# Bhutan Building Energy Efficiency Study

## Part 1 (Main Report)

Department of Renewable Energy

Ministry of Economic Affairs

September 2015

This report is a part of the studies conducted for the formulation of the draft Energy Efficiency and Conservation Policy of the Royal Government of Bhutan. The studies were conducted by Ernst and Young LLP, India as part of the Energy Plus Program: Promoting Clean Energy Development in Bhutan. This project was funded by the Government of Norway and administered by the Asian Development Bank under ADB TA-8630 BHU: F-003 Energy Efficiency.

***Disclaimer:***

***This report is intended solely for the purpose of drafting the Bhutan Energy Efficiency and Conservation Policy. It provides an outline of energy consumption in the Building Sector in Bhutan. The results from the detailed energy audits in randomly sampled buildings were used to analyze the energy consumption. Relevant agencies may use this report as a source of information on Energy Efficiency in buildings. However, professional advice must be sought for making decisions or implementing the recommendations. Ernst & Young LLP accepts no responsibility for any loss arising from any action taken or not taken by anyone using this report.***

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# *List of Units*

| | |
|---|---|
| °C | Degree Centigrade |
| ρ | Density |
| C | Specific heat |
| Hr | Hour |
| INR | Indian Rupee |
| K | Kelvin |
| kCal | kilocalorie |
| kg | kilogram |
| kgK | Kilogram Kelvin |
| kJ | kilojoule |
| kTOE | Kilotonnes of oil equivalent |
| kW | kilowatt |
| kWh | kilo Watt hour |
| kWh/day | Heat loss |
| kWh/day/m2 | Solar heat gain factor |
| L | litre |
| m | meter |
| m2,sqm | Square meter |
| M2K/W | R value |
| m3,cum | cubic meter |
| mm | millimeter |
| MW | Mega Watt |
| N | Number of air changes per hour |
| Nu | Bhutanese Ngultrum |
| Pa | Pascals |
| Q | Quantity of heat loss |
| rpm | Rotations per minute |
| M2K/W | R value |

# *List of Units (contd.)*

| | |
|---|---|
| TCO2 | Tons of CO2 |
| TOE | Tonnes of Oil Equivalent |
| TR | Tons of Refrigeration |
| U value | Conductivity |
| USD | Unite States Dollar |
| W | Watt |
| W/m2 | Solar Radiation |
| W/m2K | U value |
| w/w | Energy Efficiency Ratio |

# *List of Abbreviations and Acronyms*

| | |
|---|---|
| CO2 | Carbon dioxide |
| Etc. | Etcetera |
| hrs | hours |
| ISO | International Organization for standardization |
| No. | Number |
| O2 | oxygen |
| S. No | Serial Number |
| T 12 | 12/8 inch diameter FTL |
| T 5 | 5/8 inch diameter FTL |
| T 8 | 8/8 inch diameter FTL |
| w.r.t | With respect to |

| | |
|---|---|
| AAC | Autoclaved Aerated Blocks |
| AC | Air Conditioner |
| ADB | Asian Development Bank |
| ATF | Aviation Turbine Fuel |
| BEE | Bureau of Energy Efficiency |
| BIS | Bureau of Indian Standard |
| BTN | Bhutan Ngultrum |
| CAGR | Compounded Annual Growth Rate |
| CEC | Comparative Energy Consumption |
| CFL | Compact Fluorescent Lamp |
| CRT | Cathode Ray Tube |
| DC | Direct Current |
| DEDE | Department of Alternative Energy Development and Efficiency |
| DoHS | Department of Human Settlement |
| DoR | Department of Roads |
| DSM | Demand Side Management |
| EE | Energy Efficiency |
| EER | Energy Efficiency Ratio |
| EGAT | Electricity Generating Authority of Thailand |
| EPPO | Energy Policy and Planning Office |
| ES&L | Energy Standard and Labelling |
| FEEED | Framework for Energy Efficiency Economic Development |
| FTL | Fluorescent Tube Light |
| GHG | Green House Gas |
| HEPS | High Energy Performance standards |
| HV | High Voltage |
| IEC | International Electro-technical Commission |
| IS | Indian Standards |
| IT | Information Technology |
| LED | Light Emitting Diode |
| LPG | Liquefied Petroleum Gas |
| MEPS | Minimum Energy Performance standards |
| MoWHS | Ministry of Works and Human Settlements, RGoB |
| MV&E | Measuring, Verification and Enforcement |
| PV | Photovoltaic |
| RGoB | Royal Government of Bhutan |
| S&L | Standards and Labelling |

| | |
|---|---|
| TIS | Thai Industrial Standards |
| TISI | Thai Industrial Standards Institute |
| TV | Television |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UV | Ultraviolet |

# Executive Summary

The building sector in Bhutan contributes to 15% or 319.13 GWh of the total electricity consumption in Bhutan which is about 2094.47 GWh and 88% of low voltage consumption in the country[1]. The thermal energy consumption in Building Sector is about 4% of the total consumption in the country. Bhutan of late, has witnessed an increase in domestic electricity consumption leading to reduction of electricity exports by 8.7%.

Any effort in energy efficiency in domestic sector would result in domestic cost savings as well as in added national revenue from cross border sale of electricity.

With the support from Asian Development Bank, the Department of Renewable Energy, of the Ministry of Economic Affairs (MoEA), Royal Government of Bhutan (RGoB) has taken the initiative to prepare a report on "Bhutan Building Energy Efficiency" to assess the energy consumption and efficiency potential of this sector. The outcome of this report would be used for drafting "Bhutan Energy Efficiency and Conservation Policy". A brief summary of individual chapters covered in the report is as follows:

## Building sector in Bhutan 1

This chapter introduces the building sector, with deep focus on typology of buildings, construction techniques, use of modern and traditional materials and other parameters of building orientation and form, and identifies the impact of urbanization and increased electrification on the energy performance of Building Sector in Bhutan.

Trend of electrification shows that dependence in urban areas is increasing more and more on electrical appliances for heating in winter in cold districts, and cooling in summer in warm districts, and showing reduction in use of thermal appliances for space heating and cooking. This scenario is different from that of rural areas where dependence on electrical appliances for cooking is increasing, but not much reduction in use of thermal equipment like Bukhari.

## 2 Climate of Bhutan

This chapter explains the various climatic zones in Bhutan and the need for thermal comfort of buildings. This chapter also explains the climatic factors affecting the building thermal performance and its impact on the Bhutan energy scenario. Some of the key climatic factor affecting the building performance include Solar radiation, Ambient temperature, Wind velocity, etc.

[1] Sourced from Bhutan Energy Data Directory 2015

# Energy conscious building design 3

A building consists of several components and parameters through which heat exchange takes place and makes the construction and operation of a building energy intensive. In Bhutan, most of the districts have colder climate with low temperatures, and hence prevention of loss of heat in order to reduce dependence on artificial heating systems for restoring thermal comfort is extremely essential. Few districts have warm climate too, hence reducing heat gain is necessary for buildings in such districts' thermal comfort to maintain. Energy conscious design in buildings will help designers and building owners to economically reduce building energy costs, while improving comfort for the building's occupants.

# 4 Thermal performance evaluation

The thermal performance evaluation of a building refers to the process of modelling the energy transfer between a building and its surroundings. Various heat exchange processes are possible between a building and the external environment. This chapter explains the methodology for evaluating building thermal performance and heat loss or gain from various building envelope. It also covers the energy efficiency potential and financial viability of various building envelope through improving thermal performance. Some of the key outcomes from this chapter are,

**Findings for cold weather districts:**

- Buildings in district having higher heating degree day has higher heat loss through building envelope. Bumthang district was having the highest heating degree day followed by Paro, Thimphu and other districts.
- The heat loss from the building envelope was observed to be in the range of 40% to 70%, depending on the type of building and material used.
- Heat loss through air infiltration is also a significant component of building envelope heat loss.
- Heat loss through wall is the highest followed by air infiltration loss through windows and roof
- Wall heat loss is in the range of 40% to 70% of the total heat loss. The wall heat loss was lowest for rammed earth and highest for brick wall.
- In most of the buildings in Bhutan, single glazed windows with wooden frames are used. This leads to heat loss in the range of 20 to 25%.
- Buildings operating for more hours has higher energy saving potential.
- Usage of non-standard heating appliances leads to more power consumption.
- Buildings having south facing windows tend to have more solar heat gain and reduced

heater power consumption. Rooms having south facing window consume 25% lesser power consumption than a room with north facing window.

- Air infiltration loss was high in most of the buildings due to usage of non-seasoned wood for windows and doors.

**Findings for summer districts:**

- Buildings in district having higher cooling degree day has higher heat load through building envelope. Phuentsholing (Chhukha district) was having the highest cooling degree day followed by Samtse, Gelephu, Samdrup Jongkhar and other districts.
- The heat load through building envelope was observed to be in the range of 37% to 65%.
- Unlike cold weather districts, solar heat gain contributes to maximum heat load of buildings in summer districts.
- Roof contributes to maximum heat load of the building followed by wall.
- Heat loss through wall is the highest followed by air infiltration loss through roof, windows and floor.
- Almost 95% of the buildings in summer districts are of brick wall based constructions.
- In most of the buildings in summer districts, single glazed windows with wooden / aluminum frames are used. This leads to more heat load through solar gain.
- Buildings operating for more hours has higher energy saving potential.
- It was observed that, only institutional buildings, hospital and hotel were using air conditioners for space cooling. Households predominantly use ceiling fans for meeting the thermal comfort.
- Most of the air conditioners used in summer districts are of minimum 2 star rated imported from Indian market. However the Air conditioners were not used in a optimal level. During the audit visit it was observed that most of the air conditioners were operating at a set point of 20$^{o}$C irrespective of the outside temperature leading to more power consumption.

## Interventions 5

This report aimed at identifying the Energy Efficiency potential of various building types through improving thermal performance of building envelope and also through lighting. The interventions has been classified based on cold weather and summer weather regions. The need for heating / cooling depends on the altitude of the location.

The energy efficiency interventions for the districts in higher altitudes (more than 2000 meters above sea level) would be focusing on reducing the heating load of the building whereas the interventions for districts in lower altitudes (less than 1000 meters above sea level) would be focusing on reducing the cooling load of the building.

The districts in the mid altitude range (between 1000 to 2000 meters above sea level) do not consume much of heating / cooling load, hence the same has not been considered for thermal performance evaluation. However, the interventions towards lighting load reduction is applicable for all districts irrespective of the altitude. In this section, interventions have been identified for both retrofitting and new building constructions. The interventions have been evaluated based on technical & financial feasibility, earthquake resistance and adaptability to local conditions.

## Interventions for cold weather districts

The ambient temperature across the cold weather districts varies significantly and hence the Heating Degree Day (HDD) method has been adopted for evaluating the interventions. The districts having higher HDD require more heat load for meeting the thermal comfort of the buildings. Bumthang had the highest HDD in Bhutan followed by Paro, Thimphu and others. The HDD has a greater impact on the financial viability of the interventions. For example, higher the HDD, lower is the payback period of Energy Efficiency projects.

**Summary of Interventions for new and old buildings in winter districts of Bhutan**

| | Short term | Medium term | Long term |
|---|---|---|---|
| Existing building | ▶ Weather strip for windows<br>▶ Double / triple beading for windows | ▶ Single glazed window with low e coating<br>▶ Rockwool insulation<br>▶ LED lighting | ▶ Double glazed window with low e coating<br>▶ Glass wool / EPS |
| New construction | ▶ Weather strip for windows<br>▶ Double / triple beading for windows<br>▶ Insulated curtains<br>▶ South facing windows | ▶ Single glazed window with low e coating<br>▶ LED lighting<br>▶ Cavity wall<br>▶ Rat trap bonded wall<br>▶ AAC blocks | ▶ Double glazed window with low e coating<br>▶ Cavity wall insulation<br>▶ Trombe wall<br>▶ Variable Frequency Drives for central heating |

## Interventions for summer districts

The Cooling Degree Day (CDD) method was adopted for quantifying the energy savings and for evaluating the energy efficiency interventions. The districts having higher CDD require more cooling load for meeting the thermal comfort of the buildings. Phuentsholing (Chhukha district) was having the highest CDD in Bhutan followed by Samtse, Gelephu, Samdrup Jongkhar and others. Like HDD, the CDD also has a greater impact on the financial viability of the interventions. For example, higher the CDD, lower is the payback period of energy efficiency projects.

**Summary of Interventions for new and old buildings in summer districts of Bhutan**

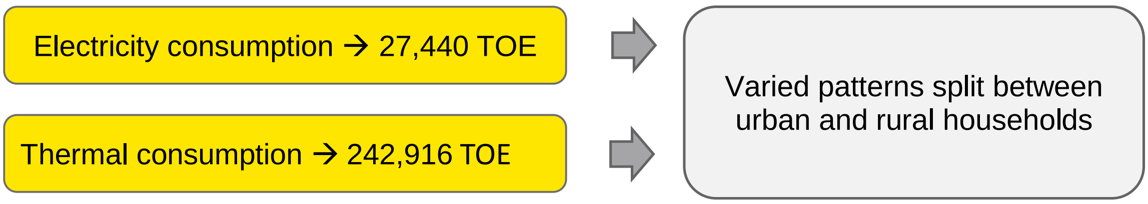
| | Short | Medium term | Long term |
|---|---|---|---|
| Existing building | ▶ Weather strip for windows<br>▶ Insulated curtains<br>▶ AC set point optimization<br>▶ High Solar Reflectance (SRI) paint for roofs | ▶ Reflective single glazed window<br>▶ Rockwool insulation<br>▶ LED lighting | ▶ Reflective double glazed window<br>▶ Glass wool / EPS insulation |
| New construction | ▶ Weather strip for windows<br>▶ Insulated curtains<br>▶ High Solar Reflectance (SRI) paint for roofs<br>▶ Cross ventilation to reduce cooling load | ▶ Reflective single glazed window<br>▶ LED lighting<br>▶ Cavity wall<br>▶ Rat trap bonded wall<br>▶ AAC blocks | ▶ Reflective double glazed window<br>▶ Cavity wall insulation |

# Chapter 1: Introduction

## 1.1 Context Setting

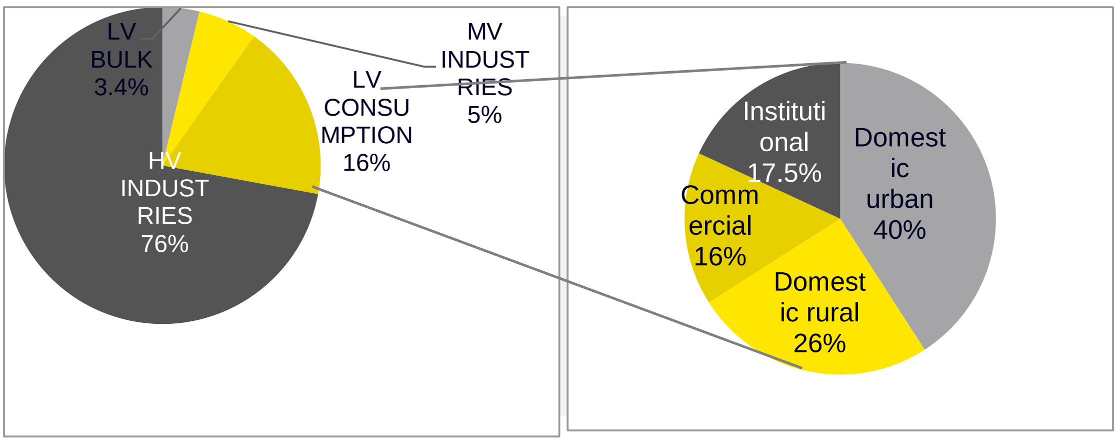
The Building Sector contributes to 15% of the total baseline electricity consumption. Buildings consume energy primarily in two forms - in terms of electricity, biomass (mostly firewood) and solid/ liquid fuel (LPG, kerosene etc.). The building energy audit observations reveal that buildings in Bhutan have a high level of dependence on firewood for space heating and cooking, and LPG cylinders for cooking. While the thermal energy consumption in buildings stands at 242,916 TOE, the electrical energy consumption is 27,440 TOE[2].

**Figure 1.1: Major areas of Energy Consumption in Buildings**




The building sector in Bhutan was responsible around 88% of low voltage consumption in the country[3]. The thermal energy consumption in Building Sector is about 52% of the total consumption in the country. Bhutan of late, has witnessed an increase in domestic electricity consumption leading to reduction of electricity exports by 8.7%.

**Figure 1.2: Electricity Consumption Split: Building Sector**



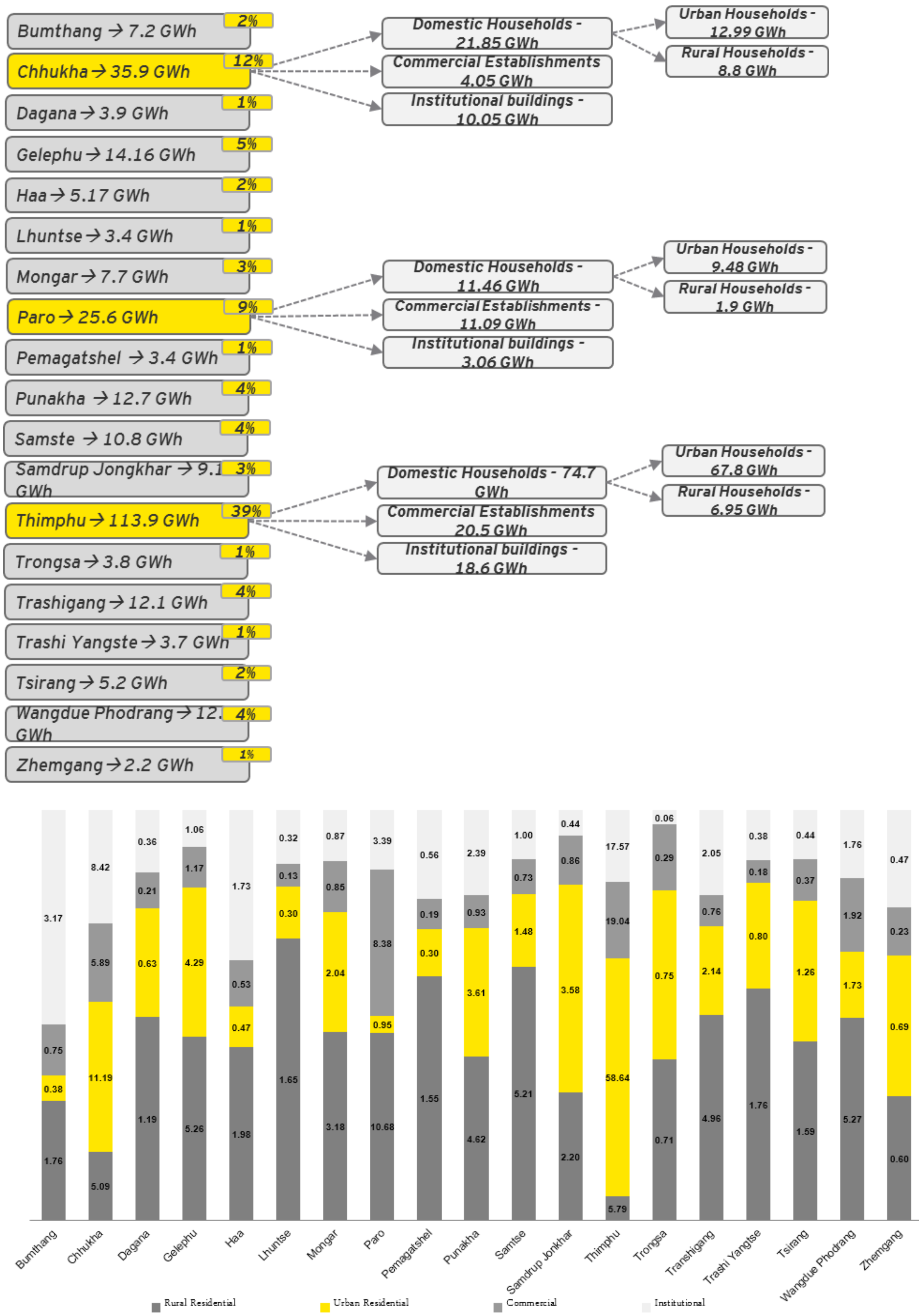

*Source: BPC power data book 2014*

The energy usage pattern has also been documented across different typologies of buildings based on use. Thimphu is the most electricity consuming district with the maximum consumption in urban residential sector. The following exhibit demonstrates share of each

[2] As per the Bhutan Energy Data Directory 2015
[3] BPC Power Data Handbook 2014

type of use in terms of electricity consumption in each district[4].

**Figure 1.3: District-wise share (%) of electricity consumption for different buildings**

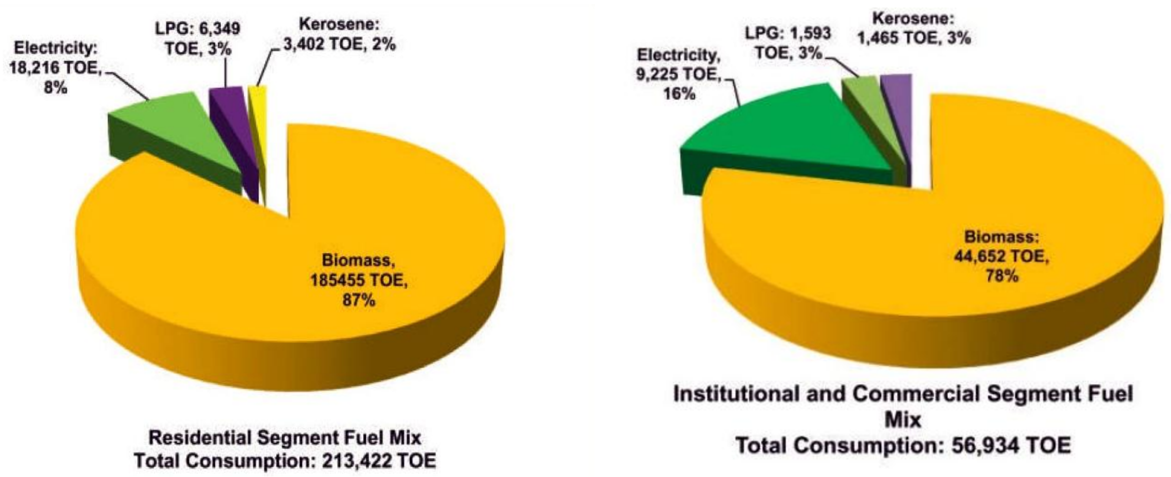



[4] Information procured from BPC Power Data Handbook 2014

*In the urban residential households, which are the highest consumption segment in buildings,* ***Thimphu Dzongkhag consumes around 60% of the electricity as per BPC Power data Handbook 2014****. It is worth noting, however, Thimphu accounts for only 48% of the number of consumers. With average urban population per electricity connection at 5.6, which is among the lowest in the country, this is an indication that with growing affluence and access to electricity, the per capita consumption is probable to increase substantially.*
*The per capita electricity consumption in the average urban household is close to 3 times that of the comparative rural household. However, the population per electricity connection is roughly the same in both* ***urban and rural households at 7.5 and 7.3*** *respectively. With increasing access to electricity and electrical appliances, based on the trends observed, it is possible to expect that the per capital electricity consumption would increase even as the addition of new consumers flatten over the next ten years.*

The predominant contribution of thermal energy (fuels) in the domestic buildings segment is through the use of firewood. Consumption of fuelwood contributed to 184,289.70 TOE., accounting for 94% of the thermal energy (fuelwood, petroleum products, coal) consumption in buildings segment (residential, commercial, institutional) .

**Figure 1.4: Fuel Consumption in Buildings**




*Source: Bhutan Energy Data Directory 2015*

The domestic consumption of Liquefied Petroleum Gas (LPG) accounted for 8,372 TOE in 2011 and 7941.97 TOE in 2014 followed by kerosene at 4,810 TOE in 2011 and 4,866.52 TOE in 2014 (outcomes from Energy Data Directory 2015 under preparation). Between 2005 and 2011, the consumption of LPG has seen a substantial growth at 6.77% CAGR.

## 1.2 Need for Energy Efficiency in Bhutan

**Increasing domestic electricity consumption**

Bhutan exports electricity generated from Hydro Power to India which is the other major revenue generating component in Bhutan's GDP, only second to agriculture. Income due to export of electricity is approximately 10% of the GDP at present.

A steady increase in domestic electricity consumption is also observed which is affecting the nation's income. About 27% increase in domestic electricity consumption during the year 2008-09 has reduced the export by around 8.5%[5]. The electricity costs to the exchequer have also been increasing for the last few years. At the end of 2011, the electricity cost due to domestic consumption was Nu. 759.8 Million and at end of 2013 it increased to Nu. 1091.8 Million[6], having increased at a CAGR of 20%. Any effort in energy efficiency improvement in domestic sector would result in domestic cost savings as well as in added national revenue from cross border sale of electricity. Bhutan has witnessed a steady rise in the cost of importing fuel for Bhutan's transport and industrial applications, and hence the pursuit of EE would also entail reduction of this import and improvement of fiscal deficit. The pursuit of EE in developmental activities is expected to lead to co-benefits like employment generation, market creation for new technologies and other economic activities. The energy saved from the EE interventions can be channelized into these new activities thereby potentially leading to increased resource productivity and GDP.

This assignment has hence identified the four sectors of the country's economy, namely Appliance Sector, Industry Sector, Building Sector and Transport Sector where energy efficiency practices may be applied, or improved upon. The need for energy efficiency in the Building Sector is discussed below.

[5] http://www.edc.uri.edu/mesm/docs/majorpapers/ulmasova_2013.pdf
[6] BPC Power Data Handbook 2013

**Need for Energy Efficiency in Building Sector**

The Building Sector accounts for 15% of electricity consumption in the country, and 88% of low voltage consumption in Bhutan. The biggest parameter responsible for consumption is space heating in colder regions and space cooling in warmer areas of the country.

Bhutan, though a power surplus country is required to import power during winter months to meet the domestic demand of the country. In 2013, Bhutan exported 5,557 million units (MU) of energy worth about Nu 11B while it has imported 108 MU worth around Nu 222M. Whereas in 2014, exports dropped to 5,044 MU and imports increased to 187 MU[7], indicating significant revenue loss. Hence this is one of the most important drivers for implementation of energy efficiency in buildings, especially domestic sector to reduce consumption during peak periods, which would reduce the requirement for power import in the country.

It was observed during the energy audits that building envelope plays an important role in preventing heat loss from a building in a cold climate, and the reverse in a warmer climate. Most of the buildings demonstrated presence of cracks or gaps in masonry joining, which were as wide as 3cm[8]. Lack of sufficient insulation, choice of building materials, orientation etc. are also reasons responsible for decreased energy performance of the building. The average energy loss of a building in Bhutan is analyzed to be around 97 kWh/year[9], which can be reduced through adoption of energy efficient practices.

## 1.3 Objectives of the study

The primary objective of this study is to understand and analyze the current energy situation in the Building Sector and its contribution to the total energy consumption in the country; evaluate thermal performance of the buildings and identify targeted energy efficiency measures and recommendations. This study is also intended to propose recommendations covering policy, regulatory and strategic measures for the Building Sector that could be adopted for formulation of the overarching National Energy Efficiency and Conservation Policy.

[7] http://www.kuenselonline.com/electricity-import-to-increase-until-2017/#.VPHst00cSM8
[8] Energy audit findings
[9] Analysis conducted by EY based on energy audit findings

## 1.4 Scope of study

This study is intended to be used for the formulation of a comprehensive Energy Efficiency and Conservation Policy which will promote and govern the energy conservation practices. In the Building Sector, the study is expected to undertake and document the following:

► Conduct detailed energy audits for buildings in different zones

► Propose recommendations for the government to improve energy efficiency in Building Sector

► Propose policy instruments related to the Building Sector.

► Present cost benefit analysis of each recommendations, guidelines and instruments where relevant.

