36	8 - 10	45 – 85
2	Temperate (Elevation 501m – 1500m)	• **Dec-Feb:** Cold & dry season with clear skies • **Mar:** Moderately cold & dry season • **Apr-May:** Warm & dry season • **Jun-Oct:** Moderately warm & humid season • **Nov:** Cool & moderately humid season	27 - 30	5 - 7	60 - 85
3	Cool Temperate (Elevation 1501m – 2500m)	• **Nov-Mar:** Cold & dry season with clear skies • **Apr:** Cool & dry season • **May-Sep:** Moderately warm & dry season • **Oct:** Cool & dry season	22 - 24	2 - 4	60 - 85
4	Cold Climate (Elevation > 2500m)	• Cold & dry season for most of the year • **Jun-Aug:** Moderately warm day-time temperature	16 - 18	-11 - -7	40 - 75

3.2 Climate analysis

3.2.1 Climate variables

Climate data is critical for building design and consists of the following climate variables:

1. **Dry bulb temperature (°C):** Refer to Section 2.2.1.1.

2. **Relative humidity (%):** Refer to Section 2.2.1.2.

3. **Wet bulb temperature (°C):** The Wet-bulb Temperature (WBT) is defined as the temperature of a parcel of air cooled to saturation (100% relative humidity, resulting in the occurrence of water droplets). At 100% relative humidity, the WBT is equal to the DBT at lower humidity levels. The WBT is always lower than the DBT.

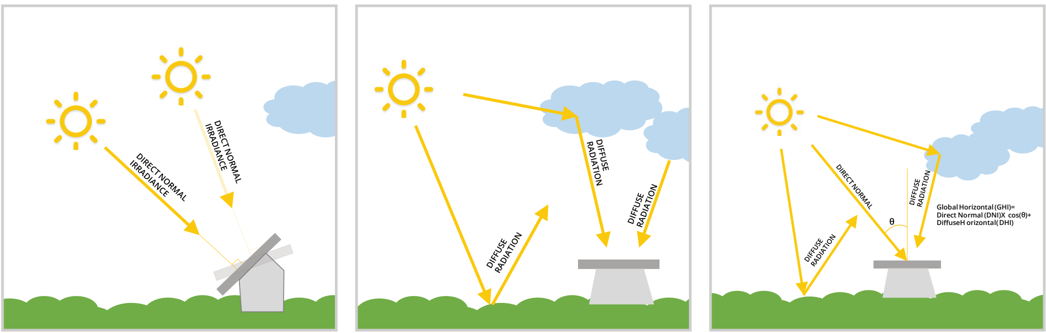
4. **Solar radiation (W/m²):** This is the energy that comes from the sun and is transmitted in the form of electromagnetic waves. The amount and intensity of solar radiation that reaches the Earth's surface can vary depending on factors such as time of day, season, latitude, altitude, and atmospheric conditions. The maximum solar radiation with no dust in the air (e.g., after rain) and no clouds is around 1000 W/m². This radiation value is taken to define the power of PV modules (including 25°C ambient temperature). Solar radiation has three components as illustrated in Figure 10:

    a. Direct Normal Irradiance (DNI): the amount of solar radiation received directly from the sun on a surface perpendicular to the sun's rays.

    b. Diffuse Horizontal Irradiance (DHI): the amount of solar radiation that is scattered by the atmosphere and reaches the Earth's surface from all directions, not just from the sun.

    c. Global Horizontal Radiation (GHI): the total amount of solar radiation received on a horizontal surface, including both direct and diffuse radiation.

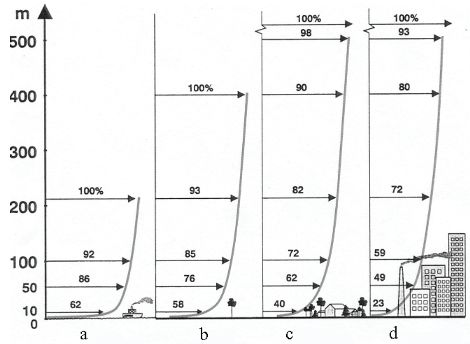
FIGURE 10: DIRECT NORMAL IRRADIANCE (ON LEFT), DIFFUSED HORIZONTAL IRRADIATION (MIDDLE), AND GLOBAL HORIZONTAL RADIATION (ON RIGHT)



5. **Wind speed and wind direction:** Wind speed is how fast the air is moving. It is usually measured in meters per second (m/s) or kilometers per hour (km/h). Wind direction is the direction from which the wind is coming from. It is usually expressed in terms of the eight points of the compass (north, northeast, east, southeast, south, southwest, west, and northwest).

Wind speed varies with the height and this variation depends on the ground roughness (obstructions), differing for each terrain category as illustrated in Figure 11. The wind blows at a given height, with lower speeds in rougher terrains and higher speeds in smoother terrains. Furthermore, in any terrain, wind speed increases along the height up to the gradient height, and the values of the gradient heights are higher for rougher terrains. Wind speeds beyond gradient heights in all terrains are equal (IS:875(Part3), 2015).

FIGURE 11: WIND PROFILE OVER HEIGHT



a. Exposed open terrain with a few or no obstructions (structure is less than1.5 m)
b. Open terrain with well scattered obstructions (surrounding structure 1.5 and 10 m)
c. Terrain with numerous closely spaced obstructions (structures up to 10 m with or without other isolated structure)
d. Terrain with numerous large high closely spaced obstructions.

(Source: IS:875(Part3), 2015)

3.2.2 Weather Files

To conduct a climate analysis, representative climate data of the location for the last 10-15 years is needed. Today, several tools can assist in climate analysis. These tools use hourly weather data files[2] as input. These data files give the values for different climate variables (discussed in Section 3.2.1) for each of the 8760 hours of representative year resulting from the previous 10-15 years of climate data. The latest available weather files should be used for climate analysis.

These weather files can be freely downloaded from the following website:

- Energy Plus Weather Data: https://energyplus.net/weather/simulation
- Climate One building: https://climate.onebuilding.org/default.html
- CBE Clima tool: https://clima.cbe.berkeley.edu/
- Ladybug: https://www.ladybug.tools/epwmap/

The downloaded weather file folder will contain all or some of the following file formats shown in Table 3.

TABLE 3: TYPES OF WEATHER DATASETS AVAILABLE

	File Type	
1	STAT	Expanded Energy Plus weather statistics
2	EPW	Energy Plus Weather Format
3	DDY	ASHRAE Design Conditions or "file" design conditions in Energy Plus format

2 Hourly weather data files are also used as input for building energy simulation software.

The .epw file is commonly used to perform climate analysis on freely available climate analysis tools. These same files are also used for carrying out the building energy simulation. The list of locations for which .epw files are available as per the climate zone of Nepal is given in Table 4.

TABLE 4: PLACES OF NEPAL WITH .EPW FILES

Warm Temperate	Temperate	Cool Temperate	Cold
Nepalgunj	Pokhara	Taplejung	Jumla
Siddharthanagar	Kathmandu	Amargadhi	
Dhangadhi	Dipayal	Okhaldhunga	
Biratnagar	Dhankuta		
Simara	Dang		
	Birendranagar		

If weather data or .epw files are not available for certain locations, the nearest .epw file meeting both requirements should be considered (EnergyPlus, 2023).

- The geographical distance between the two locations should be ≤ 50km.
- The difference in altitude between the two locations should be ≤ 100m.

If both requirements are not met, one may explore the possibility of obtaining data files from various available web sources. These sources often use statistical methods to generate the .epw file for the location. Some of the widely used web sources include:

- Climate.OneBuilding (free access)
- Power Access Data Viewer (https://power.larc.nasa.gov/data-access-viewer/)

3.2.3 Climate analysis tools

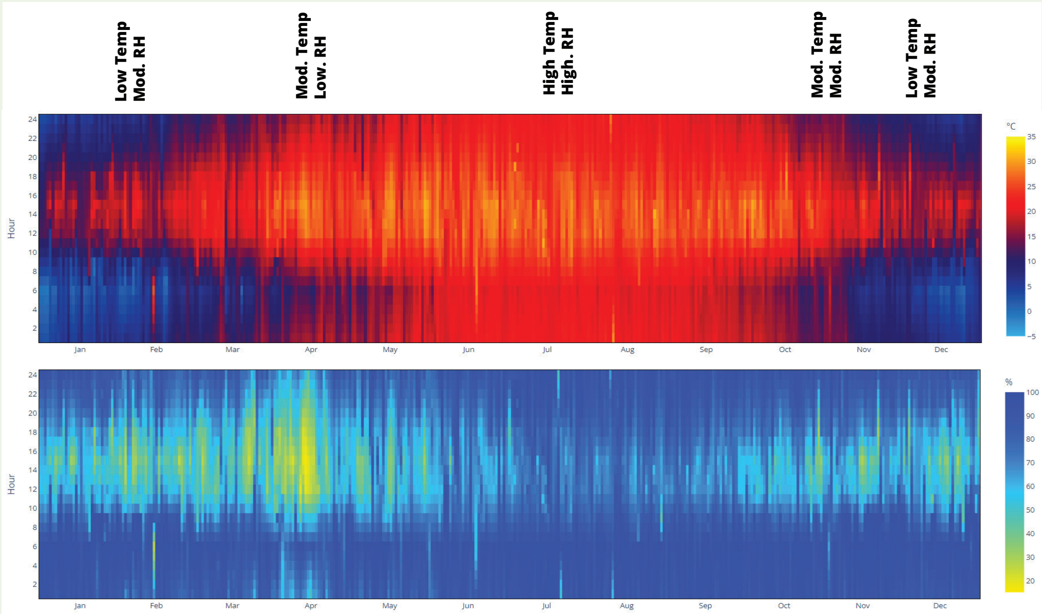
Various climate analysis tools help to visualize the climate data (stored in a .epw file) in a way so that the interpretation can easily be done. Some of the widely used tools are:

- Climate Consultant: A simple-to-use, graphic-based computer program that helps designers understand their local climate.
- CBE Clima: A web-based application built to support climate analysis specifically designed to support the needs of architects and engineers.
- Rhino + Ladybug: Ladybug Tools comprises free computer applications that facilitate environmental design analysis and are freely available. However, Rhino is not open-source.

Climate Analysis Example: Kathmandu
Dry bulb temperature and relative humidity

Typically, most people find a comfortable Dry Bulb Temperature (DBT) range to be between 20-26°C, and a comfortable Relative Humidity (RH) range between 30-70%. However, if either or both of these factors are too high or too low, it can lead to thermal discomfort. Hence, it is crucial to consider both factors together. Figure 12 shows the Heat Map Chart showing DBT and RH of Kathmandu.

FIGURE 12: HEAT MAP CHART SHOWING DRY-BULB TEMPERATURE (TOP) AND RELATIVE HUMIDITY (BOTTOM) OF KATHMANDU



(Source: CBE Clima)

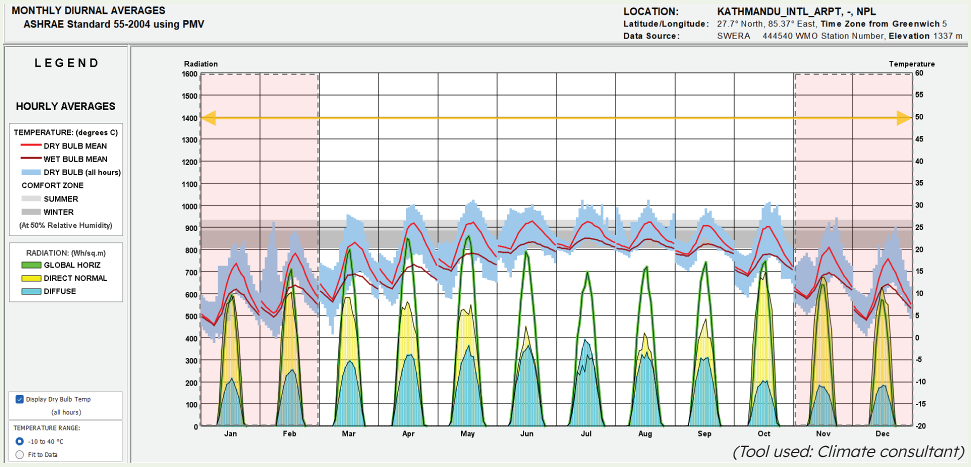
By analyzing the values of DBT and RH of Kathmandu (Figure 12), we can categorize each month to determine whether it is cold, comfortable, humid, or hot, etc. These categorizations are presented in Table 5

TABLE 5: CATEGORIZATION OF MONTHS BASED ON DBT AND RH

	DBT	RH	Remark
Nov-Feb	3°C to 20°C.	30%-70% (100% at night)	Low DBT, Mod. RH **Cold**
March-April	15°C to 25°C.	20%-60%	Mod. DBT, Low. RH **Comfortable (Mostly)**
May-Sep	20°C to 33°C.	40%-90% (100% at night)	High DBT, High RH **Hot and Humid**
October	15°C to 26°C.	30%-70% (100% at night)	Mod. DBT, Mod. RH **Comfortable**

Solar radiation

FIGURE 13: ANNUAL GRAPH SHOWING GLOBAL, DIRECT, AND DIFFUSE SOLAR RADIATION FOR KATHMANDU, NEPAL



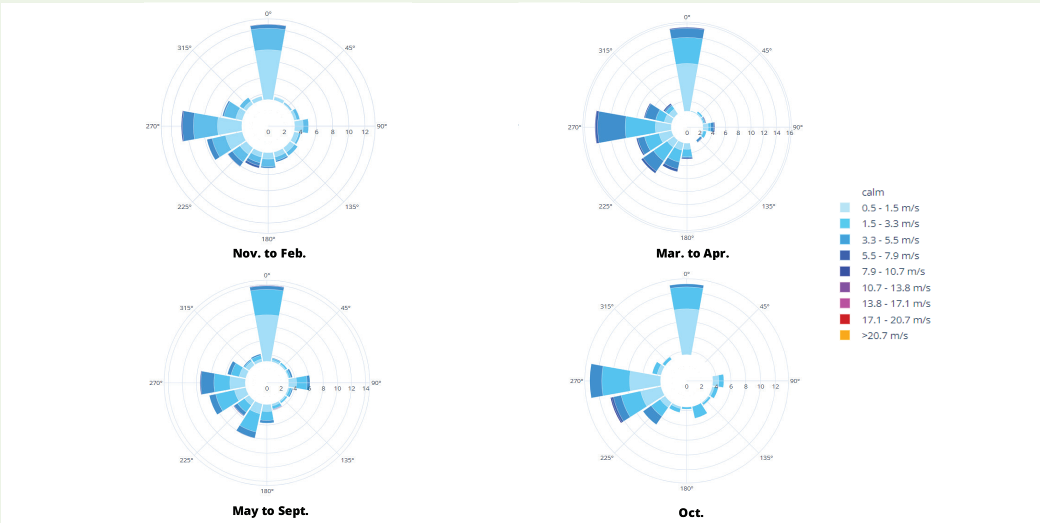
(Tool used: Climate consultant)

Figure 13 illustrates the global, direct and diffuse solar radiation annually for Kathmandu. It shows that the winter months (Nov. to Feb.) in Kathmandu have clear skies with high solar radiation. This can be used to reduce heating load in the winter. At the same time, solar radiation must be avoided in the hot and humid months.

The solar radiation graph also indicates that there is good potential for solar-based renewable energy throughout the year, except for June to September when the direct normal radiation is quite low due to clouds and precipitation

Wind

FIGURE 14: WIND RISE DIAGRAM OF MONTHS FOR WHICH DBT AND RH CATEGORIZATION WAS DONE



(Tool used: CBE Clima tool)

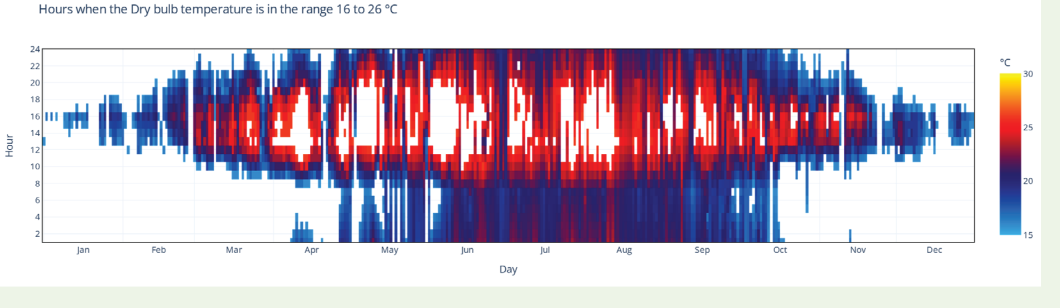
In Figure 14, the prevailing wind direction is mainly from the North and West, consistently exceeding 1.5 m/s for a significant duration. Consequently, during the comfortable months (April, March, and October) and the hot-humid months (May to September), there exists substantial potential for natural ventilation. Thus, strategic decisions regarding building orientation, placement of external and internal windows, and spatial configuration become crucial to harness the maximum benefit from the prevailing wind.

Natural ventilation potential

Addressing the following questions during climate analysis can reveal the potential for natural ventilation to contribute to cooling in a given climate:

- Which months will require cooling, and what is the relative humidity during those periods? *(Air movement becomes crucial, especially if humidity exceeds 60% alongside high temperatures.)*
- Does the outside temperature in those months drop below 24-26°C, and if so, when does this occur? This is the optimal time for leveraging natural ventilation for effective cooling. *(If outside temperatures remain above this range, outside air may not offer sufficient thermal comfort.)*
- What is the prevalent wind direction and average wind speed during this time? *(For effective wind-driven ventilation, a wind speed of at least 0.5 m/s is typically necessary.)*

FIGURE 15: GRAPH SHOWING PERIOD WHEN DBT IS BETWEEN 16°C AND 26°C IN KATHMANDU



In Kathmandu, the potential cooling months are from March to October. Figure 15 illustrates periods when temperatures in Kathmandu fall between 16°C and 26°C. Notably, these temperatures provide favourable conditions for cooling through natural ventilation in March (daytime), June-July (evenings), and August-October (all day). In April-May, natural ventilation remains viable during late evenings and early mornings. During this period, wind speeds consistently exceed 0.5 m/s for most of the time (though this may vary based on the density and features surrounding the building site).

3.3 Sun path analysis

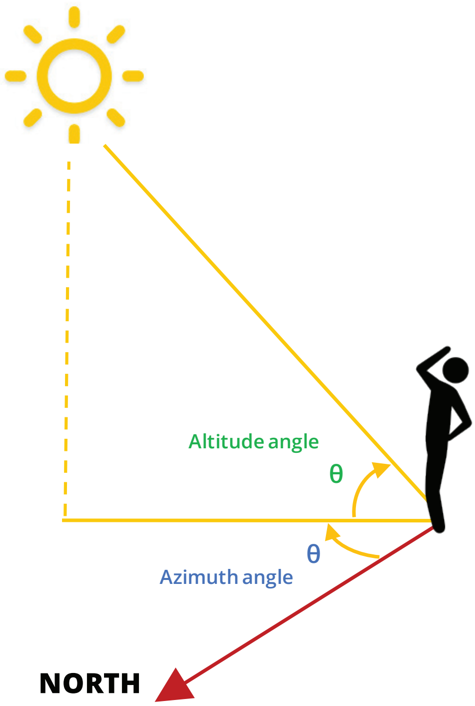
The sun's movement is dynamic and influenced by variations in altitudes, angles, and solar radiation. This movement becomes both critical and complex as it interacts with buildings. To simplify the understanding of the sun's trajectory, a 2D graphical representation known as 'Horizontal Sun Path Diagrams' or 'Sun Path Diagrams' is generated.

3.3.1 Sun path diagrams

Two essential terms for interpreting sun path diagrams are the altitude angle and the azimuth angle of the sun as shown in Figure 16.

- **Altitude angle:** This angle is the measurement between the horizon and the sun's position in the sky, ranging from 0° (when the sun is on the horizon) to 90° (when the sun is directly overhead). It is measured in degrees.
- **Azimuth angle:** This angle is the measurement between the direction of true north and the direction of the sun. It is measured in degrees clockwise from a reference direction, typically the true north, and spans from 0° to 360°. Some simulation tools may use south as the reference direction (0°), which should be double-checked when utilizing these tools.

