Civil Engineering and Architecture 9(2): 357-374, 2021 http://www.hrpub.org
DOI: 10.13189/cea.2021.090209

Materializing Low-Cost Energy-Efficient Residential Utility through Effective Space Design and Masonry Technique - A Practical Approach

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Received December 6, 2020; Revised January 6, 2021; Accepted February 25, 2021

Cite This Paper in the following Citation Styles

***(a):** [1] Hamna Bukhari, Wesam Salah Alaloul, Muhammad Ali Musarat, Sohail Akram, Iqra Tabassum, Muhammad Altaf, "Materializing Low-Cost Energy-Efficient Residential Utility through Effective Space Design and Masonry Technique - A Practical Approach," Civil Engineering and Architecture, Vol. 9, No. 2, pp. 357 - 374, 2021. DOI: 10.13189/cea.2021.090209.*

***(b):** Hamna Bukhari, Wesam Salah Alaloul, Muhammad Ali Musarat, Sohail Akram, Iqra Tabassum, Muhammad Altaf (2021). Materializing Low-Cost Energy-Efficient Residential Utility through Effective Space Design and Masonry Technique - A Practical Approach. Civil Engineering and Architecture, 9(2), 357 - 374. DOI: 10.13189/cea.2021.090209.*

Abstract The swiftly mounting world energy consumption has sparked questions regarding supply constraints, the collapse of energy resources, and dense environmental effects. Although the construction industry has much developed, yet construction is still a difficult, and costly process. Consequently, there is a necessity to find additional energy-efficient and cost-saving substitutes to sustain the urbanization of houses at a reasonable price to low-income groups. This study aims to provide an energy-efficient proposal for a housing scheme with strict control over cost allowing the low-income groups to enjoy livability stemming from the thermally comfortable and cost-saving technology. For this purpose, visits and surveys were carried out to critically analyze the respective housing scheme. Two proposals were suggested i.e. Proposal A by applying a low-cost technique called a Rat-trap bond to the walls and Proposal B, by designing an architectural plan for proficient utilization of space along with Rat-trap bond. Proposal B is highly recommended for construction as it saves 799 units of electricity and is 28% cost-effective during the construction phase than the existing housing unit. Summarized results were prepared from cost analysis and Ecotect analysis which ascertains the proposal to be energy efficient in addition to low cost. It is recommended to invest in cost-effective and energy-efficient technologies at the governmental level so that the challenge of inadequate housing can be answered once and for all.

Keywords Low Cost, Energy Efficient, Space Design, Thermal Load, Sustainable Construction

1. Introduction

Developing countries are facing an immense challenge regarding the provision of shelter particularly for low-income groups [1, 2]. The population of the developing countries is increasing dramatically, while most of the families are middle class having income below than average [3]. Millions of families are forced to live in unhygienic conditions and underprivileged living scenarios. Therefore, the governments, city administration, and metropolitan authorities are confronted with the task of providing quality accommodation to low-income families.

By the year 2030, an estimated number of 2.8 billion people need to be accommodated with a decent living environment and efficient urban services [4, 5]. Currently, about 3.3 billion, a 50% of the world's population, is living in urban areas, whereas by the end of 2030, 5 billion people will be residing in cities, which would be 60% of the world's population [6]. Although such demographic predictions could be subject to discussion, it is apparent that millions of new homes would have to be constructed to meet the rising population. Thus, the need for large-scale housing development every year, while the provision of such enormously scaled housing development and the supply of the requisite construction materials both will be challenging in the future.

In developing countries, existing sites and housing programs reflect a significant breakthrough in shelter policies, which are mostly funded by local or foreign assistance organizations [7, 8]. The aim of such projects by the government and the assistance organizations is to provide standard shelter facilities, depending on the capacity and willingness to pay off the expected recipients [9, 10]. The key concern of these initiatives is to provide low-income families with accommodation and quality services utilizing low to no subsidies [11, 12].

Keeping this challenge in mind for a country like Pakistan [13], the idea of providing low cost as well as energy-efficient housing is indispensable. The exploration of feasible and practical solutions to meet the residential demands of the growing population is the need of the hour. This research aims to propose an energy-efficient plan for a low-cost housing scheme, thus creating thermally comfortable spaces through proper space design and with the application of an innovative construction approach i.e. Rat-trap bond. Two proposals; Proposal A and Proposal B, had been suggested. Proposal A utilized only the proposed masonry technique (Rat-trap) whereas Proposal B utilized both the masonry technique as well as the proposed space design. Both are efficient than the existing housing unit (as-built). Among these, Proposal B is the recommended solution because its thermal load and cost-saving character is efficient than that of the existing housing unit and Proposal A. The proposed scheme would assist in setting up a trend that construction and energy efficiency both should run hand in hand to avoid undue energy usage while maintaining the comfort level.

2. Literature Review

Low-cost housing is an innovative approach to lower construction costs and optimizing running costs during the building life cycle, providing feasible accommodation for low-income groups to buy or rent [14-19]. Optimal construction solutions are implemented for low-cost housing schemes and are under consideration for further research to achieve affordable shelters and suitable indoor thermal environments for the community [20-23]. Large-scale housing solutions are already being introduced, providing a vast production of low-cost apartment buildings [24-26]. Specific cost-effective construction techniques and specifications were compared to conventional construction techniques [27, 28]. Similarly, the impact of monsoon weather cycles was evaluated to mitigate the downtown impact on low-cost houses [29, 30]. Besides, the difficulties encountered in the transportation of materials in developed countries are being tested towards design and construction programs [31-33].

Space design is a central part of the building interior design process which is adopted by the experts to optimize energy consumption and enhance living standards [34, 35]. It continues with an in-depth analysis of how the room is to be utilized. A plane is drawn that describes the space areas and the events that will take place within these zones. The space plane would also describe the trends of flow that demonstrate how people move around space. The space standards and construction requirements for low-cost housing are insufficient to satisfy the needs of household activities [36, 37].

The optimum temperature of the human body is 37 ± 0.5 °C (97.7–99.5 °F), regardless of environmental factors, and is dependent on human physiological requirements. Therefore, it is considered necessary to sustain indoor temperature conditions in buildings that meet the thermal comfort standards to boost human efficiency and performance [38-40]. It is noted that the buildings consume more energy during their operational period for heating and cooling, which becomes uneconomical in the long run [41, 42]. Therefore, it is very important to adopt optimal design strategies for buildings to keep energy demand at a minimal level during the operational period [39]. The passive technique used to minimize mechanical air conditioning depends on the thermal insulation of roofs and walls. Diverges in other techniques are being developed for the enhancement of indoor thermal conditions, such as the architectural shading, the very low Solar Heat Gain Coefficient (SHGC) [43-46].

Several studies were conducted to evaluate the various type of wall systems with better thermal performance than conventional wall systems [46-50]. The focus of the research was to assess sustainability as well as the indoor thermal performance of the low-cost housing scheme. Fiber reinforced mortar (FRM) and thermally enhanced sustainable hybrid (TESH) bricks have been produced by refining the mixing design utilizing Glass Powder, Palm Oil Fly Ash and Oil Palm Fibers [51]. The FRM and TESH bricks, which are part of the TESH wall framework, have been analyzed for physical, mechanical, and thermal efficiency and conform with the different standards of conduct for construction materials [44]. The thermal conductivity and the heat transfer rate via the wall device were observed to be significantly lower than the traditional wall systems. The power usage study has revealed a 10.6% decrease in energy consumption for the TESH wall system over the traditional wall system. The overall cost of energy for the house was also lowered by 10.2% for the TESH wall system.