► Provide policy recommendations for the sector to frame the overarching National Energy Efficiency and Conservation Policy

► Review existing draft Building EE Code and suggest areas of improvement/ recommendations

**Table 1.1: Focus areas covered in the study**

| **Building Sector in Bhutan** | |
|---|---|
| **Scope of Study** | |
| **Baseline energy consumption** | Inventory of different energy systems and interactions in use for buildings |
| **Energy efficiency level** | Identification and quantification of energy efficiency potential, costs and benefits. |
| **Energy efficiency interventions** | Identification of possible energy efficiency interventions and implementation strategies. |
| **Recommendations** | Recommendations covering policy, regulatory, technological, economical, financial and social aspects. |

## 1.5 Overall Approach

The following four workstreams were deployed in meeting with the objectives of the study:

► Step 1: Background Research: Review of Documents on buildings and construction segment in Bhutan

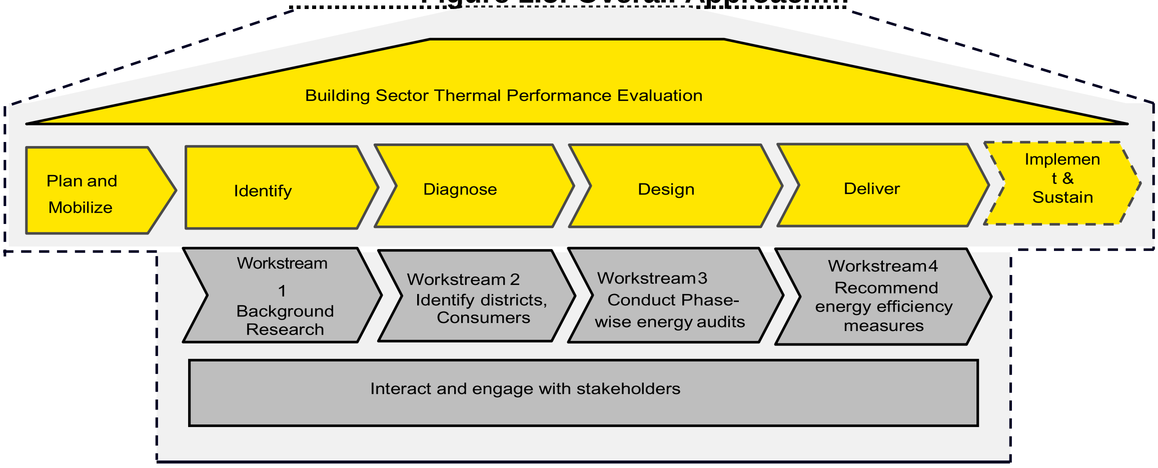
► Step 2: Identification of districts and consumers for energy audit based on energy consumption levels

► Step 3: Conduction of Phase-wise detailed energy audits

► Step 4: Evaluation of thermal performance of buildings

► Step 5: Identification of energy efficiency measures and evaluate potential energy savings

**Figure 1.5: Overall Approach…**




## Step 1: Background Research

The approach undertaken towards analysis of building energy performance consist of extensive review of existing documents in Bhutan pertaining to the buildings and construction sector. Bhutan predominantly has the presence of the following documents, policies, and strategies etc. which have been thoroughly reviewed for the purpose of analysis.

The review helped generate a platform for identification of existence of areas in which interventions would be formulated, as detailed in the subsequent chapters. In conjunction with a detailed review of existing policies in this sector in Bhutan, a review of best practices in geographies with similar climate was conducted to identify energy efficient interventions in buildings.

**List of policies, rules, and guidelines etc. in Building Sector in Bhutan which have been reviewed during course of this assignment:**

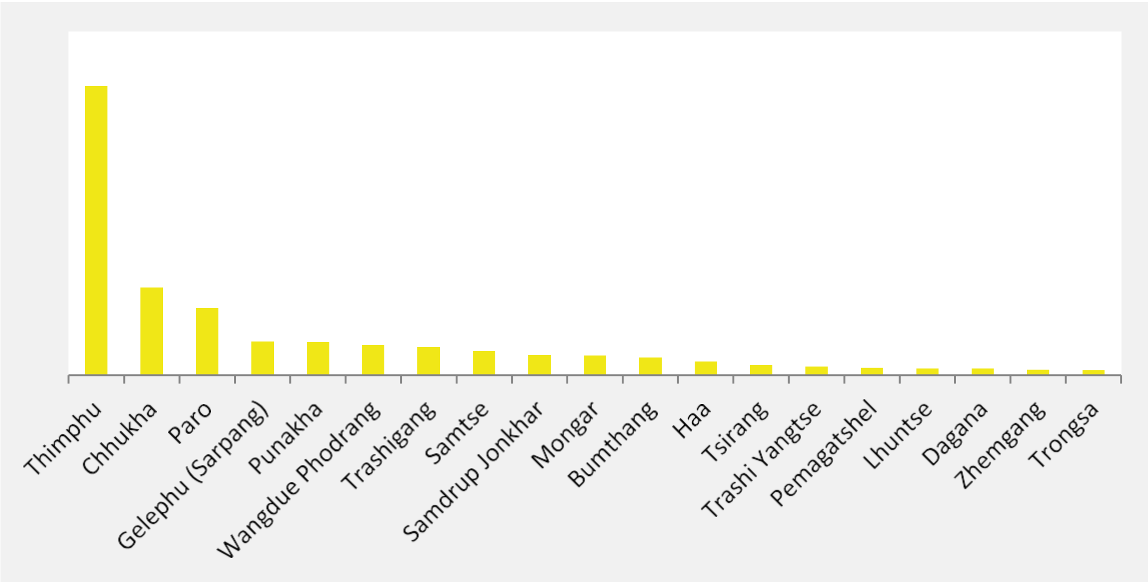
- ►Bhutan Building Rules, 2002
- ►Green Building Guidelines, 2013
- ►Guidelines For Planning and Development of Human Settlements, 2013
- ►Rural Construction Rules 2013
- ►Heritage Sites Bill of Bhutan 2015
- ►Traditional Architecture Guidelines 2011
- ►Bhutan National Urbanization Strategy 2008
- ►Attic Rules 2009
- ►Thromde Rules of Kingdom of Bhutan 2011
- ►Thimphu Municipal Development Control Regulations 2004
- ►Thimphu City Development Strategy 2008
- ►Bhutan Building Energy Efficiency Code (Draft) 2011

**Step 2: Identification of districts and consumers for building audits**

A top-down approach was adopted for selection of buildings for the purpose of conducting building audits in Bhutan. The districts were identified and selected based on energy consumption in Building Sector in each district. Electricity consumption varies from district to district based on the climatic condition of the same, which influences the consumption pattern and use of space heating equipment. The highest consuming districts for building categories were identified based on the above considerations.

The following diagram shows the rank-wise distributions of districts in terms of electricity consumption in the country. The energy consumption for each district based on each type of building has been identified to select buildings for audit, which is necessary for identification of consumers based on type of building and its consumption level, as detailed out in this report.

**Figure 1.6: Rank order distribution of districts based on electricity consumption**




Based on the energy consumption pattern of different building typologies in each district, and the documentation of top ten consumers of electricity in districts for each type of building use, the buildings to be audited were identified. The criteria considered was type of building based on use, such as residential, commercial (hotels, shops, markets), institutional (office buildings, schools, colleges, hospitals).

**Step 3: Phase wise audit -Phase I (Cold weather regions) & Phase II (summer regions)**

The buildings identified in each district for energy audit were phased out for auditing based on the climatic conditions of the district, and assessment of the period of the year when energy consumption in buildings is highest. Districts like Bumthang, Thimphu, Paro have cold winters, and December to February is primarily the duration when these districts make maximum use of space heating appliances and equipment like heaters, Bukhari etc. However, places like Gelephu in Sarpang district have summers (April, May, and June) with relatively higher temperatures due to which space cooling appliances such as fans and air conditioners are used. Hence conducting building audits in two phases to understand the peak consumption patterns in both these situations was deemed important.

The first phase, or Phase I, which were conducted in the aforementioned districts has successfully captured the consumption patterns in winter seasons in the extreme temperatures, witnessing wide use of electric heaters, centralized heating systems, firewood based Bukhari and kerosene based heaters.

The Second phase, Phase II which was conducted during the summer seasons at Gelephu in Sarpang district, Samdrup Jongkar, Chhukha and Samtse intends to document the peak consumptions predominantly for space cooling, among consumption by other appliances.

***Step 4: Evaluation of thermal performance of buildings***

Specific questionnaires/data formats were developed to collect energy data and conduct energy audit in buildings. Site visits were conducted across Thimphu, Phuentsholing, Bumthang and Mongar to collect data in varied geographies and further interact with stakeholders in Building Sector of Bhutan.

### Analysis of energy efficiency (EE) potential

During this phase, the baseline energy efficiency data was analyzed and priority areas for energy efficiency were identified. The views of stakeholders identified were incorporated while conducting this analysis.

**Step 5: Identification of energy efficiency measures and evaluate potential energy savings**

Post energy audit of buildings, the present energy consumption scenario has been identified through analysis. This aided in formulation of interventions towards increased energy efficiency of the sector, for providing suitable policy recommendations.

# *Chapter 2: Building sector in Bhutan*

The Building Sector in Bhutan is well known for its traditional architecture and extensive use of wood for construction. This chapter introduces the Building Sector, with deep focus on typology of buildings, construction techniques, use of modern and traditional materials and other parameters of building orientation and form, and identifies the impact of urbanization and increased electrification on the energy performance of Building Sector in Bhutan.

## 2.1 Types of buildings in Bhutan

The types of buildings may be identified based on category of use, building construction technology or materials used. This varies from one region to other depending on the type of climatic zone the particular region falls under. Buildings may broadly be categorized based on type of use as:

**Figure 2.1: Building typologies in Bhutan**

**Residential building**
(Single ownership bungalow type, apartment type, quarters, etc.)

**Commercial building**
(Private office buildings, shops, hotels, restaurants, etc.)

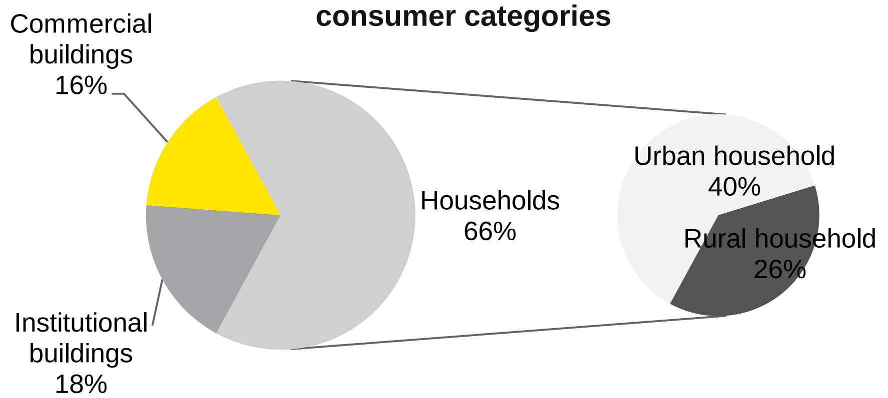
**Institutional building**
(Government buildings, academic institutions, hospitals, etc.)

The buildings were carefully observed during energy audit, which revealed that there exists difference in type of construction of buildings in urban and rural areas. The urban buildings are of a larger scale, and use of modern construction materials like glass and steel is widely seen, whereas the rural structures adhere to use of local traditional materials and are generally of a smaller scale. In rural areas, the traditional *Sa Khem* houses are prevalent and a range of variations (especially with respect to building materials) can be observed. The urban and sub-urban housing stock is dominated by reinforced-concrete (RCC) frame buildings (with infill walls) up to 6 storeys high. A common feature of all types of construction in Bhutan is the arrangement of an attic that is mostly left open. The light roof construction (mainly made of timber, in few cases made of steel tubes, or CGI) rests upon posts made of timber, masonry or RCC. Common features of a large percentage of vernacular building typologies are sloping roofs (because of high probability of heavy snowfall), open attics (for storage and air circulation purposes), and large openings in exterior walls, especially upper floors (to allow for natural lighting).

## 2.2 Electricity consumption by various building types in Bhutan:

The urban domestic households contribute to the maximum electricity consumption in the buildings segment. The urban households alone consumed 127.10 GWh of electricity from the total of the 318.13 GWh of electricity consumed by buildings segment, out of which 83.86 GWh in rural, 127.10 GWh in urban, 51.58 GWh by commercial buildings and 55.59 GWh by institutions in Bhutan in 2014 as per BPC Power Data Handbook 2014.

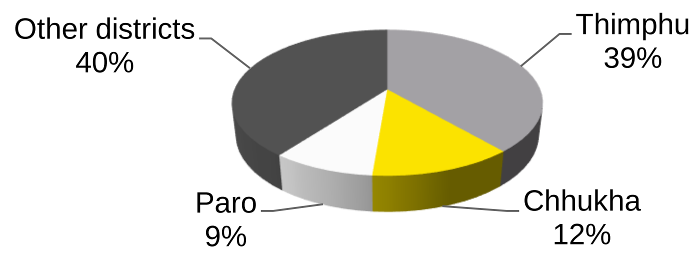
**Figure 2.2: Breakup of electricity consumption by various consumer categories**




*Source: BPC Power Data Handbook 2014*

On region-wise analysis, it is noted that the buildings in Thimphu alone has consistently accounted for more than 39% of the electricity consumption in buildings segment. Buildings in Thimphu Dzongkhag consumed more than 110 GWh of electricity in 2013[10]. The buildings in Thimphu, Chhukha and Paro Dzongkhags put together accounted for 60% of the electricity consumption in the buildings segment in Bhutan in 2013.

**Figure 2.3: Electricity consumption break up of various districts in Bhutan**




*Source: BPC Power Data Handbook 2014*

[10] BPC Power Data Handbook 2014

## 2.3 Construction practices in Bhutan

Buildings in Bhutan belong to three main typologies with respect to style, spatial planning and scale.

- The large imposing Dzong (fortresses) which are the municipal and religious headquarters in each district,
- Residential houses which are large rural farmhouses and urban structures
- Religious structures of various kinds (from large temples to small chortens or stupas).

These are mainly built with strict adherence to traditional vernacular architecture, constructed out of rammed earth, stone and timber, with a style that is quite distinct and very unique. This chapter details out the trends and practices in building construction observed in Bhutan, with a top-down approach analyzing the overall form and orientation of structures on site, and the construction techniques for each building component along with the typical material used for its construction. It is observed that buildings in Bhutan generally are built so as to maximize passive solar gain, and choice of materials also contributes to better overall energy performance in a building. The same is established through a detailed summary of observations in the subsequent sections.

**Building orientation and form:**

Bhutanese buildings have an orientation intended to reduce heat losses and maximize passive solar heat gain. The villages demonstrate arrangement of trees and houses so as to provide each other with maximum wind shelter. Rammed earth buildings make use of thermal mass and wind sheltering to create outdoor hot zones both between buildings in a cluster and around the building through construction of a 2 meters high boundary type wall.

**Figure 2.4: Typical rammed earth buildings in Bhutan**



**Construction of Building components in Bhutan: Techniques and Materials:**

As discussed earlier, Bhutan uses locally available materials for construction of buildings that are climatologically responsive as well. A building is essentially made of the following components, or elements like foundation, walls, openings and fenestrations, floors and roofs. This section would discuss the observations with respect to each component in terms of construction technology, use of materials and climate efficient nature of the buildings.

**Roof:**

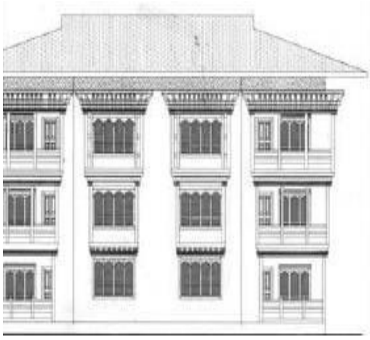
In traditional Bhutanese architecture the roof feature and associated elements signify hierarchical order and one's status in society. The roof features are Jabzhi, Jamthog and Lung-go and associated elements are Sertog, Gyaltshen, and Gungdhar.

The most common traditional Bhutanese roof is a gable roof, which consists of a heavy principle beam known as Gungchhen, Gungchhung, and Lungzey supported by a series of vertical posts. Traditional roof pitches are 12 to 15 degrees.

Roofs based on their form and shapes are of three types in Bhutan, gable roof, hipped roof and lean-to roof. The most traditional form of roof is a gable roof, finished with timber shingles, but it also suitable for any other type of modern roofing material. As per Bhutan standards, this rule is permissible on any structure. The hipped roof is a modern style of roofing gaining popularity in Bhutan with the advent of new roofing materials like Corrugated Iron Sheets and roofing tiles.

**Figure 2.5: Roof typologies in Bhutan**

*Traditional Bhutanese roof*



*Gable roof*

*Hipped roof*

**Wall:**

Buildings in Bhutan traditionally have walls of rammed earth, stone or rubble and bricks. Rammed earth buildings generally have a minimum wall thickness of 500mm, which increases if the building is more than one storey high, and Bhutan in general does not adhere to slender construction practices in case of mud construction. To offer better reinforcement in an adobe construction, bamboo strips, or wooden planks are inserted in the middle of each mud block and at the corners and towards the middle of the wall and do not incorporate ring beams or vertical reinforcement. They demonstrate good seismic performance by stabilization through mass.

**Figure 2.6: Use of materials for wall construction in Bhutan**


**Foundations:**

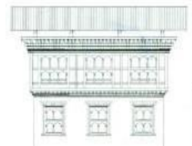
Foundations of buildings in Bhutan are strip footings made from rubble stone masonry and mud mortar, or cement mortar. In modern Bhutanese buildings, reinforced concrete footing is observed, and foundation width and depth do not exceed 400 mm. For a one to two storeyed building with load bearing structure, the depth of foundation is generally 1200 mm with width of 900 mm, and for a three storeyed building the depth of foundation is 1800 mm with width of 1000 mm and for a four storeyed building, depth of 1800 mm and width of 1200 mm. The height of plinth generally ranges from 600 mm to 900 mm in any structure in Bhutan, with a good drainage system seen in Bhutanese construction practice.

## Rabsel:

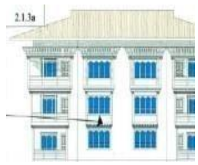
Rabsel is an element of Bhutanese buildings made of timber constructed with a series of vertical as well as horizontal members usually found in the upper storeys of traditional building structures with a symmetrical distribution of infill panels called Ekra and window openings.

**Figure 2.7: Rabsels in Bhutan**

Parop Rabsel



Go-chham Thognyim



Lobur Rabsel

Boedgo and Gyesargo Rabsel

Gomang Rabsel

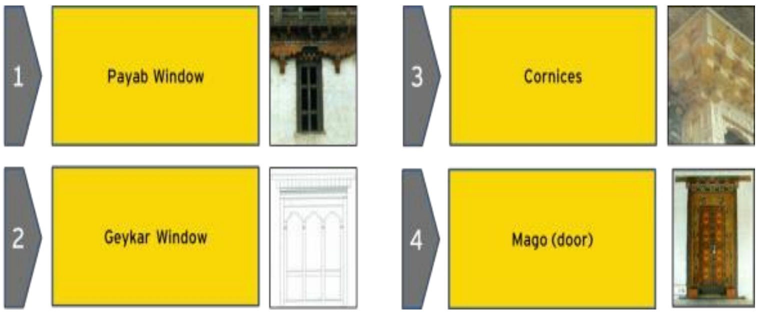
Nimchong Rabsel

## Windows and Doors as openings

Windows are of two types: Payab window and Geykar Window. The Payab Window is embedded in the wall and has less traditional decorative components. Geykar window is rectangular and embedded in the wall, with or without cornices.

Geykar openings are narrower than Payab windows. Entrance doors in Bhutanese construction are known as Ma-go, which when placed next to windows, cornices would be provided to match with window cornices.

**Figure 2.8: Payab and Geykar windows and Mago in Bhutanese Architecture**



**Kachhen and Zhu**

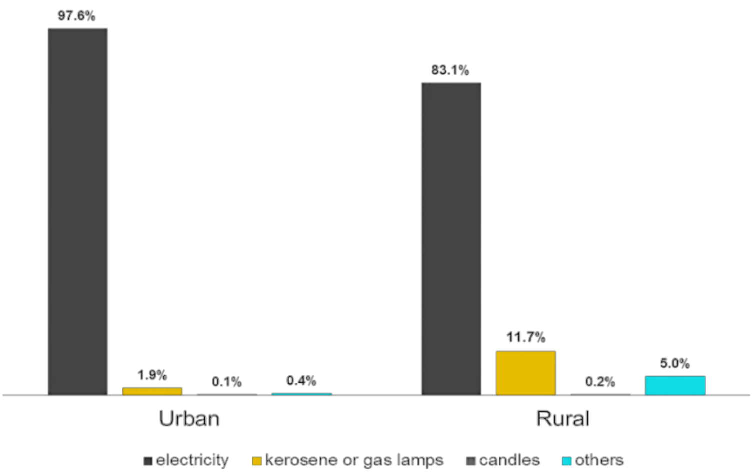
A Kachhen is the timber column that is tapered and has a distinct Kachhen head and Rap separated by a line of Cheyim or a Rosary bead. Traditionally the Kachhen was found in Dzongs Monasteries and Royal buildings. They are very rarely found in residential buildings. However, in recent times, the use of Kachhen in commercial buildings and ordinary houses has become very common.

## 2.4 Lighting practices and efficient lighting options

**Current lighting practices in Bhutan**

Electricity is the main energy source for lighting in 88% of households (98% in the urban areas, 83% in the rural areas). In the rural areas, 12% of households used kerosene or gas lamps for lighting in 2012. The use of electricity for lighting increases together with per capita consumption.

**Figure 2.9: distribution of households by source of energy used for lighting**




*Source: Bhutan Living Standards 2007*

Bhutan demonstrates use of different forms of lighting using electricity in urban and rural households, commercial and institutional buildings. Throughout all these categories, use of fluorescent tube-lights in the form of T12 lamps of rating 36/40 Watts are widely used in the country. More efficient fluorescent tube lights like T5 and T8 are also used mainly in non-residential buildings. Apart from fluorescent lamps, incandescent bulbs of wattage mostly 60W or 100W are used across the residential sector in Bhutan. Commercial and institutional buildings often use CFLs and sodium vapor downlights embedded in ceiling. Both these lighting techniques are energy efficient compared to T12 fluorescent tube-lights and incandescent bulbs. Lighting in compounds of institutional and commercial buildings accounts for a high share of the total lighting demand in Bhutan, which is mainly in the form of mast and bollard lighting, using High Pressure Sodium Vapor Lamps. Hence use of efficient lighting for not only residential and commercial/ institutional buildings is important, but also for compound lighting.

**Efficient lighting programmes in Bhutan**

Bhutan has recognized the importance of installing efficient lamps in all sectors of the economy. As per the Regional Report on the Transition to Efficient Lighting in South Asia by UNEP, in 2004, in Trongsa and Bumthang, around 8000 CFLs were distributed to consumers at the subsidized price of USD 0.5 per piece. The demand was high which led to an additional procurement of 11,000 CFLs, leading to a reduction of peak energy demand by 641 KW. Additionally, these two districts did not experience load shedding which resulted in savings of approximately USD 112 million.

**Efficient lighting options for Bhutan**

**a) Use of Light Emitting Diode (LED) lighting**

LEDs are known to be the most efficient and durable lighting options available. A good quality 7 Watt LED performs on par with a 40 Watt incandescent bulb, and the LED lasts up to 15 to 20 years. Because LEDs have no filament or tube to break, they are also very durable. LED on a global level has replaced CFLs owing to the growing concern about the mercury content of CFLs. LEDs do not contain mercury, making them a safer, more efficient way to reduce energy consumption. LED lighting in residences can help reduce electricity consumption and its durable nature makes it a more useful lighting option. LEDs in urban residences are often used as downlights embedded in false ceilings. LED lighting is a very effective option for commercial and institutional buildings as well due to their durability, high performance and ability to generate different forms of ambient lighting. The following table demonstrates the cost and energy savings by replacing current lighting practices with LED in Bhutan.

**Table 2.1: Typical energy and cost savings by installing LEDs**

| | LED | CFL | Incandescent |
|---|---|---|---|
| Light bulb projected lifespan(hours) | 50,000 | 10,000 | 1,200 |
| Watts per bulb (W) | 7 | 14 | 40 |
| Cost per bulb (Nu) | 550 | 120 | 10 |
| Electricity used over 50,000 hours (kWh) | 350 | 700 | 3,000 |
| Cost of electricity (@ Nu 2.15 per kWh) | 752.5 | 1505 | 6,450 |
| Bulbs needed for 50,000 hours of use | 1 | 5 | 42 |
| Equivalent 50,000 hours bulb expense | 550 | 600 | 420 |
| **Total cost for 50,000 hours (Nu)** | 1,302.5 | 1782.5 | 4,720 |

*Source: EY Report on Piloting, Scaling up and Distributing WLED Program under Energy Plus Project, 2014*

## Solar Compound lighting

Concerns over global climatic change, local air pollution and resource scarcity make photovoltaic an attractive energy supply technology. Using solar energy with LEDs provides a very efficient compound lighting solution.

**Benefits of using Solar LED Street lights**

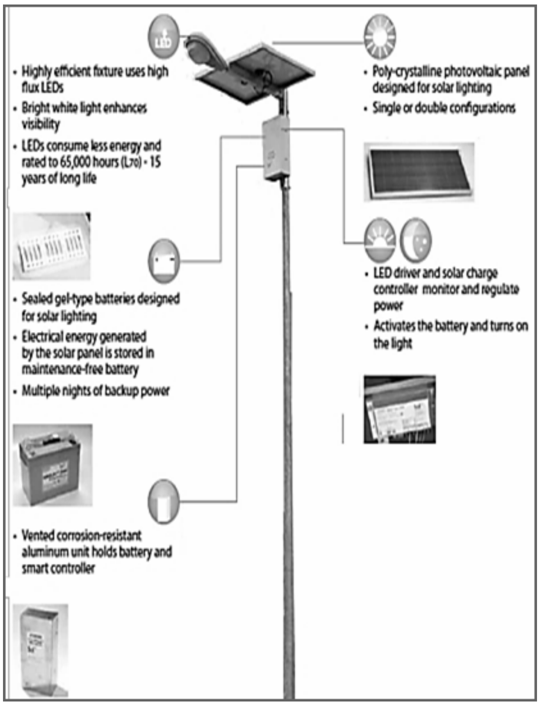
**Cost-effective:** requires no trenching, cabling or electrical grid connection

**Easy to install:** minimal technical expertise required

**Rugged reliability:** robust design is ideally suited for remote, difficult to access locations,

**Install and forget:** no scheduled maintenance or servicing for up to 5 years and no light bulbs to change

**Environmentally-friendly:** LEDs produce no CO2 emissions




## 2.5 Impact of urbanization and electrification rate in Building sector

Bhutan has witnessed a more or less stagnant growth rate in rural population, with an annual growth rate of 4.9%. Of late, the main contribution to the existing concentration of population in the Western Region is the migration from the other three regions on account of in-migration in the urban areas.

With the steady growth in demand of domestic electricity, the national coincidental load reached 276MW during the year 2011[11]. Moreover the customer base had grown to 1, 16,354 numbers largely on account of rural electrification coverage across all categories, or sectors. In the residential sector, number of rural customers increased from 24,504 in 2004 to 74,441 in 2013, and urban customers from 17,077 to 45,197 from 2004 to 2013. Total number of customers in the Building Sector has had a growth rate of about 13.8% from 2010 to 2011, clearly indicating the high rate of electrification in the country and increased urbanization.

