Energy Conservation Building Code compliant material optimization of lightweight building envelope wall construction for different climate zones of India

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Abstract

India is key within the many global corporates around the world when it comes to development and revolution as one of the rapid economic growth is seen within India, which not only opens up a lot of opportunities in the building and construction field but also needs to set a balance for the mass construction. This paper suggests an integrated design solution involving the mass of construction materials to help reduce the dead loads on the structural frame of the building, releasing pressure off the beams, columns, and footing. This resolves into keeping a healthy balance of resource utilization and reducing any sort of material exploitation. This study incorporates the use of optimization techniques to obtain the best possible solution for various cases under consideration in five climate zones by minimizing the mass of the wall assembly while meeting the U-Value constraints specified by ECBC.

Keywords: dead weight, mass optimization, lightweight construction

I. INTRODUCTION

A. Urbanization

India is one of the fastest-growing economies in the world. Industrialization, commercialization, social benefits and services, employment opportunities, modernization and changes in the standard of living, rural-urban transformation, and spread of education are some of the reasons for massive urbanization across the country. With an increasing number of people, there is an evident increase in demand for employment around the country. Thus there is a dire need for infrastructure to support this growth. Increased population also increases demand in the residential sector. The construction industry contributes up to 8% of India's GDP. The commercial building stock is expected to increase five times in over ten years from now. There is a potential 70% of floor space that is yet to be constructed over a period until 2030 in India [1].

B. Resource Optimization

Throughout the life-cycle of a building, it can contribute significantly to emissions and waste generation as it consumes an enormous amount of material and energy resources to develop and sustain the built environment. This is why the construction industry is capable of making a noteworthy contribution to the objectives of sustainability. The current and anticipated pace of global urbanization makes it imperative for the process to be accountable in all three platforms of sustainability: environmental, social, and economic [10] .
Brundtland Commission's report of " Our Common Future" from 1987, outlines various sustainable development options including sustainable construction which underscores the idea of meeting the present-day needs of housing, infrastructure, etc., without having to compromise with the future requirements. The construction industry can walk the path of sustainable construction by reducing its ecological footprint and be more socially supporting, while also creatively responding to the high demand for built spaces.

Newer technology will inevitably replace the current trend of construction. But until then we must maximize the essence of the current building practices to make it more sustainable and approachable. The current resources are getting exhausted and therefore there is a need for resource optimization to support sustained infrastructural growth.

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II. LITERATURE REVIEW

It is impossible to stunt the growth of construction in India. The increasing population and the demand will continue to grow over the years increasing the landmass of construction. Old buildings get replaced with new ones. This will lead to construction waste across the country, defying the whole concept of sustainable construction or resource optimization. Yet we need to continue with the mass construction keeping in mind the impact and trying to reduce the construction wastage as much as possible. Using newer and better materials is one-way approach to the problem but better accessibility to such material probes an issue to many cities within the country. Hence a better use and balance of the currently available materials will be the most sound option in such scenarios. One such example for better material optimization and resource management is from a study by Kishore et al., in their paper, they have analyzed the current material library users across the country and have suggested the best possible mix of the wall composition that not only will be of constrained thickness but also confides within the u-value defined as per Energy Conservation Building Code (ECBC), India. This helps everyone to follow the basic norms of sustainability in terms of thermal heat barrier that should be maintained by the external wall without having to worry about using newer materials which demand a higher level of transportation, skilled professionals, or even increased costing [2].

Sustainable construction is defined as "the creation and responsible management of a healthy built environment based on resource efficiency and ecological principles".

The Organisation for Economic Co-operation and Development (OECD) is an international platform that works to "build better policies for better lives", a project that identifies majorly five objectives for sustainable buildings: Correlation with the environment including environmental assessment; resource efficiency; prevent pollution which includes indoor air quality and noise abatement; resource efficiency; energy efficiency which includes greenhouse gas emission control and finally integrated and systematic approaches including environmental management strategies [3].

A. Gap Identification:

The domain of the paper focuses on construction materials for non-load bearing structures. This paper takes references to code compliance for wall construction specific to India like the Energy Conservation Building Code, 2017 which applies to "buildings or building complexes that have a connected load of 100 kW or greater or a contract demand of 120 kVA or greater and are intended to be used for commercial purposes" [7]. A connected load of 100 kW indicates that the building in conversation is mostly a G+2 and G+3 or more commercial structure which is normally advised to be of load-bearing structural construction. To make full use of the FAR (Floor Area Ratio) it is inevitable to go higher, thus building up great structural pressure on the beams, columns, and footing. This paper aims to lessen the dead weight of the building structure through walls, a major part of the building is consumed by walls. Using a new technique or material to achieve this goal is one approach but it's not advisable to be used across the country without this being normalized, causing problems in costing, transportation, skilled labor requirement, etc. Hence this an attempt to optimize the currently available materials in the construction market to achieve the task without facing any above-mentioned problems and also creating alternative for easier acceptance in the construction and architectural field of today. Table 1 highlights the research findings of various lightweight construction-related topics that show the importance of lightweight construction and also the current status in the field.

