Analysis of Materials in Terms of Energy Performance Used in Ancient and Modern Architecture

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***Abstract*—The paper highlights the energy performance of materials commonly used in ancient and modern architecture between the 16th and 21st centuries in Goa, India. Each material is analyzed separately in an individual study to determine its contribution to the consumption of energy. Later, a combination study is carried out to determine the change in performance and interaction with other materials. The BIM model is based on an existing single-story, load-bearing, pre-colonial structure. The structure was surveyed and modeled in Autodesk Revit and analyzed on Insight360. Material properties were obtained from a literature survey and through testing. Analysis results are obtained in Energy Use Intensity.**

Keywords- Autodesk Revit, Building Information Model (BIM), energy simulation, Insight360, sustainable materials, material analysis,

I. INTRODUCTION

The open statistics of the International Energy Agency's KWES (2020), show that Oil, Coal, and natural gas account for the majority of the world's energy supply while the contribution from renewable resources makes up less than 16.7% of the world's energy supply.

Construction activities consume over 40% of the total world energy production (Abergel et al., 2017) and hence the industry should take more responsibility for the environmental impact. Construction materials that make use of renewable energy sources, low to medium equipment and labor, and good thermal properties are considered energy-efficient materials (Dolf Gielenet et al., 2018). The incorporation of locally available natural materials in construction practices has a positive effect on the energy efficiency of the material. Opting for human resources over hefty industrial procedures and using renewable energy in the production process will reduce energy consumption (Yuksek and Karadayi, 2016).

According to Hannah Ritchie and Max Roser (2017), oil and natural gas deposits will be depleted by 2067 and coal by 2130. The rapid growth in population and industrialization and the increase in quality of life are significant reasons for the rise in energy demand. For example, an increase in population implies an increase in demand for homes, which directs pressure on the construction industry to increase their productivity. This pressure forces the industry to use more energy-intensive techniques that require more energy to power their machines. In addition to this, the processing, manufacturing, and transport of construction materials further increase energy use. While there are research papers detailing ways to reduce energy consumption during the construction stage (Biswas 2014) and (Farid 2015), this paper highlights the possibility of decreasing energy consumption throughout the project's lifecycle by selecting appropriate building materials for construction.

The building structure is defined as a combination of the roof, floor slabs, walls, doors, and windows, which play an essential role in reducing the energy use intensity of the building.

Various factors that affect the built environment and heat transmission for a structure are (1) Climatic zone, (2) Building form (the shape or configuration of a building and orientation), (3) Selection of building material, (4) Window-to-wall ratio, (5) Solar reflectivity. (Pathirana et al. 2019). In climatic zones, when the climatic situations are mild to moderate, cooling loads are comparatively less related to hot and dry climates or compound climates. The use of double-skin facades, double-glazed windows, evaporative cooling, earth air tunnels, wind-tower, green-roof, or automatic solar shades or blinds to cut sun or admit daylight contribute to improving thermal comfort (Garg et al. 2018). Kumara et al., 2017, worked to find the thermal performance of windows and buildings constructed with various glass materials in five different climate zones in India (Ahmedabad, Bangalore, Guwahati, Madras, and New Delhi). Four building materials, laterite, dense concrete, burnt bricks, and mud bricks were used. The windows made of clear glass, reflective-bronze glass, green and bronze glass were used. A building design model was designed and thermal analysis was performed. Solar heat gain in 80 buildings was studied from the perspective of minimum heat gain. Mud wall buildings with bronze reflective glass windows facing the south direction are found to be energy-efficient. The results also show that, compared with the mud-brick buildings with clear glass windows, reflective green or bronze glass reduces the heat by 2.52%, 3.83%, and 6.46% respectively. These results thus helped the authors to select an energy-efficient combination of window glass and wall materials to reduce the cooling load on residential and commercial buildings in five different climate zones in India.

This research paper considers materials commonly used in Goa, India, in the pre-colonial era (16th Century), post-colonial era (19th Century), and those currently available in the market today (21st Century); and compares their performance. We hope to understand the variation in performance of the materials selected and prove that materials used for construction today far surpass the materials used in the decades before, indicating that the construction industry, in general, is on the right track towards sustainable living.

