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# Study of Heat Loss through Air Gaps in Bhutanese Window Fittings and Walls-A Case Study

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**ABSTRACT:** The construction industry have contributed maximum impact on the environment, consuming an extensive amount of the world's energy. Vernacular buildings have evolved with minimal effect on the environment and preserved the natural resources for future generations. However, air infiltration through the building envelope has substantial impact on the thermal comfort of the dwellers apart from an increase in energy loads incurring higher energy costs of building. This study is a comprehensive review on heat loss through the gaps present in windows and walls of Bhutanese building in the western part of Bhutan due to air infiltration. After identifying these gaps, possible approaches to provide air tightness to the buildings are studied and recommended.

**KEYWORDS*:*** Air tightness, Air infiltration, Thermal transition, Thermogram, Thermal comfort

## I. INTRODUCTION

Globally, buildings consume approximately 40% of the world's total energy annually in developed countries and 10-15% in developing countries (Omer, 2008). Most of these energies are utilized in the heating purposes in the building (Acosta et al, 2010). Thermal insulation is a very crucial aspect of a building design to reduce energy consumption dues to heat gain and Loss through gaps in various fenestrations. The heat gain and loss through building envelopes are accountable about 25-30% of buildings' energy load used for heating and cooling (Energy, n.d.). Similarly, according to Bhutan Energy Efficiency baseline Study, it was found that buildings are the highest consumer of energy with 48.7% of total energy consumption in the country (DRE, 2012; WoWHS, 2013).

Today, with the focus on sustainability, building design have given much attention to energy related performance of windows and walls in a building envelope (Selkowitz& Bazanac, 1979). Air infiltration is one of the major aspects of heat loss in buildings. Ventilation along with air infiltration has a major influence on the internal environment of a building. Moreover, the performance quality of building material and structures are affected by the moisture carried by infiltrating air in a long run (Powell et al,1989; Younes, et al, 2011).

## II. CAUSES OF AIR INFILTRATION

As discussed before, air infiltration occurred due to flowing of air through the building envelopes as a result of pressure difference on both sides of the barrier caused by the temperature difference and natural driving force like wind (Jackman, 1974;Younes et al, 2011). Air leaks can occur in many zones of the building envelope; the presence of gaps in the joinery of window and door frames, construction joints of walls, holes created due to thermal expansion and contraction of materials and holes drilled for installation electrical and ICT systems. Moreover, the prominent gaps and cracks in a building envelope is occurred due to improper construction management like poor workmanship and rectification works, Mishandling with inadequate protection and using a low quality of construction materials (Kosiński, 2015).

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Bhutanese construction practices were an outcome of the trial and error method, influenced by the culture and traditions of the country. These vernacular construction techniques evolved through time and were predominant until developmental activities started in the country. In order to keep up with the advancement in modern times, Bhutan started implementing various construction materials and techniques which were actually designed considering the warm climatic conditions of India (Aris& Hut,1994;Jentsch et al, 2017). These modern construction techniques are inappropriate to the climatic conditions of Bhutan, hence deteriorating the construction quality and minimizing the application of thermal insulation techniques leading to poor thermal comfort for the occupants (Jentsch et al,2017). It was observed that both these traditional and modern construction techniques in Bhutan do not include air and wind barrier layers in building envelope as a result of which, 45% of energy is consumed for heating and cooling purposes in residential buildings (MoEA, 2015).

## III. FACTORS OF AIR INFILTRATION

Studies have proven that that air infiltration are responsible for 25-50% of the heating load in residential and commercial buildings (Jokisalo et al, 2009;Younes et al, 2011). The air infiltration in building has occurred due to the air mass flow rate, the air-specific heat capacity and the inside–outside temperature difference as shown in the equation below.

$$Q_{inf} = \dot{m}C_p(T_i - T_o)$$

Where, '$Q_{inf}$ 'represents the air infiltration energy load (W), 'm' represents the air infiltration mass flow rate (kg/s), '$T_i$ 'represents the inside indoor room temperature, '$T_o$'represents the outside ambient temperature and '$C_p$' represents the specific heat of air (J/kg _C).As stated in the formula, the air infiltration occurred due to the presence of variation of air pressure across the building envelope. This variation in pressure is cause due to wind pressure and stack effect. Wind direction and speed along with topography and building form contributes to the value of wind pressure whereas, stack pressure generates due to the height of building and its ambient air temperatures (Younes et al, 2011).

