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Life Cycle Costing of Building Envelope

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Abstract: Today, a large quantity of energy is consumed by building industry, factors influencing the energy use of the global building market include building façade, floor area, demand for energy resources, temperature variability, and how building are constructed and use. Construction envelopes and the efficiency of building energy demand and equipment are the factors that have led most to higher energy consumption. We have multiple options in envelope material are available with different initial cost and operational cost. So, this research work will make a decision making frame work for the selection of appropriate Building envelope material. This paper determines life – cycle cost over a 50 year period for 9 external façade system and 2 roofing system from 4 Indian cities. Factors affecting life cycle expenditure of commercial office building are consider in this research work including construction cost, maintenance cost, operational cost of external façade and roofing system. The most cost effective system is identified.Building envelope performance evaluation is needed to reduce the commercial building's energy consumption and to maximize the quality of the material to be used in the envelope with the aid of Life Cycle Cost Assessment. Finally, the Life cycle costing of optimized material are analyzed and compared to the cost of 9 external façade and 2 roofing system. The comprehensive and systematic approach for selection of building envelope has been documented. This research will serve as a guide to owners, architects and contractors. It will provide a prior knowledge to take a decision on the envelope materials with maximum efficiency for building envelope construction.

***Index Terms* – External facade, Building envelope, Life Cycle Cost, Commercial office, India**

I. INTRODUCTION

A building envelope is in general the exterior of a building with a special architectural treatment. Usually we cover exterior walls, roof and ground floor and windows in building envelope. Building envelope is a significant and widely applied field of construction sector operation. As the key function of the building envelope is understood is to isolate the indoor atmosphere from the outside atmosphere in such a way that the conditions of the indoor environment can be maintained at the correct level for the planned use of buildings (D., 2007) From the practical point of view, therefore, it can be characterized as the portion of the building that is a non-load-bearing exterior wall that must protect the interior spaces against invasion by water, wind, sun, light, heat and cold, and all the other natural forces. Besides this, the esthetic, fiscal, and security requirements must also be fulfilled (Kenney & Sams, 2017) The building envelope is the skin of a building that is supported by the structure's skeleton. It serves as a thermal buffer between the conditioned space enclosed and the external atmosphere from which the thermal energy is transmitted. The use of resources required for room heating and cooling can be minimized considerably by reducing the heat flow into the building envelope. As per Brook 2005, It is necessary to reduce the HVAC load in commercial buildings by judicially designing the building structure parameters i.e. position, form, walls, fenestrations, shading apparatus and roof.

Life-cycle costing (LCC) and life-cycle assessment (LCA) methods exist to determine how a plant can work over its lifespan, including the acquisition, development, construction, service, renovation, repair, reconstruction, and destruction of raw materials (F. Flager, 2012) LCC monitors economic factors including cost of production and running costs, cost of maintainance. The life- of building materials, building constructions or entire buildings ' from cradle to grave ' can be evaluated using the Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) methods.

A few studies evaluated the building envelope from the point of view of the life cycle. Baouendi et al. (Walid Belazi, 2018) suggested an interactive method for evaluating the use, pollution and costs of life cycle resources for building envelopes outside. To order to allow for the required trade-offs between costs and impacts, some researchers applied multi-objective optimisation to envelope design. Wang et al. (Bhishara, 2018)

II. NEED IDENTIFICATION AND PROBLEM STATEMENT

The physical frame and exterior of a building (roof, floor, walls, and windows) continues to account for the majority portion of embodied energy and running costs. Envelope products greatly affect a building's economic and energy use in both occupancy and pre-occupancy levels. As per CBRE market review Q3-2019, About 43 million Sq.ft. new office supply added in 2019 YTD (Year to Date) and additional led by Bangalore, followed by Hyderabad, NCR and Mumbai. These four cities are accounted for more than 80% of this supply addition. Life cycle costing is "an economic calculation of competitive concept options, taking into account the substantial ownership costs of each solution over this economic life" and the Life Cycle Energy analysis model is a key tool in assessing the cost-effectiveness of adopting energy conservation steps. This can have a higher first cost than standard measure. (Corgnati, S., Perino, M., & V., 2007)We have multiple options in envelope material with different initial cost and operational cost. So, this research work will make a decision making frame work for the selection of appropriate Building envelope material.