**Table 2.2: Rate of Electrification in Building Sector from 2004 to 2013**

| *No. of Customers* | *2004* | *2005* | *2006* | *2007* | *2008* | *2009* | *2010* | *2011* | *2012* | *2013* |
|---|---|---|---|---|---|---|---|---|---|---|
| *Domestic Rural* | *24,504* | *26,179* | *34,225* | *40,954* | *43,709* | *47,846* | *53,062* | *61,372* | *73,282* | *74,441* |
| *Domestic Urban* | *17,077* | *18,963* | *20,794* | *22,973* | *25,531* | *27,294* | *29,754* | *31,492* | *35,314* | *45,197* |

[11] BPC Power Data Handbook 2011

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Commercial*** | *4,522* | *5,373* | *6,363* | *6,943* | *8,034* | *8,564* | *9,136* | *8,428* | *9,111* | *10,752* |
| ***Institutions*** | *2,778* | *2,698* | *2,894* | *3,315* | *3,676* | *3,958* | *4,333* | *8,343* | *6,274* | *8,929* |
| ***Total*** | *48,881* | *53,213* | *64,276* | *74,185* | *80,950* | *87,662* | *96,285* | *1,09,635* | *1,23,981* | *1,39,319* |

*Source: BPC Power Data Handbook 2013*

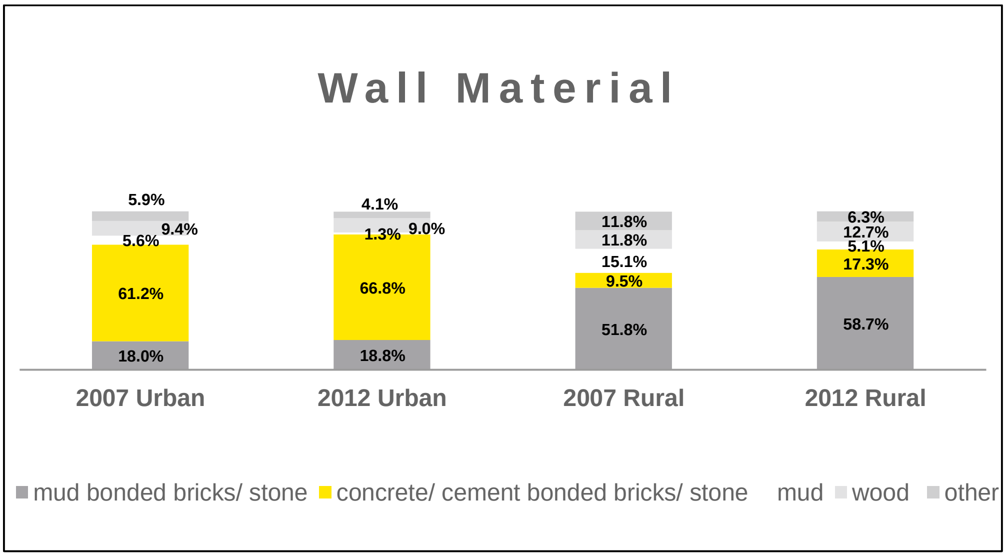
Trend analysis shows that dependence in urban areas is increasing more and more on electrical appliances, and showing reduction in use of thermal appliances for space heating and cooking. This scenario is different from that of rural areas where dependence on electrical appliances for cooking is increasing, but there is not much reduction in use of thermal equipment like Bukhari.

In 2004-05, rural to urban migration was the highest with a proportion of 42%alone[12], among rural to rural, urban to rural and urban to urban migration. In the same year span, the number of electricity consumers had a growth rate of 6% in rural consumption, and 10% in urban consumption. Hence, increased urbanization, a factor of which is rural to urban migration, is to a great extent responsible for increased number of consumers in urban regions of the country.

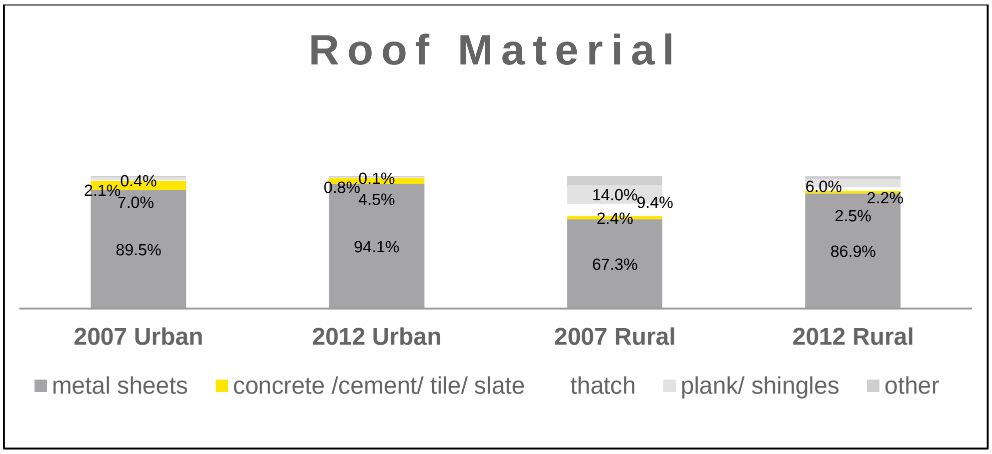
With increased rate of electrification in the country, there is increased dependence on electrical appliances across all categories of Building Sector in Bhutan, which is seen more widely in the urban areas like Thimphu, Phuentsholing and others.

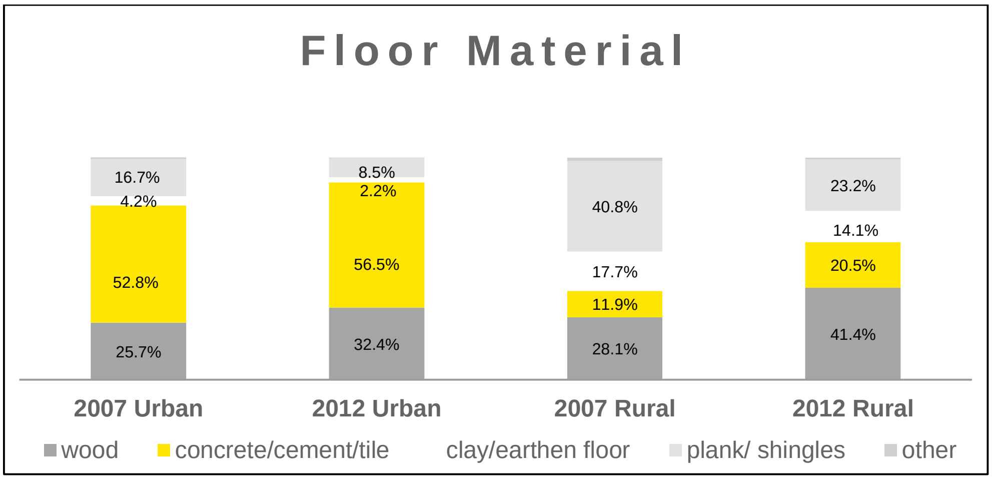
Bhutan, over time has demonstrated a significant shift to brick, concrete and other modern building construction materials from the traditional ones. The brick and concrete structures in urban areas have increased from 60% in 2007 to 67% in 2012 and rural areas from 9% to 17% with reduction in mud/ rammed earth structures14. A similar trend is seen in roof and floor construction, demonstrating increased use of modern materials. This trend is demonstrated statistically in the figure below.

**Figure 2.10: Shift to brick and concrete for use in construction from 2007 to 2012**




[12] Bhutan Living Standards 2007



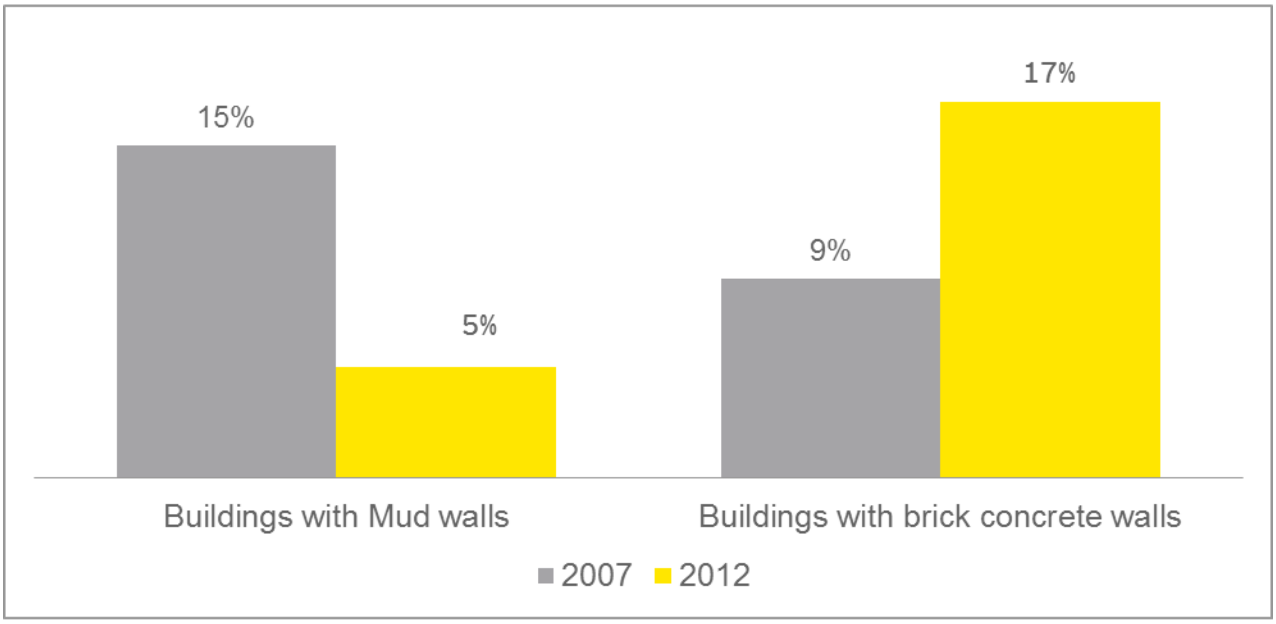



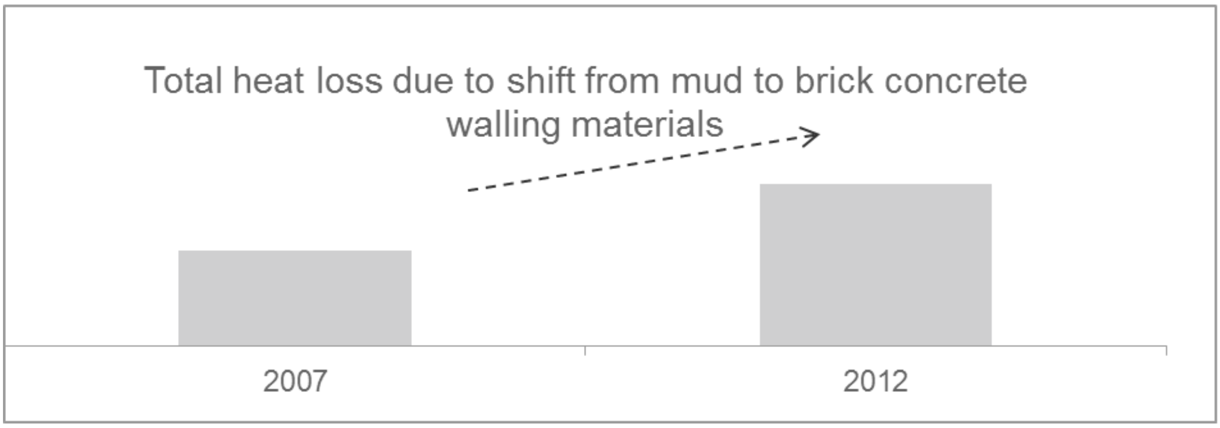

*Source: Bhutan Living Standards 2007, 2012*

This trend of increase in urban customers in the urban districts of the country has a possibility of inducing change in construction technology, with more number of brick and concrete modern traditional construction practices and materials, increased use of concrete, glass, bricks etc. a shift from traditional rammed earth and stone buildings. Hence increased electrification in urban areas of the country may imply more number of buildings adhering to urban construction technologies and materials, which have strikingly different building energy performance from a traditional building in Bhutan.

An analysis of the shift in usage of building materials from traditional mud to brick and concrete structures reveals that over the period of time, heat loss in buildings due to walls in 2012 have almost increased to 1.7 times the heat loss in 2007, due to reduction in mud construction and increased number of buildings with walls using modern materials like brick and concrete. This implies that energy efficiency of construction due to choice of walling materials has decreased over the years. The same is graphically represented below:

**Figure 2.11: Effect on energy efficiency due to shift to brick and concrete for use in construction from 2007 to 2012**



# *Chapter 3: Climate of Bhutan*

The climate in Bhutan is extremely varied. This variation in the climatic conditions and average temperature can be attributed to two main factors:

- The vast differences in altitude present in the country and
- The influence of the north Indian monsoons

This chapter explains the various climatic zones in Bhutan and the need for thermal comfort of buildings. This chapter also explains the climatic factors affecting the building thermal performance and its impact on the country's energy scenario.

## 3.1 Climatic zones of Bhutan

The country of Bhutan is divided into three distinct climatic zones corresponding broadly to the three main geographical divisions. The southern belt has a hot humid climate while central Bhutan has a cool temperate climate. The northern region has severe alpine climate and is perpetually under snow. Rainfall can differ within relatively short distances due to rain shadow effects. The three climatic zones are as follows.

- Sub-tropical
- Mid- Montana
- Alpine


The subtropical zone lies at an altitude of 5,900 sq ft between the foothills along the Indo-Bhutan border and the mid Montana ranges.

This zone is characterized by steep slopes and dense forests. This zone is warm in winter, with very hot, humid and heavy rainfall in summer. This zone may again be categorized into dry, humid and wet subtropical. The mid Montana zone consists of the area from 5,900 sq ft to 11,480 sq ft. This region experiences cold winters, hot summers and more moderate rains. There exist coniferous forests on drier slopes and also in the valleys. Several main valleys are dry for most of the year except during monsoon. This zone may be further classified into cool and warm temperate based on altitude. The northernmost region of the country is categorized as the alpine zone which lies above 11,480 sq ft or 3,500 m. This zone experiences short and cool summers, with severe cold winters having significant snowfall. It is characterized by Tundra vegetation, Alpine meadows, snow covered peaks and glaciers.

## 3.2 Climatic factors affecting thermal performance of buildings

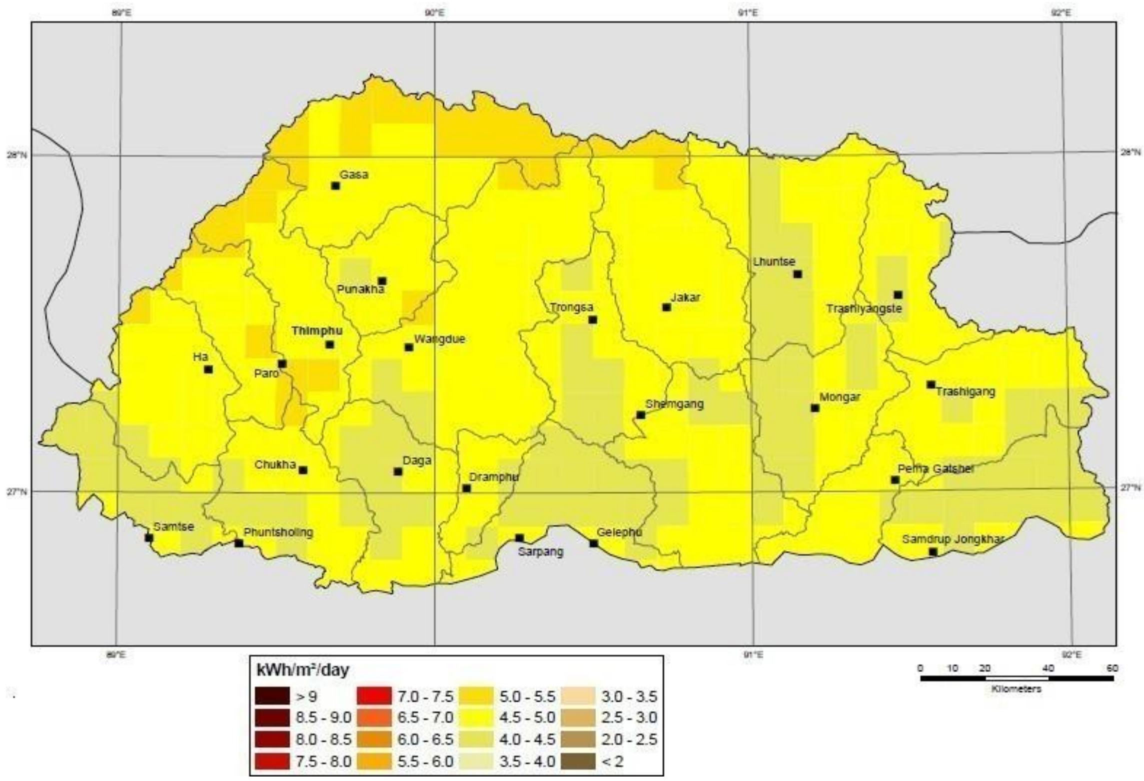
Both weather and climate are characterized by the certain variables known as climatic factors. They are:

- Solar radiation
- Ambient temperature
- Air humidity
- Precipitation
- Wind
- Sky condition

**Solar radiation:**

Solar radiation is the radiant energy received from the sun. It is the intensity of sunrays falling per unit time per unit area and is usually expressed in Watts per square metre (W/m2). The radiation incident on a surface varies from moment to moment depending on its geographic location (latitude and longitude of the place), orientation, and season, time of day and atmospheric conditions. Solar radiation is the most important weather variable that determines whether a place experiences high temperatures or is predominantly cold.

**Figure 3.1: Solar radiation for various locations in Bhutan**

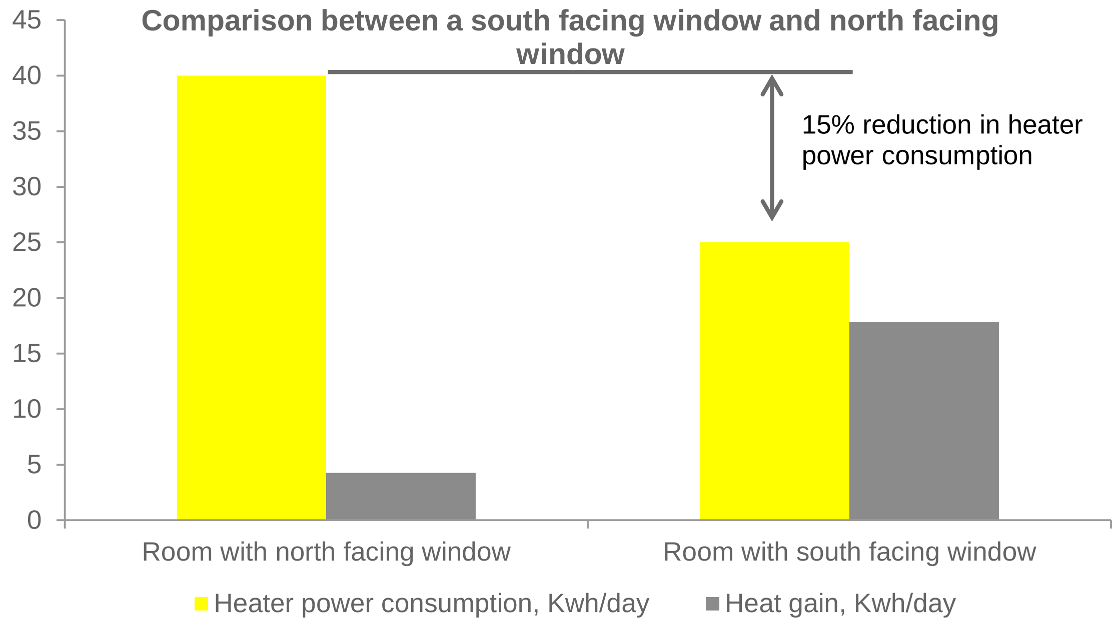



*Source: www.NREL.gov*

**Impact of solar radiation on building thermal performance:**

Solar radiation affects the building performance through adding heat gain to the building envelope. In a cold climate, a building need to gain more heat from solar radiation in order to reduce the heating load, as opposed to buildings in warm climate which need to reduce excessive heat gain. Buildings oriented towards south receives more solar heat gain during winter conditions. Buildings utilizing solar heat gain for heating spaces has the potential to reduce heater power consumption by around 15%.

**Figure 3.2: Comparison between a south facing window and a north facing window**




*Source: EY analysis*

**Ambient temperature:**

The temperature of air in a shaded (but well ventilated) enclosure is known as the ambient temperature; it is generally expressed in degree Celsius (ºC). Temperature at a given site depends on wind as well as local factors such as shading, presence of water body, sunny condition, etc. When the wind speed is low, local factors strongly influence on temperature of air close to the ground. With higher wind speeds, the temperature of the incoming air is less affected by local factors.

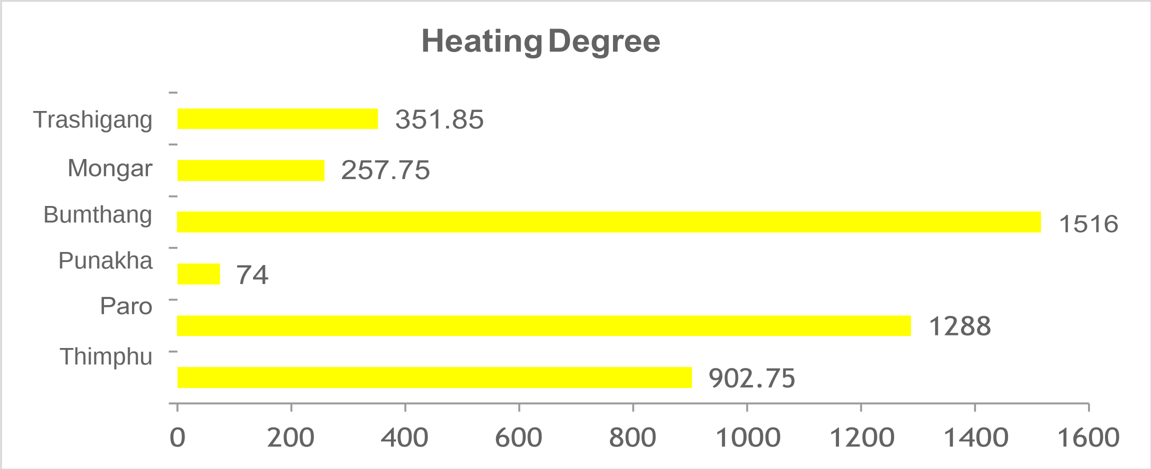
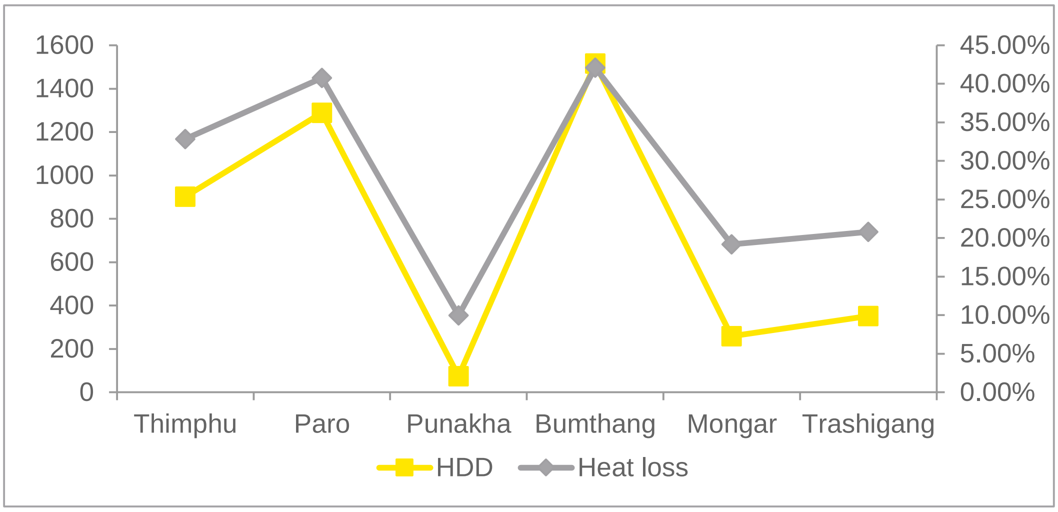



**Figure 3.3: Heating Degree Days for different districts in Bhutan**

## Impact of ambient temperature on building thermal performance:

Ambient temperature is one of the critical factors which affect the building thermal performance. The need for thermal comfort is determined by the ambient temperature of the location. In cold climates, the building envelope loses heat due to the difference in ambient temperature and the room temperature. Higher temperature difference leads to more heat loss through building envelope. The impact of temperature difference (Heating Degree Day) on the building heat loss is given below: In warm climates, Cooling degree-days are used to estimate the energy needed to cool indoor air to a comfortable temperature. The buildings here gain heat due to difference of ambient and room temperatures.

**Figure 3.4: Heat loss vs. HDD**



**Air humidity:**

Air humidity, which represents the amount of moisture present in the air, is usually expressed in terms of 'relative humidity'. Relative humidity is defined as the ratio of the mass of water vapour in a certain volume of moist air at a given temperature, to the mass of water vapour in the same volume of saturated air at the same temperature; it is normally expressed as a percentage. It varies considerably, tending to be the highest close to dawn when the air temperature is at its lowest, and decreasing as the air temperature rises. The decrease in the relative humidity towards midday tends to be the largest in summer. In areas with high humidity levels, the transmission of solar radiation is reduced because of atmospheric absorption and scattering. High humidity reduces evaporation of water and sweat. Consequently, high humidity accompanied by high ambient temperature causes a lot of discomfort. The subtropical zone of Bhutan lies at an altitude of about 1,800 m and experiences very hot and humid climate.

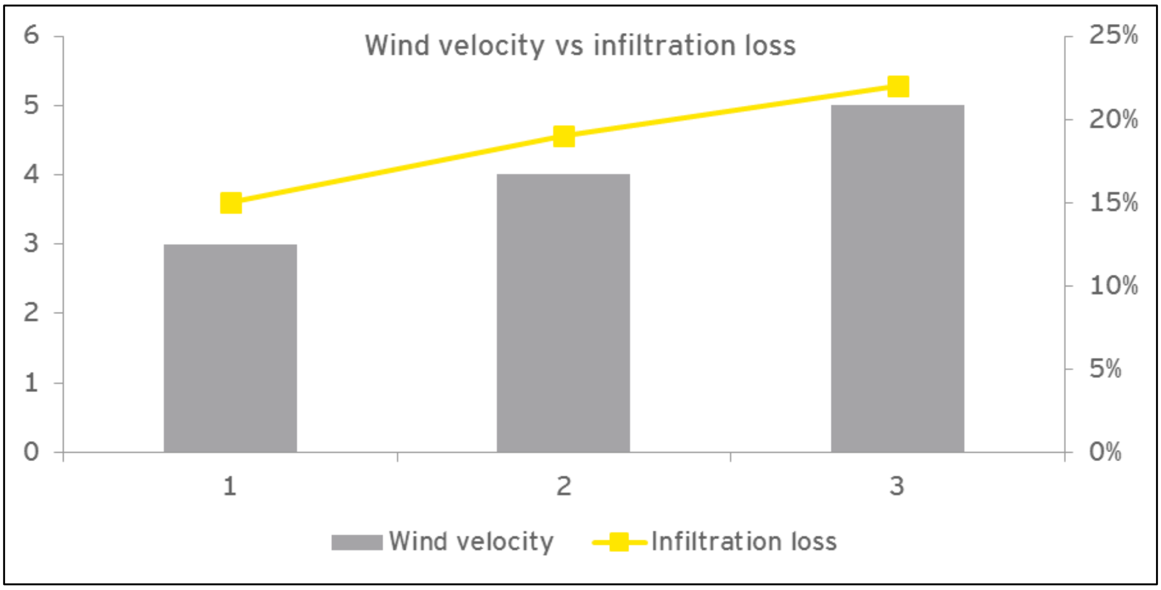
**Precipitation:**

Precipitation includes water in all its forms rain, snow, hail or dew. The sub-tropical zone in Bhutan experiences heavy rainfall whereas mid-Montana zone experiences more moderate rains. Precipitation affects the conductivity of the building materials. Higher precipitation leads to higher heat conduction through building materials.

**Wind:**

Wind is the movement of air due to a difference in atmospheric pressure, caused by differential heating of land and water mass on the earth's surface by solar radiation and rotation of earth. It is a major design consideration for architects because it affects indoor comfort conditions by influencing the convective heat exchanges of a building envelope, as well as causing air infiltration into the building.

**Figure 3.5: Wind Velocity vs infiltration loss**




In areas with higher velocity of wind, or in higher altitudes the infiltration loss is higher, with wind velocity and infiltration loss sharing a directly proportional relationship. The same is illustrated above.

**<u>Sky condition:</u>**

Sky condition generally refers to the extent of cloud cover in the sky or the duration of sunshine. Under clear sky conditions, the intensity of solar radiation increases; whereas it reduces in monsoon due to cloud cover. The re-radiation losses from the external surfaces of buildings increase when facing clear skies than covered skies.

