

Retrofitting thermal performance of building envelope and extension of Secha Sadan, Bhubaneswar

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Abstract: The built environment is responsible for 40% of the global energy demand. Efforts are to be made in existing buildings, namely in office buildings, which are statistically more energy consuming than residential buildings. One of the main components of achieving a more sustainable built environment is to improve the performance of the existing building stock by retrofitting to increase the energy efficiency and improve quality of life (Low Carbon Innovation Coordination Group 2012). The retrofit of building envelope can help in saving 50–60% of the buildings' energy consumption used for HVAC purposes. Secha Sadan is a 50 year old government office building in Bhubaneswar. Proposing a building envelope retrofitting for this structure will not only help in reducing the energy consumption of this structure but would also shed light on how this can be implemented in other such existing government office buildings in Bhubaneswar. The existing envelope has been documented and analyzed using U-Value calculations and simulation softwares like OPAQUE and Form it. A number of envelope retrofitting techniques have been studied and shortlisted through literature, desktop and case studies to propose the best strategies. It was found that 40% savings can be achieved by the retrofit strategy implemented. Also the live proposal of an extension of the existing block to accommodate a new division has been taken into consideration. An attempt has been made to design this block appropriately keeping in mind the required thermal performance standards.

Keywords: Building Envelope, Retrofitting, Thermal Performance, Insulation

1. THESIS PROPOSAL

1.1. Background

India is the 7th largest country in the world and home to over 1 billion people living across five different climatic zones. India is a rapidly growing economy with construction sector contributing to around 7.74% to the total GDP of the country. Commercial and residential development remains a priority for the construction industry due to its market potential/market demand/profit margins. These sectors also consume a large amount of energy over their life cycle, thus becoming one of the major sources of GHG emissions. Literature and current policy framework suggest that energy saving and its conservation is of prime importance to the government of India. The government is in a continuous process of suggesting and implementing policy frameworks to manage the energy usage from various sectors including the buildings sector. The government came out with a suggestive list of voluntary and mandatory programs and policies such as Energy Conservation Building Code (ECBC) for commercial buildings, Standards and Labelling

(S&L) program for appliances, Star rating program for existing building etc. to monitor and optimize the energy consumption from the sector.

1.2. Statement of problem

Retrofitting of building envelope to improve thermal performance refers to how well a building responds to the changes in external temperature during daily and seasonal cycles with respect to the building envelope (walls, roof, floor, windows, doors, skylights and other openings).

1.3. Aim of the paper

To Retrofit Existing old government office Building to improve the Thermal performance of the building to achieve thermal comfort

1.4. Objectives of thesis

- To study the principles of retrofitting technologies.
- To energy audit the existing govt. building and analyze current energy consumption.
- To find out different technologies and components of the building and ways to implement them.
- To formulate the application of retrofitting components to the building.
- To simulate and analyze the post retrofitting conditions and furnish final report.

1.5. Description of the project or the study area

1.5.1. Location and climatic zone classification

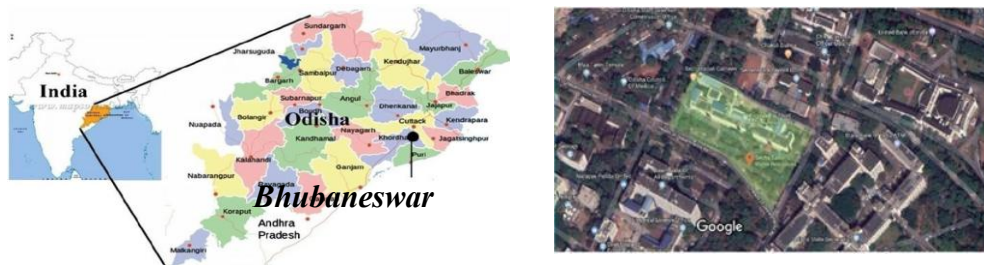


Figure 1 location of site

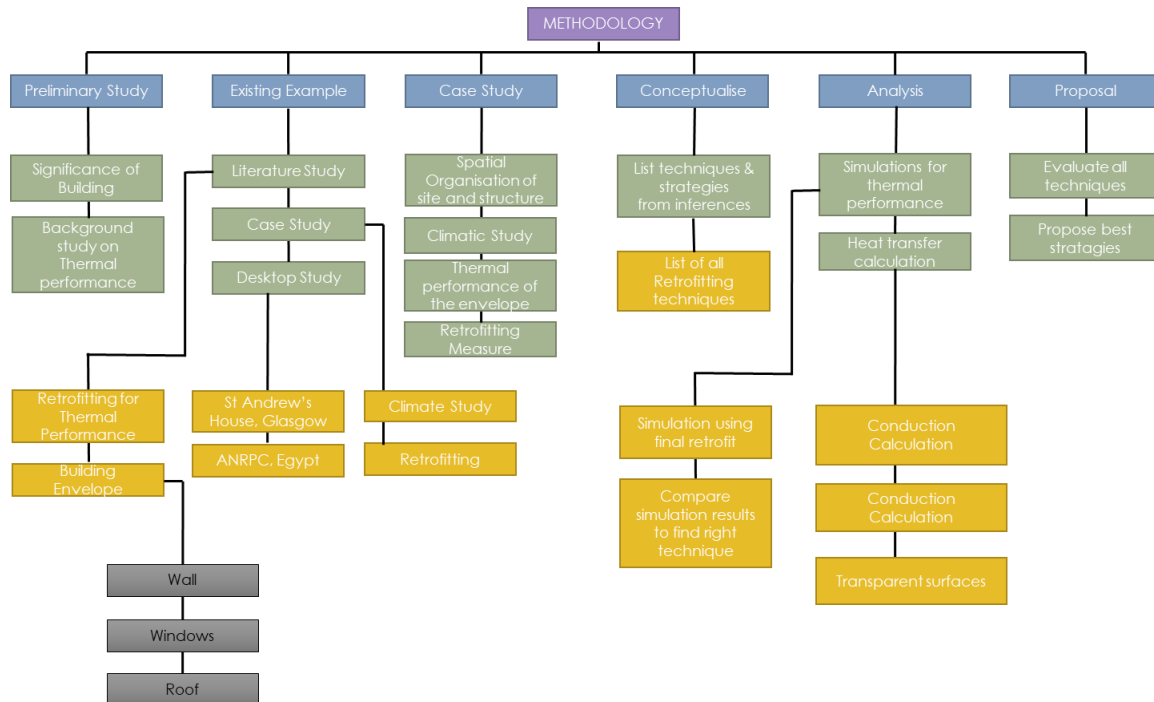
The office building is located in Bhubaneswar, Odisha. Secha Sadan (Water resources department) Bhubaneswar, Odisha was established in the year 1993.

1.5.2. Typology of the project or study area



Figure 2 Secha Sadan building

1.5.3. Proposed methodology



1.5.4. Limitation of the thesis

- Project is limited to providing thermal insulation to building envelope.
- There are some assumptions in the simulation modelling.
- For example, the data of internal gains from occupants, lighting and other appliances are taken from benchmarks and typical scenarios.
- The embodied energy is not simulated, which may be considered a limitation.

2. INTRODUCTION

A building once operational, continues to consume energy and increase its carbon footprint throughout its life. Retrofitting existing buildings can lead up to 15-20 % savings over the benchmark energy consumption. Retrofitting existing buildings to ensure energy efficiency and mitigate GHG emissions has been identified as one of the most effective mechanism by governments of various countries to reduce their energy consumption and mitigate GHG emissions.

In India major stock of office buildings was built before the implementation and access to modern energy saving technologies. According to the 17th EPS report published, it was estimated that electricity demand is estimated to increase by 37.5% by 2021-22 over a baseline of 2016-17. An ECBC Cell has been established in BDA to ensure energy efficiency in the buildings in the city through implementation of Odisha ECBC Code, 2011. A consultation meeting has been held to discuss and take feedback of all the major stakeholders vendor list has prepared who provide ECBC Compliant materials in state.

Studying the historical growth in consumption levels and population growth projections until the year 2018, it has been assessed that the energy consumption in Bhubaneswar in 2013 can be ascertained under the highest growth scenario as 1570.10 MU. The guidelines on “Retrofitting Existing commercial Buildings” presents a step by step

approach to access the saving potential in the existing building and then stimulate implementable options and method to achieve required numbers in term of energy savings and GHG mitigation

3. LITERATURE REVIEW

3.1. Building Envelope

A building envelope is the physical separator between the conditioned and unconditioned environment of a building. The building envelope of a house consists of its roof, sub floor, exterior doors, and windows and of course the exterior walls. A building envelope is normally referred to as either 'tight' or 'loose'. A loose envelope allows air to flow more freely through the building, whereas a tight envelope restricts air or controls how it is admitted. From an energy efficiency point of view, the envelope design must take into consideration both the external and internal heat loads, as well as daylighting benefits. External loads include mainly solar heat gains through windows, heat losses across the envelope surfaces, and unwanted air infiltration in the building

3.2. Heat transfer in building

Heat transfer takes place through walls, windows, and roofs in buildings from higher temperature to lower temperature in three ways-conduction, convection, and radiation.

