MJSAT 5 (4) 232-241

MJSAT

Malaysian Journal of Science
and
Advanced Technology

journal homepage: https://mjsat.com.my/

A Comparison of Feasible Energy-Saving Retrofit Alternatives for Office Buildings in Urban Cities

Hamza Shaikh[1]*, Rizwan Ahmed Memon[1], Shoukat Ali Noonari[2], Asad Shaikh[1], Abdul Hameed[3], and Ali Murad Jokhio[1]

[1]*Mehran University of Engineering and Technology, Sindh, Pakistan.*
[2]*Isra University, Hyderabad, Sindh, Pakistan.*
[3]*Sapienza University of Rome, Italy.*

KEYWORDS

Variable Refrigeration Flow (VRF)
Energy Conservation
Building Insulation
Payback Period
Cost-Benefit Analysis

ARTICLE HISTORY

Received 29 April 2025
Received in revised form 3 June 2025
Accepted 10 October 2025
Available online 8 November 2025

ABSTRACT

The major portion of the world population lives in cities and consumes around 73% of world total energy. Due to rapid rise in population, improved standard of living, urbanization and major time spend indoors, the energy consumption in buildings has skyrocketed during the past few decades. The primary portion of building's energy consumption is utilized by HVAC system. Energy crisis is worsening day by day, especially in underdeveloped countries like Pakistan. In this research work, a SketchUp model of a single zone building is created, and it is subsequently loaded into the Energy plus program to simulate the model under various insulation and HVAC schemes and ascertain the trends in annual cooling and electrical loads for the chosen cities in various scenarios for five major cities of Pakistan. Moreover, to determine optimal solution relative to the base case a cost-benefit and sensitivity analysis is also conducted. The results showed that without insulation the zone temperature can reach up to 45.2 °C , 49.9 °C , 48.6 °C , 46 °C and 41.7 °C for Karachi, Lahore, Peshawar, Islamabad and Quetta respectively which is reduced by 22–28 % by applying insulation. For Peshawar, Karachi, Quetta and Islamabad highest energy consumption was reported in the month of July, May, July and June respectively. The energy savings increased by 5–26 % by replacing conventional air conditioner with VRF AC without insulation and by 32–70 % by applying insulation with VRF AC as compared to VRF AC without insulation. The payback period ranges between 28–60, 19–42, 16–35, 18–39 and 21–45 months for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively. The longest PBP of 92 months is reported for Quetta at 5% tariff and 60% investment cost increase with VRF air conditioner, while the lowest PBP of 16 months is recorded for Lahore

1. INTRODUCTION

According to International Energy Agency (IEA), the half of the world's population lives in cities and consume 73% of world total energy with 70% CO2 emissions. In the last two decades, the growth rate of primary energy consumption and CO2 emissions is 49 and 43%, respectively with an average annual increase of 2% and 1.8% correspondingly from the year of 1994 to 2014. The annual average growth rate of energy consumption in the developing countries is 3.2% for 2017 which depends on continuous increase of population and urbanisation [1,2,3]. Currently, 30-40 % of the total primary energy demand of the world is consumed by buildings [4,5]. As revealed by recent studies on computer energy simulation software and field surveys 37 – 60 % of the total electricity use in buildings is consumed by air conditioning system [6,7] Furthermore, in order to reduce energy use, the building sector is frequently quoted as one of the largest cost-effective space [8,9].

Pakistan is facing energy crisis since last decade and its vulnerable economic situation is making this crisis worse day by day. Today world is moving towards energy conservation and energy efficiency. It is high time for Pakistan to follow the

*Corresponding author:
E-mail address: Hamza Shaikh < shaikhhamza331@yahoo.com >.
https://doi.org/10.56532/mjsat.v5i4.524

path of energy conservation. Like other parts of the world major portion of total electricity generation is utilized by HVAC system. Steps taken to minimize energy consumption by HVAC system without compromising thermal comfort can drastically reduce the energy consumption. The two best options available to reduce energy consumption by HVAC system is to apply thermal insulation on the building envelope and to replace the conventional air conditioner (CAC) with Variable refrigerant flow (VRF) type air conditioners. The insulation materials are made up of such materials that reduces cooling load by decreasing the amount of heat gain through the roof and walls while VRF type air conditioner have a specialized motor that runs the compressor at variable speed depending upon the difference between setpoint and zone temperature.

This study aims to evaluate and compare the effectiveness of building envelope insulation and VRF air conditioning systems in five major cities in Pakistan using simulation-based analysis and compare the feasibility of these options by computing the payback of various systems for the selected cities.

2. Literature Review

The literature review presented in this section discovers strategic traits of energy-efficient building scheme that contribute to energy conservation in buildings. Each Section underscores the economic considerations, recent innovations, and real-world applications crucial for sustainable buildings.