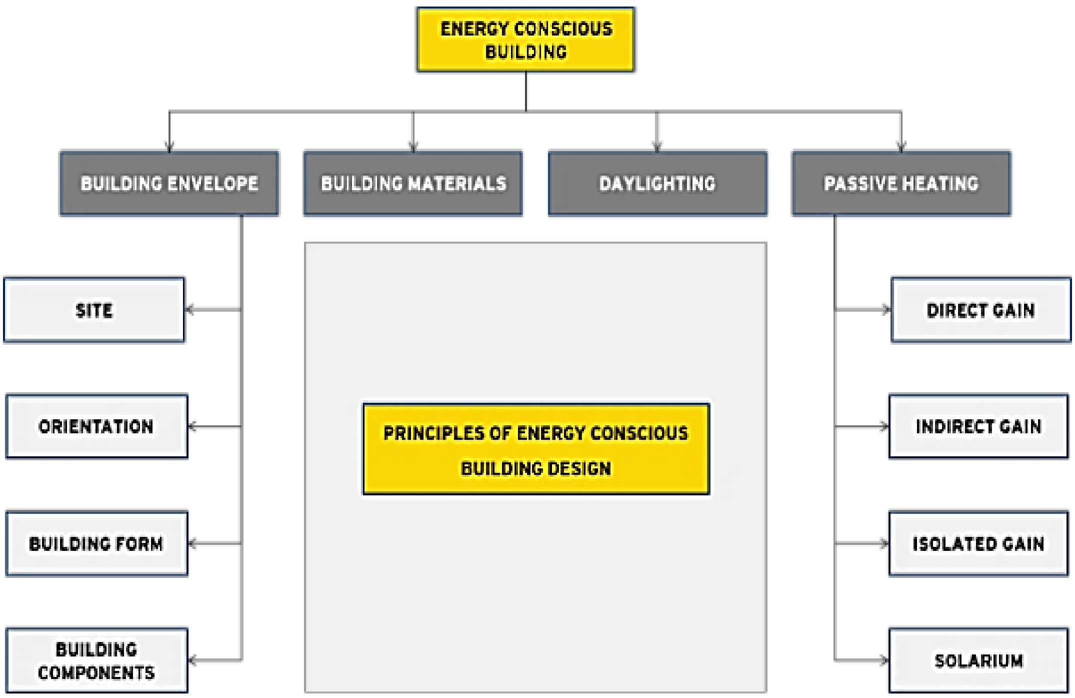
# Chapter 4: Principles of energy conscious building design

## 4.1 Introduction

A building consists of several components and parameters through which heat exchange takes place and makes the construction and operation of a building energy intensive. In Bhutan, most of the districts have colder climate with low temperatures, and hence prevention of loss of heat in order to reduce dependence on artificial heating systems for restoring thermal comfort is extremely essential. Energy conscious design in buildings will help designers and building owners to economically reduce building energy costs, while improving comfort for the building's occupants.

The energy consumed by a building depends on its use (whether residential, commercial or industrial), the type of building (air-conditioned or otherwise), the interaction of spaces, and the climate. Building energy performance is largely governed by the design of a building which includes orientation of the structure, placement on site, choice of materials and form of the building. Another major component of building energy performance is the building envelope, which consists of walls, roof, floor, openings, and fenestration, as detailed in the subsequent sections. All these elements are responsible for heat loss, or gain in a building, which is required to be monitored for reduced loss/ gain in a building.

**Figure 4.1: Principles of energy conscious building design**



## 4.2 Components of energy conscious building design

The principles of energy conscious building design are guided by the overarching needs at two levels:

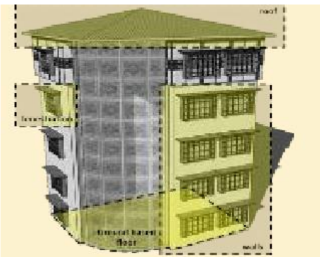
- **Reduce Energy consumption**

A building in cold climate is required to conserve internal heat, maximize heat gain so as to reduce dependence on artificial methods of heating like use of electrical heaters, and other fuel consuming space heating systems. This may be done through effective building design, choice of construction materials and use of heat trapping elements. The reverse is required in warm climates that is to maximize heat loss or reduce internal heat, by use of air conditioners and fans.

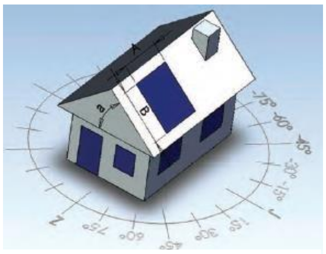
- **Generate energy through use of renewable sources**

Use of innovative modern technologies like rooftop solar panels and their integration with the efficient building design aids in generation of energy which may be used for building operations.

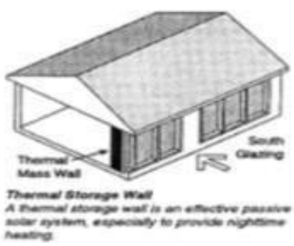
**Figure 4.2: Components of energy conscious building design**



**Building Envelope**: To reduce losses and maximize solar gain



**Building Orientation:** To maximize exposure to sun



**Thermal Storage:** To trap heat during day and provide night time heating

*Source: www.greenpassivesolar.com*

**<u>Building envelope</u>** – also known as the building shell, fabric or enclosure – is the boundary between the conditioned interior of a building and the outdoors. The energy performance of building envelope components, including external walls, floors, roofs, ceilings, fenestrations, windows and doors, is critical in determining how much energy is required for heating and cooling.

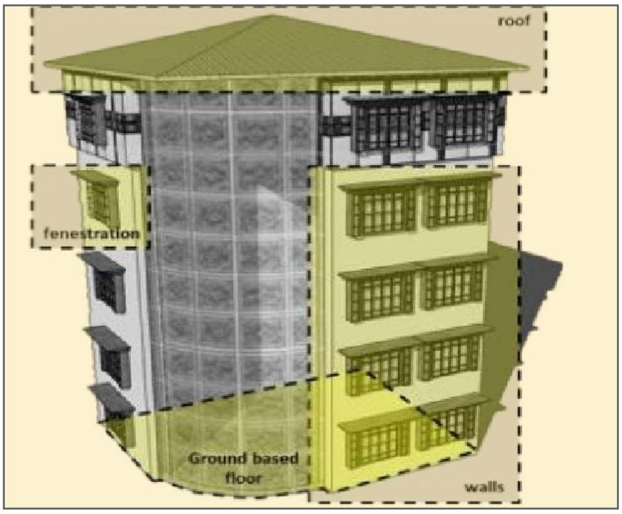
Globally, space heating and cooling account for over one-third of all energy consumed in buildings, rising to as much as 50% in cold climates and over 60% in the residential sub-sector in cold climate countries. Overall, buildings are responsible for more than one-third of global energy consumption. Also the envelope's design and construction also affects the comfort and productivity of occupants.

The different elements of a building envelope are listed as follows.

- Roof
- Walls
- Ground-based floor
- Fenestrations
- External colour and texture

In Bhutan, buildings have long been constructed using local materials to maximize comfort given the local climate. Thus, thick thatched roofs which offered insulating properties were typical used for many years in cold climates. The use of natural ventilation was also very common.

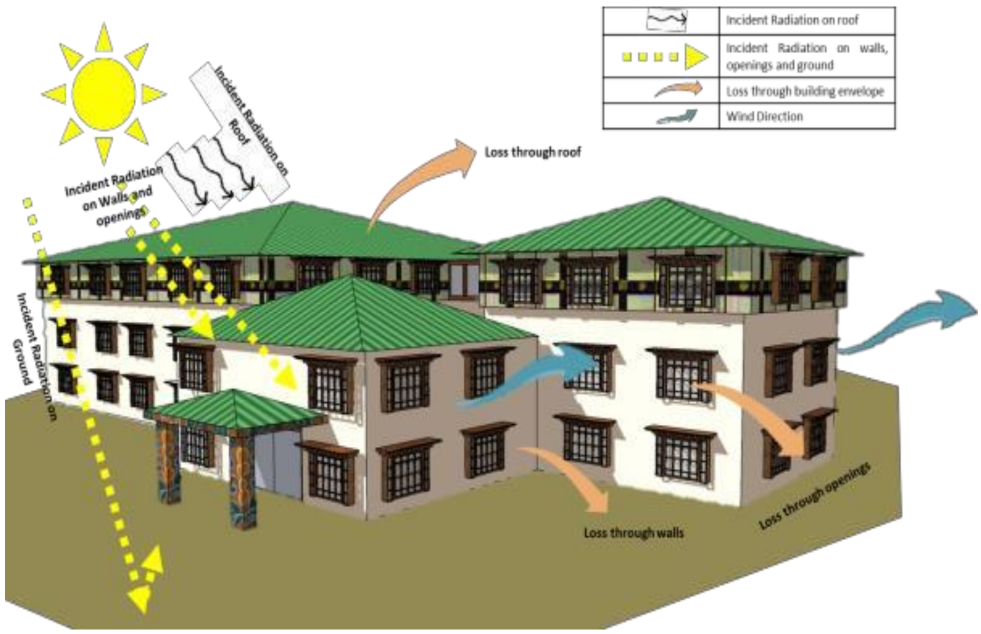
**Figure 4.3: Components of a Building envelope**




*Source: simulation model generated by EY on 3D modelling platform*

Further, modernization has resulted in higher densities in urban areas, the need for faster construction techniques, and more affordable approaches that in many cases result in less efficient structures than old techniques. A primary goal when designing advanced buildings is to eliminate the need for heating equipment in cold areas and cooling appliances in warm districts. This may not be possible in Bhutan with severe cold climates, but should still be a key design aim.

**Figure 4.4: Heat Exchange/ interactions in components of building envelope**



Among the above elements, most heat is lost/ gained from/in buildings through walls, roofs and floors, which represent the largest external area of most residential and services sub-sector buildings. Uneven joinery points of windows and doors, and use of unseasoned wood result in creation of fissures, or gaps which are responsible for a large amount of heat loss in buildings. Some of these cracks are shown below:

**Figure 4.5: Gaps/ Cracks in buildings**

**Energy conscious building design for Building envelope (Wall / Roof / Floor):**

To prevent heat loss in cold climates and unnecessary heat gain in warm climates through components of building envelope, some of the energy saving measures in roof, walls and floors as part of energy conscious building design are as follows:

**Insulation:**

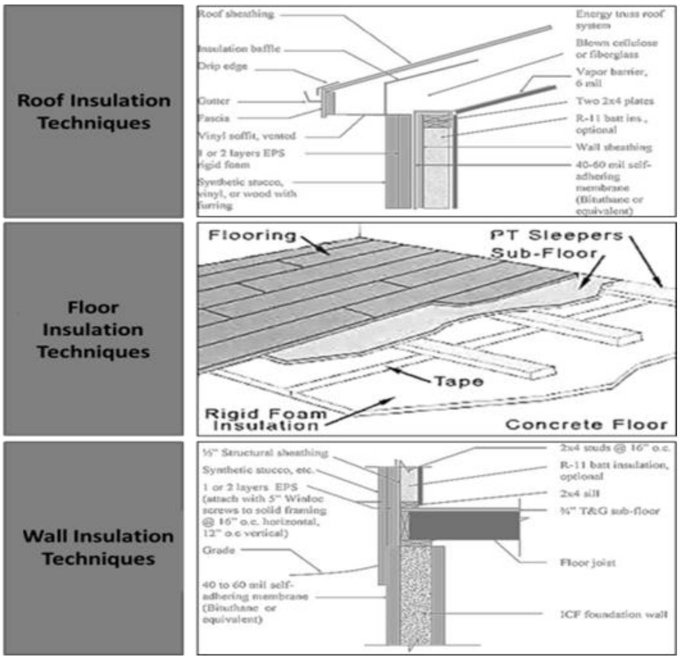
Proper insulation reduces heat loss in cold weather, keeps out excess heat in hot weather, and helps maintain a comfortable indoor environment without incurring maintenance costs. The type and amount of insulation needed varies considerably according to building type. Many service-sector buildings have higher internal thermal loads, for example, because of a higher density of people, more electrical equipment and more artificial light, so they may need less insulation than a residential building. There are many types of insulating material, and certain types are better suited to different applications.

In some parts of Bhutan, the level of insulation is not as high as economically justified. Furthermore, many existing buildings have little or no insulation. In cold regions in Bhutan, many new buildings are being constructed without any insulation, thus substantially increasing heating loads. Policy makers need to make significant efforts to ensure that the buildings use more insulation.

The majority of the wall construction involves a “stick built” framing structure (wood) or a high thermal mass structure (stone, masonry or concrete). Framing structures allow for cavities to be filled with insulation, but the structural members remain as thermal bridges, with significantly higher heat transfer properties.

High thermal mass structures were often built without any insulation but conserve some energy because of their thermal mass. Older framed structures often do not have insulation in cavities. Insulation strategies need to take into account these different characteristics, which can make integrated solutions very complex if they involve a variety of insulation materials. The Different practices of insulation in the different components of a building like roof, walls and floor are diagrammatically represented in the figure 4.6.

**Figure 4.6: Insulation Techniques for roof, walls and floor**



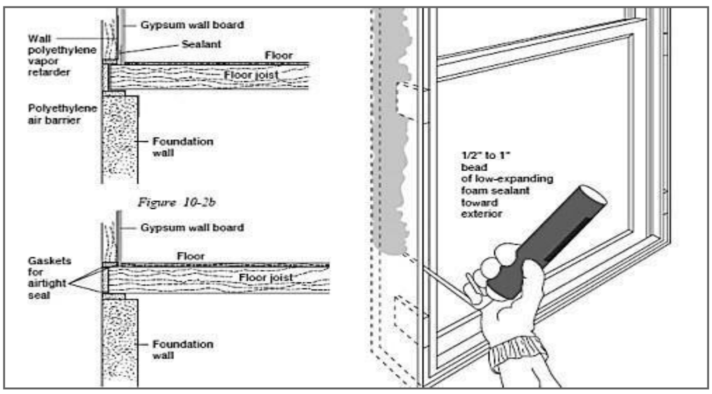

*Source: Cold Climate Housing Research Center, University of Alaska*

**<u>Air Leakage:</u>**

Normal air movement in and out of buildings – infiltration and exfiltration – is known as air leakage and is usually measured using air changes per hour (ACH). ACH is equal to the fraction of the volume of air in a structure that is exchanged with the outside at a specified pressure difference in one hour (e.g. ACH of five would be a flow rate that equals five times the volume of the building leaking in one hour). Natural weather conditions, such as wind and temperature differences, can increase air leakage. Air-distributed heating and cooling systems can also increase air leakage if they create pressure differences between the inside and outside of a building. To measure ACH, the structure is pressurized and air leakage rates are collected over a range of pressures. The overwhelming majority of buildings in the Bhutan have not been air-sealed. Even in the European Union, many mandatory energy performance certificates do not require validated air leakage measurements.

Buildings should be sealed as tightly as possible, but if there is no ventilation, air quality can deteriorate and combustion gases can accumulate, leading to safety concerns. Thus, air leakage rates are often specified with consideration of mechanical ventilation for fresh air.

**Figure 4.7: Using spray sealant to cover cracks in joineries**




*Source: Energy Efficient New Construction for Virginia*

Potential energy savings also vary significantly. Simulations on a large number of building types in widely varying climates have shown that reducing air leakage can save 5% to 40% of heating energy. With reasonably tight structures in cold climates, typical energy savings are 20% to 30%. Air sealing is needed in all buildings, regardless of climate, except those without mechanical equipment that are fully conditioned with natural ventilation.

While all "joints" (interfaces and building envelope penetrations) contribute to air leakage, windows require particular attention, especially during installation or replacement. Using correct window installation techniques, including flashing, sealants and insulation can significantly reduce air leakage and thermal bridges. Windows that can be opened and closed – operable windows – are also susceptible to air leakage around sashes. New windows tend to have lower leakage rates, which are or should be specified in window performance criteria. Air leakage from older windows can be reduced by using sealants, gaskets and additional window panels (interior or exterior).

**Figure 4.8: Air leakage rate for various geographies**

| Geographies | Northern European Union without ventilation (code) | Northern European Union with ventilation (code) | United States, residential (code) | Old leaky houses |
|---|---|---|---|---|
| Performance metrics, air leakage at 50 Pa | 2.5 ACH to 3.0 ACH | 1.0 ACH to 0.6 ACH | ≤ 3.0 ACH | 10 ACH to 20 ACH |

**Windows:**

Windows have several functions, including giving access to the building, providing outlook, letting in daylight and offering safety egress. In most cases, windows should let in as much light as possible, but heat gain needs to be minimized in summer and maximized in winter. Appropriate choices of sizing, orientation and glazing are essential to balance the flows of heat and natural light.

Heat flow (or energy balance) depends on the season, building type and operation of the building. If the building is heated and the outdoor temperature is cold, the window should retain heat (low U-values), minimize losses and let in as much solar radiation as possible (high SHGC). On the other hand, if the temperature inside the building is too high and cooling is needed, the windows should keep out heat from the sun (low-SHGC or g-value) and if possible enable heat to be shed from the building.

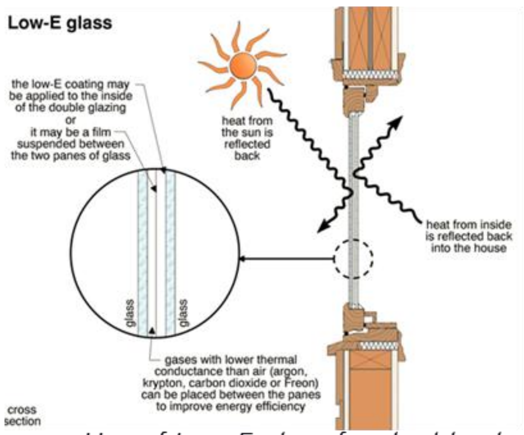
## Energy conscious building design for Building envelope (Windows):

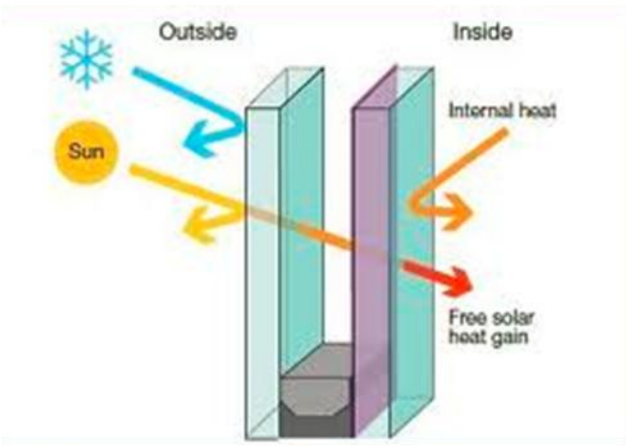
### Glass in Window

Energy-efficient glazing incorporates coated (low-emissivity) glass to prevent heat escaping through the windows. This makes the windows highly thermally insulating hence improving the energy efficiency of buildings. Low-emissivity glass (or low-e glass as it is commonly referred to) is a type of energy-efficient glass designed to prevent heat escaping through your windows to the cold outdoors and vice versa for summer districts. Low-e glass is essential for rooms or buildings with a high proportion of windows or glass doors, such as conservatories and sun rooms. The use of low-e glazing helps to retain heat even in winter, allowing users to comfortably use these rooms for more months of the year. Low-e glass is also recommended for north facing windows, where a larger proportion of heat loss would be expected.

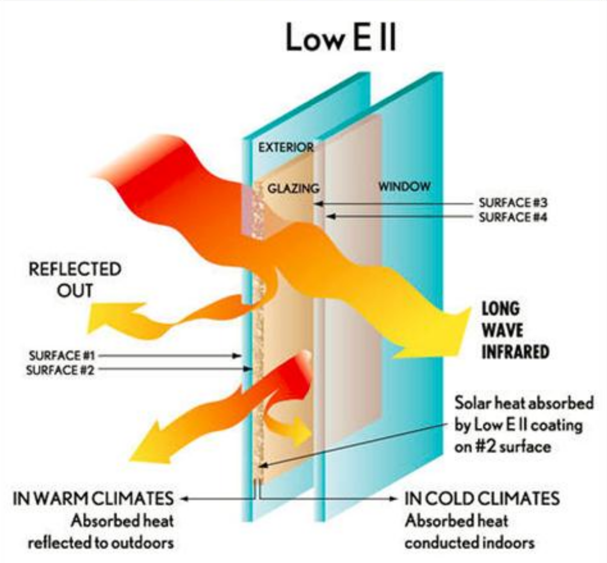
**Figure 4.9: Use of Double Glazing in windows**

*Use of Low E Glass* *Use of Double glazing*




*Use of Low E glass for double glazed windows as means of increasing thermal performance in a building in cold and hot climate*



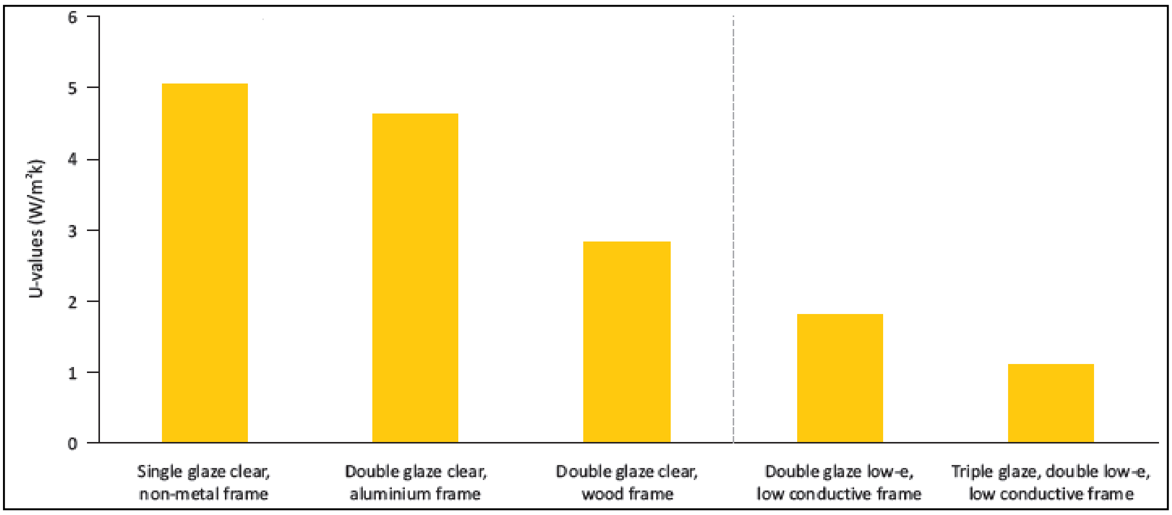

*Source: The Performance House– a Cold Climate Challenge Home, US Dept. of Energy, Aug 2013*

In specifying window performance for a specific region, it is necessary to consider both heating and cooling loads to maximize performance and achieve the lowest total annual energy impact, or best energy balance. In some climates, a positive energy balance – or energy gain – can be achieved using advanced static glazing combined with well-insulated window systems and architectural shading optimized for seasonal impacts (e.g. a triple-glazed window system with two layers of low-e glass, high solar heat gain, low-conductive frame, exterior shading, in a moderate European climate). Well-insulated window systems are especially important for cold climates. The solar or optical characteristics of glass which determine how much of the sun's energy is transmitted into the building or rejected, need to be seasonally optimized for the climate.

Most cold-climate countries are making a significant effort to promote high performance windows, but triple-glazed windows, which have been available for many decades, have not achieved full market share in any country.

Single glazed windows have U-values of approximately 4.5 W/m2K to 5.6 W/m2K. Performance (U-values) of various types of windows has been depicted below:

**Figure 4.10: U values for various glazing**



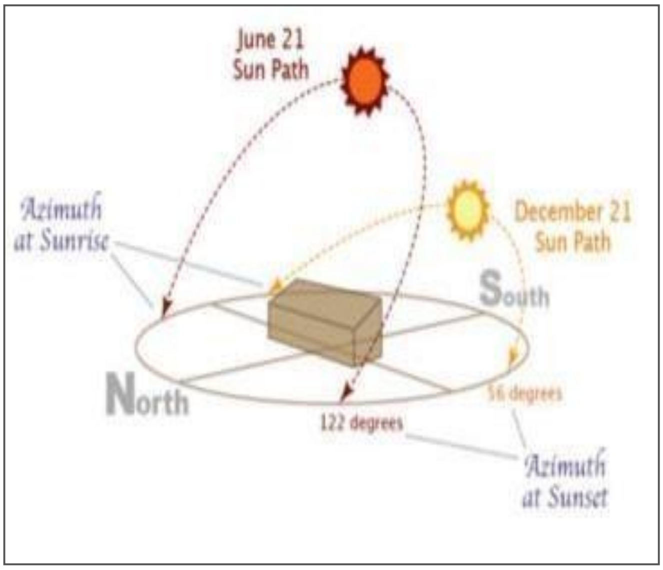

Higher-performance windows with lower U-values and warmer interior surfaces in winter reduce occupant discomfort near windows. In summer, these cut off radiations of the sun thereby preventing direct glare and heating. Solar control still needs to be improved, however, because occupants often complain of too much solar heat and glare, especially in service-sector buildings. Advanced solar control glazing that are tuned to reject as much heat as possible while transmitting high levels of visible light, perform significantly better than clear or tinted glass. Combining these advanced solar control glazing (static SHGC) and exterior architectural shading offers an improved solution. However, automated exterior shading provides the best viable technology to improve occupant comfort and save energy by modulating the solar energy that is hitting the glass.  Such systems are still expensive from an energy efficiency perspective for many parts of the world, but they provide many non-energy benefits as well.

**Building orientation and form and site selection:**

Appropriate orientation of buildings can provide physically and psychologically comfortable conditions in the building. It can help to eliminate the undesirable effects of severe weather to a great extent. For example, in cold weather conditions, a building must be oriented to receive maximum solar radiation into the living areas for warmth on one hand, while keeping out the prevailing cold winds on the other. The quantity, orientation and proportion of the glazed surface are factors that influence energy performance of a building with respect to orientation. The huge glass surface on the southern side of the building increases the heat absorbing capacity of the building during the winter seasons. There is need to avoid big window surfaces on the north from an insulation point of view.

Configuring the geometry of the building appropriate to the climate and usage can control the magnitude of the heat flow. Wind when obstructed by a building creates pressure differences, creating positive pressure on the windward side and negative pressure on the leeward side. Consequently, a new airflow pattern gets developed around the building. Thus, wind pattern across any building can get modified by shaping it appropriately.

**Figure 4.11: Sun path during winter and Summer**




*Source: www.sunearthtools.com/dp/tools/pos_sun.php*

Structures can be designed to conserve energy in both winter and summer. Shading devices such as chajjas, or projected Rabsels block the solar radiation incident on the exposed surfaces of a building, consequently reducing heat gain which is undesired in cold climates. The shape of the building is required to be such that maximum solar gain is possible along with maximum daylighting.

In a new construction, energy-conserving planning and passive solar design begins with site selection. Analysis of a development site and its characteristics is a key element in the design process for maximizing use of the sun's energy, heat and light. Site analysis involves assessing a range of environmental factors that can affect the development of a site. Site planning is an interactive process, beginning with defining the overall goal for energy use and cost in the proposed building determining the most effective solar concepts to achieve this goal, and using that information to determine how to site plan for the building. Site-specific conditions such as land form, vegetation, open spaces, water bodies etc. play an important role in design of any building.

**Passive heating:**

Passive solar heating is one of several design approaches collectively called passive solar design. When combined properly, these strategies can contribute to the heating, cooling, and daylighting of nearly any building.