FIGURE 16: SOLAR POSITION ANGLES

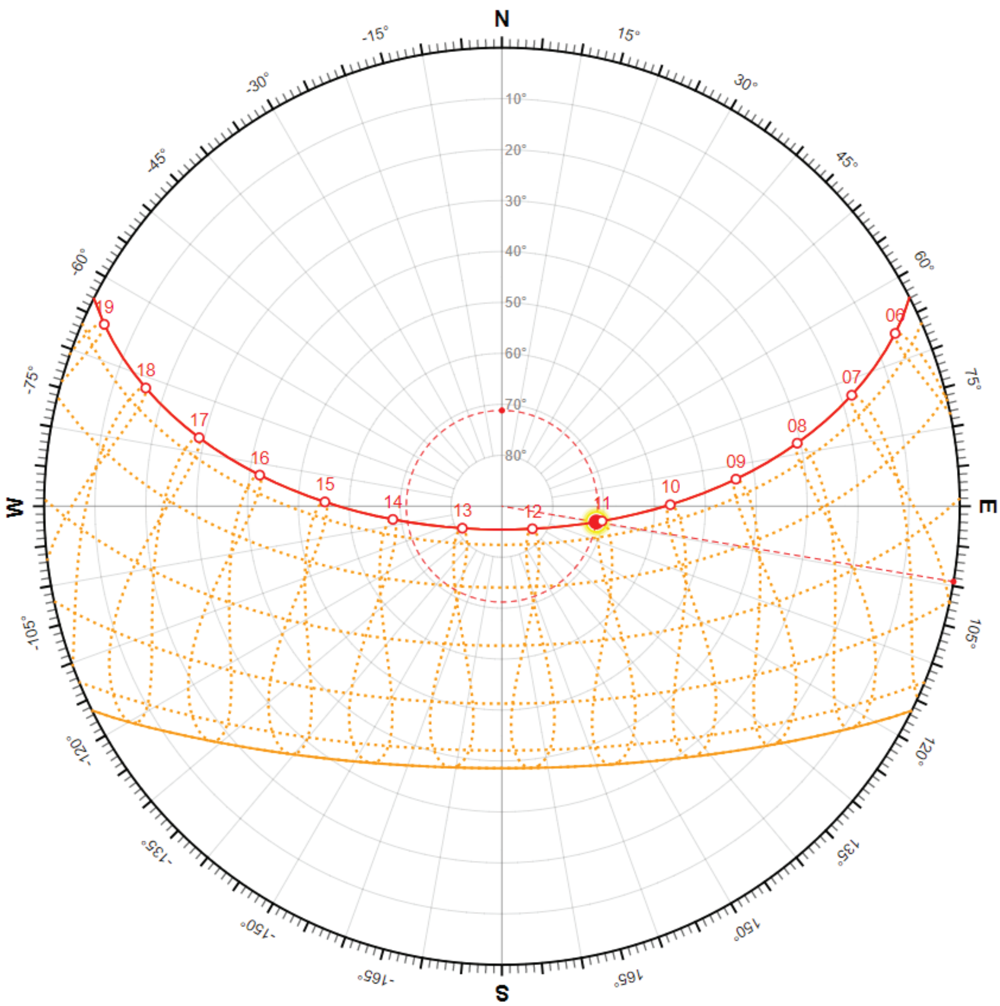


3.3.2 Sun-path diagram tools

Several online tools offer sun-path diagrams for specific locations based on their latitude and longitude. For example, the Sun Path Diagram of Kathmandu is shown in Figure 17. Two notable free tools include:

- **Andrewmarsh.com:** This online tool provides both 2D and 3D sun path diagrams.
- **CBE Clima:** (https://clima.cbe.berkeley.edu/)

FIGURE 17: SUN PATH DIAGRAM OF KATHMANDU, NEPAL



(Tool Used: AndrewMarsh.com)

By understanding the altitude angle and the azimuth angle of the sun at different times of the day and year, architects and building designers can optimize:

- The placement (direction) of windows and skylights.
- Shading devices to control the amount of solar heat gain.
- Designers can take advantage of the sun's angle in the winter to maximize passive solar heating in buildings, while also minimizing heat gain in the summer by incorporating shading devices (southern walls).

3.3.3 Important dates for sun-path analysis

The sun's position, indicated by altitude and azimuth angles, can be extracted from the sun path diagram for any specific date and hour of the year. For designers, understanding the sun's position on the dates in Table 6 is crucial.

TABLE 6: IMPORTANT DATES FOR SUN-PATH ANALYSIS

	Date (Northern Hemisphere)	Description
Summer Solstice	20 or 21 June	The Extreme of the sun's position i.e., **at the highest altitude.** Sunrise and sunset slightly north. Longest day.
Autumn Equinox	21 September	Average of the sun position i.e., **sun rises due east and sets due west.** Equal day length day/night.
Winter Solstice	21 or 22 December	The extreme of the sun's position i.e., **at the lowest altitude.** Shortest day. Sunrise and sunset slightly south.
Spring Equinox	21 March	Average of the sun position i.e., **sun rises due east and sets due west**. Equal day length day/night.

Summary

- This manual adopts the following climate zone classification for Nepal:
    1. Warm temperate climate (below 500m)
    2. Temperate climate (501-1500m)
    3. Cool temperate (1501-2500m)
    4. Cold climate (above 2500m)
- Conducting climate analysis, involving the examination of various climate variables like DBT, RH, solar radiation, wind speed, and direction for a specific location, helps in identifying:
    1. The comfortable and uncomfortable months of the year.
    2. The periods when achieving indoor comfort for building occupants requires minimal or no effort.
    3. The necessary passive strategies and their anticipated effectiveness.
- Weather files encapsulate climate variable data for a representative year (8760 hrs.), derived from the recorded climate data of the location over the past 10-15 years. The .epw (Energy Plus Weather) format is widely employed for climate analysis, as well as building energy and comfort simulation.
- Analyzing a location's sun path, which depicts the sun's position at various times throughout the day and year, empowers architects and building designers to make informed decisions regarding:
    1. Building orientation
    2. Window and skylight placement
    3. Implementation of shading devices to regulate solar heat gain in summer
    4. Maximizing passive solar heating in winter

4
HEAT TRANSFER IN BUILDINGS

What's in this section?

Heat Transfer in Buildings

Thermal comfort inside a building depends on the heat transfer that happens through the building envelope. It is important to understand the principles of these heat exchanges to implement appropriate passive strategies.

Forms of heat: Sensible & Latent

- **Sensible heat:** Sensible heat refers to the heat transfer that causes a change in the temperature of a substance without changing its state (phase). For e.g., when you warm up a cup of tea, the heat you're adding is sensible heat. It's the heat that makes the tea hotter.
- **Latent heat:** Latent heat is involved when a substance changes its form, like from ice to water or water to steam, without changing its temperature. It's the heat that's hidden or "latent" during these phase changes.

4.1 Heat sources for Buildings: Internal & External

4.1.1 Internal heat gains

Building occupants generate heat based on their metabolic rate. In addition to this, heat is produced within the space by electrical lighting and equipment. This heat generation within the building, collectively referred to as internal heat gains (refer to Figure 18), is closely associated with the building type (e.g., office, education, or residential) and its occupancy.

FIGURE 18: INTERNAL HEAT GAINS THROUGH OCCUPANTS, EQUIPMENT AND ARTIFICIAL LIGHTING

Occupancy heat gains

To determine the occupancy heat gains in a space, one must know the activity-related heat gain from a person and the number of occupants in the space. Occupancy also varies throughout the day. Thus, occupancy schedules should be ascertained. These schedules are important especially when using energy simulation software to predict energy use in buildings.

The activity related to heat gain/person or rates of heat (sensible and latent) given off by humans at different states of activity are given in ASHRAE 55: Thermal Environmental Conditions for Human Occupancy.

Lighting heat gains

The heat gained from artificial lighting in a building is found by multiplying the number of lights of each type and its respective wattage. Multiplying this with the number of hours of use of the lights gives the total heat gains from artificial lighting.

Alternatively, recommended Lighting Power Density (LPDs) may be used to ascertain the lighting heat gains. LPD represents the power consumed by lighting per unit of floor area and is typically measured in watts per square meter (W/m^2). Recommended LPD for different types of spaces are given in various standards, including ASHRAE 90.1.

Equipment heat gains

The heat gained during the use of equipment (such as micro oven, toasters, ovens, computers, etc.) in a building can be determined by multiplying the rated input of the equipment (in watts) by the usage factor of the equipment and the fraction of heat radiated to the space.

ASHRAE Fundamentals 2017 provides heat gain values for appliances. Equipment Power Density (EPD) is another term used, representing the power consumed by equipment per unit of floor area and is typically measured in watts per square meter (W/m^2).

4.1.2 External heat gains

The heat from the sun, earth, and the external environment, which is transferred through the building envelope, constitutes external heat gains. Further examination of heat transfer through the building envelope is provided in Section 4.3.

4.1.3 Internal vs. External heat gains

Densely populated buildings with high activity and/or energy-intensive equipment, such as office buildings, malls, and cinema halls, are typically characterized by dominant internal loads. On the other hand, less populated buildings with minimal activity or equipment, such as residences and warehouses, are generally dominated by external loads. The significance of internal heat loads in comparison to external loads from the sun, wind, and ambient temperatures is determined by the building design, envelope and usage.

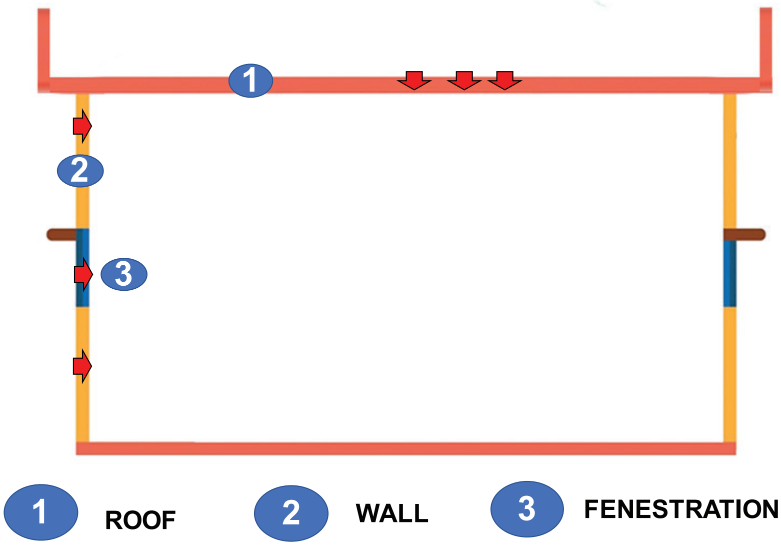
4.2 Modes of heat transfer through the building envelope

Heat is a form of energy, and it always flows from warm to cold. This can be explained at the molecular level. Temperature at the molecular level signifies the movement of molecules, which is a form of kinetic energy. The higher the temperature, the faster the molecules move. If one side of a solid is hotter than the other side, the fast-moving molecules will likely collide with the slower ones, transferring energy and accelerating them. Eventually, all molecules reach a uniform speed due to the uniform temperature, and the overall movement slows down. There is a less possibility for slower molecules to collide with faster ones and become even slower, while the faster molecules become even faster. This phenomenon is similar to pouring hot tea into lukewarm water, which does not make the water colder and the tea hotter. This is explained by the second law of thermodynamics, which states that heat flows from hotter regions to colder regions. The first law of thermodynamics asserts that heat cannot be lost but only transferred to another form.

4.2.1 Conduction

Conduction is the process of heat transfer that occurs through heat flux in non-moving material. In buildings, conduction occurs when heat moves through walls, floors, roofs, and other solid components. The amount of heat exchange through these envelope components depends on the properties of these envelopes and the temperature difference between the two sides. In a building, conduction happens through the roof, walls, and fenestration (refer to Figure 19). The conduction of the different wall layers is part of the U-value of a wall.

FIGURE 19: TRANSFER OF HEAT BY CONDUCTION THROUGH ROOF, WALL AND FENESTRATION



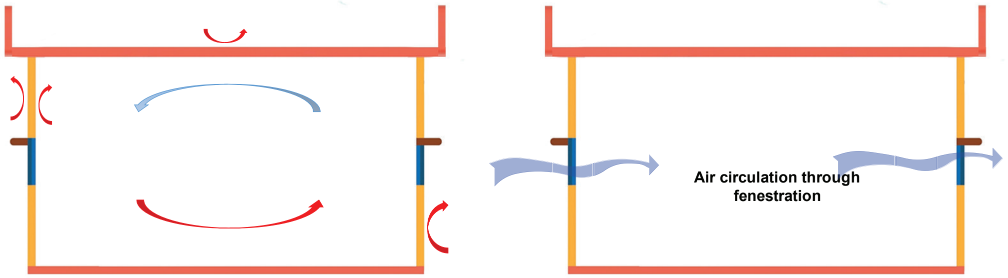
(Source: Reproduced image from Indo-Swiss BEEP)

4.2.2 Convection

Convection is the transfer of heat through the movement of fluids (liquids or gases). In the building, the spaces and the outside consist of air. There are two different ways in which convection heat transfer occurs in buildings:

- Heat is transferred from the surface of a wall to the surrounding air. If the wall surface temperature is higher than the air, the air molecules near the wall surface are heated up by the wall. Their speed increases, and they need more space. This results in the decrease of the density of air (number of molecules in a volume). This air layer near the wall now has less weight than the air away from the wall and starts moving upwards. Colder air from the bottom comes to the wall surface, and as the temperature difference between the wall surface and surrounding air molecules remains high, heat is transferred continuously. This process is natural convection, and it is a part of the whole U-value of a wall.
- Air exchange happens through openings in the building (e.g. fenestration, cracks, and crevices). This happens in both directions (infiltration and exfiltration). E.g. in cold climates, the air coming in from outside will mix with the inside air and must be heated to the needed room temperature. On the other hand, the heat of the warm air leaving the room is lost to the cold outside air. The amount of heat exchange happening through air exchange depends on the size of the openings, outside wind speed, the orientation of the openings with wind direction, and the temperature difference between the outside and inside air. Figure 20 demonstrates the exchange of heat by Convection.

FIGURE 20: EXCHANGE OF HEAT BY CONVECTION (LEFT: NATURAL CONVECTION AND RIGHT: AIR EXCHANGE)



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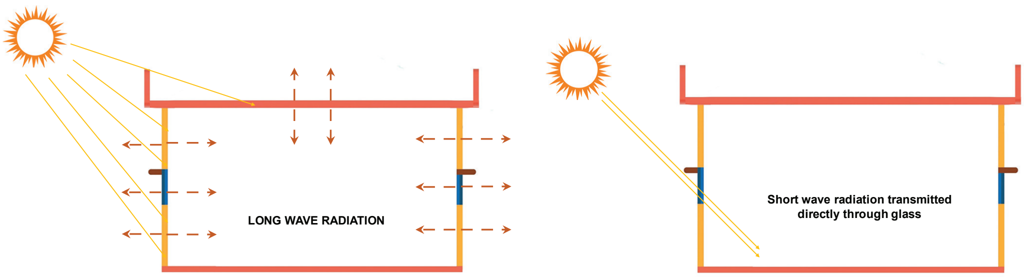
4.2.3 Radiation

Radiation is the transfer of heat in the form of electromagnetic waves without the need for a medium. Every body (especially, solids and liquids, but also some gases) with a temperature above 0 K (-273°C) emits radiation. The higher the temperature, the higher will be the radiation power and the shorter the wavelength of the emitted radiation. There are many wavelengths of radiation emitted by a body distributed around a maximum like a normal distribution. Wavelengths between 380 and 780 nm (Nanometer) are visible from blue to red. UV-radiation has a shorter wavelength. Thermal radiation of materials of buildings has wavelengths higher than 3000 nm. Two types of radiative heat transfer happen in buildings.

- Short-wave radiation, released by the sun between 250 and 2500 nm with a peak at 500 nm, passes through transparent building elements, such as the glass in windows and doors. Due to its transparency, glass allows short-wave solar radiation to enter the building directly. Additionally, some of the short-wave radiation is absorbed (partly) by the roof and walls, leading to an increase in the outside surface temperatures. This, in turn, induces additional conductive heat flux into the interior and convection heat flux to the surrounding environment.
- Long-wave radiation is emitted by all elements of the building and the surface of the human body based on their respective temperatures. Whether there is a net heat flux from one surface to another depends on the emissivity of the surfaces, how the radiation from one surface interacts with the other (view factor), and the temperature difference between both surfaces (expressed not linearly, but as $T_1^4 - T_2^4$, T in Kelvin).

Figure 21 demonstrates the heat transfer through radiation.

FIGURE 21: HEAT TRANSFER THROUGH RADIATION



(Source: Reproduced image from Indo-Swiss BEEP)

4.3 Heat transfer through the building envelope

Heat exchange through the building envelope primarily occurs through its three main components: the roof, walls, and windows.

4.3.1 Through walls and roof (opaque components)

The transfer of heat through walls and roofs is primarily determined by their materials. Different materials possess varying properties that impact their ability to conduct, absorb, and reflect heat. The key metrics for assessing these wall and roof assemblies are as follows:

- Reflectance of shortwave & Emissivity of long wave radiation, collectively referred to as the Solar Reflective Index (SRI)

- Thermal conductivity & transmittance (ability to conduct heat)
- Thermal mass (ability to absorb and store heat)

The roof and external wall surfaces are predominantly exposed to outside/ambient conditions and possess a substantial surface area. During the daytime, when solar radiation falls on these surfaces, a portion of the radiation is reflected, while some is absorbed and subsequently re-emitted. The extent to which heat is reflected and emitted is influenced by the SRI of the surface.

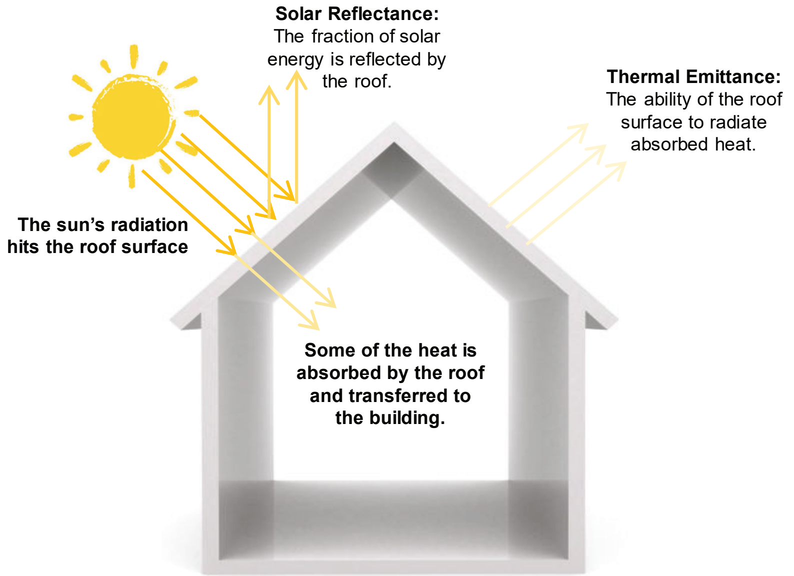
Throughout the day, solar radiation falling on the outer surface leads to an increase in the outside surface temperature through the absorption of the radiation. Moreover, the ambient air contributes to heating or cooling the surface through convection. Depending on both the outside and inside surface temperatures, heat will either flow from the outside to the inside or vice versa through conduction. The extent of heat flow depends on thermal transmittance and mass of the wall and roof assembly.

4.3.1.1 Solar Reflective Index (SRI)

The SRI is a calculated value that combines solar reflectance and thermal emittance into a single number. Both solar reflectance and thermal emittance are expressed on a scale of 0.0 to 1.0, where 1.0 represents 100% reflectance.

SRI serves as an indicator of heat a surface is likely to absorb when exposed to solar radiation. SRI values typically range from 0 to 100, although values outside this range are possible. High SRI roof and wall finishes are particularly beneficial in warm and hot climates. Figure 22 shows the Solar Reflectance and Emissivity.