III. METHODOLOGY

A. Code compliance-based wall construction in India

Thermal transmittance is one of the critical parameters for understanding heat loss or gain from the envelope of a building. Walls constitute a major part of the building envelope and receive maximum solar radiation along with exposure to extreme temperature and other weather conditions. To maintain steady indoor thermal comfort conditions, it is necessary to reduce heat transfer through exterior walls. It is very important to consider the heat storage capacity of the wall along with its thermal conduction properties. Energy Conservation Building Code (ECBC) for commercial buildings 2017 regulates the compliance conditions for the wall assemblies in terms of its U-factor(Thermal Transmittance). ECBC, ECBC +, and ECBC Super are the three categories for compliance specified in ECBC 2017 [7] for five climate zones in India as classified by the Indian Meteorological Department (IMD) which are "C1-Composite, C2-Hot and Dry, C3-Warm and humid, C4-Temperate and C5-Cold". Thermal transmittance in terms of the opaque wall construction assemblies (U- factor limitations), maximum U-factor (W/m^2.K) mentioned for E1-ECBC, E2-ECBC +, and E3-ECBC Super categories in different climate zones of India for different building typologies namely B1- All building types except the following, B2- No star hotel <10000 sq.m AGA, B3- Business <10000 sq.m AGA, B4- School <10000 sq.m AGA and B5- unconditioned building, are detailed in table 2, 3, and 4.

The Bureau of Indian Standards approved 'Handbook for the functional requirement of buildings other than industrial buildings', SP-41, divided into four sections which include climatology, heat insulation, ventilation, and lighting [8]. The calculation methodology for thermal heat transfer through the wall surface is acquired from this handbook as a reference. "Total Thermal Resistance (Rt) is the sum of the thermal resistance of each layer of the wall section."

"$R_t = R_1 + R_2 + \ldots + R_n = L_1/K_1 + L_2/K_2 + \ldots + L_n/K_n$

Where L_{1-n} is the thickness and K_{1-n} is the thermal conductivity for all the layers of the assembly."

U-factor is given by:

$U = 1/R_t$ where,

$R_t = 1/h_i + 1/h_o + L_1/K_1 + L_2/K_2 + \ldots + L_n/K_n$

Where, h_i and h_o represent the inside and outside air heat transfer coefficients. The heat transfer for the inside and outside film of air is stated in the Heat Insulation section of the SP-41 handbook. At an air velocity of 8km/h, the outside film coefficient (h_0) is 19.86W/m^2 K and for still air, the inside film coefficient (h_i) is 9.36W/m^2 K [8].

B. Mass calculation and considerations

Mass = Density * Volume

To compare results among the various combination of wall assemblies comprising of various inside finish material, outside finish material, and block material making up the assembly type, the cross-section of that wall is taken as per 1m^3 volume of the assembly, for the calculation of the mass of each assembly type.

C. Data collection

The materials selected for the wall assemblies in the study are code amenable with ECBC 2017 and verified and tested per the Indian standards[2]. The study pivots on the mass of these materials listed in the paper which are currently being used in India. Tables 5 and 6 list the materials classified as block opaque wall material, exterior finish material, and interior finish material respectively. Thickness (T) is shown in meters(m) and conductivity (k) is measured by the unit W/mK. Density is represented in kg/m^3 and the rate is identified as Indian Rupees per sqm (INR/m^2).

