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EMBODIED ENERGY CALCULATION AND ASSESSMENT OF BUILDING PERFORMANCE

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Abstract: In this rapid growing world the misuse of available resources is causing global warming due to ozone layer depletion which is the outcome of greenhouse gases emitted. In present scenario construction industry is the biggest contributor to energy consumption. In this paper it is discussed how different materials have different embodied energy and impact in different energy usage. For this study,two residential buildings are takenfor calculation of total energy and then simulation is performed with present and alternative building materials.

1. Introduction

In last 2 decades energyconsumption is grown by approx. 50%,thus,carbon emission is increased by 45%approx. of total energy consumption at global level.Due to population growth in residential sector, the energy consumption at national, state and regional level has increasedthe demand of building services for achieving comfort levels. Carbon emissions are associated with energy consumption and chemical processes during lifecycle (the extraction, manufacture, transportation, assembly, replacement and deconstruction) of building materials or products are "embodied energy".(Manish Dixit, 2010) While the energy associated with heating, cooling,lighting and operating appliances for maintaining the inside environmentis "operational energy".Embodied energy and operating energy together gives the total life cycle energy of a building. (Ashok Kumar, 2012)(B.V.V. Reddy, 2003)

2. Methodology

This paper is divided in two major parts. First one is calculation of embodied energy and second one is analysis of building performance.

2.1 Embodied energy

For a building, calculation of total embodied energy can be divided in two parts, which are manufacturing and installation.

Manufacturing energy (ME)is the energy used for manufacturingproduct/material, whether in industries or on-site. The ME also includes the energy used in transportation of products to desired construction site where the manufacturing is going to be done. Manufacturing energy can be broadly categories in 3 parts-energy used for extraction of material, energy used in processing of extracted material, and energy used while prefabricating materials/products. (Manish Dixit, 2010)

$$ME = MaterialExtractionenergy + Processingenergy + Prefabricationenergy$$

Total energy required for installation of the product on construction site is installation energy (IE).

$$IE = TE + AE$$

Where TE is transportation energy which is the energy used for importing materials from manufacturing sites to construction site and AE is energy used for assembling material on construction site.

$$\text{Total emboided energy} = ME + IE$$

Based on market survey, literature studies(Institute, 2010)and previous researches, production energy of various materials are identified and transportation energy is also calculated. Table 1showsthetotal embodied energy of different material used in building.(Ashok Kumar, 2012)(B.V.V. Reddy, 2003)(Satprem, 2008)(Deepak Bansal, 2014)(Gumaste, 2008)(PS Chani, 2003)

S.no.	Materials	Unit	Production Energy of materials (MJ)	Transportation Energy of materials (MJ)	Total Embodied Energy of materials (MJ)
1	Brick(203x115x75)	No.	4.18	0.1346	4.3182
2	Aggregate 6 - 25mm	Kg	0.1011	0.0064	0.10
3	Aggregate 25-40mm	Kg	0.1011	0.0064	0.10
4	Aggregate 6mm	Kg	0.1011	0.0064	0.10
5	Concrete (1:1.5:3)	Kg	1.13	0.0000	1.1250
6	Tile clay	Kg	8.15	0.1603	8.3103
7	Tile ceramic	Kg	7.25	0.1603	7.4103
8	Vinyl flooring	Kg	65.64	2.0033	67.6433
9	Timber	Kg	6.25	00.00	6.2500
10	Ply wood	Kg	15.00	00.00	15.0000
11	Marble	Kg	2.00	0.2585	2.2585
12	White wash	Kg	0.50	00.00	0.5000
13	Cement	Kg	5.75	0.0296	5.7796
14	Steel	Kg	35.78	0.0389	35.8146
15	Steel plate	Kg	33.63	0.0389	33.6639
16	Stainless steel	Kg	62.80	0.0389	62.8389
17	Galvanized steel (steel/wire)	Kg	50.80	0.0389	50.8389
18	Glass	Kg	19.48	0.1795	19.6628
19	Sand natural	Kg	0.00	0.0112	0.0161
20	Sand crusher	Kg	0.01	0.0112	0.0240
21	Iron (general)	Kg	25.00	0.0389	25.0389
22	Copper	Kg	84.67	0.0050	84.6717
23	Aluminum	Kg	214.72	0.1662	214.8862
24	Steel pipe	Kg	19.80	0.0389	19.8389
25	PVC (general)	Kg	89.80	0.0457	89.8457
26	GI pipe	Kg	49.97	0.0389	50.0089

Table 1 - Embodied energy of different building material

In a building Materials listed in table 1, is considered as base case while the best suitable alternative material with low embodied energy for building materials is considered as optional case.