Various type of building envelope material are available in market and there are lots of study provided about the thermal performance of the material. But this research work is focused to fulfill the gap in selection of envelope material on the basis of their cost and thermal performance. The study about the selection of envelope material is not readily available So, This research will serve as a guide to owners, architects and contractors. It will provide a prior knowledge to take a decision on the envelope materials with maximum efficiency for building envelope construction.

III. OBJECTIVES

1. To analyze types and components of building envelope which contribute to the cost in the calculation of Life Cycle Costing.
2. To identify building envelope and prepare a list of cost required for Life Cycle Costing calculation.
3. To perform Life Cycle Cost analysis of building envelope.
4. To create a Life Cycle Costing calculation matrix for the selection of building envelope and validate it through case study.

IV. RESEARCH METHODOLOGY

To address the research questions or meet the research objectives, the following research steps are proposed-

Step 1 – Examine required r- value of the external façade and roofing system.

Step 2 **-** Calculating the construction cost of façade system and roofing system. Construction cost include Material cost, Transportation cost and Labour cost,

Step 3 – Calculating the operational cost. It include heating and cooling cost.

Step 4 – Calculating the space maintenance cost.

Step 5 – Identifying the inflation and discount rate.

Step 6 – Exploring Life Cycle Costing.

V. LITERATURE REVIEW

This chapter provides us an summary of the numerous published and unpublished studies referred to in order to create a thorough understanding of the subject matter and to determine the status of the study carried out in the following fields.

5.1 Buildig Envelope

The building envelope is, according to (Bhatia, 2002) the exterior of a building that is protected by the backbone of the structural framework. It serves as a thermal buffer between the conditioned space enclosed and the external atmosphere from which the thermal energy is transmitted. The use of resources required for room heating and cooling can be minimized considerably by reducing the heat flow into the building envelope. Hence the HVAC load in commercial buildings may be minimized by judicially designing the building structure parameters i.e. direction, form, walls, fenestrations, shading system and roof.

5.2 Building envelope design process

A building envelope has the primary function of distinguishing and preserving the living conditions of an indoor environment, protecting it from being influenced by sudden changesin seasonal weather. A building envelope design is determined by a variety of factors such as expense, specifications for structural, environmental, and aesthetic efficiency. A list of principal requirements for the design of external walls, extended from the suggested by (Harry, 2016) is given below

1. Heat flow control
2. Air flow control
3. Water vapour flow control
4. Rain penetration control
5. Light, solar and other radiation control
6. Noise control
7. Fire control
8. Structural safety (strength and rigidity)
9. Durability
10. Aesthetic quality
11. Cost
12. Buildability
13. Maintainability
14. Special requirements

5.3 Thermal efficiency of building envelope

The structures are energy-dependent, and existing energy-saving construction codes and energy-saving techniques do not apply. There has been increasing interest in studying the thermal characteristics of building envelopes in recent years to reduce the energy use of buildings (Yang, 2017) optimized energy saving technology (BEEST) for building envelopes to increase the energy efficiency in office buildings. The best combinations of BEESTs appropriate for office buildings were placed forth in various climatic regions and the detailed energy-saving results of the optimum combinations were also analyzed

5.4 Energy efficiency of building envelope

Term energy efficiency involves reducing the amount of electricity required to have warm rooms indoors. When a building requires less electricity from outside to maintain it may be renewable or electricity-efficient according to the qualification for building efficiency, but not sustainable (Dempsey, 2012) A designer's job is to build a structure that retains physical conditions within a given fixed point range and users, company culture, place and other contextual influences have no part to play in ensuring comfort and happiness (Haj, 2008)