In hot and humid climates, the residential and commercial buildings are often equipped with ventilation and air conditioning systems to prevent uncomfortable indoor thermal conditions [52, 53]. Whereas the low-income groups, who cannot afford the mechanical means of HVAC technologies because of financial constraints, face the challenge of the offensive thermal indoor climate. Therefore, it is required to find alternative options that give lesser-income residents a greater likelihood of handling indoor thermal conditions without burdening themselves with expensive technologies or building designs in various climate conditions [54].

Due to their highly embodied energy, traditional construction materials have negative environmental implications (clay bricks: 2.0 kWh per brick; cement bricks: 1.5 kWh per brick) [55-57]. In anticipation of this issue, several researchers explored the use of waste materials for the manufacturing of bricks [58, 59]. However, there is also a shortage of functional applicability in the use of sustainable wall materials. Another construction material is the gypsum fiber reinforced glass board (GFRG), which was originally developed in Australia as a prefabricated building product manufactured from calcined gypsum, plaster, reinforced with glass fibers. It was adopted as a method of low-cost housing by constructing walls from GFRG boards. Its panel size is 12m long, 3m high, and 124mm thick. Although having lightweight, low cost and high construction speed, this technique cannot be adopted as it requires a manufacturing industry first [60].

A masonry technique called Rat-trap was extracted from the literature review. A Rat-trap bond is a type of wall brick masonry in which the bricks are mounted on the edge such that the shiner and the rowlock are evident on the masonry surface [61]. The placement of the bricks is made such that a 3” cavity is created in the wall. This is the prime reason where traditional products such as brick clay and cement can be saved dramatically. Also, because of the creation of a cavity, this technique becomes energy efficient too. For best Rat-trap brickwork, there should be no half bricks/quarter bricks used in brickwork, as compared to their typical usage in traditional brickwork [61]. This would distract the stunning joints in Rat-trap brickwork and impact the reliability of the brickwork. A module of the Rat-trap bond is presented in Figure 1. The technical details of the bond are already present in the body of knowledge; therefore, it is unnecessary to requote the details [62-65]. This research seeks to keep the cost low therefore such a technique had to be selected, which is feasible to the local circumstances. Hence, the technique selected was the utilization of a Rat-trap masonry bond.

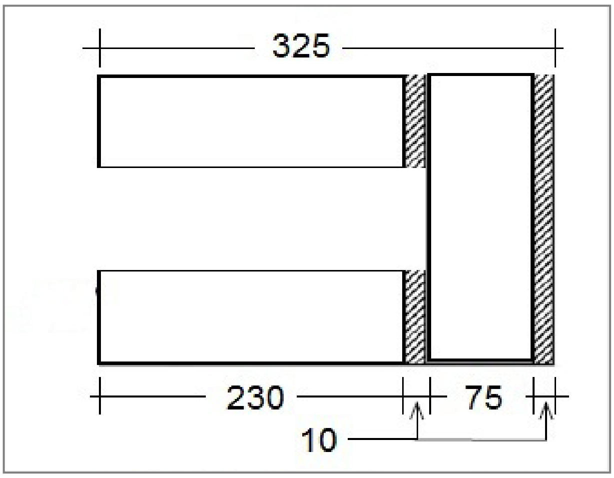


Figure 1. Module of Rat-trap Bond using a brick of size 230mm x 75mm x 115mm

3. Methodology

The methodology consists of six stages to achieve the research aim which is to propose a cost-effective and energy-efficient solution for a housing unit as shown in Figure 2. In the first stage, the need for research was established keeping in view the request for proposals from the government. The basic information about the kind of housing scheme was gathered. In the second stage, the housing society was critically analyzed with the help of visits and interviews. Interviews were made with residents of the society and authorities. The housing society and the site offices were visited. The third stage is about the literature review. As the objective was to recommend a proposal that is both energy-efficient and cost-effective, therefore, the body of knowledge was searched thoroughly for efficient space designs and low-cost construction techniques. In the fourth stage, with the help of the literature and critical analysis of the housing scheme, a new space design was proposed, and the construction technique was selected. Later, the analysis was conducted in the fifth stage. The analysis was performed using three techniques, i.e. a) Comparison of space design, b) Thermal load analysis, and c) Cost estimation. From these analyses, results were inferred in the last stage of the research. The solution was proposed and discussed along with future research directions in the sixth stage.

