ROLE OF INSULATION IN ENERGY CONSUMPTION IN COMMERCIAL AND OFFICE BUILDINGS

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ABSTRACT

Buildings, as climate modifiers, are usually designed to shelter occupants and achieve thermal comfort in the occupied space backed up by mechanized cooling and heating systems as necessary. The heating and air-conditioning load can be reduced through many means; notable among them is the proper design and selection of building envelope components. In India, which has different climatic conditions, past research were done in the building envelope optimization however, when it comes to choosing the insulation materials and their thickness to be used in different climatic conditions information is not available to architects and simulation experts to substantiate their recommendations to different projects.

In this research paper the effect on reduction in energy consumption by using insulation materials is the major thrust. The aim of this paper is to develop a set of guidelines in respect to the thickness of insulation to be chosen by architects & energy analyst in office & commercial buildings in different climatic conditions.

Also, the life cycle energy cost of a building has been realized to be critical to the energy consumption in buildings, which is reaching a serious proportion, as the energy needs have to be met for the fast growing population and to sustain the development. The life cycle cost of a building, includes the initial cost, energy cost, other operation and maintenance cost. The effect of increase in the initial energy cost, constituted by the insulation materials to the energy savings that can be obtained, is also studied by simulating two case buildings chosen, using eQUEST simulation tool. Parametric studies were carried out with different insulation materials at different climatic conditions in Indian context. Correlation between the resistance and thickness of the insulation material, to the percentage of energy savings were found to obey a logarithmic relationship.

The life cycle energy cost analysis showed that energy savings up to 47% could be achieved during a 50 year life span of a building, with a very negligible increase in embodied energy due to the insulation materials. These findings shall be used as a guideline by energy analysts and architects while optimizing the building envelope for commercial and office buildings in different climates of India.

INTRODUCTION

Building Materials, Lighting systems, Energy supply systems, and Building envelope are the major factors that affect the energy consumption of a building. Initially used building materials directly constitute to the embodied energy, which includes extraction, processing, manufacture and transport of the materials and its components. The relative significance of embodied energy forms a higher proportion of the total amount of energy used over the lifetime of a building. Potential to reduce energy consumption at the initial stages in the materials selection plays a vital role.

Building codes are crucial to help induce the improvement of the energy efficiency of the building sector. A number of building codes currently include energy performance standards, limiting the amount of energy that buildings can consume. In India, Energy Conservation Building Code standards 2006, and ASHRAE 90.1.-2004 [1] are the codes followed for 'LEED' certification. LEED Green building Rating System is a voluntary, consensus-based, market-driven building rating system based on existing proven technology. It evaluates environmental performance from a whole building perspective over a building's life cycle, providing a definitive standard for what constitutes a "green building". The above mentioned standards have given importance and strategies for use of thermal insulation materials in buildings. In ASHRAE 90.1-2004, sections 5.4 and 5.5 gives the mandatory provisions of insulation materials to be provided for the walls, roofs, and floor. Section 5.8 specifies the insulation product information and installation requirements. ECBC standards specify the prescriptive requirements of insulations in section 4.3 for roofs, and opaque walls.

In this paper, embodied energy contribution of thermal insulation is analyzed followed by analysis whereby proportion of embodied energy in comparison of total energy consumption during the life of a building is presented. Finally, the role of thermal insulation is presented to demonstrate that operation energy is dominant of the two and role of insulation on energy saving in operation energy is analyzed.

CASE STUDIES

Two case buildings were chosen to carry out the simulation in eQUEST, namely Building 'A' and Building 'B'.

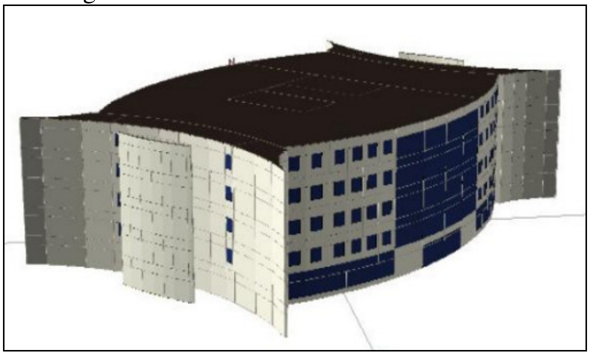

Figure 1: Model of Building 'A'

Building 'A' is a four storey office building, constructed in 2003-04 in Chennai, a city in southeast coast of India (Lat – 13.04N, Long - 80.17E, Alt 6m above sea level). The building comprises seminar halls, conference rooms and museum in ground floor, and open offices in the top floors (2400 sqm each floor). The open office is built as a column free space; the concrete floor slab is supported by the 150mm thick shear concrete wall at the periphery, and by the central service core of the building. The air-conditioned and un-conditioned spaces were modelled as per the HVAC design of the building. The total built-up area is 12,000 sqm and the air-conditioned area is 11,245 sqm.