Table 1. Literature review and gap finding

Sl. No.	About	Title	citation	input variables	output variables	aim of the study	usefulness(to your research/ or to a particular topic)	GAP IDENTIFICATION
1	lightweight construction	Functional assessment of lightweight construction solutions in view of sustainability	Braganca, L., & Mendonca, P. (2005). Functional assessment of lightweight construction solutions in view of sustainability. ResearchGate, DOI: 10.1201/9780203970843.ch64.	construction materials	minimum transport cost, reduced raw material requirement	* The study highlights the relevance of use of lightweight construction materials in terms of thermal, acoustic and visual comfort. * Optimizing the total primary energy consumption (PEC) of construc-tion materials and their transport and reducing the energy operating consump-tions for maintaining thermal comfort, even using the maximum possible passive solar gains are two main focuses in this study. * The study makes use of mixed-weight housing principle, which uses thermal zoning concept and passive solar indirect gain to determine the weight reduction on construction without increase in the operating energy.	* Almost all the materials mentioned within this study is easy to dismantle and reusable/recyclable compared to steel reinforced concrete structure with clay hollow brick walls and pavements popularly used in Portugal. * Despite the recent popularity of lightweight maaterials and systems, durability and stability are considerations that are still in process. * The study concludes that solar passive optimized solution is more sustainable in a Sunspace configuration then in a Trombe wall configuration.	** the study highlights how environmentally acceptable the concept of lightweight materials and systems could be. ** Durability and stability are still two aspects of lightweight materials that still needs work on.
2	polystyrene waste- wall panels	Utilization of polystyrene waste for wall panel to produce green construction materials	Siswosukarto, S., Suputra, A., & Kafrain , I. Y. (2017). Utilization of polystyrene waste for wall panels to produce green construction materials. Elsevier, Procedia Manufacturing, Sustainable civil engineering structures and construction materials, 664 – 671.	polystyrene		* The study exhibits the importance of reusing the polystyrene waste as wall panel to create a lightweight wall panel construction. * The study asks for particular attention towards tensile characteristics of the concrete mix for better use of this technique.	*compressive strength, flexural strength, density and water absorption are certain parameters explain within the paper * Researches also simulated the action of forces on wall to study the behavior of the wall panel under repeated load.	** Polystyrene wall panel for lightweight construction indicates the various studies taking place across the world to promote and benefit from lightweight construction.
3	lightweight concrete vs reinforced concrete	A Review Paper on Comparative Study of Lightweight Concrete and Reinforced Concrete	Jagtap, P. J., Rathod, M. R., & Sheikh Murtuja, S. S. (2020). A Review Paper on Comparative Study of Lightweight Concrete and reinforced concrete. International research journal of engineering and technology, Volume: 07 Issue: 03.	lightweight concrete, reinforced concrete	compressive strength, flexural strength, density	*Based on properties, uses, ingredients, characteristics, the difference between lightweight concrete and reinforced concrete is analysed.	*reduction of dead load, faster building rates in construction and lower haulage and handling costs are some of the advantages of lightweight concrete over reinforced concrete specified in the study. * lightweight concrete has low density and thermal conductivity which proves to be effective characteristics for building construction, however, it is important that the cement to water ratio has to be sufficient for adequate cohesion between cement and water.	** reinforced concrete utilises more quantity of raw materials and increases the overall mass of the building whereas, lightweight concrete with low density and thermal conductivity proves a better and sustainable solution.
4	thermal mass	THERMAL MASS IMPACT ON ENERGY PERFORMANCE OF A LOW, MEDIUM, AND HEAVY MASS BUILDING IN BELGRADE	Andjelkovic, B. V., Stojanovic, B. V., Stojilkovic, M. M., Janevski, J. N., & Stojanovic, M. B. (2012). THERMAL MASS IMPACT ON ENERGY PERFORMANCE OF A LOW, MEDIUM, AND HEAVY MASS BUILDING IN BELGRADE. Thermal Science, 16, Suppl. 2, pp. S447-S459.	heavy mass materials	energy performance, thermal comfort	* the main agenda of this study was to bring out the effect of thermal mass has on internal environment of a building, resulting in lower energy requirements from the mechanical systems. *A three-dimensional building model was generated to represent a typical office building. Building shape, orientation, glazing to wall ratio, envelope insulation thickness, and indoor design conditions were held constant while location and thickness of building mass (concrete) was varied between cases in a series of energy simulations.	*The simulation results indicated that with addition of thermal mass to the building envelope and structure: 100% of all simulated cases experienced reduced annual space heating energy requirements, 67% of all simulated cases experienced reduced annual space cooling energy requirements, 83% of all simulated cases experienced reduced peak space heating demand and 50% of all simulated cases experienced reduced peak space cooling demand. * the space heating and cooling demand indicates that lightweight consumes 1.5kW and higher thermal mass consumes lesser i.e., 1.1 kW. In the case of peak cooling demand also the higher thermal mass consumes lesser than lightweight construction. * The simulations demonstrated that radiation had a positive impact on lowering the space heating and cooling requirement than convection, radiation being an important aspect of thermal mass. *The location of the thermal mass located at the inner side of the insulation also affected in bringing down the requirement of cooling and heating demands.	** lightweight construction reacts positively towards lesser raw material consumtion and reduced dead loads on the building, but this study helps rethink the solution for thermal mass can provide a better insulation of the envelope reducing the energy requirement of the entire building making it more efficient.
5	foam concrete	Foam Concrete: A State-of-the-Art and State-of-the-Practice Review	Fu, Y., Wang, X., Wang, L., & Li, Y. (2020). Foam Concrete: A State-of-the-Art and state of the practice review. Advance in materials science and engineering, Volume 2020, Article ID 6153602, 25 pages; https://doi.org/10.1155/2020/6153602.			*Foam concrete (FC) has the potential of being an alternative to ordinary concrete, as it reduces dead loads on the structure and foundation, contributes to energy conservation, and lowers the cost of production and labor cost during the construction and transportation.	*method of preparation of foam, type of foaming agent, the accuracy of the mixture, type of surfactants and additives used, usage of nano particles and mix design, etc are some of the factors to be considered for better efficiency of foam concrete. * Foam Concrete with uniformly distributed closed circular air pores exerts good thermal and mechanical properties.	** foam concrete is one such material that can be a lightweight material but with the efficiency of providing the qualities of a higher thermal mass material because air molecules embedded within the concrete act as a great thermal resistance.
6	seismic performance	Seismic Performance of Lightweight Concrete Structures	Vandanapu, S., & Krishnamurthy, M. (2018). Seismic Performance of Lightweight Concrete Structures. Advances in civil engineering, Hindawi, Volume 2018, Article ID 2105784, 6 pages; https://doi.org/10.1155/2018/2105784.			*Due to the mass of the concrete, the building is usually prone to earthquakes. *In order to reduce the impact of earthquake forces on buildings, use of lightweight building materials enables structural designers to cut loads off the structural members of the building. *This paper attempts to predict the seismic response of a six-storied reinforced concrete frame with the use of lightweight concrete.	*A comparison between normal weight concrete and lightweight concrete shows that the bending moment and shear forces are reduced to 15% and 20 %, respectively, in lightweight concrete. The density difference observed was 28% lower when compared normal weight concrete to lightweight concrete. *A building using lightweight concrete when subjected to seismic analysis resulted in reduction of cross section of members or to reduce the steel in moment and shear resisting sections.	** against a seismic situation a lightweight construction is preferred over conventianal methods to reduce overall dead load of the structure.