II. BUILDING INFORMATION MODELING

Building Information Modeling (BIM) is the industry standard for organizing and digitizing information on buildings and works in the construction industry. After creating a 3D model using BIM software, a clear picture of the project at every construction stage is obtained. Simulations may be carried out based on the scenarios it is to be built. Structural performance, energy performance, and other information can be obtained with adequate knowledge of different specialized tools. BIM benefits humanity by ensuring minimum wastage of resources, determining inaccuracies in design, and identifying low-performing components in energy audits (Kubba 2012). The following factors are taken into consideration during this energy audit:

1. Thermal Properties: How fast a material can gain/ lose heat from the Sun. (Lotfabadi et al 2019)

2. Luminous Intensity: The amount of light from the Sun entering through openings

3. Building Elements: The mass of each element is considered to obtain the energy analysis plane

Autodesk Revit is a BIM tool used by architects, structural, and MEP engineers to collaborate in an organized workflow. Charles River, initially developed this software and, in 2002, was acquired by Autodesk. It allows users to model a structure in 3D with information from a building model database. Revit's advantage against other rival software like ArchiCAD and Reflex is that a change made to any element automatically propagated throughout the model as the users create parametric components in a graphical format rather than as a programming language (Kubba 2012). Autodesk Insight360 empowers architects and integrated groups and provides centralized access to performance data and advanced analysis engines. Robust combination with Revit coupled with the direct access to guidance and recommendations from trustworthy simulation engines and industry benchmarks like the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE 90), architects will be able to approach the design process with an understanding of the elements that will lead to better building performance outcomes throughout the building lifecycle (Egger 2015, Ar Neeti 2017).

A. SITE SELECTION

Address: 1068 Grande Carona, Bardez, Goa,
Nearest Landmark: St Thomas Church, Aldona, Goa
Distance from nearest landmark: 2.2kms.
Plinth Area: 414.35m2

B. OBJECTIVES

The paper is based on the following objectives: (1) To compare the performance of the Pre-Colonial era (16th Century), Post-Colonial era (19th Century), and current common materials available in the market (21st Century) and (2) To conduct analysis based on the performance of the structure using different combinations of materials.

III. MATERIALS & PROPERTIES

The selection of materials was based on a survey of the commonly used materials in the 16th, 19th, and 21st Centuries. The properties of each of the selected materials are available in the Autodesk Material Browser or can be found in the Autodesk Material Library. The materials are to be used for walls (W), flooring (F), roofing (R), and window glassware (G). The properties of each material can be found in Table I.

- Thermal Conductivity: The ability of a material to transfer or conduct heat.
- Specific Heat: Heat energy required to raise the temperature of unit mass by one degree.
- Density: It is the mass of the object per unit volume.
- Electrical Resistivity: The electrical resistance offered by a material.
- Emissivity: The relative power of a surface to emit heat by radiation.

IV. METHODOLOGY

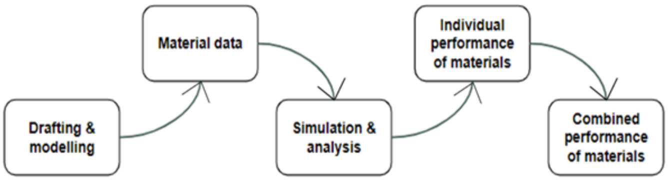

Fig. 1. Proposed methodology

The proposed methodology consists of five main steps which are (1) Drafting and modeling using Autodesk Revit; (2) Assigning material data; (3) Simulation and analysis; (4) individual performance of materials; and (5) combined performance of materials. Each step is discussed in brief.

A. DRAFTING AND MODELING

A colonial-era house was selected and surveyed. The doors, windows, and other building components were measured and drafted accordingly in Autodesk Revit 2019. A 3D model of the house was created and can be seen in Figure 2.