Material	Alliterative materials	
	Base case	Optional case
Hollow concrete block	Brick	Soil cement block
Ceramic wall tiles	Wall tile	Clay wall tiles
Flooring	Vinyl flooring	Terrazzo flooring
Paints	Emulsion Paints	White wash
Roofing	RCC Slab	Filler slab

Table 2 -current used materials and alternative materials

2.2. Building performances

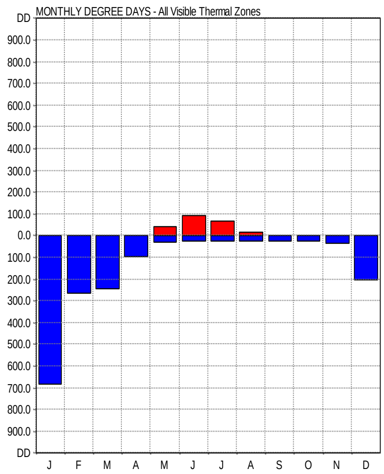
Performances of buildingcan be assessed in 3 parts- Daylight level, monthly degree day and Passive gains.Energy used in maintenance of building is the total energy consumed by the building in operational phase.

2.2.1 Tool for analyzingBuilding performances:-

Autodesk Ecotect analysis 2011 student version is used as a tool for analysisof thermal comfort and energy requirement in building. Ecotectis a product of Autodesk India for basic energy calculation of pre-occupied building and post occupied building for energy load calculation. This software is a useful tool for understanding various mysterious factors which affect the planning decision in buildings.

Day light level is the level of lux at working plane which is 300 lux for residential building.(National Building Code of India , 2005)For simulation two case studies are done at Hamirpur, Himachal Pradesh, India where on an average sunrisesaround 06:18 hours and setsaround 18:29 hours.

The estimationof annual heating and cooling load of building is called Monthly degree days. Temperaturefrom 22.0^0C to 29.10^0C is considered for achieving comfort level.



Graph 1 Monthly degree days for Hamirpur

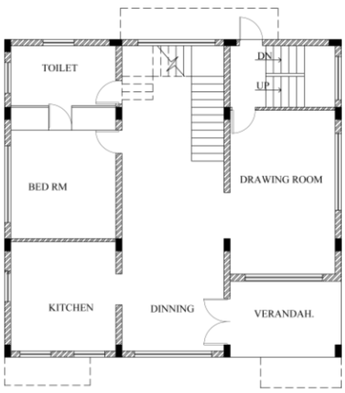
Graph 1 represents the monthly heating and cooling degree days (DD) .In month of January heating DD are very high(682 DD) while from May to October heating DD are very low (22DD to 33.4DD). Cooling DD are required only from May to August where it reaches to its peak in June (93.4DD).

Passive Gain Breakdown gives the annual heat gain and heat loss because of six different factors- fabric, sol-air, solar, ventilation, internal and inter-zonal.

3. Case study

Two studies of residential building are doneat Hamirpur, Himachal Pradesh.Case1 is of duplex house for single household and case2 is of G+ 3 storied building for four different households.

Case 1 is the house of Mrs. RenukaChandelat housing board colony, Salasi, Hamirpur (H.P.). It is a G+1 detached type of house with 3.2 m floor to floor height on total plot areaof 240 m^2 (constructed in 2009-12) (fig 1,2)