## IV. STUDY AREA

Four buildings in Thimphu with different functional aspect and construction materials and techniques are selected for this particular study. Thimphu is a capital city of Bhutan, located at 27°28′00″N latitude and 89°38′30″E longitude at an altitude between 2248 m and 2,648 meters above mean sea level. It lies in the temperate zone with warm summer and the cold winter (ICIMOD, 2016) with a maximum average temperature of 23˚C and minimum of 7˚C. It receives the total annual rainfall of 607mm (NCHM, 2017).

Two out of four selected buildings are constructed with traditional building material like rammed earth for wall and timber for fenestration. The traditional Bhutanese farm house was constructed with the conventional construction technique using putlog and the library building of the Royal University of Bhutan (RUB) was constructed with modern construction technology. Moreover, the RUB library building has double glazed windows whereas, the traditional Bhutanese building's windows were singly glazed. The other two buildings are the Office building of Attorney General (OAG) and the two storied residential apartment in Changjiji housing complex. Both the buildings are constructed using modern technology with RCC framed structure, brick as infill material and timber windows. The building of OAG has double glazed windows, while the residential apartment in Changjiji are singly glazed.

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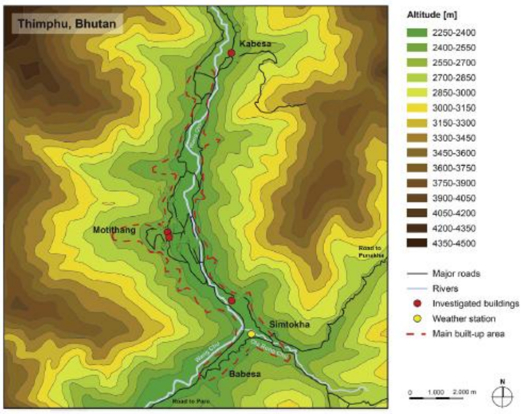


Figure 1: Location of buildings in Thimphu

## V. HEAT LOST DUE TO AIR INFILTRATION IN BUILDING CONSTRUCTED WITH LOCAL MATERIAL

Traditional farmhouses in Bhutan apart from few in the southern belt follow a common prototype, with minimal local differences in building material and construction details (Aris& Hut, 1994; Jentsch, 2017). Most of the Traditional buildings in Bhutan have two to three floors by earth, stone and timber as their commonly used vernacular materials. The rammed earth construction in the western part of Bhutan use putlog holes to support timber formwork and these holes are left unattended once the building is constructed in most of the buildings.

Forward-looking Infrared camera (FLIR) camera as shown in Figure 2 is used to detect the surface temperature of an object and analyse the temperature difference and heat lost due to infiltration. A ray of infrared light from the special lens of the FLIR camera is emitted on the surface of selected windows and walls of these selected buildings and detects the surface temperature, this process is called the Thermal imaging.

### A. TWO STORIED TRADITIONAL RAMMED EARTH FARMHOUSE

This two storey village farm house located at an altitude of 2478 m, was constructed in 1995 using locally available rammed earth using the traditional construction techniques with the upper floor partially in timber-framed structure known as rabsel. However, later on extensions was made with reinforced concrete frame structure. Initially, the ground floor was used to keep cattle and the first floor served for residential purposes. Currently, both the floors are used as residential purpose.

Thermal imaging of the singly glazed HorgoPagab window in the ground floor as shown in Figure 3 was done to understand and comprehend the heat loss through the timber window made with no sealing. It was carried out on 27th October, 2018 at 1:45 P.M. with the outdoor and indoor temperature of 17°C and 10ºC respectively. The level of humidity was 36% and the wind velocity of 6 km/h. It was found that the inner surface temperature of the window frame was 10.9 ºC shown in Figure 4 and outside was detected as 16.2 ºC as shown in Figure 5 with a temperature difference of 5.3 ºC.