Table 1 Definition

| | CONDUCTION | CONVECTION | RADIATION |
|-------------------|--|------------------------------------|---|
| DEFINITION | The transfer of heat through a solid material. | The transfer of heat by moving air | The transfer of heat In the form of electromagnetic waves |

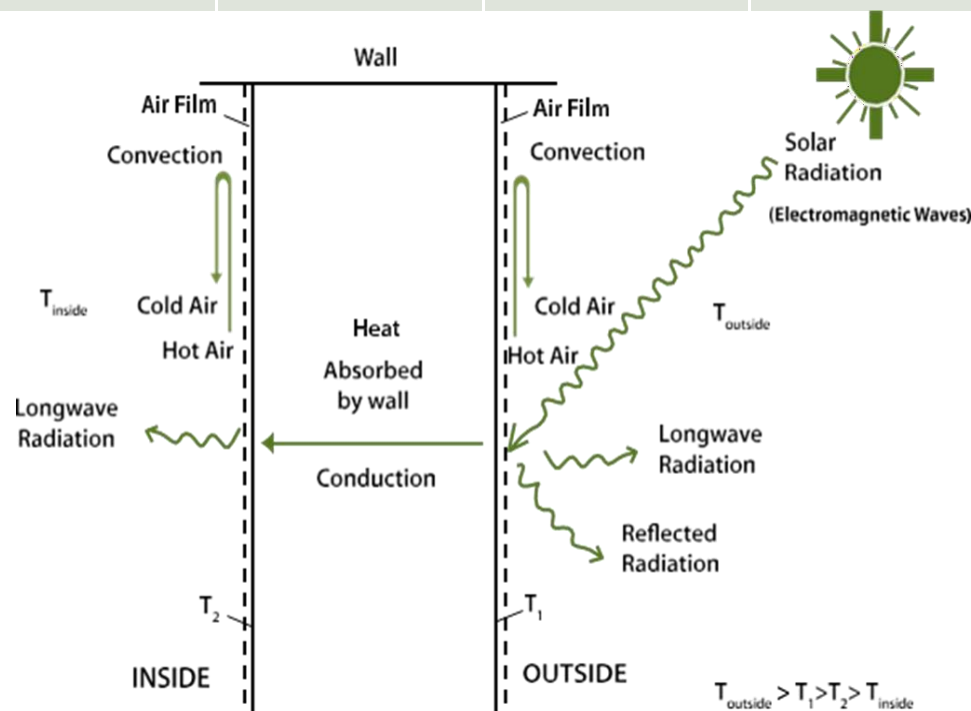


Figure 3 wall section showing heat transfer

3.3. Thermal properties

3.3.1. Thermal Conductivity of insulating materials

Thermal conductivity, also known as Lambda (λ), is the measure of how easily heat flows through a specific type of material, independent of the thickness of the material in question. The lower the thermal conductivity of a material, the better the thermal performance. It is measured in Watts per Meter Kelvin (W/mK).

3.3.2. R-Values

The R-value is a measure of resistance to heat flow through a given thickness of material. So the higher the R-value, the more thermal resistance the material has and therefore the better its insulating properties.

$$R = l / \lambda$$

Where:

l is the thickness of the material in meters and λ is the thermal conductivity in W/mK. The R-value is measured in meters squared Kelvin per Watt (m²K/W)

3.3.3. U-Values

The U value of a building element is the inverse of the total thermal resistance of that element. The U-value is a measure of how much heat is lost through a given thickness of a particular material, but includes the three major ways in which heat loss occurs – conduction, convection and radiation.

$$U = 1 / [R_{si} + R_1 + R_2 + \dots + R_{so}]$$

In practice this is a complicated calculation, so it is best to use U-Value calculation software.

3.4. Retrofitting Envelope

3.4.1. Opaque Wall

Insulation of walls is also important for reducing conduction losses especially where significant difference exist between inside and outside temperature. Many insulation materials require an Air Barrier and Weather Resistive Barrier to prevent air and moisture movement into and out of the conditioned space, as well as for maintaining their installed R-value. Opaque Wall Assembly U-Factor and Insulation R-value Requirements (ECBC Table4.2).

| Climate Zone | Hospitals, Hotels, Call Centers (24-Hour) | | Other Building Types (Daytime) | |
|----------------|--|---|--|---|
| | Maximum U-factor of the overall assembly (W/m ² ·K) | Minimum R-value of insulation alone (m ² ·K/W) | Maximum U-factor of the overall assembly (W/m ² ·K) | Minimum R-value of insulation alone (m ² ·K/W) |
| Composite | U-0.440 | R-2.10 | U-0.440 | R-2.10 |
| Hot and Dry | U-0.440 | R-2.10 | U-0.440 | R-2.10 |
| Warm and Humid | U-0.440 | R-2.10 | U-0.440 | R-2.10 |
| Moderate | U-0.440 | R-2.10 | U-0.440 | R-2.10 |
| Cold | U-0.369 | R-2.20 | U-0.352 | R-2.35 |

Table 2 opaque wall assembly recommendation

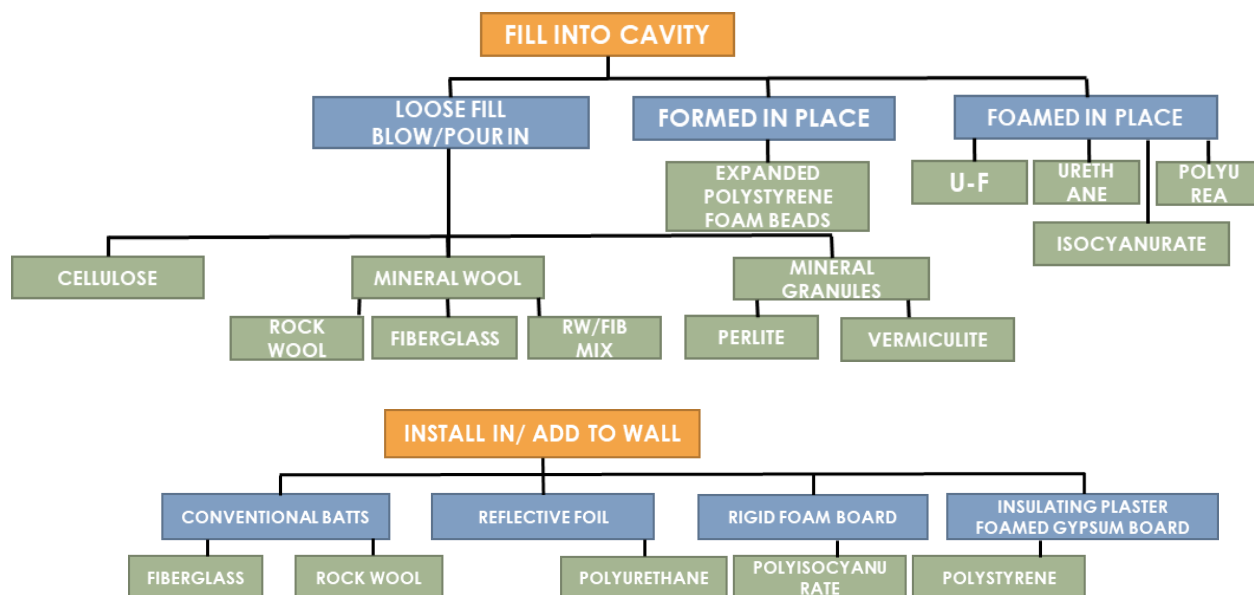


Table 3 recommended materials by IGBC

| Material | U-value (W/m ² K) | Thickness (mm) |
|----------------------------|------------------------------|----------------|
| Extruded Polystyrene (XPS) | 0.028 | 60 |
| Glass Wool stuffing | 0.25 | 150 |
| Expanded Polystyrene (EPS) | 0.30 | 100 |
| Air (Still) | 0.20 | 30 |

3.4.2. Roof

Roof can be insulated either over the deck or under the deck. Generally, over deck insulation is preferred, so as to avoid the absorption and retention of heat by the concrete surface. Under deck insulation can also be considered but the thickness of insulation should be higher.

Table 4 Recommendation for roof

| Climate Zone | 24-Hour use buildings Hospitals, Hotels, Call Centers etc. | | Daytime use buildings Other Building Types | |
|----------------|---|--|---|--|
| | Maximum U-factor of the overall assembly (W/m ² · K) | Minimum R-value of insulation alone (m ² · K/W) | Maximum U-factor of the overall assembly (W/m ² · K) | Minimum R-value of insulation alone (m ² · K/W) |
| Composite | U-0.261 | R-3.5 | U-0.409 | R-2.1 |
| Hot and Dry | U-0.261 | R-3.5 | U-0.409 | R-2.1 |
| Warm and Humid | U-0.261 | R-3.5 | U-0.409 | R-2.1 |
| Moderate | U-0.409 | R-2.1 | U-0.409 | R-2.1 |
| Cold | U-0.261 | R-3.5 | U-0.409 | R-2.1 |


3.4.3. Fenestration

Most large commercial buildings are dominated by cooling loads, so window selection for commercial buildings is usually an exercise in maximizing daylighting and keeping summer heat out. Today's best windows block heat transfer more than five times better than single-pane glass, the standard windows of just two decades ago. High-performance

windows are not only a wise investment for new construction, but sometimes can be cost-effectively retrofitted, especially when timed with planned replacement and downsizing of HVAC equipment. Glazing products (windows, skylights, etc.) can be specified to reduce solar heat gain and control light levels and glare. As a rule of thumb, double glazing should always be preferred over single glazing since facades with double glazing not only offers superior thermal performance but can also help in significantly reducing unwanted external noise of traffic.

Windows are affected by many factors, which in turn affect the comfort and energy performance of buildings. Understanding these factors is critical to designing buildings that meet the needs of building owners and users. Once these factors are identified, a designer can then apply the appropriate technology to address them.

