Financial Feasibility of Opaque Envelopes in ECBC Complaint Energy Efficient Indian Commercial Buildings: An Approach for Maximising the Internal Rate of Return

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Abstract: Buildings are one of the major contributors to energy consumption and Green House Gas emissions. To regulate harmful emissions the government is trying its best to overcome these problems by enforcing energy conservation codes and rating systems for buildings in India. The developers and the investors of project are more interested in the profit. The Internal Rate of Return of a project supports the selection of the project, which is widely used worldwide. This study has been conducted to optimize the Internal Rate of Return (IRR) to find out the best opaque wall section in the warm and humid climate of India with Energy Conservation Building Code (ECBC) compliance, using wall thermal transmittance values as the constraints to control the energy consumption within buildings. This will lead to the reduction electricity demand contributing towards a mitigating the climate change and also to gain profit for the investors by annual energy savings from sustainable commercial buildings. This study estimates an 18% to 40% IRR from the commercial building by conforming with ECBC benchmarks.

1 INTRODUCTION

The world is undergoing a serious issue related to climate change and buildings are one of the contributors. The greenhouse gas emissions especially, Carbon dioxide emissions have led to an increase in the global surface temperature, which results in an increase of the mean sea level due to the melting of glaciers, thus harming the environment that we live in. Global surface temperatures have exceedingly increased over the last decade (2011-2020) concerning 6500 years ago ranging from 0.2^0C to 1^0C and now even further according to The Intergovernmental Panel on Climate Change (IPCC) report (IPCC). In the year 2015, the United Nations adopted The 2030 Agenda for Sustainable development which has a total of 17 goals called the Sustainable Development Goals (SDGs), an urgent call for action for all countries, which results in global development while tackling climate change to preserve the current environment (Nations, n.d.). Among these 17 SDGs 4 of the goals (affordable and clean energy, industry, innovation, and infrastructure, sustainable cities and communities, responsible consumption and production) are directly or indirectly linked to the building sector. As responsible architects, they must reduce the negative impact on the climate and maximize the profit of stakeholder or investor over the buildings for whoever is requiring to help. On global level, the building sector has become one of the major sources of CO_2 emissions. Efforts are being made to develop a more sustainable environment (Jiang, Liu, Czarnecki, & Zhang, 2019). Everything started with the United Nations Framework for Convention on Climate Change (UNFCCC), introduced by United Nations in 1992. The ultimate objective of UNFCCC is to stabilize the greenhouse gases in the atmosphere at a level which resulted in the formation of the United States Green Building Council (USGBC) and Leadership in Energy and Environmental Design (LEED) – a Green building rating system.

Scientific literature shows that even if the most aggressive mitigation measures are successful, we

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can expect climate-related changes, such as increasing temperatures over the next 30 years (Aijazi & Brager, 2018). In the total GHG emissions 16% of the emissions are due to embodied energy and the remaining 86% is because of the operation of the systems (Filippin, Larsen, & Ricard, 2018). So, it is required to reflect on the operational energy consumption, which leads to the price of the total energy consumed. There is a spike of 29.2% increase in the Energy Performance Index of the buildings i.e. 60 KWh/Sq.m per year to 78 KWh/Sq.m per year (Gercek & Arsan, 2019).

India is responsible for 8% of the total GHG emission (IPCC). The building sector in India is accountable for 35% of the summed up energy consumption and the energy use is increasing at the rate of 8% (Khosla & Janda, 2019). To deal with climate change, the Indian government introduced the Energy Protection Act in 2001 which also oversees the Bureau of Energy Efficiency (BEE) in its framework. The BEE introduced the Energy Conservation Building Code (ECBC) in the year 2007. Various Initiatives were taken by the Government of India like National Building policies, Smart city initiatives, building codes, and rating systems to incorporate Energy Efficiency and to set new benchmarks for building performance (Garg, Kumar, Pipralia, & Garg, 2018).

A study conducted by Kishore N says that five cities under all climate zones in India according to National Building Code (NBC) were analyzed which resulted in a temperature rise of 3.7-4.2 °C in the future. The study propounds that there is a significant overall increase in the energy load ranging from 18% to 89% in 2020, 32% to 132% in 2050, and 85% to-184% in 2080 if the residential buildings are operated in the same manner. The use of passive strategies may reduce the load by 50% to 60% in the future (Kishore, 2021).