Figure 3: Building 01: Traditional Farm House

Figure 3: Front elevation of the window

Similarly, thermal imaging of the rammed earth wall of 600 mm thick was carried out to understand heat gain and loss through holes and openings of a wall on the same day and time having a same physical parameters. It was observed that inner surface wall near the putlog hole was detected with 14.6 ºC and outside was detected as 21.2 ºC shown in Figure 6 having a temperature difference of about 6.6 ºC. It was observed that the building lacked air-tightness, due to air gaps present in the windows and walls. The air leaks were noted between wall and window structure, joints between window panes and frames using thermal imaging process.

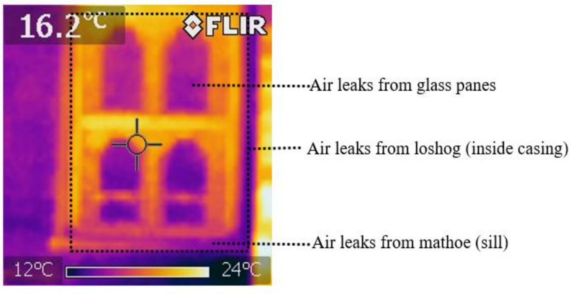


Figure 4: Thermogram of the external surface of window

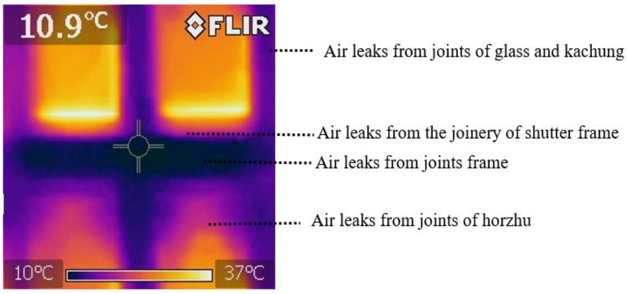


Figure 5: Thermogram of the internal surface of window

According to the Energy saving regulations EN 13829: 2000, the n50 value of a new building must not exceed 3 $h^{-1}$ (ENEV, 2001).However, the air infiltration of this building was found to be 5.3 $h^{-1}$ as per study carried out by (Jentsch et al, 2017) on the same building. This establishes that the building is leaky as Thermogram images of Figure 5 and 6 show that maximum amount of heat is lost through air leaks from the various joinery of a window frame. It was found that the joineries are found to be poorly finished and does not have proper sealant in the window frames while doing visual physical verification as shown in Figure 4. Similarly, ahuge amount of air infiltration occurs through walls due to putlog holes as shown in Figure 6 and cracks developed around these holes in due course of time which further add to the air infiltration rate. Similarly, Gedkar windows which were traditionally used as ventilators, significantly add to the air infiltration as shown in figure 7.

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### B. TWO STORIED MODERN UNIVERSITY LIBRARY BUILDING

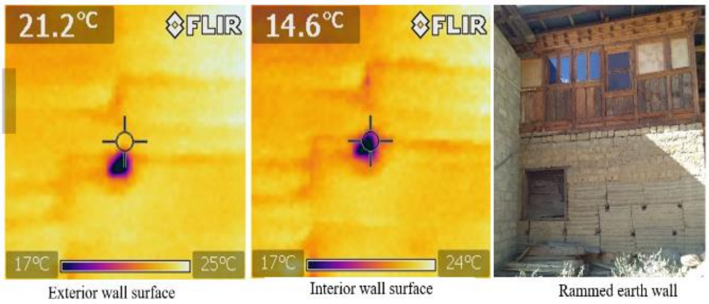


Figure 6: Thermogram of rammed earth with putlog hole


Figure 7: Thermogram of Gedkar payab

The two storied Library building of the Office of the Royal University building was constructed in 2014 with locally available rammed earth without putlog holes on the ground floor and the upper floor with a timber-framed structure (rabsel) using modern technologies. It is located at an altitude of 2445 m in Motithang,Thimphu.