2.1 Insulation Strategies

D. Kumar. et al., (2020) [10] Introduced the concept of embodied energy, embodied carbon and summer overheating prospective for selecting optimal insulation material. A novel optimization structure is also proposed in this study which included four optimization criteria i.e. (comfort , functioning energy and carbon, embodied energy and carbon and life cycle cost). L. Aditiya et al., (2017) [11] in this article aims to summarise the most recent advances in building thermal insulation, deliver life-cycle evaluations, and discourse possible emissions diminutions with the suitable insulation materials. J. Lee et al., (2017) [12] investigated the influence of amalgamation the exterior insulation proportion on the energy consumption for cooling as well as heating with several interior heat gains. M.W. Alram et al., (2023) [13] by using a holistic and thematic approach, this research aims to assess various factors, including double-glazed windows, (VGS), integration of semi-transparent PV devices with building architectural design, energy saving through shading, passive climate control methods, heat reflecting coating, building energy performance enhancement through optimisation techniques, double skin green facade, etc., both qualitatively and quantitatively. Of the aforementioned methods, VGS (Vertical Greenery System) is determined to be the most dependable, effective, and long-lasting option. Attractive VGS may enhance the urban environment, boost biodiversity, reduce pollution, and have a positive economic impact on buildings by reducing surface temperature and using less energy. H. Shaikh et al (2023) [14] investigated the impact of applying different insulation and replacing conventional Air conditioner with VRF type airconditioner on energy saving for Hyderabad, Pakistan and also presented Payback Period to evaluate the economic viability of proposed options.

2.2 Cost-effectiveness Studies

F. Ascione et al., (20219) [15] to discourse the energy design of building envelop suggested a multi-objective optimization approach Implemented a generic algorithm to reduce primary energy utilization, global cost and hours of discomfort. M. Farghali et al., (2023) [16] examined energy-saving measures, concentrating on the real energy problem, environmentally friendly substitutes for fossil fuel heating, energy conservation in buildings and vehicles, artificial intelligence applications for sustainable energy, and the ramifications for society and the environment. case studies in China that focus on the technical and financial elements of creating compressed air storage and Germany that plans to transition to 100% renewable energy by 2050. Buildings may lower their energy usage by 19 – 43 % by utilising deep neural networks. A. Heidari and F. Olivieri, (2023) [17] in light of increased energy consumption and environmental concerns, this research explores the energy efficiency of traditional Iranian architectural buildings with dome-shaped in locations experiencing extreme weather conditions. In this work, using Design Builder software three discrete models of Nowzari caravanserai with dome, flat, and sloping roofs were simulated. In comparison to other buildings, in managing interior temperatures the dome-shaped structures show superior efficacy, as evidenced by a noticeable increase in indoor temperatures during the colder months and a drop in indoor temperatures during the summer months. A greener, more ecological constructed environment may be achieved by balancing sustainability and aesthetics in buildings via the merging of traditional skills and current technologies.

2.3 VRF Applications

W. M. Elzanati and S. Y. Ameen, (2013) [18] The study and assessment of the two methods in terms of their capacity to lower peak load and their optimal cost-effectiveness are included in the article, along with a thorough description of the proposed rules. Because DC inverter air conditioning systems are thought to be the most economical, the research suggested using them in Bahrain. M. B. Yurtseven et al., (2014) [19] as a field test, this study compares the energy consumption of two similar public office rooms with non-inverter (CRF) and inverter (VRF) AC while accounting for user comfort. The findings demonstrated that, despite having nearly equivalent EER values, the inverter and non-inverter air conditioners had different energy consumptions. G. Atallah and F. trlochan, (2021) [20] to assess the practicality and sustainability of Variable Refrigerant flow systems and Conventional ducted (CRF) in an office building in Qatar. The results showed that VRF system has approximately 27% energy saving and lower litetime costs as compared to the CRF system despite costing 23% higher than the Conventional constant flow refrigerant system. These findings provide credence to the broader usage to VRF schemes in HVAC systems for more sustainable consumption of energy.

3. Methods and Material

Following steps are adopted to evaluate the impact of applying insulation material and VRF air conditioner on the energy consumption and cost of energy.

a. First SketchUp software is employed to model a reference office building, which is then imported into EnergyPlus.

b. The reference building is simulated for the summer season for major cities of Pakistan in EnergyPlus software for following different cases:

- Uninsulated building with conventional air conditioner (Base Case)
- Insulated building with conventional air conditioner.
- Uninsulated building with VRF type air conditioner.
- Insulated building with VRF type air conditioner.

c. The annual cooling and electrical load components with VRF and building wall insulation material are determined.

d. The simulation results are evaluated by comparing the energy and cost savings of each case with the base case.

e. Cost benefit analysis is carried out by comparing the payback period of above mentioned cases for different cities, which helps determine the best possible option for cost saving.

f. Lastly, the impact of increasing the cost of energy, insulation material, and air conditioning system is evaluated and compared for each case with the base case.