Green building technology can be promoted by strengthening the policy and incentive system. Special training for employees, awareness towards technological innovation, and an approach towards integrated design application act as direct driving forces towards Green Building Implementation (Zhang, et al., 2019).

1.1 Technical Challenges

In the year 2002, India started the Green building movement in India. In the following years, ECBC was enforced which set benchmark constraints for the building construction. The reference building model developed by Bhatnagar Et al. performs better in the Energy Performance Index than just the guidelines from ECBC and ECBC+ in all the five climate zones of India as per National Building Code (NBC), due to the market transformation to LEDs. But, the envelope in the reference buildings are inefficient due to the higher cost of insulations (Bhatnagar, Mathur, & Garg, 2019). On the contrary, the study in this paper will help to deal with the envelope. Many benchmarks and standards have been defined for the Indian context but the implementation needs reinforcement (Sharma, 2018). India has different climate zones and needs different types of buildings, hence no single code applies in the same manner to all these situations.

1.2 Financial Challenges

Higher occupancy generates higher demand for electricity, causing a hike in energy loads leading to energy poverty, especially in highly populated areas in India. To tackle the energy poverty issue in India the government has enforced policies such as the Electricity Act of 2003, the National Electricity policy of 2005, and so on with the agenda to expand electricity supply, especially to rural areas which have resulted in a considerable decline in energy poverty across the country. Multi-dimensional energy poverty index and district-level information are examined to estimate the extent of energy poverty at a place (Sadath & Acharya, 2018). Also, for every building implementing sustainability, the buyer has to pay a premium price and the gap between the buyer's willingness to pay and the cost of sustainable building imposes an economic challenge, hence both these issues have to be negotiated. Finally, the public views that the construction industry and buyers are focused on short-term benefits and not convincingly invested in the concept of sustainability and hence withdraw their idea of accepting change (Hoxha & Shala, 2019).

2 BACKGROUND STUDY

The reference building model of India states that the cooling load of commercial buildings ranges from 16% to 28% based on the typology and occupational hours of the building (Bhatnagar, Mathur, & Garg, 2019). The heat in the building can be cooled with many strategies in which HVAC systems like VAV and VRF systems are used which consume electricity. The electricity demand is increasing every day. In India, 56% of the electricity is generated by coal fired power plants which release the highest amount of CO_2 emissions into the atmosphere when compared to any other source (IEA, 2021). One of the approaches to reduce energy consumption within the building is to reduce heat transfer into the building. Studying the building life cycle and certain market participants, it is identified that “going green” can be financially feasible and also profitable over the life span of the building. But, certain factors delay the decision-making of the developers and occupants in choosing to "go green", especially in terms of economic viability (Zhang, Wu, & Liu, 2017).

Scope: Literature over the past decade show experiments and case studies conducted for the financial returns in buildings due to the higher investments in construction. However, this extra investment should have brought higher rental because of the characteristics of the green buildings. But the situation is complex because the financial benefits of green building have not been accounted for. As such a study has not been conducted which can establish a relation between the financial benefit and energy efficiency of green building in a rapidly developing economy like that of India. So this study uses the reference building model of India for commercial buildings as a base case to understand the same. RBM (Reference Building Model) has been simulated against the building energy codes of India to calculate the Internal Rate of Return using the financial savings from the energy efficiency of the building and also bringing the extra cost associated with the construction of green buildings to understand the design decisions by various professionals of AEC(Architecture, Engineering, and Construction) industry.

3 METHODOLOGY

3.1 Energy Simulation

3.1.1 Reference Building Model (RBM)

The reference building model of India for commercial buildings has been considered for the study. In the RBM, the buildings were divided into 2 types based on, no. of floors and types of functional hours in each building, – Low-rise -8hr, Low-rise – 24hr, high-rise – 8hr and high-rise – 24hr. A total of 230 commercial buildings have been analyzed for the RBM study. Indian climate zones are divided into five types according to NBC 2006, however development of Indian RBM is only for four climate zones excluding cold climate zone. The RBM analysis is based on various inputs such as form, envelope, loads, and systems, along with certain general categories like location, ventilation requirements, etc. The study is a four-step process: 1. Identification of building typologies, 2. Building parameters identification, 3. Sample size and data collection, 4. Determining values of building parameters. (Bhatnagar, Mathur, & Garg, 2019).