Figure 8: Building 02-Univerisy Library building, OVC

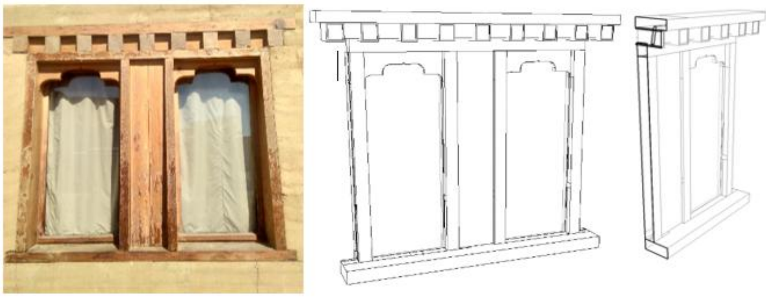

Figure 9: Front elevation of the selected window

Thermal imaging of the double-leaf casement with rabbet edge wooden window frame with proper sealing of the ground floor was carried out. However, the double glazed window shutter with air gab in between does not have sealant finish. Similar to building no. 1, this test was carried out to understand the heat loss through the timber window made with proper sealing. The test was carried out on 27th October, 2018 at 10:02 a.m. The outdoor and indoor temperature was 17°C and 12ºC respectively. The humidity level of an atmosphere was 42% with the wind velocity of 5 km/h. It was observed that the outer surface temperature of window glass was 17 ºC shown in Figure 10 and the inner surface was detected as 15.6 ºC as shown Figure 10with a temperature difference of 1.4 ºC.

It was observed that, there is very less variation of outdoor and indoor air temperature on window glasses due to use of the double glazing. The thermal transmittance of the window was 0.48 W/m2 K, which is less than a single glazing i.e, 1.09 W/m2 K according to study carried out by (Jentsch et al, 2017). The heat loss in this building has occurred due to air gaps formed in the poor joinery sections of the window frame and the rammed earth wall as shown in figure 13. These cracks between the wall section and wooden frames were formed due to use of poorly seasoned timber material.

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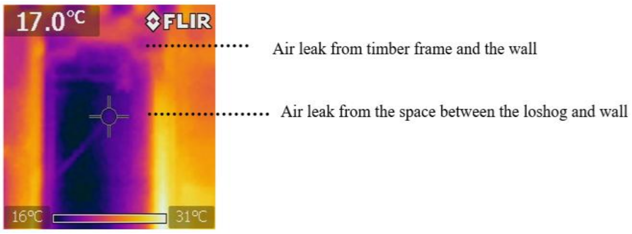


Figure 10: Thermogram of the external surface of window

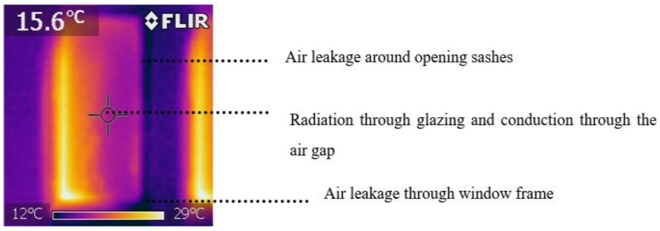


Figure 11: Thermogram of the internal surface of window

DIN 4108–4:2013 specifies a thermal conductivity of a traditional rammed earth wall as 1.1 W/m2 K and thermal transmittance i.e, U value of 1.1-1.2 W/m2 K (DIN, 2013). The huge variation in the interior and exterior temperature of the building wall is due to its low thermal transmittance and its exterior wall thickness. Application of modern construction techniques in this building has reduced the air gaps like traditional farm house, due to proper finishing in carpentry and masonry works. The low thermal transmittance results in a cold interior during the daytime. However, rammed earth having a high thermal conductance dissipates its absorbed heat and maintains a favorable indoor climate at night. At the same time, the wooden paneling in the interior of the wall easily helps in heating up the room (Dabaieh& Elbably, 2015).