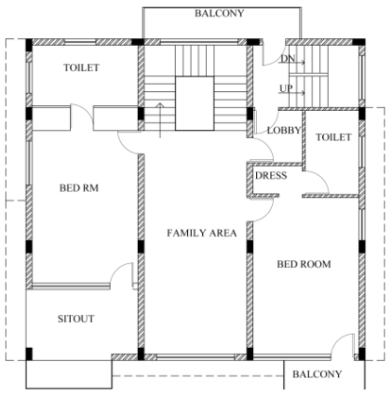


Fig 1 Ground Floor PlanFig 2 First Floor Plan

Case 2 is a residential building of Mr. VikasDhiman atJhaniyara, Hamirpur HP. It is a G+3 structure catering four different house hold with different living standards.(Constructed in 2013-14) (fig3, 4,5and6)

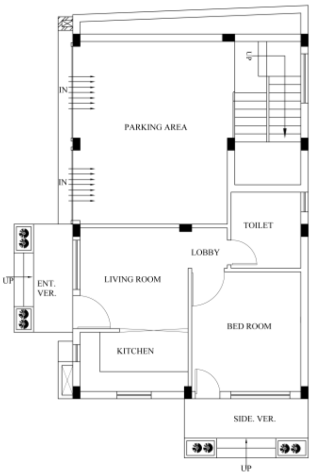


Fig. 3 Ground Floor Plan

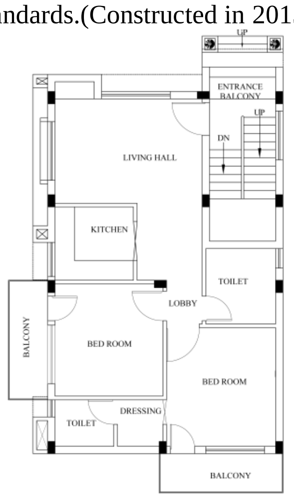


Fig. 4 First Floor Plan

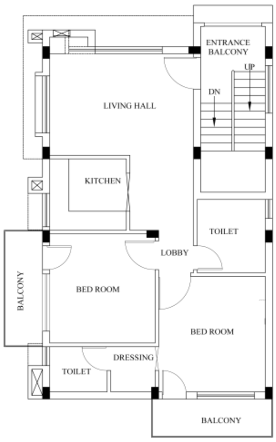


Fig. 5 Second Floor Plan

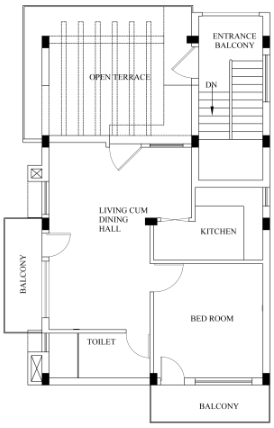


Fig. 6 Third Floor Plan

4. Calculation of embodied energy and building performances in base cases

4.1. Case 1

Total Embodied energy in base case of case 1 is listed in table 3.

Material	Quantity	Units	Embodied Energy (MJ)
Brick	38522.22	NO	166338.95
OPC Cement	16473.58	Kg	95217.31
Sand	34.441	M^3	779.74
Aggregate	19.47	M^3	4688.37
Steel	3820.9	Kg	136845.53
Wall Tiles Clay	50.732	M^2	5227.42
Vinyl Floors	253.77	M^2	17165.76
Emulsion Paints	8677.405	M^2	201749.66
RCC Slab	39	M^3	223712.91
Total			851725.69

Table 3 - Embodied energy in Base Case of case 1

Ecotect simulations areperformed for day lighting calculation for thebuilding; result shows that almost 100%of the area on all the floors have day lighting level above 100 lux. Ground floor and first floor have lux level 83% and 84% respectively above 300 lux. (Table 7)

In case 1, required energy for heating in month of January is 13509Wh as heating degree days are very high. While from May to October energy required for heating varies from 444Wh to 452Wh as heating DD is very low. The required energy for cooling in month of June is 10303Wh.(Table 8)

Highest passive energy losses are through fabric which is increased by 69.50% and minimumpassive energy losses are through sol-air, solar, and internal which are 0.0%. Highestpassive energy gains are through internal increased by 52.00% and minimum passive energygainsare through inter-zonal by 3.7%. (Table -9)

4.2. Case 2

Total Embodied energy in base case of case 2 is listedin table 4.