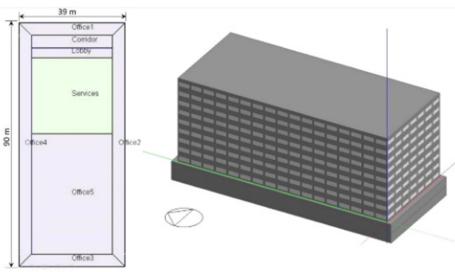


Figure 1: High-rise building model Image by: (Bhatnagar, Mathur, & Garg, 2019).

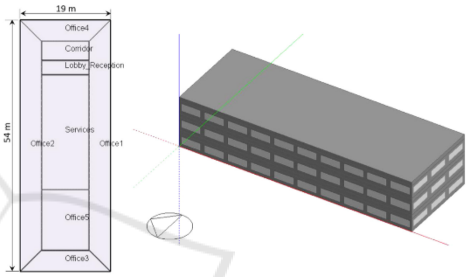


Figure 2: Low-rise building model Image by: (Bhatnagar, Mathur, & Garg, 2019).

Figures 1 and 2 show the reference building models for high-rise and low-rise building typology respectively.

3.1.2 Energy Performance Calculator

For this study the RBM in the Warm and humid climate is modeled in the Energy Performance Calculator (EPC). EPC is an Excel-based tool that can be used to calculate the energy performance of a building. It is developed by IMAGINE lab at the Georgia Institute of Technology. EPC uses energy plus weather files, systems in building like Lighting systems and HVAC systems, Building Integrated Energy Generation System, zones and their occupancy, and building envelope details to calculate Energy Performance Index (EPI).

3.1.3 Thermal Transmittance

The heat from the exterior spaces transmits to the spaces through a building envelope which has conductivity in it known as thermal conductivity. Thermal transmittance is a function of the thermal conductivity and thickness of the envelope material.

$$u = \frac{k}{t} \tag{1}$$

$$u - thermal\ transmittance$$
$$k - thermal\ conductivity$$
$$t - thickness\ of\ the\ wall$$

3.2 Material Data

Opaque wall materials are combined to make different sections, which causes a change in the thermal transmittance of the combined wall section. The different materials for the exterior finish, interior finish, and block are taken as the variables for the materials. These materials are taken from optimization-based feasibility analysis for ECBC for different opaque wall assemblies in India taken from a study by Pranav Kishore et al (Kishore, Kini, & Raj, 2020) as shown in Table 1 and Table 2.

The 4 different types of wall finish typologies (F1 = both side finish, F2 = both exposed, F3 = finished inside and exposed outside and F4 = exposed inside and finished inside) have been considered for the study. The number of layers of finishes has been restricted to three layers as per practical application. The materials used in the study are accepted and used in the compilation of materials used in the industry which complies with ECBC 2017 and is tested by CARBSE, CEPT Ahmedabad, and verified by CSBE, MAHE, Manipal.

3.3 Energy Conservation Building Code

Buildings consume a significant proportion of energy resources, so the Bureau of Energy Efficiency (BEE – India) has launched Energy Conservation Building Code (ECBC) in the year 2007 to establish minimum building performance standards for the commercial buildings of India, which is a regulatory tool to limit the energy footprint of the commercial buildings. Section 4 in ECBC explains the building envelope.

The building envelope is considered as skin of building, which consists of walls, openings, and roof. These components play a crucial role in the heat transfer into the building. It is required to maintain the thermal comfort of the occupants in a building as it affects the functionality of the occupants. If the heat transfer is very high then the temperature in the space increases and HVAC systems are used to achieve thermal comfort. As the HVAC systems consume more amount of energy, which leads to more expenditure on the systems. So ECBC 2017 provides us the different benchmarks for the envelope based on climate zone, type of building and different levels of

Table 1: Block materials and exterior finish materials for wall (Shetty, Kishore, Kini, Acharya, & Raj, 2020).

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 2: interior finish materials for wall (Shetty, Kishore, Kini, Acharya, & Raj, 2020).

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

efficiency like ECBC, ECBC+, and super ECBC. In this study, only warm and humid climate was considered, so the benchmarks used for the wall of different levels of ECBC in warm and humid climate for commercial buildings are as per Table 3.

Table 3: maximum u-factor values.

