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Embodied Energies of Conventional and Alternate Building Materials in Residential Sector of Himachal Pradesh

Ridima Sharma, Sakshi Tanwar

***Abstract:** In the past years, the architects and entrepreneurs were more interested in the utilization of intelligent building features for achieving energy-efficient buildings that comply with stringent energy codes and national goals of reducing dangerous emissions, together with improving overall environment. The aim of this paper is to explore the influence of incorporating passive intelligence in buildings in terms of alternate sustainable building materials in residential sector, through the perspective of embodied energies of building materials and user comfort with an emphasis on thermal gains and losses. Result shows a considerable decrease of in a shift from conventional building materials towards alternate materials. Considerable change is also visible in the resultant comfort levels.*

***Keywords:** Embodied Energy, Building Materials, Monthly degree days, Passive solar gains, residential buildings*

I. INTRODUCTION

Energy crisis was first realized in the year 1973 and then people started rethinking about energy consumption pattern. About 50% of world carbon emission is due to residential sector and 25% of the total energy consumed in the building sector accounts for the residential sector which depends upon day to day life and occupancy pattern. Thus to reduce the green house emission and conservation of energy becomes more important. (B.V Venkatarama Reddy, February 2003,) It is estimated that by year 2020 the urban population will increase to 40% of the total population which will result in manifold increase in energy demand. In India, 24% of primary energy and 30% of electrical energy is consumed in building sector. (Deepak Bansal, 2013)With growing energy demand, increased production has viably increased the consumption of energy in the building. The total life cycle energy of a building can be calculated as a sum total of embodied energy and operational energy together i.e. processes of production, on-site construction, and final demolition and disposal; and energy consumed in heating and cooling, lighting and operating appliances for maintaining the inside environment. (Manish Kumar Dixit ∗, 2010) Building intelligence is not about using building automation systems but designing a building by using passive design features which further are incorporated with active automations to enhance its intelligence. Active design features accounting for operational energy consumption such as lighting, HVAC etc. have shown large impacts on energy consumptions during building operation. About 20% of the energy consumed in a building is embodied energy (EE) and the rest 80% is operational energy (OE). These energies can be calculated in terms of thermal comfort taking the occupancy patterns into account through simulations.

The embodied energy (EE) of a building is therefore the total energy required to construct it - that is to procure the raw materials, process and manufacture them as necessary, transport them to site and put them together. It is the combination of Production Energy (PE) and Transportation Energy (TE).

In green building the main focus is on the usage of Construction wastes, materials available locally to reduce the transportation cost and the usage of materials having less embodied energy. With the effective utilization of water, rain water harvesting, solar, wind, landscaping and orientation of buildings to minimize the usages of energy in buildings (D.B.Nandy, 2010). A considerable change in EE can be witnessed using the alternate building materials which further can lead to an alteration in the micro environment or the indoor thermal comforts. These alterations can cause a considerable change in the operational energy of the area. Thus Building materials are directly related to both construction and operational phase energy consumption. An effect is seen both in terms of embodied energies and operational energy making the study of indoor thermal environment important. Building material and technology selection should satisfy the user need and development, which in any way should not harm the environment and society.

In this paper the effect of construction materials in the form of embodied energy and thermal comfort has been studied.

II. METHODOLOGY

A study is conducted for EE and Thermal comfort in two residential units and the effect of alternate building materials is analyzed on the same. Embodied Energy calculations are taken manually keeping in view the production energy and transportation energy accounting for the same.

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* Correspondence Author
Ar Ridima Sharma*, Research Scholar, Department of Architecture NIT Hamirpur HP, India. Email: ridima4@gmail.com
Ar Sakshi Tanwar, HP Public works Department, Himachal Pradesh India. Email: sakshitanwar.nith@gmail.com

Initially total EE is calculated for the building materials used in both the case studies (Fig.1 & fig.2) with present conventional building materials(Base model) along with alternate models (Experimental Model) using alternate sustainable building material.. Ecotect simulations are done for Passive heat gain breakdowns and Monthly degree days for both the models. Comparisons are then drawn for the change in EE and the respective influence in the thermal comfort parameters for both the models.

Similar study is conducted for the second case (case study 2) which validates the above analysis to study both the EE of base model and experimental model of the second residential unit keeping all the other attributes, climate etc. similar to the main object of study.