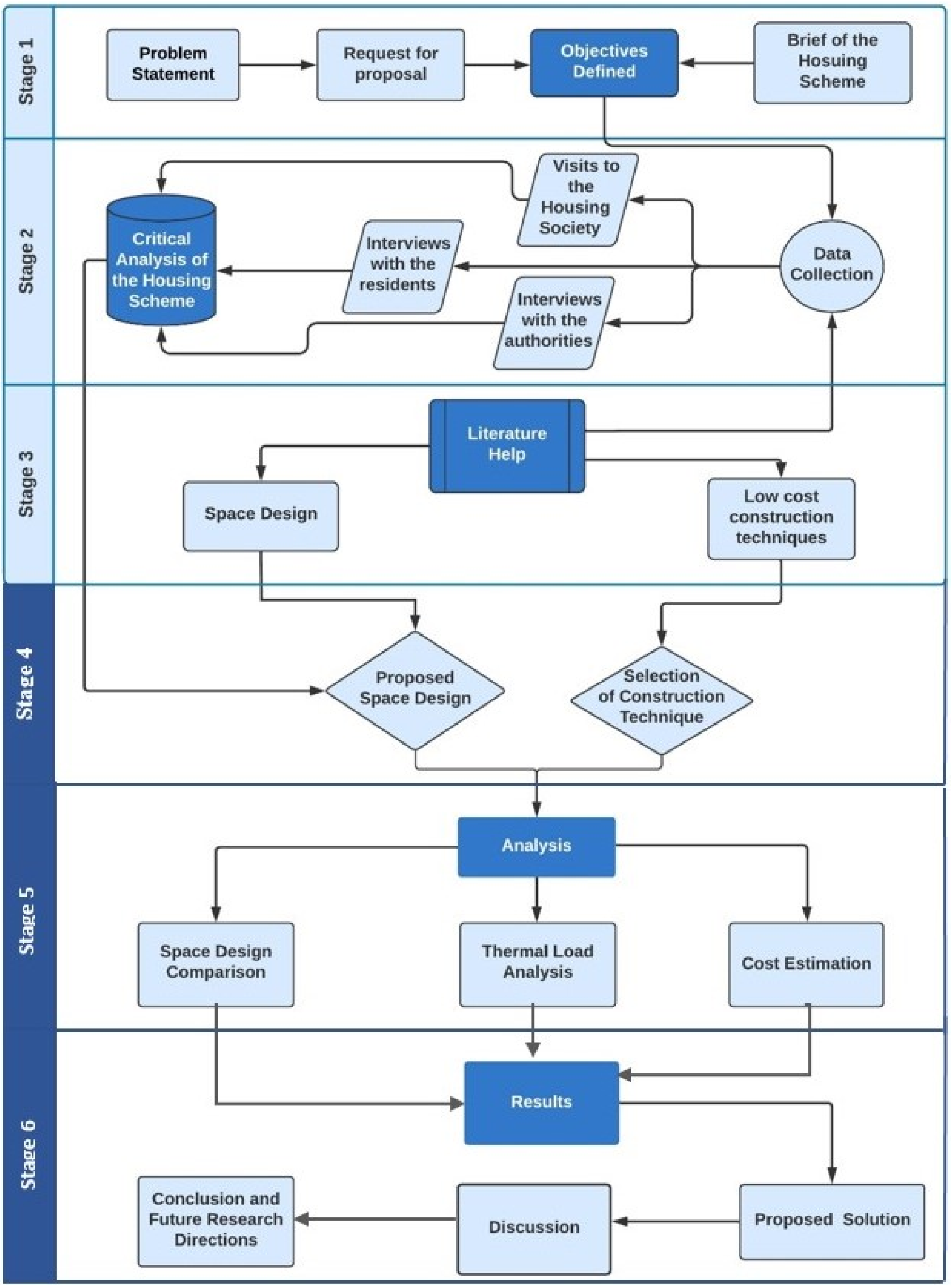


Figure 2. Methodology of Research

4. Overview of the Housing Scheme

Land and urban development in Punjab, a Province in Pakistan, are under tremendous pressure from unchecked urban expansion and lack of accommodation and social facilities. Forcefully alarmed by the ongoing crises of housing and human settlement, the Government of Punjab launched a housing scheme, especially for the low-income group. The purpose was to deliver reasonable and decent housing units with all the required up-to-date amenities to low or middle-class families who cannot afford their own homes. 380 acres of land has been suggested for the development of flats and houses under this housing scheme and other amenities.

In phase 1, it has launched two housing societies in Lahore; one of the two societies has been constructed. In the future phase, phase 2, it will be extended to other major cities of the province where 125 and 100 houses will be constructed in Sahiwal and Faisalabad respectively, and 200 houses each in Bahawalpur, Kasur, and Chiniot. The societies will have all the modern living requirements like carpeted roads, sewerage, drainage, water supply, electricity supply, and facilities like schools, parks, commercial areas, community centers, playgrounds, health care centers, etc.

4.1. Critical Analysis of the Constructed Housing Scheme

To put forward a practical proposal, it was imperative to analyze the housing scheme critically. For this purpose, data collection was done in two stages i.e. through a) visits & b) interviews. The first visit was to the developer. The management showed interest in having a solution that is not only low cost but energy efficient as well. The second visit was to the site office. the developer provided the required data, arranged visits to the community, Nespak site office, and Bahria site office.

The space design of low-cost housing is of much importance [66]. Different questions were asked from the residents of the society regarding the house design, its deficiencies, comfort level, required additional changes, different means which they adopt for thermal comfort in summers and winters, opinion about precast houses and recommendations for the upcoming schemes, etc. As the residents belong to the low-income class so they seemed content with what they had. The existing space design of the housing scheme is shown in Figure 3. After visiting the society and conducting interviews, the following issues have been observed in phase 1 construction:

- There are no shades upon windows.
- At the terrace, the wall height is short, and it disturbs the privacy of residents.
- When it rains, the rainwater penetrates inside.
- The water storage system is placed at terrace without any shades, so it receives direct sunlight and water gets hot in summers and cold in winters resulting it difficult to use.
- It has got maintenance issues.
- The roof and walls have developed cracks.
- Electrical wiring design is poor in some places.
- Seepage issues have also been observed.
- Some units do not receive sunlight.
- Considering the houses are low cost, some residents are satisfied with the comfort level of the house. According to them, a house of their own is more than enough for them, but critically it needs amendments.
- In winters, warm clothing and coal are used for heating purposes. Some people use heaters as well.
- In summers, fans and room coolers are used. As far as room coolers are concerned, in August and September, they are not efficient and do not work well because of humidity issues.
- Opinions about prefabricated houses vary. According to some, these are efficient and modernized and according to other traditional ways of construction imparting more strength to the buildings.
- Extension of main gate and car parking is a general requirement.
- Residents require the front area to be involved in the house.
- The size of the washroom is small.
- Kitchen and bedroom sizes may vary.
- There is room for better ventilation and shades should be provided.
- The store is very important, and planning should incorporate space for it.
- Space Design can be made better.

(a) Ground floor (b) First floor

Figure 3. Existing design

5. Analysis and Results

Two proposals (Proposal A and Proposal B) are made against the government's call for proposals. Both are thermally efficient and cost-effective than the existing housing units. Thermal load analysis and cost estimation were done for an existing housing unit, Proposal A, and Proposal B. Analysis and results in part of the research consists of three phases i.e. I) Space design and comparison, II) Thermal load calculation and comparison, and III) Cost estimation and comparison.

5.1. Space Design and Comparison

Following the feedback received from the residents of the housing society and visits made, a space design is suggested in Proposal B as shown in Figure 4, in phase I. The dimensions of the plot were modified with the consultation of the developer. The increases or decreases in different areas were made according to the requirements. The patio was placed in the center of the house. Because of the central position of the patio, there would be maximum ventilation and minimum heat gain. The kitchen was designed at the outer periphery of the house because the kitchen is the major source of heat gain. In the existing space design of the housing scheme, the kitchen is in the center of the house.

5.1.1. Comparison of existing and proposed space designs

The comparison of the new space design of Proposal B with the existing 787 ft^2 plan was made. In the suggested space design, essential modifications are made that enhance the mobility of the inhabitants and ensure the living standards as shown in Table 1. In Proposal B, space has been incorporated wisely such that the area becomes spacious and user friendly. It has improved air circulation and it receives more natural light too.

Table 1. Space design comparison of existing plan with Proposal B

Comparison of Space design			
Components	Existing	Proposed	Area increased
Kitchen	5'-10" X 10'	11' X 7'	18.5 ft^2
	58.5 ft^2	77 ft^2	
Bedroom	10' X 11'	11' X 11'	11 ft^2
	110 sq ft^2	121 ft^2	
Bathroom	6' X 4'-4.5"	7' X 5'	8 ft^2
	27 ft^2	35 ft^2	
Patio	Backside	Centre	
Terrace	Backside	Front	
Total Covered Area	787 ft^2	769 ft^2	

(a) Ground floor (b) First floor

Figure 4. Space design for suggested Proposal B

5.2. Thermal Load Calculation and Comparison

For thermal load analysis, in the second phase, different software were taken into consideration which was overruled because of certain limitations as shown in Table 2.

Table 2. Different software limitations

Software	Limitations
EnergyPlus	It is used for modeling complex systems, but it consumes more time.
	It gives text-based results.
Elite Chvac	There is no option for specifications of the window. For each wall, windows are defined individually.
	To find out the change in one zone, it requires the calculation of all zones.
Hap	It does not work out for orientation analysis and shading geometries.
IES	It has a very long steep learning curve.
Design builder	It is limited to work with one type of window per surface.
	Therefore, this software was overruled.

5.2.1. Selected Software

The Ecotect software was selected to evaluate the house for its cooling and heating load. It is an effective tool for evaluating the data generated by the simple collection of weather data in which the building is located. Ecotect software is not restricted to material specifications as it can incorporate different materials placed on the same surface. Thermal load calculations at different times of the year can also be calculated. Moreover, by using it, any required orientation can be taken into consideration and different areas for measurement of heat gain/loss can be computed separately. Because of these features, this software best suited the research under discussion.

A 3D model of the house built in Ecotect software is shown in Figure 5. Lahore has a blended climate with humid, long, and exceptionally hot summers, cold foggy winters, monsoon, and dust storms. The weather in Lahore, a city of Punjab, is intense during May, June, and July when temperatures increase to 40-48°C (104-118 oF). The Monsoon season begins from late June to August, with heavy rainfall in the province.