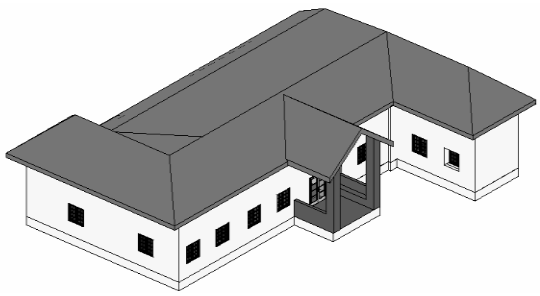

Fig. 2. 3D view of the model

B. ASSIGNING MATERIAL DATA

The Material Browser is used to edit or select predefined material properties. The material data was obtained through literature reviews. The editable material categories include:

(1) Graphics, (2) Appearance, (3) Physical properties, and (4) Thermal properties

TABLE I. MATERIALS AND THEIR PROPERTIES

Sr. No	Material	Century	Thermal Conductivity (W/(m·K))	Specific Heat J/(g·°C)	Density kg/m³	Electrical Resistivity (Ω·m)	Emissivity
Materials for Roofing							
1	Straw Thatch	16th	0.070	0.180	240	1 E+10	0.90
2	Mud	16th	1.506	2.929	1600	1E+02	0.38
3	Tiles	19th	0.840	0.800	1900	1E+18	0.90
4	Lightweight Concrete (LWC)	21st	0.209	0.657	950	2E+06	0.95
Materials for flooring							
1	Mud	16th	1.506	2.929	1600	1E+02	0.38
2	Concrete	19th	1.046	0.657	2300	2E+06	0.95
3	Ceramic	19th	1.200	0.850	2000	1E+18	0.90
4	Terracotta	19th	0.810	0.840	1700	1E+18	0.50
5	Marble	21st	2.900	0.840	2750	1E+07	0.75
6	Granite	21st	3.490	0.790	2880	1E+05	0.90
Materials for walls							
1	Laterite	16th	1.369	1.926	1000	-	-
2	Mud	16th	1.506	2.929	1600	1E+02	0.38
3	Clay Burnt	19th	1.300	0.840	2000	1E+18	0.95
4	Flyash	19th	0.360	0.857	1700	-	-
5	Lightweight concrete (LWC)	21st	0.209	0.657	950	2E+06	0.95
6	Autoclaved Aerated Concrete (AAC)	21st	0.240	1.000	750	2E+06	0.95
Glassware for windows							
1	Standard Glass	16th	1.000	0.840	2300	1E+10	0.95
2	Lime Silica	19th	1.100	0.840	2480	1E+10	0.95
3	Low-e- bronze	21st	1.000	0.753	2300	1E+10	0.84
4	Ceramic Pyroceram	21st	2.050	0.807	2500	1E+10	0.90

C. *SIMULATION AND ANALYSIS*

Various energy and building settings are selected to run the energy simulation and analysis depending on the scenario that it is being tested for. IGBC guidelines are used as per the "Simulation Approach" on page 110 of the code. After the settings are applied, the Sun path simulation as seen in Figure 3 will be seen in the Autodesk Revit workspace.

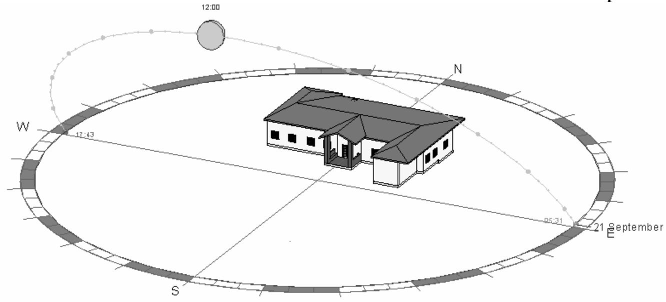

Fig. 3. Sun path simulation

1) Using Coordinate Location, Date, Time: The location is set using latitude and longitude coordinates via User Defined Location. As mentioned in the IGBC guideline, the time and place corresponding to noon (12:00 pm) on 21st September 2021 are set as per the code.

2) Solar Study: Evaluates the impact of natural lighting on the building. Various types of solar studies are offered, i.e., Still, Single Day, Multi-Day, and Lighting. Still, the solar study is selected and depicts the Sun's position at the specified date and time.