The external wall of the building is 6-inch thick shear concrete wall, plastered on both sides, with a u-value of 4.33 W/m^{2}K. The roof slab has a u-value of 0.028 W/m^{2}K. Double glazing systems with a u-value of 2.895 W/m^{2}K, Shading coefficient of 0.23 were modelled. The Open office spaces are lit with Compact fluorescent lamps (2 X 36 W), and the corridors with Compact fluorescent lamps (2 X 18 W). The lighting power density was modelled as per the lighting system design of the building. Building 'A' uses Multi zone Air handler, with chilled water coils as its HVAC system. The Fan control is of variable speed drive. Four screw type chillers of 163 ton each, which gives output at 1.407kW/ton full load efficiency.
Building 'B', one of the commercial buildings in Chennai, was selected as a case study because of the proximity and the ease of collection of data. It is a ten story office building, spread over an area of 6,00,00sqm, constructed in 2004-05 in Chennai, a city in southeast coast of India (Latitude 13.04 N, Longitude 80.17E, altitude- 6m). The building comprises of shopping complexes in ground and first floor, the second and third floor used for car parking, and open plan offices in the top eight floors (60,00 sqm per floor).
The case building 'B' was also simulated like the building 'A'.

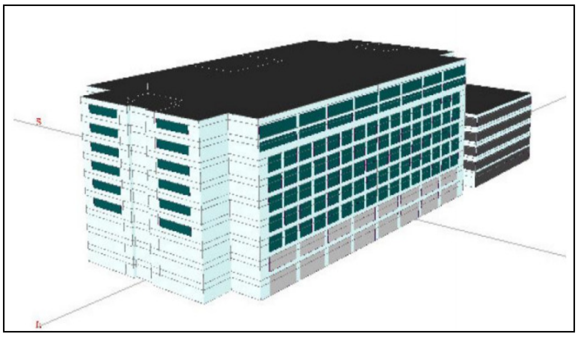

Figure 2: Computer model of Building 'B'.

Both the cases buildings A & B were modeled in eQUEST by using the gathered information and the physical properties that were determined from the architectural drawings, and manufacturer data. A detailed computer model was setup representing the whole building. Details of building 'A' are show as follows:

SIMULATION OUTPUT

The computer model was simulated using the eQUEST energy simulation tool to obtain monthly energy consumed for space cooling, area lighting, miscellaneous equipments, ventilation fans and the pumps. eQUEST which has DOE2.2 simulation engine is used to perform an hourly simulation of the building design for a one year period. It calculates heating and cooling loads for each hour of the year, based on the factors such as walls, windows, glass, people, plug loads, and ventilation. DOE2.2 also simulates the performance of fans, pumps, chillers, boilers and other energy consuming devices. During the simulation, DOE2.2 also tabulates the building's projected use for various end uses. The simulation results for the building 'A' and building 'B' is shown in Figure 3 & 4 respectively.

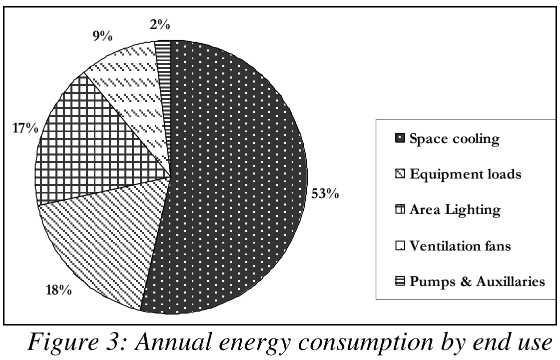

Figure 3: Annual energy consumption by end use under various parameters of building'A'

Space cooling consumes the maximum percentage of the total energy consumption, which has huge potential to reduce energy consumption.