Thermal load (Ecotect) analysis was done in four stages: 1) Thermal load analysis of the existing housing unit with conventional construction, 2) Thermal load analysis of Proposal A having Rat-trap Bond i.e. Analysis of the existing housing unit constructed by using the Rat-trap Bond 3) Thermal load analysis of Proposal B with suggested space design and masonry technique (Rat-trap Bond), and 4) Comparison of thermal loads and saving of existing housing unit, Proposal A and Proposal B.

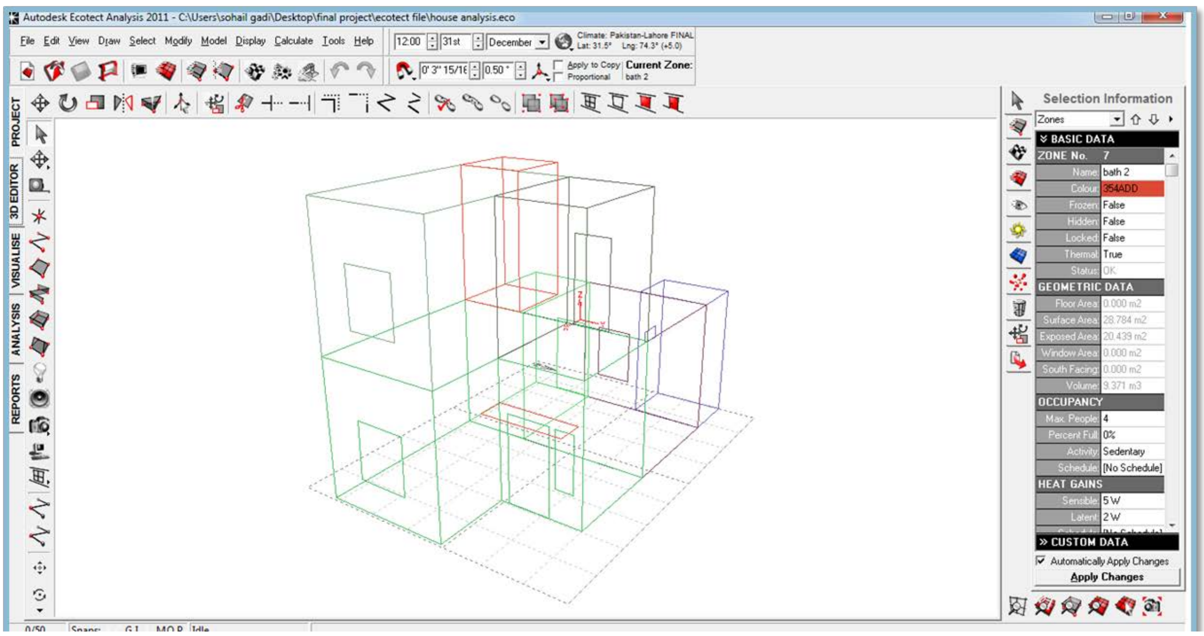


Figure 5. 3D Model on Ecotect

5.2.2. Existing housing unit with conventional construction

In the first stage of thermal load analysis, the monthly heating and cooling load of the existing housing unit constructed by the conventional method was calculated. The details of which are attached in Appendix A. Monthly distribution of loads as calculated by Ecotect is given in Appendix B. Maximum heating is required in January and maximum cooling is required in June. Annually 2467.78 KWh of energy is required to achieve the comfort zone 18-26 °C (64.4- 78 °F) of this house. Figure 6 shows the monthly electricity cost of the conventional construction house.

During summers, the electricity bills are maximum. In the peak summer months, from May to August, the cost of the bill per month is greater than USD 35.

In the second stage of thermal load analysis, the same existing housing unit constructed with the Rat-trap bond i.e. Proposal A was analyzed for thermal loads. The details of the monthly heating and cooling load of the house are given in Appendix C. Monthly distribution of loads as calculated by Ecotect software is given in Appendix D. Maximum heating is required in January and maximum cooling is required in June. Annually 1698.78 KWh of energy is required to achieve the comfort zone 18^0 - 26^0 (64.4- 78 °F) of this house. Figure 7 shows the monthly electricity cost of the conventional construction house built with a Rat-trap bond.

It is evident that only by replacing the conventional construction method with a Rat-trap bond, there is a significant decrease in the electricity bills. The cost of the bill in the month of summers has remained below USD 30.

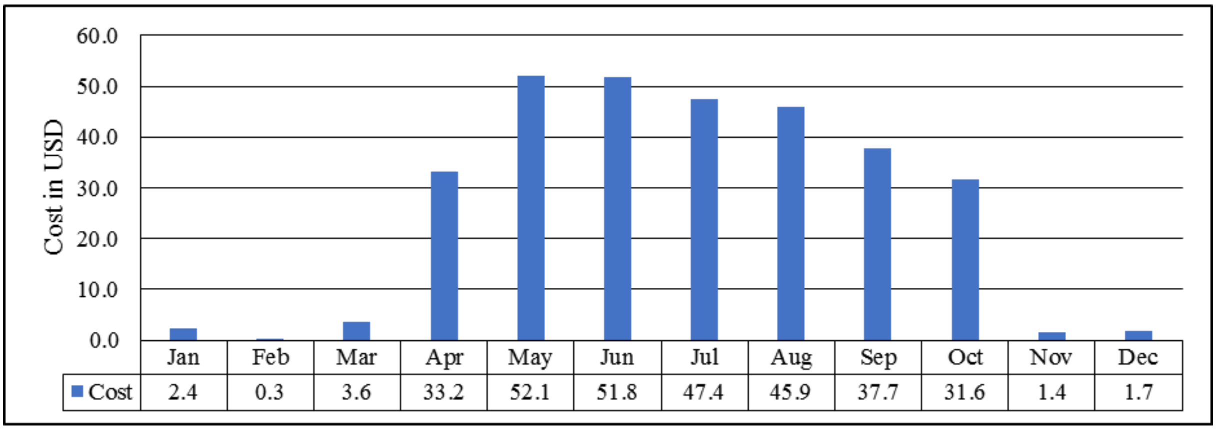


Figure 6. Monthly electricity cost of existing housing unit with conventional construction

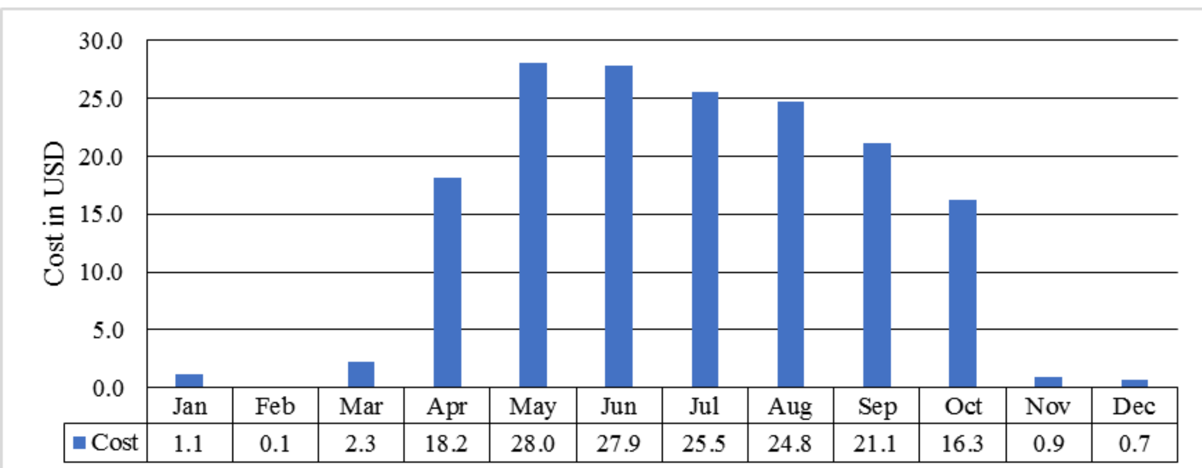


Figure 7. Monthly electricity cost of existing housing unit built with Rat-trap bond (Proposal A)