Typically, passive solar heating involves:

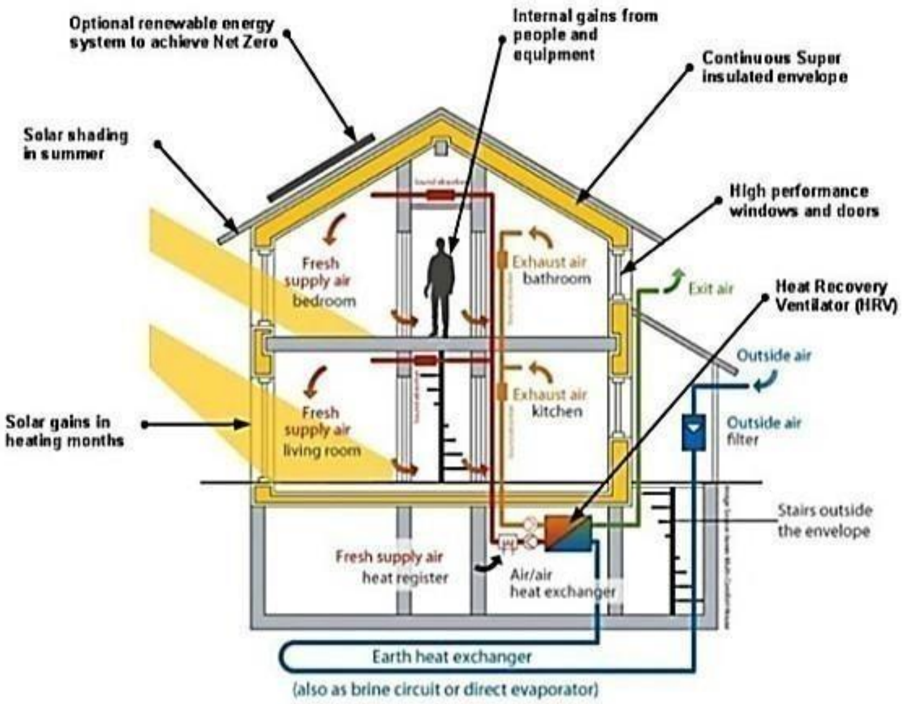
- The collection of solar energy through properly-oriented, south-facing windows
- The storage of this energy in "thermal mass," comprised of building materials with high heat capacity such as concrete slabs, brick walls, or tile floors
- The natural distribution of the stored solar energy back to the living space, when required, through the mechanisms of natural convection and radiation
- Window specifications to allow higher solar heat gain coefficient in south glazing.

**Passive Cooling:**

Passive cooling strategies are required to be taken in warm districts. Specifically, utilizing passive cooling strategies like natural ventilation, air cooling, and shades are capable of reducing demand for mechanical cooling while maintaining thermal comfort. The efficiency of the building envelope can be maximized in a number of ways to minimize heat gain:

- shading windows, walls and roofs from direct solar radiation
- using lighter coloured roofs to reflect heat
- using insulation and buffer zones to minimize conducted and radiated heat gains
- making selective or limited use of thermal mass to avoid storing daytime heat gains.

**Figure 4.12: Passive House Diagram**




There exist broadly four types of passive solar heating approaches for skin-load dominated buildings, namely:

- Sun tempered

  Sun-tempering is achieved through modest increases in south-facing windows. Such a house typically has about one quarter of its windows on each facade with a south glass equal to about 3% of the house's total floor area.

- Direct Gain

  Direct gain is the most basic form of passive solar heating. Sunlight admitted through south-facing glazing (in the Northern Hemisphere) enters the space to be heated, and is stored in a thermal mass incorporated into the floor or interior walls. Depending on climate, the total direct gain glass should not exceed about 12% of the house's floor area.

- Indirect Gain

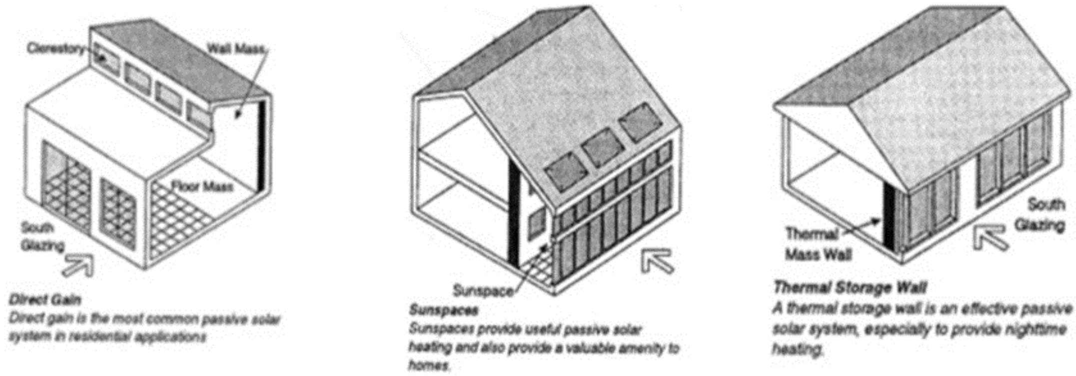
  An indirect gain passive solar heating system (also called a Trombe wall or a thermal storage wall) is a south-facing glazed wall, usually built of heavy masonry, but sometimes using containers of water or phase change materials. Sunlight is absorbed into the wall and it heats up slowly during the day. Then, as it cools gradually during the night, it releases its stored heat over a relatively long period of time indirectly into the space.

- Isolated Gain

  Isolated gain, or sunspace, passive heating collects the sunlight in an area that can be closed off from the rest of the building. The doors or windows between the sunspace and the building are opened during the day to circulate collected heat, and then closed at night, allowing the temperature in the sunspace to drop. Small circulating fans may also be used to move heat into adjacent rooms.

**Figure 4.13: Passive Solar Structure**

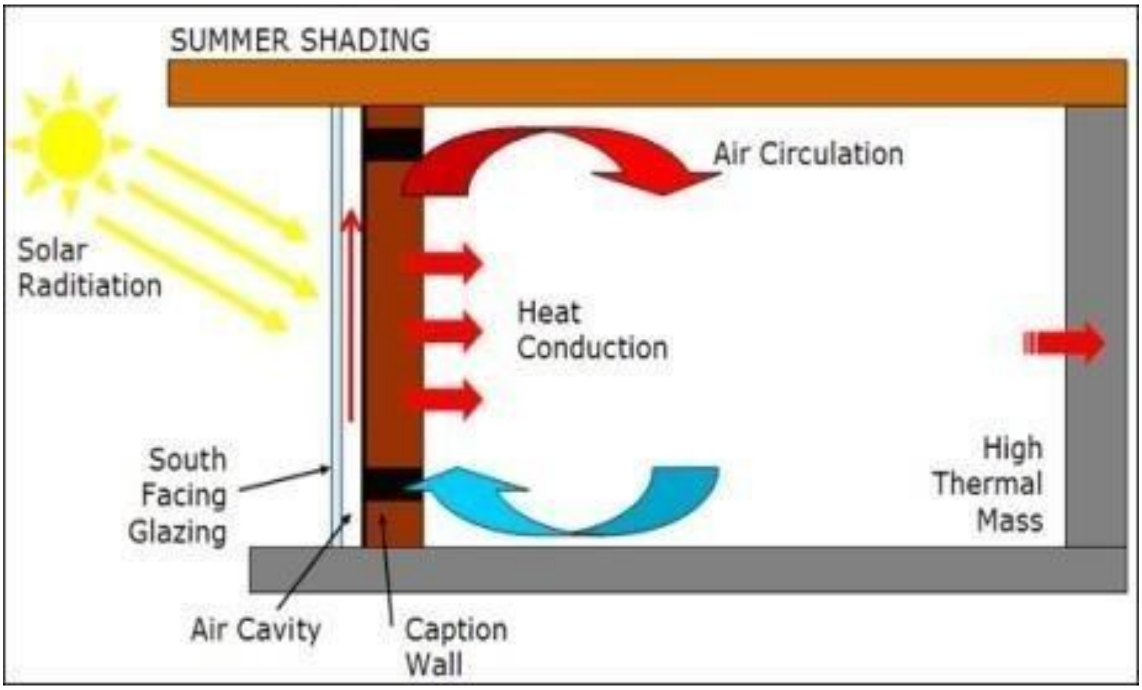
| *Direct Gain through South glazing and Clerestory Lighting* | *Isolated Gain through creation of sunspaces* | *Indirect Gain through use of Trombe walls for thermal storage* |
|---|---|---|



**Trombe Wall**

It is a south-facing masonry wall covered with glass, spaced a few inches away. Sunlight passes through the glass and is absorbed and stored by the wall. The glass as well as the airspace keeps the heat from radiating back to the outside. Heat is transferred by conduction since the masonry surface warms up, and is slowly delivered to the building, a couple of hours later. The night heat losses are lesser through a Trombe wall than that for a direct gain window. The structure is very simple without fans, ducts or controllers and it does not provide day lighting or views. The inside surface of the wall should not be covered with anything that reduces heat transfer from the wall to the living space. Depending on the current wall construction, it is easier to retrofit a solar wall than to retrofit a direct gain window.

**Figure 4.14: Role of a Trombe Wall in passive building design**




Source: www.greenpassivesolar.com

| Energy efficiency potential due to Trombe wall | | |
|---|---|---|
| **Glazing type** | **Potential** | **Payback** |
| **Double glazed window** | 25% | 8 to 14 years |
| **Double glazed with low e coating** | 29% | 10 to 16 years |

**The advantages of using a Trombe wall are elaborated below,**

► Comfortable heat: It radiates in the infra-red, which is more penetrating and pleasant than traditional convective forced air heating systems.

► Passive: It has no moving parts and essentially no maintenance.

- ► Simple construction: This is relatively easy to incorporate into building structure as an internal or external wall. Materials (masonry, concrete) are relatively inexpensive.
- ► Effective: It can reduce heating bills by large amounts.

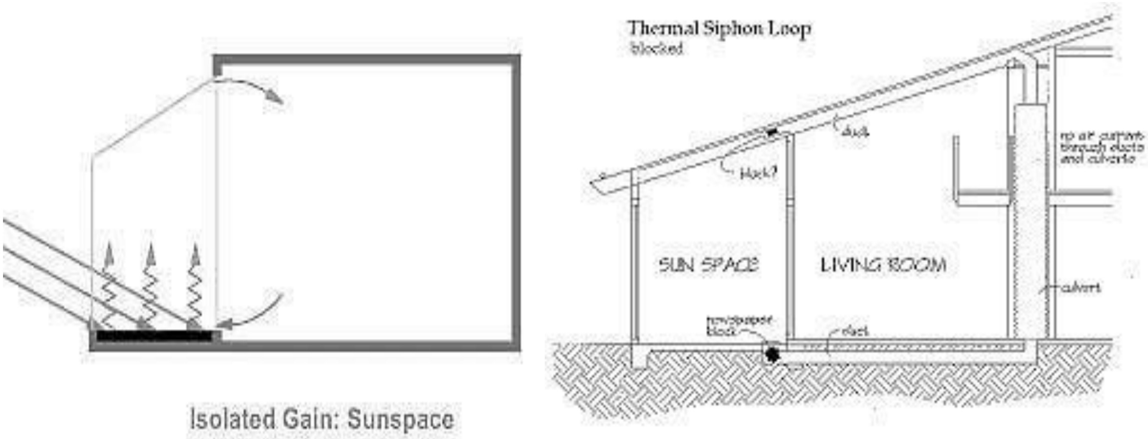
## Sunspaces

A sunspace or solarium is a combination of direct and indirect gain systems. Solar radiation heats up the sunspace directly, which, in turn, heats up the living space (separated from the sunspace by a mass wall) by convection and conduction through the mass wall. Insulated panels, shades, or blinds are more important for sunspaces than for Trombe walls, as sunspaces are sometimes occupied. As with Trombe walls, the darker the internal surfaces of the sunspace, the more effectively the thermal mass can store heat during the day.

The basic requirements of buildings heated by sunspace are as follows:-

- A glazed south facing collector space attached yet separated from building and living space is separated from sunspace by thermal storage wall
- Sunspaces can be used as winter gardens adjacent to living space

**Figure 4.15: Role of sunspaces in passive building design**

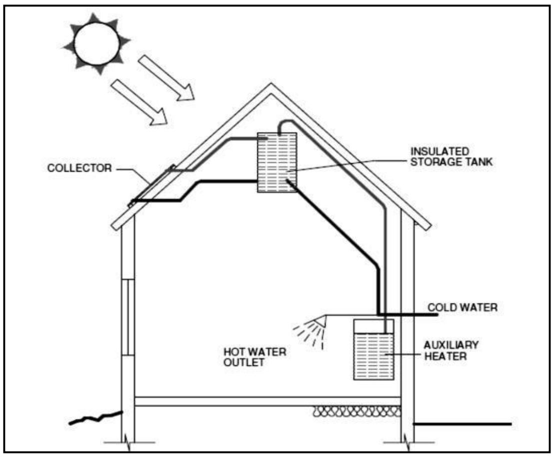



*Source: Siegel House Case Study, Centre for Environmental Design Research at the University of California, Berkeley*

## Integration of emerging technologies:

Systems based on renewable energy sources that are being used in the building sector include solar hot water systems, solar hot air systems, solar cookers, solar photovoltaic units, gasifiers and biogas plants. These are commercially available and can easily be integrated into a building for reducing its dependence on conventional power. Some of them can become elements of the architectural design; examples have been presented to demonstrate how this is done.

## Solar water heating:




Solar water heating is one of the most economically attractive applications of solar energy and is widely used throughout the world. There are broadly two types of water heating systems: (i) Forced and (ii) Thermo-siphon. Also known as active systems, the former are suitable for large capacity systems and find applications in hotels, hostels, hospitals, multi-storied buildings, industries, etc.

The latter are usually meant for small capacity systems, and are commonly used in low-rise buildings or bungalow-type buildings. They are also called natural-circulation or passive systems.

## Solar Space Heating

An alternative approach is to heat air in the building spaces directly in the collectors and store the heat in a tank packed with rock, gravel or pebbles. When hot air is needed for a living space, cool air is pushed through the storage to get heated up before it is circulated in the room.

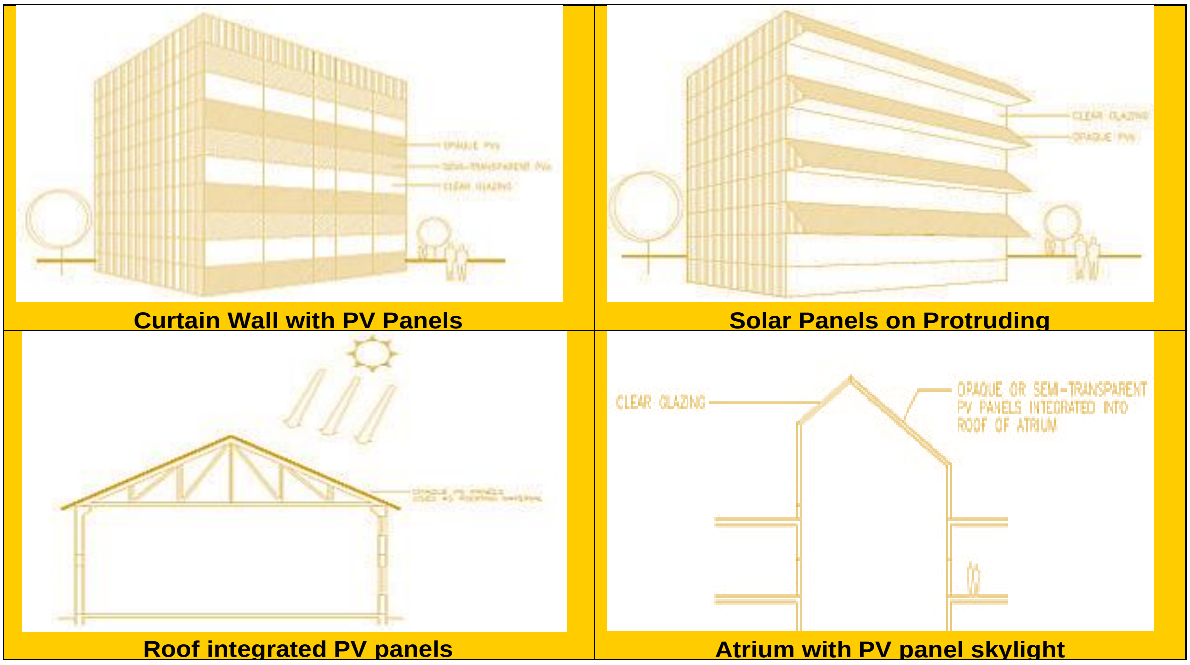
## Solar Photovoltaic Devices

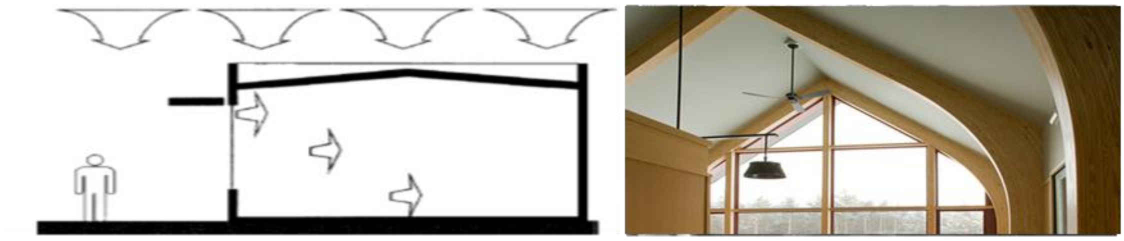
Photovoltaic conversion is the direct conversion of sunlight into electricity by means of solar cells. The main advantage of solar photovoltaic devices is that they can produce power from microwatts up to kilowatts. Consequently, they are used in many applications such as calculators, watches, water pumps, buildings, communications, satellites, space vehicles, etc. Building Integrated Photovoltaic (BIPV) systems have become a reality. Photovoltaic panels can be made to form components of a building. Positioned on the façades or roof of a building, PV panels can generate electricity either for internal use or for distribution to an external network. They may become elements of the architectural design.

**Figure: 4.16: Solar Air Heating System used in Cold Climate**

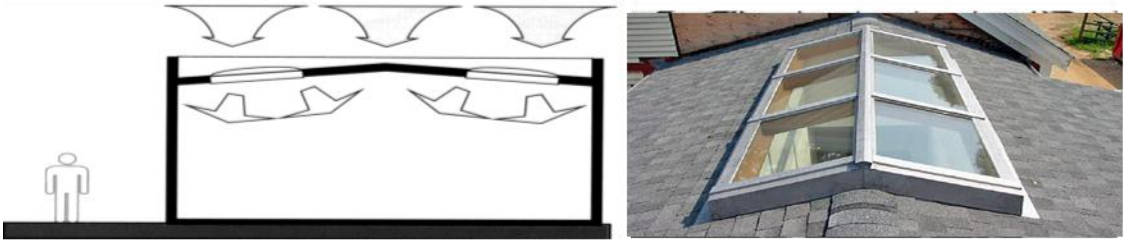
*Source: BEE Report on Energy Efficiency in Buildings, Chapter 6*

**Figure: 4.17: Integrating solar technologies in buildings and maximizing daylighting through roof sky lighting**

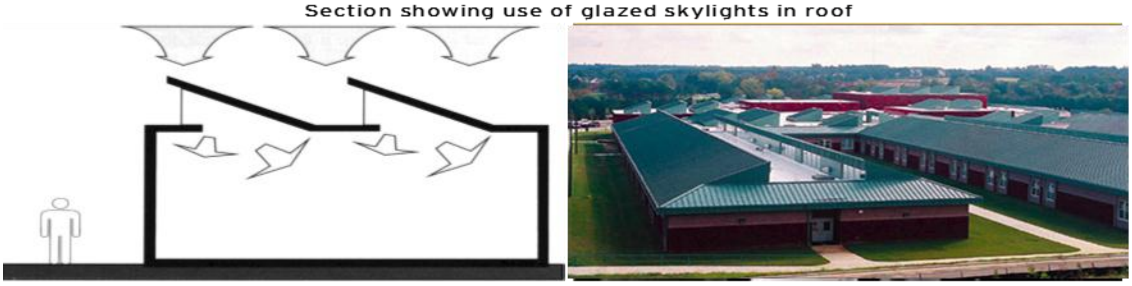


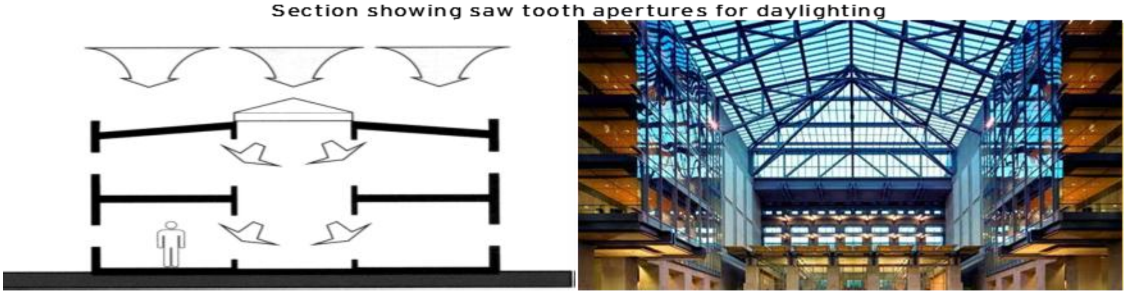
Section showing general role of windows



Section showing use of glazed skylights in roof



Section showing saw tooth apertures for daylighting



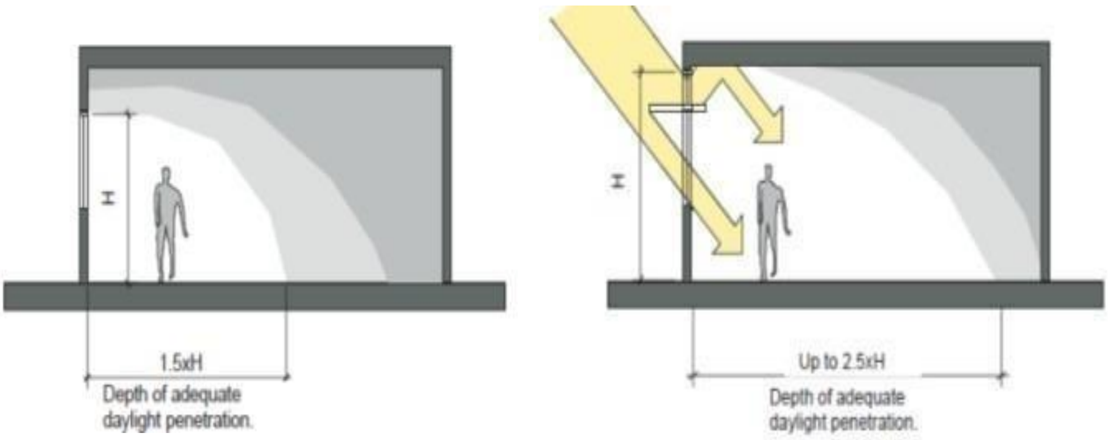
Section showing role of an atrium as a daylighting technique

**Daylighting:**

The level and distribution of natural light within a space depends primarily upon the following three factors: The geometry of the space, the location and orientation of windows and other openings, and the characteristics of the internal surfaces. Daylighting design shapes these factors to accommodate the lighting requirements of activities within the space and the aesthetic intent of the design. Certain usage patterns require particular light levels and overall distribution patterns. Integration of passive solar heating, cooling, and thermal storage features, along with daylighting, into a building can yield considerable energy benefits and added occupant comfort. Incorporation of these items into the building design can lead to substantial reduction in the load requirements for building heating and cooling mechanical systems. The passive solar measures need to be evaluated during the design

There is need to minimize heat gain generated by lights, people, and equipment through the use of daylighting, thermal mass, efficient equipment selection, and venting. Daylighting reduces lighting and cooling energy use; creates a better working environment, leading to increased comfort and productivity. Considerable electrical and thermal energy can be saved through facility design that incorporates daylighting and the other passive energy conserving strategies appropriate to the local climatic environment.

**Figure 4.18: Increased daylight penetration using light shelf contrasted against**




**daylighting due to normal window**

*Source: Daylighting Guide for Buildings, CMHC – SCHL, Canada*

Daylight penetration is governed by the type, size and direction of glazing in a building. This section stresses on the role of atrium and overhead glazing for increased daylighting in buildings.

The best daylighting performance is offered by horizontal roof openings, which collect daylight from a large section of sky with few obstructions. However, these can also have issues of glare, summer heat gain and winter heat loss. Northern light is best for avoiding glare and strong reflections. South-facing clerestories should be shaded from direct sunlight, or the view of the sun must be hidden from the occupants. Translucent or diffusing glazing can also alleviate glare problems associated with direct sunlight. Reflective roof surfaces can be used to advantage to increase light entering monitors and clerestories, by bouncing the light off the ceilings. Sunlight hitting a north wall can be an excellent diffused light source.

## 4.3 Energy conscious building design in Bhutan: Need and aspects of climate

In Bhutan, the energy performance of building envelopes has been significantly neglected. Many buildings are still being constructed that are leaky, have no insulation or exterior shade control, and have single-glazed clear glass windows and solar- absorbing roofs in hot climates. Given that space heating account for larger energy consumption in the Building Sector in Bhutan, optimizing building envelope design should be a key part of any long-term energy reduction strategy.

The quality and energy efficiency of building envelopes are the most important factors that affect the amount of energy consumed by heating equipment. Since investments in both envelope and mechanical equipment are attempting to save the same portion of end-use energy consumption, investment in either is likely to result in diminishing returns for the other.

There are two predominant perspectives on the relative importance of the building envelope and heating equipment. The passive design approach supports high levels of energy efficiency in building envelope components, with any remaining need for space heating met by basic, efficient mechanical equipment. The smart technology approach promotes high energy efficiency in mechanical equipment because it is routinely replaced and installing it is easier than retrofitting old, inefficient building envelopes. Either approach can be appropriate. The balance between advanced envelopes and advanced equipment needs to be established at the regional or local level while considering product availability, cost, climatic conditions and energy prices. Whenever possible, however, it is usually better to invest in the most energy-efficient building envelope that is justified, because it will be in place for many years and in most cases advanced envelopes provide greater comfort. Improved comfort can foster behavior that leads to additional energy savings, such as not raising thermostat set points.

Considering extremely varied climate in Bhutan, buildings types would be varied in line with the weather pattern. The various type of building materials w.r.t., climate is as follows:

**Sub-Tropical Zone (Hot/moist climates)**

In hot/moist climate, materials with low thermal capacity could be used. In hot/moist climates, where night time temperatures do not drop considerably below daytime highs, light materials with little thermal capacity could be preferred. Roofs and walls could be protected by plant materials or overhangs. Large openings protected from the summer sun could be located primarily on the north and south sides of the envelope to catch breezes or encourage stack ventilation.

### Mid-Montana Zone (Temperate climates)

In temperate climates, select materials based on location and the heating/cooling strategy could be used. The thermal capacity of materials for buildings in temperate climates could be estimated based upon the specific locale and the heating/cooling strategy employed. Walls should be well insulated. Openings in the skin could be shaded during hot times of the year and unshaded during cool months. This can be accomplished by roof overhangs sized to respond to solar geometries at the site or by the use of awnings.

### Alpine Zone (Cold climates)

In colder climate, wind-tight and well-insulated building envelopes can be employed. The thermal capacity of materials used in colder climates will depend upon the use of the building and the heating strategy employed. A building that is conventionally heated and occupied intermittently should not be constructed with high mass materials because they will lengthen the time required to reheat the space to a comfortable temperature. A solar heating strategy will necessitate the incorporation of massive materials, if not in the envelope, in other building elements. Where solar gain is not used for heating, the floor plan could be as compact as possible to minimize the area of building skin. Assess the site's solar geometry: Solar gain on roofs, walls, and the building interior through window openings can be either a benefit or a hindrance to heating, cooling, and occupant comfort. A thorough understanding of solar geometry specific to the site is crucial to proper envelope design and should be applied. The quality and energy efficiency of building envelopes are the most important factors that affect the energy consumed by heating equipment. Since investments in both envelope and mechanical equipment are attempting to save the same portion of end-use energy consumption, investment in either is likely to result in diminishing returns for the other.