3) Energy Settings: Energy Settings are used to define the scenario and specify parameters used to create the analytical energy model. Revit uses the properties of the materials (physical, thermal) to create the energy model and perform the analysis

a) Mode: Revit offers three options for creating the energy model, namely, "Use Building Elements," "Use Conceptual Masses," and "Use Conceptual Masses and Building Elements." Use building elements is selected to consider the detailed information regarding the modeled elements' shape, size, and material properties.

b) Advanced Energy Settings: Offers various settings to control energy model simulation that is "Building Type", "Building Operating Schedule", and "Detailed Elements".

c) Building Type: Single-Family dwelling is selected from the options available as it is a residential structure. The assumption for Single Family dwelling can be found on the Revit Products Autodesk website. Occupancy Schedule, People Heat Gain, People Latent Heat Gain, Lighting Load Density, Infiltration Flow, etc., based on Single Family dwelling is considered. The premises are used to provide reasonable energy usage estimates and not for code compliance. These assumptions are based on the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE-90.1-2010, 90.2-2010, 62.1), Commercial Building Energy Consumption Survey (CBECS) data, and other building surveys.

d) Building Operational Schedule: 12/7 Facility is considered for analysis. People living within the residential house consume energy and have the most effective house usage for a minimum of twelve hours a day in a week. Whereas no or little quantity of energy is consumed throughout half the amount of time particularly late night, hence 12/7 operational schedule has been opted to run the analysis A range of active schedules used for energy analysis is available, 24/7- 24/5, 12/7-12/5, year-round schedule, schedule for theatres, etc.

e) Detailed Elements (Should be selected): It gives realistic results as it considers the properties of each element modeled. Elements such as walls, roofs, and floors associated with the material thermal properties are used during the energy simulation to get realistic results.

4) Creating Energy Model: Revit converts the existing building components and layout while considering the location, weather data, thermal and physical properties into an analytical energy-dependent model for computation purposes. This network captures all critical paths of heat transfer throughout the structure and generates the energy model in the form of base color codes for different components for analysis.

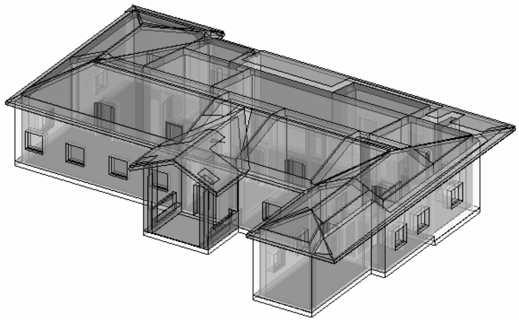

Fig. 4. Energy-dependent model

5) Lighting Analysis Illuminance Settings: The Autodesk Insight360 Cloud Service is used by the Lighting Analysis plug-in to execute a quick and accurate analysis. The minimum and maximum values set by IGBC (Page 110) for illuminance testing are 110 Lux and 1100 Lux, respectively, which measure the available daylight on a defined plane and depict the amount and intensity of light falling on the surface.

6) Generating the Report: The model is uploaded on Insight360 cloud, where it is analyzed, and the detailed results are updated on the Insight360 website. The Analysis takes about 10-20 minutes to run the simulation and get the results. The report includes the potential performance outcomes from the newly created analytical energy model. It helps set ranges to define envelope construction, mechanical systems, and operational schedules and determine the energy cost range. Updating Energy Analytical Model runs a simulation for a fresh model and updates the simulation result on Insight360.

7) Understanding Features in the report: Insight360 offers a panel containing detailed information on various possible scenarios and their performances. A user will try to identify the most efficient scenario and make changes manually to the model with the understanding of the panel.

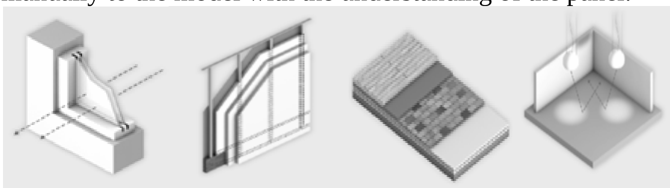

Fig. 5. (left to right) construction of window, wall, roof, and lighting efficiency

a) Wall construction: The construction of the wall can be modified easily in the structure's tap. A user can introduce insulating layers and any other material of definite thickness. When using various materials for the wall, an "Energy Analysis Surface" is created by Autodesk Revit that considers the material properties and obtains an average for the wall as a whole. Both exterior and interior walls are modeled as 660mm thick. Exterior walls consist of 20mm plaster on the external faces and 12mm plaster on the inner faces. Interior walls have both faces as 12mm. The wall construction is used to model the wall as realistically as possible.

b) Window glass: Glass properties control the amount of daylight, heat transfer, and solar heat gain into a building, along with other factors. While the physical and thermal properties on their own do not contribute any change to the performance of the structure, glass with a glazing factor affects the performance considerably.

c) Roof construction: Similar to Wall Construction, various layers can be introduced to the roof in the structures tab. The topmost layer of the roof construction has maximum insulation ability. Hence choosing an appropriate outer layer is of grave importance.

d) Lighting efficiency: The lighting efficiency panel is used to help see the various scenarios of the positioning of windows and lighting fixtures. As the solar study is done using "Still," corresponding to noon (12:00 pm) on 21st September 2021, electrical fixtures are not considered by the software. This has been tested and confirmed.