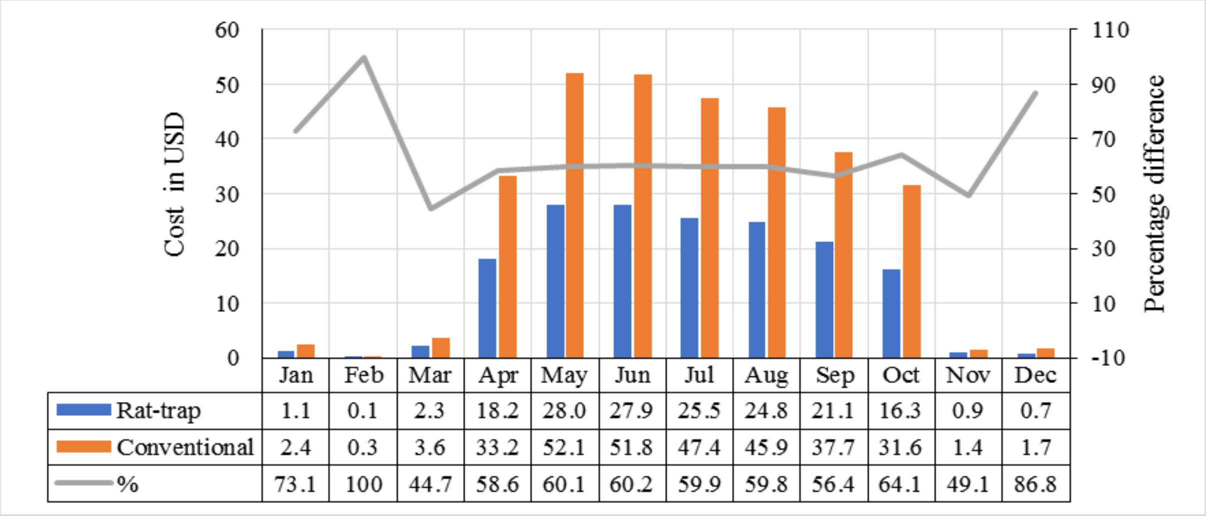
Figure 8 shows the electricity bill comparison of both the options (Existing housing unit and Proposal A) per month. The cost of electricity consumption in the Rat-trap bond house is much lower than the conventional construction house. The cost of the electricity overall reduces to 46% which means a decrease in the operational cost.

The comparison shows that the operational cost of the existing housing unit is greater than Proposal A. Rat-trap construction helps in lowering the operational cost of the building too, which becomes a lifelong character of the building. In Proposal A, none of the monthly bills has increased from USD 38.20 as in the case of the existing housing unit. A straight cut of more than USD 9.55 per month can be achieved in the summertime as the billing of existing housing is above USD 38.20 and the billing of Proposal A is below USD 28.65.

5.2.5. Analysis of proposed space design with proposed masonry technique (Rat-trap Bond) - Proposal B

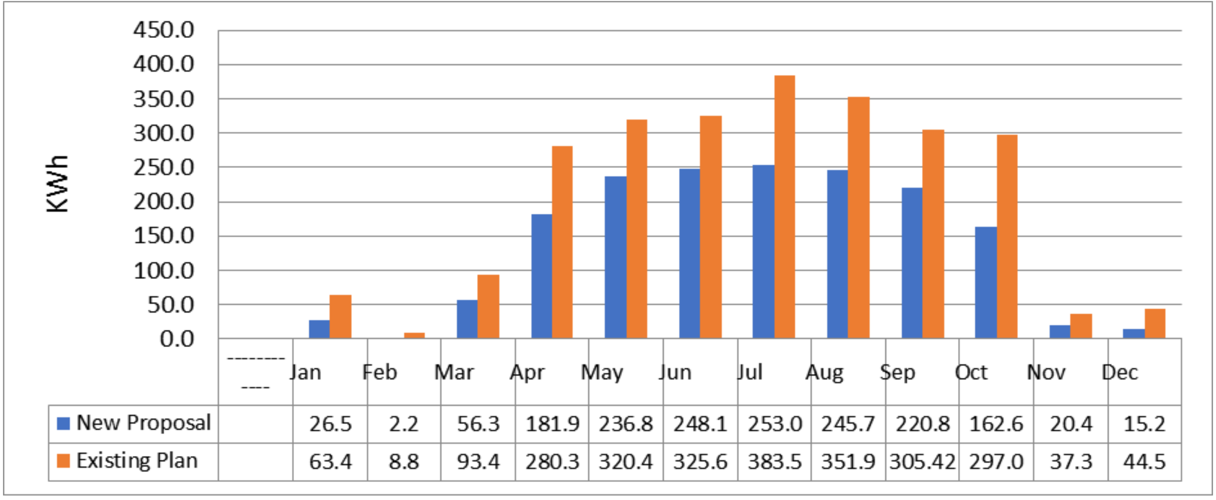
In stage 3 of thermal load analysis, the proposed house plan as shown in Figure 4 was analyzed using the proposed construction technique (Proposal B). The results were found very satisfactory. The details of the monthly heating and cooling load of the house are given in Appendix E. Maximum heating is required in January and maximum cooling is required in June. Annually 1669.48 KWh energy is required to achieve the comfort zone (18^o – 26^o) of this proposed design. Figure 9 shows the thermal load comparison of the Existing housing unit and Proposal B. The load of the Existing housing unit is greater than the new proposed house testifying the upper hand of Proposal B.

Thermal load comparison of Existing housing units and Proposal B shows a prominent difference in energy consumption. Both options consume the greatest amount of energy in July, but the energy consumption of the Existing housing unit is 383.5 KWh and the energy consumed by Proposal B is 253 KWh which is quite less than the former.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rat-trap	1.1	0.1	2.3	18.2	28.0	27.9	25.5	24.8	21.1	16.3	0.9	0.7
Conventional	2.4	0.3	3.6	33.2	52.1	51.8	47.4	45.9	37.7	31.6	1.4	1.7
%	73.1	100	44.7	58.6	60.1	60.2	59.9	59.8	56.4	64.1	49.1	86.8

Figure 8. Electricity cost comparison of existing housing unit and Proposal A



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New Proposal	26.5	2.2	56.3	181.9	236.8	248.1	253.0	245.7	220.8	162.6	20.4	15.2
Existing Plan	63.4	8.8	93.4	280.3	320.4	325.6	383.5	351.9	305.42	297.0	37.3	44.5