	ECBC	ECBC+	ECBCSuper
Maximum thermal transmittance for the opaque external walls in W/sqmK	0.40	0.34	0.22

3.4 Internal Rate of Return

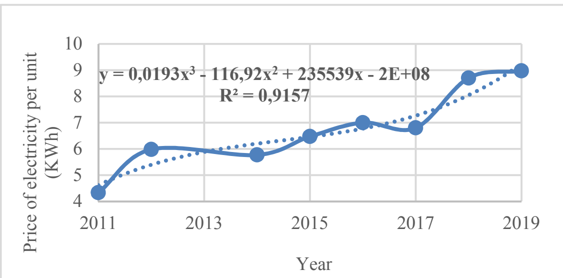
IRR is an evaluation method that measures the financial gains of an investment. The rate (R) at which NPV is zero is the IRR.

$$NPV = \sum_{t-1}^{t} \frac{C_t}{(1+R)^t} - C_o \quad = 0 \qquad (2)$$

Where, NPV = net present value
R= discount rate
t= time of the cash flow
C_t= net cash flow at time t
C_o= total initial investment cost

3.5 Regression for Electricity Price

The study makes use of linear regression for calculations. All the electricity prices from 2011 to 2019 have been collected and a simple curve is plotted with the available data points and the equation of the curve is used for the prediction of the price of electricity per unit in the future as in Graph 1. In the past prices did not change much, due to communist government in the state and also due to COVID crisis. This graph infers the rise in electricity price per unit over the building life span along with the rise in trend of price related to the internal rate of return across the expected life-span of the building (Ramesh, Prakash, & Shukla, 2010).



Graph 1: Regression line showing electricity prices over the year.

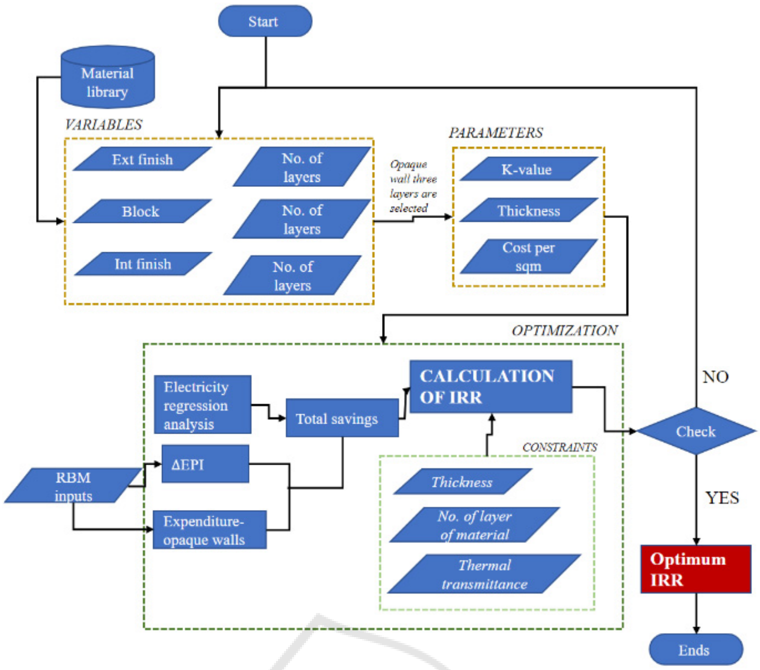


Figure 3: Optimization process flowchart.

3.6 Optimization

The process of obtaining the best solution from a set of solutions that support the objective is termed optimization. Optimization starts with selecting an objective function and determine dependent and independent variables to make a complete domain of results and the final solution is obtained from the domain which gives the best solution to the objective function satisfying all constraints (Fogel, 1994).

The MS Excel evolutionary solver has been used for optimization. The objective function is given in terms of f(x_1, x_2, x_3, … x_n), where 'x' can be the point of minima or maxima of the function. The objective function is taken as maximizing the IRR, variables are block material for wall, exterior wall finish material, interior wall finish material, and their respective number of layers along with constraints as their respective thicknesses which can range from 6 inches to 12 inches. The maximum thermal transmittance of the opaque wall section will be determined by the selected level of ECBC from ECBC 2017 handbook. The income will be determined from the savings of EPI by changing the building envelope which leads to the parameters which affecting the objective i.e. roof, wall, and fenestrations. After choosing a wall, the thermal transmittance of the wall changes due to the materials present in it. Table 4 summarizes the categories considered within the study to optimize the data in terms of IRR.