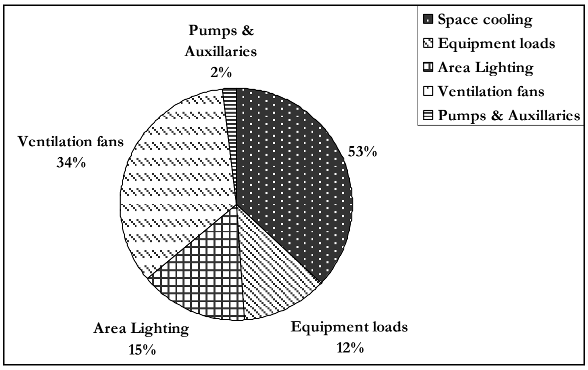

Figure 4: Annual Energy consumption under various parameters of building 'B'

The model developed and its simulation results obtained, the monthly energy consumption for the year 2006, was compared with the actual energy consumption for the same year, as recorded in the electric meters in the building. Figure 5 gives the actual and simulated energy consumption values in kilowatt-hour.

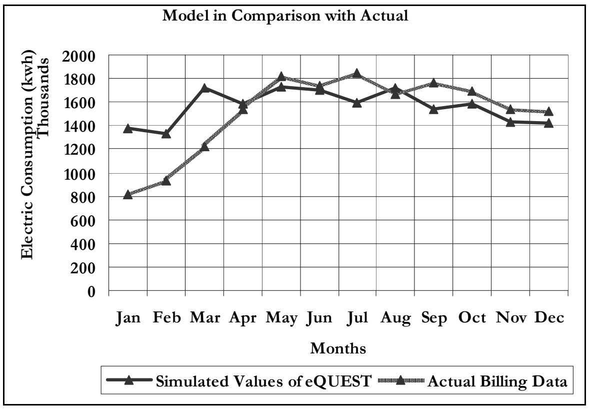

Figure 5: Comparison of the actual billing data and building simulation results.

The result shows that energy simulation program predicts the energy use pattern of the building. The higher difference in January, February and March is significant as all the floors of building 'B' was not fully occupied by the tenants. The graph shows that there is less than 8% difference for the months of April, May, June, August, October, November and December and a 3.3% difference for the annual energy consumption between the simulation results and the actual energy bill data of building'B'.

EMBODIED & OPERATING ENERGY

Embodied energy can be calculated on an industrial sector basis (i.e., total embodied energy divided by the total material used in a sector, e.g., manufacture of steel) or by process analysis in which the embodied energy of a particular material is tracked from extraction to end-use. The figures produced by each approach differ, particularly for low-volume commodities [6]. The figures used in this study, are referred from Embodied energy of common and alternative building materials and technologies by B.V.Venkatarama Reddy, K.S.Jagadish [3] and Eco balance assessment tool (Eco –BAT,www.eco-bat.ch) developed by Stephane Cithrelet [6].

Figure 6 and 7 show the embodied energy calculated for building 'A' and building 'B' respectively.

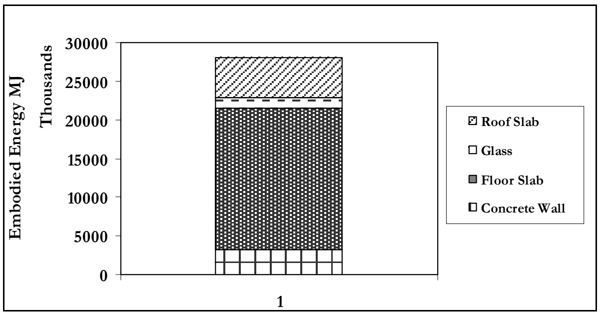

Figure 6: Embodied energy of Building 'A'

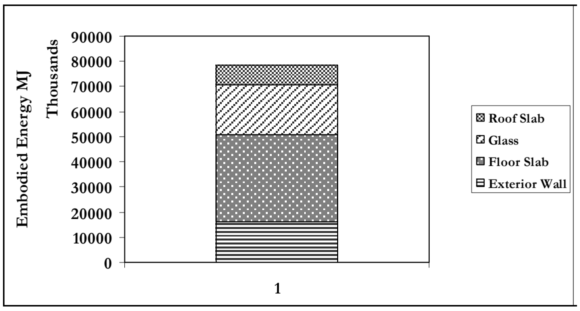

Figure 7: Embodied energy of Building 'B'

Energy used in buildings during their operational phase, as for cooling, ventilation, hot water, lighting, heating, and other electrical appliances contributes to the operating energy. It might be expressed either in terms of end-use or primary energy. End-use energy is measured at final use level, so it somehow expresses the performance of a building. Primary energy is measured at the natural resource level, including losses from the processes of extraction of the resources, their transformation and distribution, and so it expresses the real load on the environment caused by a building.