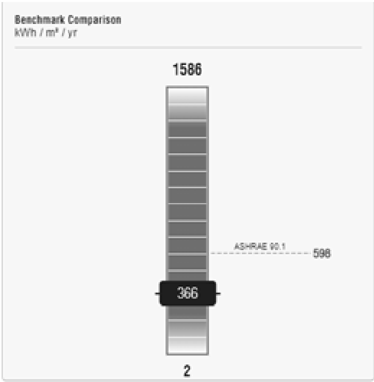

Fig. 6. Insight360 benchmark

8) Results: Insight360 offers a benchmark comparison of the structure according to various set standards as shown in Figure 6. It shows the overall performance of the structure. We determined that the energy contribution from the architectural design would be 366 kWh/m²/year. Plaster and rubble, cast in-situ-concrete in foundation along with architectural elements are taken into consideration. This value helps to identify the individual performance of the material while keeping all other factors constant.

V. OBSERVATION AND RESULTS

A. *INDIVIDUAL MATERIAL ANALYSIS*

1) Roofing materials

Straw thatch, mud, tiles, and lightweight concrete are commonly used for roofing in Goa, India. The material was changed using the material browser and edit type tab of the roof element. The analysis was carried out on Insight360. A graph of Materials vs. Energy Use Intensity (kWh/m²/yr) is plotted to compare the materials as seen in Figure 7.

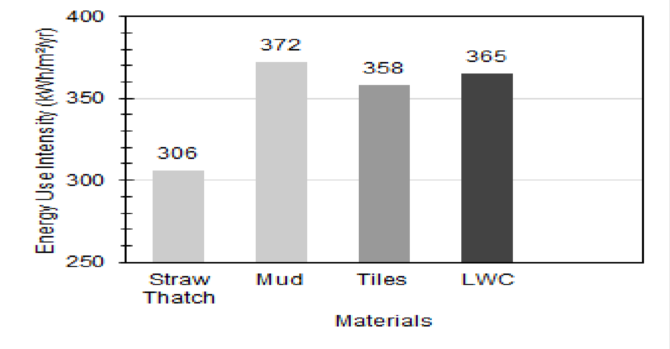

Fig. 7. Energy use intensity for roofing materials

The data shows that straw thatch is the most energy-efficient roofing material with the least EUI of 306 kWh/m²/yr. The thermal conductivity (0.070 W/mK) and specific heat (0.180 J/gC for straw thatch are the least as compared to mud, tiles, and lightweight concrete. Mud has a higher value of thermal conductivity (1.506 W/mK) and specific heat (2.929 J/gC) and hence consumes the most amount of energy at 372 kW/m²/yr. Tiles and LWC are comparable EUI with a difference of only 7 kWh/m²/yr.

While straw thatch consumes the least amount of energy, it does not provide the essential requirement of a shelter, that is, to protect one from external environmental conditions like rain and wind. Mud cracks over time due to moisture loss and is impracticable considering it may not give a good finish and may collapse during heavy rains.

Tiles and lightweight concrete roofs not only keep us safe but can be used for overhead storage when designed to take loads from overhead water tanks and other electronic appliances. Except for the mud roof, we observe that the choice of material of the roof decreases the overall energy consumption between 1 to 8 kWh/m²/yr. This residential home implies saving anywhere between 415.35 and 3,322.8 kWh/yr in electrical consumption for the 415.35m² residential home.

2) Flooring materials

While mud flooring was predominant in the 16th century, concrete, ceramic, terracotta, marble, and granite are commonly found in newer flooring constructions. The latter two materials are imported into Goa and are widely used. The results are shown in Figure 8.