D. Mass and u value distribution

A Business as Usual wall in India consists of the wall assembly shown in Figure 1.

The objective of this paper is to focus on finding the optimized solution for the wall section that not only abide by the thermal transmittance constraint imposed by ECBC India but also with the least possible mass to reduce the overall dead load of the structure reducing the load on the structural components of the building like beams, columns, and footings.

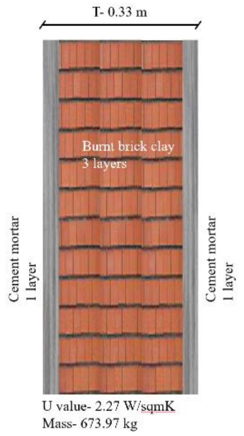


Figure 1. Wall assembly for a Business as Usual wall in India

Table 2 ECBC compliance category suggested maximum U-factor for various climate zones of India and different building categories [7]

Type of building	Composite	Hot & dry	Warm & humid	Temperate	Cold
1.All building types except below	0.4	0.4	0.4	0.55	0.34
2.No star hotel <10000 sqm aga	0.63	0.63	0.63	0.63	0.4
3.Business< 10000 sqm aga	0.63	0.63	0.63	0.64	0.4
4.School <10000sqm aga	0.85	0.85	0.85	1	0.4

Table 3 ECBC + compliance category suggested maximum U-factor for various climate zones of India and different building categories [7]

Building typology	Composite	Hot & dry	Warm & humid	Temperate	Cold
1.All building types except below	0.34	0.34	0.34	0.55	0.22
2.No star hotel <10000 sqm aga	0.44	0.44	0.44	0.44	0.34
3.Business< 10000 sqm aga	0.44	0.44	0.44	0.55	0.34
4.School <10000sqm aga	0.63	0.63	0.63	0.75	0.44

Table 4 ECBC Super compliance category suggested maximum U-factor for various climate zones of India and different building categories [7]

Building typology	Composite	Hot & dry	Warm & humid	Temperate	Cold
1.All building types	0.22	0.22	0.22	0.22	0.22

Table 5. Material dataset for block material and exterior wall finish materials [2]

S no.	Material- Block	Thickness (m)	K-value (W/m.K)	Density (kg/m³)	Rate (INR/sqm)	S no.	Material-Exterior finish	Thickness (m)	K-value (w/m.K)	Density (kg/m³)	Rate (INR/sqm)
1	Aerated autoclaved concrete block	0.2032	0.18	642	726.56	1	Ac sheet	0.006	0.25	1145	279.86
2	Aerated autoclaved concrete block	0.1016	0.18	642	363.28	2	Aluminium	0.004	212.2	2700	1399.31
3	Armor rock boulders	0.2032	0.07	270	1076.39	3	Armor rock boulders	0.025	0.07	270	645.83
4	Autoclaved aerated concrete block	0.1524	0.18	642	322.92	4	Asbestos sheet	0.008	0.51	1377	753.47
5	Autoclaved aerated concrete block	0.2032	0.18	642	430.56	5	Black coarse granite	0.025	2.54	3473	1184.03
6	Brick - burnt red clay	0.1016	1.27	2049	538.2	6	Black fine granite	0.019	2.44	3535	1506.95
7	Brick - burnt red clay	0.0762	1.27	2048	403.65	7	Brick cladding	0.02	1.27	1892	538.2
8	Cellular concrete	0.2032	0.19	704	645.83	8	Brick tile	0.015	0.8	1892	459.26
9	Cellular concrete	0.1016	0.19	704	322.92	9	Cement board	0.01	0.44	1340	215.28
10	Cement stabilized soil block	0.0762	1.3	1900	1216.32	10	Cement board	0.016	0.44	1340	322.92
11	Cement stabilized soil block	0.1016	1.3	1900	1621.76	11	Cement bonded particle board	0.016	0.33	1251	355.21
12	Cement stabilized soil block	0.1016	0.84	1700	807.29	12	Cement fibre board	0.016	0.39	1376	430.56
13	Compressed mud blocks	0.09	1.21	1840	555.18	13	Cement mortar	0.012	0.72	1648	161.46
14	Compressed mud blocks	0.15	1.21	1840	926.87	14	Cement mortar	0.015	0.72	1648	215.28
15	Fly ash brick	0.0762	0.64	1240	236.81	15	Cement plaster	0.015	1.21	1880	236.81
16	Fly ash brick size -9x4x3in density-40kg/m4 4 inch	0.1016	0.64	1240	315.74	16	Clay roof tile	0.012	0.63	2531	484.38
17	Foam cement block	0.0508	0.16	481	322.92	17	Clay ceiling tile	0.012	0.63	2531	322.92
18	Foam cement block	0.0762	0.16	481	484.38	18	Composite marble	0.02	2.44	3146	2960.07
19	Foam concrete	0.1016	0.07	320	322.92	19	Concrete paver tiles	0.06	1.72	2210	699.65
20	Foam concrete	0.2032	0.07	320	645.83	20	Dholpuri stone	0.02	3.08	2262	807.29
21	Perforated burnt clay brick	0.0762	0.63	1520	645.83	21	Floor board– Shera wood type – fibre cement	0.015	0.27	954	968.75
22	Perforated burnt clay brick	0.1016	0.63	1520	861.11	22	Granite - lakha red	0.018	3.57	2569	3229.17
23	Solid burnt clay brick	0.0762	0.62	1400	301.39	23	Jaisalmer yellow stone	0.02	2.74	3006	861.11
24	Solid burnt clay brick	0.1016	0.62	1400	401.85	24	Kota stone	0.02	3.02	3101	484.38
25	Solid concrete block	0.1016	1.4	2427	363.28	25	Kota stone	0.03	3.02	3010	592.01
26	Solid concrete block	0.2032	1.4	2427	726.56	26	Mangalore roof tile	0.02	0.61	2531	129.17
27	Solid concrete block	0.1524	1.4	2427	411.72	27	Mild steel	0.004	44.12	7823	1076.39
28	Solid concrete block	0.2032	1.4	2427	548.96						
29	Solid concrete block	0.2032	1.4	2427	484.38						