Table 5 Fenestration global recommendation

|  Southern Zone Required Properties (mostly cooling) | | | |
|---|---|---|---|
| U-factor | Solar Heat Gain Coefficient (SHGC) | Visible Transmittance (VT) | Air Leakage (AL) |
| Windows: $U \leq 0.40$ Skylights: $U \leq 0.60$ | Windows: $SHGC \leq 0.25$ Skylights: $SHGC \leq 0.28$ | Windows: VT=No Requirement Skylights: VT=No Requirement | Windows: $AL \leq 0.30$ Skylights: $AL \leq 0.30$ |
| <i>EWC Recommendation:</i> A low U-factor is useful during cold days when heating is needed. A low U-factor is also helpful during hot days when it is important to keep the heat out, but it is less important than SHGC in warm climates. | <i>EWC Recommendation:</i> A low SHGC is the most important window property in warm climates. For superior energy performance, use windows with a SHGC of 0.25 or less. | <i>EWC Recommendation:</i> Select windows with a higher VT to maximize daylight and view. | <i>EWC Recommendation:</i> Select windows with an AL of 0.30 or less. |

3.5. Insulation Strategies

Table 6 minimum U value for wall and roof

| Climatic zones | 24-Hour use buildings (Hospitals, Hotels, Call Centers etc.) | | Daytime use buildings (Other Building Types) | |
|---------------------------------------|---|--|---|--|
| | Maximum U - factor of the overall assembly ($W/m^2 \cdot ^\circ C$) | Minimum R - value of insulation alone ($m^2 \cdot ^\circ C/W$) | Maximum U - factor of the overall assembly ($W/m^2 \cdot ^\circ C$) | Minimum R - value of insulation alone ($m^2 \cdot ^\circ C/W$) |
| Composite, Hot & Dry and Warm & Humid | | | | |
| Roof Assembly | 0.261 | 3.50 | 0.409 | 2.10 |
| Wall Assembly | 0.440 | 2.10 | 0.440 | 2.10 |

Table 7 measures for reduction of heat gain

| Measures | Wall | Roof | Window |
|--|--|---|--|
| Minimize Conduction Losses | Use insulation with low U-factor | Use insulation with low U-factor | Use material with low U-factor |
| Minimize Convection Losses | Reduce air leakage using a continuous air barrier system | Reduce air leakage using a continuous air barrier system | Use prefabricated windows and seal the joints between windows and wall |
| Minimize Moisture Penetration | Reduce water infiltration- use continuous drainage plane Reduce air transported moisture- use continuous air barrier Reduce moisture diffusion into the wall – use vapor barrier/retarder* | Watertight Airtight: continuous air barrier Use vapor barrier/retarder* | Use prefabricated windows and seal the joints between windows and walls |
| Minimize Radiation Losses | Use light colored coating with high reflectance | Use light colored coating with high reflectance | Use glazing with low Solar Heat Gain Coefficient (SHGC); Use shading devices |
| * See the discussion about where to place a vapor barrier/retarder. (Fig. 7) | | | |

| Form | Method of Installation | Where Applicable | Advantages |
|---|---|--|--|
| Blankets: Batts or Rolls, Fiberglass, Rock wool | <ul style="list-style-type: none"> Fitted between studs, joists and beams. Insulation must be protected by an air barrier membrane in order to maintain the installed R-value (conductive loops & wind washing) The air barrier can be installed over exterior and/or interior sheathing and must be continuous | <ul style="list-style-type: none"> Unfinished walls, floors and ceilings | <ul style="list-style-type: none"> Easy installation, suited for standard stud and joist spacing, which is relatively free from obstructions |
| Loose-Fill: Spray-applied Rock wool, Fiberglass, Cellulose Polyurethane foam | <ul style="list-style-type: none"> Blown into place or spray applied by special equipment. Insulation must be protected by an air barrier membrane in order to maintain the installed R-value (conductive loops & wind washing) The air barrier can be installed over exterior and/or interior sheathing and must be continuous | <ul style="list-style-type: none"> Enclosed existing wall cavities or open new wall cavities Unfinished attic floors and hard to reach places | <ul style="list-style-type: none"> Commonly used insulation for retrofits (adding insulation to existing finished areas) Good for irregularly shaped areas and around obstructions |
| Rigid Insulation: Extruded polystyrene foam (XPS), Expanded polystyrene Foam (EPS or Beadboard), Polyurethane foam, Polyisocyanurate foam | <ul style="list-style-type: none"> Interior applications: Must be covered with 1/2-inch gypsum board or other building-code approved material for fire safety Exterior applications: Must be covered with weather-proof facing or continuous Air and Weather Resistive Barrier (WRB) | <ul style="list-style-type: none"> Basement walls, Exterior walls under finishing (Some foam boards include a foil facing which will act as a vapor retarder. Additionally, some insulation materials- e.g. XPS and closed cells polyurethane foams—are vapor retarders. Please read the discussion about where to place, or not to place a vapor retarder) Unvented low slope roofs | <ul style="list-style-type: none"> High insulating value for relatively little thickness Can block thermal short circuits when installed continuously over frames or joists |
| Reflective Systems: Foil-faced paper, Foil-faced polyethylene bubbles, Foil-faced plastic film, Foil-faced cardboard | <ul style="list-style-type: none"> Foils, films, or papers: Fitted between wood-frame studs joists, and beams | <ul style="list-style-type: none"> Unfinished ceilings, walls, and floors (for wall applications, must consider that most foil faced systems act as a vapor retarder) | <ul style="list-style-type: none"> Easy installation: All suitable for framing at standard spacing Bubble-form suitable if framing is irregular or if obstructions are present |

4. DESKTOP STUDY

4.1. Alexandria National Refining & Petrochemicals Co.(ANRPC)

Alexandria National Refining & Petrochemicals Co. (ANRPC) is a refinery based **office building in El-Max, Alexandria, Egypt**. The company has an administrative building. It was designed in 1995 and construction in 2000 finished.



Figure 12 location of project and Building

4.1.1. Building typology

Office Building

| Floors | Functions |
|--------------|-----------------------------|
| Ground floor | Meeting Room – Reception |
| 1st floor | Chairman + Managerial Board |
| 2nd floor | Engineering Departments |
| 3rd floor | Human Resources Departments |
| 4th floor | Financial Departments |

Total construction area of 3370 Sq.m.
22% reduction in both energy consumptions and Carbon emissions.

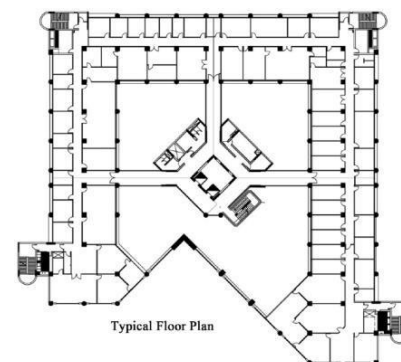


Figure 13 plan

4.1.2. Energy Data for the building

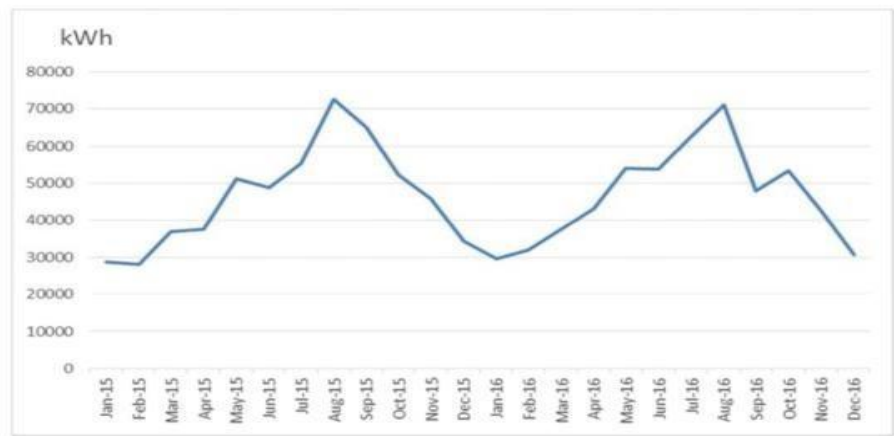
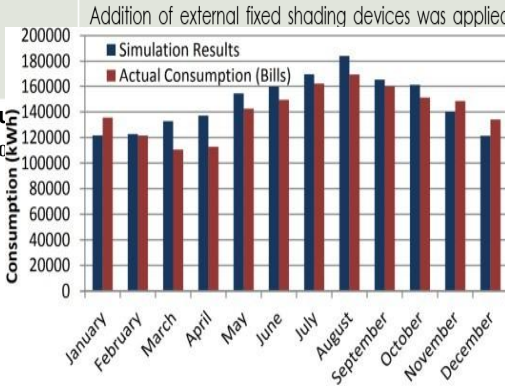
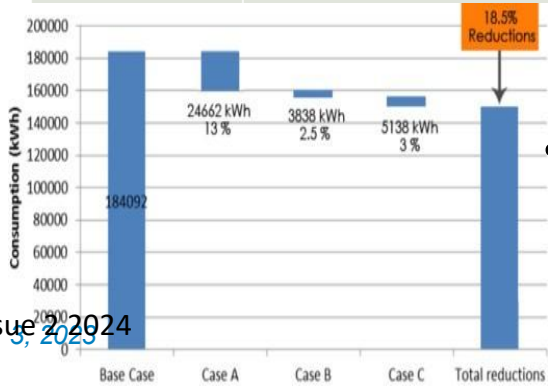


Figure 14 Electricity consumption pattern

| ELEMENTS | DESCRIPTION |
|-----------------------|---|
| Ventilation | The building uses mechanical ventilation |
| Building Dimension | 60m x 67m and height 20m |
| Exterior Shading | unshaded externally with large area of fixed curtain walls |
| Glazing | Tinted blue double glazed curtain walls u-value = 2.7 W/m2 K |
| WWR | All elevations = 80% ,north and north west elevations = 90% |
| Exterior walls | not insulated, 20cm brick wall, 2cm interior and exterior paint , u-value of 1.5 W/m2K. |
| Unshaded windows area | north-east elevation is 880 Sq.m, the north-west is 1098 Sq.m ,the south-west is 1072 Sq.m and the south-east is 960 Sq.m. |
| Roof | 3130 Sq.m roof assembly consists of 20cm reinforced concrete roof, interior paint and insulation material having a u-value of 0.5 W/m2K |

Table 8. Strategy Used

| CASES | AREA OF RETROFIT | TECHNIQUE APPLIED |
|-------|--|--|
| A | WWR adjustments(to accommodate the requirements of the Egyptian code for improvement of energy efficiency) | WWR changed to 30% for all elevations except for the north elevation which was kept as it is. |
| B | Thermal characteristics of the building envelope | improved its u-value by addition of 20cm insulation to external walls, also glazing was changed to triple glazed clear with argon fill instead of blue double glazing with air fill as well as green roof. |