FIGURE 22: SOLAR REFLECTANCE AND EMISSIVITY



4.3.1.2 Thermal conductivity

Thermal conductivity is a property that defines a material's ability to conduct heat. It serves as a measure of how easily heat can traverse through a substance. Specifically, it quantifies the rate at which heat is transferred through a unit area (1 m^2) and unit thickness (1 m) of material when there is a temperature difference of one degree (1 K or 1° C) across it. Figure 23 shows the thermal conductivity of a material. Thermal conductivity is typically represented by the symbol "k" and is measured in units of watts per meter-Kelvin (W/(m.K)). This property is denoted by the equation 4:

$$k = \frac{Qd}{A\Delta T} \qquad (4)$$

Where,

k = thermal conductivity (W/(m.K))

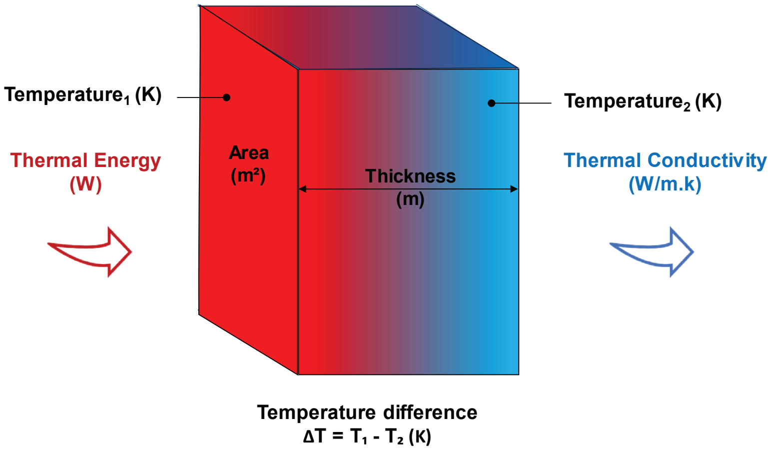
Q = amount of heat transferred (W)

d = distance between the two isothermal planes (m)

A = area of the surface (m^2)

ΔT = difference in temperature (K)

FIGURE 23: THERMAL CONDUCTIVITY OF A MATERIAL



Materials with high thermal conductivity effectively conduct more heat, while those with low thermal conductivity serve as better insulators by impeding the transfer of heat.

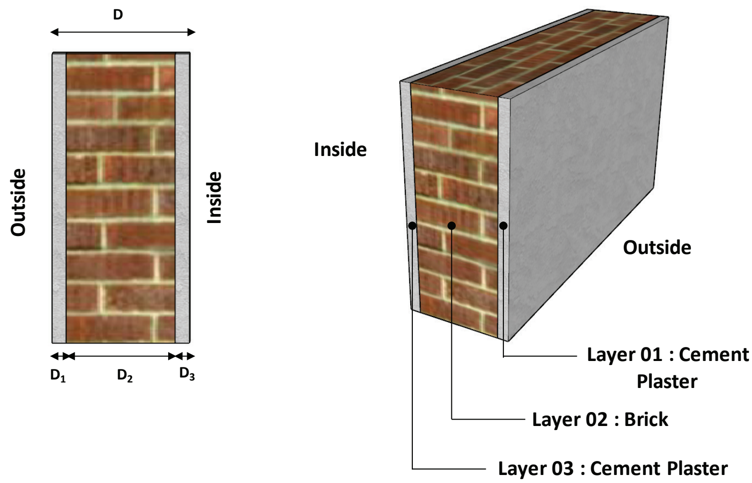
The majority of common walling masonry and roofing materials used today, including RCC roofs and solid burnt clay brick walls, typically exhibit thermal conductivities between 0.6 and 1.0 W/m·K. However, AAC blocks stand out as an exception with lower thermal conductivity. Thermal insulation products, on the other hand, boast thermal conductivities of less than 0.1 W/m·K. For a detailed list of thermal conductivities for common building materials and insulating materials, please refer to Annex 1.

Typically, materials with high thermal conductivities also possess high densities and high specific heat capacities. In the case of high-insulating materials, where thermal conductivity (k) is low, the volume of the material is often air, and in some instances, other gases or even a vacuum. Compared to solids and liquids, gases exhibit much lower molecular density for heat transfer and considerably lower k values. Consequently, all materials employed for thermal insulation are lightweight.

4.3.1.3 Thermal transmittance

Thermal conductivity is an intrinsic property that solely depends on the material. However, conductive heat transfer is influenced by both the material and the thickness used. Moreover, roof and wall assemblies are typically constructed with layers of different materials, each having varying thickness. For example, consider the conventional brick wall shown in Figure 24. The overall heat transfer through these wall assemblies is described by thermal transmittance, often represented as the U-value.

FIGURE 24: WALL SECTION OF CONVENTIONAL BRICK WALL



Thermal transmittance, or U-value (also known as Overall Heat Transfer Coefficient), is defined as the heat transmission per unit time through the unit area of a material or construction induced by a unit temperature difference between the environments on either side. This encompasses convection and radiation heat transfer at the surfaces, as well as conduction within the solid layers. The unit of the U-value is $W/m^2 \cdot K$, as denoted by Equation 5.

$$U = \frac{Q}{A\Delta T} \quad (5)$$

Where,

U = thermal transmittance ($W/m^2 \cdot K$)

Q = amount of heat transferred (W)

A = area of the surface (m^2)

ΔT = difference in temperature (K)

4.3.1.4 Thermal mass

Thermal mass is a property of a building's mass that allows it to store heat, offering "inertia" against temperature fluctuations. Scientifically, thermal mass is synonymous with heat capacity, representing the amount of heat required to produce a unit change in temperature for a given mass of material. This property is measured in Joules per Kelvin per kilogram. Heat stored in the building's mass is given by Equation 6.

$$\mathbf{Q = m \times c \times \Delta T} \qquad (6)$$

Where,

Q = Heat Stored (J)

m = Mass (kg)

c = specific heat of capacity (J.kg/K)

ΔT = temperature difference (K)

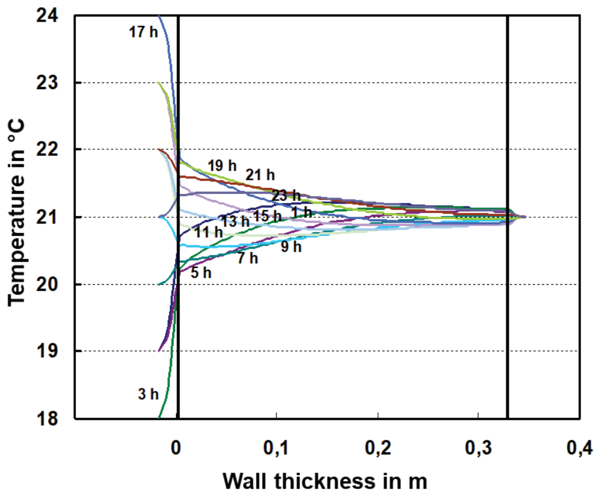
Thermal mass depends on both the mass and specific heat capacity of a material. Furthermore, for effective heat transfer, the material's conductivity is crucial, allowing heat to move from the surface into the material and back out. This is particularly important for heating or cooling places deeper within the material. The thermal variations in buildings follow a day-night rhythm. During the day, heat is transported into the wall, and during the night, it moves out.

The advantage of high thermal mass within a building's interior envelope is that the heat absorbed by the wall throughout the day doesn't directly impact the air within the space. This reduces the load on cooling and heating systems. To absorb heat effectively the next day, the room temperature must be lower than the wall temperature throughout the night. If the wall remains warm, the room must be even warmer the following day for the wall to retain its heat.

In Figure 25, the temperature profile of a 0.33 m thick concrete wall is illustrated, featuring a 24-hour temperature fluctuation between 18°C – 24°C on one side and a constant temperature of 21°C on the other side. Despite the concrete wall's excellent conductivity, it is notable that the temperature variation and, consequently, the stored heat become significantly smaller with a wall thickness exceeding 0.10 m.

The utilization of materials with high thermal mass proves most advantageous when there is a substantial daily temperature difference, characterized by significant variations between day and night temperatures. In summer, where outdoor temperatures vary greatly from day to night, thermal mass can absorb the sun's heat during the day. The room can then be cooled at night, for example, through night ventilation by keeping windows open. Conversely, in winter, the room can harness more solar heat through the windows during the day without overheating. The retained heat in the thermal mass then warms the room at night.

FIGURE 25: TEMPERATURE COURSE IN A 0.33 M CONCRETE WALL WITH 24 H TEMPERATURE VARIATION



How to Calculate the U-Value of a Wall/Roof Assembly

Step 1: Calculate the thermal resistance of each uniform material layer that constitutes the building component using Equation 7:

$$R = \frac{t}{k} \qquad (7)$$

Where,

R_i is the thermal resistance of the material, $m^2.K/W$

t_i is the thickness of material, m

k_i is the thermal conductivity of the material, W/m.K

Step 2: Find the total thermal resistance, R_T, using Equation 8:

$$R_T = R_{si} + R_{se} + R_1 + R_2 + R_3 + ...R_n \qquad (8)$$

Where,

R_T is the total thermal resistance, $m^2.K/W$

R_{si} is the interior surface film (convection and radiation) thermal resistance, $m^2.K/W$

R_{se} is the exterior surface film (convection and radiation) thermal resistance, $m^2.K/W$

R_1 is the thermal resistance of material 1, $m^2.K/W$

R_2 is the thermal resistance of material 2, $m^2.K/W$

R_3 is the thermal resistance of material 3, $m^2.K/W$

Values of Interior and Exterior Surface Film Thermal Resistance as per Climate Zone are given in Table 7.

TABLE 7: VALUES OF INTERIOR AND EXTERIOR SURFACE FILM THERMAL RESISTANCE AS PER CLIMATE ZONE (FOR WALL AND ROOF)

	Wall	Roof	
	All Climatic Zones	Warm-Temperate and Temperate Climate	Cool Temperate and Cold Climate
R_{si}	0.13	0.17	0.10
R_{se}	0.04	0.04	0.04

The thermal conductivity of commonly used building materials is provided in Annex 1, which can be utilized to calculate the thermal resistance (R-value).

Step 3: Calculate the thermal transmittance (or overall heat transfer coefficient, U-value) of a wall or roof assembly as given by Equation 9:

$$U = \frac{1}{R} \quad (9)$$

Where,

U is the overall heat transfer coefficient, $W/m^2.K$

R_T is the total thermal resistance, $m^2.K/W$

Thermal bridging

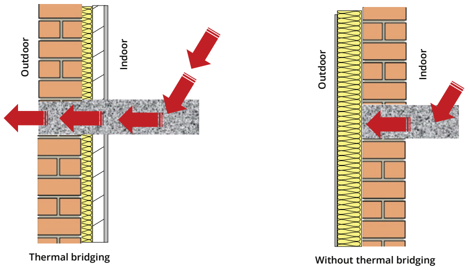
A thermal bridge refers to an area in a building construction with significantly higher heat transfer compared to the surrounding materials. When thermal bridging occurs in an insulated or low U-value building envelope, it results in undesirable heat gains or losses.

Thermal bridges can manifest at various locations within a building envelope, frequently occurring at junctions between two or more building elements, including:

- Floor-to-wall or balcony-to-wall junctions
- Roof/ceiling-to-wall junctions
- Window-to-wall junctions
- Wall-to-wall junctions
- Concrete or steel members, such as columns and beams in an external masonry wall
- Windows and doors, particularly frame components

External insulation offers more advantages than internal insulation in reducing thermal bridges. Additionally, strategic placement of insulation in and around junction details proves effective in minimizing thermal bridging. Example of thermal bridging is shown in Figure 26.

FIGURE 26: EXAMPLE OF THERMAL BRIDGING



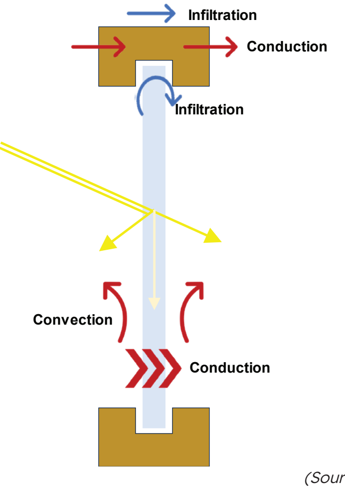
4.3.2 Through fenestration (Non-opaque components)

In a building, fenestration comprises both opaque and solid elements (such as wood, aluminium, etc.) and non-opaque or transparent elements (i.e., glass). Between the two, a significant amount of heat transfer occurs through the glass. The crucial thermal properties of fenestration include:

- Solar Heat Gain Coefficient or SHGC (fraction of solar radiation radiated inside through the glass).
- Thermal conductivity and transmittance of frames and glass (ability to conduct heat).

In addition to conduction, heat transfer also occurs through infiltration, i.e., unintentional air entering a space through the cracks and gaps in the fenestration elements. This is part of the air exchange process. Figure 27 shows the modes of heat transfer through the Fenestration.

FIGURE 27: MODES OF HEAT TRANSFER THROUGH THE FENESTRATION



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4.3.2.1 Solar Heat Gain Coefficient (SHGC)

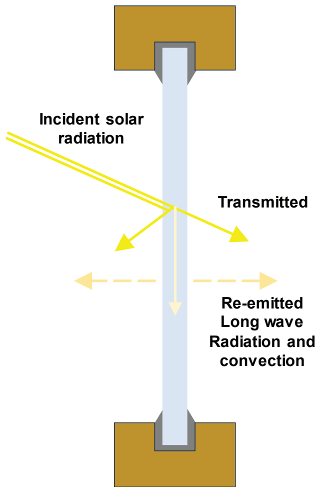
When solar radiation strikes the glass component of fenestration, some of the radiation is directly transmitted inside, while another portion is absorbed and re-emitted as long-wave radiation and convection. Additionally, some of the radiation is reflected (refer to Figure 28). The re-emitted radiation into the indoor space is referred to as secondary heat gain. The SHGC represents the fraction of solar radiation admitted through a glass — either transmitted directly and/or absorbed — and subsequently released as heat inside a home. It is calculated using the following Equation 10:

$$SHGC_{unshaded} = \frac{\text{Transmission} + \text{Secondary heat gain}}{\text{Incident solar radiation}} \qquad (10)$$

The SHGC is measured on a scale from 0 to 1, with a lower value indicating less solar heat gain. Conversely, a higher SHGC implies that a window or glazing system allows more solar radiation to pass through, resulting in increased heat gain inside the building.

Typically, 5mm – 6mm clear glass has an SHGC of 0.8 – 0.85. Glass with even lower SHGC values is also available. Another effective method to reduce SHGC is by implementing external shading for windows.

FIGURE 28: SOLAR HEAT GAIN



(Source: Reproduced image from Indo-Swiss BEEP)

External shading devices influence the SHGC of fenestration by affecting the incident solar radiation. The impact of the shading device on the un-shaded SHGC leads to the concept of SHGC equivalent. The calculation of the SHGC equivalent is detailed in Annex 2.

Shading Coefficient (SC)

The Shading Coefficient is a measure of how much heat is transferred through a glazing system. It typically falls within the range of 0 to 1 and has no units. As the shading coefficient decreases, less heat is transferred through the system.

SC is the ratio of solar radiation at a given wavelength and angle of incidence passing through a glass unit to the radiation that would pass through a reference window of frameless 3 mm Clear Float Glass.

The following Equation 11 is used to convert between SC and SHGC:

$$SC = \frac{SHGC}{0.86} \qquad (11)$$

SC = Shading Coefficient

SHGC = Solar heat gain coefficient

For example, if SHGC of a glass is given as 0.5, then SC is 0.5/0.86 = 0.58

SHGC is more commonly used as the standard property for assessing window solar gains in the US and Asia.

4.3.2.2 U-Value

In addition to heat transfer through direct solar radiation, fenestration elements also contribute to heat transfer through radiation, conduction, and convection.

Heat is also transferred through conduction in both the glass and the frame. The U-value of the glass and frame represents this conductivity, with lower U-values indicating lower heat transfer. Table 8 illustrates the U-values of various glass types. Among common frame materials, timber and UPVC generally have lower U-values compared to aluminium frames.

TABLE 8: U_g (U VALUE OF GLASS) FOR DIFFERENT GLASS TYPES

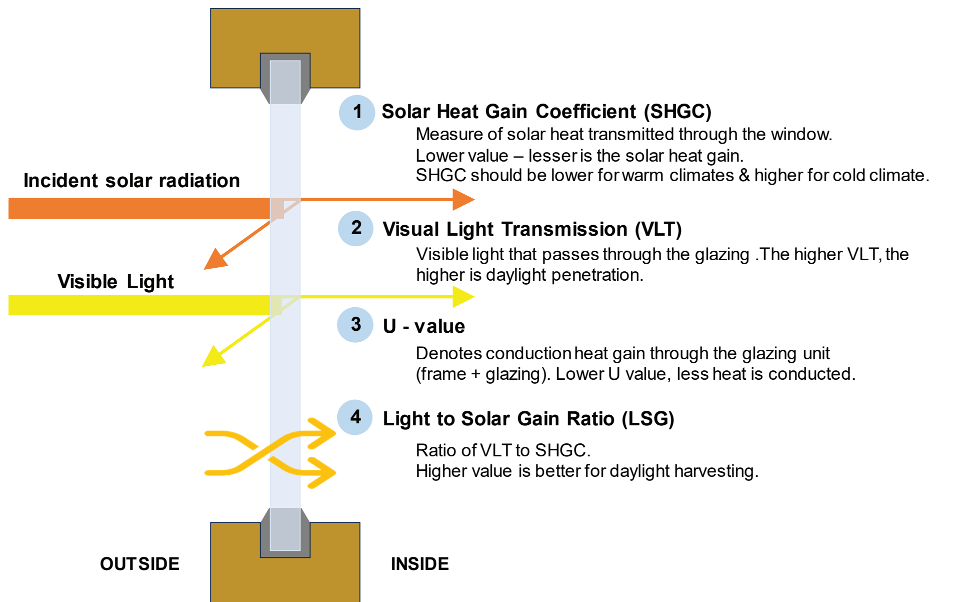
Glass type	Thickness of glass (mm)	U_g (W/m². K)
Single clear	6	5.8
Single Clear (with coating) Saint Gobain India	6	3.6 – 5.6
DGU (air gap) Saint Gobain India	6 (Glass)-12 (Air gap)-6 (Glass)	1.5 – 2.8
DGU (air gap) (assembled in Nepal)	6 (Glass)-12 (Air gap)-6 (Glass)	2.4 – 2.8
DGU (Argon gap, low e coating) (assembled in Europe)	4 Glass – 14 (Argon gap) – 4 Glass	1.3

Visible Light Transmittance (VLT) of glass

One of the primary functions of a window is to facilitate daylight inside a space. The property of glass that indicates the amount of visible light entering through the glass into the space is known as Visible Light Transmission (VLT). VLT is expressed as a number ranging from 0 to 1. The higher the VLT, the greater is the amount of light passing through the glass, and vice versa.

Figure 29 shows Image Explaining Solar Heat Gain Coefficient (SHGC), Visual Light Transmission (VLT), Thermal Transmittance (U-Value), and Light to Solar Gain Ratio for a Window (LSG).

FIGURE 29: IMAGE EXPLAINING SOLAR HEAT GAIN COEFFICIENT (SHGC), VISUAL LIGHT TRANSMISSION (VLT), THERMAL TRANSMITTANCE (U-VALUE), AND LIGHT TO SOLAR GAIN RATIO FOR A WINDOW (LSG)



(Source: Reproduced image from www.nzeb.in)

SUMMARY

- Heat gains or "heat sources" for a building
  - External heat: Outdoor heat that is transferred through the building envelope.
  - Internal heat: Generated by occupants' activity as metabolic heat, electrical devices, or thermal emission from artificial lighting.
- Heat transfer in a building occurs through conduction, convection, and radiation.
- The following properties impact heat transfer for opaque building envelope components, i.e., walls and roof:
  - Solar Reflective Index (SRI)
  - Thermal conductivity and thermal transmittance (U-value)
  - Thermal mass
- The following properties impact heat transfer for non-opaque building envelope components, i.e., glazed windows, doors etc.
  - Solar heat gain coefficient (SHGC)
  - Thermal transmittance (U-value)

5

PASSIVE STRATEGIES FOR COMFORT AND ENERGY EFFICIENCY

What's in this section?