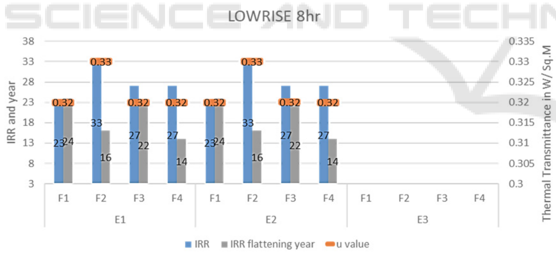
Table 4: Input, objective function, variables, and constraints.

Input	ECBC Compliance	
	Type of building	
	Functional hours	
	Type of finish	
Objective function	Maximizing the IRR	
Variables	Interior finish	Number of layers
	Block material	Number of layers
	Exterior finish	Number of layers
Constraints	thermal transmittance of wall <=0.40 - ECBC	
	thermal transmittance of wall <=0.34 - ECBC+	
	thermal transmittance of wall <=0.22- ECBC Super	
	6 inches < Thickness of wall < 12 inches	

The optimization starts with the change of the values in the variable which is the opaque wall material and then checks for the optimality which is maximum IRR and then the solver is run until the iterations are repeating the same solution and then converged. The detailed flow of result identification is depicted in Figure 3.

4 RESULTS AND DISCUSSION

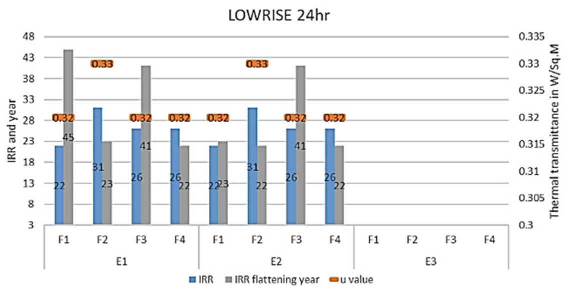
From graph 2 of the results of the evolutionary optimization of IRR for Low-rise 8hr functional building, we can say that ECBC and ECBC+ have shown similar results for all kinds of wall finish typology. The IRR in both the compliances ranges from 23% to 33% for finish type F1 and F2. The years from which the IRR change becomes very minimal range from 24th year to 14th year for finish type 1 and finish type 4 respectively. The achieved thermal transmittance (u-value) for the highest IRR i.e. 33% is 0.33 W/Sq.mK. The selected block material for wall is ECBC rated foam concrete of dimensions 24in x 8in x4in, the exterior finish for all the cases is Mangalore roof tile (terracotta tile) and interior finish of ECBC rated hardboard of thickness 6 mm in all the types of ECBC and types of finishes. All the finishes are of one layer only to achieve the maximum IRR. The growth of IRR for every case is increasing for certain years and the change is becoming negligible after some years. There is no optimum solution for ECBC super low-rise 8hr because of the thickness constraint, which gives the minimum thickness as 6 inches and maximum of 12 inches of thickness for attaining a thermal transmittance (u-value) value of 0.22 W/Sq.mK. The solution for ECBCSuper can be achieved only by adding insulation to the wall or by increasing the thickness of the block material.



Graph 2: Low-rise 8hr building.

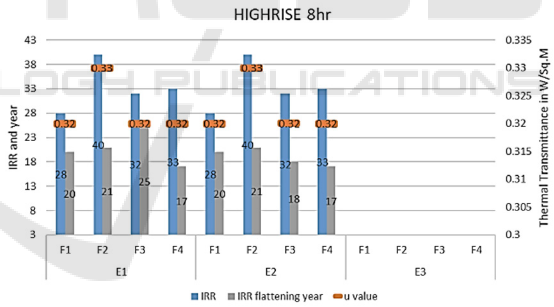
From graph 3 of the results of the evolutionary optimization of IRR for Low-rise 24hr functional building, the IRR in both the compliances ranges from 22% to 31% for finish type F1 and F2. The years from which the IRR change becomes very minimal range from 22nd year to 45th year for finish type 4 and finish type 2 in ECBC and ECBC+ respectively, and finish type 1 in ECBC.

The achieved thermal transmittance (u-value) for the highest IRR i.e 31% is 0.33 W/Sq.mK. The selected block material for wall is ECBC rated foam concrete of Size- 24in x 8in x4in for results of all finishes in ECBC and finish type F1 but for the finish



Graph 3: Low-rise 24hr building.