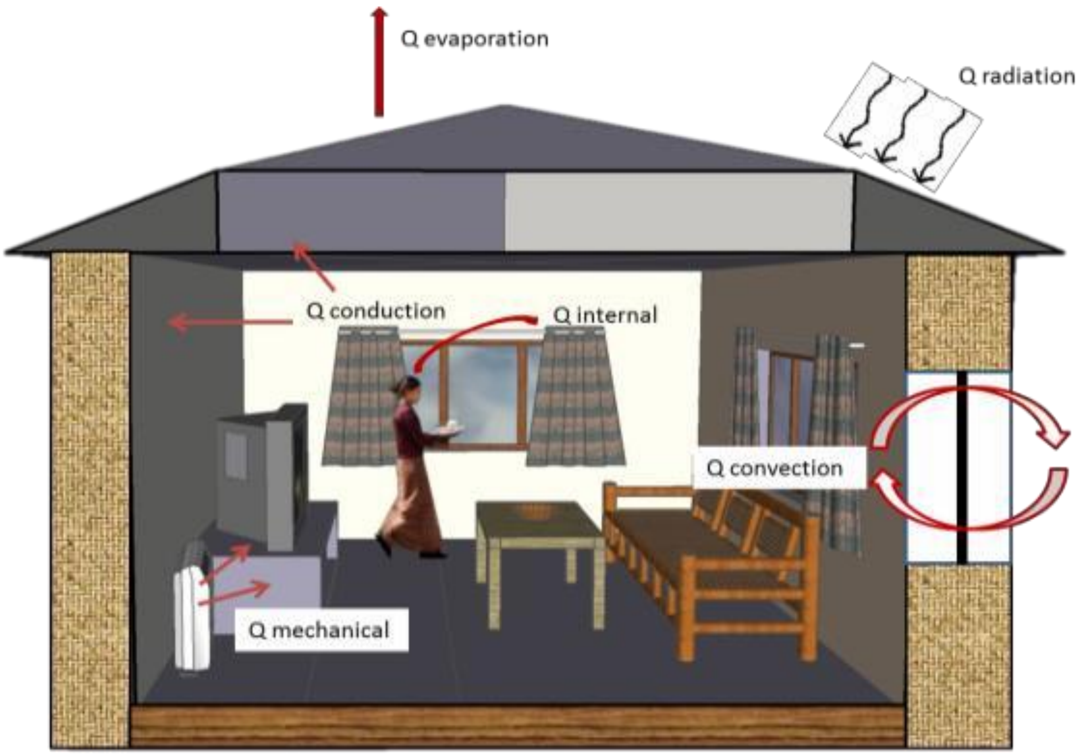
An energy-efficient building balances all aspects of energy use in a space-conditioning, building lighting, and ventilation by giving an optimized mix of passive solar design strategies, equipment that are energy efficient, and renewable sources of energy. Materials usage with low embodied energy forms a major component in energy efficient building designs. However, buildings can be designed to meet the occupant's need for thermal and visual comfort at reduced levels of energy and resources consumption. Energy efficiency in buildings can be achieved through a multi-pronged approach involving adoption of bioclimatic architectural principles responsive to the climate of the particular location; use of materials with low embodied energy; reduction of transportation energy; incorporation of efficient structural designs; implementation of energy-efficient building systems; and effective utilization of renewable energy sources to power the building. The potential for energy savings can be as high as 40-50 % if addressed right at the design stage for new buildings. The incremental cost incurred for achieving energy efficiency is 5-8% vis-a-vis conventional design cost and can have a payback period of 2-4 years.

# Chapter 5: Thermal performance evaluation of buildings

## 5.1 Introduction

The thermal performance evaluation of a building refers to the process of modelling the energy transfer between a building and its surroundings. Various heat exchange processes are possible between a building and the external environment. This chapter explains the methodology for evaluating building thermal performance and heat loss/gain from various building envelope. It also covers the energy efficiency potential and financial viability of various building envelope through improving thermal performance.

**Figure 5.1: Heat transfer in a typical building**




## 5.2 Components of thermal performance evaluation

Various heat exchange processes are possible between a building and the external environment. Heat flows by conduction through various building elements such as walls, roof, ceiling, floor, etc. Heat transfer also takes place from different surfaces by convection and radiation. Besides, solar radiation is transmitted through transparent windows and is absorbed by the internal surfaces of the building. Heat is also added to the space due to the presence of human occupants and the use of lights and equipment.

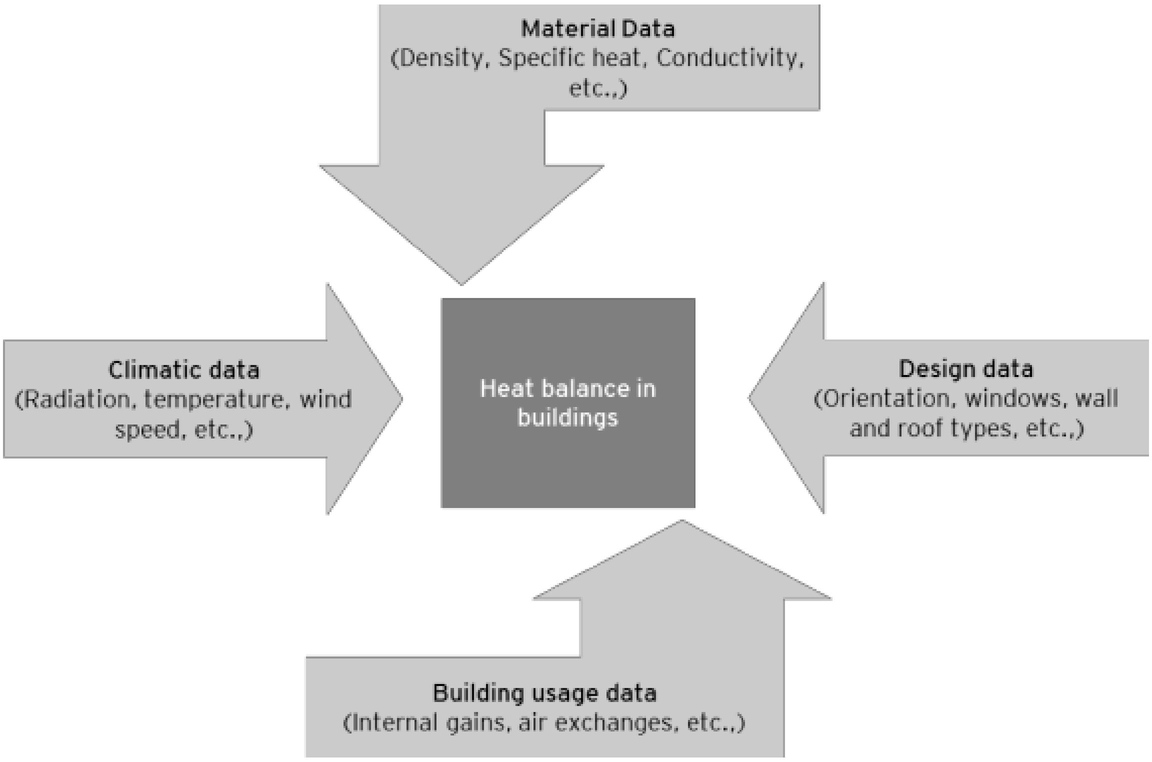
The thermal performance of a building depends on a large number of factors. They can be summarized as

(i) design variables (geometrical dimensions of building elements such as walls, roof and windows, orientation, shading devices, etc.);

(ii) material properties (density, specific heat, thermal conductivity, transmissivity, etc.);

(iii) weather data (solar radiation, ambient temperature, wind speed, humidity, etc.); and (iv) a building's usage data (internal gains due to occupants, lighting and equipment, air exchanges, etc.).

**Figure 5.2: Components of heat balance in a building**




The basic concepts on conduction, convection, radiation and evaporation heat transfer is given below:

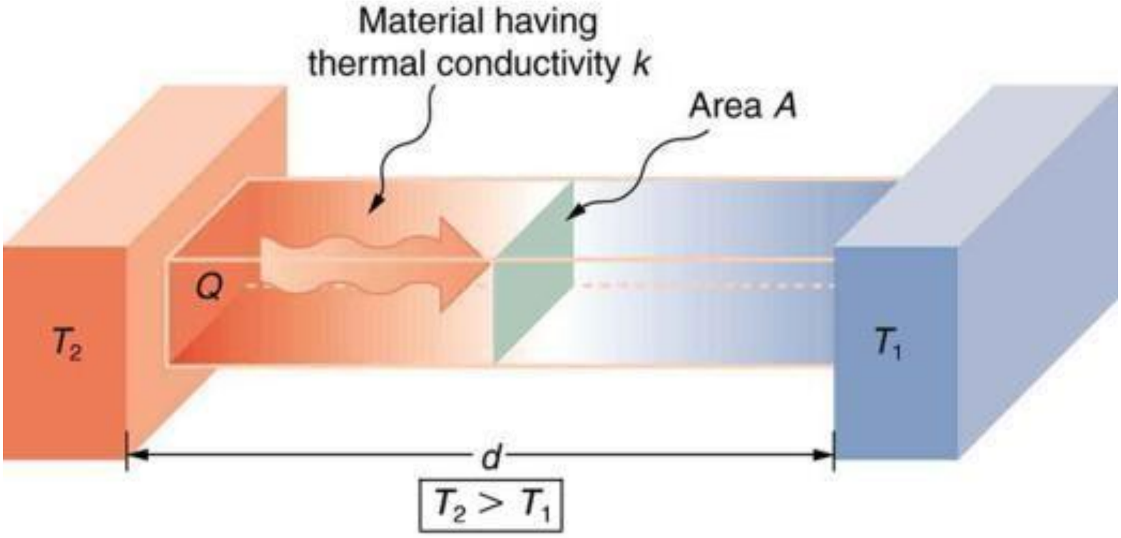
**Conduction:**

Thermal conduction is the process of heat transfer from one part of a body at a higher temperature to another (or between bodies in direct contact) at a lower temperature. This happens with negligible movement of the molecules in the body, because the heat is transferred from one molecule to another in contact with it. Heat can be conducted through solids, liquids and gases. Some materials conduct more rapidly than others. The basic equation of heat conduction is:

$$Q_{conduction} = \frac{k\ A\ (T_h - T_c)}{L}$$

| | |
|---|---|
| $Q_{conduction}$ = quantity of heat flow (W) | k = thermal conductivity of the material (W/m-K) |
| A = area (m2) | L = thickness (m) |
| $T_h$ = temperature of the hot surface (K) | $T_c$ = temperature of the cold surface (K) |

**Figure 5.3: Illustration of conduction heat transfer**



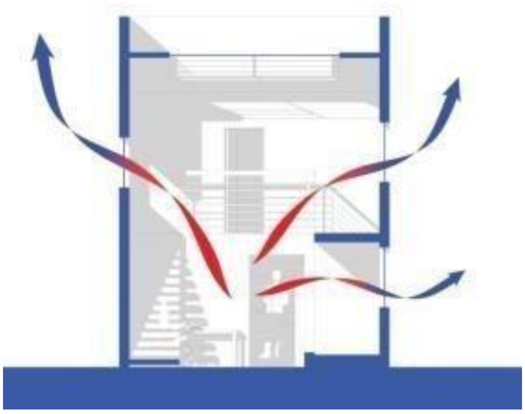

**Convection:**

The convection is the transfer of heat from one part of a fluid (gas or liquid) to another part at a lower temperature by mixing of fluid particles. Heat transfer by convection takes place at the surfaces of walls, floors and roofs. Because of the temperature difference between the fluid and the contact surface, there is a density variation in the fluid, resulting in buoyancy. This results in heat exchange between the fluid and the surface and is known as free convection. However, if the motion of the fluid is due to external forces (such as wind), it is known as forced convection. These two processes could occur simultaneously. The rate of heat transfer ($Q_{convection}$) by convection from a surface of area A, can be written as

$$Q_{convection} = h\,A\,(T_s - T_f)$$

| | |
|---|---|
| h = heat transfer coefficient (W/m2-K) | Ts = temperature of the surface (K) |
| Tf = temperature of the fluid (K) | |

**Figure 5.4: Illustration of convection heat transfer**



## Radiation:

Radiation is the heat transfer from a body by virtue of its temperature; it increases as temperature of the body increases. It does not require any material medium for propagation. When two or more bodies at different temperatures exchange heat by radiation, heat will be emitted, absorbed and reflected by each body. The radiation exchange between two large parallel plane surfaces (of equal area A) at uniform temperatures T1 and T2 respectively, can be written as:

$$Q_{12} = \varepsilon_{eff} \; A \; \sigma \,(T_1^4 - T_2^4)$$

$$\text{with } \varepsilon_{eff} = [\, 1/\varepsilon_1 + 1/\varepsilon_2 - 1]^{-1}$$

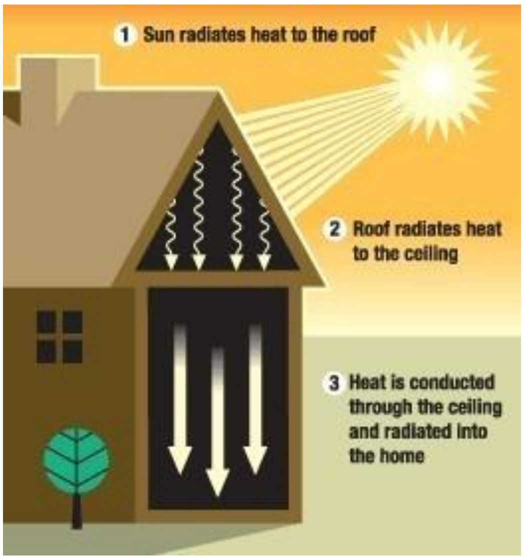
| | |
|---|---|
| Q12 = net radiative exchange between surfaces (W) | |
| σ = Stefan-Boltzmann constant ( 5.67x10-8W/m2K-4) | A = area of surface (m2) |
| T1 = temperature of surface 1 (K) | T2 = temperature of surface 2 (K) |
| ε 1 and ε 2= emissivity of surfaces 1 and 2 respectively | |

In case of buildings, external surfaces such as walls and roofs are always exposed to the atmosphere. So the radiation exchange (Q radiation) between the exposed parts of the building and the atmosphere is an important factor and is given by

$$Q_{radiation} = A \, \varepsilon \, \sigma \,(T_s^4 - T_{sky}^4)$$

| | |
|---|---|
| A = area of the building exposed surface (m2) | e = emissivity of the building exposed surface |
| Ts = temperature of the building exposed surface (K) | Tsky = sky temperature (K) |

**Figure 5.5: Illustration of radiation heat transfer**




## 5.3 Methodology adopted for thermal performance evaluation

Thermal performance evaluation involves collection of data (climatic, energy & dimensional) through measurements, computation of heat loss and heat gain for various building envelope and evaluation of energy efficiency measures.

Data collection:

The following measuring instruments have been used for measuring the data required for computation of thermal performance evaluation of a building.

**Table 5.1: Instruments for auditing**

| | | |
|---|---|---|
|  Three phase power analyzer |  Single phase clamp meter | **Objective:** To measure electrical parameters<br>**Parameters monitored:** KW, kWh, V, A & PF<br>**Use of this data:** This data is used for computing the power consumption by heating appliances |
|  Sling Psychrometer |  Infrared Gun Thermometer | **Objective:** To measure climatic parameters<br>**Parameters monitored:** Dry bulb, wet bulb, surface temperature<br>**Use of this data:** This data is used for computing the heat loss through various building envelope |

| | |
|---|---|
| <br>Lux meter | **Objective:** To measure lighting level<br>**Parameters monitored:** Lux<br>**Use of this data:** This data is used for computing the lighting requirement |
| <br>Anemometer | **Objective:** To measure air flow<br>**Parameters monitored:** flow rate of air<br>**Use of this data:** This data is used for computing the heat loss through infiltration |
|  <br>Digital tape Regular tape | **Objective:** To measure design parameters<br>**Parameters monitored:** Length, Breadth, Height and Volume of room **Use of this data:** This data is used for computing the heat loss through various building envelopes |

Computation of heat loss and heat gain:

The following equations have been used for computing the thermal performance of buildings

| Computation of Heat loss | |
|---|---|
| **Heat loss through walls** | The steady state conductive heat loss through wall has been computed based on the following equation, $$Q_{heatloss,wall} = A_{wall} \times U_{wall} \times \Delta T$$ $Q_{heat\ loss,\ wall}$ = Quantity of heat loss through wall W)<br>$A_{wall}$ = Surface area of wall (m2)<br>$U_{wall}$ = Thermal transmittance of wall (W/m2-K)<br>▲T = Temperature difference between inside and outside air (K)<br>Source: ASHRAE Fundamentals Handbook |
| **Heat loss through roof** | The steady state conductive heat loss through roof has been computed based on the following equation, $$Q_{heatloss,roof} = A_{roof} \times U_{roof} \times \Delta T$$ $Q_{heat\ loss,\ roof}$ = Quantity of heat loss through roof W)<br>$A_{roof}$ = Surface area of roof (m2)<br>$U_{roof}$ = Thermal transmittance of roof (W/m2-K)<br>▲T = Temperature difference between inside and outside air (K)<br>Source: ASHRAE Fundamentals Handbook |
| **Heat loss through floor** | The steady state conductive heat loss through floor has been computed based on the following equation, $$Q_{heatloss,floor} = A_{floor} \times U_{floor} \times \Delta T$$ $Q_{heat\ loss,\ floor}$ = Quantity of heat loss through floor W)<br>$A_{floor}$ = Surface area of floor (m2)<br>$U_{floor}$ = Thermal transmittance of floor (W/m2-K)<br>▲T = Temperature difference between inside and outside air (K)<br>Source: ASHRAE Fundamentals Handbook |

<table>
<tr><th colspan="2">Computation of Heat loss</th></tr>
<tr><td>Heat loss through window</td><td>The steady state conductive heat loss through window has been computed based on the following equation,<br>$$Q_{heatloss,window} = A_{window} \times U_{window} \times \Delta T$$<br>$Q_{heat\ loss,\ window}$ = Quantity of heat loss through window (W)<br>$A_{window}$ = Surface area of window (m2)<br>$U_{window}$ = Thermal transmittance of window (W/m2-K)<br>▲T = Temperature difference between inside and outside air (K)<br>Source: ASHRAE Fundamentals Handbook</td></tr>
<tr><td>Heat loss through air infiltration</td><td>The steady state conductive heat loss through floor has been computed based on the following equation,<br>$$Q_{heatloss,infiltration} = C_p \times Q \times \rho \times \Delta T$$<br>$Q_{heat\ loss,\ infiltration}$ = Quantity of heat loss through infiltration (W)<br>$C_p$ = Specific heat of air<br>Q = Volumetric flow rate of air<br>ρ = Density of air<br>▲T = Temperature difference between inside and outside air (K)<br>Source: ASHRAE Fundamentals Handbook<br>
<table>
<tr><td>$A_L$ = Area of the air gap, $cm^2$</td><td>$C_s$ =Stack coefficient, (L/s)2/(cm4·K)</td></tr>
<tr><td>V = Wind velocity, m/s</td><td>$C_w$ = Wind coefficient, (L/s)2/[cm4 · (m/s)2]</td></tr>
<tr><td colspan="2">▲T = Temperature difference between inside and outside air</td></tr>
</table>
$$Q = \frac{A_L}{1000}\sqrt{C_s \Delta t + C_w V^2}$$</td></tr>
</table>

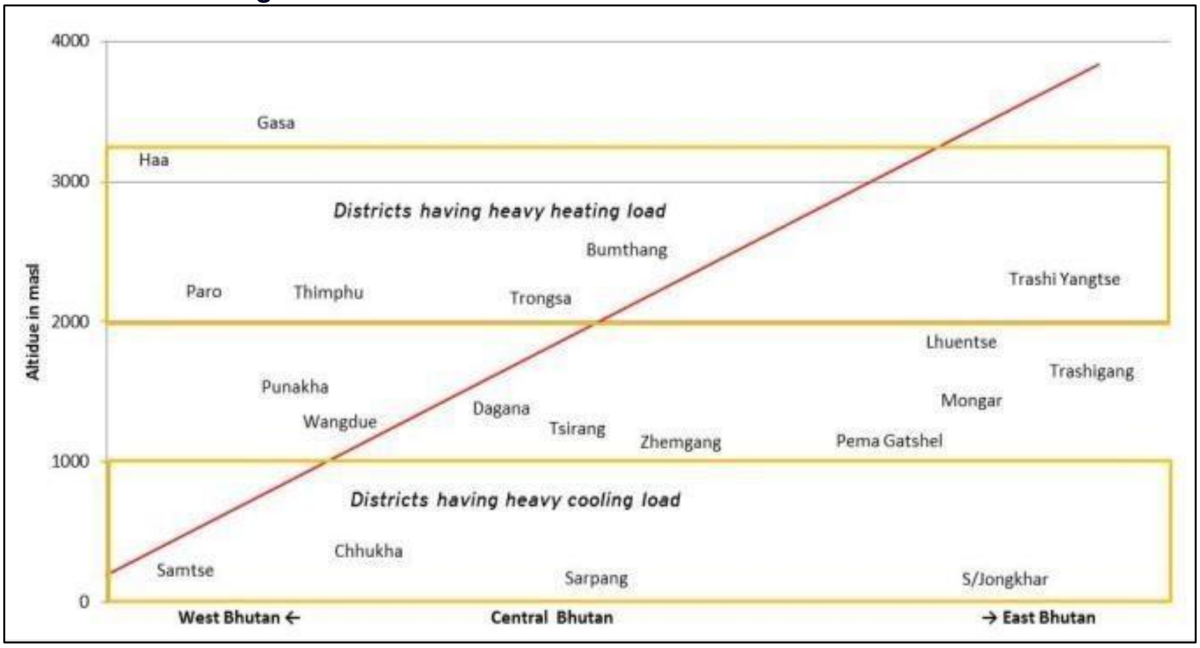
<table>
<tr><th colspan="2">Computation of Heat</th></tr>
<tr><td>Heat gain through solar radiation</td><td>
Heat gain through solar radiation has been computed using the following equation,<br>
$$Q_{sol\arg ain} = SC \times SHGF \times A$$<br>
$Q_{solar\ gain}$ = Quantity of heat gain through solar (W)<br>
A = Surface area of fenestration – window (m2)<br>
SC = Shading Coefficient<br>
SHGF = Solar Heat Gain Coefficient (W/m2)<br>
Source: ASHRAE Fundamentals Handbook
</td></tr>
<tr><td>Heat loss through air infiltration</td><td>
The steady state conductive heat loss through floor has been computed based on the following equation,<br>
$$Q_{heatloss,\inf iltration} = C_p \times Q \times \rho \times \Delta T$$<br>
$Q_{heat\ loss,\ infiltration}$ = Quantity of heat loss through infiltration (W)<br>
$C_p$ = Specific heat of air<br>
Q = Volumetric flow rate of air<br>
ρ = Density of air<br>
▲T = Temperature difference between inside and outside air (K)<br>
Source: ASHRAE Fundamentals Handbook<br>
<br>
For computing the volumetric flow rate o f air, the following equation has been used.<br>
<table>
<tr><td>$A_L$ = Area of the air gap, $cm^2$</td><td>$C_s$ = Stack coefficient, (L/s)2/(cm4·K)</td></tr>
<tr><td>V = Wind velocity, m/s</td><td>$C_w$ = Wind coefficient, (L/s)2/[cm4 · (m/s)2]</td></tr>
<tr><td colspan="2">▲T = Temperature difference between inside and outside air</td></tr>
</table>
$$Q = \frac{A_L}{1000}\sqrt{C_s \Delta t + C_w V^2}$$
</td></tr>
</table>

# Chapter 6: Interventions

## 6.1 Introduction

This report aimed at identifying the Energy efficiency potential of various building types through improving thermal performance of building envelope and also through lighting. The interventions has been classified based on cold weather and summer weather regions. The need for heating / cooling depends on the altitude of the location. The following figure illustrates the classification of districts based on altitude.

**Figure 6.1: Classification of districts based on altitude**



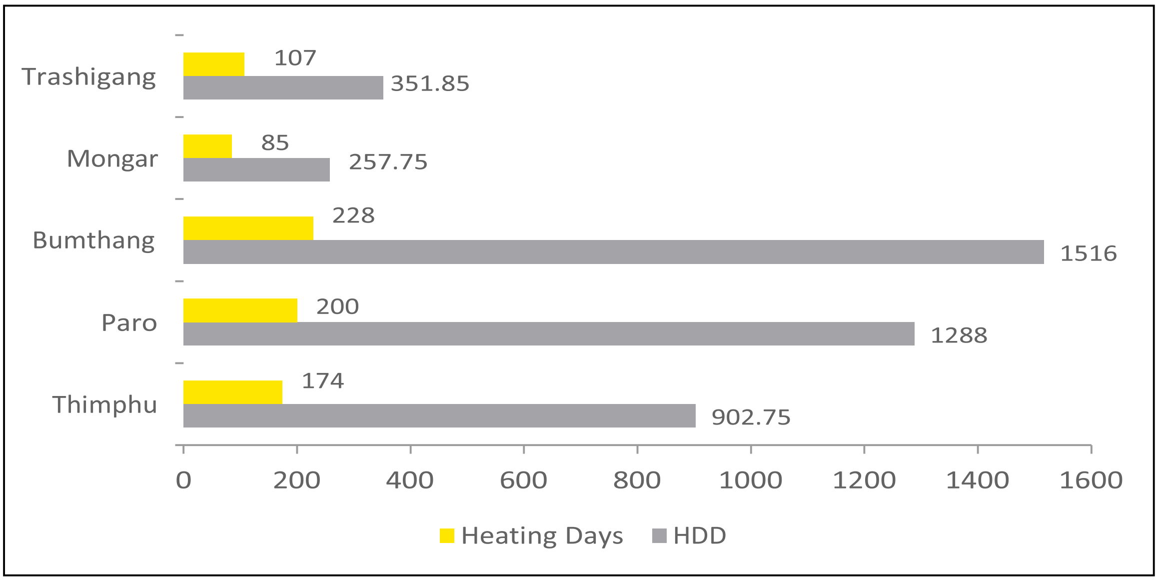

*Source: EY analysis*

The energy efficiency interventions for the districts in higher altitudes (more than 2000 meters) should be focused on reducing the heating load of the building whereas the interventions for districts in lower altitudes (less than 1000 meters) should be focused on reducing the cooling load of the building. The districts in the mid altitude range (between 1000 to 2000 meters) do not consume significant amount of heating/ cooling load, hence the same has not been considered for thermal performance evaluation. However, the intervention towards lighting load reduction is applicable for all districts irrespective of the altitude. In this section, the interventions have been identified for both retrofit and new building constructions. The interventions have been evaluated based on technical & financial feasibility, earthquake resistance and adaptability to local conditions.

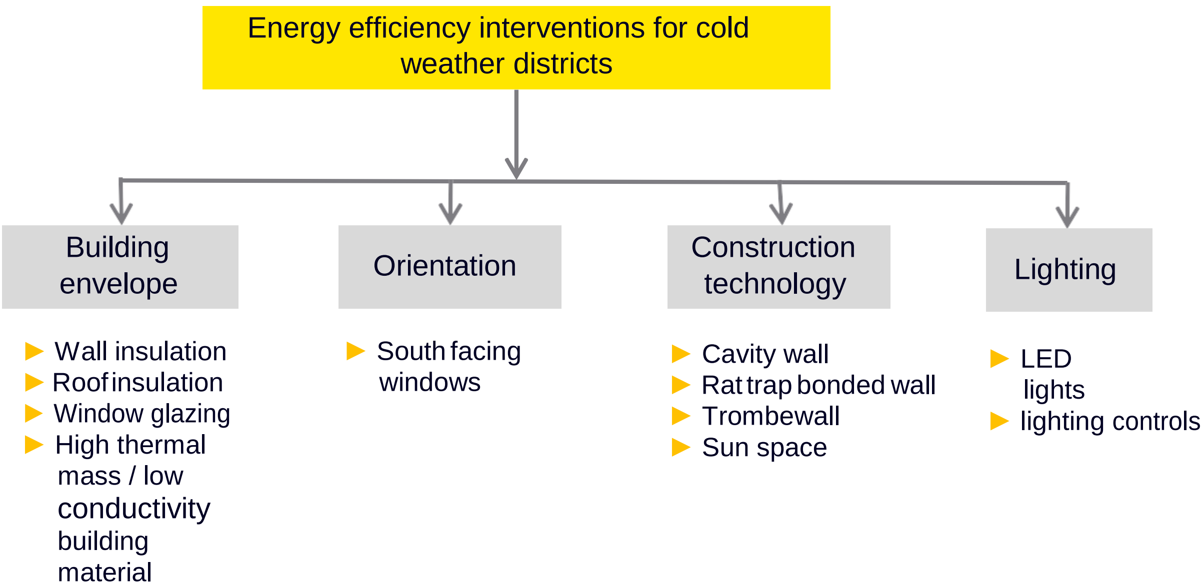
## 6.2 Interventions for cold weather districts

The ambient temperature across the cold weather districts varies significantly and hence the Heating **Degree** Day (HDD) method was conducted for evaluating the interventions. The districts having higher HDD require more heat load for meeting the thermal comfort of the buildings. Bumthang was having the highest HDD in Bhutan followed by Paro, Thimphu and others. The HDD has a greater impact on the financial viability of the interventions. For example, higher the HDD lower is the payback period of Energy Efficiency projects.