5. CASE STUDY

5.1.Vastukar design studio, Bhubaneswar

5.1.1. Building Location

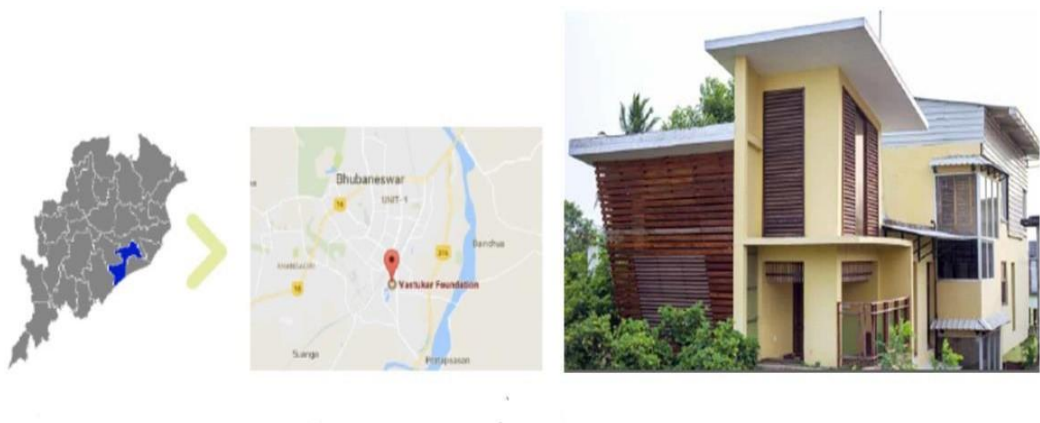


Figure 17 Building Location

5.1.2. Building Basics

| | |
|------------------|----------------------------------|
| Location | Bhubaneswar, Odisha |
| Climate Zone | Warm and Humid |
| Site Area | 308 Sq.m. |
| Built-up Area | 453 Sq.m. (48% of plot area) |
| Coordinates | 20.2482° N, 85.8378° E |
| Number of Floors | 2 Floors |
| Building Use | Office space |
| Constructed | 2015 |
| Certified | 2016 |
| Building Owner | Ar. S.S. Ray, director, Vastukar |
| Certification | SVA Griha rating- 5 star (47/50) |

5.1.3. Building Strategy

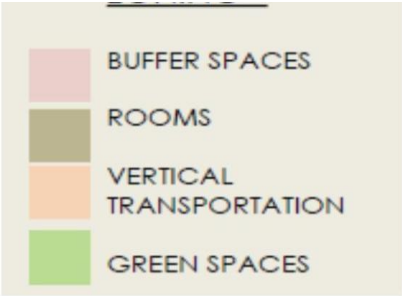
| EAST FACADE | WEST FACADE | NORTH FACADE | SOUTH FACADE |
|--|---|--|---|
|  |  |  |  |
| Table 12 Comparative Analysis | | | |
| Wall area exposed to the solar radiation is 17.6m² | Wall area exposed to the solar radiation is 48.2m². | Wall area exposed to the solar radiation is 17.6m². | Wall area exposed to the solar radiation is 150m². |
| WWR 26% which is less than 40% allows less amount of light penetrating through fenestrations. | WWR 15% which is less than 40% allows less amount of light penetrating through fenestrations. | WWR 65% which is more than 40% allows ample amount of light penetrating through fenestrations. | WWR 15% which is less than 40% allows less amount of light penetrating through fenestrations. |
| Wall thermal conductivity (K) 0.17 W/m k | Wall thermal conductivity (K) 0.40 W/m k | Wall thermal conductivity (K) 0.48 W/m k | Wall thermal conductivity (K) 0.40 W/m k |
| Wooden cladding over the glass opening is used to penetrate the radiation in to the room. Awing shading devices are suitable for all orientations. It is effective solar shading but reduce the daylight in summer and gain heat in winter. | There is no opening in the conference hall in the ground floor towards west side. | Appropriate design of openings and shading devices help to keep out sun and wind or allow them into the building. Ventilation lets in the fresh air and exhausts hot room air, resulting in cooling. | The size of windows are less compared to other sides decrease radiation |



Figure 18 ground floor plan



Figure 19 First floor plan



| | FACADE | | | | FENESTRATION | | ROOF |
|--|---|----------------------------|---------------------------------|-----------------------------|-----------------------------|--|----------------|
| | NORTH | SOUTH | EAST | WEST | WINDOW GLAZING | W.W.R. | COOL ROOF |
| CASE STUDY 1 GODREJ BHAVAN, MUMBAI | | | | | | | |
| | ALLUMINIUM CLADING | ALLUMINIUM CLADING | ALLUMINIUM CLADING | ALLUMINIUM CLADING | DOUBLE GLAZED | 60% | Terrace garden |
| CASE STUDY 2 VASTUKAR DESIGN STUDIO, BHUBNESWAR | | | | | | | |
| | iron hollow sections, creepers, plywood, buildtec sheet ,stone wall | Wooden louvers, stone wall | plywood, low voc paints, glass, | vertical green wall, glass, | Single Glazed, Wooden frame | 26% EAST 15% WEST 65% NORTH 15% SOUTH | ALBIDO PAINT |

5.1.4. SUMMARY

It was observed that facade on the south, east and west should be shaded by any shaded device and must be insulated properly to have a lower U value. Windows must be double glazed for good thermal performance and air leakage must be checked in air conditioned spaces. Green roof is better option as it gives a satisfactory decrease in surface temperature. Insulation can be applied to the exterior as the project is not of any heritage importance, which will also leave the internal space unharmed.

6. SITE ANALYSIS

6.1. Secha Sadan(Water Resources Department), Bhubaneswar

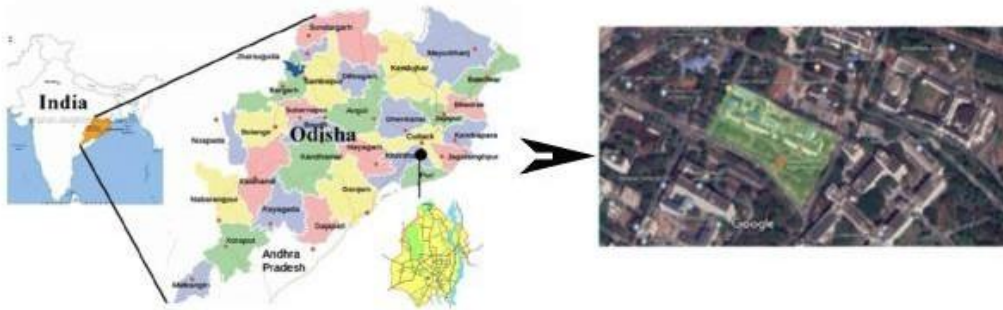


Figure 20 Location

6.2. Building Basics



**SECHA SADAN
(WATER RESOURCES DEPARTMENT)
Bhubaneswar, Odisha
ESTD. 1993**

Type- Institutional (office building)

Total area- 3.5 Acres (approx.)

Built-up area- 12000 Sq.m (approx.)

No of floors- 3

No of rooms- Around 270

Figure 21 Building View

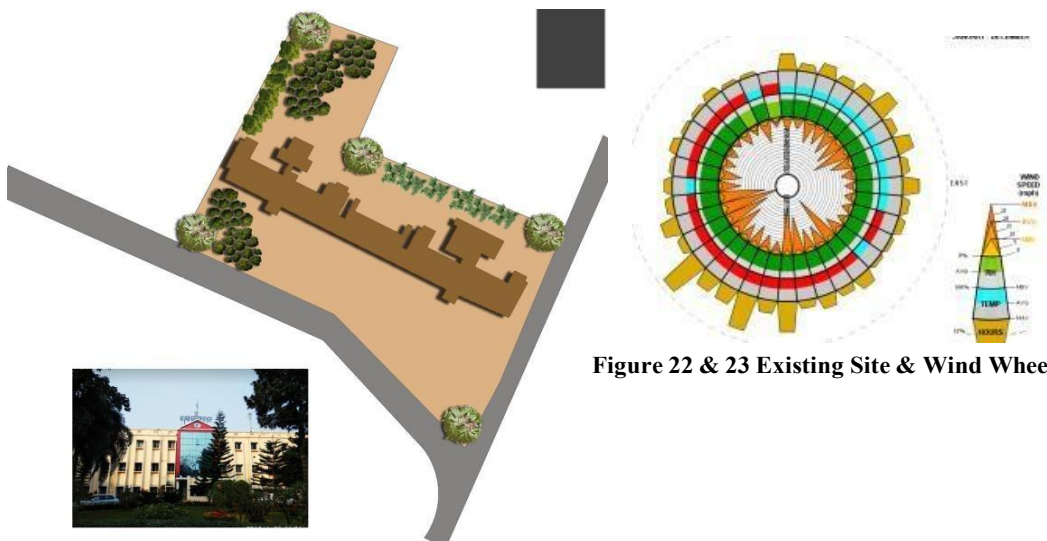


Figure 22 & 23 Existing Site & Wind Wheel



Figure 24. Site section AA



Figure 25. Site section AA

6.3. Site proximity

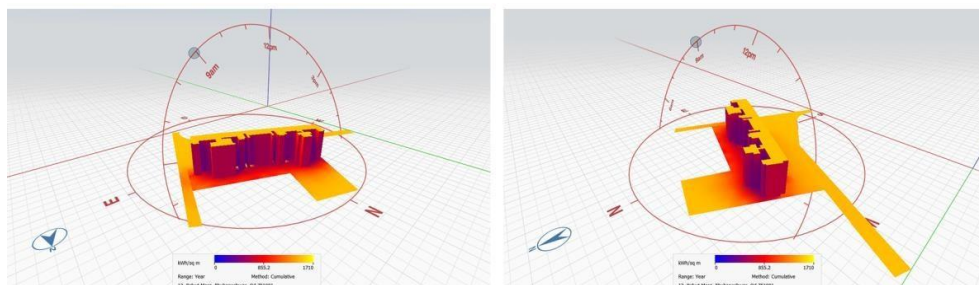


Figure 26 Proximity

6.4. Problems

- The South side of the office gets heated up which brings uncomfortable situations.
- The air conditioners are split and window type and they demand a lot of maintenance.
- Not much daylight enters into the building and current lights are not energy efficient.
- Uncontrolled thermal performance.
- Building is installed with older technology hence does not fit the energy saving compliance