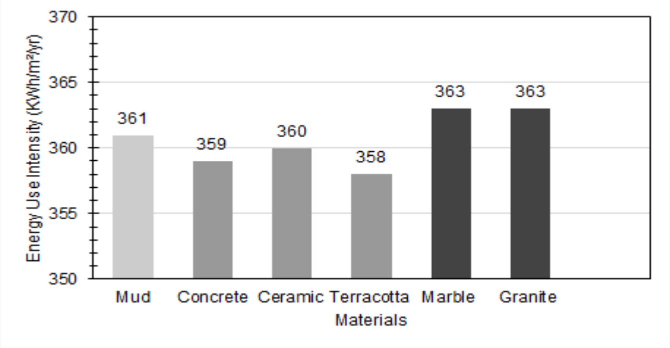

Fig. 8. Energy use intensity for flooring materials

With a EUI of 358 kWh/m²/yr, Terracotta tiles, made from clay and iron oxide, decrease energy consumption by 8 kWh/m²/yr. Terracotta with thermal conductivity of 0.810 W/mK and specific heat of 0.840 J/gC can effectively keep the house warm in cold weather because of its excellent insulating properties.

Marble and granite having high thermal conductivity values of 2.900 and 3.490 W/mK, respectively, are the least efficient flooring material having the same EUI value of 363 kWh/m²/yr. Concrete, beating ceramic tiles by 1 kWh/m²/yr are mainly used for commercial spaces like office buildings or storage warehouses.

While the energy consumption decreases for all the tiles, the use of ceramic, concrete, or terracotta floorings can save energy anywhere between 6 and 8 kWh/m²/yr (2492.1-3,322.8 kWh/yr in case of this residential home). While most modern households prefer to use ceramic or marble for their impressive designs, strength, and toughness, most colonial-era homes have terracotta tiles due to easy availability and insulating properties. There is a need to develop and use better quality terracotta tiles in terms of strength and resistance to chipping at the edges.

3) Wall materials

Laterite soil is commonly found in tropical areas like Goa due to rich Iron oxide deposits. The reddish-brown stone is the most widely used material for walls due to its good strength, durability, and availability. Other commonly used materials for walls are clay burnt bricks, lightweight concrete bricks, and Autoclaved Aerated Concrete Blocks. Some old colonial houses are constructed with mud having a thickness greater than 0.600m which is not feasible for construction. The results are shown in Figure 9.

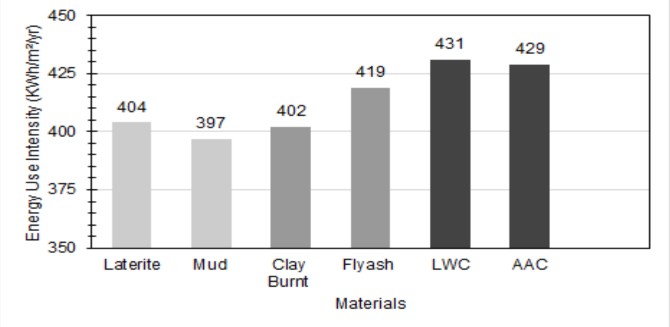

Fig. 9. Energy use intensity for wall materials

Mud consumes the least amount of energy with a EUI of 397 kWh/m²/yr. Mud walls being porous helps maintain comfortable indoor temperature irrespective of harsh weather conditions by allowing cool air to enter through the pores.

Recently there has been a trend to use Lightweight concrete and Autoclaved Aerated Blocks for walls, but due to their low density, the specific heat is much lesser than other materials. Hence while they conduct heat slowly, the amount of heat needed to raise the temperature is much less than materials having higher densities. This is believed to be the reason for the higher values of EUI of 431 kWh/m²/yr and 429 kWh/m²/yr respectively.

Laterite (404 kWh/m²/yr) and clay burnt (402 kWh/m²/yr) bricks are observed to be much more efficient in terms of performance, having a difference of only 2 kWh/m²/yr. Flyash has a much higher EUI than Laterite and Clay burnt, while it should be kept in mind that flyash leeches when exposed to water and is only used when constructing interior walls. Hence a designer considering using a single type of material for walls should consider using either laterite or clay burnt depending on the availability of the material.

4) Glass materials

The commonly available materials in Goa selected for Analysis are Standard Glass, Lime Silica. Low-e-bronze and Ceramic Pyroceram are relatively newer innovations in the market and need to be imported into Goa on special request.

During the analysis and study of window glass, observations were made that concluded that the insulation for glass is independent of thermal and physical properties when glazing is not added.