**Figure 6.2: Heating Degree Days for various districts of Bhutan**




Apart from the HDD, there are other factors which affect the energy efficient performance of a building which includes thermal conductivity of the material, construction technology used, occupancy pattern, orientation and appliances used. The energy efficiency interventions for cold weather districts have been broadly classified as follows:



## Energy efficiency measures for existing buildings:

### Building envelope 1: Wall

Walls contribute to majority of the heat loss in a building. The type of wall material used varies with the type of consumers. For example, rural households predominantly use rammed earth and stone as a wall material whereas in urban households and commercial buildings brick wall is being used. Ekra (made of bamboo and cement) is also used as a wall material. The percentage of wall material used by different consumers in various districts is given below.

**Table 6.1: The percentage of wall material used by different consumers in various districts**

| District | Category | Bricks | Hollow blocks | Stone / Rammed Earth | Ekra / Wooden Frames / Others |
|---|---|---|---|---|---|
| Thimphu | Urban | 65.0% | 20.0% | 8.0% | 7.0% |
| | Rural | 8.0% | 2.0% | 75.0% | 15.0% |
| Paro | Urban | 70.0% | 10.0% | 13.0% | 7.0% |
| | Rural | 6.0% | 0.0% | 90.0% | 4.0% |
| Haa | Urban | 47.0% | 5.0% | 46.0% | 2.0% |
| | Rural | 0.5% | 0.1% | 98.0% | 2.0% |
| Punakha | Urban | 75.0% | 12.0% | 10.0% | 3.0% |
| | Rural | 10.0% | 3.0% | 85.0% | 2.0% |
| Bumthang | Urban | 10.0% | 5.0% | 20.0% | 65.0% |
| | Rural | 3.0% | 1.0% | 85.0% | 11.0% |
| Mongar | Urban | 80.0% | 3.0% | 8.0% | 9.0% |
| | Rural | 2.0% | 1.0% | 87.0% | 10.0% |
| Trashigang | Urban | 30.0% | 2.0% | 55.0% | 13.0% |
| | Rural | 1.0% | 1.0% | 86.0% | 12.0% |
| Trashiyangtse | Urban | 2.0% | 0.0% | 90.0% | 8.0% |
| | Rural | 0.0% | 0.0% | 85.0% | 15.0% |

The percentage heat loss for different wall material is given below.

**Table 6.2: Interventions- choice of wall materials**

| Wall material | U Value | Percentage heat loss |
|---|---|---|
| Brick | 2.69 | 65.30% |
| Rammed earth | 2.41 | 62.80% |
| Stone wall | 3.40 | 70.40% |

The heat loss through wall can be reduced by applying suitable insulation. The following insulation materials were considered for evaluating the thermal performance of buildings. These materials were identified based on some of the best practice observed in other countries of similar weather conditions.

**Table 6.3: Interventions- choice of insulation materials**

| Insulation material | R Value | Cost, Nu./Sq. M |
|---|---|---|
| **1 Inch rock wool** | 0.44 | 85 |
| **1 Inch glass wool** | 0.90 | 160 |
| **1 Inch Expanded Polystyrene (EPS)** | 0.63 | 130 |

**Energy efficiency potential due to Wall insulation:**

The energy efficiency potential by using the above mentioned insulation material varies from 37% to 47% depending on the type of insulation material, type of building and Heating Degree Day of the location.

**Financial viability:**

The financial viability of this intervention is dependent on the electricity tariff, usage hours and Heating Degree Day of the location. The payback period for wall insulation ranges from 0.52 years to more than 8.11 years for different districts. The energy efficiency potential and pay-back period for different building envelope is given below:

The following are some of the key factors/ assumptions considered for calculation

- Area of the building envelope
- Material of construction (thickness, U Value, etc.,)
- Heating Degree Day of the district
- Occupancy rate
- R value of insulation materials
- Cost of insulation material
- Tariff rate

**Table 6.4: Interventions- choice of insulation materials for different districts**

| Thimphu District | | | | | | |
|---|---|---|---|---|---|---|
| **Insulation type** | **Potential** | **Payback period** | | | | |
| | | **Urban household** | **Rural household** | **Institutional building** | **Hospital** | **Hotel** |
| **1 inch Rock wool** | 37% | 1.88 | 2.98 | 2.43 | 0.87 | 1.02 |
| **1 inch Glass wool** | 47% | 2.53 | 3.94 | 3.23 | 1.19 | 1.38 |

| Thimphu District | | | | | | |
|---|---|---|---|---|---|---|
| **Insulation type** | **Potential** | **Payback period** | | | | |
| | | **Urban household** | **Rural household** | **Institutional building** | **Hospital** | **Hotel** |
| **1 inch EPS** | 42% | 2.33 | 3.65 | 2.99 | 1.09 | 1.27 |

| Paro District | | | | | | |
|---|---|---|---|---|---|---|
| **Insulation type** | **Potential** | **Payback period** | | | | |
| | | **Urban household** | **Rural household** | **Institutional building** | **Hospital** | **Hotel** |
| **1 inch Rock wool** | 37% | 1.35 | 2.17 | 1.76 | 0.61 | 0.72 |
| **1 inch Glass wool** | 47% | 1.83 | 2.91 | 2.37 | 0.85 | 0.99 |
| **1 inch EPS** | 42% | 1.69 | 2.69 | 2.18 | 0.78 | 0.91 |
| **Bumthang District** | | | | | | |
| **Insulation type** | **Potential** | **Payback period** | | | | |
| | | **Urban household** | **Rural household** | **Institutional building** | **Hospital** | **Hotel** |
| **1 inch Rock wool** | 37% | 1.16 | 1.88 | 1.51 | 0.52 | 0.61 |
| **1 inch Glass wool** | 47% | 1.57 | 2.52 | 2.04 | 0.72 | 0.84 |
| **Trashigang District** | | | | | | |
| **Insulation type** | **Potential** | **Payback period** | | | | |
| | | **Urban household** | **Rural household** | **Institutional building** | **Hospital** | **Hotel** |
| **1 inch Rock wool** | 37% | 4.28 | 6.40 | 5.36 | 2.11 | 2.43 |
| **1 inch Glass wool** | 47% | 5.55 | 8.11 | 6.87 | 2.83 | 3.24 |
| **1 inch EPS** | 42% | 5.17 | 7.60 | 6.42 | 2.61 | 2.99 |

**Recommendation for Building envelope 1: Wall:**

From the above analysis it is evident that, wall insulation is feasible only for the districts having high Heating Degree Days. Also under each district, the buildings which operate for more hours have lower payback periods like hospitals, hotels and urban households. Among the insulation types identified for evaluation, 1 inch rock insulation has the lowest payback period. Glass wool and EPS insulation with medium payback period has a high energy saving potential. For rural and urban households which have constraint on the capital investment, rock wool insulation would be the viable option whereas for hospitals and hotels which operates for more hours and having relatively higher electricity tariff, glass wool and EPS insulation with medium payback period and high energy saving potential could be adopted.

**Building envelope 2: Window glazing**

Windows play a major role in the thermal performance of buildings. Windows contribute to heat loss as well as heat gain (solar). Windows also act a source of natural day lighting. In most of the buildings in Bhutan, single glazed window with wooden frame have been used. Heat loss through windows is in the range of 15% to 18%.

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**Table 6.5: Interventions- double glazing**

| Thimphu District | | | | | | |
|---|---|---|---|---|---|---|
| Glazing type | Potential | Payback period | | | | |
| | | Urban household | Rural household | Institutional building | Hospital | Hotel |
| 6 mm single glass | 11.31% | 5.67 | 8.28 | 7.03 | 2.89 | 3.31 |
| 6 mm single glass with low e | 12.10% | 7.08 | 10.08 | 8.64 | 3.72 | 4.24 |
| 6 mm double glass | 18.50% | 8.80 | 12.20 | 10.58 | 4.80 | 5.44 |
| 6 mm double glass with low e | 18.95% | 9.23 | 12.72 | 11.07 | 5.09 | 5.75 |
| **Paro District** | | | | | | |
| Glazing type | Potential | Payback period | | | | |
| | | Urban household | Rural household | Institutional building | Hospital | Hotel |
| 6 mm single glass | 11.31% | 4.27 | 6.41 | 5.36 | 2.11 | 2.42 |
| 6 mm single glass with low e | 12.10% | 5.41 | 7.94 | 6.71 | 2.74 | 3.14 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **6 mm double glass** | 18.50% | 6.85 | 9.78 | 8.37 | 3.58 | 4.09 |
| **6 mm double glass with low e** | 18.95% | 7.21 | 10.24 | 8.79 | 3.80 | 4.33 |

| **Bumthang District** | | | | | | |
|---|---|---|---|---|---|---|
| **Glazing type** | **Potential** | **Payback period** | | | | |
| | | **Urban household** | **Rural household** | **Institutional building** | **Hospital** | **Hotel** |
| **6 mm single glass** | 11.31% | 4.27 | 6.41 | 5.36 | 2.11 | 2.42 |
| **6 mm single glass with low e** | 12.10% | 5.41 | 7.94 | 6.71 | 2.74 | 3.14 |
| **6 mm double glass** | 18.50% | 6.85 | 9.78 | 8.37 | 3.58 | 4.09 |
| **6 mm double glass with low e** | 18.95% | 7.21 | 10.2 | 8.79 | 3.80 | 4.33 |

The payback period for window glazing varies in the range of 2.11 years to 12.72 years. From the above analysis it is evident that, window glazing is feasible only for the districts having high Heating Degree Days. Additionally, under each district, the buildings which operate for more hours have lower payback periods like hospitals, hotels and urban households. Among the glazing types identified for evaluation, 6mm single glass has the lowest payback period. 6mm double glass with low e coating with medium payback period has a high energy saving potential. For rural and urban households who have constraint on the capital investment, window glazing is not a viable option whereas for hospitals and hotels which operate for more hours and having relatively higher electricity tariff, double glazed window with medium payback period and high energy saving potential could be adopted.

**Building envelope 2: Weather strip and beading for windows**

Most of the infiltration loss in a building occurs through windows. This is mainly due to usage of non-seasoned wood and poor craftsmanship of windows. Using a weather strip and beading for closing the air gap in windows would reduce the infiltration heat loss. This is one of the low cost option to improve the energy efficiency of the building. The energy efficiency improvement potential of using weather strip and window beading is around 10%.

**Building envelope 2: Insulated curtain for windows**

Single glazed windows contribute to majority of the conduction heat loss during night time. In order to reduce the conductive heat loss through windows, insulated curtain of suitable thickness should be used. This option in combination with weather strip and beading could lead to energy saving of around 15%.

**Figure 6.3: weather strip and curtains**

## Energy Efficiency – Lighting Systems

Lighting contributes to a significant amount of power consumption in a building. Due to rapid electrification in Bhutan, lighting load has grown significantly over the years. There is a huge potential for improving energy efficiency in lighting system. The energy efficiency potential of different lighting system is given below:

**Table 6.6: Interventions- EE lighting measures**

| Energy Efficient Light fixture | Baseline fixture | Energy efficiency potential |
|---|---|---|
| 28 W T5 tube light | 40 W T12 tube light | 30% |
| 16 W LED tube light | 40 W T12 tube light | 60% |
| 10 W LED light | 18 W CFL | 44% |
| 80 W LED light | 250 W Mercury Vapour light | 68% |
| 9 W LED light | 45 W incandescent | 30-40% |

*Source: EY analysis*

**Table 6.7: Impact of Energy Efficient lighting**

The impact of efficient lighting fixture for a typical Dzong is given below:

| Baseline | Proposed | Energy cost saving (Nu.) | Investment (Nu.) | Payback period (years) |
|---|---|---|---|---|
| 40 W T12 tube lights X 128 nos | 16 W LED tube light X 128 nos | 243,639 | 234,496 | 6.80 |
| 18 W CFL X 110 nos | 10 W LED light X 110 nos | 149,474 | 147,361 | 6.90 |
| 250 W Mercury vapour lamp X 35 nos | 80 W LED light X 35 nos | 848,730 | 319,998 | 3.40 |

*Source: EY analysis*

The impact of Energy Efficient lighting fixture for a typical hospital is given below:

| Baseline | Proposed | Energy cost saving (Nu.) | Investment (Nu.) | Payback period (years) |
|---|---|---|---|---|
| 40 W T12 tube lights X 225 nos | 16 W LED tube light X 225 nos | 741,037 | 412,200 | 4.60 |
| 18 W CFL X 1697 nos | 10 W LED light X 1,697 nos | 3,144,536 | 2,273,386 | 5.60 |
| 250 W Mercury vapour lamp X 35 nos | 80 W LED light X 35 nos | 848,730 | 319,998 | 3.40 |

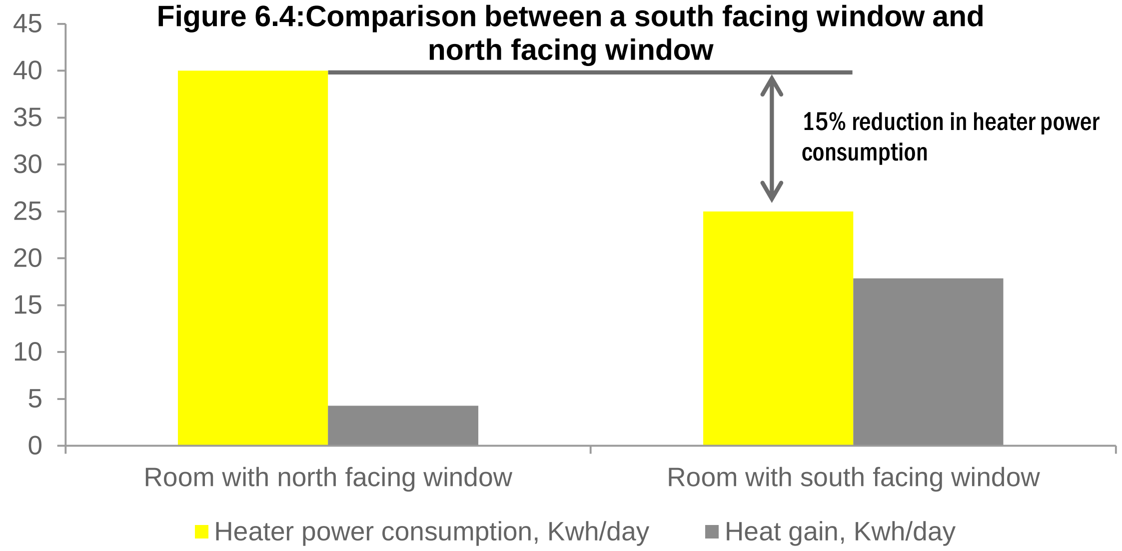
Average electricity tariff rate has been considered as 3.23 Nu/kWh for the hospital for the first year and thereafter 10% escalation year on year has been considered. All costs reflected for analysis on Energy Efficiency in lighting segment includes the cost of fixtures also. Operational hours of a building have a greater impact on the financial viability of the lighting system intervention. The same is evident from the above two tables.

**Energy efficiency interventions for new buildings:**

**Orientation: South facing window:**

The orientation of windows plays a major role in reducing the heat load of a building. Windows oriented towards south tend to gain more heat from incident solar radiation. This reduces the heat load of a building to a greater extent. This intervention does not require investment and it is one of the cheapest options for energy savings in countries like Bhutan. The comparison of heat gain between a south facing window and north facing window for a typical hotel in Thimphu is given below:

**Figure 6.4:Comparison between a south facing window and north facing window**



**Autoclaved Aerated Blocks:**

For new buildings, the wall material having low thermal conductivity should be chosen. Among the common wall material used in Bhutan, Rammed earth has the lowest thermal conductivity due to its heavy thermal mass. The other alternative wall material that could lead to reduction in heat loss is Autoclaved Aerated Concrete (AAC) blocks. This material has thermal conductivity in the range of 0.67 W/m2K. The impact of using AAC block instead of brick wall for a typical urban house hold in Thimphu is given below:

**Figure 6.5: use of AAC blocks in new buildings**

| Material | Percentage reduction in heat loss | Additional Investment | Payback |  |
|---|---|---|---|---|
| **AAC block** | 25 to 30% | Nu. 600-800/$m^3$ | 1.8 Years | |

**Figure 6.6: Comparison of AAC block with concrete block and Brick**

| Parameter | AAC Block | Concrete Block | Brick |
|---|---|---|---|
| **Size** | (600x200x75-300) mm | (400x200x100-200) mm | (230x115 x75) mm |
| | (625x240x75-300) mm | | |
| **Variation in dimensions** | +/-1mm | +/-3mm | +/-5mm |
| **Compressive strength** | 35-40 kg/cm2 | 40-50 kg/cm2 | 25-30 kg/cm2 |
| | (As per IS : 2185) | (As per IS : 2185) | (As per IS : 1077) |
| **Dry Density** | 550-650 kg/m3 | 1800 kg/m3 | 1950 Kg/m3 |
| **Fire Resistance** | 4-6 Hour depending on thickness | 4 hours | 2 hour |
| **Sound Reduction Index (dB)** | 60 for 200 mm thick wall | | 40 for 230 mm thick wall |
| **Thermal Conductivity W/(K-m)** | 0.16 | 0.51 | 0.81 |

**Advantages of AAC Block:**

- Very light weight concrete blocks (550 - 650 kg/m3), 1/4th weight of normal bricks/blocks.
- Numerous advantages especially for high rise buildings,
- Reduction in dead weight.
- Saving in steel / concrete (>10% - Steel and Concrete Combined)
- Increase in floor area due to reduction in size of columns.
- Better Thermal /Sound Insulation.
- Good sound absorption properties - reduces echo effect in an empty room
- Easy to transport on upper floors.
- Time saving in construction.
- The moments due to earth quake gets minimised.

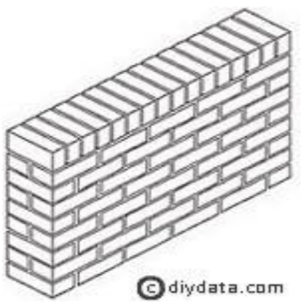
**Applications of AAC Block**

- Walls Internal/External
- Load Bearing in low and medium rise Buildings
- Non Load Bearing walls in framed construction
- Partitions Walls
- Thermal Insulation Tiles

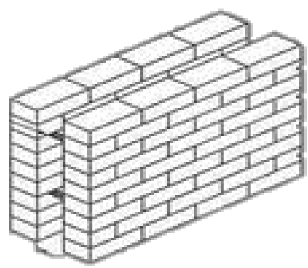
**Brick wall with cavity:**

Cavity walls consist of two 'skins' separated by a hollow space (cavity). This is one of the low cost construction practices for reducing the heat load in the building. The thermal conductivity of this wall is in the range of 1.37 W/m2K whereas the thermal conductivity of conventional brick wall is in the range of 2.69 W/m2K.

*Conventional brick wall*




*Brick wall with cavity*



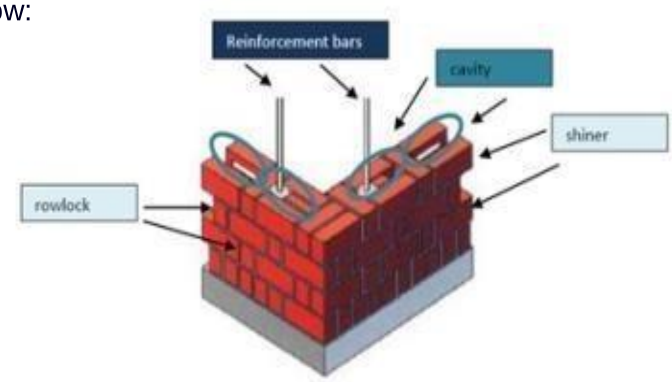
| Conventional Brick wall: 250 thick external wall (including plaster in both sides) | | | | |
|---|---|---|---|---|
| Dimension of a UK metric brick = | 215 | 102.5 | 65 | mm |
| height of wall = | | | 2.5 | m |
| length of wall= | | | 1.5 | m |
| Rule of Thumb: | Double brick wall requires 120 bricks per sq. m | | | |
| So, total no. of bricks for wall= | | | 450 | nos |
| U Value | | | 2.69 | W/m²K |

| | | |
|---|---|---|
| **Heat loss for Paro weather condition** | 255 | kWh/Year |
| Source: DIY data UK | | |

| | | | | |
|---|---|---|---|---|
| **Brick wall with cavity: 2 separate single brick walls with cavity in between** | | | | |
| **Dimension of a UK metric brick =** | 215 | 102.5 | 65 | mm |
| **height of wall =** | | | 2.5 | m |
| **length of wall=** | | | 1.5 | m |
| **Rule of Thumb:** | Single brick wall requires 60 bricks per sq. m | | | |
| **So, total no. of bricks for each wall=** | | | 225 | nos |
| **No. of such** | | | 2 | nos |
| **So, total no. of bricks for both walls combined=** | | | 450 | nos |
| **U Value** | | | 1.37 | $W/m^2K$ |
| **Heat loss for Paro weather condition** | | | 134 | kWh/Year |
| **Percentage reduction in heat loss** | | | 45 | |
| Source: DIY Data UK | | | | |

### Rat-trap bonded cavity wall:

A “Rat-Trap Bond” is a type of wall brick masonry bond in which bricks are laid on edge (i.e. the height of each course in case of a brick size 230x110x75 mm, will be 110 mm plus mortar thickness) such that the shiner and rowlock are visible on the face of masonry as shown below:




The advantage of this type of wall includes reduction in brick requirement by around 20-35% and 30-50% less mortar. This leads to reduction in 20-30% of the cost of a 9 inch wall. The U-value of this wall is almost same as the brick wall with cavity. When compared to brick wall with cavity, the reduction in heat loss is achieved with lower brick requirement.

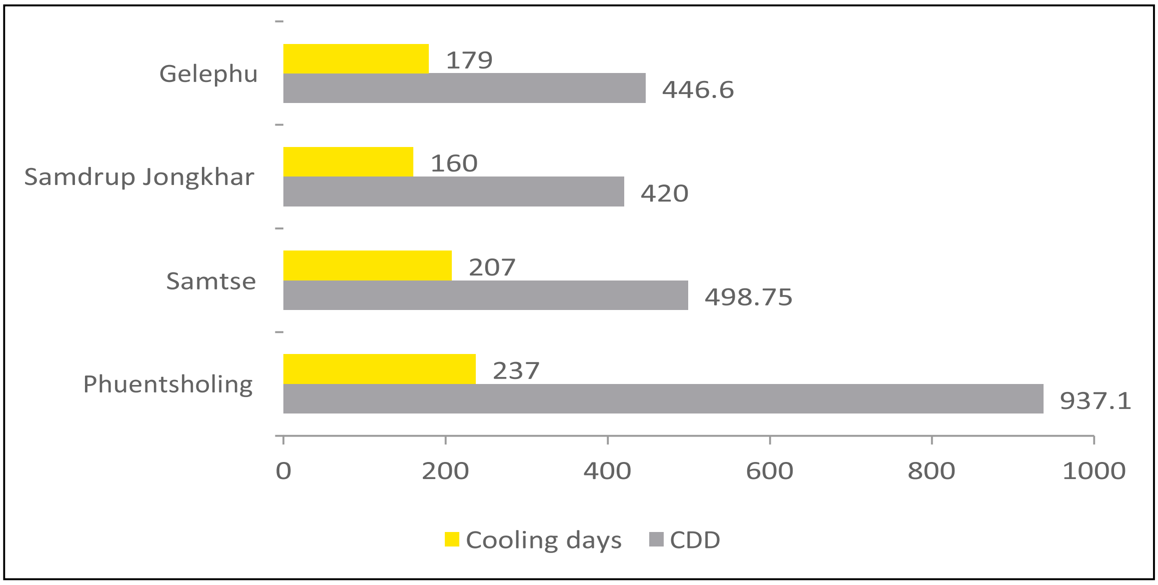
| Conventional Brick wall: 250 thick external wall (including plaster in both sides) | | | | |
|---|---|---|---|---|
| Dimension of a UK metric brick = | 215 | 102.5 | 65 | mm |
| height of wall = | | | 2.5 | m |
| length of wall= | | | 1.5 | m |
| Rule of Thumb: | Double brick wall requires 120 bricks per sq. m | | | |
| So, total no. of bricks for wall= | | | 450 | nos |
| U Value | | | 2.69 | $W/m^2K$ |
| Heat loss for Paro weather condition | | | 255 | kWh/Yea r |
| Source: DIY data UK | | | | |

| Rat Trap Bonded Wall with Cavity | | | | |
|---|---|---|---|---|
| Dimension of a UK metric brick = | 215 | 102.5 | 65 | mm |
| height of wall = | | | 2.5 | m |
| length of wall= | | | 1.5 | m |
| Assumption | Rat trap bond saves 20-30% bricks than normal double course brickwork | | | |
| So, total no. of bricks for entire wall= | | | 338 | Nos |
| U Value | | | 2.11 | $W/m^2K$ |
| Heat loss for Paro weather condition | | | 134 | kWh/year |
| Percentage reduction in heat loss | | | 45 | |
| Percentage reduction in overall cost of wall construction | | | 25 | |

## 6.3 Interventions for summer districts

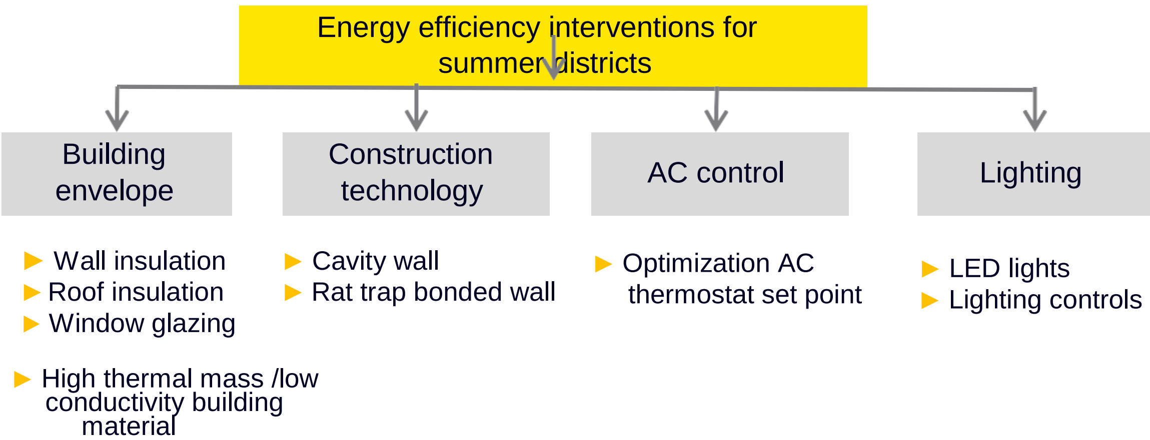
The ambient temperature across the summer districts does not vary significantly due to same altitude range. The Cooling Degree Day (CDD) method has been adopted for quantifying the energy savings and for evaluating the energy efficiency interventions. The districts having higher CDD require more cooling load for meeting the thermal comfort of the buildings. Phuentsholing (Chhukha district) is noted to have the highest CDD in Bhutan followed by Samtse, Gelephu, Samdrup Jongkhar and others. Like HDD, the CDD also has a greater impact on the financial viability of the interventions, for example, higher the CDD lower is the payback period of energy efficiency projects.

**Figure 6.7: Cooling Degree Days for various districts of Bhutan**




Unlike buildings in cold weather districts, there is not much of variation in the energy consumption pattern of buildings in summer districts. During the energy audit in summer districts, it was observed that majority of the air conditioner usage were in institutional buildings and hotels. Most of the residential buildings use only ceiling fans for meeting thermal comfort.

Almost 99% of the buildings in summer districts are of brick wall based construction. The energy efficiency interventions for summer districts have been broadly classified as follows:



***Building envelope 1: Wall***

Walls contribute to significant quantum of heat gain in the building. Unlike cold weather districts, majority (almost 95%) of the buildings in summer districts are of brick wall based construction. The percentage of heat loss (gain) for brick wall construction for different weather conditions is given below: Though the type of wall is same across summer districts, the heat loss (gain) is different for each district due to the variation in Cooling Degree Day (CDD).