Passive Strategies for Comfort and Energy Efficiency

Passive design strategies refer to design approaches that focus on utilizing the natural environment to provide comfort both thermal and visual in a building, unlike active design strategies that rely on mechanical systems and processes. They take advantage of the climate, site conditions, materials, and design elements to provide comfort.

One way of describing passive strategies is that they help in “load avoidance”. Passive strategies in warm and hot climates help in cooling load avoidance. In cold places, they help in heating load avoidance. Generally, in climates that are “cooling dominated”, passive strategies should:

- Reduce solar radiation falling on the building envelope.
- Reduce external heat gains through the building envelope.
- Remove excess heat that has built-up inside through ventilation.

In “heating dominated” climates, passive strategies should:

- Optimize solar access inside the building during the day.
- Reduce heat loss from inside to outside through the building envelope.
- Prevent cold draughts in the building.

In moderate climates, cooling strategies should be used in summer and heating strategies in winter. Thermal mass is always reducing the indoor air variation between day and night.

5.1 Building orientation, massing, and spatial configuration

In the context of this manual,

- Orientation refers to the direction that the larger walls and glazed windows face
- Building massing refers to the compactness of a building,
- Spatial configuration is how buildings are arranged about each other defining built and open spaces.

Building orientation determines the amount of solar radiation that the exposed surfaces receive. In all four climatic zones in Nepal:

- The roof receives the greatest intensity.
- Any exposed wall or window facing south receives the highest intensity in winter (when the sun is low and is positioned largely in the south) but it receives very little in summer (as the sun is high when shining from the south).
- East and west facing walls receive large intensities in summer and less intensities in winter compared to south facing walls.
- North facing walls receive the least intensity in both summer and winter.

Table 9 shows the favourable orientation for energy efficiency for the different climate zones.

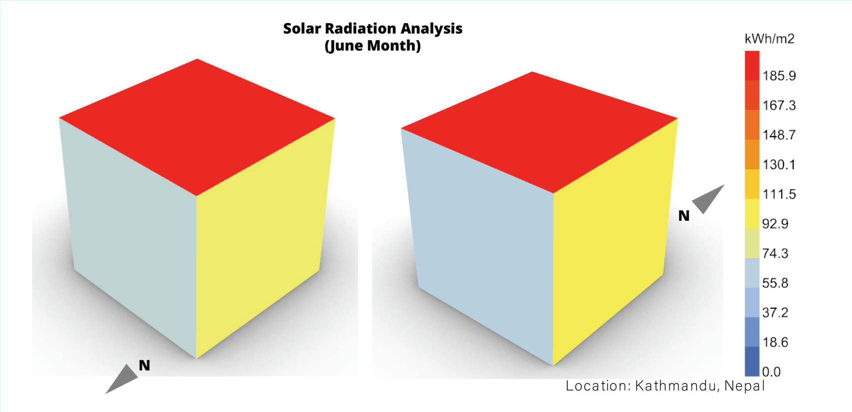
TABLE 9: FAVOURABLE ORIENTATION FOR ENERGY EFFICIENCY FOR THE DIFFERENT CLIMATE ZONES

Climate zone	Favourable Orientation
Warm-temperate	Longer exposed walls and major windows face north and south
Temperate	Longer exposed walls face north and south. Habitable spaces and large windows facing south
Cool-temperate	
Cold	

Solar Radiation and Orientation

Figure 30 shows the incident solar radiation on the roof and walls of a cuboidal building in the temperate climate in June.

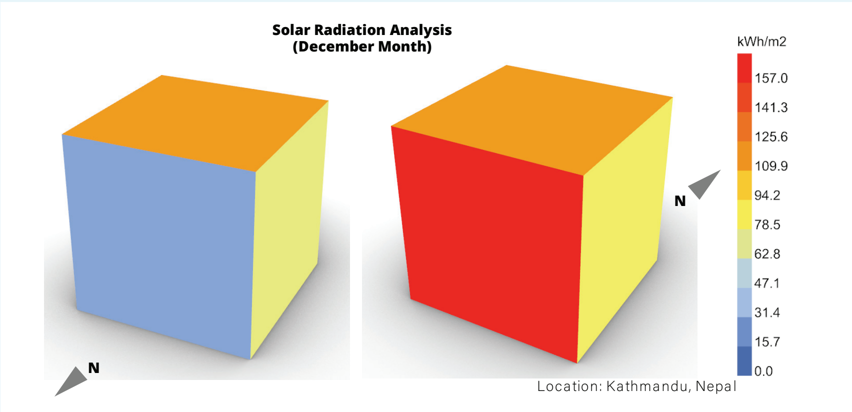
FIGURE 30: INCIDENT SOLAR RADIATION ON ROOF AND WALLS (JUNE)



The roof receives the maximum amount of radiation. The west and east façades receive high amounts of solar radiation due to the low-altitude afternoon and morning sun, respectively. In contrast, the north façade receives the least amount of radiation. Similarly, the south façade also receives a lower amount of solar radiation due to the higher altitude of the sun in the south during summer.

Figure 31 illustrates the incident solar radiation on the roof and walls of a cuboidal building in a temperate climate during January.

FIGURE 31: INCIDENT SOLAR RADIATION ON ROOF AND WALLS (JANUARY)



The highest radiation is received by the south façade and the roof, followed by the west and east façades. The south façade receives high solar radiation, particularly due to the low altitude of the sun in winter. In contrast, the north façade receives the least amount of radiation.

Building massing is a crucial factor influencing heat loss and gain, often measured by the surface area to volume (S/V) ratio. A greater surface area results in more heat gain or loss. Therefore, smaller S/V ratios imply minimal heat gain and loss. However, this may not always ensure comfort in all climates or for all types of buildings. For instance, in warm climates where natural ventilation is essential and heating demand is low, a small S/V may not be the optimal choice. Similarly, a building prioritizing daylight may not be designed with a small S/V.

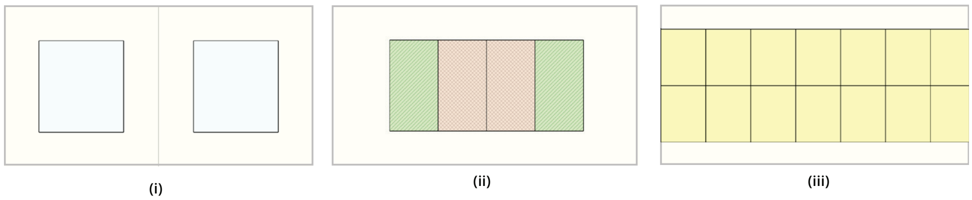
In the cold climate zone of Nepal, a small S/V or a compact building design proves beneficial. However, in the remaining climate zones, where natural ventilation is essential to prevent overheating and remove heat during the summer, a compact building may not effectively utilize natural ventilation as a strategy.

The **spatial configuration of a building** plays a crucial role in determining the amount of solar radiation it receives and its potential for utilizing natural ventilation. Broadly, building configurations may fall into one of the following categories (refer to Figure 32):

- Detached buildings: These are exposed on all sides.
- Three-side exposed buildings (e.g., buildings at the end of a row).
- Two-side exposed buildings, usually the front and back (e.g., buildings in the middle of a row).
- Buildings with only one side exposed.

The greater the number of exposed walls, the higher will be the potential for heat gains or losses. Simultaneously, the ventilation potential will also be greater.

FIGURE 32: DIFFERENT BUILDING SPATIAL CONFIGURATIONS



Detached Building (All side exposed) | Three side exposed | Two side exposed | One Side exposed

Orientation, massing, and spatial configuration are not the only passive design aspects that determine the heating and cooling loads of a building. These factors, along with the properties of the building envelope, collectively influence the amount of energy the building will consume for heating and cooling.

5.2 Building envelope

The building envelope serves as the interface between the indoor spaces of the building and the outdoor environment. It essentially comprises two components: the opaque component (roof, external walls, and slab-on-grade) and the non-opaque or fenestration component (external glazed windows, doors, ventilators, etc.).

Regardless of the spatial configuration or exposure of the building (i.e., whether it's a detached building, two-side exposed building, etc.), the properties of the building envelope components play a crucial role in regulating interior temperatures and influencing the energy consumption required to maintain thermal comfort.

Sections 5.3 to 5.6 describe the impact of different building envelope properties on the heating and cooling loads of a simple "detached" building in the four climate zones of Nepal. This building model was simulated to assess the impact of applicable passive strategies compared to the baseline construction[3] of each respective climate zone. The simulation of the building model included the following inputs:

- Detached building, rectangular with longer facades facing north and south.
- 3-4 storey building (all except cold climate). Single-storey building (cold climate).
- Cooling set point temperature (°C): 24°C (for all climates).
- Heating set point temperature (°C): 22°C (for all climates).
- No internal heat gains were considered in the model. It's important to note that in real-life scenarios, varying amounts of internal heat gains will be generated based on the use and occupancy of the building.

The simulations were conducted with a strict expectation of comfort (cooling set point 24°C, heating set point 22°C) based on the assumed user preferences, and consequently, the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) comfort model were considered. This decision was made to optimize simulation time to present in this manual. It's important to note that using the adaptive comfort model would yield similar recommendations for passive strategies and a comparable trend in annual and heating load reduction. The main difference would be in the absolute values of the loads, with the adaptive comfort model resulting in lower absolute heat load values.

3 The baseline construction in each zone has been created by using the inputs from a baseline study done in 2023 by the BEEN project in the respective climate zone. The construction used is for residential buildings.

5.3 Building envelope for warm temperate zone in Nepal

5.3.1 Climate characteristics

The **warm temperate climate zone** in Nepal is characterized by a monsoon-influenced humid subtropical climate with a dry winter (Dec – Feb). There is a short dry summer period in April – May, with the remaining year being warm and humid. This climate is considered "cooling-dominated," emphasizing the importance of reducing external heat gains and removing built-up heat inside the space.

For this example, the climate file of Siddharth Nagar was used to represent this climate zone.

5.3.2 Baseline construction

The typical construction in the warm temperate climate zone consists of the constructions as shown in Table 10:

TABLE 10: BASELINE CONSTRUCTION (WARM TEMPERATE ZONE)

Exterior Wall Assembly	10mm internal plaster + Solid fired brick wall (230mm thk) + 10 mm external plaster (U-value: 2.07 W/m².K)
Roof Assembly	10mm internal plaster + RCC Slab (125mmthk) + 50mm Screed +Tile, (U-value: 3.564 W/m².K)
Window Assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 W/m².K, VLT: 88%) with wooden frame
Window-to-Wall Area Ratio (WWR)	25%
Window Openability	Casement windows
Shading	Continuous overhang of depth 600 mm

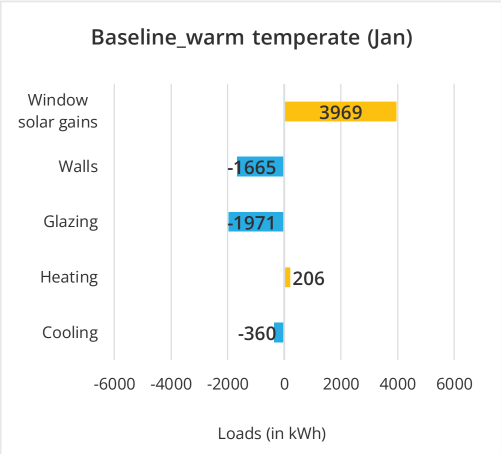
In the warm temperate climate zone, multi-storey buildings are common. Therefore, the building model was simulated for both an intermediate floor and a top floor to capture the varying conditions experienced at different levels.

5.3.2.1 Heat Balance of the baseline construction

Figure 33 illustrates the heat gains and losses from the envelope for an intermediate floor during a typical summer month (June) and winter month (January) in the warm temperate climate zone. In this climate, the summer cooling load is more critical. Heat gains on an intermediate floor primarily occur through solar gains from glazed windows, conduction through the walls, and conduction through the glass.

In January, there is a minimal heating requirement, which can be adequately compensated by the internal gains from occupants and appliances. Additionally, a small cooling requirement is observed, which can be effectively addressed through natural ventilation by opening the windows.

FIGURE 33: HEAT GAINS & LOSSES THROUGH BASELINE BUILDING ENVELOPE IN WARM TEMPERATE CLIMATE (INTERMEDIATE FLOOR)



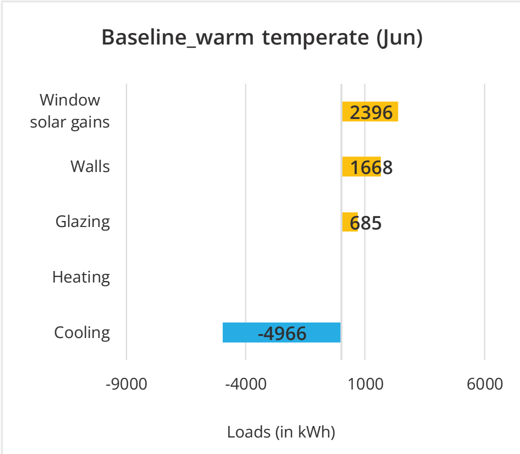
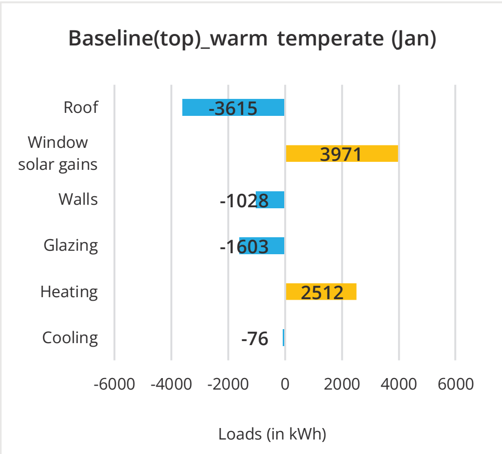
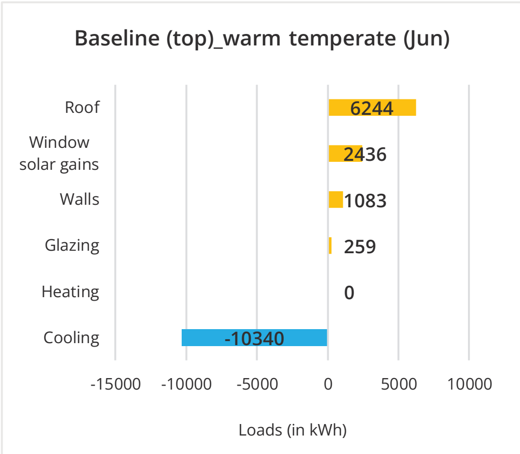


Figure 34 demonstrates that on the top floor, the roof significantly influences heat gains during the summer and heat losses during the winter.

FIGURE 34: HEAT GAINS & LOSSES THROUGH BASELINE BUILDING ENVELOPE IN WARM TEMPERATE CLIMATE (TOP FLOOR)





5.3.3 Impact of passive strategies

To mitigate heat gains through the windows and walls, the following strategies were analyzed:

- Implementing better shading for glazed windows on the south, west, and east sides to reduce solar gains in the summer. This could involve deeper fixed shading or external movable shading (EMSyS). The latter provides superior shading in the summer compared to fixed shading but can be moved to allow solar gains in the winter when needed.

- Utilizing a roof assembly with a lower U-value to decrease conduction heat gains and losses through the roof.
- Leveraging the full potential of natural ventilation during the cooling period by opening windows whenever the outside temperature is cool.
- Employing a wall assembly with a lower U-value to minimize heat gains and losses through the walls.
- Using glass with a lower U-value to reduce conduction heat gains and losses through the glass.

An example of external movable shading from India is shown in Figure 35 and traditional examples of good solar shading in Nepal is shown in Figure 36.

FIGURE 35: EXAMPLES OF EXTERNAL MOVABLE SHADING (EMSYS)

FIGURE 36: TRADITIONAL EXAMPLES OF GOOD SOLAR SHADING IN NEPAL

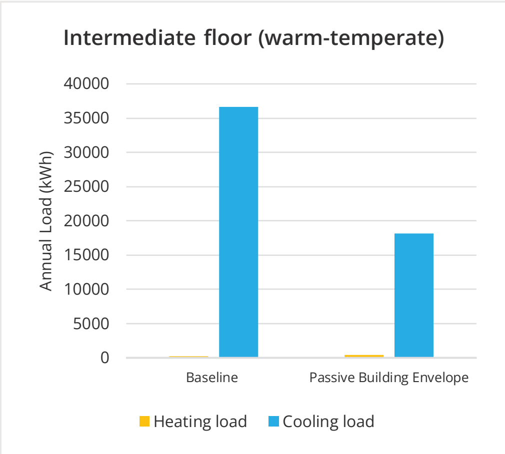
The above passive building envelope strategies can be applied in different ways in the building. Table 11 shows the passive building envelope options taken as an example for analysis in this manual.

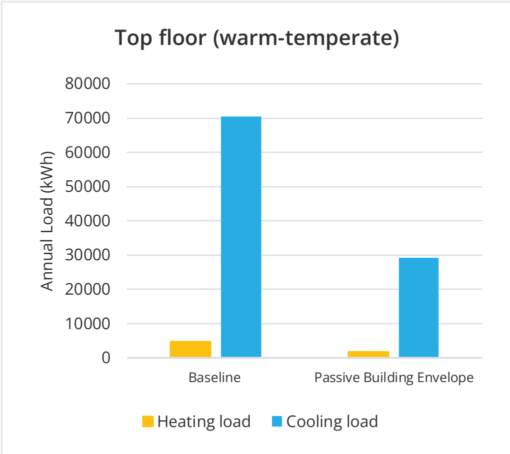
TABLE 11: BASELINE CONSTRUCTION AND PASSIVE BUILDING ENVELOPE STRATEGIES FOR WARM-TEMPERATE CLIMATE

	Baseline	Passive Building Envelope
Exterior Wall Assembly	10mm internal plaster + Solid fired brick wall (230mm thk) + 10 mm external plaster (U-value: 2.07 W/m².K)	10mm internal plaster + Hollow brick wall (240mm thk) + 10 mm external plaster (U-value: 1.6 W/m².K)
Roof Assembly	10mm internal plaster + RCC Slab (125 mm thk) + 50mm Screed +Tile, (U-value: 3.564 W/m².K)	10mm internal plaster + RCC Slab (125 mm thk) + 25mm XPS insulation + 50mm Screed +Tile, (U-value: 0.8 W/m².K)
Window Assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 W/m².K, VLT: 88%) with wooden frame	Double glazed Unit (SHGC: 0.54, U-value: 2.8 W/m².K, VLT: 58%) with wooden frame
Window-to-Wall Area Ratio (WWR)	25%, uniformly distributed on all directions	25% Overall. Higher distribution on north façade, followed by south façade.
Window Openability	Casement windows, but windows kept closed	Same as baseline
Shading	Continuous overhang of depth 600 mm	Continuous overhang of 600mm + EMSyS on south, west and east facing windows

Figure 37 shows a comparison of the annual cooling and heating loads of the baseline construction and the passive building envelope strategies used.

FIGURE 37: ANNUAL HEATING AND COOLING LOADS FOR AN INTERMEDIATE FLOOR AND TOP FLOOR, WITH BASELINE CONSTRUCTION AND PASSIVE STRATEGIES (WARM TEMPERATE CLIMATE)





In this cooling-dominated climate, the implementation of passive building envelope strategies has resulted in a notable reduction of more than 50% in the cooling load for both the intermediate and top floors. Additionally, the small annual heating load of the top floor has been reduced by almost 60%.