Table 6. Material dataset for interior wall finish materials [2]

S no.	Material- Interior finish	Thickness (m)	K value (W/m.K)	Density (kg/m³)	Rate (INR/sqm)	S no.	Material- Interior finish	Thickness (m)	K value (W/m.K)	Density (kg/m³)	Rate (INR/sqm)
1	Acrylic sheet	0.01	0.22	1145	699.65	28	Hard board	0.014	0.28	979	376.74
2	Ambaji marble	0.019	2.81	3128	775	29	Hard board	0.016	0.28	979	452.08
3	Asbestos cement board	0.015	0.47	1404	322.92	30	Italian black granite	0.019	2.36	2911	5920.15
4	Asbestos mill board	0.01	0.25	1397	376.74	31	Italian marble	0.019	2.78	2630	4843.76
5	Asbestos sheet	0.008	0.51	1377	753.47	32	Laminated particle board	0.019	0.18	656	484.38
6	Bamboo	0.015	0.2	913	3928.82	33	Medium density fibreboard	0.012	0.2	133	538.2
7	Black fine granite	0.019	2.44	3535	1506.95	34	Melamine fibreboard	0.012	0.25	807	269.1
8	Calcium silicate board	0.016	0.28	1016	322.92	35	Oak laminated floor tiles	0.012	0.27	949	807.29
9	Cement mortar	0.012	0.72	1648	161.46	36	Plain particle board	0.012	0.27	902	322.92
10	Cement mortar	0.015	0.72	1648	215.28	37	Pop board	0.01	0.5	1080	484.38
11	Ceramic frit glass	0.006	0.69	2520	861.11	38	Pumice square - bronze tile	0.01	0.99	2327	861.11
12	Ceramic tile	0.005	1.6	2700	538.2	39	Rajnagar marble	0.019	5.64	3332	699.65
13	Ceramic tile	0.005	0.8	2549	699.65	40	Rubber wood	0.008	0.17	472	1754.52
14	Chile wood 15 mm	0.015	0.14	362	1345.49	41	Saag wood	0.02	0.29	959	3229.17
15	Engineer wood floored tile	0.015	0.25	570	1883.68	42	Sandstone	0.019	3.01	2530	861.11
16	Ghana teak wood	0.02	0.21	529	2095.5	43	Soft board	0.012	0.09	249	1076.39
17	Granite - cat eye	0.019	3.44	2660	1237.85	44	Steam beech wood	0.012	0.23	241	1453.13
18	Granite - green galaxy	0.019	2.62	2690	968.75	45	Teak wood	0.075	0.24	665	15607.66
19	Granite - ivory fantasy	0.019	2.55	2540	1776.04	46	Udaipur brown marble	0.019	2.92	3197	1076.39
20	Granite - Kashmiri gold	0.019	2.47	2710	2690.98	47	V-board	0.018	0.3	1191	376.74
21	Granite - tan brown	0.019	2.95	2610	1399.31	48	Veneered particle board	0.012	0.24	788	322.92
22	Green marble	0.019	2.37	2650	807.29	49	Veneered particle board	0.016	0.24	788	484.38
23	Gypsum board	0.012	0.25	623	484.38	50	Vitrified tile	0.006	1.48	2719	376.74
24	Gypsum plaster	0.002	0.51	1120	258.33	51	Wall board	0.006	0.05	2622	269.1
25	Hard board	0.006	0.28	979	193.75	52	Wall board	0.008	0.05	2622	322.92
26	Hard board	0.01	0.28	979	258.33	53	Wall board	0.01	0.05	2622	376.74
27	Hard board	0.012	0.28	979	301.39	54	Wall board	0.012	0.05	2622	409.03

E. Optimization

Optimization is the technique of selecting the best and most effective resources while conforming to a set of rules and precisely achieving the solution for a given problem statement. The objective function is represented as $f(x_1, x_2, \ldots x_n)$. This function is inclusive of variables and their constraints. The function can achieve minima or maxima at some values of variables ranging from x_1 to x_n. A tangent is drawn just before the point 'x' to determine a point of minima or maxima.