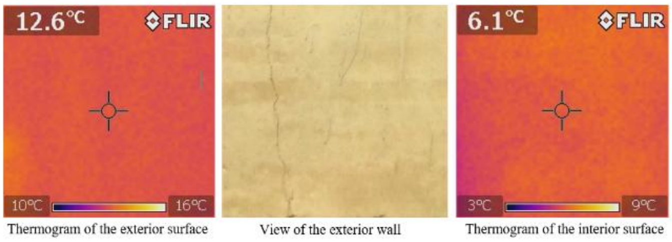


Figure 12: Thermogram of rammed earth and wooden paneled wall

Figure 13: Typical causes of air leaks

## VI. HEAT LOST THROUGH AIR INFILTRATION IN BUILDING CONSTRUCTED MODERN BUILDINGS MATERIALS

After the introduction of modern construction materials in Bhutan from neighbouring countries, construction techniques and building types have changed rapidly. Most of the load bearing masonry structures were replaced with reinforced concrete frame structures (Watson& Bertaud, 1976). The magnificent traditional timber rabsel are replaced by concrete facades and the wooden shingles that served as the roofing material were replaced by more corrugated galvanized iron (CGI) sheets, imported from neighboring counties. Due to the presence of appropriate bye law and regulation, the imported modern construction material and techniques have less impact on traditional Bhutanese architectural elements despite compromising some quality (MoWHS, 2014). However, it was found that these modern materials and construction technology have greatly influenced the thermal properties of the buildings (WoWHS, 2013).

### A. Office Building of Attorney General

This five storey office building was constructed in 2013 using a RCC frame structure with brick infill walls. The office building of Attorney General is located at an altitude of 2418 m. Modern construction techniques were adopted for the construction of this building. Timber windows are used in the building façade.

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Figure 14: Building no.3: Office of Attorney General

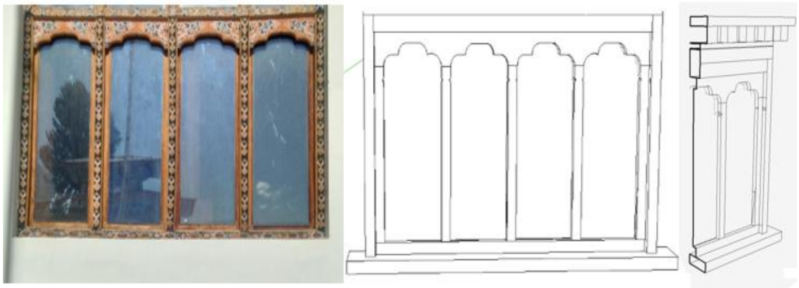

Figure 15: Front elevation of the selected window

Thermal imaging of a selected typical wooden framed window without proper sealing was carried out to comprehend the heat loss through it. The test was carried out on 27th October, 2018 at 10:41 a.m. Outdoor and indoor temperatures are noted at 17°C and 15°C with a humidity of 36% and the wind velocity of 6 km/h.It was observed that the outer surface temperature of the wooden window frame was 64.3 ºC shown in Figure 16 and internal surface was detected as 24.4 ºC as shown Figure 17 with a temperature difference of 39.9 ºC.Similarly, it was observed that the outer surface temperature of brick wall was 64.2 ºC shown in Figure 18 and internal surface was detected as 15.3 ºC as shown Figure 19 with a temperature difference of 39.9 ºC.It was found that air infiltration rate is 1.0 $h^{-1}$ proving the building is air tight, However, joints between window casements and frames have observed some signs air leakage. Due to the absence of cracks in the wall, no heat loss was due to infiltration was observed.