6.5. Solar Insolation



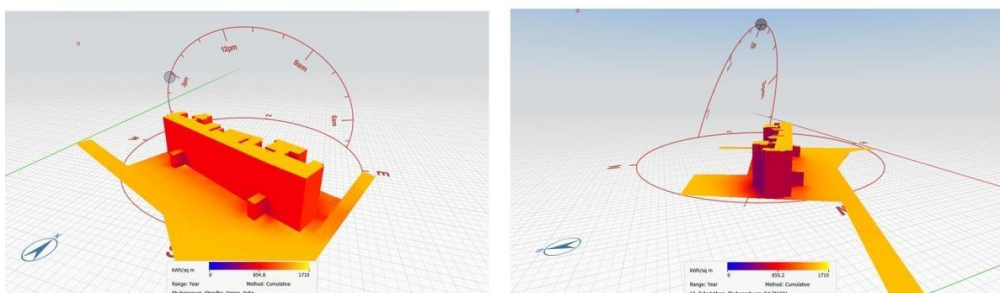


Figure 27 Insolation simulation

South-West Facade receives maximum insolation in year cumulative, followed by NW, SE and in the last NE. South-West Facade being the longest and front facade needs Envelope Retrofitting to increase thermal performance of the building.

6.6. Shadow analysis

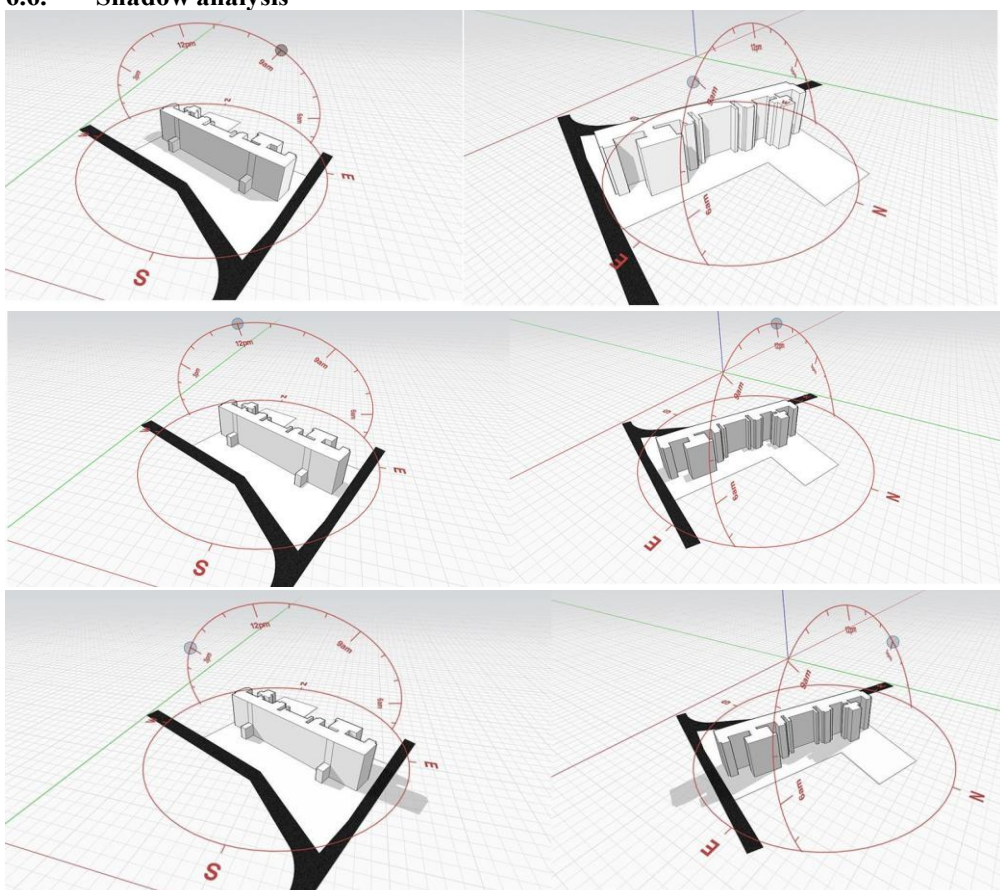
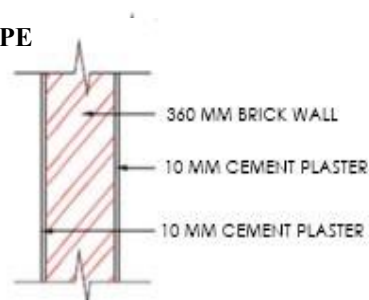


Figure 28 Shadow Analysis

7. THERMAL PERFORMANCE OF THE ENVELOPE

7.1. Wall

$L_1 = 0.01M$, $K_1 = 0.721 W/M.K$ $L_2 = 0.36M$,
 $K_2 = 0.811 W/M.K$, $L_3 = 0.01M$, $K_3 = 0.721 W/M.K$,
 $h_i = 8.3 W/M^2.K$, $h_o = 22.7 W/M^2.K$,
 $RT = 1/8.3 + 0.01/0.721 + 0.36/0.811 + 0.01/0.721 +$
 $1/22.7 = 0.636$, $U = 1/RT = 1/0.636 = 1.57$



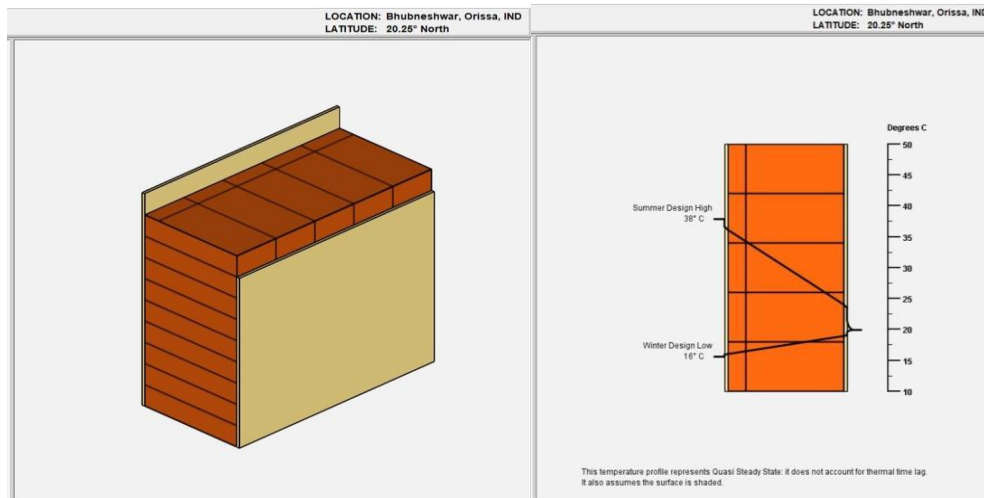


Figure 29 wall cut view and wall section

7.2. Roof

$L_1 = 0.01\text{M}$, $K_1 = 0.721\text{ W/M.K}$ $L_2 = 0.15\text{M}$, $K_2 = 1.580\text{ W/M.K}$ $L_3 = 0.01\text{M}$,
 $K_3 = 0.721\text{ W/M.K}$ $h_i = 6.1\text{ W/M}^2\text{.K}$, $h_o = 22.7\text{ W/M}^2\text{.K}$

$$RT = 1/6.1 + 0.01/0.721 + 0.15/1.580 + 0.01/0.721 + 1/22.7 = 0.331$$

$$U = 1/RT = 1/0.331 = 3.02$$

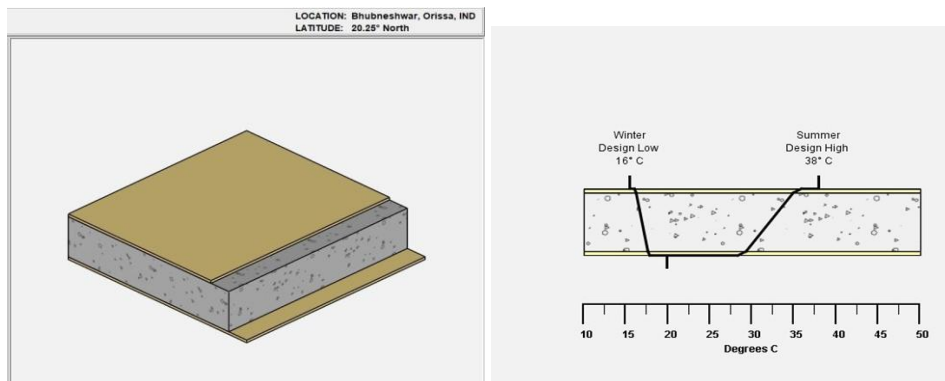


Figure 30 Roof cut view and section

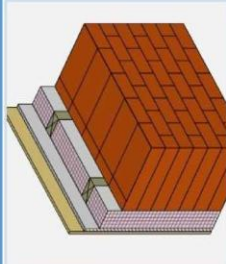
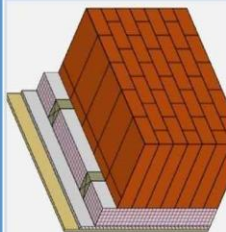
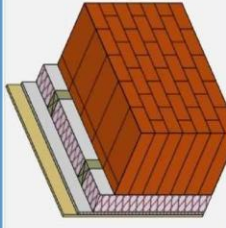
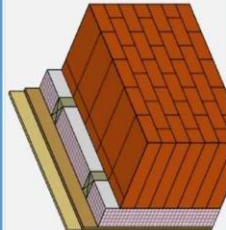
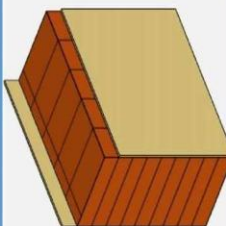
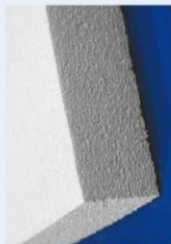



7.3. Fenestration

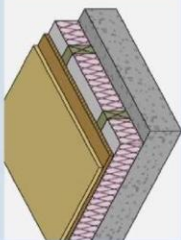
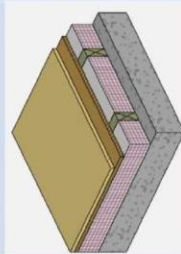
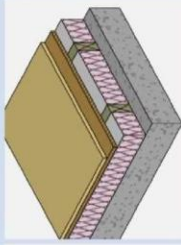
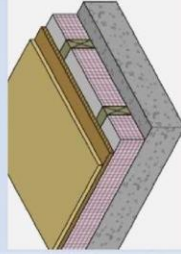
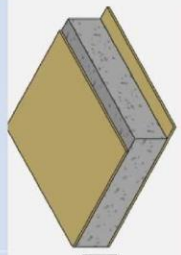




Uncoated single-glazed windows are considered to be the weakest thermal component in the building envelope, transmitting large amounts of heat into and out of a building.