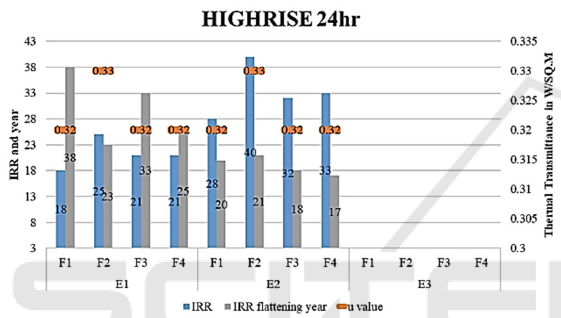
type 2, finish type 3, and finish type 4 the optimum material for maximizing the IRR is ECBC rated foam concrete of Size- 24in x 8in x4in of 2 layers, the exterior finish for all the cases is Mangalore roof tile (terracotta tiles) and ECBC rated hardboard of thickness 6 mm in all the types of ECBC and types of finishes. All the finishes are of one layer only to achieve the maximum IRR. There is no optimum solution for ECBCSuper for low rise-24hr building because of the thickness constraint which gives the minimum as 6 inches and maximum of 12 inches for attaining a thermal transmittance (u-value) value of 0.22 w/Sq.mK. The solution for ECBC can be achieved only by adding insulation to the wall or by increasing the thickness of the block material.



Graph 4: high-rise 8hr building.

From graph 4 of the results of the evolutionary optimization of IRR for High-rise 8hr functional buildings, we can say that ECBC and ECBC+ have shown similar results for all kinds of finishes in high-rise 8hr functional buildings. The IRR in both the compliances ranges from 28% to 40% for finish type F1 and F2. The years from which the IRR change becomes very minimal range from 17th year to 25th year for finish type 4 in ECBC and ECBC+ respectively, and finish type 3 in ECBC. The achieved thermal transmittance (u-value) for the highest IRR i.e. 40% is 0.33 W/Sq.mK. The selected block material is ECBC rated foam concrete of Size- 24in x 8in x4in for finish type 1, finish type 2 in

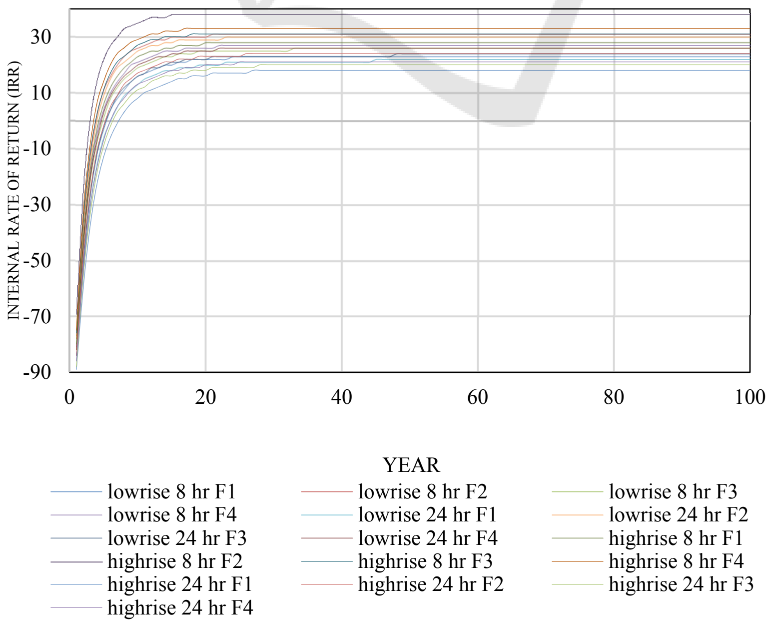
ECBC, and finish type 1 in ECBC+ but the optimum material for maximizing the IRR is ECBC rated foam concrete of Size- 24in x 8in x4in of 2 layers in finish type 3 and finish type 4 in ECBC and finish type 2, finish type 3 and finish type 4, the exterior finish for all the cases is Mangalore roof tile (terracotta tiles) and ECBC rated hardboard of thickness 6 mm in all the types of ECBC and types of wall finishes. All the finishes are of one layer only to achieve the maximum IRR. There is no optimum solution for ECBCSuper for high rise-8hr buildings because of the thickness constraint which gives the minimum as 6 inches and maximum of 12 inches for attaining a thermal transmittance (u-value) value of 0.22 w/Sq.mK. The solution for ECBC can be achieved only by adding insulation to the wall or by increasing the thickness of the block material.