Using an exhaustive search method of optimization, the best practicable wall assembly scenarios are attained with the minimum possible mass for each U-value constraint as provided by ECBC 2017 for five different climate zones with the wall thickness constraints of T1- 0.15m, T2- 0.2m, T3- 0.25m, T4-0.3m, T5-0.35m, T6-0.4m, and T7- 0.45m. The algorithm ceaselessly tries to obtain the results every time it runs for every probable case considered. The optimization algorithm does not make any supposition. Constraints are added to the optimizer to keep in check the inputs along with variables ensuring that the optimizer resolves every possible case and gives the best possible solution which will be practically possible to consider. If the constraints are not satisfied, the system re-runs.

Inside finish material, outside finish material, and opaque block material and their respective thicknesses are mentioned in the dataset considered for the study in the paper [2]. Constraints comprise U-values specified by ECBC 2017, the number of layers of finish materials and block materials that can be used to form a particular wall assembly, and various thicknesses of wall section practically possible are included within the study. Figure 2 gives an overall flow of the process that has been adopted in this study. Keeping in mind the practical possibility of the number of layers of materials that can be used to comprise a wall assembly, the minimum and maximum limit for the number of layers of each material is 0-3 i.e., it was decided not to exceed 3 layers of material for either of Inside finish material nor outside finish material. The lower and upper limit of layers for block material is considered from 1-3 layers. The four different combinations of finish material are represented as, F1- no interior wall finish, opaque, no exterior wall finish; F2- interior wall finish, opaque, exterior wall finish; F3- no interior wall finish, opaque, exterior wall finish; F4- interior wall finish, opaque, no exterior wall finish. The objective function of mass was minimized to understand the feasibility of lightweight wall construction with respect to the 'The Code 2017'.

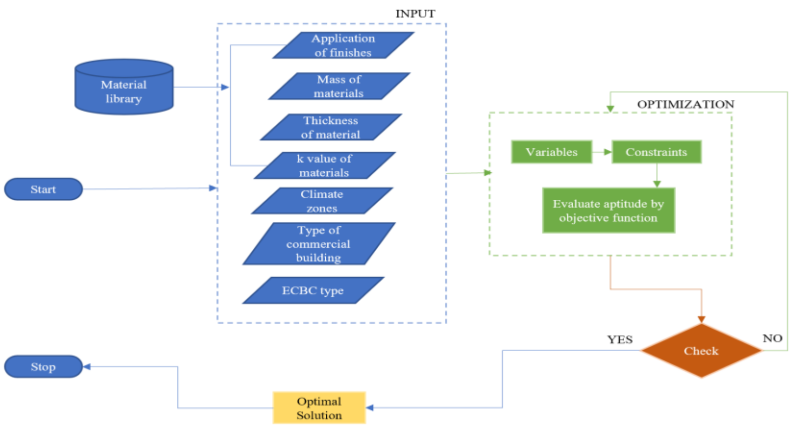
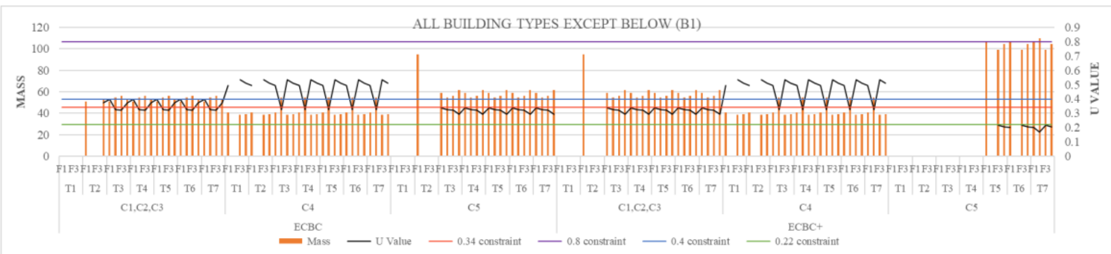


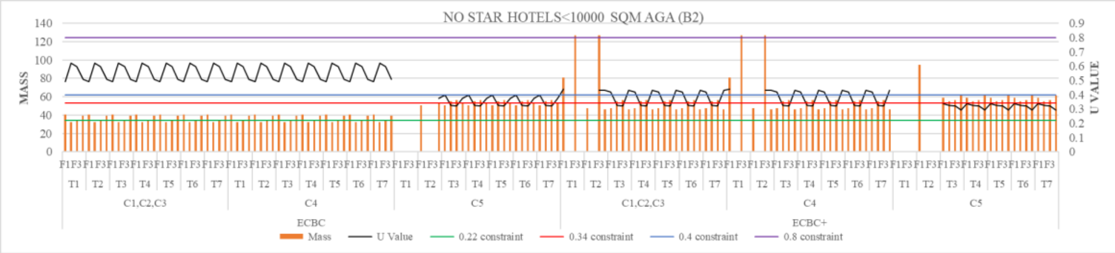
Figure 2. Process flow chart of evolutionary optimization