In other words, the same building placed in different countries but with similar climates is likely to have similar figures about end-use energy. The difference in terms of primary energy, however, can be significant because of the different energy carriers available for thermal purposes (like cooling, heating, electricity) and because of the different ways to produce electricity. For example, in India, Thermal 66%, Hydropower 26.5%, Nuclear 3%, and renewable 4.8% [Ministry of Power, India].

With respect to Operating energy, eQUEST tool used in this study gives the end use energy consumption. A linear relationship exists between operating and total energy consumed by a building [4]. Life cycle assessment, provide better understanding and better estimation of energy aspects in the life cycle of any sort of good. Hence, this study focuses only on operating energy and embodied energy in the life cycle of buildings.

LIFE CYCLE ENERGY CALCULATION

The total energy used in a building over its life is the sum of the operational energy and embodied energy. The embodied energy of the building envelope components is tabulated in table 6, and the operating energy (end-use) of the buildings, obtained from the simulation carried out in eQUEST, is sum totalled to obtain the Life cycle energy of the building from 20 years till the life span of the building. The sum total energy calculation for building 'A' & building 'B' shown in the Figure 8 and Figure 9.

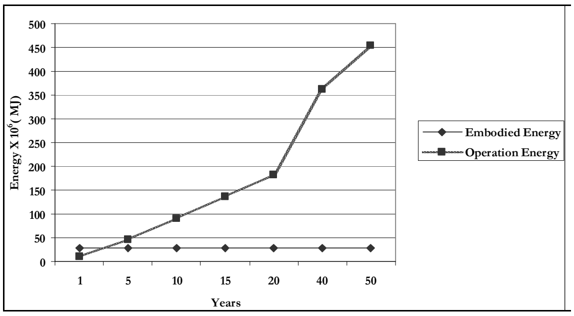

Figure 8: The life cycle energy of building'A'

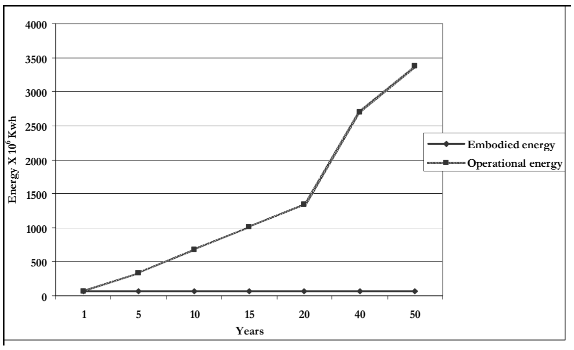

Figure 9: The life cycle energy of building 'B'

ROLE OF INSULATION IN REDUCTION OF ENERGY CONSUMPTION

To determine the role of insulation in reduction of operative energy & thermal mass parametric simulations were performed in building 'A' & building 'B'. For this analysis different insulation materials like Mineral Wool, Expanded polystyrene, Polyisocyanurate were applied on the exterior walls of building 'A'. Different climatic conditions of India namely, warm & humid, composite, Hot & Dry and Temperate were considered for this parametric simulation study.

Firstly, the thickness of insulation materials was considered as the variable and simulations were performed in different climatic zones. The results of the simulations are shown in Figure 11. It indicates that increasing the resistance value of insulation material does not yield proportional return in percentage of energy saving (Y) beyond a certain point. The relationship between the percentage of energy savings (Y) and the resistance of insulation material (X) is not linear. It obeys a logarithmic function of

$$y = 1.2612 \ln(x) + 8.3158, R^2 = 0.9588 \quad (1)$$

with respect to Hot-dry climate (Jodhpur). In respect with composite climate (New Delhi), it obeys

$$y = 1.4302 \ln(x) + 7.559, R^2 = 0.7476 \quad (2)$$

Warm-Humid climate (Chennai) it obeys

$$y = 0.9732 \ln(x) + 5.7066, R^2 = 0.9692 \quad (3)$$

and in Moderate Climate (Bangalore) it obeys

$$y = 0.7547 \ln(x) + 5.1813, R^2 = 0.97 \quad (4).$$

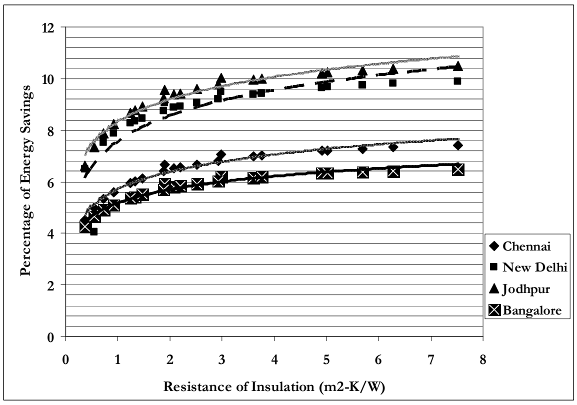

Figure 10: Energy savings after application of insulation material on the exterior wall surface.