Graph 5: high-rise 24hr building.

From graph 5 of the results of the evolutionary optimization of IRR for high rise-24hr functional building, the IRR in both the compliances ranges from 28% to 40% for finish type F1 in ECBC and F2 in ECBC+. The years from which the IRR change becomes very minimal range from 17th year to 38th year for finish type 4 in ECBC+ and finish type 1 in ECBC. The achieved thermal transmittance (u-value) for the highest IRR i.e. 40% is 0.33 W/Sq.mK. The selected block material for the wall is ECBC rated foam concrete of Size- 24in x 8in x4in in results of all finishes in ECBC and finish type 3 and finish type 4 in ECBC and all the finishes of ECBC+, the optimum material for maximizing the IRR is ECBC rated foam concrete of Size- 24in x 8in x4in of 2 layers, the exterior finish for all the cases is Mangalore roof tile (terracotta tiles) and ECBC rated hardboard of thickness 6 mm in all the types of ECBC and types of finishes. All the finishes are of one layer only to achieve the maximum IRR. There is no optimum solution for ECBC super for high rise-24hr building because of the thickness constraint which gives the minimum as 6 inches and maximum of 12 inches for attaining a thermal transmittance (u-value) value of 0.22 w/Sq.mK. The solution for ECBC can be achieved only by adding insulation to the wall or by increasing the thickness of the block material.

Graph 6 is an IRR over a total of 100 years of the building. It explains how it changes over a period of time. At the beginning of the time, the IRR is in negative values as there is only expenditure on the walls and no income from it and the savings from the energy-saving starts from the first year and it goes on as the maintenance for the walls are considered as



Graph 6: Change of IRR over time.

negligible. In the initial approximate time duration of 20 years the IRR is increasing in a haste and does not increase rapidly after the 20 years. The change in IRR over the time duration is almost constant (as the change is very minimal). Similarly, it is repeated for every building and every finish but the year over which it becomes almost the same with the next year, changes in every case.

A study conducted by Sau Wai Lee for the economic evaluation of roof thermal insulation in the equatorial climate of Malaysia says that the IRR ranges from 6.33% to 15.83% based on the material that is used as the insulation for the roof. By increasing the performance of the building using the correct composition of the roof, they were able to achieve the IRR (Lee, Lim, Chan, & Von, 2017).

5 CONCLUSION

This study shows that converting a conventional building to an energy-efficient building even with optimization of one component of the building envelope yield a lot of savings. The savings are considered as the income with the cost of the wall as the expenditure and the IRR is calculated. The results explain that the best block material is foam concrete with the required thickness and the exterior finish is Mangalore tiles (terracotta tiles) and the interior finish is hardboard, which gives us a range of 18% to 40% IRR which is very high. Figure 4 shows the sections of the optimum exterior wall composition.

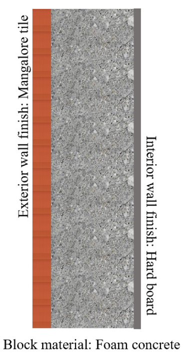


Figure 4: Cross-section image of a wall section using the most recurring material selection after optimization.

Anyhow there was no feasible solution that could satisfy the constraints of ECBCSuper because an increase in thickness of the wall will reduce the thermal transmittance (u-value) but for the thermal transmittance (u-value) constraint of the ECBCSuper was 0.22 W/Sq.mK which cannot be attained with the given constraint of thickness i.e. it lies between 6 inches and 12 inches. For ECBCSuper the solution can be obtained by adding insulation to the interior finish so adds high resistance to heat in the walls.

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REFERENCES

Aijazi, A., & Brager, G. S. (2018). Understanding Climate change impacts on building energy use. *ASHRAE Journal*, 60(10).

Bhatnagar, M., Mathur, J., & Garg, V. (2019). Development of reference building models for India. *Journal of building engineering, Elsevier*, Journal of building engineering 21 (2019) 267-277; https://doi.org/10.1016/j.jobe.2018.10.027.

Filippin, C., Larsen, S. F., & Ricard, F. (2018). Improvement of energy performance metrics for the retrofit of the built environment. Adaptation to climate change and mitigation of energy poverty. *Energy and Buildings, Elsevier*, Volume 165, 15 April 2018, Pages 399-415; https://doi.org/10.1016/j.enbuild.2017.12.050.