EnergyPlus is a program designed to simulate the energy usage and costs of an entire building. It is used in this study because it can evaluate a building's energy efficiency in a hot, dry climate while considering air movement, humidity, temperature, and solar radiation. EnergyPlus performs a comprehensive heat balance calculation on every surface within the structure to ensure that all energy flows are balanced. This is achieved by conducting a series of energy balancing equations for both the interior and exterior surfaces of walls, floors, and roofs, as well as for zone air. EnergyPlus can replicate a wide range of building principles and components, including various types of air conditioning systems, making it a valuable tool for comparing and assessing the energy efficiency of different cooling systems in an office building.

3.1 3.1 Reference Building

The reference building of the study is modelled in SketchUp software. The 3D view of the model reference building is shown in figure 1. The technical specifications and simulation conditions of the model building are shown in Table 1.

Table 1. Building information and simulation conditions

Building information	Location	Pakistan
	Type of Zone	Office building
	Zone height	3 m
	Floor area	50 m²
	Zone Volume	150 m³
	Material and Construction	-Wall: 2.61 W/m² K (Without insulation) -Window: 6.424 W/m² K, 0.252 (SHGC), 0.72 m² (glass area) -Roof: 5.08 W/m² K (Without insulation) -Floor: 2.94 W/m² K
	Window to Wall Ratio	0.8 %
Simulation Condition	Cooling Set Point Temperature	25 °C
	Weather Data	Karachi, Lahore, Quetta, Peshawar, Islamabad
	Internal thermal Loads	People: 0.057 person/m² Lighting: 10.66 W/m² Equipment: 7.4 W/m² Schedule: 8:00 to 18:00 (PST)
HVAC	Cooling System	- Conventional Single speed air conditioner - Variable Refrigerant Flow air conditioner

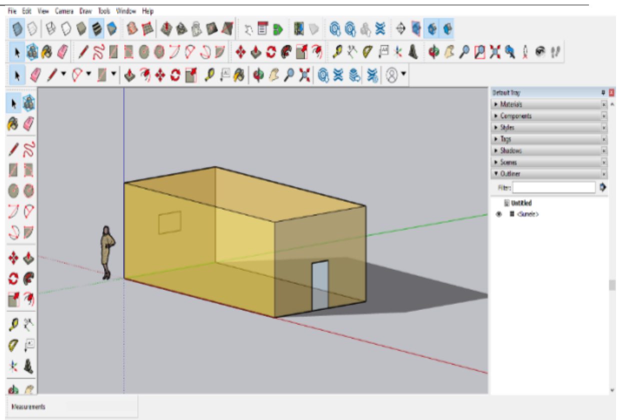


Fig. 1. 3D model of office building in SketchUp

3.2 Description of insulation material

The use of thermal insulation materials lowers heat fluxes that are radiative, convective, and conductive. When installed correctly in building envelopes, they will improve energy efficiency by reducing the building's heat gain or loss and regulating temperature at the surface for occupant comfort. The appropriateness of the insulating materials employed in this study for hot temperatures and their accessibility in the local market were taken into consideration. The local market in Pakistan is surveyed to ascertain the cost of the chosen material, which is suitable for the country's environment. Polyurethane insulation is used in this study due to its suitability with the hot climate and availability in the local market. Polyurethane is an organic polymer and can be made in a variety of densities, thickness and harnesses. Polyurethane insulation is available in two forms foam spray and sandwich panels. Spray foam is usually employed on the walls and sandwich panels are best suited to be installed on the roofs. Table 2 shows the properties of polyurethane insulation.

Table 2. Properties of polyurethane insulation

Parameter	Description	Unit
Material	Polyurethane (PU) spray foam	-
R-value per inch	6.50	F.ft².h/Btu
Cell formation	95.0% closed cell formation	-
Density	32 - 35	Kg/m³
Thermal conductivity	0.02	W/m.K
Bending Strength	100	Psi
Water absorption	0.55% immersion	-
Estimated useful life	25+	Years

Installation	Foam Sprayed on walls	-
Recommended Thickness	1.5	Inch

3.3 Weather Profile

In order to select time of operation of the HVAC system an exploration of the weather profile was carried out. For this determination Meteonorm 7.2 software was used to simulate a year's environmental conditions obtained from meteorological data for the selected cities.