III. CASE STUDY I

The selected base model is a duplex residential unit, situated at 31°41'07.9"N 76°31'28.7"E with an altitude of 785m from the mean sea level at Hamirpur. The climate is not a typical "Hilly & Chilly", but comparatively hotter as it is closer to the plains. The temperature usually remains between 3°C and 39°C. Maximum temperature can sometimes reach up to 450C. The building unit is a residential unit with an occupancy of 5 adults and a kid. Building includes one drawing room, one living & dining area, two bedrooms, three toilets, kitchen, puja room & store on the ground floor and three bedrooms &two toilets on the first floor. (Fig. 1 floor plans). The building materials specifications which are used for the calculation of embodied energy are given in table no 1.

Table 1: Material Specifications

Components	Material	
	Base model	**Experimental model**
Walls	Burnt clay brick	Soil cement block
Binding Materi	Cement mortar	Cement mortar
Reinforcemen	Steel	Steel
Wall tile	Clay tile	Clay tile
Wall Finish (Paints)	Emulsion	White wash
Floor Finish	Vinyl Flooring	Terrazzo Flooring
Roofing Mater	RCC Slab	Filler Slab

A. Embodied Energy of Building Materials

The total embodied energy considered for the analysis include both the production energy used in the manufacturing of the building materials which was sited in average from previous researches undertaken in the area (Ashok Kumar, 2012) (P S Chani, 2003) (Maïni, 2008) (B.V Venkatarama Reddy, February 2003,) (Deshmukh Rohit and More Ashok, April 2014,) (Jayasinghe, December 2011.) (Nitin Tanwar, September 2005) (Krishna A. Joshi) and the transportation energy involved in the transfer of respective materials from the production site to the construction site.

Table 2: Embodied energy: Base model

Base Model					
Material	**Quantity**	**Units**	**Transported from**	**EE (Mj/unit)**	**EE(Mj)**
Brick	51038.22	No,	Amritsar, Punjab	4.318	220383.03
OPC cemen	14217	Kg	Barmana	5.78	82174.26
Sand	36.86	Cum	Beas river	22.64	834.51
Aggregate	16.83	Cum	Pungh Khad	240.8	4052.66
Steel	3632.2	Kg	Mandi Govindgarh, Punjab	35.815	130087.24
Wall tiles clay	96.65	Sq. m	Galipur Haryana	103.04	9958.81
Vinyl floors	268.18	Sq. m	Galipur Haryana	67.643	18140.5
Emulsion paints	1272.01	Sq. m	Delhi	23.25	29574.419
Material	Quantity	Units	Transported from	EE (Mj/unit)	EE(Mj)
Rcc slab	316.3	Sq. m	In situ casting		238062.96
Total					733268.4

Figure 1: Floor Plans

Thus total embodied energy (table no 2) of any material is a sum total of production energy and transportation energy (EE = PE + TE). Using the conventional materials a total energy utilization of 733.26GJ is observed (Table no.2).

B. Experimental Model

Considering the similar attributes for planning and occupancy patterns as the base model a few sustainable alternative materials (table no 1) were introduced in the experimental model to take into account the embodied energy behavior (table no 3) with different building materials.

Table 3: Embodied energy: Experimental Model

Base Model					
Material	**Quantity**	**Units**	**Transported from**	**EE (Mj/unit)**	**EE(Mj)**
Soil Cement Block	28051.58	No,	In situ casting	3.8	107539.4
OPC cement	14217	Kg	Barmana	5.78	82174.26
Sand	36.86	Cum	Beas river	22.64	834.51
Aggregate	16.83	Cum	PunghKhad	240.8	4052.66
Steel	3632.2	Kg	Mandi Govindgarh, Punjab	35.815	130087.2
Wall tiles clay	96.65	Sq. m	Galipur Haryana	103.04	9958.81
Terrazzo flooring	268.18	Sq.m	Galipur Haryana	88.92	23846.56
White wash	1272.01	Sq.m	Parwanoo Himachal Pradesh	0.5	636.01
Filler slab	316.3	Sq.m	In situ casting		90649.88
Total(Experimental model)					449779
Total(Base model)					733268
Decrease					283489 = 38.66 %

Constituent materials of components such as filler slab & soil cement block were considered broken for analysis of EE using the alternatives in the building materials in the base model an embodied energy of 449.78GJ is observed (Table no 3).