5.5 Life Cycle Costing

Life-cycle cost analysis (LCCA) is a way of calculating the overall cost of maintenance of the buildings. This takes into consideration all expenses involved with constructing, maintaining, and disposing of a building or development program. LCCA is extremely helpful because it is important to evaluate project alternatives that satisfy the same efficiency criteria but vary in terms of original costs and running costs in order to choose one that maximizes net savings. (Stazi, 2012) Life cycle cost analysis is suitable for calculating the total expense of the alternatives of a project. It is often used to choose the correct configuration and ensure the selected option has a lower total cost of ownership compatible with feature and efficiency.

Prepare literature matrix from Indian literature and mark the materials. And select those materials for study which score 50 and more than 50%.

Table 1: Indian Literature matrix

MATERIAL	Percentage of LITERATURE talking about material
Brick	75%
Autoclaved Aerated Concrete (AAC) Block	63%
Stone Cladding	63%
Glass	50%
Aluminum Composite panel	50%

VI. PILOT PROJECT

The concept of floats will be applied on a pilot project testing project to analyses the ways and methods of float utilization on a construction project schedule. Prior to pilot project testing, an example of few activities with network diagram is used to demonstrate the process of generation of floats and its optimum utilization. This example acts as a precursor to the pilot project demonstration.

Example –

Table 2: Case study

Typical Floor Size	10483.33 Sq Ft
Number of Floors	12
Floor to Floor height	15’
Total Height	180’
Basement	3

6.1 **Specification of the External Wall**

In specification of external wall and roof calculating the r - value and u – value of specification of various external wall and roofing system.

Table 3: R - Value

Table 4: Specification of Roof

S.NO.	Specification of Roof	U –Value W/m2.K
1.	150 mm RCC Slab + Waterproofng layer + 75 mm brick bat coba + 25 mm cement slurry + 20 mm mortar + 12mm Tile.	1.61
2.	Under deck insulation + 150 mm RCC Slab + Over deck + Water proofing + 12 mm Heat resistant Tile	0.27

Table 5: Specification of External Wall

S.NO.	Specification of Wall	U –Value W/m2.K
1.	Coating of External paint + 20 mm plaster + 230 mm brick + 12 mm plaster + Coating of Internal paint (Brick masonry with paint)	2.56
2.	Coating of External paint + 15 mm plaster + 200 mm AAC Block + 12 mm gypsum plaster + Coating of Internal paint (AAC wall with paint)	0.86
3.	4mm ACP +70 mm air cavity + 20 mm cement plaster + 230 mm brick wall + 12mm plaster (Brick masonry with ACP Cladding)	1.56
4.	4mm ACP +70 mm air cavity + 20 mm cement plaster + 230 mm AAC wall + 12mm gypsum plaster (AAC wall with ACP Cladding)	0.70
5.	30 mm thick stone fix with structure steel frame work with the help of cramp pin etc. + 70 mm air gap + 230 mm brick wall + 12 mm plaster + Internal paint (Brick masonry with Stone Cladding)	1.64
6.	(Double – glazed) External air film + External 6 mm toughened glass + 12 mm air cavity + Internal 6mm float glass + Curtain wall framing + 50 mm air cavity + internal air film	1.69
7.	(Single – glazed) External air film + 6 mm bronze and grey glass incorporated into 100 mm aluminum frame + Curtain wall framing + 50 mm air cavity + internal air film	3.16
8.	RCC + Paint (Shear wall with paint)	0.83
9.	RCC + ACP (Shear wall ACP Cladding)	0.81