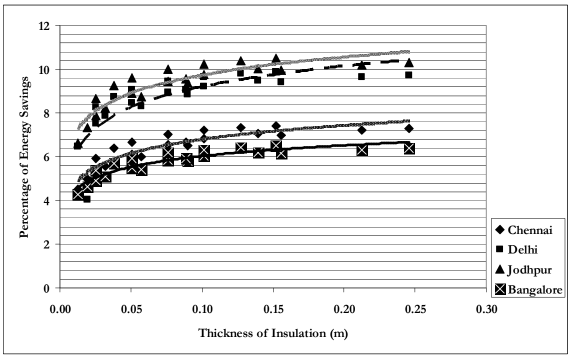

Figure 11: The energy savings in reference with the thickness of insulation.

Increasing the resistance value of insulation materials is achieved by increasing the thickness of the insulation material. The results on the percentage of energy savings, in relation with the thickness of insulation materials, shows that beyond a certain level, there is no considerable savings even after increasing the thickness of the insulation. Which means additional insulation thickness is not effective anymore. It shows that the relationship between the percentage of energy savings (Y) and thickness of insulation (x) is non-linear as shown in Figure 14. It obeys a logarithmic function of

$$y= 1.2001 \, Ln (x) + 11.09, R^2 =0.8506 \quad (5)$$

in Hot dry climate (Jodhpur). In respect with composite climate (New Delhi), it obeys

$$y = 1.3584 \, Ln (x) +10.701, R^2 =0.6607 \quad (6)$$

Warm-Humid climate (Chennai) it obeys

$$y= 0.9259 \, Ln (x) + 7.847, R^2 =0.8594 \quad (7)$$

and in Moderate Climate (Bangalore) it obeys

$$y= 0.709 \, Ln (x) +6.8207, R2 =0.8592 \quad (8).$$

The above equations show that the insulation materials with thickness from 50 to 100 mm provides the maximum savings in all climates of India and increasing the thickness more than 100 mm does not yield proportional return under energy savings in the building. Also the resistance of the insulation materials within 2 to 4 m^2-K/W provides the maximum energy saving and beyond which there no proportional return in energy savings.

These energy savings due to the thickness and resistance values of the insulation material is more in Climates of New Delhi and Jodhpur, moderate in Chennai and least in Bangalore. In composite climate zones the effect of insulation is significant and yield 8 to 10% energy savings annually. In warm humid climate zones the effect of insulation is moderate and yield 5 to 7% energy savings annually. In Temperate climate zones the effect of insulation is 4 to 5% energy savings annually.

ROLE OF THERMAL MASS AND STORAGE

Thermal mass reduces heat gain in the structure by delaying the entry of heat into the building. Internal mass stores excess heat, whether from the sun or internal loads of the building, for release during unoccupied or cooler periods. Material thermal mass is characterized by its time lag, which is the length of time from when the outdoor temperature reaches its peak until the indoor temperature reaches its peak.

In multi-layer walls, the combined effect of thermal resistance and heat capacity depends on the overall thermal transmittance, heat capacity, and on the specific order of the various layers, which might differ in thickness and thermo physical properties. To analyze this, the product of (ρLc/k) (L), where L is the thickness, c is the specific heat, ρ is the density and k the thermal conductivity was plotted against the percentage of energy savings. Figure 12 shows that the equivalent thermal resistance-capacity product(x) has logarithmic relationship with the percentage of energy savings(y). It does not give proportional return to percentage of energy savings.

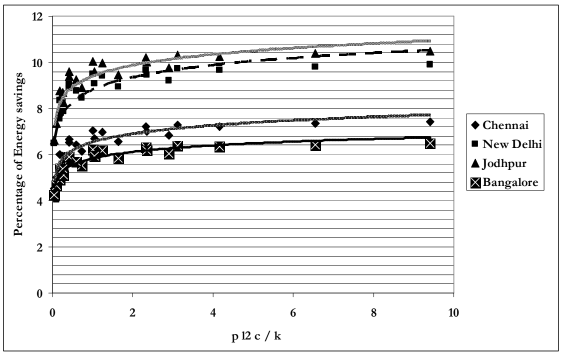

Figure 12: Effect of increase in thermal capacity to the percentage of energy savings.