Material	Quantity	Units	Embodied Energy (MJ)
Brick	37379.28	NO	161403.72
OPC cement	25756.39	Kg	148871.94
Sand	48.07	M^3	1088.34
Aggregate	35.40	M^3	7.08
Steel	4553.78	Kg	163093.80
Wall tiles clay	36.222	M^2	3732.31
Vinyl floors	290.53	M^2	19652.82
Emulsion paints	2041.30	M^2	47460.36
RCC slab	33.23	M^3	213910.45
Total			759220.86

Table 4- Embodied energy in Base Case of case 2

Ecotect simulations areperformed for day lighting calculation for thebuilding; result shows that almost 100% of the area on all the floors have day lighting level above 100 lux.Ground floor, first floor, second floor and third floor have lux level 90, 71, 83 and 89% respectively above 300 lux.(Table 10)

In case 2 required energy for heating in month of January is38585Wh as heating degree days are very high. While from May to November energy for heating varies from 15471Wh to 21675Wh as heating DD is very low. The required energy for cooling in month of June is 2104Wh.(Table 11)

Highest passive energy losses are through inter-zonal increased by 84.90% and minimumpassive energy losses through sol-air, solar, and internal are 0.0%.Highestpassive energy gains are through internal which is increased by 35.00% and minimum passive energygains through inter-zonal which is 0.0%. (Table -12)

5. Calculation of embodied energy and building performances in optional cases

After finding out the best suitable materials for low embodied energy the same simulations has been done with new models as per described in methodology.

5.1. Case 1

Total Embodied energy in optional case of case 2 is listedin table 5.

Material	Quantity	Units	Embodied Energy (MJ)
Soil cement block	25867.89	No	99167.98
OPC cement	20596.67	Kg	119048.77
Sand	214.41	M^3	4854.24
Aggregate	48.52	M^3	11685.75
Steel	9018.9	Kg	323011.90
Clay wall tiles	81.9	M^2	8438.97
Terrazzo flooring	324.45	M^2	28850.24
White wash	1225.99	M^2	612.99
Filler slab	412.53	M^2	118390.17
Total			714061.07

Table 5- Embodied energy in optional case ofcase 1

Ecotect simulations areperformed for day lighting calculation for thebuilding, result shows that almost 100% of the area on all the floors have day lighting level above 100 lux. Ground floor and first floor have lux level 83.12 and 85.04% respectively above 300 lux. (Table 7)

In case 1 required energy for heating in month of January is 17453Wh as heating degree days are very high. While from May to October energy required for heating varies from 583Wh to 592Wh as heating DDare very low. The required energy for cooling in month of June and July is 10873Wh and 10281Wh respectively. (Table 8)

Highest passive energy losses are through fabric which is increased by 59.50% and minimumpassive energy losses are through sol-air, solar, and internal are 0.0%. Highestpassive energy gains are through internal which isincreased by 48.80% and minimum passive energygainsare through inter-zonal which is 5.7%. (Table -9)

5.2. Case2

Total Embodied energy in optional case of case 2 is listed in table 6.

Material	Quantity	Units	Embodied Energy (MJ)
Soil cement block	16372.33	NO	62765.51
OPC cement	25756.39	Kg	148871.94
Sand	48.07	M^3	1088.34
Aggregate	35.40	M^3	7.08
Steel	4553.78	Kg	163093.80
Clay wall tiles	36.22	M^2	3732.31
Terrazzo flooring	290.53	M^2	25834.59
White wash	2041.30	M^2	1020.65
Filler slab	33.23	M^3	89132.43
Total			495546.69

Table 6- Embodied energy in Optional Case of case 2

Ecotect simulations areperformed for day lighting calculation for thebuilding, result shows that almost 100% of the area on all the floors have day lighting level above 100 lux.Ground floor, first floor, second floor and third floor have lux level 94.28, 76.09, 87.21 87.21 and 92.59% respectively above 300 lux.(Table 10)

In case 2 required energy for heating in month of January is46901Wh as heating degree days are very high. While from May to October energy required for heating varies from 13779Wh to 20559Wh as heating DD are very low. The required energy for cooling in month of June is 3974Wh.(Table 11)

Highest passive energy losses are through inter-zonal increased by 81.40% and minimumpassive energy losses through sol-air, solar, and internal are 0.0%.Highestpassive energy gains are through internal which are increased by 29.80% and minimum passive energygains through inter-zonal which is 0.0%. (Table -12)