R- Vale Calculation				
S.No.	Material	(L) Thickness (m)	(K) Thermal Conductivity (W/mk)	(R)Resistance to heat flow (m2k/w) R = L/K
1	Brick	0.23	0.63	0.36
2	AAC Block	0.2	0.18	1.09
3	Tempered Glass	0.006	1.05	0.01
4	Clear/Float Glass	0.006	0.05	0.12
5	Stone Cladding	0.03	2.36	0.01
6	ACP Sheet	0.004	0.15	0.03
7	RCC Wall	0.3	0.25	1.20
8	Gypsum Plaster	0.012	0.18	0.07
9	Cement Plaster	0.012	1.21	0.01
10	Cement Plaster	0.015	1.21	0.01
11	Cement Plaster	0.02	1.21	0.02
12	RCC Slab	0.15	0.25	0.60
13	Terrace Tile	0.012	0.61	0.02
14	Under decking Glass wool	0.05	0.04	1.43
15	Over decking Rigid Polyurethane foam	0.04	0.03	1.54
16	Heat Resistance Tile	0.12	1.59	0.08
17	Air Cavatiy	0.05	0.31	0.16
18	Air Cavatiy	0.07	0.31	0.22
19	Air Cavatiy	0.012	0.31	0.04

6.2 Construction Cost

In Construction cost may include capital investment costs for Material cost, Transportation Cost and Installation Cost.

6.2.1 Material Cost – In material cost may include cost for purchasing of material.

6.2.2 Transportation Cost – In transportation cost may include cost for transporting material to site with care from their stores/ quarry.

6.2.3 Installation Cost – In installation cost may include cost of fixing of material which include their labour charges and charges of other resources used.

All these costs are put under category of construction cost or Initial cost.

Table 6: Construction Cost of External facade

S.No	Alternatives	Amount
1.	Brick + Paint	15369079.7
2.	AAC + Paint	14415896.4
3.	Brick + ACP	33270583.9
4.	AAC + ACP	32317620
5.	Brick + Stone	18894728
6.	Single Glazing	16176910.5
7.	Double Glazing	17831735
8.	RCC + Paint	21136008.7
9.	RCC + ACP	38592460

Table7: Construction Cost of Roof System

S.No	Alternatives	Amount
1.	RCC + Waterproofing and Tile	29712797.39
2.	RCC + Under decking insulation	73538463.28

6.3 Operation Cost

Operation costs including energy costs are used to keep track of the money that will be needed for such item as fuel and salaries of worker required to operate the facility. The operational Energy for the various combinations of walling and flooring materials were

6.3.1 Space heating and cooling cost

Space heating and Cooling cost is the cost of the electricity required for heating and cooling the specific space or building and how much it reduce due to the thermal performance of building envelope.

Table8: Operational cost of façade system

Operational cost of types of façade system - New Delhi				
S.No.	Alternatives	Operational energy	Electricity Cost	Operational Cost
1	Brick + Paint	1111521	12	13338252
2	AAC + Paint	1022574	12	12270888
3	Brick + ACP	1042577	12	12510924
4	AAC + ACP	1003728	12	12044736
5	Brick + Stone	1045561	12	12546732
6	Single Glazing	1151767	12	13821204
7	Double Glazing	1051504	12	12618048
8	RCC + Paint	1009870	12	12118440
9	RCC + ACP	1008008	12	12096096

6.4 Maintenance Cost

Maintenance cost includes regular care and repair cost, annual maintenance contract costs and salaries of facility staff performing maintenance task. It also include cleaning cost of the material and replacement if any.

Table 9: Maintenance Cost

Maintenance Cost					
S.No.	Alternatives	Cost (per sq.mt.)	Area (Sq.mt.)	Amount	Time
1	Paint Work	150	5485	822750	5 Years
2	ACP Cladding Cleaning	19	5485	104215	6 Months
3	ACP Cladding (New)	1630	5485	8940550	15 Years
4	Stone Cladding	750	5485	4113750	10 Years
5	Glass Cleaning External	19	5485	104215	6 Months
6	Glass Cleaning Internal	16	5485	87760	6 Months
4	Stone floor	750	974	730500	10 Years