Figure 13 shows that there is a linear relationship between percentage of energy savings (Y) and overall U-value (x) of the wall. Hence there is always increase in percentage of energy savings with the reduction in overall u-value.

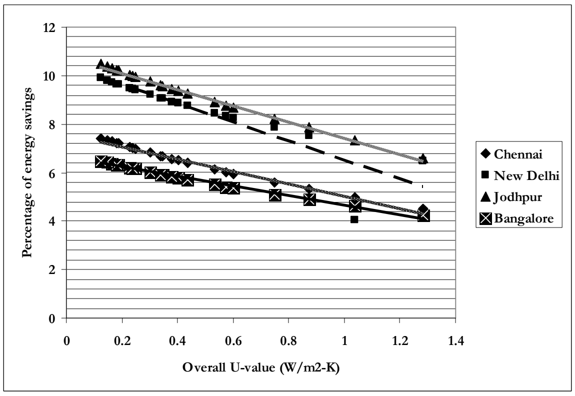

Figure 13: Overall thermal u-value of wall to the percentage of energy savings

LIFE CYCLE IMPACT ASSESSMENT

The life cycle impact assessment of the two case buildings presented in this study were done using Eco Balance Assessment tool, ECO-BAT 2.4 developed by Stephane Cithrelet, HES.SO [6]. The environmental effects used as the environmental indicators are as follows:

1. Non-Renewable Energy (NRE).
2. Global warming potential over a 100 year period (GWP 100)
3. Acidification potential (AP)
4. Photochemical Ozone Creation Potential (POCP)

These indicators are related to global external environment. However, a part of the environmental problems related to the building sector might arise locally and connection with the indoor environment, such as Volatile organic compounds (VOCs), these are not considered in this tool. The building materials data according to Indian context were modified and fed in ECO-BAT.

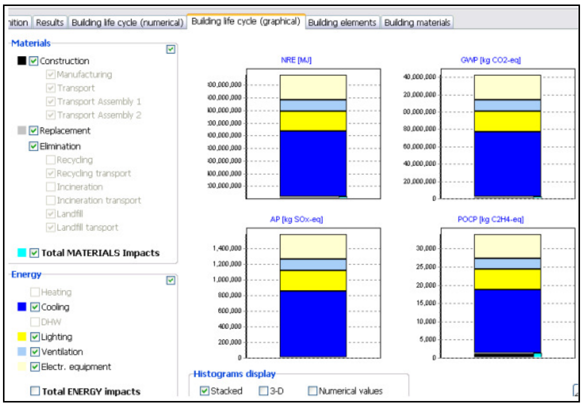

Figure 14: Life cycle impact assessment of materials and energy in building 'A'

Figure 14 shows the building life cycle impact caused by all the materials used in the envelope and structure of the building 'A', and the energy consumed during operation of the building. It is seen that the materials used, has a negligible quantity in comparison with the impact of energy consumed. Energy used for space cooling is dominant in all the four indicators. Hence, potential to reduce this energy consumption is more significant, which would help in considerable reduction in the impact on the environment.

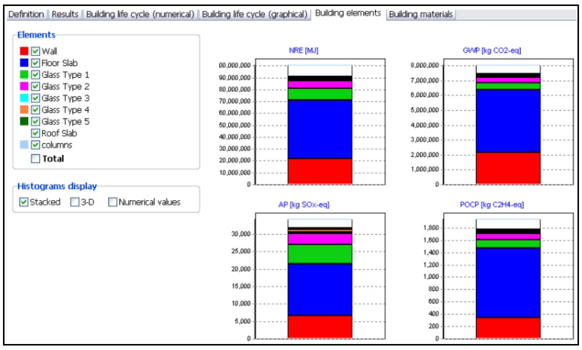

Figure 15: Life cycle impact assessment of the building elements of building 'B'

Figure 14 shows that NRE (MJ), GWP (kg Co2), AP (kg Sox), POCP (kgc2H4) indicators of the Building elements in building 'A'. The building elements of the envelope considered for assessment are the exterior wall, glazing, concrete floor slab, roof slab, columns and insulation material if applied on the exterior walls. It is seen that, concrete floor slab element is dominant in all the four indicators. Glazing shows a very less percentage of impact in comparison with the other elements.