5.4 Building envelope for temperate zone in Nepal

5.4.1 Climate characteristics

The **temperate climate zone** in Nepal, similar to the warm temperate climate, is characterized as a monsoon-influenced humid subtropical climate. However, both summer and winter temperatures are lower than those of the warm temperate climate zone. This climate experiences a slightly longer winter period (mid-Nov to mid-Mar) with January and December being the more intense cold months. There is a short dry summer period in April – May, with the remaining year being warm and humid. The climatic conditions could be termed comfortable for most of the year, with some cold stress in winter and heat stress in summer. Buildings in this climate will require both cooling and heating to varying extents depending on the building design. There is also good potential for thermal comfort with natural ventilation in this climate.

The climate file of Kathmandu was used as an example of this climate.

5.4.2 Baseline construction

The typical construction in the temperate climate zone consists of the constructions as shown in Table 12:

TABLE 12: BASELINE CONSTRUCTION (TEMPERATE ZONE)

Exterior Wall Assembly	10mm internal plaster + Solid fired brick wall (230mm thk) + 10 mm external plaster (U-value: 2.07 W/m².K)
Roof Assembly	10mm internal plaster + RCC Slab (125mmthk) + 50mm Screed +Tile, (U-value: 3.564 W/m².K)
Window Assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 W/m².K, VLT: 88%) with wooden frame
Window-to-Wall Area Ratio (WWR)	30%
Window Openability	Casement windows
Shading	Continuous overhang of depth 600 mm

Multi-storey buildings are also common in this climate; therefore, the building model was simulated for both an intermediate floor and a top floor.

5.4.2.1 Heat balance of the baseline construction

Figure 38 illustrates the heat gains and losses from the envelope for an intermediate floor in a typical summer month (June) and winter month (Jan). Meanwhile, Figure 39 presents the same information for the top floor. Notably, heat loss in winter primarily occurs through the roof (specifically for the top floor), conduction through the walls, and conduction through the glass.

In summer, heat gain predominantly occurs through transmission from glazed windows and conduction through the roof (specifically for the top floor).

FIGURE 38: HEAT GAINS & LOSSES THROUGH BASELINE BUILDING ENVELOPE IN TEMPERATE CLIMATE (INTERMEDIATE FLOOR)

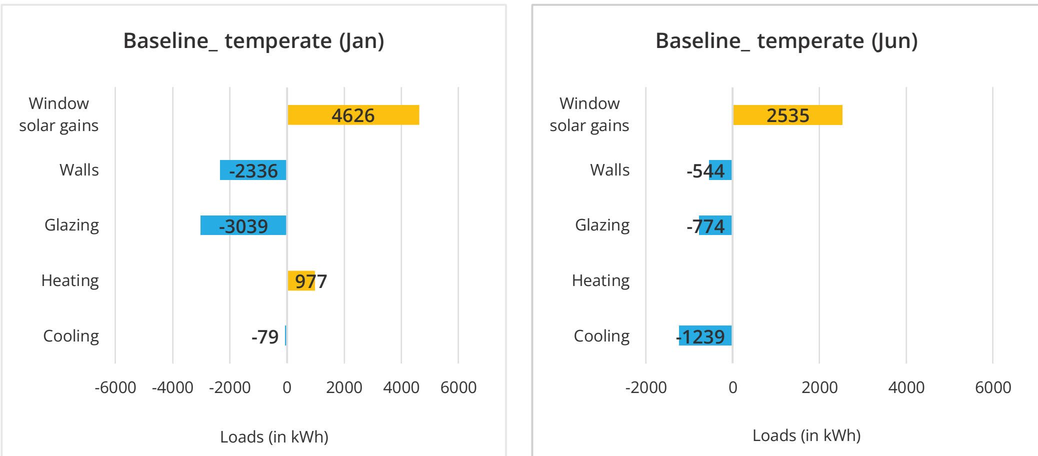
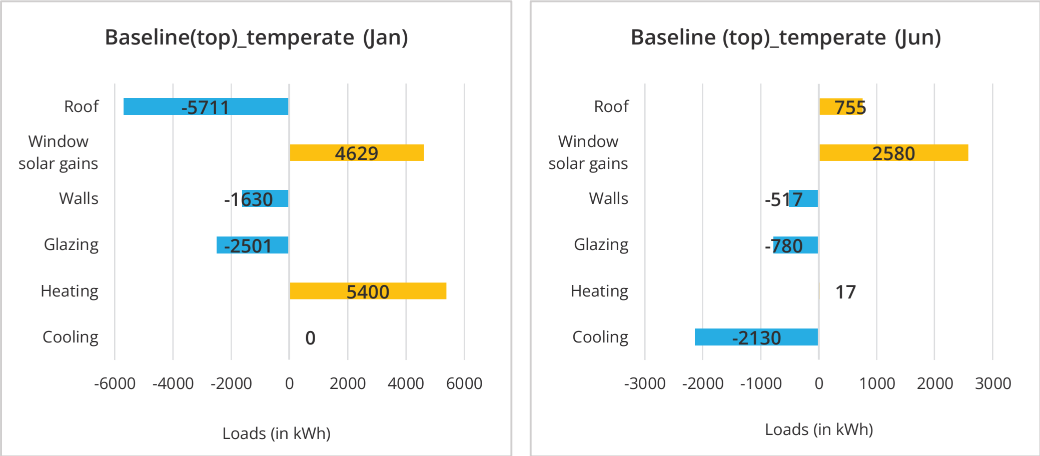


FIGURE 39: HEAT GAINS & LOSSES THROUGH BASELINE BUILDING ENVELOPE IN TEMPERATE CLIMATE (TOP FLOOR)



5.4.3 Impact of passive building envelope strategies

Taking the above considerations into account, the following strategies were analyzed:

- Using a roof assembly with a lower U-value to reduce conduction heat gains and losses through the roof.
- Implementing better shading for glazed windows on the south, west, and east sides to minimize solar gains through the windows in summer.
- Maximizing the potential of natural ventilation during the cooling period by opening windows when the outside temperature is cool.
- Utilizing a wall assembly with a lower U-value to reduce heat gains and losses through the walls.
- Choosing glass with a lower U-value to minimize conduction heat gains and losses through the glass.

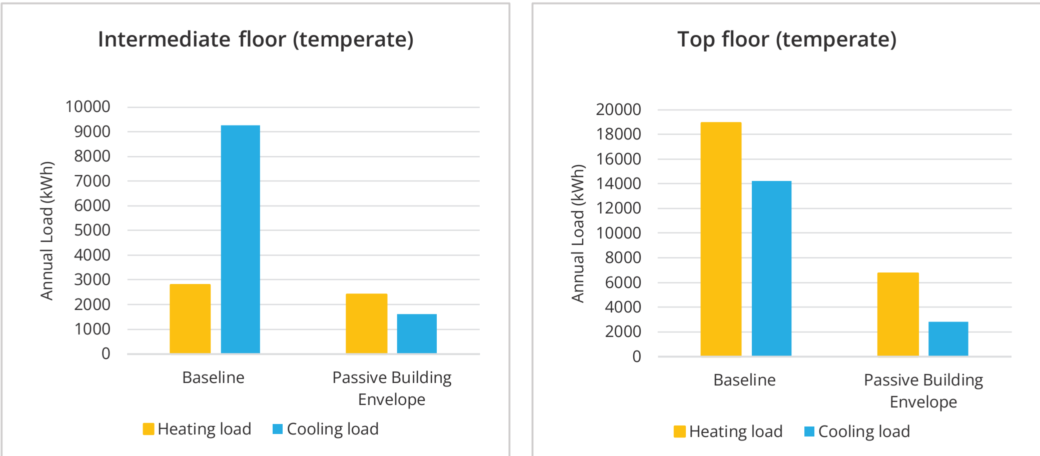
Table 13 shows the passive building envelope options taken as an example for analysis in this manual.

TABLE 13: BASELINE CONSTRUCTION AND PASSIVE BUILDING ENVELOPE STRATEGIES FOR TEMPERATE CLIMATE

	Baseline	Passive building envelope
Exterior Wall Assembly	10mm internal plaster + Solid fired brick wall (230mm thk) + 10 mm external plaster (U-value: 2.07 W/m².K)	10mm internal plaster + Hollow brick wall (240mm thk) + 10 mm external plaster (U-value: 1.6 W/m².K)
Roof Assembly	10mm internal plaster + RCC Slab (125 mmthk) + 50mm Screed +Tile, (U-value: 3.564 W/m².K)	10mm internal plaster + RCC Slab (125mmthk) + 25mm XPS insulation + 50mm Screed +Tile, (U-value: 0.8 W/m².K)
Window Assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 W/m².K, VLT: 88%) with wooden frame	Double glazed Unit (SHGC: 0.54, U-value: 2.8 W/m².K, VLT: 58%) with wooden frame
Window-to-Wall Area Ratio (WWR)	30%, uniformly distributed on all directions.	30% Overall. Higher distribution on south façade.
Window Openability	Casement windows, but windows kept closed	Casement windows, and windows are kept open when there is natural ventilation potential
Shading	Continuous overhang of depth 600 mm	Continuous overhang of 600mm + EMSyS on south, west and east facing windows

Figure 40 provides a comparison of the annual cooling and heating loads between the baseline construction and the passive building envelope strategy options employed.

FIGURE 40: ANNUAL HEATING AND COOLING LOADS FOR AN INTERMEDIATE FLOOR AND TOP FLOOR, WITH BASELINE CONSTRUCTION AND PASSIVE STRATEGIES (TEMPERATE CLIMATE)



The cooling load can dominate in this climate if natural ventilation is not utilized during the summer months. However, with the passive envelope features outlined in Table 14, there is an 80% decrease in the cooling load for both the intermediate and top floors. This significant reduction can be attributed to the effective implementation of shading, natural ventilation, and roof insulation.

The annual heating load reduction is almost 15% on the intermediate floor and 60% on the top floor. The impact of roof insulation in decreasing winter heat losses from the top floor is particularly noteworthy. To further minimize the heating load on the intermediate floor, one or more of the following strategies can be considered:

- Using a double-glazed unit (DGU) with a low U-value but a high Solar Heat Gain Coefficient (SHGC). The DGU mentioned in this manual has a U-value of 2.8 $W/m^2 \cdot K$ and SHGC of 0.54. While this glass is effective in reducing conductive heat transfer, it also diminishes desirable solar radiation gains in winter. Hence, a glass with a low U-value and high SHGC may offer better performance. However, it's essential to ensure adequate shading for all windows during the summer months.
- Reducing the wall U-value while doing this, it is crucial to providing good natural ventilation; otherwise, it might be counterproductive in the summer.

5.5 Building envelope for cool temperate zone in Nepal

5.5.1 Climate characteristics

The **cool temperate climate zone** in Nepal experiences a longer winter period, extending from November to March. However, the climatic conditions during the remaining months are generally comfortable. Buildings in this climate may require cooling in these months if heat gains during the summer are unchecked and natural ventilation is not utilized.

For this climate, the climate file of Gosaikunda rural municipality headquarters was created and used as an example.

5.5.2 Baseline construction

The typical construction in the **cool temperate climate zone** consists of the constructions as shown in Table 14:

TABLE 14: BASELINE CONSTRUCTION (COOL TEMPERATE ZONE)

Exterior wall Assembly	10mm internal plaster + Solid fired brick wall (230mm thk) + 10 mm external plaster (U-value: 2.07 $W/m^2.K$)
Roof Assembly	10mm internal plaster + RCC Slab (125mm thk) + 50mm Screed +Tile, (U-value: 3.564 $W/m^2.K$)
Window Assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 $W/m^2.K$, VLT: 88%) with wooden frame
Window-to-Wall Area Ratio (WWR)	25%
Window Openability	Casement windows.
Shading	Continuous overhang of depth 600 mm

Multi-storey buildings are common in this climate; therefore, the building model was simulated for both an intermediate floor and a top floor.

5.5.2.1 Heat balance of the baseline construction

Figure 41 illustrates the heat gains and losses from the envelope for an intermediate floor in a typical summer month (June) and winter month (Jan). Meanwhile, Figure 42 presents the same information for the top floor. Notably, heat loss in winter primarily occurs through the roof (specifically for the top floor), conduction through the walls, and conduction through the glass.

In summer, heat gain predominantly occurs through transmission from glazed windows and conduction through the roof (specifically for the top floor).

FIGURE 41: HEAT GAINS & LOSSES THROUGH BASELINE BUILDING ENVELOPE IN COOL TEMPERATE CLIMATE (INTERMEDIATE FLOOR)

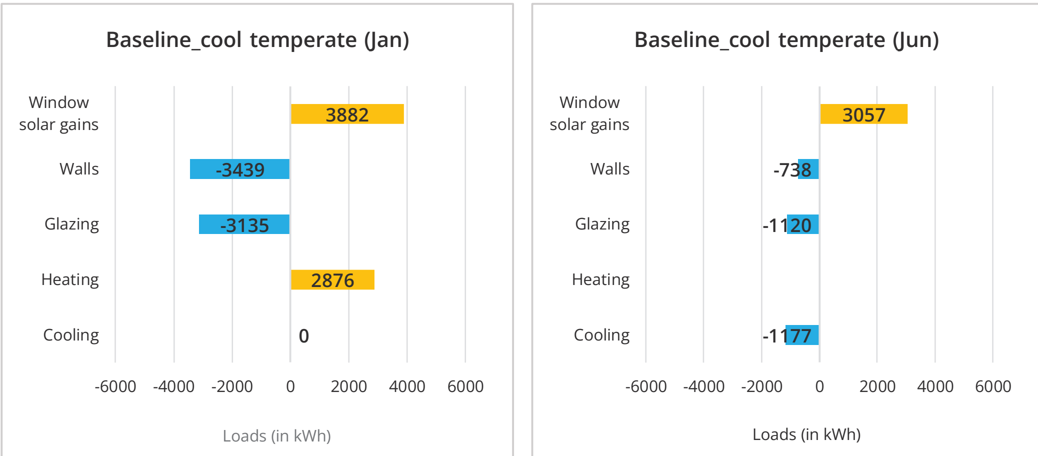
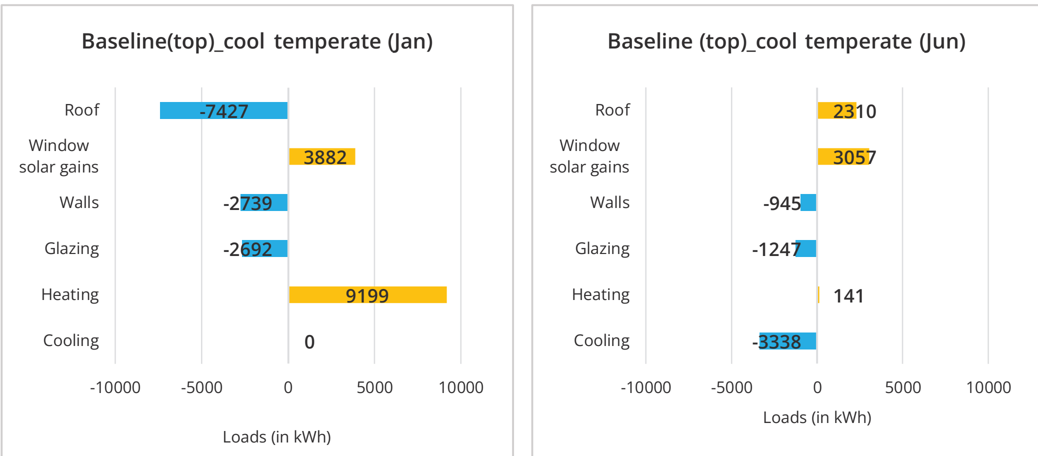


FIGURE 42: HEAT GAINS & LOSSES THROUGH BASELINE BUILDING ENVELOPE IN COOL TEMPERATE CLIMATE (TOP FLOOR)



5.5.3 Impact of passive strategies

The strategies mentioned in Section 5.4.3 can be applied here as well.

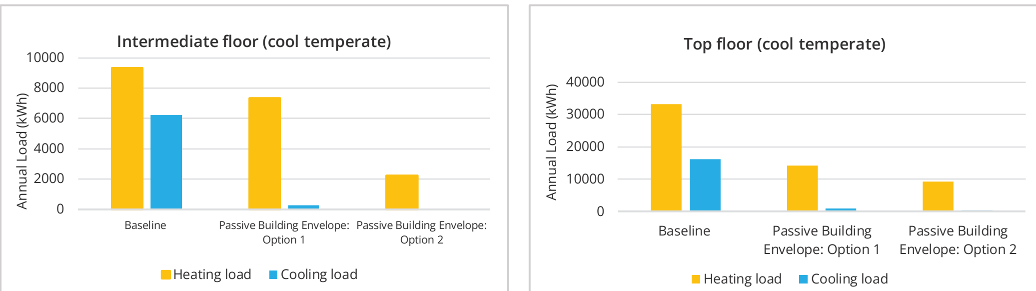
Table 15 presents the passive building envelope options used as examples for analysis in this manual. Two sets of building envelope strategies were analyzed.

TABLE 15: BASELINE CONSTRUCTION AND PASSIVE BUILDING ENVELOPE STRATEGIES FOR COOL-TEMPERATE CLIMATE

	Baseline	Passive building envelope: Option 1	Passive building envelope: Option 2
Exterior Wall Assembly	10mm internal plaster + Solid fired brick wall (230 mm thk) + 10 mm external plaster (U-value: 2.07 W/m².K)	10mm internal plaster + Hollow brick wall (240mm thk) + 10 mm external plaster (U-value: 1.6 W/m².K)	10mm internal plaster + Solid fired brick wall (230 mm thk) + 25 mm XPS + 10 mm external plaster (U-value: 0.8 W/m².K)
Roof Assembly	10mm internal plaster + RCC Slab (125mmthk) + 50mm Screed +Tile, (U-value: 3.564 W/m².K)	10mm internal plaster + RCC Slab (125mmthk) + 25mm XPS insulation + 50 mm Screed +Tile, (U-value: 0.8 W/m².K)	Same as option 1
Window Assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 W/m².K, VLT: 88%) with wooden frame	Double glazed Unit (SHGC: 0.54, U-value: 2.8 W/m².K, VLT: 58%) with wooden frame	Same as option 1
Window-to-Wall Area Ratio (WWR)	25%, uniformly distributed on all directions.	25% overall. Higher distribution on south façade	Same as option 1
Window Openability	Casement windows, but windows kept closed	Casement windows, and windows are kept open when there is natural ventilation potential	Same as option 1
Shading	Continuous overhang of depth 600 mm	Continuous overhang of 600mm + EMSyS on south, west and east facing windows	Same as option 1

Figure 43 shows a comparison of the annual cooling and heating loads between the baseline construction and the passive building envelope strategy options employed.

FIGURE 43: ANNUAL HEATING AND COOLING LOADS FOR AN INTERMEDIATE FLOOR AND TOP FLOOR, WITH BASELINE CONSTRUCTION AND PASSIVE STRATEGIES (COOL TEMPERATE CLIMATE)



Cooling loads can be nearly negated for both the intermediate and top floors, primarily attributed to the effectiveness of natural ventilation, shading, and roof insulation.

Regarding the heating load, Passive Building Envelope Option 1 results in a nearly 20% reduction on the intermediate floor and a 50% reduction on the top floor. With Option 2, the heating load can be reduced by more than 70%. It's crucial to ensure the full potential of natural ventilation is utilized in the summer months to prevent the building from overheating.

5.6 Building envelope for cold zone in Nepal

5.6.1 Climate characteristics

The **cold climate zone** in Nepal is characterized as a "heating-dominated" climate, experiencing winter from October to April. The remaining months are generally cool and comfortable, with slightly warm daytime temperatures from June to August due to intense solar radiation. The primary focus in this climate should be on reducing heat losses and optimizing solar gains during winter.

For this climate, the climate file of Jomsom was created and used as an example.