Figure 31 Window

7.4. Comparative analysis

| | CASE 1 | CASE 2 | CASE 3 | CASE 4 | BASE CASE | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------------------------|---|---|--|---|---|----------------|-------|-------------------|-------|-----------|--------------|---|-----------------------|----------------------------|----------------|------|----------------|-------|-------------------|-----------------|-----------|------|--|-----------------------|-------|--|----------|----------------|---------|------------------------|------|-----------|-------|--|-----------------------|--------------|----------------|------|-------------------|-------|-------------------|---------------|-----------|-------|--|-----------------------|-------|------------------|-------|----------------|--|-------------------|-------|-----------|------------------------|-----|------|-------|-------|-----|--------------|-------|------|---------------|-------|------|--------------|------|-----|-----------------|------|------|------------------|-----|------|--|----------|----|-------|------------------------|-----|------|-------|-------|-----|--------------|-------|------|-----------------|-------|------|---------|------|------|-----------------|------|------|------------------|-----|------|--|----------|----|-------|-----------------|------|------|-------|-------|-----|-----------------|------|------|------------------|-----|------|
| 3D SECTION |  |  |  |  |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| MATERIALS | <table><tr><th>Material</th><th>mm</th><th>R Value</th></tr><tr><td>Inside Air Film (wall)</td><td>0.0</td><td>0.12</td></tr><tr><td>Brick</td><td>360.0</td><td>0.4</td></tr><tr><td>Studs (wood)</td><td>101.6</td><td>0.78</td></tr><tr><td>Expanded Polystyrene (EPS)</td><td>101.6</td><td>2.54</td></tr><tr><td>Gypsum Board</td><td>15.9</td><td>0.1</td></tr><tr><td>Plaster (dense)</td><td>12.7</td><td>0.02</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R Value | Inside Air Film (wall) | 0.0 | 0.12 | Brick | 360.0 | 0.4 | Studs (wood) | 101.6 | 0.78 | Expanded Polystyrene (EPS) | 101.6 | 2.54 | Gypsum Board | 15.9 | 0.1 | Plaster (dense) | 12.7 | 0.02 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R Value</th></tr><tr><td>Inside Air Film (wall)</td><td>0.0</td><td>0.12</td></tr><tr><td>Brick</td><td>360.0</td><td>0.4</td></tr><tr><td>Studs (wood)</td><td>101.6</td><td>0.78</td></tr><tr><td>Polyurethane Foam</td><td>101.6</td><td>4.06</td></tr><tr><td>Plaster Board</td><td>16.0</td><td>0.03</td></tr><tr><td>Plaster (dense)</td><td>12.7</td><td>0.02</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R Value | Inside Air Film (wall) | 0.0 | 0.12 | Brick | 360.0 | 0.4 | Studs (wood) | 101.6 | 0.78 | Polyurethane Foam | 101.6 | 4.06 | Plaster Board | 16.0 | 0.03 | Plaster (dense) | 12.7 | 0.02 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Inside Air Film (wall)</td><td>0.0</td><td>0.12</td></tr><tr><td>Brick</td><td>360.0</td><td>0.4</td></tr><tr><td>Studs (wood)</td><td>101.6</td><td>0.78</td></tr><tr><td>Bloomin Fibre</td><td>101.6</td><td>2.54</td></tr><tr><td>Gypsum Board</td><td>15.9</td><td>0.1</td></tr><tr><td>Plaster (dense)</td><td>12.7</td><td>0.02</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Inside Air Film (wall) | 0.0 | 0.12 | Brick | 360.0 | 0.4 | Studs (wood) | 101.6 | 0.78 | Bloomin Fibre | 101.6 | 2.54 | Gypsum Board | 15.9 | 0.1 | Plaster (dense) | 12.7 | 0.02 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Inside Air Film (wall)</td><td>0.0</td><td>0.12</td></tr><tr><td>Brick</td><td>360.0</td><td>0.4</td></tr><tr><td>Studs (wood)</td><td>101.6</td><td>0.78</td></tr><tr><td>Batt Insulation</td><td>101.6</td><td>2.03</td></tr><tr><td>Plywood</td><td>15.9</td><td>0.13</td></tr><tr><td>Plaster (dense)</td><td>12.7</td><td>0.02</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Inside Air Film (wall) | 0.0 | 0.12 | Brick | 360.0 | 0.4 | Studs (wood) | 101.6 | 0.78 | Batt Insulation | 101.6 | 2.03 | Plywood | 15.9 | 0.13 | Plaster (dense) | 12.7 | 0.02 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Plaster (dense)</td><td>10.0</td><td>0.02</td></tr><tr><td>Brick</td><td>360.0</td><td>0.4</td></tr><tr><td>Plaster (dense)</td><td>10.0</td><td>0.02</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Plaster (dense) | 10.0 | 0.02 | Brick | 360.0 | 0.4 | Plaster (dense) | 10.0 | 0.02 | Outside Air Film | 0.0 | 0.04 |
| Material | mm | R Value | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (wall) | 0.0 | 0.12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Brick | 360.0 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 101.6 | 0.78 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Expanded Polystyrene (EPS) | 101.6 | 2.54 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Gypsum Board | 15.9 | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 12.7 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R Value | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (wall) | 0.0 | 0.12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Brick | 360.0 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 101.6 | 0.78 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Polyurethane Foam | 101.6 | 4.06 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster Board | 16.0 | 0.03 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 12.7 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (wall) | 0.0 | 0.12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Brick | 360.0 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 101.6 | 0.78 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bloomin Fibre | 101.6 | 2.54 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Gypsum Board | 15.9 | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 12.7 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (wall) | 0.0 | 0.12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Brick | 360.0 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 101.6 | 0.78 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Batt Insulation | 101.6 | 2.03 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plywood | 15.9 | 0.13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 12.7 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 10.0 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Brick | 360.0 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 10.0 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SIMULATION RESULTS | <table><tr><td>Total Thickness (mm):</td><td>490.2</td></tr><tr><td>Total R Value:</td><td>2.48</td></tr><tr><td>Total U Value:</td><td>0.403</td></tr><tr><td>Decrement Factor:</td><td>0.06</td></tr><tr><td>Time Lag:</td><td>10.0</td></tr></table> | Total Thickness (mm): | 490.2 | Total R Value: | 2.48 | Total U Value: | 0.403 | Decrement Factor: | 0.06 | Time Lag: | 10.0 | <table><tr><td>Total Thickness (mm):</td><td>490.3</td></tr><tr><td>Total R Value:</td><td>2.95</td></tr><tr><td>Total U Value:</td><td>0.339</td></tr><tr><td>Decrement Factor:</td><td>0.06</td></tr><tr><td>Time Lag:</td><td>9.58</td></tr></table> | Total Thickness (mm): | 490.3 | Total R Value: | 2.95 | Total U Value: | 0.339 | Decrement Factor: | 0.06 | Time Lag: | 9.58 | <table><tr><td>Total Thickness (mm):</td><td>490.2</td></tr><tr><td>Total R Value:</td><td>2.48</td></tr><tr><td>Total U Value:</td><td>0.403</td></tr><tr><td>Decrement Factor:</td><td>0.06</td></tr><tr><td>Time Lag:</td><td>10.09</td></tr></table> | Total Thickness (mm): | 490.2 | Total R Value: | 2.48 | Total U Value: | 0.403 | Decrement Factor: | 0.06 | Time Lag: | 10.09 | <table><tr><td>Total Thickness (mm):</td><td>490.2</td></tr><tr><td>Total R Value:</td><td>2.28</td></tr><tr><td>Total U Value:</td><td>0.439</td></tr><tr><td>Decrement Factor:</td><td>0.06</td></tr><tr><td>Time Lag:</td><td>10.14</td></tr></table> | Total Thickness (mm): | 490.2 | Total R Value: | 2.28 | Total U Value: | 0.439 | Decrement Factor: | 0.06 | Time Lag: | 10.14 | <table><tr><td>Total Thickness (mm):</td><td>380.0</td></tr><tr><td>Total R Value:</td><td>2.085</td></tr><tr><td>Total U Value:</td><td>0.34</td></tr><tr><td>Decrement Factor:</td><td>-9.47</td></tr><tr><td>Time Lag:</td><td></td></tr></table> | Total Thickness (mm): | 380.0 | Total R Value: | 2.085 | Total U Value: | 0.34 | Decrement Factor: | -9.47 | Time Lag: | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 490.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 2.48 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.403 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.06 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | 10.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 490.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 2.95 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.339 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.06 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | 9.58 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 490.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 2.48 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.403 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.06 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | 10.09 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 490.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 2.28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.439 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.06 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | 10.14 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 380.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 2.085 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.34 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | -9.47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ECBC REQUIREMENT | Maximum assembly U value = 0.40 | Maximum assembly U value = 0.40 | Maximum assembly U value = 0.40 | Maximum assembly U value = 0.40 | Maximum assembly U value = 0.40 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| COMPLIANCE | NO | YES | YES | NO | NO | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSULATION |  |  |  |  | NO | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | CASE 1 | CASE 2 | CASE 3 | CASE 4 | BASE CASE | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---------------------------|---|--|---|---|---|----------------|-------|-------------------|-------|-----------|--------------|--|-----------------------|------------------|----------------|------|----------------------|-------|-------------------|-----------------|-----------|-------|--|-----------------------|-------|---|----------|----------------|-------|---------------------------|------|-----------|----------|--|-----------------------|--------------|----------------|------|-------------------|-------|-------------------|----------------------|-----------|-------|--|-----------------------|-------|------------------|------|----------------|--|-------------------|------|-----------|---------------------------|-----|------|----------|-------|------|--------------|-------|------|-------------|-------|------|----------------------|------|------|-----------------|------|------|------------------|-----|------|---|----------|----|-------|---------------------------|-----|------|----------|-------|------|--------------|-------|------|-----------------|-------|-----|----------------------|------|------|-----------------|------|------|------------------|-----|------|--|----------|----|-------|---------------------------|-----|------|-----------------|------|------|----------|-------|------|-----------------|------|------|------------------|-----|------|