IMPACT OF ADDITIONAL THERMAL INSULATION MATERIAL ON OPERATING ENERGY & EMBODIED ENERGY

The energy initially embodied in a building could be as much as 67% of its operating energy over a 25 year period [5]. Figure 23 shows that the initial embodied energy of the envelope and structural components constitutes as mush as 76% of the operating energy at the first year of operation phase in building 'A', and 49% of the operating energy in building 'B' shown in Figure 16 and 17 respectively. The difference in the two buildings is because of the main constituent of concrete wall and polystyrene filling in the roof slab, used in building 'A'. In further years, it is observed that the operating energy constitutes higher percentage to the total energy consumption in comparison with the embodied energy.

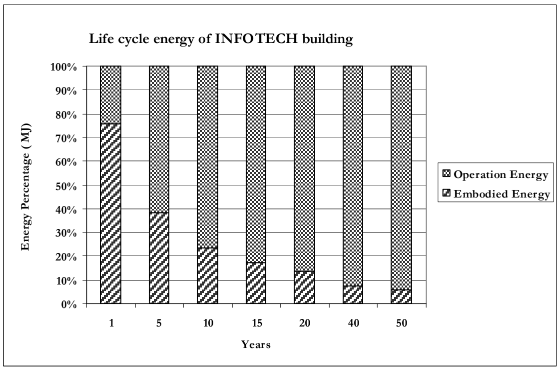

Figure 16: Life cycle energy consumption of building'A'

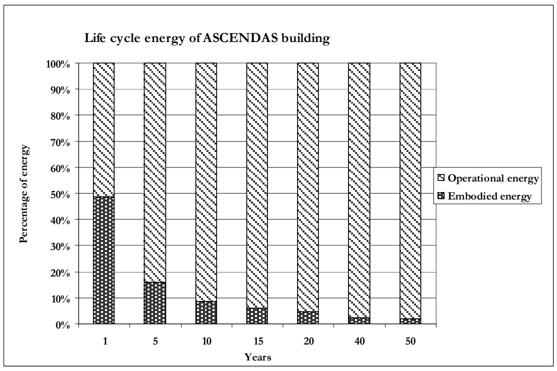

Figure 17: Life cycle energy consumption of building 'B'

Figure 18 shows the embodied energy of the envelope and structural components, in addition to it, the polystyrene insulation, which has comparatively higher embodied energy, constitutes as much as only 6% to it.

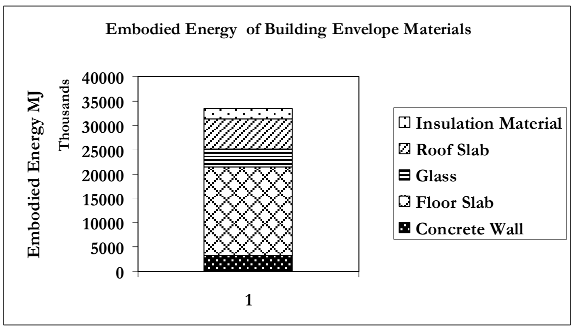

Figure 18: Embodied energy of the building materials and the additional insulation material.

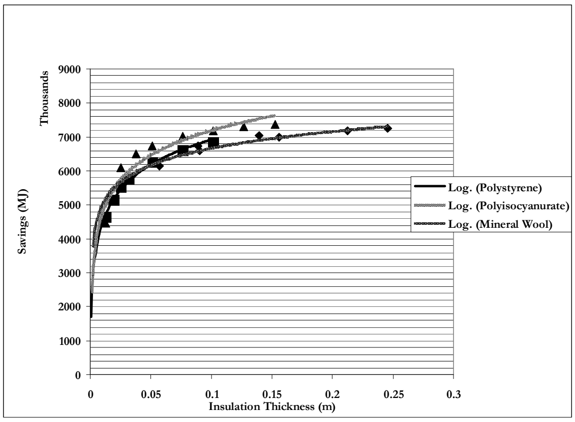

Figure 19: Comparison saving for insulation material studied.

The energy savings in specific with the different insulation materials of varying thickness is shown in Figure 19. It shows that polysicocyanurate insulation, which has higher embodied energy, gives higher energy savings than polystyrene or mineral wool insulations. It also shows that with the increase of insulation thickness, there is significant energy savings but not beyond a certain point. The relationship between percentage of energy savings (Y) and the thickness of insulation material (x) is non-linear.