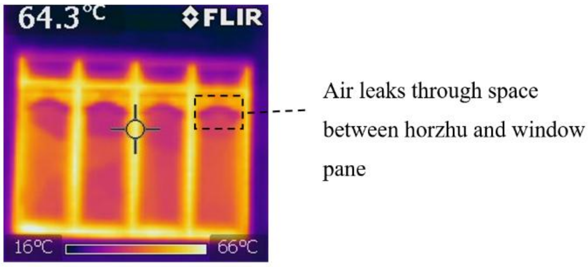


Figure 16: Thermogram of the external surface of window

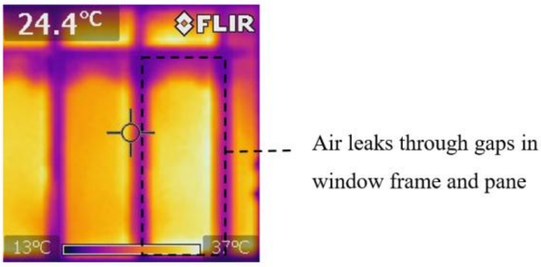


Figure 17: Thermogram of the internal surface of window

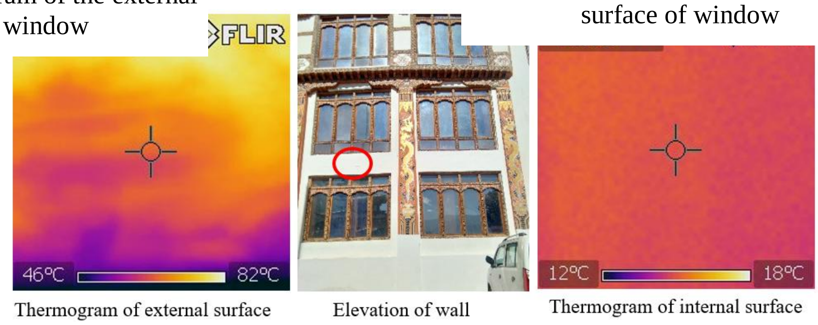


Figure 18: Thermogram of Brick wall surface

### B. TWO STOREY RESIDENTIAL BUILDING BLOCK

This two-storied residential building is constructed at Changigi housing complex in 2011 by National Housing Development Corporation Ltd. It was constructed with RCC frame structure and brick infill walls using modern construction techniques. Apart from brick and concrete, the window and doors are made up of timber.

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Figure 19: Building no.4: Residential building


Thermogram of external side of window | Elevation of a window | Thermogram of internal side of window

Figure 20: Thermogram of window surface

Thermal imaging of this typical window without sealing of the living room as shown in figure 20 was carried out on 27th October, 2018 at 4:40 p.m. The outdoor temperature was 16°C and internal temperature was 12ºC with a humidity of 48% and the wind velocity of 10 km/h.It was observed that the outer and inner surface temperature of window glass was 13.5ºC and 12.7ºC respectively as shown Figure 20. Similarly, the outer and inner surface temperature of brick wall was 11.6ºC and 10.9ºC as shown in Figure 21.The air infiltration rate of this building was 0.8 $h^{-1}$ as per the study carried out by (Jentsch et al, 2017). Hence, this building was established as is air tight where, very less heat loss occurred through air gaps, due to the absence of cracks in the wall.


Thermogram of external surface of wall | Elevation of wall | Thermogram of internal surface of wall

Figure 21**:** Thermogram of wall surface

## VII. COMPARATIVE ANALYSIS

Out of four the buildings, it was analyzed and found that the worst performing building was the two-storied traditional farmhouse with air infiltration rate of 5.3 $h^{-1}$, despite the building constructed with locally available rammed earth using vernacular construction technologies. Rammed earth is considered as an energy efficient building material (Minke, 2000; (Morgan, 2008; Venkatarama, 2014) due to its thick thermal mass, which act as a huge heat sink and absorbs solar energy during the daytime keeping the indoor environment cool and keeps the structure warm at night. However, due to poor construction technology and the presence of putlogs, considerable heat was lost in this farm house.On the contrary, the modern rammed earth construction adopted by the library building in RUB has a minimum heat loss through its walls, which was denoted by the substantial temperature variation. The heat loss through windows were observed in both cases, which has occurred through the joints between elements of the wooden casements, window frames and window lintels as interpreted from the thermograms.

However, it was observed that the double glazed window in the library building had very low thermal transmittance with minimal heat loss compared to singly glazed window in the traditional building. It was found that the heat lost from the air gaps in windows and walls is mainly due to the poor construction technique and poor maintenance. Hence it was analyzed that locally available materials can be used in conjunction with modern materials and construction techniques to optimize its thermal performance and to reduce heat loss to create a favorable indoor thermal comfort.As per this study, it was found that the buildings constructed with modern technology with imported materials performed significantly better than traditional buildings. These buildings had their air infiltration rate at a minimum of 1 $h^{-1}$ w with less amount of crack and holes in their building envelope. It was observed that the modern construction techniques facilitate minimum air infiltration due to its adoption of new construction materials and better workmanship.

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However, if the primary materials used are similar to that of the locally available material such as timber for windows, modern interventions should be carried out to minimize the heat loss.