Figure 9. Thermal load comparison of existing housing unit and Proposal B

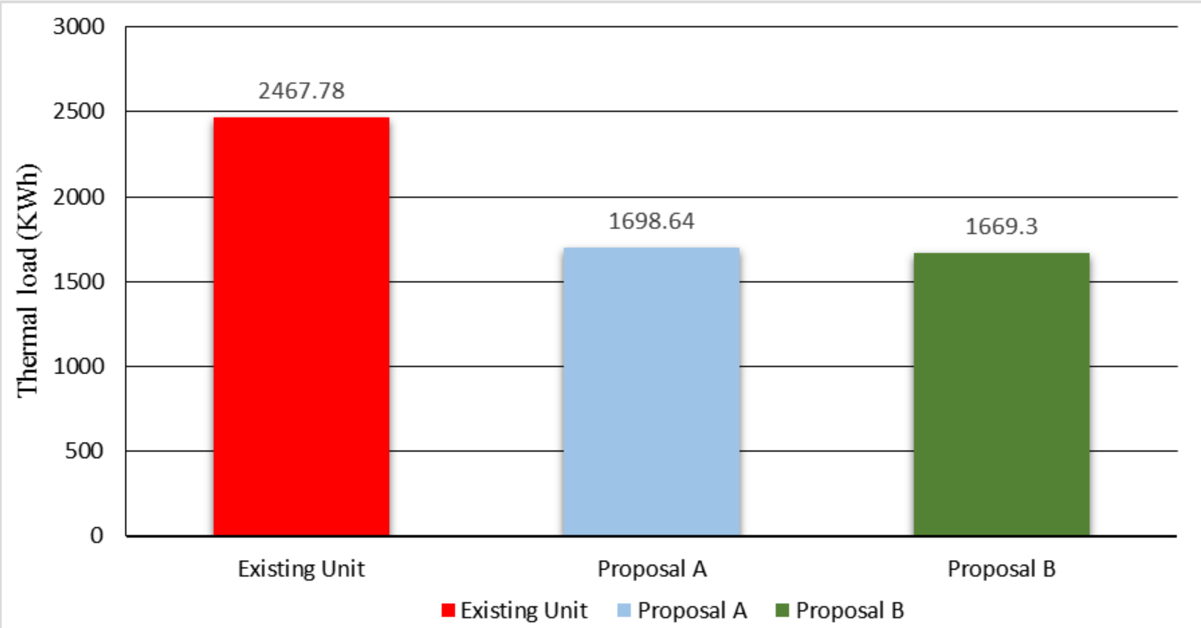


Figure 10. Annual thermal load comparison

5.2.6. Comparison of thermal loads and saving of Existing unit, Proposal A and Proposal B

The last stage of thermal load analysis is the comparison of different housing units. The annual thermal load of the Existing house with conventional masonry technique is 2467.78 KWh per year, 1669.3 KWh for the same unit built with Rat-trap bond (Proposal A) and 1669.3 KWh for Proposal B to achieve thermal comfort as shown in Figure 10. It indicates that among the three design options, Proposal B is best in terms of thermal load performance.

The two proposed options are also compared with the existing unit in terms of units of electricity saved annually from the overall society. Proposal A saves 769 units of electricity per house per year whereas Proposal B saves 799 units per house per year. The details are given in Table 3. With these details from the thermal analysis portion, it is evident that the first objective of imparting thermal efficiency to the housing unit has been achieved from both Proposals. Although the recommended option is Proposal B as it is greater in efficiency when compared to the other option.

Table 3. Thermal load saving from society

Thermal Load Saving in the whole Society		
	Proposal A	**Proposal B**
Thermal Load saving per house per Year	769 units	799 units
No of Houses in Society	2500	2500
Total saving from the Society	2500 X 769	2500 X 799
Total No of Units Saved annually	1922500 KWh	1997500 KWh

5.3. Cost Estimation and Comparison

Phase 3 is about the cost estimation of the Existing housing unit and proposed housing unit i.e. Proposal B. It is a difficult task to achieve energy efficiency by keeping the cost low. Rat-trap is a technique that is not only energy efficient but is also cost-effective. Cost estimation of the housing units was done in three stages: 1) Analysis of the Existing housing unit with conventional construction, 2) Analysis of proposed space design and proposed masonry (Rat-trap Bond) i.e. Proposal B & Comparison of Existing housing unit and proposed Proposal B.

Detailed estimation is provided in Appendix 1, 2 and 3 in which the cost and quantity estimation for brick masonry is shown for ground and first floor. In stage 1, the cost estimation of the Existing housing unit was performed. Table 4 shows the materials quantity and labor cost of the brick masonry of the house. Only the superstructure of the house is considered. It shows that is 19265 no. of bricks, 81 no. of cement bags and 505 cft of sand is used in the existing housing unit constructed with the conventional construction method.

Table 4. Estimation details of existing housing unit

Items	Quantity	Units	Rate	Cost (USD)
Bricks	19265	no.	0.08	1656.2
Cement	81	bags	4.77	386.9
Sand	505	cft	0.19	96.5
Mason	72	days	9.55	687.7
Labor	48	days	4.77	229.2

In stage 2, the estimation for material quantity and labor cost for brick masonry of the proposed plan when constructed with Rat-trap (Proposal B) is given in Table 5. It also includes the superstructure of the building. It requires 13540 no bricks, 69 no. of cement bags and 341 cft of sand.

Table 5. Estimation details of Proposal B

Items	Quantity	Units	Rate	Cost (USD)
Bricks	13540	No.	0.08	1164
Cement	69	bags	4.77	329.5
Sand	341	cft	0.19	65.1
Mason	50	days	9.55	477.6
Labor	34	days	4.77	162.2

Stage 3 is about the comparison between the material cost of the Existing housing unit and proposed Proposal B. It shows that the cost of bricks for the existing unit is higher than that of the proposed construction. The same is true for cement and sand cost as shown in Figure 12.

The labor and mason cost has also been compared as shown in Figure 13. As the material cost of the Existing housing unit (conventional construction) is higher than the proposed Rat-trap construction, similarly, the labor cost of conventional construction is also higher than that of conventional construction. The difference for mason cost is USD 210.14 and for labor cost is USD 66.86.