C. Simulations

Ecotect simulations were also conducted for the alternate study in both the materialistic options to look into the comfort level of the residents focusing on thermal passive gain breakdowns through different mediums and Monthly degree days experienced by the different spaces (zones) throughout the year.

Passive Solar Gains

The passive gains breakdown graph shows thermal gains and losses occurring through various heat transfer mechanisms such as conduction, sol-air, direct solar gains, ventilation, internal and internal gains and losses and are indicated by different colors. Fabric is very strong factor for passive losses and gains. As they are highly effected by outer fabric of any built mass. Sol-Air and solar does not affect the passive losses and gains to a larger extent. Few percentage of difference in gains are normally seen showing that sol-air and solar gains does not affect passive gain strongly.

Ventilation is another strong factor for passive losses and gains. But its affect is negligible in present case. Internal losses does not affect the passive losses. But it affects in gains. Inter zonal interactions are among the strong factors for passive gain and loss. Inter-zonal losses have very high value due to compact planning of structure.

Base model along with the experimental model were simulated for the total thermal gains and loses the breakdown and compared. (Table no 4).

Table 4: Thermal Gains breakdown (Case Study 1)

Mechanisms	Comparison of Base model & experimental model	
	Decrease in losses (%age)	**Decrease in Gains (%age)**
Fabric	Increase of 3.36%	Increase of 2.26%
Sol-air	0.00%	Increase of 80.34%
Solar	0.00%	27.55%
Ventilation	24.69%	20.83%
Internal	0.00%	23.91%
Inter-zonal	17.54%	25.00%

Monthly Degree Days

To get a sense for the heating and cooling requirements for your building site, a comfortable temperature range needs to be set. This range, often referred to as the "comfort zone," can then be compared to the building site's actual temperatures over time. When the site's temperature is outside of the comfort zone, it is measured in heating or cooling "degree days." The number of degree days is calculated as the (no of days for which the average temp is outside the comfort zone) difference between average temp and the comfort zone limit. Warmer days which require cooling are referred as cooling degree days and cooler days which require heating are heating degree days. Simulation results for base model along with the experimental model when simulated for the monthly degree days. (Table no 5).

Table 5: Monthly degree days: Case Study 1.

Monthly Degree days: All visible thermal zones.		
Comparison EM to BM		
Month	**Growth in losses (%age)**	**Growth in gains (%age)**
Jan	36.65%	0.00%
Feb	27.14%	10.69%
Mar	31.34%	33.13%
Apr	36.51%	40.83%
May	37.23%	39.37%
Jun	36.96%	38.36%
Jul	36.40%	36.90%
Aug	36.91%	35.06%
Sep	37.37%	34.07%
Oct	37.37%	35.30%
Nov	37.35%	34.84%
Dec	29.58%	24.56%
Total	34.42%	35.81%

D. Results

The total embodied energy depicts a total decrease of around 38% in the EE of experimental model, with the alternate building materials as compared to the base model built as per conventional building materials.

In terms of passive gains breakdown a decrease in heat losses is seen in mechanisms such as solar air, solar radiations, and ventilation, internal and inter zonal interactions along with an increase in losses through fabrics. In case of heat gains a decrease is seen in mechanisms such as solar radiations, ventilation, internal and inter zonal interactions along with an increase in gains through fabrics and solar air interactions. Thus considering both the cases the materials used in the experimental model, the changes in heat losses and gains counteract on each other creating a better microclimate.

Analyzing monthly degree days through a yearly comparison we can observe a total increase of 34.42% and 35.81% in the total thermal losses and gains in the experimental model as compared to the base model throughout the year. It is seen that there is a considerable increase in the losses in the winter (nov-feb), which increases the heating load. But on the same time the amount of overall increases in gains and losses counteract each other and lead to a pleasant indoor environment throughout the year decreasing the cooling loads.