**Table 6.8: Interventions- choice of wall materials**

| Wall material | U Value | Percentage of heat loss (gain) | | | |
|---|---|---|---|---|---|
| | | Phuentsholing | Samtse | Samdrup Jongkhar | Gelephu |
| Brick wall | 2.11 | 30.50% | 23.56% | 21.62% | 22.31% |

From the above table it is evident that the places with high Cooling Degree Days have more heat loss (gain) through building envelope. The following insulation materials have been considered for evaluating the thermal performance of buildings. These materials are identified based on some of the best practice observed in other places with similar weather conditions.

**Table 6.09: Interventions- choice of insulation materials**

| Insulation material | R Value | Cost, INR/Sq. |
|---|---|---|
| 1 Inch rock wool | 0.44 | 85 |
| 1 Inch glass wool | 0.90 | 160 |
| 1 Inch Expanded Polystyrene (EPS) | 0.63 | 130 |

Energy efficiency potential due to Wall insulation:

The energy efficiency potential by using the above mentioned insulation material varies from 4.6% to 13.96% to depending on the type of insulation material, type of building and Cooling Degree Day of the location. Phuentsholing district with highest Cooling Degree Day have high energy saving potential.

**Financial viability:**

The financial viability of this intervention is dependent on the electricity tariff, usage hours and Cooling Degree Day of the location. The payback period for wall insulation ranges from 1.61 years to more than 11.22 years for different districts.

The energy efficiency potential and payback period for wall insulation for different districts and different consumer type has is below:

**Table 6.10: Interventions- choice of insulation materials for different districts**

| Chhukha (Phuentsholing) District | | | | |
|---|---|---|---|---|
| Insulation type | Energy efficiency potential | Payback period (in years) | | |
| | | Institutional building | Hospital | Hotel |
| 1 inch Rock wool | 10.26% | 3.63 | 1.61 | 2.07 |
| 1 inch EPS | 12.16% | 4.69 | 2.08 | 2.68 |
| 1 inch Glass wool | 13.96% | 5.03 | 2.23 | 2.87 |

| Samtse District | | | | |
|---|---|---|---|---|
| Insulation type | Potential | Payback period (in years) | | |
| | | Institutional building | Hospital | Hotel |
| 1 inch Rock wool | 5.45% | 6.84 | 3.04 | 3.90 |
| 1 inch EPS | 6.46% | 8.82 | 3.92 | 5.04 |
| 1 inch Glass wool | 7.41% | 9.46 | 4.20 | 5.40 |

| Samdrup Jongkhar District | | | | |
|---|---|---|---|---|
| Insulation type | Potential | Payback period | | |
| | | Institutional building | Hospital | Hotel |
| 1 inch Rock wool | 4.60% | 8.11 | 3.60 | 4.63 |
| 1 inch EPS | 5.45% | 10.46 | 4.65 | 5.98 |
| 1 inch Glass wool | 6.26% | 11.22 | 4.98 | 6.41 |

| Gelephu District | | | | |
|---|---|---|---|---|
| Insulation type | Potential | Payback period | | |
| | | Institutional building | Hospital | Hotel |
| 1 inch Rock wool | 4.88% | 7.64 | 3.39 | 4.36 |
| 1 inch EPS | 5.79% | 9.85 | 4.38 | 5.63 |
| 1 inch Glass wool | 6.65% | 10.56 | 4.69 | 6.03 |

**Recommendation for Building envelope 1: Wall:**

From the above analysis it is evident that, wall insulation is feasible only for the districts having high Cooling Degree Days. Also under each district, the buildings which operate for more hours have lower payback periods like Hospitals and Hotels. Among the insulation types identified for evaluation, 1 inch rock insulation has the lowest payback period. Glass wool insulation with medium payback period has a high energy saving potential. Rock wool insulation would be the viable option for institutions, hospitals and hotels.

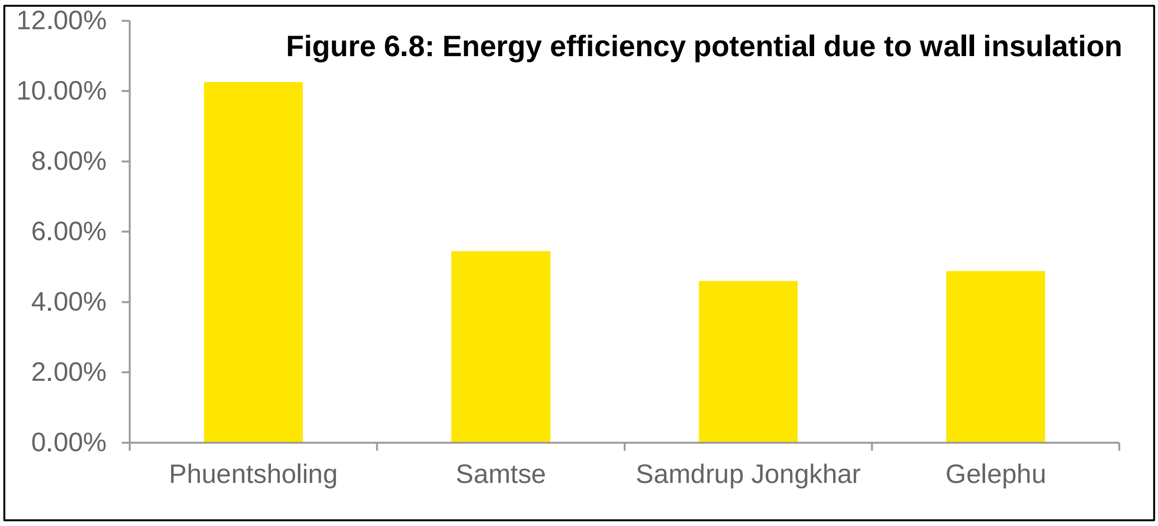


**Figure 6.8: Energy efficiency potential due to wall insulation**

**Building envelope 2: Ceiling and Roof**

Ceiling and Roof contributes to around 27%of heat loss (gain) in a building. In summer districts, most of the buildings have concrete ceiling and CGI roof. The percentage of heat loss for concrete ceiling and roof in different weather conditions is given below:

**Table 6.11: Interventions- choice of roof materials**

| **Roof material** | **U Value** | **Percentage of heat loss** | | | |
|---|---|---|---|---|---|
| | | Phuentsholing | Samtse | Samdrup Jongkhar | Gelephu |
| **Concrete ceiling with CGI roof** | 5.91 | 27% | 21% | 19% | 20% |

**Energy efficiency potential due to Roof insulation:**

The energy efficiency potential by using the below mentioned insulation material varies from 5.90% to 14.5% depending on the type of insulation material, type of building and Cooling Degree Day of the location. Phuentsholing (Chhukha district) with highest Cooling Degree Day has high energy saving potential.

**Table 6.12: Interventions- choice of roof insulation materials**

| Insulation material | R Value | Cost, Nu./Sq. M |
|---|---|---|
| 1 Inch rock wool | 0.44 | 85 |
| 1 Inch Expanded Polystyrene (EPS) | 0.63 | 130 |

**Financial viability:**

The financial viability of this intervention is dependent on the electricity tariff, usage hours and Cooling Degree Day of the location. The lowest payback period due to roof insulation is 1 year and the maximum is around 12 years. Considering the energy efficiency potential and payback period, roof insulation is a viable option for buildings in summer districts.

***Building envelope 3: Windows***

Windows play a major role in the thermal performance of buildings. Windows contribute to the maximum heat loss (heat gain) in a building in summer districts. Windows also act a source of natural day lighting. In most of the buildings in Bhutan, Single glazed window with wooden frame / aluminium frame are used. Heat load through windows is around 55% to 65%. The following window material has been considered for evaluating the thermal performanse:

| Window material | U Value | Cost, Nu./Sq. M |
|---|---|---|
| 6 mm reflective single glazed window | 5.81 | 1800 |
| 6 mm double glazed window | 3.12 | 3100 |
| 6 mm reflective double glazed window | 2.95 | 3500 |

The impact of glazing for different districts is given below:

| **Samtse District** | | | | |
|---|---|---|---|---|
| **Window Glazing Type** | Energy efficiency potential | Payback period (in years) | | |
| | | Institutional building | Hospital | Hotel |
| **6mm reflective single glazed window** | 33% | 1.00 | 0.99 | 0.87 |
| **6mm double glazed** | 7% | 6.57 | 5.60 | 5.36 |
| **6mm reflective double glazed window** | 37% | 1.49 | 1.43 | 1.29 |

| **Gelephu (Sarpang District)** | | | | |
|---|---|---|---|---|
| **Window glazing type** | Energy efficiency potential | Payback period (in years) | | |
| | | Institutional building | Hospital | Hotel |
| **6mm reflective single glazed window** | 33% | 1.00 | 0.99 | 0.87 |
| **6mm double glazed** | 7% | 6.62 | 5.73 | 5.46 |
| **6mm reflective double glazed window** | 37% | 1.49 | 1.44 | 1.29 |

| **Samdrup Jongkhar District** | | | | |
|---|---|---|---|---|
| **Window glazing type** | Energy efficiency potential | Payback period (in years) | | |
| | | Institutional building | Hospital | Hotel |
| **6mm reflective single glazed window** | 33% | 1.00 | 0.999 | 0.877 |
| **6mm double glazed** | 7% | 6.66 | 5.81 | 5.52 |
| **6mm reflective double glazed window** | 37% | 1.49 | 1.45 | 1.30 |

The payback period for window glazing varies in the range of 0.87 years to 6.66 years. Among the glazing types identified for evaluation, 6mm reflective single glass has the lowest payback period. 6mm reflective double glass with medium payback period has a high energy saving potential. 6mm reflective single glazing with suitable shading devices and insulated curtains would reduce the energy consumption up to 40%.

### Energy efficiency - Lighting

Lighting contributes to significant power consumption of the buildings in Bhutan. Due to rapid electrification in Bhutan, Lighting load has grown significantly over the years. There is a huge potential for energy efficiency in lighting system. The energy efficiency potential of different lighting system is given below:

**Table 6.13: Interventions- EE lighting measures**

| Light fixture | Baseline fixture | Energy efficiency potential (in %) |
|---|---|---|
| **28 W T5 tube light** | 40 W T12 tube light | 30 |
| **16 W LED tube light** | 40 W T12 tube light | 60 |
| **10 W LED light** | 18 W CFL | 44 |
| **80 W LED light** | 250 W Mercury Vapour light | 68 |

The impact of efficient lighting fixture for a typical Dzong is below:

**Table 6.14: Impact of efficient lighting**

| Baseline | Propose | Energy cost saving (Nu.) | Investment (Nu.) | Payback period (years) |
|---|---|---|---|---|
| 40 W T12 tube lights X 128 nos | 16 W LED tube light X 128 nos | 243,639 | 234,496 | 6.80 |
| 18 W CFL X 110 nos | 10 W LED light X 110 nos | 149,474 | 147,361 | 6.90 |
| 250 W Mercury vapour lamp X 35 nos | 80 W LED light X 35 nos | 848,730 | 319,998 | 3.40 |

The impact of efficient lighting fixture for a typical hospital is given below:

| Baseline | Propose | Energy cost saving (Nu.) | Investment (Nu.) | Payback period (years) |
|---|---|---|---|---|
| 40 W T12 tube lights X 225 nos | 16 W LED tube light X 225 nos | 741,037 | 412,200 | 4.60 |
| 18 W CFL X 1697 nos | 10 W LED light X 1697 nos | 3,144,536 | 2,273,386 | 5.60 |

| | | | | |
|---|---|---|---|---|
| 250 W Mercury vapour lamp X 35 nos | 80 W LED light X 35 nos | 848,730 | 319,998 | 3.40 |

Average electricity tariff rate has been considered as 3.23 Nu/kWh for the hospital for the first year and thereafter 10% escalation year on year has been considered. All costs reflected for analysis on Energy Efficiency in lighting segment includes the cost of fixtures also. Operational hours of a building have a greater impact on the financial viability of the lighting system intervention. The same is evident from the above two tables.

### Energy efficiency – AC thermostat set point optimization

In the summer districts of Bhutan, majority of the air conditioner usage is in Institutional buildings, hospital & hotels. Very low percentage of households use air conditioners. Most of the air conditioners used (especially the new purchases) were of minimum 2 star rated procured from India. However, during the energy audit it was observed that the air conditioners were not optimally used leading to more power consumption. Most of the time the air conditioners were operated at a set point of 20ºC irrespective of the outside temperature. There is a potential to save up to 12% of the energy consumption of air conditioners by using at a optimum thermostat set point (24ºC). For every 1ºC increase in the thermostat set point, there will be 3% reduction in the compressor power consumption. This measure does not require any investment and the returns are immediate. The energy savings due to AC set point optimization for a typical institutional building in Phuentsholing is given below:

| AC type | Hours of operation | Thermostat set point | Energy consumption / month | Energy cost / month |
|---|---|---|---|---|
| **1.5 Ton Split AC 2 star rated** | 8 hrs. / day | 20ºC | 384 kWh/month | Nu 1180 / month |
| **1.5 Ton Split AC 2 star rated** | 8 hrs. / day | 24ºC | 337 kWh/month | Nu 1037 / month |
| **Benefits (energy & cost savings)** | | | 46 kWh/month | Nu 141 / month |

***Energy efficiency interventions for new buildings:***

### Autoclaved Aerated Blocks:

For new buildings, the wall material having low thermal conductivity should be chosen. Among the common wall material used in Bhutan, Rammed earth has the lowest thermal conductivity due to its heavy thermal mass. The other alternative wall material that could lead to reduction in heat loss is Autoclaved Aerated Concrete (AAC) blocks. This material has thermal conductivity in the range of 0.67 W/m2K. The impact of using AAC block instead of brick wall for a typical institutional building in Phuentsholing is given below:

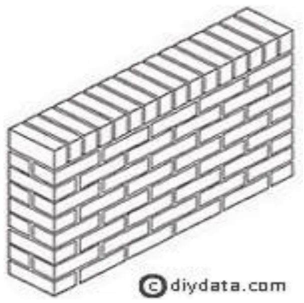
**Figure 6.9: Use of AAC blocks in new buildings**

| Material | Percentage reduction in heat loss | Additional Investment | Payback |  |
|---|---|---|---|---|
| **AAC block** | 25 – 30 | Nu. 600-800/m$^3$ | 2.5 Years | |

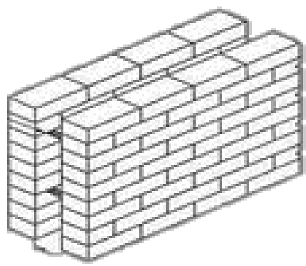
**Brick wall with cavity:**

Cavity walls consist of two 'skins' separated by a hollow space (cavity). This is one of the low cost construction practices for reducing the heat load in the building. The thermal conductivity of this wall is in the range of 1.37 W/m2K whereas the thermal conductivity of conventional brick wall is in the range of 2.69 W/m2K.

*Conventional brick wall*




*Brick wall with cavity*



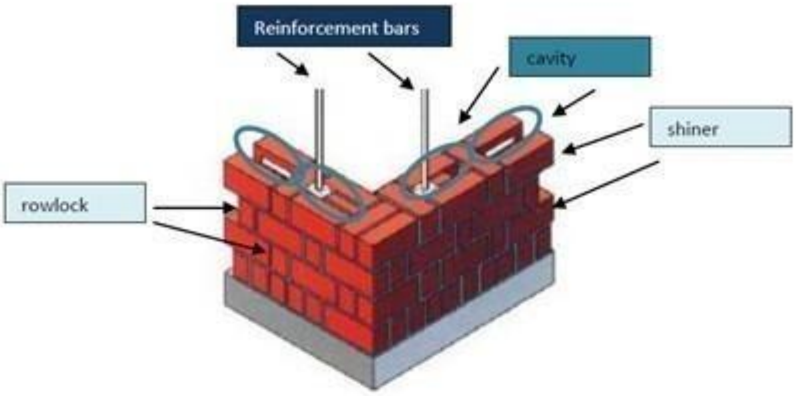
| Conventional Brick wall: 250 thick external wall (including plaster in both sides) | | | | |
|---|---|---|---|---|
| **Dimension of a UK metric brick =** | 215 | 102.5 | 65 | mm |
| **height of wall =** | | | 2.5 | m |
| **length of wall=** | | | 1.5 | m |
| **Rule of Thumb:** | Double brick wall requires 120 bricks per sq. m | | | |
| **So, total no. of bricks for wall=** | | | 450 | nos |
| **U Value** | | | 2.69 | W/m$^2$K |
| **Heat load for Phuentsholing weather condition** | | | 59.31 | kWh/Year |
| **Source: DIY data UK** | | | | |

| Brick wall with cavity: 2 separate single brick walls with cavity in between | | | | |
|---|---|---|---|---|
| **Dimension of a UK metric brick =** | 215 | 102.5 | 65 | mm |
| **height of wall =** | | | 2.5 | m |
| **length of wall=** | | | 1.5 | m |

| | | |
|---|---|---|
| **Rule of Thumb:** | Single brick wall requires 60 bricks per sq. m | |
| **So, total no. of bricks for each wall=** | 225 | nos |
| **No. of such** | 2 | nos |
| **So, total no. of bricks for both walls combined=** | 450 | nos |
| **U Value** | 1.37 | $W/m^2K$ |
| **Heat load for Phuentsholing weather condition** | 38.51 | kWh/Year |
| **Percentage reduction in heat load** | 35 | |
| **Source: DIY Data UK** | | |

**Rat-trap bonded cavity wall:**

A “Rat-Trap Bond” is a type of wall brick masonry bond in which bricks are laid on edge (i.e. the height of each course in case of a brick size 230x110x75 mm, will be 110 mm plus mortar thickness) such that the shiner and rowlock are visible on the face of masonry as shown below:




The advantage of this type of wall includes reduction in brick requirement by around 20-35% and 30-50% less mortar. This leads to reduction in 20-30% of the cost of a 9 inch wall. The U-value of this wall is almost same as the brick wall with cavity. When compared to brick wall with cavity, the reduction in heat loss is achieved with lower brick requirement.

| Conventional Brick wall: 250 thick external wall (including plaster in both sides) | | | | |
|---|---|---|---|---|
| | | | | |
| Dimension of a UK metric brick = | 215 | 102.5 | 65 | mm |
| height of wall = | | | 2.5 | m |
| length of wall= | | | 1.5 | m |
| Rule of Thumb: | Double brick wall requires 120 bricks per sq. m | | | |
| So, total no. of bricks for wall= | | | 450 | nos |
| U Value | | | 2.69 | W/m²K |
| Heat load for Phuentsholing weather condition | | | 59.31 | kWh/Year |
| Source: DIY data UK | | | | |

| Rat Trap Bonded Wall with Cavity | | | | |
|---|---|---|---|---|
| Dimension of a UK metric brick = | 215 | 102.5 | 65 | mm |
| height of wall = | | | 2.5 | m |
| length of wall= | | | 1.5 | m |
| Assumption | Rat trap bond saves 20-30% bricks than normal double course brickwork | | | |
| So, total no. of bricks for entire wall= | | | 338 | Nos |
| U Value | | | 2.11 | W/m²K |
| Heat load for Phuentsholing weather condition | | | 38.51 | kWh/Year |
| Percentage reduction in heat loss | | | 35 | |
| Percentage reduction in overall cost of wall construction | | | 25 | |

**Summary of interventions:**

Buildings in summer districts has a great potential to improve energy efficiency. The energy efficiency potential depends on the following factors,

- Cooling degree day
- Operational hours
- Consumer category
- Orientation
- Materials used

Considering the above mentioned factors, the energy efficiency interventions has been identified for existing as well as new constructions. The summary of interventions is given below:

**Table 6.15: Summary of Interventions for new and old buildings in Bhutan**

| | Short term | Medium term | Long term |
|---|---|---|---|
| Existing building | ► Weather strip for windows<br>► Insulated curtains<br>► AC set point optimization<br>► High Solar Reflectance (SRI) paint for roofs<br>► Positioning of Refrigerators on northern wall | ► Reflective single glazed window<br>► Rockwool insulation<br>► LED lighting | ► Reflective double glazed window<br>► Glass wool / EPS insulation |
| New construction | ► Weather strip for windows<br>► Insulated curtains<br>► High Solar Reflectance (SRI) paint for roofs<br>► Positioning of Refrigerators and air conditioners on northern wall | ► Reflective single glazed window<br>► LED lighting<br>► Cavity wall<br>► Rat trap bonded wall<br>► AAC blocks<br>► Use of appropriate shading techniques on west wall to prevent overheating | ► Reflective double glazed window<br>► Cavity wall insulation |

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# *Annexure I – List of buildings audited*

| Identified Districts | Identified buildings | |
|---|---|---|
| Paro | ▶ Paro College of Education<br>▶ Paro Airport<br>▶ National Seed Centre<br>▶ Hotel Zhiwa Ling<br>▶ Hotel Olathang<br>▶ Hotel Holiday Home | ▶ District Hospital, Paro<br>▶ Urban Household 1<br>▶ Urban Household 2<br>▶ Rural Household 1<br>▶ Rural Household 2 |
| Thimphu | ▶ Hotel Phuentsho Pelri<br>▶ Sinchula restaurant<br>▶ Terma Linca Resort<br>▶ Golf Club Restaurant<br>▶ Shearee Square Shopping Mall<br>▶ Shopping area near Hotel Phuntsho Pelri<br>▶ Jamyang Resort<br>▶ Atsara Restaurant<br>▶ 8 eleven<br>▶ Hotel Galinkha<br>▶ Hotel Sambhav<br>▶ Durga Niwas<br>▶ Old Residence near CFM<br>▶ Department of Geology and Mines | ▶ Residential apartment near Tarayana Centre<br>▶ Residential apartment near Hotel Phuentsho Pelri<br>▶ Doctors' Quarter<br>▶ Nurses' Quarter<br>▶ NPPF Colony (Class I, Class II, Class III)<br>▶ Changiji Colony<br>▶ Old apartment near CFM<br>▶ Residential Apartment of RN Adhikari<br>▶ Energy Building<br>▶ BPC Headquarters<br>▶ Changankha Lhakhang |
| Punakha | ▶ Hotel Meri Punsum<br>▶ District Hospital, Punakha<br>▶ Damchen resort<br>▶ UMA, Punakha<br>▶ Amankora, Punakha<br>▶ Hotel Zhangdopelri<br>▶ Rural Household 1 | ▶ Rural Household 2<br>▶ Rural Household 3<br>▶ Rural Household 4<br>▶ Urban Household 1<br>▶ Urban Household 2<br>▶ Hotel Shivling |
| Bumthang | ▶ Bumthang Dzong<br>▶ Amankora, Bumthang<br>▶ Swiss Guest House<br>▶ Kaila Guest House | ▶ District Hospital, Bumthang<br>▶ RNR R&D Center, Bumthang |
| Mongar | ▶ Hotel Wangchuk<br>▶ Eastern Regional Referral Hospital, Mongar<br>▶ RNR R&D Center, Mongar<br>▶ Hotel KD<br>▶ Urban Household 1<br>▶ Urban Household 2<br>▶ Rural Household 1 | ▶ Rural Household 2<br>▶ Rural Household 3<br>▶ Rural Household 4<br>▶ Rural Household 5<br>▶ Rural Household 6<br>▶ Rural Household 7 |
| Trashigang | ▶ Hotel Druk Deothjung<br>▶ Druk Deothhjung Resort<br>▶ Urban Household 1 | ▶ Urban Household 2<br>▶ Rural Household 1<br>▶ Rural Household 2 |
| Haa | ▶ Rural Household 1<br>▶ Rural Household 2<br>▶ Rural Household 3 | ▶ Urban Household 1<br>▶ Urban Household 2 |
| Trashiyangtse | ▶ Yeshey Dema Hotel<br>▶ Zangmo Dolma Hotel<br>▶ Urban Household 1 | ▶ Rural Household 1<br>▶ Rural Household 2<br>▶ Rural Household 3 |

| Identified Districts | Identified buildings |
|---|---|
| **Phuentsholing** | ▶ City corporation office<br>▶ District hospital, Phuentsholing<br>▶ Regional revenue & customs office<br>▶ Park Hotel<br>▶ Household 1<br>▶ Household 2 |
| **Samtse** | ▶ Samtse College of education<br>▶ District hospital, Samtse<br>▶ BPC office, Samtse<br>▶ Hotel Sonam<br>▶ Household 1<br>▶ Household 2 |
| **Samdrup Jongkhar** | ▶ JN Polytechnic College, Deothang<br>▶ Tashi-gasel lodge<br>▶ Dzongkhag office<br>▶ RNR center<br>▶ Menjong hotel<br>▶ Household 1<br>▶ Household 2 |
| **Gelephu** | ▶ City corporation office<br>▶ Khamsang hotel<br>▶ Regional revenue & customs office<br>▶ Regional trade office<br>▶ RNR center<br>▶ Household 1<br>▶ Household 2 |

# Annexure 2 – Case Studies

To gain a better understanding of the interventions undertaken in buildings of similar climates, an exhaustive case study and best practice review of several buildings in similar climatic conditions were conducted, some of which are presented in this section.

## Case 1: Ladakh Ecological Development Group Trainees' Hotel, Leh

| Building Background | |
|---|---|
| **Location** | Leh, India |
| **Altitude** | ~3500m |
| **Climate** | Cold and sunny |
| **Building type** | Institutional building (hostel) |
| **Built-up area** | 300 sq. m. |

### Energy Efficiency Measures

| | |
|---|---|
| **Building Envelope** | ▶ Predominantly south exposure with no overhangs for maximum winter gains.<br>▶ Traditional materials and methods of construction modified and adapted to achieve energy efficiency<br>▶ All rooms south facing to enable winter heat gain<br>▶ Double glazing in windows<br>▶ Load bearing mass walls: stone in ground floor, sundried mud bricks in first floor<br>▶ Floors and roofs: timber framed with wooden joists covered by grass, earth, no overhangs |
| **Use of RE** | ▶ Flat plate thermo-siphonic collector system |
| **Other Passive Solar Design Elements** | ▶ Solarium at centre of building, heated by south glazing<br>▶ Bedrooms provided with various types of Trombe walls (half Trombe, unvented Trombe, vented Trombe) or direct gain systems for passive heating. |

## Case 2: Office building for Himachal Pradesh Energy Development Agency

Annexure 2 – Case Studies

| Building Background | |
|---|---|
| **Location** | **Shimla, Himachal Pradesh – India** |
| **Altitude** | **~2000m** |
| **Climate** | **Cold and cloudy** |
| **Building type** | **Institutional building (public office)** |
| **Built-up area** | **635 sq. m.** |

### Energy Efficiency Measures

**Building Envelope**

- Air heating panels built as an integral part of the south wall provide effective heat gain
- Insulated RCC diaphragm walls on the north to prevent heat loss
- Distribution of heat gain in the building through a connective loop that utilizes the stairwell as a means of distributing heated air
- Double-glazed windows with proper sealing to minimize infiltration

**Use of RE**

- Installation of a roof-mounted solar water heating system
- Solar PV based building lighting; artificial lighting only needed on cloudy days

**Other passive solar design elements**

- Orientation of building intended to maximize solar heat usage – internal temperature maintained at 18- 28 deg C compared to outside ambient temperature of 9-15 deg C
- Specially designed solarium on south for heat gain
- Design of a solar chimney to maximize natural ventilation by using convection of air heated by passive solar energy.

## Case 3: Enermodal Engineering Office Building, Ontario

### Building Background

| | |
|---|---|
| **Location** | **Ontario, Canada** |
| **Climate** | **Long cold winters, short summers** |
| **Building type** | **Institutional (office building)** |
| **Built-up area** | **2150 sq. m** |

### Energy Efficiency Measures

| | |
|---|---|
| **Building Envelope** | ► Insulated concrete forms (R-value of 25) used for the building'swalls<br>► Triple-glazed, low-emissivity, argon-filled, fiberglass windows<br>► Insulation-lined window openings that prevent thermal bridging between them and the thick, concrete walls<br>► Hollow-core slab floors that provide thermal mass to control diurnal heating and cooling requirements |
| **Use of RE and other techniques** | ► A 5.5-peak-kW solar PV array enables sunlight to be converted directly into electricity.<br>► Presence of Variable refrigerant-flow heat-pump system, heating, ventilating and air-conditioning (HVAC) sensors and controls |
| **Other passive solar design elements** | ► A 12-metre-wide footprint enabling most interior spaces to benefit from window on at least one external wall<br>► A large skylight providing natural light to the central atrium, stairs and corridors<br>► Interior glass walls allowing light to pass through and brighten spaces. |