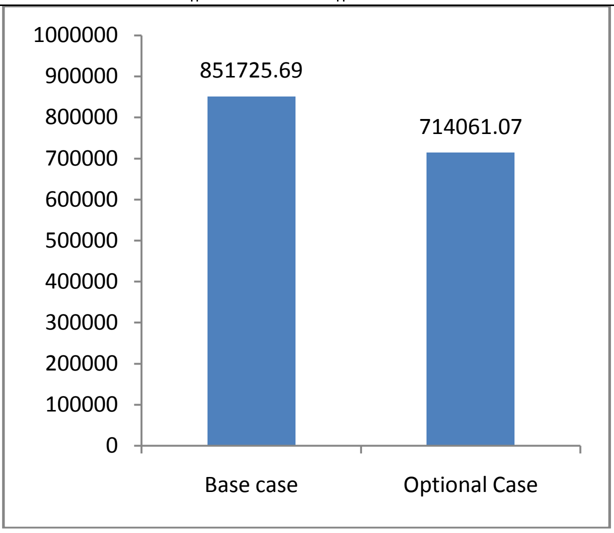
6. Comparison between base case and optional case

The comparative analysis is done between base case and optional case of case 1 and case 2 based on embodied energy, daylight level; monthly degree day and passive gain break down.

6.1. Case 1

6.1.1. Comparison of Embodied Energy

Embodied energy in optional case is 16.12% less then base case. It shows that alternative materials used are more energy efficient.



Graph 2 Embodied Energy in case 1

6.1.2. Comparison of daylight level

Contour Band	Case	Lux level (%)	
		Ground floor	First floor
0-100	Base case	100	100
	Optional case	100	100
100-200	Base case	85.2	86.08
	Optional case	85.84	86
200-300	Base case	83.04	84.4
	Optional case	83.12	83.92

Table 7- Comparison of Daylight Level in case 1

The lux level in building increases or decreases due to difference in color of material and their reflection. As we can see Contour Band of 100-200 is same in both cases at both floors. Contour Band of 100-200 get increased by 0.5% at ground floor and lux level decreases by 0.08% and at first floor and Contour Band 200-300 is increased by 0.08% in ground floor and lux level decreases by 0.48% at first floor.

6.1.3. Comparison of monthly degree days

	Base case		Optional Case		Base case – Optional case	
Month	Losses	Gains	Losses	Gains	Losses	Gains
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)
Jan	13509	0	17453	0	-29.20%	0%
Feb	2187	1825	3376	1601	-54.37%	12.27%
Mar	2006	2627	3109	2356	-54.99%	10.32%
Apr	467	5169	656	4792	-40.47%	7.29%
May	444	8148	583	8220	-31.31%	-0.88%
Jun	452	10343	592	10873	-30.97%	-5.12%
Jul	447	9890	588	10281	-31.54%	-3.95%
Aug	442	7086	580	6946	-31.22%	1.98%
Sep	451	5249	591	4813	-31.04%	8.31%
Oct	447	5516	586	5082	-31.10%	7.87%
Nov	445	5907	584	5593	-31.24%	5.32%
Dec	891	2843	1730	2542	-94.16%	10.59%

Table 8 - Comparison of Monthly Degree Days for case 1

The heat loss in January to December got increased by 29.2, 54.34, 54.99, 40.47, 31.31, 30.97, 31.54 31.22 31.04 31.1 31.24 and 94.16% respectively. Heat gain in month of February, March, April, August September October November December is decreased by 12.27, 10.32, 7.29, 1.98, 8.31, 7.87, 5.32 and 10.59% respectively. Heat gain in month of May Jun and July is increased by 0.88, 5.12 and 3.95% respectively. There is no heat gain in month of January.