| 3D SECTION |  |  |  |  |  | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| MATERIALS | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Inside Air Film (ceiling)</td><td>0.0</td><td>0.16</td></tr><tr><td>Concrete</td><td>150.0</td><td>0.11</td></tr><tr><td>Studs (wood)</td><td>110.0</td><td>0.85</td></tr><tr><td>Insulation Board</td><td>110.0</td><td>3.67</td></tr><tr><td>Fiberboard Sheathing</td><td>20.0</td><td>0.29</td></tr><tr><td>Plaster (dense)</td><td>20.0</td><td>0.04</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Inside Air Film (ceiling) | 0.0 | 0.16 | Concrete | 150.0 | 0.11 | Studs (wood) | 110.0 | 0.85 | Insulation Board | 110.0 | 3.67 | Fiberboard Sheathing | 20.0 | 0.29 | Plaster (dense) | 20.0 | 0.04 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Inside Air Film (ceiling)</td><td>0.0</td><td>0.16</td></tr><tr><td>Concrete</td><td>150.0</td><td>0.11</td></tr><tr><td>Studs (wood)</td><td>110.0</td><td>0.85</td></tr><tr><td>Polyurethane Foam</td><td>110.0</td><td>4.4</td></tr><tr><td>Fiberboard Sheathing</td><td>20.0</td><td>0.29</td></tr><tr><td>Plaster (dense)</td><td>20.0</td><td>0.04</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Inside Air Film (ceiling) | 0.0 | 0.16 | Concrete | 150.0 | 0.11 | Studs (wood) | 110.0 | 0.85 | Polyurethane Foam | 110.0 | 4.4 | Fiberboard Sheathing | 20.0 | 0.29 | Plaster (dense) | 20.0 | 0.04 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Inside Air Film (ceiling)</td><td>0.0</td><td>0.16</td></tr><tr><td>Concrete</td><td>150.0</td><td>0.11</td></tr><tr><td>Studs (wood)</td><td>110.0</td><td>0.85</td></tr><tr><td>Blown Fibre</td><td>110.0</td><td>2.75</td></tr><tr><td>Fiberboard Sheathing</td><td>20.0</td><td>0.29</td></tr><tr><td>Plaster (dense)</td><td>20.0</td><td>0.04</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Inside Air Film (ceiling) | 0.0 | 0.16 | Concrete | 150.0 | 0.11 | Studs (wood) | 110.0 | 0.85 | Blown Fibre | 110.0 | 2.75 | Fiberboard Sheathing | 20.0 | 0.29 | Plaster (dense) | 20.0 | 0.04 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Inside Air Film (ceiling)</td><td>0.0</td><td>0.16</td></tr><tr><td>Concrete</td><td>150.0</td><td>0.11</td></tr><tr><td>Studs (wood)</td><td>110.0</td><td>0.85</td></tr><tr><td>Batt Insulation</td><td>110.0</td><td>2.2</td></tr><tr><td>Fiberboard Sheathing</td><td>20.0</td><td>0.29</td></tr><tr><td>Plaster (dense)</td><td>20.0</td><td>0.04</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Inside Air Film (ceiling) | 0.0 | 0.16 | Concrete | 150.0 | 0.11 | Studs (wood) | 110.0 | 0.85 | Batt Insulation | 110.0 | 2.2 | Fiberboard Sheathing | 20.0 | 0.29 | Plaster (dense) | 20.0 | 0.04 | Outside Air Film | 0.0 | 0.04 | <table><tr><th>Material</th><th>mm</th><th>R ...</th></tr><tr><td>Inside Air Film (ceiling)</td><td>0.0</td><td>0.16</td></tr><tr><td>Plaster (dense)</td><td>10.0</td><td>0.02</td></tr><tr><td>Concrete</td><td>150.0</td><td>0.11</td></tr><tr><td>Plaster (dense)</td><td>10.0</td><td>0.02</td></tr><tr><td>Outside Air Film</td><td>0.0</td><td>0.04</td></tr></table> | Material | mm | R ... | Inside Air Film (ceiling) | 0.0 | 0.16 | Plaster (dense) | 10.0 | 0.02 | Concrete | 150.0 | 0.11 | Plaster (dense) | 10.0 | 0.02 | Outside Air Film | 0.0 | 0.04 |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (ceiling) | 0.0 | 0.16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Concrete | 150.0 | 0.11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 110.0 | 0.85 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Insulation Board | 110.0 | 3.67 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fiberboard Sheathing | 20.0 | 0.29 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 20.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (ceiling) | 0.0 | 0.16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Concrete | 150.0 | 0.11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 110.0 | 0.85 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Polyurethane Foam | 110.0 | 4.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fiberboard Sheathing | 20.0 | 0.29 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 20.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (ceiling) | 0.0 | 0.16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Concrete | 150.0 | 0.11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 110.0 | 0.85 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Blown Fibre | 110.0 | 2.75 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fiberboard Sheathing | 20.0 | 0.29 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 20.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (ceiling) | 0.0 | 0.16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Concrete | 150.0 | 0.11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Studs (wood) | 110.0 | 0.85 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Batt Insulation | 110.0 | 2.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fiberboard Sheathing | 20.0 | 0.29 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 20.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Material | mm | R ... | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inside Air Film (ceiling) | 0.0 | 0.16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 10.0 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Concrete | 150.0 | 0.11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Plaster (dense) | 10.0 | 0.02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Outside Air Film | 0.0 | 0.04 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SIMULATION RESULTS | <table><tr><td>Total Thickness (mm):</td><td>300.0</td></tr><tr><td>Total R Value:</td><td>3.6</td></tr><tr><td>Total U Value:</td><td>0.277</td></tr><tr><td>Decrement Factor:</td><td>0.21</td></tr><tr><td>Time Lag:</td><td>-8.67</td></tr></table> | Total Thickness (mm): | 300.0 | Total R Value: | 3.6 | Total U Value: | 0.277 | Decrement Factor: | 0.21 | Time Lag: | -8.67 | <table><tr><td>Total Thickness (mm):</td><td>300.0</td></tr><tr><td>Total R Value:</td><td>4.05</td></tr><tr><td>Total U Value:</td><td>0.247</td></tr><tr><td>Decrement Factor:</td><td>0.21</td></tr><tr><td>Time Lag:</td><td>-8.62</td></tr></table> | Total Thickness (mm): | 300.0 | Total R Value: | 4.05 | Total U Value: | 0.247 | Decrement Factor: | 0.21 | Time Lag: | -8.62 | <table><tr><td>Total Thickness (mm):</td><td>300.0</td></tr><tr><td>Total R Value:</td><td>2.99</td></tr><tr><td>Total U Value:</td><td>0.334</td></tr><tr><td>Decrement Factor:</td><td>0.22</td></tr><tr><td>Time Lag:</td><td>-7.84</td></tr></table> | Total Thickness (mm): | 300.0 | Total R Value: | 2.99 | Total U Value: | 0.334 | Decrement Factor: | 0.22 | Time Lag: | -7.84 | <table><tr><td>Total Thickness (mm):</td><td>300.0</td></tr><tr><td>Total R Value:</td><td>2.59</td></tr><tr><td>Total U Value:</td><td>0.386</td></tr><tr><td>Decrement Factor:</td><td>0.22</td></tr><tr><td>Time Lag:</td><td>-7.66</td></tr></table> | Total Thickness (mm): | 300.0 | Total R Value: | 2.59 | Total U Value: | 0.386 | Decrement Factor: | 0.22 | Time Lag: | -7.66 | <table><tr><td>Total Thickness (mm):</td><td>170.0</td></tr><tr><td>Total R Value:</td><td>0.34</td></tr><tr><td>Total U Value:</td><td>2.922</td></tr><tr><td>Decrement Factor:</td><td>0.58</td></tr><tr><td>Time Lag:</td><td>-4.99</td></tr></table> | Total Thickness (mm): | 170.0 | Total R Value: | 0.34 | Total U Value: | 2.922 | Decrement Factor: | 0.58 | Time Lag: | -4.99 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 300.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 3.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.277 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | -8.67 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 300.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 4.05 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.247 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | -8.62 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 300.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 2.99 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.334 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.22 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | -7.84 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 300.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 2.59 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 0.386 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.22 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | -7.66 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Thickness (mm): | 170.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total R Value: | 0.34 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total U Value: | 2.922 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Decrement Factor: | 0.58 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Time Lag: | -4.99 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ECBC REQUIREMENT | Maximum assembly U value = 0.33 | Maximum assembly U value = 0.33 | Maximum assembly U value = 0.33 | Maximum assembly U value = 0.33 | Maximum assembly U value = 0.33 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| COMPLIANCE | YES | YES | YES | NO | NO | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSULATION |  |  |  |  | NO | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | CASE 1 | CASE 2 | CASE 3 | CASE 4 | BASE CASE |
|----------------------------|---|--|---|---|---|
| 3D SECTION |  |  |  |  |  |
| NAME | Double-Glazed, Clear Glass | Double-Glazed, Low-solar-gain Low-E Glass | Triple-Glazed, High-solar-gain Low-E Glass | Triple-Glazed, Low-solar-gain Low-E Glass | Single-Glazed, Clear Glass |
| PROPERTY (METAL FRAME) | U VALUE- 0.71-0.99 SHGC- 0.41-0.55 VLT- >0.60 | U VALUE- 0.56-0.70 SHGC- 0.25 VLT- 0.51 | U VALUE- 0.21 SHGC- 0.41 VLT- 0.41 | U VALUE- ≤0.22 SHGC- ≤0.25 VLT- ≤0.40 | U VALUE- 1.04 SHGC- 0.86 VLT- 0.90 |
| PROPERTY (NON METAL FRAME) | U VALUE- 0.41-0.55 SHGC- 0.41-0.60 VLT- >0.60 | U VALUE- 0.23-0.30 SHGC- 0.25 VLT- 0.51 | U VALUE- 0.19 SHGC- 0.41 VLT- 0.41 | U VALUE- ≤0.21 SHGC- ≤0.25 VLT- ≤0.40 | NA |
| U VALUE (ECBC) | Maximum U value 3.00 | Maximum U value 3.00 | Maximum U value 3.00 | Maximum U value 3.00 | Maximum U value 3.00 |
| VLT(ECBC) | Minimum VLT= 0.27 | Minimum VLT= 0.27 | Minimum VLT= 0.27 | Minimum VLT= 0.27 | Minimum VLT= 0.27 |
| SHGC(ECBC) Effective | Maximum SHGC Non north=0.27 North=0.50 | Maximum SHGC Non north=0.27 North=0.50 | Maximum SHGC Non north=0.27 North=0.50 | Maximum SHGC Non north=0.27 North=0.50 | Maximum SHGC Non north=0.27 North=0.50 |
| COMPLIANCE | YES NORTH | YES NON NORTH | YES NORTH | YES NON NORTH | NO |