IV. RESULTS, DISCUSSION, AND ANALYSIS

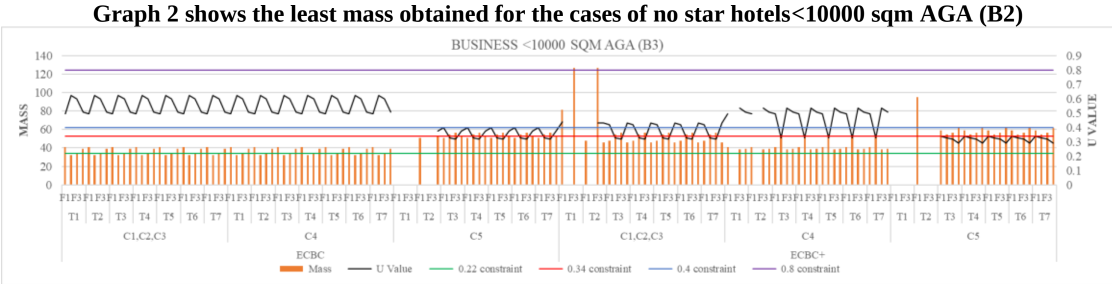
Graphs 1 to 4 depict the scenarios as a result of minimizing the objective function i.e., mass construction for a wall section that conforms with the ECBC criteria of thermal transmittance for various building typologies, across five climate zones of India. The x-axis of the graph explains the hierarchy of the combination of constraints that are applied to the six variables considered in the study i.e., type of wall finish materials (interior and exterior), block material and their respective thicknesses. The primary y-axis of the graph shows the mass of the construction assembly in kg/sq.m while the secondary y-axis shows thermal transmittance in W/sq.m.K. The constraints include various u-values for different categories of compliance, namely ECBC, ECBC +, and ECBC Super, different for different category of building and five climate zones of India. Graph 1-4 shows ECBC and ECBC + results only. The cases included within the study are the different climate zones, overall thickness of the wall assembly from T1-T7 and the type of ECBC compliance category. There are scenarios shown in the graphs for which no practical solution exist, which indicates that there is no possible solution i.e., there is no combination of material from the dataset that abides by the given level of ECBC compliance category for that particular climate zone



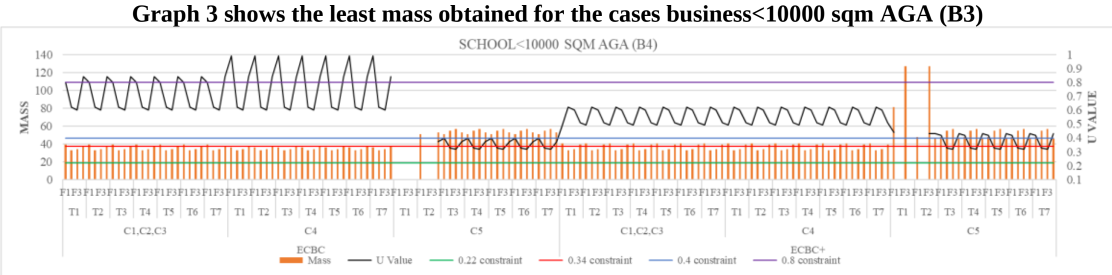
Graph 1 shows the least mass obtained for the case all building types (B1)



Graph 2 shows the least mass obtained for the cases of no star hotels<10000 sqm AGA (B2)

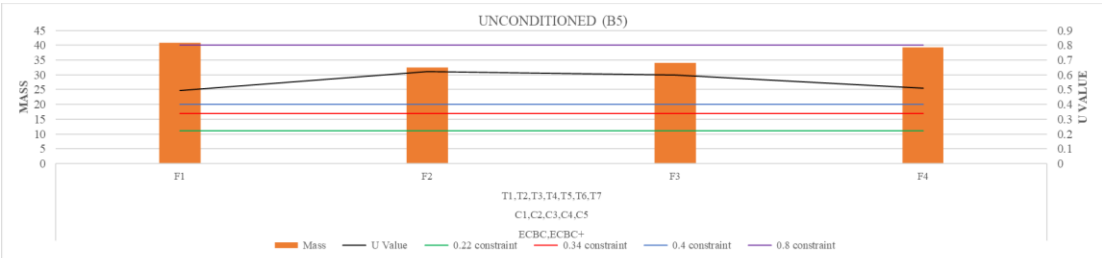


Graph 3 shows the least mass obtained for the cases business<10000 sqm AGA (B3)



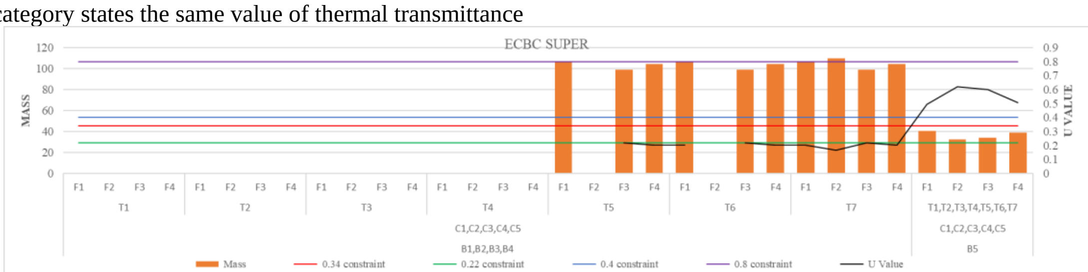
Graph 4 shows the least mass obtained for the cases of school<10000 sqm AGA (B4)