6.1.4. Comparison of passive gain breakdown

	Base case		Optional case		Base case – Optional case	
Category	Losses	Gains	Losses	Gains	Losses	Gains
Fabric	69.50	15.50	59.50	17.00	14.39%	-9.68%
Sol-air	0.00	18.00	0.00	20.10	0%	-11.67%
Solar	0.00	4.80	0.00	5.70	0%	-18.75%
Ventilation	22.20	6.10	20.40	7.20	8.11%	-18.03%
Internal	0.00	52.00	0.00	48.80	0%	6.15%
Inter-zonal	8.30	3.70	20.10	1.40	-142.17%	62.16%

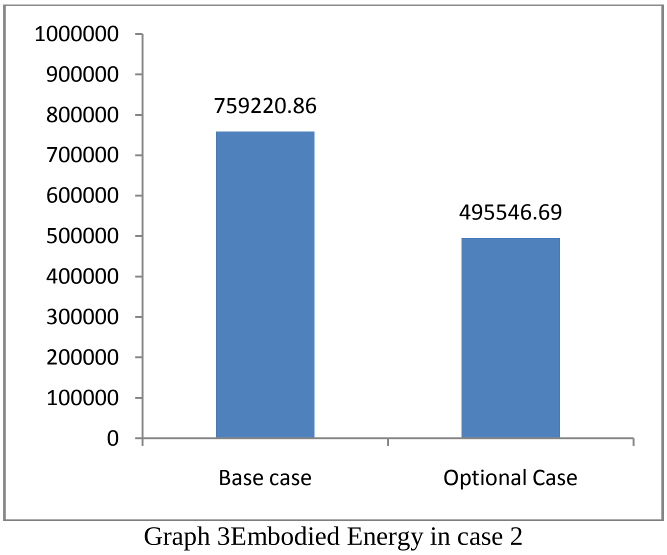
Table 9- Comparison of Passive Gain Breakdown in case 1

The heat loss in passive gain breakdown through fabric fall is 10% from base case to optional case. There is 14.39% increase inheat losses. The gain through fabric is increased by 1.5 % from base case to optional case. There is increase of 99.68% in heat gains. There is no heat loss in passive gain breakdown through sol-air from base case to optional case. The heat gain through sol-air is increased by 2.1% from base case to optional case. There is 11.67% increase in gains. There is no heat loss in passive gain breakdown through solar from base case to optional case. Heat gain through solar isincreased by 0.90% from base case to optional case. There is decrease of 18.75% in heat gain. The losses through ventilation is decreased by 1.80% from base case to optional case. There is decrease of 8.11 % in heat loss. The gain through ventilation is increased by 1.10% from base case to optional case. There is increase of 18.03% in heat lossthrough ventilation. there is no heat loss through internal from base case to optional case. Heat gain through internal is decrease by 3.20% from base case to optional case. There is decrease of 6.15% inheat gains. The losses through inter-zonal area are increased by 11.80 % from base case to optional case. There is increase of 142.17% in heat gain. Heat gains through inter-zonal area are decreased by 2.30% from base case to optional case. These is decrease of 62.16% from base case to optional case.

6.2. Case 2

6.2.1. Comparison of Embodied Energy

Embodied energy in optional case is 34.72% less then base case. It shows that alternative materials are more energy efficient.



Graph 3Embodied Energy in case 2

6.2.2. Comparison of daylight level

Contour Band	Case	Lux level (%)			
		Ground Floor	First Floor	Second Floor	Third Floor
0-100	Base case	100	100	100	100
	Optional case	100	100	100	100
100-200	Base case	97.3	88.85	94.95	98.31
	Optional case	97.98	89.9	95.61	96.63
200-300	Base case	90.2	71.62	83.11	89.19
	Optional case	94.28	76.09	87.21	92.59

Table 10- Comparison of Daylight Level in case 2

In a building,the lux level increases or decreases due to different color of material and their reflation. Contour Band of 100-200 is same in both cases at all floors. Contour Band of 100-200 is increased by 0.68, 1.05, 0.66 and 1.68% at ground floor, first floor second floor and third floor respectively and Contour Band 200-300 is increased by 4.08, 4.47, 4.1, and 3.4% in ground floor, first floor second floor and third floor respectively.