IV. CASE STUDY 2 (VALIDATION)

Considering an alternate second case study with similar location at 31°42'10.9"N longitude and 76°29'14.6"E latitude along with the similar climatic and materialistic attributes. This is a three storied multi dwelling residential building unit with an occupancy of five.fig.2 (Floor Plans) An alternate base model is considered as per the earlier criteria with same climatic, planning and occupancy, material transportation and energy behavior parameter but different building materials. In the Experimental model conventional materials of the base model (present scenario) were replaced by alternate sustainable building materials for the calculation of embodied energies. (Table no 6).

Table 6: Embodied Energy: BM & EM (Case Study 2)

Base Model				Experimental model		
Material	Quantity	Units	EE (MJ)	Material	Quantity	EE (MJ)
Brick	56115.08	No	242304.92	Soil cement blk.	25867.89	99167.99
OPC cement	20596.67	Kg	119048.78	OPC cement	20596.67	119048.78
Sand	214.42	Cum	4854.25	Sand	214.42	4854.25
Aggregate	48.53	Cum	11685.76	Aggregate	48.53	11685.76
Steel	9018.9	Kg	323011.90	Steel	9018.9	323011.91
Wall tiles clay	81.9	Sqm	8438.976	Clay wall tiles	81.9	8438.97
Vinyl floors	324.451725	Sqm	21946.88	Terrazzo flooring	324.46	28850.25
Emulsion paints	1225.9935	Sqm	28504.34	White wash	1225.99	612.99
RCC slab	412.5357167	Sqm	262592.02	Filler slab	412.54	118390.18
Total			1022387.84	Total		714061.07
Decrease in embodied energy from base model to experimental model						308326.77
Percentage decrease in alternate study					30.15%=0.09%/sqm	
Percentage decrease in main study					38.6%=0.12%/sqm	

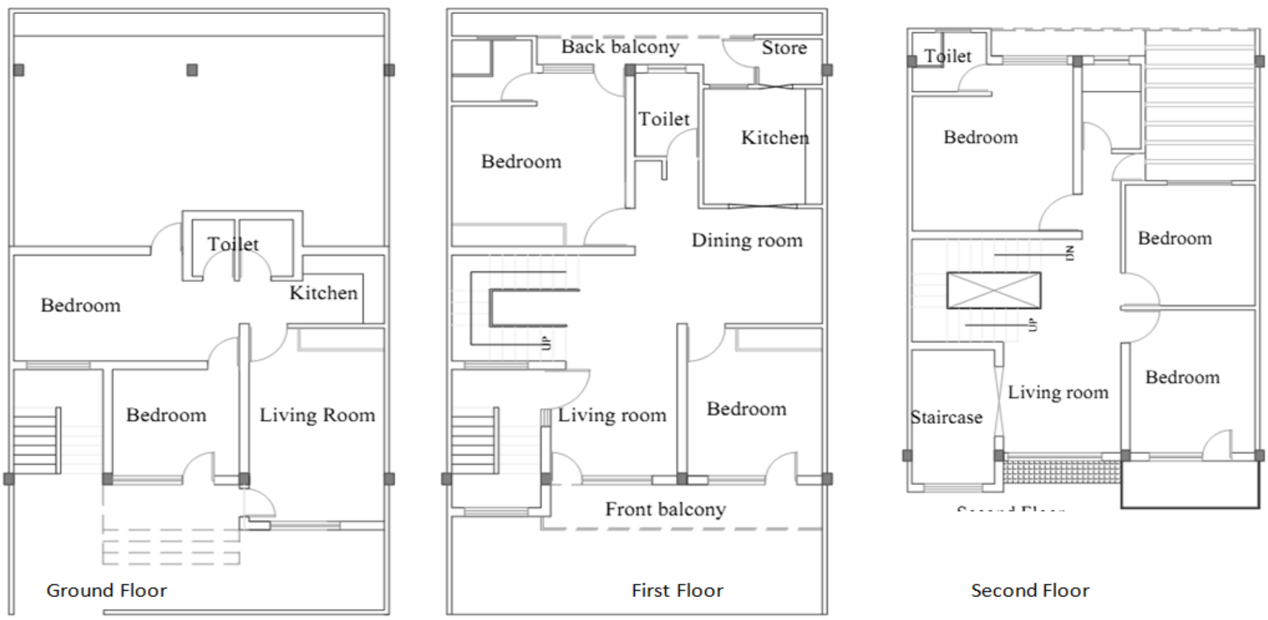

Figure 2: Floor Plans (Alternate Study)

A total decrease of around 30% i.e. 0.09% per sq. m is seen in the embodied energies of experimental model as compared to the base model built in the alternate study.