Garg, N., Kumar, A., Pipralia, S., & Garg, P. (2018). Initiatives to achieve energy efficiency for residential buildings in India: A review. *Indoor and built environment, Sage journals*, https://doi.org/10.1177%2F1420326X18797381.

Gercek, M., & Arsan, Z. D. (2019). Energy and environmental performance based decision support process for early design stages of residential buildings under climate change. *Sustainable cities and societies*, Volume 48, July 2019, 101580; https://doi.org/10.1016/j.scs.2019.101580.

Hoxha, V., & Shala, F. (2019). The benefits and challenges of sustainable buildings in Prishtina, Kosovo. *Facilities*, Facilities, Vol. 37 No. 13/14, pp. 1118-1152. https://doi.org/10.1108/F-08-2018-0097.

IEA, I. E. (2021). *India Energy Outlook 2021*. World Energy Outlook Special Report.

IPCC, T. I. (n.d.). *Global Warming of 1.5 degrees Celcius.* The Intergovernmental Panel on Climate Change.

Jiang, A., Liu, X., Czarnecki, E., & Zhang, C. (2019). Hourly weather data projection due to climate change for impact assessment on building and infrastructure. *Sustainable cities and society, Elsevier*, Volume 50, October 2019, 101688; https://doi.org/10.1016/j.scs.2019.101688.

Khosla, R., & Janda, K. B. (2019). India's building stock: towards energy and climate change solutions. *Building research and information, Taylor and Francis*, Volume 47, 2019; https://doi.org/10.1080/09613218.2019.1522482.

Kishore, N. (2021). Impact of climate change on future bioclimatic potential and residential building thermal and energy performance in India. *Indoor and built environment, Sage journals*, https://doi.org/10.1177%2F1420326X21993919.

Kishore, P., Kini, P., & Raj, A. (2020). Optimization-based feasibility analysis for Energy conservation building code compliance of opaque wall assemblies in different climatic zones of India. *Procedia Manufacturing, Elsevier*, Volume 44(2020), pages 221-228.

Nations, U. (n.d.). *Department of Economic and social affairs, Sustainable Development*. Retrieved from United Nations: https://sdgs.un.org/goals

Sadath, A., & Acharya, R. H. (2018). Energy Poverty and Economic Development: Household-level Evidence from India. *Energy and Buildings, Elsevier*,183:785-791; http://dx.doi.org/10.1016/j.enbuild.2018.11.047.

Sharma, M. (2018). Development of a 'Green building sustainability model' for Green buildings in India. *Journal of cleaner production, Elsevier*, Volume 190, 20 July 2018, Pages 538-551; https://doi.org/10.1016/j.jclepro.2018.04.154.

Shetty, S., Kishore, P., Kini, P., Acharya, R. R., & Raj, A. (2020). Energy Conservation Building Code (ECBC) based optimum wall composition with respect to thermal transmittance and thickness for different commercial pockets of Tier-1 city in temperate climatic zone of India. *Procedia Manufacturing, Elsevier*, Volume 44, 2020, Pages 229-236; https://doi.org/10.1016/j.promfg.2020.02.226.

Zhang, L., Wu, J., & Liu, H. (2017). Turning green into gold: A review on the economics of green buildings. *Journal of cleaner productions*, doi: 10.1016/j.jclepro.2017.11.188.

Zhang, Y., Wang , H., Gao, W., Wang, F., Zhou, N., Kammen, D. M., & Ying, X. (2019). A Survey of the Status and Challenges of Green Building Development in Various Countries. *Sustainability, MDPI*, Sustainability 2019, 11(19), 5385; https://doi.org/10.3390/su11195385.

Ramesh, T., Prakash, R., & Shukla, K. K. (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings; Elsevier*, Energy and Buildings 42 (2010) 1592–1600; doi:10.1016/j.enbuild.2010.05.007.

Lee, S. W., Lim, C. H., Chan, S. A., & Von, K. L. (2017). Techno-economic evaluation of roof thermal insulation for a hypermarket in equatorial climate: Malaysia. *Sustainable cities and society*, Volume 35, November 2017, Pages 209-223; https://doi.org/10.1016/j.scs.2017.08.011.

Fogel, D. B. (1994). An Introduction to Simulated Evolutionary Optimization. *IEEE Transactions on Neural Networks,*, Vol. 5, No. 1, January 1994.