## VIII. RECOMMENDATIONS

In general, heat lost through the building enveloped especially, window, door openings and the wall can be reduced improving construction and retrofitting techniques as discussed below.

### A. IMPROVING THE AIR-TIGHTNESS OF WINDOWS

The timber used in windows of these four case buildings are not only durable but also consider as environment friendly due to its nature of sustainability (Ortiz et al, 2009). Therefore retrofitting these windows to enhance its efficiency would be preferred over replacing it with windows made of imported materials such as PVC and aluminum. Shrinkage of wooden frames and elements occur in any heavy timber assemblies, where timber has the tendency to lose its moisture and shrink its sizes creating wide air gaps in joinery intersections and elongated cracks (Andrews, 1967) as shown in figure 22. But, a well-seasoned timber would undergo less shrinkage, thus provide tight joinery and a few problems during its retrofitting works like sealing.

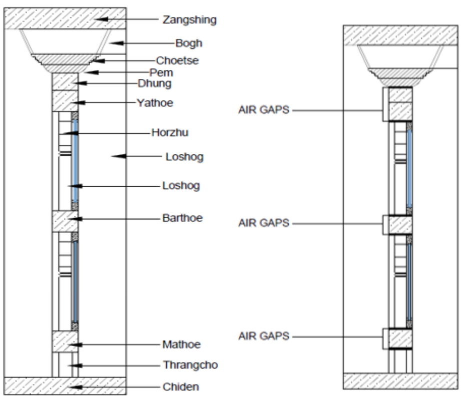


Figure 22: Typical window section and Air gaps

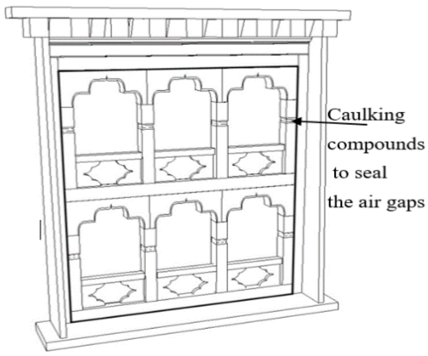


Figure 23: Sealing of air gaps

It is recommended to caulk the air gaps around the window frame and the adjacent wall and between the window frame and the shutter. Moreover, it is more preferable to use water resistant, durable and adhesives on the cracks formed by the shrinkage due to weathering of timber shown in figure 23. To reduce the velocity of the infiltrating air, levels should be created to obstruct the air flow. This level can be created using groove joints. Example, thrangcho grooved inside the Chiden (wooden sill) to splinter the velocity of the air and reduce its infiltration. The single glazing should be replaced with double glazing or a triple glazing which reduces the thermal transmission value by 6 times as compared to the single glazing (Fang et al, 2007).

### B. IMPROVING THE AIR-TIGHTNESS OF WALLS

The study recommend that conventional construction techniques of rammed earth walls like traditional farmhouse should be replaced with modern techniques used in library building as most of the heat loss were occurred through putlog holes of olden techniques. Moreover, it would be more efficient is the external surface of the wall is further coated weatherproof materials to reduce the weathering due to rain and wind, and minimize the air-infiltration rate in the building envelope (Karlsson, 2013). It would further increase the efficiency in reducing heat transmission through the wall, if the internal surface of the walls are treated with materials having high U-value or a new layer of paneling is done to create a cavity, increasing the time lag in the thermal mass.

## IX. CONCLUSION

The building located in cold climate like Thimphu consumes a huge amount of energy in heating the internal space to maintain the human comfort. This consumption pattern of energy is not only uneconomical but also creates a lot of environmental pollution leading to climate change. Therefore, it would be more efficient, if existing leaky building envelopes are retrofit with better workmanship using appropriate sealant and seasoned timbers. Moreover, the modern construction techniques using locally available material like rammed earth would be more suitable to construct the building economical with less air infiltration rate to reduce heat loss. No windows or walls can be made completely air-tight but the recommended interventions can effectively enhance its performance in the building envelope and greatly reduce heat loss through air infiltration to enhance an indoor air quality with minimum requirement external energy for heating and cooling.

## X. ACKNOWLEDGEMENT

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