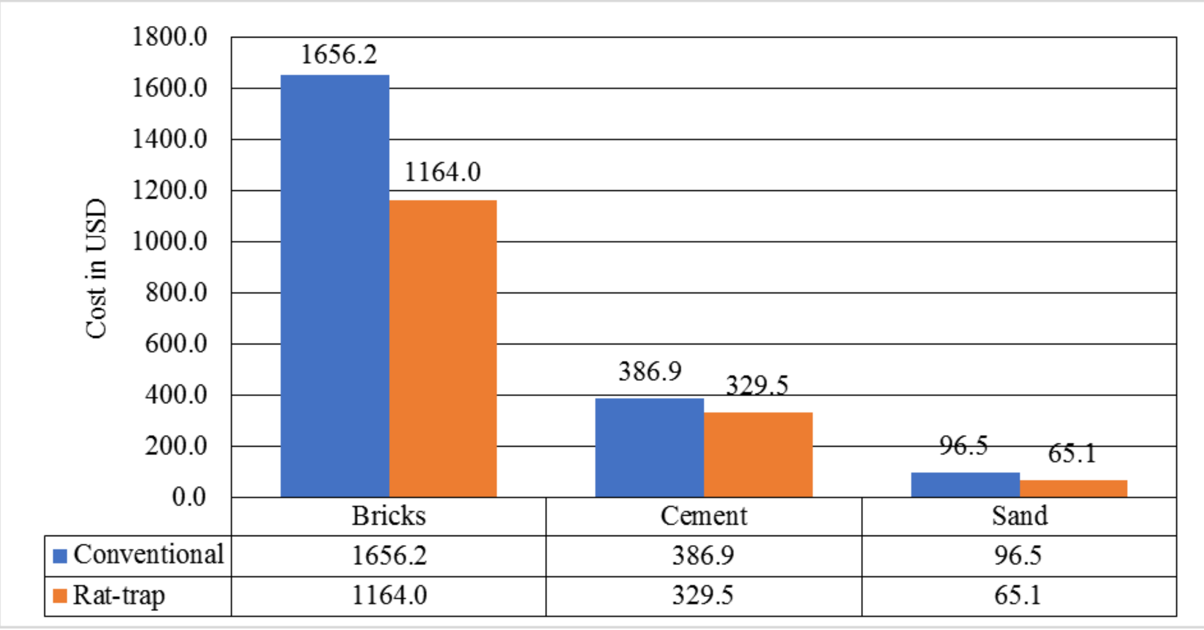


Figure 12. Materials Cost Comparison

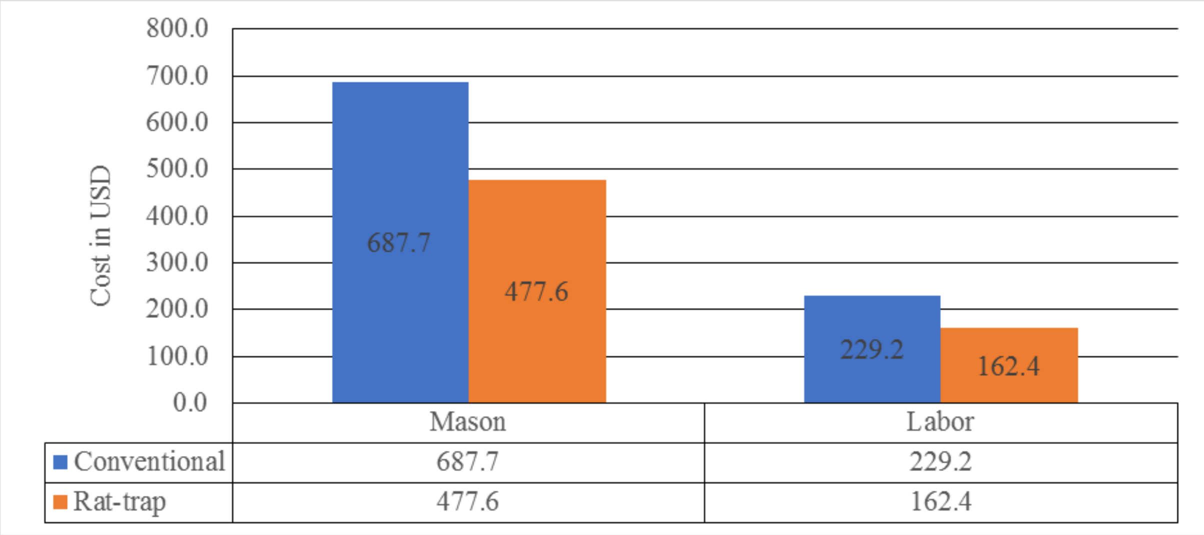


Figure 13. Labor and Mason Cost Comparison

The overall masonry cost of the Existing conventional house is USD 3056.5 whereas the cost of the proposed Rat-trap construction i.e. Proposal B is USD 2198.68. The comparison is shown in Figure 14. This means that USD 857.82 can be saved from each unit which impressively makes the proposal cost efficient too. Proposal B is 28% efficient than the Existing housing unit in terms of cost, therefore the second objective of the research has also been achieved.

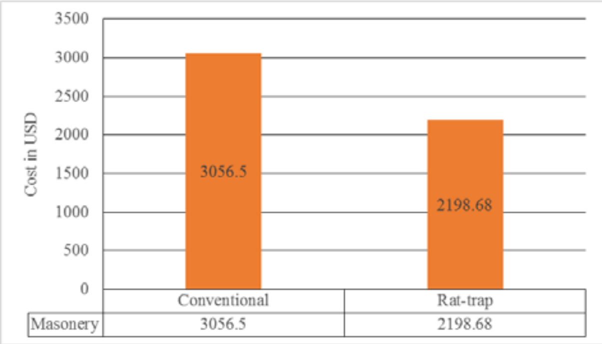


Figure 14. Cost Comparison of Brick Masonry

6. Discussion

A practical approach was needed to provide low-income groups with sustainable and comfortable accommodation conditions. As the population is increasing, the scarcity of residential units is also increasing. Moreover, the overall construction activities in the world have immensely increased which results in environmental pollution as well. The world now faces a shortage of resources too. The proposal offered help in answering both the problems. By using less material during its construction and by providing thermal insulation during its operation, it is surely a feasible option to be adopted. It is to be noted that, Pakistan is a developing country with strict financial constraints, therefore, this research aims to propose a solution that should not increase the cost in comparison to the budget allocated to a single unit by the developer.

The existing constructed units utilize more resources. It has been recommended to adopt Proposal B because of its efficient results. However, if management, at any point in time, is not willing to adopt any major changes i.e., changes in space design, then Proposal A is still better than the Existing unit. Other cost-effective techniques are also available but due to financial and traditional constraints, those cannot be adopted. For instance, GFRG boards are efficient in working. Its manufacturing materials are also available in Pakistan, but only in raw form. These boards require to be manufactured, without manufacturing raw material cannot be utilized. Using them in the proposal involves their manufacturing cost to be added which as well, in turn, increases the cost of per unit house. Therefore, this feasible option is no more viable in the given circumstances.

The existing construction is not energy efficient as well. Proposal B is a two in one proposal as its utilization would further decrease the allotted budget and will impart energy efficiency too. By using less material, the self-weight of the building also decreases. In this research, because of financial constraints, the considered building component was 'Wall' only. Roof and openings like windows and doors were not in the scope of the research. Proposal B is also efficient in the operational cost of the building. It has not only reduced the constructional cost of the unit, but it will also reduce the operational cost in the long run through its energy-efficient character. The same can be achieved by Proposal A. It is important to note that the proposal with all its beneficial characteristics, requires no extra effort to be employed as brick is the local material of Punjab.

7. Conclusion

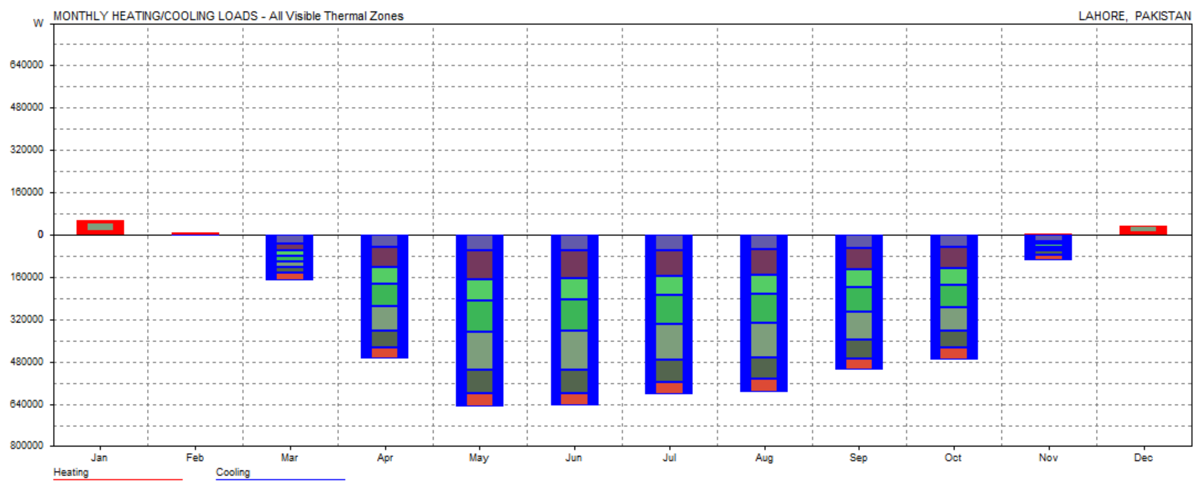
In this research, a cost-effective and energy-efficient proposal has been suggested to an existing housing scheme. Proposal B is 28% more efficient than the existing housing unit. It can annually save 799 units of energy consumption along with savings of USD 857.82 per house during its construction phase. Adoption of the proposal will make houses thermally comfortable hence helping the poor/middle class is not only lowering the construction cost but also in reducing the operational cost of the building. This will also cast a general impact on resource conservation and energy consumption of the country. The scope of the research is limited to the walls of the building. It is recommended that energy-efficient construction should be enforced by the government at all levels to meet the energy demands and wise utilization of resources. New practical technologies must be devised. For the Rat-Trap bond, labor should be made skilled and friendly with this technique. Future research directions should consider roof and building openings through which low-cost thermal comfort can be created inside the buildings.