5.6.2 Baseline construction

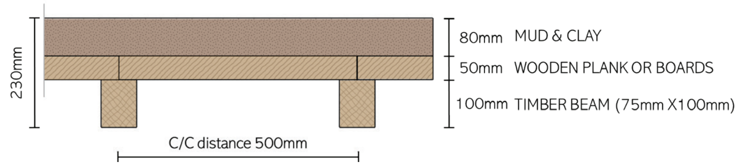
The typical construction in the **cold climate zone** consists of the constructions as given in Table 16:

TABLE 16: BASELINE CONSTRUCTION (COLD ZONE)

Exterior wall assembly	10mm internal plaster + Stone masonry(400mm thk) (U-value: 3.3 W/m².K)
Roof assembly	Mud over wooden planks (Figure 44) (U-value: 1.6 W/m².K)
Window assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 W/m².K, VLT: 88%) with wooden frame
Window-to-wall area ratio (WWR)	15%
Window openability	Casement windows.
Shading	Continuous overhang of depth 300mm

The baseline roof assembly in cold climates is shown in Figure 44.

FIGURE 44: BASELINE ROOF ASSEMBLY IN COLD CLIMATE



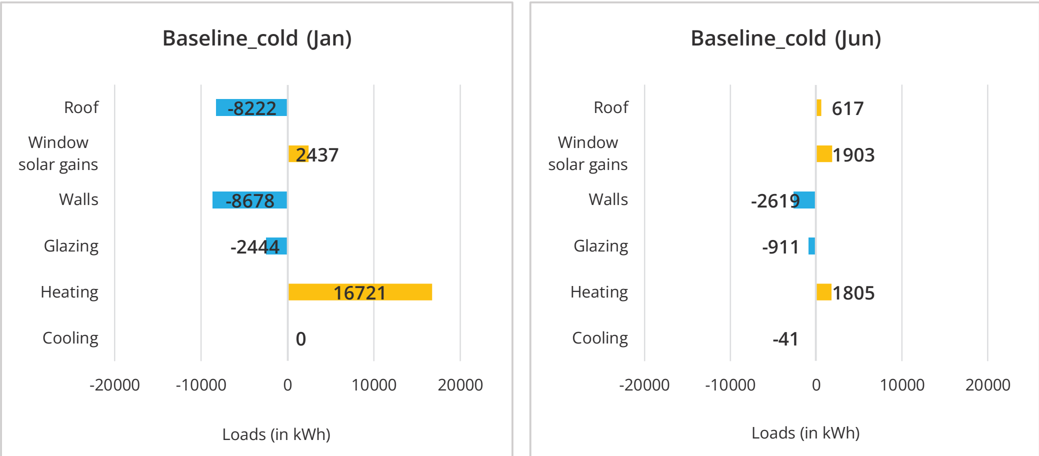
Single-storey buildings are common in this climate; therefore, the building model was simulated as a single floor.

5.6.2.1 Heat balance of the baseline construction

Figure 45 illustrates the heat gains and losses from the envelope in a typical winter month (Jan) and summer month (Jun). The cooling load in June is negligible and can be effectively managed with natural ventilation by opening the windows.

In this climate, the heating load is critical. Heat losses primarily occur through the roof and conduction through the walls. Conduction heat loss through the glass is less significant as the Window-to-Wall Ratio (WWR) in this climate is low (around 15%).

FIGURE 45: HEAT GAINS & LOSSES THROUGH BASELINE BUILDING ENVELOPE IN COLD CLIMATE



5.6.3 Impact of passive strategies

To mitigate heat losses, the following strategies were analyzed:

- Implementing a roof assembly with a lower U-value to reduce conduction heat loss through the roof.
- Choosing glass with a lower U-value to minimize conduction heat loss through the glass.
- Employing a wall assembly with a lower U-value to reduce heat loss in winter.

Table 17 shows the passive building envelope options taken as an example for analysis in this manual. Two sets of building envelope strategies were analysed.

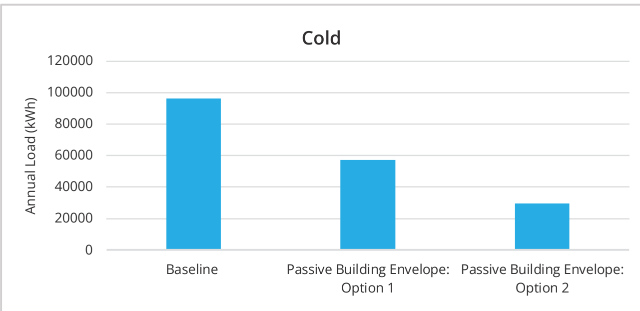
TABLE 17: BASELINE CONSTRUCTION AND PASSIVE BUILDING ENVELOPE STRATEGIES FOR COLD CLIMATE

	Baseline	Passive building envelope: Option 1	Passive building envelope: Option 2
Exterior Wall Assembly	10mm internal plaster + Stone masonry(400 mm thk) (U-value: 3.3 W/m².K)	10mm internal plaster + Hollow brick wall (240 mm thk) + 10 mm external plaster (U-value: 1.6 W/m².K)	10mm internal plaster + Stone masonry(400mm thk) + 40mm XPS + 10mm external plaster (U-value: 0.6 W/m².K)
Roof Assembly	Mud over wooden planks (Figure 44) (U-value: 1.6 W/m².K)	10mm internal plaster + RCC Slab (125mmthk) + 25mm XPS insulation + 50 mm Screed +Tile, (U-value: 0.8 W/m².K)	Same as option 1
Window Assembly	6mm clear glazing (SHGC: 0.82, U-value: 5.8 W/m².K, VLT: 88%) with wooden frame	Double glazed Unit (SHGC: 0.54, U-value: 2.8 W/m².K, VLT: 58%) with wooden frame	Triple glazed unit (SHGC: 0.6, U-value: 0.6 W/m².K, VLT: 69%)
Window-to-Wall Area Ratio (WWR)	15%, uniformly distributed on all directions	15% Overall. Higher distribution on south façade.	Same as option 1
Window Openability	Casement windows. Windows are kept closed	Same as baseline	Same as baseline
Shading	Continuous overhang of depth 300mm	Same as baseline	Same as baseline

Unlike in the other climate zones, the roof taken in the baseline construction here is not a simple 125 mm RCC slab (U-value 3.5 W/m2.K), but a more traditional roof made of mud and wood (U-value 1.6 W/m2.K). To reduce heat losses further, the roof value must be lower than this. An RCC slab with 25mm XPS insulation has a U-value of 0.8 W/m2.K. In no circumstance should an un-insulated RCC roof be used in the cold climate.

Figure 46 shows a comparison of the annual cooling and heating loads of the baseline construction in the two options of passive building envelope strategies.

FIGURE 46: ANNUAL HEATING AND COOLING LOADS WITH BASELINE CONSTRUCTION AND PASSIVE STRATEGIES (COLD CLIMATE)



Being a heating-dominated climate with negligible cooling load, Option 1 results in a 40% decrease in the annual heating load. Option 2, with a more insulated wall and a more stringent glass specification, can achieve a reduction of nearly 70% in the annual heating load.

SUMMARY

- Passive design strategies involve design approaches that leverage the natural environment to achieve comfort.
- Depending on the climate and desired thermal comfort, passive strategies aim to:
  - Reduce or optimize solar radiation falling on the building envelope.
  - Minimize heat gains or losses through the building envelope.
  - Enable cooling through natural ventilation and reduce infiltration losses through the building envelope.
- The orientation, massing, spatial configuration of a building, along with the properties of the building envelope, are the key passive design aspects that influence the building's energy consumption for heating and cooling.

6

NATURAL VENTILATION

What's in this section?

Natural Ventilation

Natural ventilation holds significant potential in reducing cooling loads in the warm temperate, temperate, and cool temperate climates in Nepal. This chapter covers the principles of improving ventilation. It's crucial to note that minimizing heat gains through other passive strategies. Natural ventilation can be used to have the most significant impact.

6.1 Ventilation and natural ventilation

Ventilation is the intentional introduction of outdoor air into a space, primarily employed in buildings to maintain indoor air quality. In hot climates, it can additionally enhance thermal comfort by extracting heat from the interior. Typically, around 10 ACH (Air Changes per Hour) is required for this purpose.

Ventilation contributes to improved thermal comfort through:

- Cooling indoor air by either replacing it with outdoor air or diluting it if outdoor temperatures are lower than indoor temperatures.
- Cooling the building structure or the thermal mass of the building.
- Providing a direct cooling effect on the human body through convection and evaporation.

Air Changes per Hour (ACH)

Air Changes per Hour (ACH) is a metric representing the number of times that the total air volume in a room or space is completely replaced within an hour. The higher the ACH, the greater is the ventilation as given by the Equation 12.

$$ACH = \frac{3.6\,Q}{vol} \qquad (12)$$

Where,

Q = Volumetric flow rate of air in litres per second (L/s)

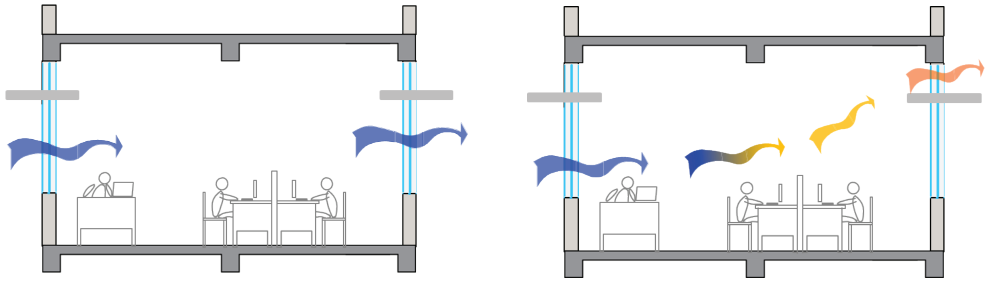
Vol = Space volume = L × W × H, in cubic metre

Natural ventilation, devoid of mechanical systems, can be categorized into wind-driven or buoyancy-driven modes.

- Wind-driven ventilation relies on wind pressure to propel air movement. Wind striking the windward facade generates positive pressure, creating a pressure difference that induces air movement. Similarly, as wind flows away from the leeward facade, a region of lower pressure is formed, further driving air movement.
- Stack or buoyancy-driven ventilation involves the natural movement of air through a building due to differences in vertical pressure caused by temperature variations in the air. Warm air escapes from openings at a considerable height on the building envelope, drawing in colder, denser outside air through lower openings in the building.

Figure 47 shows the Wind-Driven and Buoyancy-Driven Natural Ventilation.

FIGURE 47: WIND-DRIVEN (LEFT) AND BUOYANCY-DRIVEN (RIGHT) NATURAL VENTILATION



(Source: Reproduced image from Indo-Swiss BEEP)

For most buildings, enhancing wind-driven natural ventilation or employing a fan to accelerate air movement is often more feasible. The stack effect becomes significant only when there is a considerable vertical distance between higher outlet openings and lower inlet openings, coupled with a substantial temperature difference.

6.2 Guidelines to utilise maximum natural ventilation potential through windows

6.2.1 Orientation

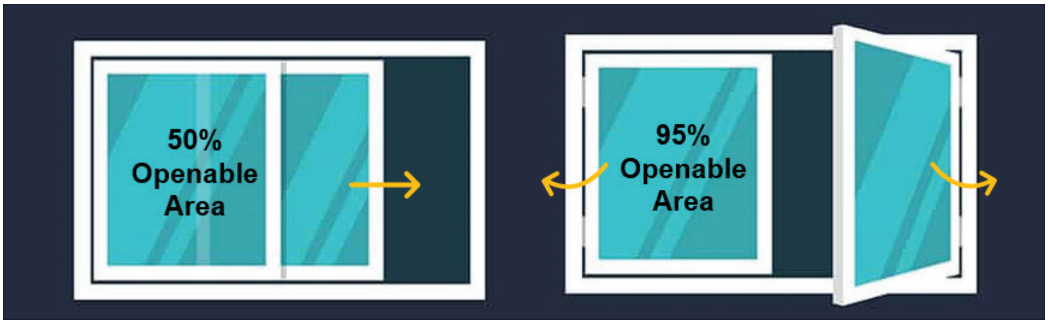
Orienting a building for a favourable wind direction is not as straightforward as aligning it according to the constant sun path of the location. Wind direction is unpredictable, and even for a given site, it keeps changing in terms of both direction and speed.

The requirements to manage solar gains and utilize wind flows may sometimes lead to conflicting results. Analyzing such conflicts is crucial for each case to find the optimum solution. Regardless of the orientation of the building and windows, it's essential to ensure that critical facades and windows are well-shaded to prevent solar radiation from directly impacting them.

6.2.2 Design for openability and better air distribution inside

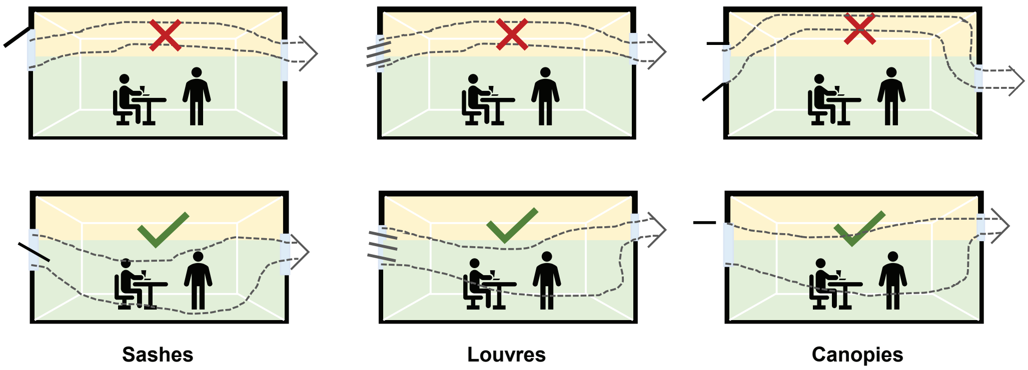
- Casement windows provide more openable area than a sliding window of the same size as shown in Figure 48.

FIGURE 48: SLIDING WINDOW (LEFT) AND CASEMENT WINDOW (RIGHT)



- The position of overhangs, louvers, etc. can be used to direct the air inside at the required level and area as shown in Figure 49.

FIGURE 49: USE OF LOUVERS, OVERHANGS ETC. TO DIRECT AIR INSIDE



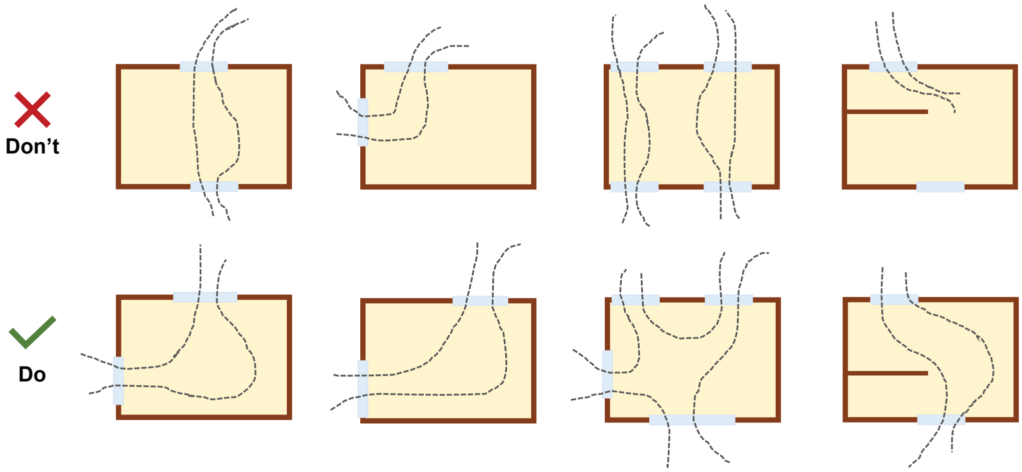
(Source: Reproduced image from www.nzeb.in)

6.2.3 Improving cross ventilation

The following is the preferred method for ensuring effective natural ventilation:

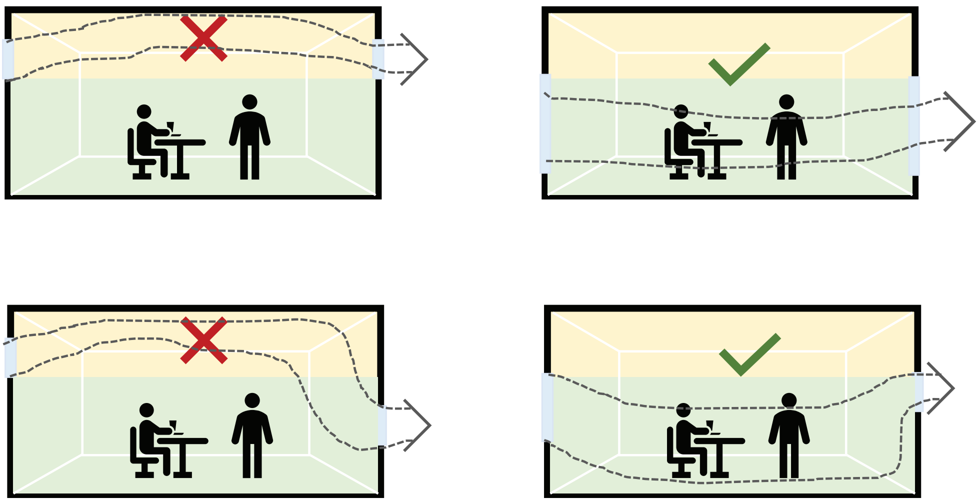
- Windows should be positioned on two walls in a manner that allows incoming air to travel through a larger area of the room and at the level of the occupants (refer to Figure 50 and Figure 51).
- The inlet and outlet openings should be either of the same size, or the outlet opening should be larger than the inlet opening.

FIGURE 50: ARRANGEMENTS FOR CROSS-VENTILATION (PLAN)



(Source: Reproduced image from www.nzeb.in)

FIGURE 51: ARRANGEMENTS FOR CROSS-VENTILATION (SECTION)

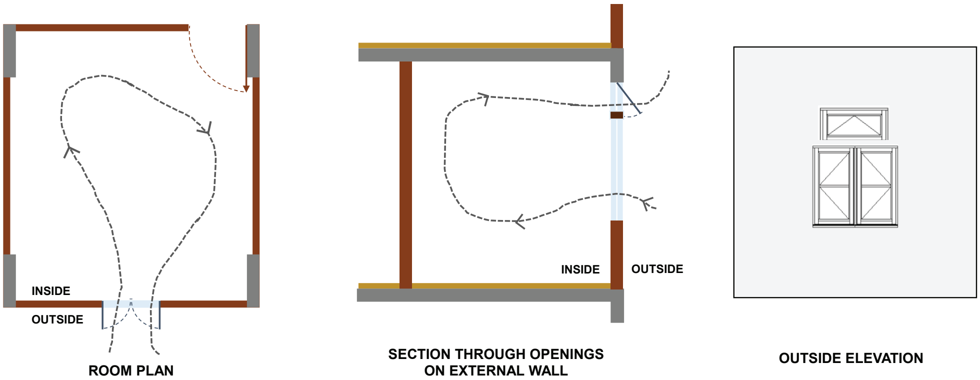


(Source: Reproduced image from www.nzeb.in)

6.2.4 Improving single-sided ventilation

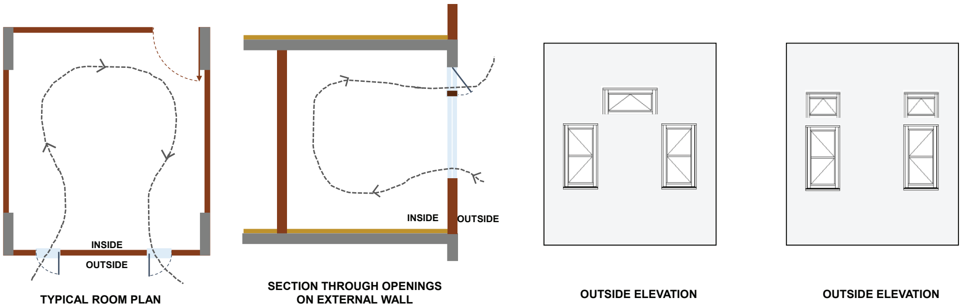
Single-sided ventilation occurs when only a single façade of the building is exposed to wind, and openable windows are located solely on that particular wall. In such cases, it is recommended to provide at least two windows on the façade. Two examples of how this can be achieved are illustrated in Figure 52 and Figure 53.