The replacement of the insulation materials (or) the life span of insulation materials varies from 15 to 30 years. Figure 20 shows the total embodied energy with additional insulation, operating energy and the energy savings achieved from the first year of operations phase of the building till the life span of 80 years of building A'. It shows that the energy savings due to installation of insulation is as much as 19% at the first year and reaches a maximum of 44% during the life span of 80 years.

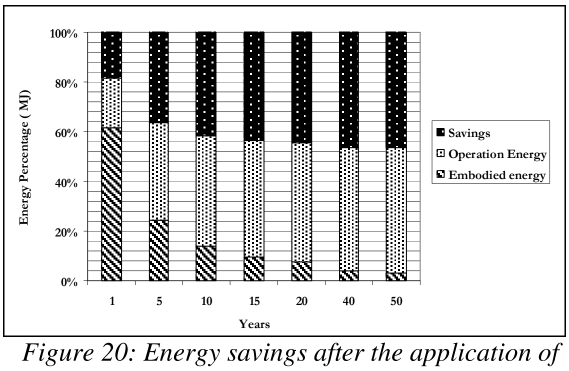

Figure 20: Energy savings after the application of insulation materials of different thickness.

CONCLUSIONS

The work and analysis done in this project to evaluate the role of insulation in energy consumption in commercial and office buildings, has lead to the following conclusions.

The analysis of the case studies of the building on their performance shows that, they do not comply with the ECBC, 2006 and ASHRAE 90.1.2004, standards. Building 'A' showed energy consumption to be 25% more in comparison with ASHRAE standards and 3.5% more than ECBC standards. Building 'B' showed 9.6% of energy consumption more than ECBC standards.

The results of the analysis done on the influence of different parameters of the buildings that affect the energy consumption, shows that, firstly, in respect with the application of insulation materials on the exterior walls, shows that, the relationship between the percentage of energy savings(y) and the resistance of insulation materials(x) is non-linear. It obeys a logarithmic function in respect with all climates in India. Beyond a certain value of (X) the resistance value of the insulation material does not yield proportional return in percentage of energy savings. The thickness of the insulation material also obeys a logarithmic function with the percentage of energy savings.

The role of thermal mass in energy consumption showed that the equivalent thermal resistance-capacity product has logarithmic relationship with the percentage of energy savings. It does not give proportional return to percentage of energy savings. There is a linear relationship between percentage of energy savings and overall U-value of the wall. Hence there is always increase in percentage of energy savings with the reduction in overall u-value.

The effect of window shades, movable interior or exterior do not have any considerable effect in the reduction, since the ratio of the glass area to the floor area in building 'A' is 10.6% and in building 'B' it is 12.97%, which is very less percentage to have any considerable effect in reduction in energy consumption.

The result on analysis on the parameters of glass type, the shading coefficient and visual light transmittance shows a linear relationship with the percentage of energy savings. Energy savings as much as 6 to 7% with higher values of these parameters can be achieved. Three parameters have to be considered simultaneously they are Shading Coefficient and Visual Light Transmittance and the u-value of the glass.

The results of analysis on the additional energy cost of insulation material to the initial embodied energy showed that the embodied energy of the insulation material is as much as only 6% of the total initial embodied energy of the building envelope components. The energy savings is specific with the insulation material with the highest embodied energy yield higher energy savings, which exhibit a logarithmic function.

The non-linear relationship between energy savings and thickness and resistance of insulation materials show that the insulation materials with thickness from 50 to 100 mm provides the maximum savings in all climates of India and increasing the thickness more than 100 mm does not yield proportional return under energy savings in the building. Also the resistance of the insulation materials within 2 to 4 m^2-K/W provides the maximum energy saving and beyond which there no proportional return in energy savings.
These energy savings due to the thickness and resistance values of the insulation material is more in Climates of New Delhi and Jodhpur, moderate in Chennai and least in Bangalore. In composite climate zones the effect of insulation is significant and yield 8 to 10% energy savings annually. In warm humid climate zones the effect of insulation is moderate and yield 5 to 7% energy savings annually. In Temperate climate zones the effect of insulation is 4 to 5% energy savings annually.

The results of analysis on the lifecycle energy cost, sum total of the energy and the operating energy, shows that in the first year the energy savings is as much as 19% initially and reaches a maximum of 47% during the life span of 50 years with a very negligible increase in the embodied energy of the insulation material.

This research paper throws open to further study on the effect of building envelope optimization to reduce chiller load in various climate zones in India. The building envelope design and the facade systems optimization to reduce the chiller load and energy consumption in buildings shall be studied in future to guide the simulation analyst, mechanical engineers and architects.

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