Appendices

Appendix A: Per month thermal load statistics as calculated by Ecotect for existing housing unit

Month	Heating	Cooling	Total	Total load
	(Wh)	(Wh)	(Wh)	KWh
Jan	63424	0	63424	63.424
Feb	8766	0	8766	8.766
Mar	163	93196	93358	93.358
Apr	0	329658	299658	299.658
May	0	481298	381298	381.298
Jun	0	479936	399936	399.936
Jul	0	443491	383491	383.491
Aug	0	431921	351921	351.921
Sep	0	365420	305420	305.42
Oct	0	316998	296998	296.998
Nov	3911	33384	37294	37.294
Dec	44484	0	44484	44.484
Total load				2467.78

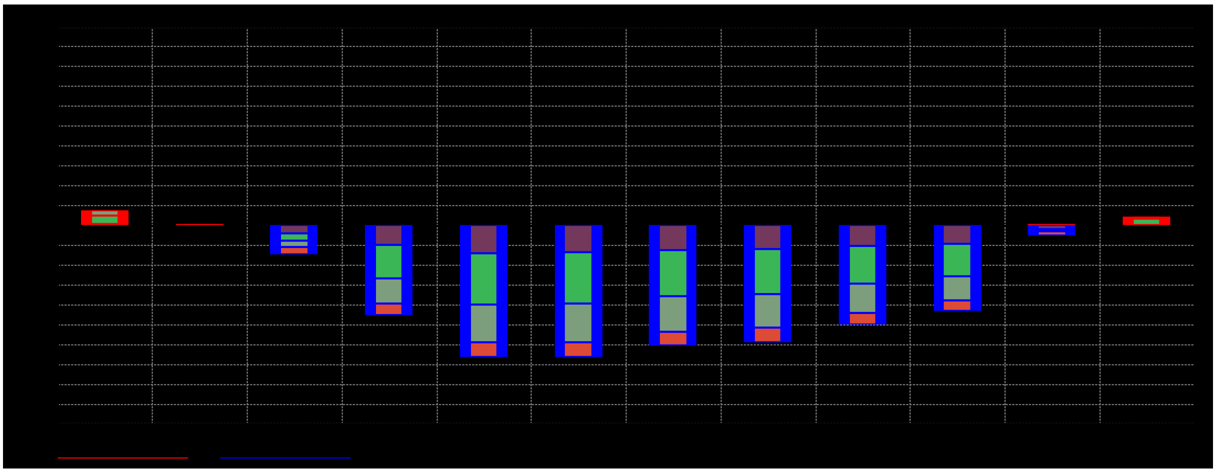
Appendix B: Monthly heating and cooling loads of existing housing unit as analyzed by Ecotect



Appendix C: Per month thermal load statistics as calculated by Ecotect for Proposal A

Month	Heating	Cooling	Total	Total load
	(Wh)	(Wh)	(Wh)	(KWh)
Jan	29464	0	29464	29.464
Feb	2683	153	2836	2.836
Mar	70	59205	59275	59.275
Apr	0	181903	181903	181.903
May	0	266766	266766	266.766
Jun	0	265064	265064	265.064
July	0	243032	243032	243.032
Aug	0	235684	235684	235.684
Sep	0	200788	200788	200.788
Oct	0	173739	173739	173.739
Nov	1399	21184	22584	22.584
Dec	17510	0	17510	17.51
Total Load				**1698.645**

Appendix D: Monthly heating and cooling loads of Proposal A as analyzed by Ecotect



Appendix E: Per month thermal load statistics as calculated by Ecotect for Proposal B

Month	Heating	Cooling	Total	Total
	(Wh)	(Wh)	(Wh)	(KWh)
Jan	29464	0	26464	26.464
Feb	2683	153	2236	2.236
Mar	70	59205	56275	56.275
Apr	0	181903	181903	181.903
May	0	266766	236766	236.766
Jun	0	265064	248064	248.064
Jul	0	243032	253032	253.032
Aug	0	235684	245684	245.684
Sep	0	200788	220788	220.788
Oct	0	173739	162639	162.639
Nov	1399	21184	20374	20.374
Dec	17510	0	15210	15.21
Total Load				**1669.435**

Appendix 1: Estimation of Brick Masonry for ground floor

Brick Masonry in Ground Floor (Vertical walls dealt as long wall)							
Sr. No	Description	Nos	Measurement			Quantity	Unit
			Length	Breadth	Depth		
1	H1	1	11.5	0.75	10	86.25	cft
2	H2	1	7.62	0.75	10	57.15	cft
3	H3	1	6.5	0.375	10	24.38	cft
4	H4	1	10.75	0.75	10	80.63	cft
5	H5	1	12	0.75	10	90	cft
6	H6	1	6	0.75	10	45	cft
7	H7	1	7.5	0.75	10	56.25	cft
8	V1	1	30	0.75	10	225	cft
9	V2	1	29.75	0.75	10	223.13	cft
10	V3	1	10	0.75	10	75	cft
Total GF						**962.78**	

Appendix 2: Estimation of Brick Masonry for first floor

Brick Masonry in First Floor							
Sr. No	Description	Nos	Measurement			Quantity	Unit
			Length	Breadth	Depth		
1	H1	1	19.88	0.75	10	149.06	cft
2	H2	1	12.5	0.75	10	93.75	cft
3	H3	1	7	0.75	10	52.5	cft
4	H4	1	5.6	0.375	10	21	cft
5	V1	1	26.13	0.75	10	195.94	cft
6	V2	1	14.75	0.75	10	110.63	cft
7	V3	1	8.5	0.375	10	31.88	cft
Total FF						**654.75**	

Appendix 3: Estimation of Brick Masonry for doors, windows and lintel level

Sr. No	Description	Nos	Measurement			Quantity
			Length	Breadth	Depth	
1	**Doors**					
	D1	1	3.5	0.75	7	18.38
	D2	3	3	0.75	7	47.25
	D3	2	2.5	0.375	7	13.13
	D4	1	3	0.75	7	15.75
	D4	1	3.25	0.75	7	17.06
Total						**111.56**
2	**Windows**					
	W1	2	4	0.75	4.5	27
	W2	1	3	0.75	4.5	10.13
	W3	2	2	0.75	4.5	13.5
	W4	1	1.5	0.75	4.5	5.06
	V1	2	0.83	0.75	0.83	1.03
Total						**56.72**
3	Lintle	1	59.375	0.75	0.5	22.27
Total Deduction						**190.55 cft**
Total Brick Masonry						**1426.98**

Acknowledgement

The authors would like to thank the University of Engineering and Technology (UET), Lahore and Universiti Teknologi PETRONAS (UTP), Malaysia for the support provided for this research.

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