When only thermal and physical properties are considered for analysis, the results showed that the EUI was the same as the architectural design value (366 kWh/m²/yr.). The properties of glass alone did not affect the performance of the structure.

The glazing or glaze factor is the ratio of visible light transmitted upon the floor to window ratio. For 10% glazing, only 10% light is allowed to enter. When the glazing was added to the glass, different outcomes were observed. This implied that the glazing for the corresponding thickness of glass played a vital role in light and heat entering through the window.

Three-millimeter-thick glass is most commonly used in residential structures. The least amount of glazing is 10%, while the highest is 80%. Glazing factors of 10%, 50%, and 80% were selected for the study.

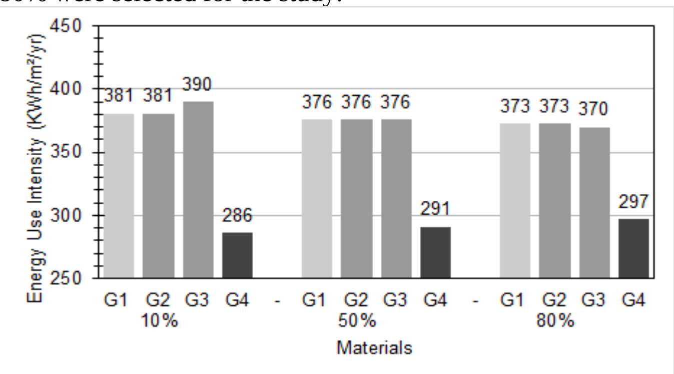

Fig. 10. Energy use intensity for glassware materials

From Figure 10, Ceramic Pyroceram with 10%, 50%, and 80% glazing decreases the energy use by more than 69 kWh/m²/yr as compared to the other commonly used materials.

While it is known that the orientation of the structure plays a vital role in ventilation and the amount of light/ heat entering the building, it also plays an important role in the selection of the glassware for the windows.

Considering an example, in a structure, only the windows in the East-West direction need to be fitted with proper quality glassware to ensure the required amount of heat enters. While windows in the North-South direction play an important role in ventilation, their role in light and heat transfer may be limited. Hence a proper study on the placement of windows and glassware is to be given importance.

B. COMBINATION ANALYSIS

A combination study was carried out to determine the structure's performance to give a realistic understanding of the contribution of different selected materials as a whole. The materials were short-listed for each element based on the availability, known problems with the material, and performance of the individual materials found in the analysis above.

TABLE II. COMBINATION OF SELECTED MATERIALS

No	Roof	Floor	Window Glass	Wall
C1	Tiles	Terracotta	Pyroceram 10%	Clay Burnt
C2	LWC	Ceramic	Pyroceram 10%	Laterite
C3	LWC	Marble	Pyroceram 10%	Clay Burnt
C4	Tiles	Terracotta	Pyroceram 10%	AAC
C5	Tiles	Marble	Pyroceram 10%	AAC

The roofing materials selected for the combination study are tiles and lightweight concrete. Tiles offer longer life spans, are locally available, durable, and resistant to harsh weather conditions. Lightweight concrete’s low thermal conductivity and density may be seen as a double-edged sword. The benefits of transferring less load to the structural elements outweigh the need to decrease costs during the life cycle by reducing costs during construction.

The least energy consumed materials for flooring are terracotta tiles, commonly used and have low thermal conductivity and specific heat. Ceramic tiles are tough, are difficult to crack, and last between 10-20 years or longer when installed properly. Marble too is considered due to its durability and ability to withstand any external pressure

Wall materials taken for the combination are clay burnt bricks, laterite, and AAC blocks. Clay bricks are abundantly available and, from the individual study, are seen to exhibit good thermal insulation properties. Laterite is the most commonly used stone for construction in Goa as it is readily available. Laterite is also known to help in the regulation of indoor air humidity.

There is a trend to consider the use of AAC blocks. Structures are specially designed as the foundation takes lesser loads from walls as the density of the walls is much lower. At times, AAC blocks are not available and need to be imported into the state; the benefits of using AAC blocks at times outweigh the cons.

Ceramic Pyro Ceram 10% glazed was only considered as the material outperformed standard glass, Lime silica, and Low-e-bronze, which all had higher and if not similar values of EUI.