FIGURE 52: SINGLE-SIDED VENTILATION (PLAN, SECTION AND ELEVATION) - 1



(Source: Reproduced image from Eco-Niwas Samhita Part 1, Bureau of Energy Efficiency, Government of India)

FIGURE 53: SINGLE-SIDED VENTILATION (PLAN, SECTION AND ELEVATION) - 2

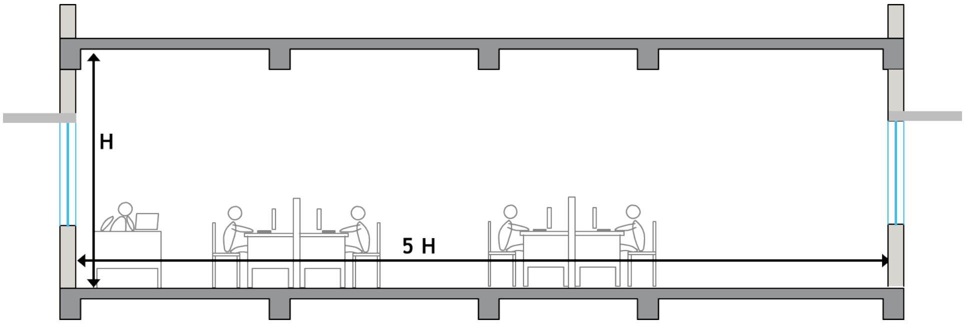


(Source: Reproduced image from Eco-Niwas Samhita Part 1, Bureau of Energy Efficiency, Government of India)

6.2.5 Shallow depth of floor plan

A shallow floor plan facilitates better cooling through natural ventilation. In a cross-ventilated space with appropriately sized and located windows (openable windows on opposite walls or adjacent walls), a depth of up to 5 times the room height can be effectively considered for cooling. For a single-side ventilated space, a depth of up to 2.5 times the room height can be considered. Figure 54 shows the depth of the floor plan for good cross ventilation.

FIGURE 54: DEPTH OF FLOOR PLAN FOR GOOD CROSS VENTILATION



(Source: Reproduced image from Indo-Swiss BEEP)

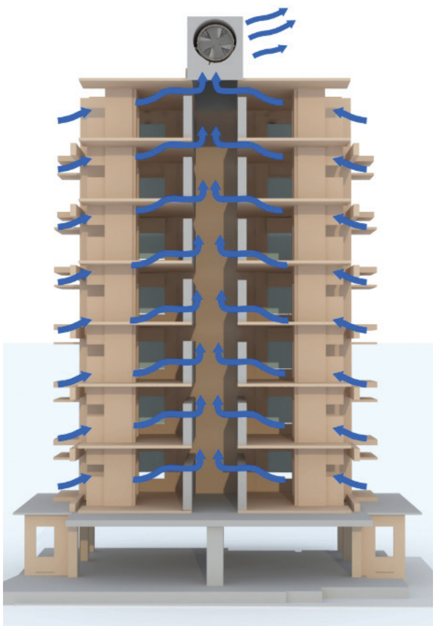
6.3 Fan-assisted ventilation

In situations where ambient wind velocity or wind direction is insufficient for cooling, fan-assisted ventilation becomes a viable option. Fans can be employed to generate a pressure difference, enabling controlled air movement. This ensures the desired air circulation, as fan requirements can be calculated and controlled.

In Figure 55, an example in the context of an apartment building is illustrated. The system operates as follows:

- A roof-top fan, situated above the common utility shaft between flats, creates a negative pressure.
- Flats open into the shaft through openings in the bathrooms. All other openings into the shaft are closed to establish a closed system, allowing air flow only as required.
- The negative pressure generated by the fan draws ambient air through the flats.

FIGURE 55: FAN-ASSISTED VENTILATION



(Source: Reproduced image from Indo-Swiss BEEP)

This strategy involves exchanging all the air in the building many times every hour, particularly when sufficiently cool outside air is available for cooling. It becomes particularly useful when external temperatures are lower than internal temperatures and the ambient wind speed is not sufficient for natural ventilation.

It is important to note that, as fans use electricity, they come with operational expenses. To achieve an effective ventilation cooling effect, the Air Changes per Hour (ACH) should be 10 or higher, indicating a high level of ventilation. Whenever possible, pure natural ventilation should be prioritized.

Opening windows at night for natural ventilation when the building is unoccupied may not always be possible due to security concerns. In such cases, louvred shutters, security grills, fly-mesh screens, and blinds inclined towards the outside and overlapped to prevent water infiltration, even during heavy rains, can be valuable. When manufactured with sufficient strength, these elements also provide adequate security.

Use of Personal Fans (Ceiling Fans, Table Fans, etc.)

The use of personal fans does not contribute to increased ventilation rates through a space. Nevertheless, they prove to be an effective means of enhancing convective heat transfer around the human body, creating a sensation of cooler temperatures. Fans can provide a perceived temperature that is 2°C–4°C lower, offering a low-energy cooling option before resorting to air-conditioning.

SUMMARY

- Natural ventilation holds significant potential in reducing cooling loads, particularly in warm temperate, temperate, and cool temperate climates in Nepal.
- Ventilation involves intentionally introducing outdoor air into a space. Natural ventilation, which doesn't rely on mechanical systems, can be wind-driven or buoyancy-driven.
- To improve natural ventilation through windows, consider the following guidelines:
    - Orient windows for favourable wind direction, and ensure shading for all windows.
    - Casement windows generally allow better ventilation compared to sliding windows.
    - Strategically locate windows to enhance cross-ventilation and single-sided ventilation.
    - Consider a shallow depth for the building floor plate.
- In cases where ambient wind velocity or direction is insufficient for cooling, fan-assisted ventilation can be employed.
- Louvered shutters, security grills, and fly-mesh screens are options that enable night ventilation while ensuring security.

7
VISUAL COMFORT & DAYLIGHTING

What's in this section?

Visual Comfort & Daylighting

Lighting stands as the next largest consumer of energy in buildings. Passive design for lighting revolves around maximizing the use of daylight when available. Beyond contributing to energy efficiency, daylight plays a crucial role in human health and performance. This chapter explores both the qualitative and quantitative assessment of daylighting, presenting various strategies and rules that can be implemented to enhance daylight in a building.

7.1 Lighting terminology

7.1.1 Quantitative terminology

7.1.1.1 Luminous flux

Luminous flux is defined as the amount of light flowing through space, measured in lumens (lm). The quantity of lumens is contingent on the specifics of the lighting fixture, where a higher lumen value corresponds to more light. However, lumens are also associated with energy consumption, indicated by a term known as efficacy as given by Equation 13.

$$Efficacy = \frac{\text{light output (lumens)}}{\text{energy input (watt)}} \quad (13)$$

Table 18 displays the luminous efficacy of typical lighting fixtures, presenting the lumen output considering typical efficiency. Notably, daylight exhibits the highest luminous efficacy.

TABLE 18: LIGHT FIXTURES AND THEIR LUMINOUS EFFICACY

Light Fixture/Light Source	Luminous Efficacy with Typical Efficiency
Incandescent Bulb	10 - 15 lm / W
Halogen Light	15 - 20 lm / W
CFL	50 - 70 lm / W
LED	80 - 150 lm / W
Daylight through Window Glass	75 - 130 lm / W

Source 1: https://lamphq.com/led-energy-efficiency/
Source 2: https://spectrum.ieee.org/our-best-lamps-still-cant-equal-the-luminosity-of-the-sun

7.1.1.2 Irradiance or Illuminance

Light falling on a surface is termed illuminance, measured in lumens per square meter (lux) in the SI system, and lumens per square foot (foot-candles) in IP units. Illuminance is not solely a property of the light source; it depends on factors such as lumens emitted, distance from the surface, and often the lightness or darkness of surrounding surfaces. A lux meter is commonly used to measure illuminance.

Recommended illuminance levels for various spaces are specified by different standards. Some of these standards include:

- Illuminating Engineering Society (IES Standard)
- European standards - EN 17037, EN 12464-1, and EN 15193
- Chartered Institution of Building Services Engineers (CIBSE)

7.1.1.3 Luminance/Radiance

Light reflected from a surface is termed luminance, with its SI unit expressed as candela per square meter and in IP units as foot-lambert per square foot. It's important to note that luminance and brightness, while closely related, are distinct concepts. Luminance is a quantitative measurement of light reflected from a surface, whereas brightness is a qualitative aspect representing human perception.

7.1.1.4 Reflectance

This metric, known as reflectance and measured in percentage (%), expresses a surface's ability to reflect light. The higher the reflectance value, the more light the surface will reflect, and vice versa. Lighter surfaces generally have higher reflectance than darker ones.

In interior spaces, using materials with high reflectance values on the interior surfaces is advisable. This practice enhances daylight within the space through internal reflection.

7.1.2 Qualitative terminology

7.1.2.1 Brightness

Brightness is the subjective visual sensation linked to the intensity of light produced or reflected from a surface or a point source. Humans perceive the brightness of a subject relative to its surroundings. For instance, a car with its headlamp on during the day doesn't significantly affect driving. However, during the night when the surroundings are dark, the car's headlamp becomes a source of brightness, making it challenging to drive.

7.1.2.2 Contrast

Contrast is the distinction between the brightness of an object and its immediate background. Objects with higher contrast are easier to see than those with lower contrast.

7.1.2.3 Glare

Glare is commonly defined as discomfort to the eye caused by bright light or extreme contrasts. Glare may be direct, i.e., caused by the light source, or indirect, i.e. caused by light reflected off of surfaces.

7.2 Daylighting strategies

When designing for daylight, achieving the right balance between heat ingress and daylight is crucial, particularly in climates requiring cooling during the summer. Designers can make critical decisions in the early stages of building design to strike a balance between effective daylighting and controlling heat ingress. Further sections will discuss important aspects and thumb rules for early-stage design.

7.2.1 Orientation and planning the spaces for optimum daylight and heat Ingress

In the warm temperate, temperate, and cool-temperate climates of Nepal, the optimal placement for glazed openings for daylight is on the north and south facades. The north facade, receiving the least direct radiation, requires minimal shading and glazed openings provide glare-free daylight without excessive heat. On the other hand, the south facade, while receiving significant solar radiation, can be shaded in the summer easily.

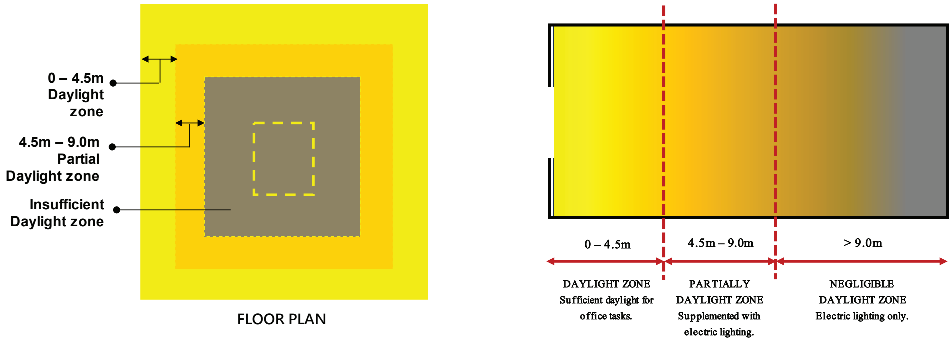
In the cold climate of Nepal, placing glazed windows on the south facade is ideal for maximizing daylight and allowing in the sun's heat for thermal comfort. Some shading should be implemented to prevent overheating in the summer months. Conversely, the north facade, although providing daylight, is less suitable for large glass areas due to minimal heat ingress and heat loss on this side.

7.2.2 Planform depth: The 15/30 rule

Typically, in buildings, a 15 ft (4.5 m) perimeter zone can be fully daylit, with an additional 15 ft (4.5 m) beyond that partially daylit by windows. Beyond 30 ft (9 m), insufficient or no daylight is expected, necessitating the use of electric lighting. This rule serves as a practical guideline for determining the form and zoning of internal spaces in cases where window height is unknown.

Figure 56 shows the daylight availability about the distance from the envelope or fenestration.

FIGURE 56: DAYLIGHT AVAILABILITY IN RELATION TO DISTANCE FROM ENVELOPE OR FENESTRATION (PLAN AND SECTION)

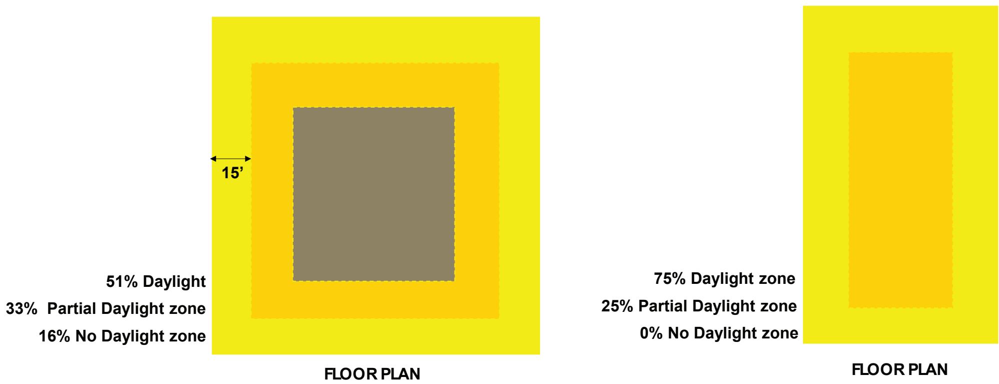


Note: Use this rule to determine the form/zoning of the internal spaces (if the window height is not known)

(Source: Reproduced image from Environmental Design Solution, India)

The square plan in Figure 57 illustrates that 16 percent of the area receives no daylight, and an additional 33 percent can only be partially daylit. If this square plan is replaced with a rectangular plan of the same area, it can eliminate the core area without daylight entirely. However, there will still be a substantial area that receives only partial daylight.

FIGURE 57: DAYLIGHT AVAILABILITY IN A SQUARE VS. A RECTANGLE



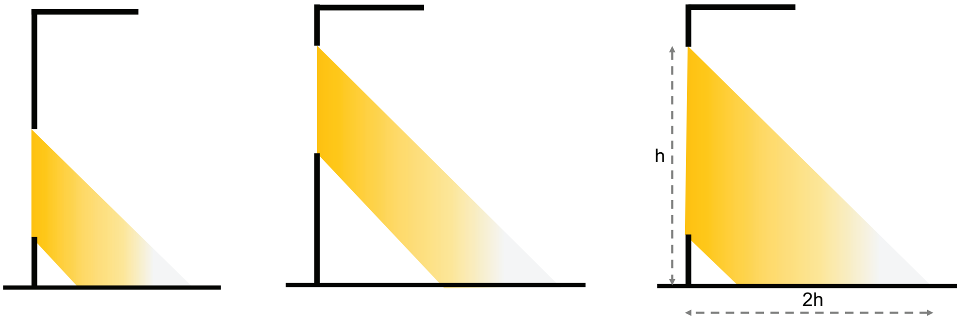
(Source: Reproduced image from Environmental Design Solutions, India)

A narrow building design enables daylight to reach the maximum depth of the structure. If windows are placed on only one side, the optimal building width falls within the range of 7.5m to 10.5m. Alternatively, when windows are provided on both sides, the recommended building width extends to the range of 15m to 21m.

7.2.3 Vertical position of glazed openings on the wall: The 2H rule

The 2H rule estimates the depth of daylight penetration when the window head height or lintel height is known. According to this rule, the daylight penetration is approximately 2 to 2.5 times the height of the head (H). Refer to Figure 58 for a visual representation. Therefore, the higher the head height, the greater will be the amount of light that can reach deeper areas within the spaces.

FIGURE 58: 2H RULE – THE HIGHER THE HEAD HEIGHT, THE DEEPER THE LIGHT PENETRATES INTO SPACE



(Source: Reproduced image from Environmental Design Solutions, India)

7.2.4 Area of glazed openings on walls: The 20% area rule

In designing for daylight, a general guideline is to allocate window area equivalent to about 20% of the total floor area of the space. However, it's crucial to consider this rule in conjunction with the specific daylight requirements of the space, balancing it against potential solar heat gains through the windows. Additionally, this rule should be complemented by appropriate orientation and space configuration for optimal daylight, along with adherence to the 15/30 rule.

7.2.5 Area of Skylights: Skylight-to-Roof Ratio (SRR)

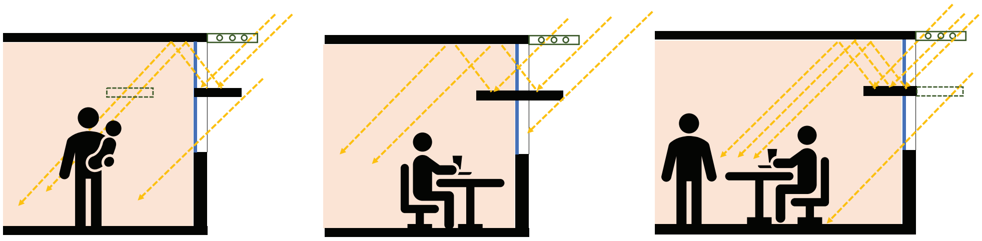
The recommended ratio of the total skylight area to the roof area falls within the range of 3% to 5%. As an example, if the roof area is 100 m^2, the maximum skylight area should be 5 m^2.

7.2.6 Reflecting light further inside: Light coloured interiors and light shelves

The use of light-coloured interior surfaces, especially on the ceiling, enhances daylight coverage in space and reduces luminance contrast.

The term "light shelves" typically refers to horizontal surfaces installed partway up a glazed opening. These shelves can be mounted inside a building, outside, or both. Light shelves serve to divide windows, separating the viewable portion from the section that allows additional natural light. They bounce this light upward, reflecting it off the ceiling to enable deeper penetration of daylight into the floor plate. The working principle of light shelves Figure 59.

FIGURE 59: WORKING PRINCIPLE OF LIGHT SHELVES



(Source: Reproduced image from www.nzeb.in)

7.3 Daylight performance metrics

These metrics are employed to assess the daylight potential within a designed space, necessitating the utilization of daylight simulation tools.

7.3.1 Daylight Factor (DF)

The Daylight Factor (DF) is defined as the ratio of interior illuminance to outdoor illuminance, at the same time, under overcast skies. This metric is calculated and expressed as a percentage as given by Equation 14.

$$\text{Daylight factor} = \frac{\text{Interior Illuminance}}{\text{Outer Illuminance}} \times 100\% \qquad (14)$$

Various standards, including those set by the Illuminating Engineering Society (IES), EN 17037, EN 12464-1, EN 15193, and the Chartered Institution of Building Services Engineers (CIBSE), provide daylight factor values for different types of buildings and spaces. However, it is important to note that the daylight factor doesn't account for the impact of factors such as orientation, building location, time of day, and local sky conditions. It is calculated under overcast sky conditions, which represent the worst-case scenario and may lead to oversized window designs. Due to these limitations, other daylight performance metrics have been developed.

7.3.2 Daylight Autonomy (DA) and Continuous Daylight Autonomy (CDA)

Daylight Autonomy is expressed as a percentage of annual daytime hours during which a specific point in space is illuminated above a designated illumination level as given by Equation 15.

$$CDA_{\text{illumination level}} = \frac{\text{Daytime hours above the specified illumination level}}{\text{Total Annual Da time Hours}} \times 100 \qquad (15)$$

Specified illumination levels, or lux levels, for different spaces, are defined by various standards such as IESNA and CIBSE.

The daylight autonomy metric, however, doesn't account for lux values just below the specified lux level. To address this limitation, "continuous daylight autonomy (CDA)" was introduced. Continuous daylight autonomy is a modification of daylight autonomy that linearly assigns partial credits to values below the user-defined threshold as given by Equation 16.

$$CDA_{illumination\ level} = \frac{\text{DH (Daylight Hours)above specified lux level+partial DH below specified lux level}}{\text{Total Annual Daytime Hours}} \times 100 \quad (16)$$

However, continuous daylight autonomy doesn't account for the upper threshold of lux levels, which is crucial as higher lux levels can lead to discomfort due to glare. To address this, "Useful Daylight Illuminance" was introduced. This metric considers both the lower and upper thresholds of the useful lux levels.