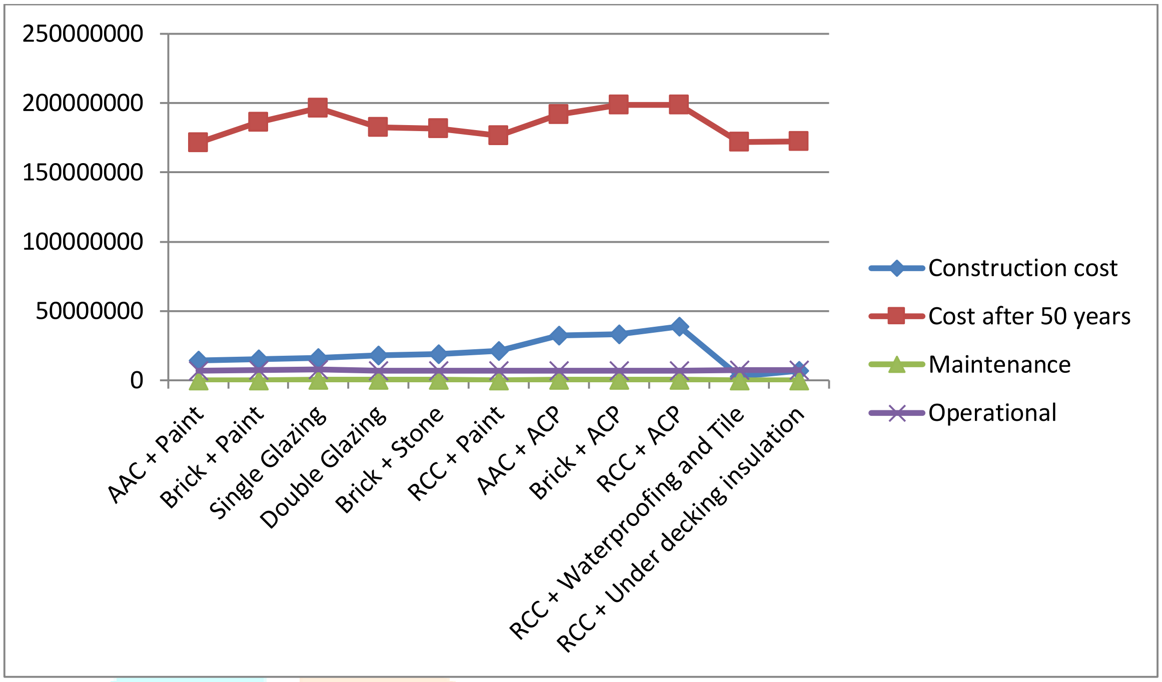
6.5 Inflation Rate and Discount rate

In economics, inflation rate is a increase in the general price level of goods and services in an economy over a period of time. Inflation rate is 4% in India. Discount rate is 12%.