The C1 combination consisted of the lowest energy-consuming materials chosen for the combination study. The result of which the C1 combination consumed the least amount of energy compared to the other combinations. Hence a structure constructed from low energy consuming materials will consume the least energy throughout its lifecycle.

What happens when only one material is different in a combination? We expect that if material A consumes more energy than material B in Individual Study, the combination study would also show the same difference in value when only that material is changed. This is not true.

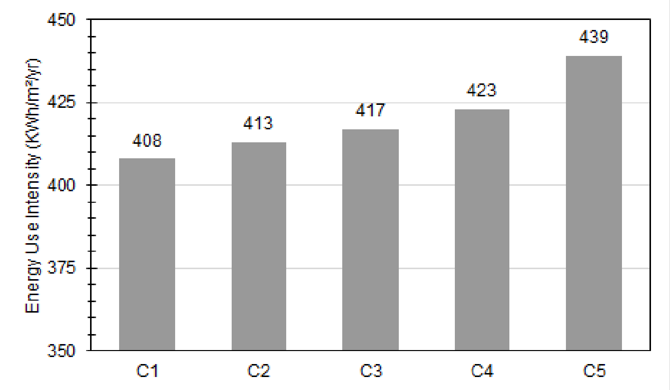

Fig. 11. Energy use intensity of combination

Combination C4 (423 kWh/m²/yr) and C5 (439 kWh/m²/yr) have the exact composition of materials except for the choice of flooring materials. Marble is seen to consume more energy by 5 kWh/m²/yr. The difference between C4 and C5 shows an increase of 16 kWh/m²/yr while marble is used. While in combination, C1 (408 kWh/m²/yr) and C4 (423 kWh/m²/yr) have the exact composition of materials except for the choice of wall materials. AAC is seen to consume more energy by 27 kWh/m²/yr. The difference between the C1 and C4 shows only an increase of 15 kWh/m²/yr. Hence what can be concluded is that while the use of higher energy-consuming materials will undoubtedly increase the energy consumption of the structure, the increase isn't proportional to the difference in energy consumed by the materials alone but concerning other materials. There is a possibility of a non-linear relation which would require further research.

VI. CONCLUSION

There have undoubtedly been improvements in selecting materials used in construction (Izzat 2015, Ariana 2019) from the 16th to the 19th to the 21st century. In comparison, materials used before the 19th-century didn't undergo any chemical processing, while materials after were processed from recycled items or through complicated industrial processes to obtain the desired strength and quality. This itself proves that the construction industry has evolved.

The effort in the course of this paper has been to reduce energy consumption at the residential level. This study focused on using selected materials for a given structure to check for energy efficiency. The roof, window glass, flooring, and walls were modeled in Autodesk Revit and analyzed through Insight360.

The individual study for roofing showed that tiles placed on a concrete roof offer the best insulation. Flooring using concrete, ceramic, and terracotta shows similar results and depends on the type of building. Laterite and clay burnt bricks are seen to be well-performing materials, mainly when a designer uses only one type of material for all the walls. The use of glazing for glass is critical for the amount and intensity of light and heat entering a building through an opening. While Ceramic Pyro Ceram glass is seen to outperform in use, it is not economical to fit all windows with this high-quality glass. Hence a proper study of the orientation is necessary before selecting a type of windows and glassware.

The combination study shows that using higher energy-consuming materials will undoubtedly increase the structure's energy consumption. While the increase is not proportional to the energy difference between the materials, all materials must be energy efficient to obtain the most efficient outcome.

The use of BIM can help the designer and the architect to obtain the best orientation of the proposed structure, to get the most energy-efficient materials for the structure, and, in the long run, reduce the running and maintenance costs. In particular, Autodesk Revit helps designers create sustainable designs with the help of analytical tools featured in it. These tools help to measure the impact that the building design can have on the environment. It allows users to visualize the impacts of their design with the energy optimization tool built into Revit and an additional plug-in like Insight360.

The construction industry is shifting to greener materials and energy-efficient designs. The amount of progress in reaching new standards set by IGBC, LEED, ASHRAE, and Autodesk depends on the architects, civil engineers, and designer's ability to innovate and apply the research. Research-based on materials and performance is incredibly beneficial in selecting appropriate materials in construction.

We hope that through this research paper, we have increased knowledge on some of the materials used in the construction industry and helped in the progress to a greener future.

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