6.2.3. Comparison of monthly degree days

	Base case		Optional case		Base case – Optional case	
Month	Losses	Gains	Losses	Gains	Losses	Gains
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)
Jan	38585	0	46901	0	-21.55%	0
Feb	21332	15	22829	63	-7.02%	-320.0%
Mar	23045	41	24137	140	-4.74%	-241.46%
Apr	20180	177	19442	426	3.66%	-140.68%
May	17970	707	16552	1782	7.89%	-152.05%
Jun	15471	2104	13779	3974	10.94%	-88.88%
Jul	16487	1771	14638	3206	11.21%	-81.03%
Aug	19251	513	17622	822	8.46%	-60.23%
Sep	20012	161	18931	171	5.40%	-6.21%
Oct	21675	15	20559	92	5.15%	-513.33%
Nov	19574	51	18462	268	5.68%	-425.49%
Dec	23770	12	24323	58	-2.33%	-383.33%

Table 11- Comparison of Monthly Degree Days in case 2

The heat loss in January February march and December are increased by 21.55, 7.02, 4.74, and 2.33% respectively. The heat loss in April to November is decreased by 3.66, 7.89, 10.94, 11.21, 8.46, 5.4, 5.15, and5.68% respectively.A heat gain in month of February to December isdecreased by 320, 241.46, 140.68, 152.05, 88.88, 81.03, 60.23, 6.21, 513.33, 425.49 and 383.33% respectively. There is no heat gain in January.

6.2.4. Comparison of passive gain breakdown

	Base case		Optional case		Base case – Optional case	
Category	Losses	Gains	Losses	Gains	Losses	Gains
Fabric	13.60	18.40	17.40	21.00	-27.94%	-14.13%
Sol-air	0.00	14.30	0.00	21.50	0%	-50.35%
Solar	0.00	29.40	0.00	25.50	0%	13.27%
Ventilation	1.50	2.90	1.20	2.20	20.00%	24.14%
Internal	0.00	35.00	0.00	29.80	0%	14.86%
Inter-zonal	84.90	0.00	81.40	0.00	4.12%	0%

Table 12- Comparison of Passive Gain Breakdown in case 2

The heat loss in passive gain breakdown through fabric is increased by 3.8% from base case to optional case. There is increase of 27.94% in heat loss. The gain through fabricis increased by 2.6% from base case to optional case. There is increase of 14.13% in heat gain. There is no heat loss in passive gain breakdown through sol-air from base case to optional case. The heat gainthrough sol-airis increased by 7.2% from base case to optional case. There isincrease of 50.35% in heat gains. There is no heat loss in passive gain breakdown through solar from base case to optional case. Heat gain through solar is decreased by 3.9% from base case to optional case. There is decrease of 13.27% in solar gain. The losses through ventilation is decreased by 0.3% from base case to optional case. There is decrease of 20.00% in heat loss. The heat gain through ventilation is decreased by 0.7% from base case to optional case. There is decrease of 24.14% in heat loss through ventilation. There is no heatlossthrough internal from base case to optional case. Heat gain through internal is decreased by 5.2% from base case to optional case. There is decrease of 14.86% in heat gains. The heat loss through inter-zonal area is decrease by 3.5% from base case to optional case. There is decrease of 4.12% in heat gain. There is no heat gain through inter-zonal from base case to optional case.

7. Conclusion

With the help of simulations and analysis carried out we can conclude that in India, selection of building material for construction is generalized and there is lack of emphasis given on the embodied energy of building material. This study proves that material having low embodied energy should be selected for environmental benefits.

On the other hand alternative building material have different effects on building performances such as change in passive heat gain andchange in monthly degree days. This study also gives the clear idea that vernacular andlow embodied energy materials which has good thermal quality provides pleasant ambience to building. Here case 1 and case 2 has different style of planning as well as number of stories. The lux level in building is increased or decreased due to different color of material and their reflection factor.

The conclusion drawn from the studies conducted are:

1. Contemporary building materials such as Cement, Steel, Bricks and Glass are the major contributors to the total embodied energy of buildings.
2. Soil-cement block is one of the most energy efficient alternative materials for wall construction. Embodied energy of soil-cement block is half of the energy of burnt clay brick.
3. Vernacular materials has low embodied energy due to less transportation energy.
4. Low rise Buildings are more energy efficient than multi-storied buildings.
5. This paper also provides the useful data for selection of building material for energy efficient practices. In India and other developing nations this data will be beneficial for environmental friendly design.

8. Reference

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