8. STRATEGY ANALYSIS

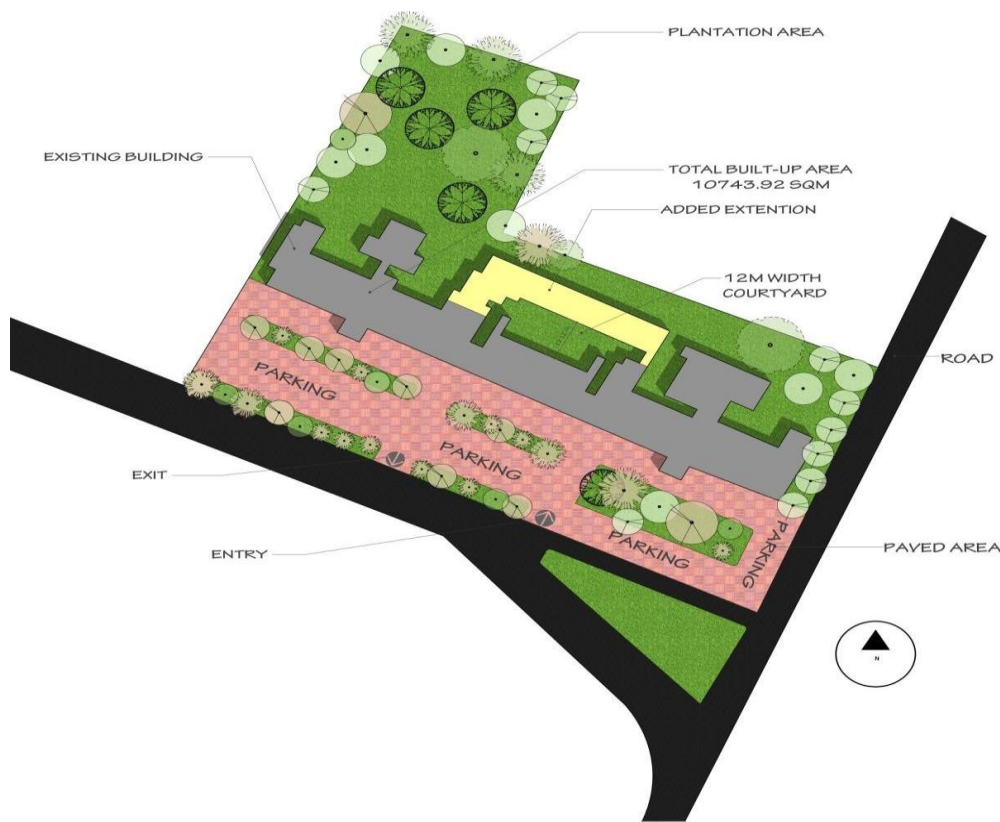
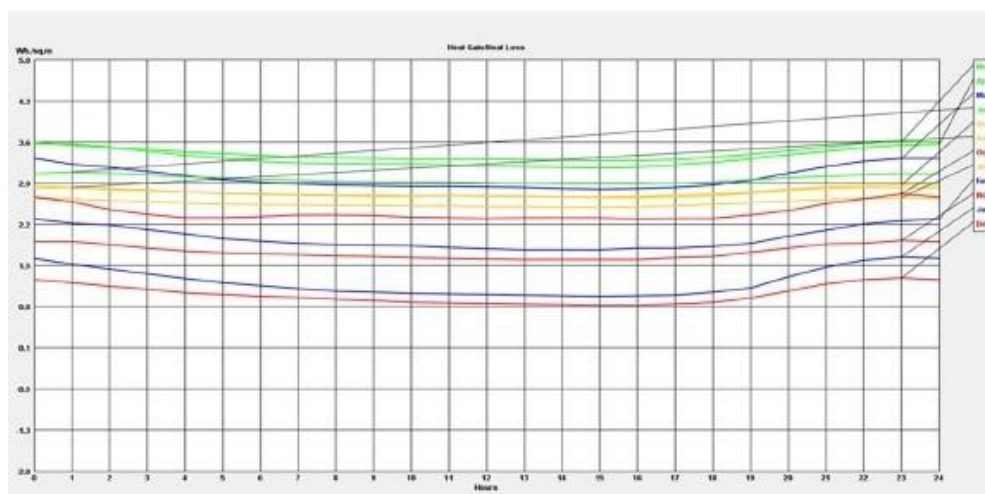


Figure 32. Site plan

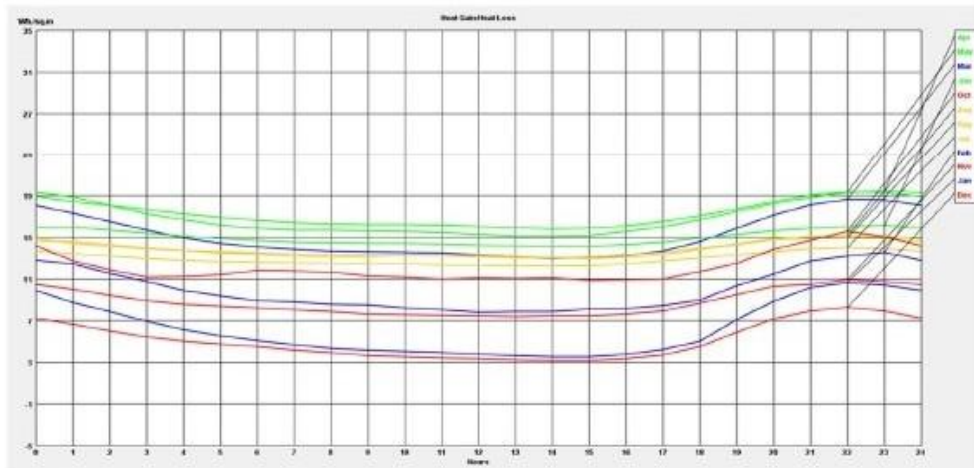
9 RESULT

9.1 Heat Gain Simulations

HEAT GAIN SIMULATION RESULT OF YEAR



BEFORE RETROFITTING : 7 to 19.2 Wh/sq.m



AFTER RETROFITTING : 1 to 3.6 Wh/sq.m

Project: Retrofitting for Energy Efficiency

Building:

Address of project: Keshari Nagar, Bhubaneswar

Occupant/Owner: Government of Odisha

Building parameters:

Building type: Residential building

Total building area: 10,213.92 m²

Climatic zone: Bhubaneswar (Warm & Humid)

Created with: EnEffResBuild:India Version 1.0.1.0

| | This building | Reference building |
|-------------------|---------------|--------------------|
| Internal lighting | 12.58 | 12.58 |
| Common lighting | 1.64 | 1.64 |
| Parking lighting | 0.00 | 0.00 |
| Cooling | 8.20 | 22.03 |
| Heating | 0.00 | 0.00 |
| Hot water | 11.29 | 11.29 |
| Ceiling fans | 0.72 | 0.72 |
| Appliances | 0.28 | 0.28 |

Consumption of electrical energy in kWh/m²yr*:

*The consumption is related to the building area:

This building: 20 kWh/m²yr

Reference: 34 kWh/m²yr

Savings: 40%

Energy shares considered for the loan application certificate:

☐ Internal lighting ☐ Common lighting ☐ Parking lighting ☒ Cooling ☐ Heating ☒ Hot water ☒ Ceiling fans ☒ Appliances

Qualitative parameters (0 out of 6 measures are applied in this building):

☐ Daylit area in the core area is 20% to 40% ☐ Presence detection or photo sensors for outdoor and s

☐ Solar street lights ☐ Efficient water pumps

☐ Efficient transformers ☐ Tailored user manual

Issuer:

5/7/2020 **Signature**

Date

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