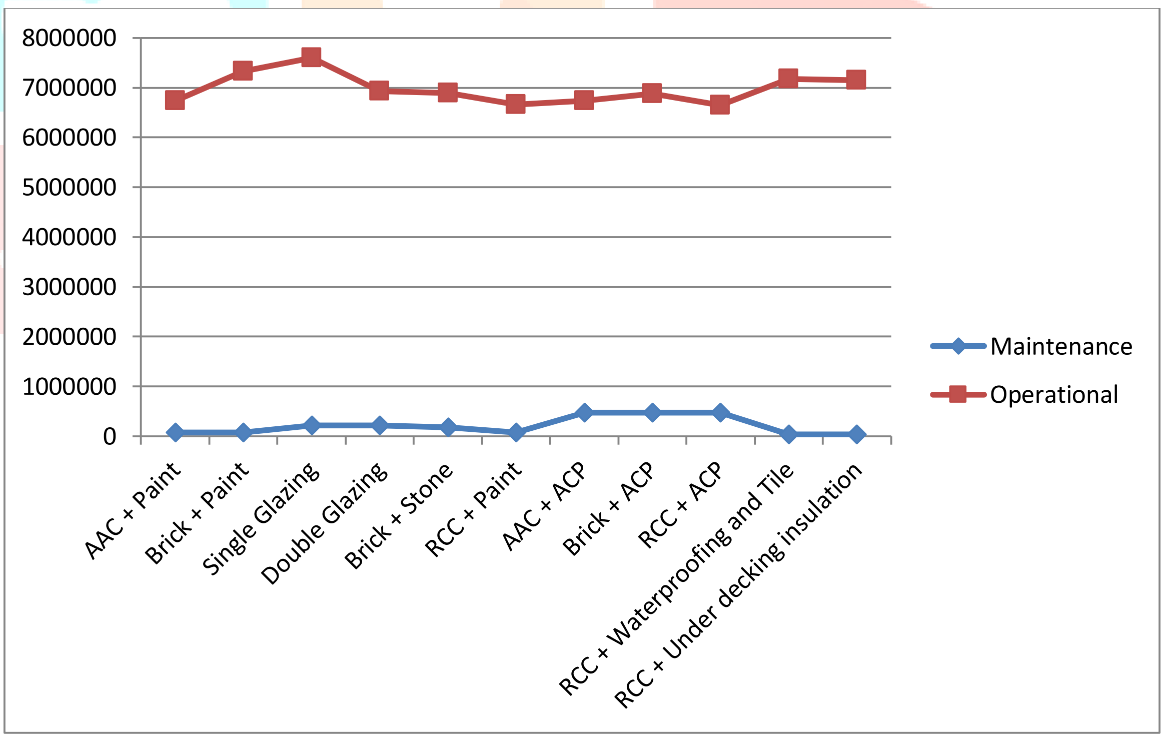
Table 10: Life Cycle Costing

LCC of Brick + Paint in New Delhi Discount Rate = 12% Inflation Rate = 4% Operation Cost = 13338252 Maintenance Cost = 822750						
Years	Construction Cost	Operational Cost	Maintenance Cost	Replacement	Total Cost	PV of cost
0	15369080	0	0	0	15369080	15369080
1	0	13871782	0	0	13871782	12385520
2	0	14426653	0	0	14426653	11500840
3	0	15003719	0	0	15003719	10679351
4	0	15603868	0	0	15603868	9916540
5	0	16228023	1001001	0	17229024	9776211
6	0	16877144	0	0	16877144	8550486
7	0	17552230	0	0	17552230	7939737
8	0	18254319	0	0	18254319	7372613
9	0	18984492	0	0	18984492	6845998
10	0	19743871	0	0	19743871	6356998
11	0	20533626	1266586	0	21800212	6267040
12	0	21354971	0	0	21354971	5481289
13	0	22209170	0	0	22209170	5089769
14	0	23097537	0	0	23097537	4726214
15	0	24021438	0	0	24021438	4388627
16	0	24982296	0	0	24982296	4075154
17	0	25981588	1602635	0	27584223	4017486
18	0	27020851	0	0	27020851	3513780
19	0	28101685	0	0	28101685	3262796
20	0	29225753	0	0	29225753	3029739
21	0	30394783	0	0	30394783	2813329
22	0	31610574	0	0	31610574	2612377
23	0	32874997	2027845	0	34902842	2575409
24	0	34189997	0	0	34189997	2252509
25	0	35557597	0	0	35557597	2091615
26	0	36979901	0	0	36979901	1942214
27	0	38459097	0	0	38459097	1803485
28	0	39997461	0	0	39997461	1674664
29	0	41597359	2565870	0	44163229	1650966
30	0	43261253	0	0	43261253	1443971
31	0	44991703	0	0	44991703	1340830
32	0	46791372	0	0	46791372	1245056
33	0	48663026	0	0	48663026	1156124
34	0	50609548	0	0	50609548	1073544
35	0	52633929	3246645	0	55880574	1058352
36	0	54739287	0	0	54739287	925657
37	0	56928858	0	0	56928858	859539
38	0	59206012	0	0	59206012	798143
39	0	61574253	0	0	61574253	741133
40	0	64037223	0	0	64037223	688195
41	0	66598712	4108041	0	70706753	678456
42	0	69262660	0	0	69262660	593393
43	0	72033167	0	0	72033167	551008
44	0	74914493	0	0	74914493	511650
45	0	77911073	0	0	77911073	475103
46	0	81027516	0	0	81027516	441167
47	0	84268617	5197983	0	89466600	434924
48	0	87639361	0	0	87639361	380394
49	0	91144936	0	0	91144936	353223
50	0	94790733	0	0	94790733	327993
TOTAL COST					**2154150201**	**186039696**