V. SIMULATION RESULTS

Passive Solar Gains

A decrease in heat losses is seen in mechanisms such as ventilation along with an increase in losses through fabrics and intern zonal interactions. In case of heat gains an increase is seen in mechanisms such as fabric, direct solar gains, solar radiations, ventilation, internal and inter zonal interactions along with a decrease in gains through ventilations. (Table no 7).

Thus considering both the cases the materials used in the experimental model the changes in heat losses and gains counteract on each other creating a better microclimate in both the main study and the alternate study.

Table 7: Thermal gains breakdown: (Case Study 2)

Mechanisms	Comparison of base model & Experimental model	
	Decrease in Losses%	Decrease in Gains %
Fabric	Increase of 134%	Increase of 61%
Sol-air	0	Increase of 85%
Solar	0	Increase of 10%
Ventilation	28	96
Internal	0	Increase of 36%
Inter-zonal	Increase of 154	Increase of 10%

Monthly Degree Days

Simulations were again done for monthly degree days throughout the year both for the base model and experimental model. (Table no 08). Considering monthly degree day's analysis for both the base model and experimental model in experimental model experimental model as compared to the base model throughout the year. It is seen that there is a considerable increase in the losses in the winter (nov-feb), which increases the heating load. But on the same time the amount of overall increases in gains and losses counteract each other and lead to a pleasant indoor environment throughout the year decreasing the cooling loads in both the case studies.(Table no.9).

Table 8: Monthly Degree Days: case study 2

Monthly Degree Days - All Visible Thermal Zones		
Comparison BM to EM		
Month	Growth in losses (%)	Growth in gains (%)
Jan	40%	0%
Feb	Fall of 21%	264%
Mar	Fall of 10%	264%
Apr	01%	211%
May	47%	129%
Jun	50%	96%
Jul	50%	100%
Aug	48%	135%
Sep	49%	198%
Oct	48%	214%
Nov	47%	192%
Dec	Fall of 35%	279%
Total	19%	15.3%

Table 9: Comparison of degree-days in main study and alternate study

Comparison of monthly degree days throughout the year		
	Case Study 1	Case Study 2
%age Increase in losses	34.42%	19%
%age Increase in Gains	35.85%	15.3%

VI. CONCLUSION

Huge quantity of energy is consumed by the building sector in a highly inefficient manner. The prevailing building technologies, for construction tend to be highly energy intensive. There exists potential for adopting alternative building materials, which can contribute to significant savings in energy. This paper explores the use of alternate building materials with low embodied energy contents to have an overview of the total embodied energy and thermal comfort in residential buildings. The analysis has been performed taking a case of residential buildings. The use of sustainable alternate building materials was the area of main focus. The study reveals significant energy savings are possible using energy efficient building materials in terms of embodied energy. A decrees of 0.09%-0.12% is seen per square meter floor area in both the cases when the conventional building materials were replaced by alternate ones. The change in the thermal gains and losses through different mediums also add to the comfort level in the interiors when one moves from the conventional materials to the alternate ones, which decreases the heating and cooling loads. Thus when sustainability is a driving force, the understanding of the embodied energy of materials used in architecture will lead to sustainable decisions rather than decisions based on fashion and profit.

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AUTHORS PROFILE

Ar Ridima Sharma is a research Scholar pursuing her PhD in Architecture from Department of Architecture, National Institute of Technology Hamirpur have received a master's degree in sustainable architecture from and have received a master's degree in sustainable architecture from the same institute. Her current research focuses on sustainability in vernacular architecture of hill areas. Previous published works include papers on areas like sustainable architecture, land reforms, urbanization patterns and hill architecture. She has also published book chapter on the advent of land reforms in the state of Himachal Pradesh

Ar Sakshi Tanwar, presently working as Head drafts man at HPPWD have received a master's degree in sustainable architecture from have received a master's degree in sustainable architecture from NIT Hamirpur. Majority of her research focuses on conservation of vernacular architecture. Previous published works include areas like sustainable architecture, land reforms, and urbanization patterns. She has also co Authored book chapter on the advent of land reforms in the state of Himachal Pradesh