Graph 5 shows the results obtained for unconditioned building (naturally ventilated building) type mentioned in The Code 2017 manual. The hierarchy of the x-axis remains the same and also the graph shows the possible solutions for only two levels of the ECBC compliance category i.e., ECBC + and ECBC. The thickness, climate zones, and ECBC constraint are considered the same for all four wall finish types throughout this study.



Graph 5 shows the least mass obtained for the cases of unconditioned buildings (B5)

Graph 6 is a compiled result of all building typologies from B1- All building types except the following, B2-no-star hotels<10000 sqm AGA, B3-School <10000 sqm AGA, B4-Business<10000 sqm AGA and B5-Unconditioned type. This is because the ECBC Super compliance category states the same value of thermal transmittance irrespective of different building typologies and different climate zones. The variations shown in the graph are for seven wall thicknesses and four combination of wall finish.



Graph 6 shows the least mass obtained in all five building categories for ECBC Super criteria

V. CONCLUSION

The results of the optimization show that foam concrete is the most recurring solution to the least mass construction material that can be used as a block material for minimum mass construction than the rest of twenty-eight block materials from the material library. Higher mass construction in buildings has a higher saving on building energy consumption because of the time lag provided by thermal mass but adversely impacts on the dead load of the structure and results in unbalanced material utilization. This paper suggests a lower mass solution for wall construction while conforming with the thermal transmittance requirements per ECBC, 2017. This makes it an efficient and practical solution that is more sustainable. Foam concrete has reduced mass due to air pockets embedded within the block. This in turn acts as an extra layer of insulation as air is the bad conductor of heat. Lesser mass also helps with lowering the dead load overall. In solid mechanics bending moment is a reaction that is seen in structural elements when an external force is applied which causes the element to 'bend'. The moment is given by force * distance; force is given by mass * acceleration. This relation shows the connectivity of how mass will affect the practicality of beams and columns in construction. Reduced dead loads through walls are indicative of reduced sizes of these structural elements which lower the cost of construction materials and helps with sustainability by reducing resource consumption. Lean structures help tackle lateral forces such as earthquakes and wind load better than the conventional heavier buildings. The conventional mode of construction does not allow mass as an element of consideration in construction or design. The best solution can come up from what is already available to us and our ability to integrate it into our design to result in a sustainable yet achievable solution. Considering mass along with thermal transmittance is an Integrated Design Approach (IDA) to reduce the dead weight of the non-structural and structural elements of the building without compromising the energy efficiency. This paper sets a foreground to further exploit the chance of increasing lightweight construction within the country which can be done by a trade-off between mass and u-value of the wall assembly with feasible cost. Hence this paper offers a solution that is efficient in a more justified way.

VI. REFERENCES

[1]TERI, t. e. (2015). *Green growth and sustainable development in India.* Seoul, South Korea: Global and green growth Institute

[2] Shetty, S., Kishore, P., Kini, P., Acharya, R. R., & Raj, A. (2019). Energy Conservation Building Code based optimum wall composition with respect to thermal transmittance and thickness for different commercial pockets of Tier-1 cities in the temperate climatic zone of India. *Procedia Manufacturing, Elsevier*, 229-236.

[3] OECD. (2021). *OECD secretary general's report to ministers.* Paris, https://doi.org/10.1787/8cd95b77-en: OECD Publishing.

[4] Braganca, L., & Mendonca, P. (2005). Functional Assessment of lightweight construction solutions in view of sustainability. *Improvement of Buildings' structural quality by new technologies, Taylor and Francis Group*.

[5] Jagtap, P. J., Rathod, M. R., & Sheik Murtuja, S. (2020). A review paper on comparative study of lightweight concrete and reinforced concrete. *International research journal of engineering and technology*.

[6] Vandanapu, S. N., & Krishnamurthy, M. (2018). Seismic performance of lightweight concrete structures. *Advances in civil engineering, Hindawi*, https://doi.org/10.1155/2018/2105784.

[7] ECBC. (2017). *Energy Conservation Building Code.* Bureau of Energy Efficiency, Ministry of Power, Government of India.

[8] SP-41. (1987). *Handbook on functional requirements of building (other than industrial building).* Bureau of Indian Standards.

[9] Mirsaeedie, L., Zabihi, H., & Habib, F. (2012 December). Sustainability in Building and construction: Revising definitions and concepts. *International Journal of Emerging science and engineering, ResearchGate*, 570-578.

[10] U. S., Bhuvandas, N., & Aggarwal, V. (2012). Impacts of urbanization on environment. *International Journal of Research in Engineering and Applied Sciences*, Volume 2, Issue 2 ; ISSN: 2249-3905.