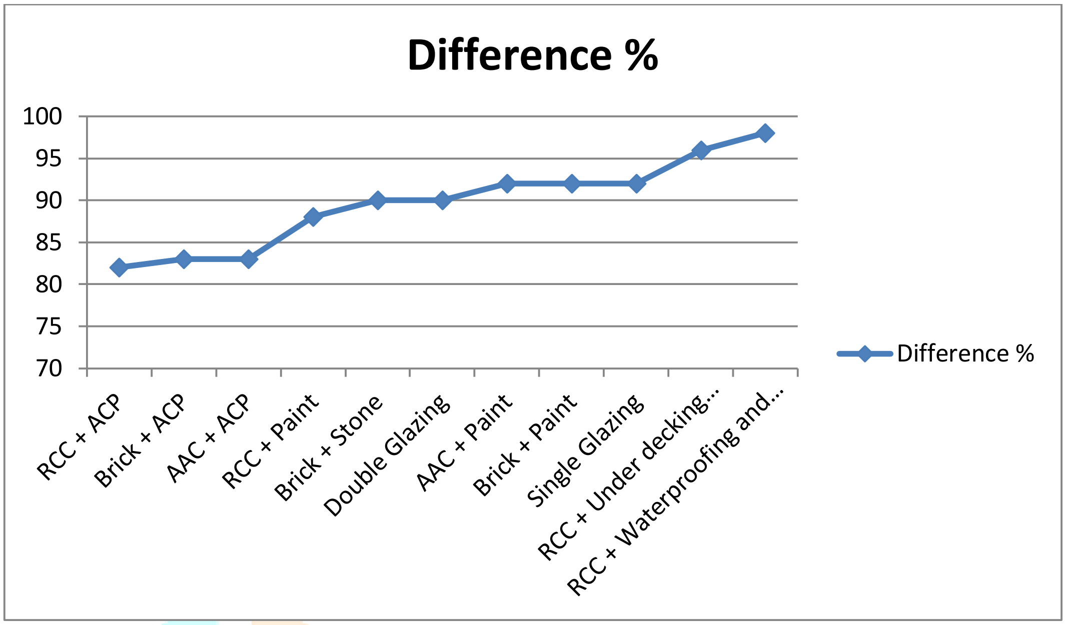
Graph 1: Case Study - 1 Life Cycle Costing



Graph 2: Case Study - 1 Maintenance and operational cost



Graph 3: Case Study - 1 Difference % of maintenance and operational cost



VII. CONCLUSION AND INFERENCES

This study investigate cost effectiveness of nine external façade system and two roofing system by determining their life cycle cost in a 50 year period for 4 major Indian cities. Construction cost, space heating and cooling cost, maintenance cost, inflation rate and discount rate are considered in the life cycle cost calculation. It is found that cost of Brick wall is less than AAC Wall and RCC wall in terms of construction cost but in terms of operational cost, cost of RCC wall and AAC wall is lesser than brick wall.

For Cladding material, it is concluded that Construction cost of ACP Cladding is higher than paint, glazing and stone cladding. But the cost of ACP cladding is lesser in terms of operational cost from paint, glazing and stone cladding.

For roofing system, It is analyzed that construction cost of under decking insulation is more than waterproofing and tile but the operational cost of under decking insulation is less than water proofing and tile roofing.

This paper can help designers in determining the most cost effective external façade at an early planning stage.

VIII. ACKNOWLEDGMENT

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