7.3.3 Useful Daylight Illuminance (UDI)

Useful Daylight Illuminance (UDI) represents the percentage of annual daytime hours during which a specific point on a work plane receives daylight between the lower threshold of lux level (usually 100 lux) and the upper threshold of lux level (usually 2000 lux). Currently, UDI is the most widely accepted daylight performance metric.

In various standards, the minimum percentage of annual daylit hours for a point with UDI is specified. For instance, if UDI should account for 90% of annual daylight hours, then Useful Daylight Illuminance (i.e., ≥ 100 lux and ≤ 2000 lux) for a point receiving daylight for ≥90% of the annual daylight hours will be considered and represented as UDI(100-2000,90%).

7.3.4 Useful daylight spatial daylight autonomy and annual sun exposure

Spatial Daylight Autonomy is defined as the percentage of floor area that receives at least 300 lux for at least 50% of the annual occupied hours. Achieving Spatial Daylight Autonomy with at least 50% of the floor area is considered acceptable, and if ≥ 75% of the floor area achieves this, it is preferred.

Annual Solar Exposure (ASE) measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year. A minimum of 10% of the floor area should meet the requisite ASE.

7.4 Evaluating daylight design: Simplified manual method

The simplified method provides a straightforward approach to assessing the floor area likely to be daylit, as outlined in the Energy Conservation Building Code (ECBC) 2017, India. Compliance with this code requires a minimum daylit area of 40%. This method utilizes the Daylight Extension Factor (DEF), which is provided in Table 19, and is most effectively applied using an AutoCAD plan.

TABLE 19: VALUE OF DAYLIGHT EXTENSION FACTOR (DEF) FOR DIFFERENT DIRECTIONS

Shading	Latitude	Window Type	VLT of glass<0.3				VLT of glass ≥ 0.3			
			North	South	East	West	North	South	East	West
No shading or PF < 0.4	≥15°N	All window types	2.5	2.0	0.7	0.5	2.8	2.2	1.1	0.7
Shading with PF≥0.4	All Latitudes	All window types (Without light shelf)	2.8	2.3	1.5	1.1	3.0	2.5	1.8	1.5

The Daylit Area is calculated as follows:

- In a direction perpendicular to the fenestration (refer to Figure 60):
  - Multiply the Daylight Extension Factor (DEF) by the head height of the fenestration or until the opaque partition surpasses the head height of the fenestration. Choose the lesser of the two.
- In the direction parallel to the fenestration (refer to Figure 61), the daylit area extends to:
  - A horizontal dimension equal to the width of the fenestration plus either 1 meter on each side of the aperture,

  OR
  - The distance to an opaque partition of 2 m high,

  OR
  - One-half the distance to an adjacent fenestration.

Choose the least of the above three.

- For skylights, the daylit area is determined as shown in Figure 62.
- For overlapping daylit areas, such as windows on different orientations or in the case of skylights, subtract the overlapping daylit area from the sum of daylit areas.

FIGURE 60: HEAD HEIGHT (SECTION)

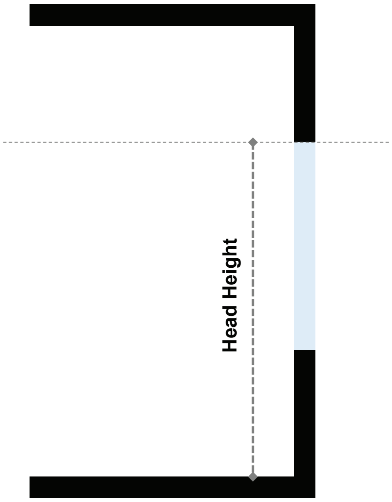


FIGURE 61: DAYLIT AREA FOR WINDOWS

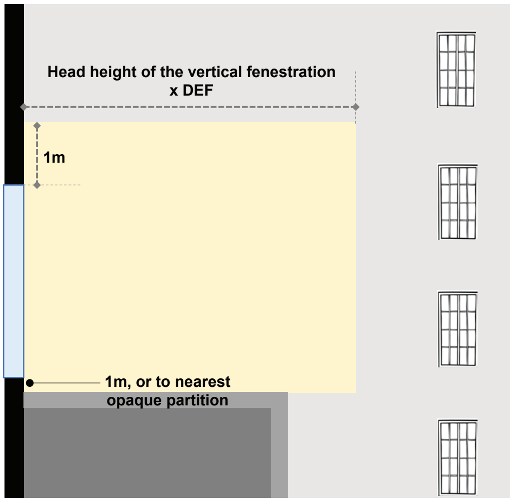
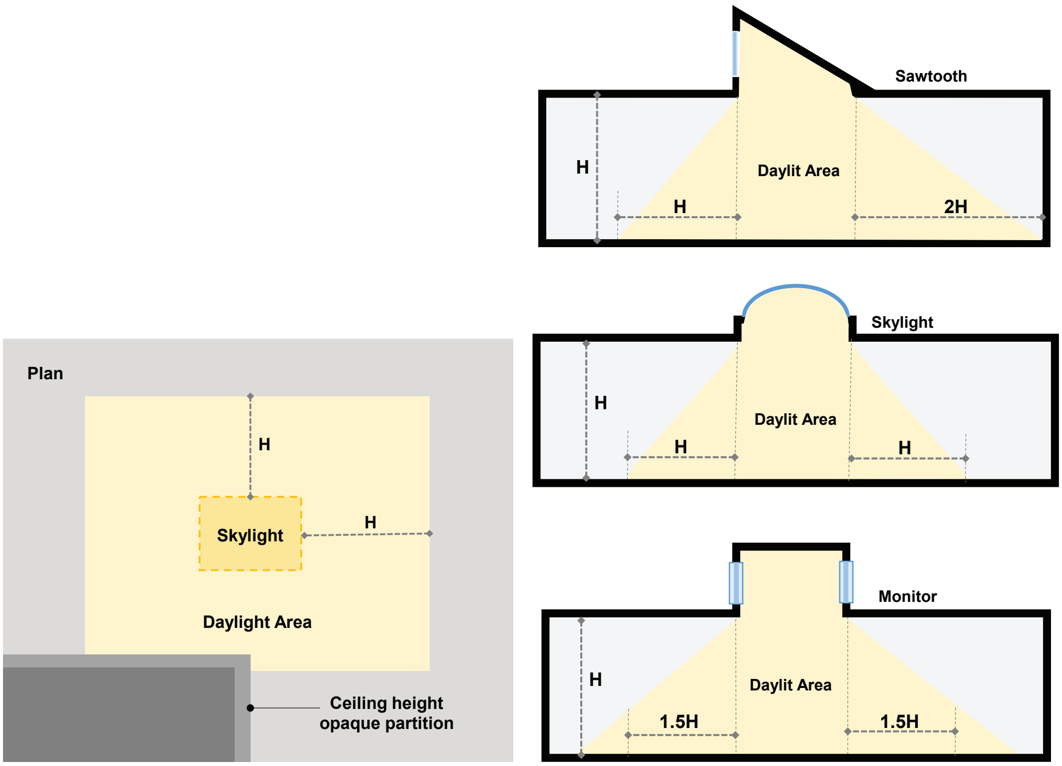


FIGURE 62: ILLUSTRATION OF DAYLIT AREA FOR SKYLIGHT



(Source: Figures 60, 61, 62 reproduced image from Energy Conservation Building Code 2017, Bureau of Energy Efficiency, Government of India)

SUMMARY

- The quantity of light is defined by terms such as luminous flux, illuminance, luminance, and reflectance. The quality of light is characterized by brightness, contrast, and glare.
- Daylighting strategies encompass various considerations:
  - Window orientation for optimal daylight.
  - Shallow planform depth to enhance light penetration.
  - High placement of windows on walls.
  - Optimization of window area for daylight while balancing solar heat gains.
  - Utilization of reflective finishes inside and incorporation of light shelves.

ANNEX

Annex 1

TABLE 20: THERMAL PROPERTIES OF BUILDING AND INSULATING MATERIALS (BUREAU OF ENERGY EFFICIENCY, ECO-NIWAS SAMHITA 2018, (ENERGY CONSERVATION BUILDING CODE FOR RESIDENTIAL BUILDINGS), PART I: BUILDING ENVELOPE, 2018)

S.N.	Type of Material	Density (kg/m³)	Thermal Conductivity (W/m.K)	Specific Heat Capacity (kJ/kg.K)
1	Solid burnt clay brick	1920	0.81–0.98	0.80
2	Solid burnt clay brick	1760	0.71–0.85	NA
3	Solid burnt clay brick	1600	0.61–0.74	NA
4	Solid burnt clay brick	1440	0.52–0.62	NA
5	Resource efficient hollow brick	1520	0.631	0.99
6	Fly ash brick	1650	0.856	0.93
7	Solid concrete block 25/50	2427	1.396	NA
8	Solid concrete block 30/60	2349	1.411	NA
9	Aerated autoclaved concrete (AAC) block	642	0.184	0.79
10	Cement stabilized soil block (CSEB)	1700–1900	1.026	1.03
11	Cement stabilized soil block (CSEB)	1800	1.201	1.07
12	Cement stabilized soil block (CSEB)	1900	1.303	1.07
13	Dense concrete	2410	1.740	0.88
14	Reinforced concrete cement (RCC)	2288	1.580	0.88
15	Brick tile	1892	0.798	0.88
16	Lime concrete	1646	0.730	0.88
17	Mud Phuska	1622	0.519	0.88
18	Cement mortar	1648	0.719	0.92
19	Cement plaster	1762	0.721	0.84
20	Gypsum plaster	1120	0.512	0.96
21	Cellular concrete	704	0.188	1.05
22	AC sheet	1520	0.245	0.84
23	GI sheet	7520	61.060	0.50
24	Timber	480	0.072	1.68
25	Timber	720	0.144	1.68
26	Plywood	640	0.174	1.76
27	Glass	2350	0.814	0.88
28	Tar felt (2.3 kg/m²)		0.479	0.88

S.N.	Type of Material	Density (kg/m³)	Thermal Conductivity (W/m.K)	Specific Heat Capacity (kJ/kg.K)
II. Insulating materials				
1	Expanded polystyrene	16.0	0.038	1.34
2	Expanded polystyrene	24.0	0.035	1.34
3	Expanded polystyrene	34.0	0.035	1.34
4	Foam glass	127.0	0.056	0.75
5	Foam glass	160.0	0.055	0.75
6	Foam concrete	320.0	0.070	0.92
7	Foam concrete	400.0	0.084	0.92
8	Foam concrete	704.0	0.149	0.92
9	Cork slab	164.0	0.043	0.96
10	Cork slab	192.0	0.044	0.96
11	Cork slab	304.0	0.055	0.96
12	Rock wool (unbonded)	92.0	0.047	0.84
13	Rock wool (unbonded)	150.0	0.043	0.84
14	Mineral wool (unbonded)	73.5	0.030	0.92
15	Glass wool (unbonded)	69.0	0.043	0.92
16	Glass wool (unbonded)	189.0	0.040	0.92
17	Resin bonded mineral wool	48.0	0.042	1.00
18	Resin bonded mineral wool	64.0	0.038	1.00
19	Resin bonded mineral wool	99.0	0.036	1.00
20	Resin bonded mineral wool	16.0	0.040	1.00
21	Resin bonded mineral wool	24.0	0.036	1.00
22	Exfoliated vermiculite (loose)	264.0	0.069	0.88
23	Asbestos mill board	1397.0	0.249	0.84
24	Hard board	979.0	0.279	1.42
25	Straw board	310.0	0.057	1.30
26	Soft board	320.0	0.066	1.30
27	Soft board	249.0	0.047	1.30
28	Wall board	262.0	0.047	1.26
29	Chip board	432.0	0.067	1.26
30	Chip board (perforated)	352.0	0.066	1.26
31	Particle board	750.0	0.098	1.30
32	Coconut pith insulation board	520.0	0.060	1.09
33	Jute fibre	329.0	0.067	1.09

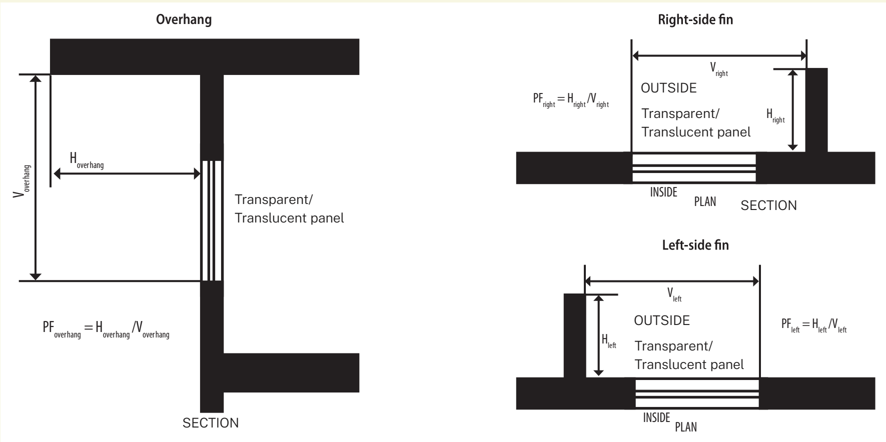
S.N.	Type of Material	Density (kg/m³)	Thermal Conductivity (W/m.K)	Specific Heat Capacity (kJ/kg.K)
34	Wood wool board (bonded with cement)	398.0	0.081	1.13
35	Wood wool board (bonded with cement)	674.0	0.108	1.13
36	Coir board	97.0	0.038	1.00
37	Saw dust	188.0	0.051	1.00
38	Rice husk	120.0	0.051	1.00
39	Jute felt	291.0	0.042	0.88
40	Closed cell flexible elastomeric foam - NBR	40–55	0.043	1.20

Annex 2

Calculation of Equivalent SHGC

Equivalent Solar Heat Gain Coefficient (SHGC) is the SHGC of an opening that incorporates a permanent external shading projection, such as an overhang and side fins.

Step 1: Calculate projection factor (PF)



Step 2: Select the External Shading Factor (ESF) value for each shading element from the Table 22, Table 23, and Table 24, corresponding to the PF and the orientation.

Step 3: Calculate the total external shading factor (ESF_{total})

$$ESF_{total} = ESF_{overhang} \times ESF_{sidefin} \qquad (A2\text{-}1)$$

where,

$$ESF_{sidefin} = 1-[(1-ESF_{right}) + (1-ESF_{left})] \quad (A2\text{-}2)$$

Step 4: Calculate the equivalent SHGC of the fenestration ($SHGC_{eq}$)

$$SHGC_{eq} = SHGC_{unshaded} \times ESF_{total} \qquad (A2\text{-}3)$$

TABLE 21: EXTERNAL SHADING FACTOR FOR OVERHANG ($ESF_{overhang}$) FOR LAT ≥ 23.5˚N. (BUREAU OF ENERGY EFFICIENCY, ECO-NIWAS SAMHITA 2018, (ENERGY CONSERVATION BUILDING CODE FOR RESIDENTIAL BUILDINGS), PART I: BUILDING ENVELOPE, 2018)

	External Shading Factor for Overhang ($ESFo_{verhang}$) for LAT ≥ 23.5˚N							
Orientation	North	North-east	East	South-east	South	South-west	West	North-west
$PF_{overhang}$	(337.6˚-22.5˚)	(22.6˚-67.5˚)	(67.6˚-112.5˚)	(112.6˚-157.5˚)	(157.6˚-202.5˚)	(202.6˚-247.5˚)	(247.6˚-292.5˚)	(292.6˚-337.5˚)
<0.10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.10-0.19	0.955	0.930	0.922	0.906	0.881	0.905	0.922	0.930
0.20-0.29	0.922	0.876	0.855	0.824	0.789	0.823	0.853	0.875
0.30-0.39	0.897	0.834	0.796	0.755	0.719	0.753	0.794	0.834
0.40-0.49	0.877	0.803	0.745	0.697	0.665	0.695	0.743	0.802
0.50-0.59	0.860	0.779	0.702	0.652	0.626	0.650	0.700	0.778
0.60-0.69	0.846	0.761	0.666	0.617	0.598	0.614	0.663	0.760
0.70-0.79	0.834	0.747	0.635	0.590	0.580	0.587	0.632	0.746
0.80-0.89	0.825	0.737	0.609	0.569	0.569	0.566	0.606	0.736
0.90-0.99	0.817	0.729	0.587	0.554	0.563	0.551	0.585	0.728
≥1	0.810	0.722	0.569	0.542	0.559	0.539	0.566	0.721

TABLE 22: EXTERNAL SHADING FACTOR FOR SIDE FIN-RIGHT (ESF_{right}) FOR LAT ≥ 23.5˚N. (BUREAU OF ENERGY EFFICIENCY, ECO-NIWAS SAMHITA 2018, (ENERGY CONSERVATION BUILDING CODE FOR RESIDENTIAL BUILDINGS), PART I: BUILDING ENVELOPE, 2018)

	External Shading Factor for Side Fin-Right (ESFright) for LAT ≥ 23.5˚N							
Orientation	North	North-east	East	South-east	South	South-west	West	North-west
PF_{right}	(337.6˚-22.5˚)	(22.6˚-67.5˚)	(67.6˚-112.5˚)	(112.6˚-157.5˚)	(157.6˚-202.5˚)	(202.6˚-247.5˚)	(247.6˚-292.5˚)	(292.6˚-337.5˚)
<0.10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.10-0.19	0.968	0.942	0.972	0.982	0.961	0.965	0.988	0.985
0.20-0.29	0.943	0.894	0.949	0.968	0.933	0.934	0.977	0.972
0.30-0.39	0.924	0.855	0.931	0.957	0.912	0.907	0.968	0.961
0.40-0.49	0.911	0.824	0.917	0.950	0.898	0.884	0.960	0.953
0.50-0.59	0.899	0.798	0.905	0.944	0.887	0.865	0.954	0.945
0.60-0.69	0.890	0.777	0.895	0.939	0.880	0.849	0.948	0.939
0.70-0.79	0.883	0.762	0.887	0.936	0.875	0.837	0.943	0.934
0.80-0.89	0.877	0.750	0.881	0.933	0.872	0.827	0.939	0.930
0.90-0.99	0.871	0.739	0.875	0.930	0.868	0.819	0.935	0.926
≥1	0.865	0.731	0.870	0.927	0.865	0.812	0.932	0.922

TABLE 23: EXTERNAL SHADING FACTOR FOR SIDE FIN-LEFT (ESF_{left}) FOR LAT ≥ 23.5˚N. (BUREAU OF ENERGY EFFICIENCY, ECO-NIWAS SAMHITA 2018, (ENERGY CONSERVATION BUILDING CODE FOR RESIDENTIAL BUILDINGS), PART I: BUILDING ENVELOPE, 2018)

	External Shading Factor for Side Fin-Left (ESFleft) for LAT ≥ 23.5˚N							
Orientation	North	North-east	East	South-east	South	South-west	West	North-west
PF_{left}	(337.6˚-22.5˚)	(22.6˚-67.5˚)	(67.6˚-112.5˚)	(112.6˚-157.5˚)	(157.6˚-202.5˚)	(202.6˚-247.5˚)	(247.6˚-292.5˚)	(292.6˚-337.5˚)
<0.10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.10-0.19	0.968	0.985	0.988	0.965	0.961	0.982	0.972	0.942
0.20-0.29	0.943	0.972	0.977	0.933	0.932	0.967	0.949	0.895
0.30-0.39	0.925	0.961	0.968	0.906	0.911	0.957	0.931	0.857
0.40-0.49	0.912	0.953	0.961	0.883	0.897	0.949	0.916	0.826
0.50-0.59	0.900	0.946	0.954	0.863	0.886	0.943	0.904	0.801
0.60-0.69	0.890	0.939	0.948	0.846	0.879	0.938	0.895	0.781
0.70-0.79	0.884	0.935	0.944	0.834	0.874	0.935	0.887	0.766
0.80-0.89	0.877	0.931	0.940	0.824	0.871	0.932	0.881	0.754
0.90-0.99	0.871	0.927	0.936	0.815	0.867	0.929	0.875	0.744
≥1	0.866	0.923	0.932	0.808	0.864	0.927	0.870	0.736

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