Meteonorm software was used to generate the weather profile that will be presented in this section. The results were presented in graphical form reflecting essential factor that can affect the performance of the system. Figure 2 shows the mean monthly ambient temperature. Highest mean monthly temperatures were recorded for Lahore with June as the hottest month. Lowest temperatures were recorded for Quetta with lowest temperature of 24.2 °C in the month of April. Figure 3 shows monthly global radiation from April to September. Highest global radiation was recorded for Quetta and it outpaced all the cities for the selected months. Lowest global radiation was recorded for Lahore except for two months July and August where Karachi recorded lowest global radiation. After comprehensive examination of weather profile for the selected cities the period from April to September was selected for performing energy analysis of HVAC system.

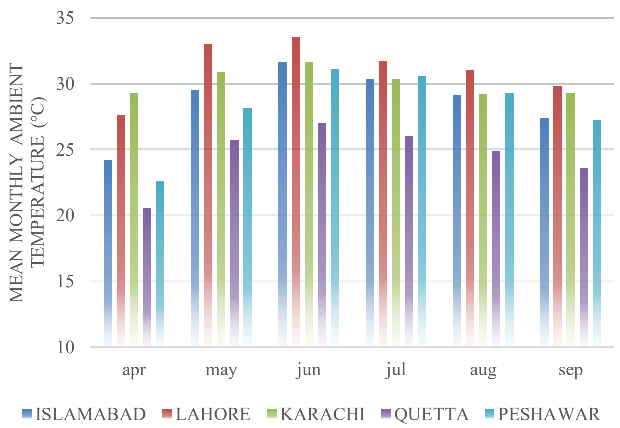


Fig. 2. Mean monthly ambient temperature

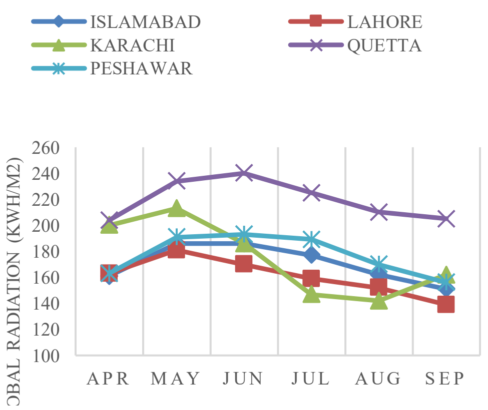


Fig. 3. Comparison of Global radiation for the selected cities

4. Results and Discussion

The system is simulated for summer season from April till September. For the validation of simulated results, the results were compared from the already published results. The relevant part of other studies is compared with relevant part of this study. [21,22] evaluated and presented the energy saving potential and payback of VRF system respectively. [11] estimated the cost saving by applying polyurethane insulation.

4.1 Peak and mean monthly Zone Air temperature

Figure 4 shows the peak zone air temperature for selected cities with and without applying insulation material. The highest zone air temperature with and without insulation was recorded for Lahore and lowest zone air temperature was recorded for Quetta. By applying polyurethane insulation peak zone air temperature reduced by 26.1%, 28%, 27.8%, 26% and 22.9% for Karachi, Lahore, Peshawar, Islamabad and Quetta respectively.

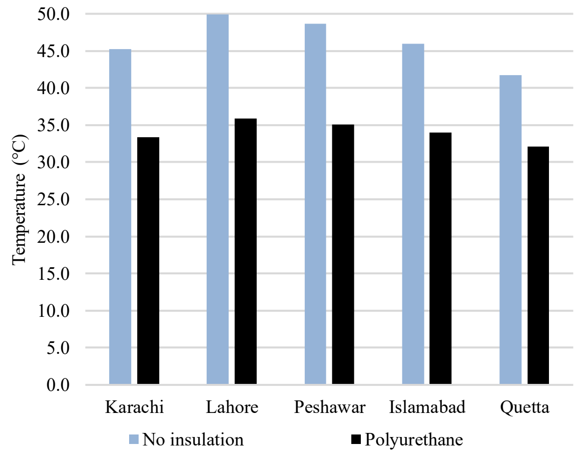


Fig. 4. Peak zone air temperature for selected cities

Figure 5 shows the mean monthly zone air temperature for selected cities with and without applying insulation material. The month of June recoded highest mean monthly temperatures for Islamabad (34.0 °C), Peshawar (34.3 °C), and Lahore (35.8 °C) while the month of May and July recorded highest mean monthly temperatures for Karachi (33.6 °C) and Quetta (31.7 °C) respectively.

4.2 Mean monthly Heat flux rate

The mean monthly heat flux rate for selected cities with and without insulation is shown in Figure 6 (a) – (e). Figure 6 (a), (b), (c), (d), and (e) displays the heat flux rate for Karachi, Lahore, Peshawar, Islamabad, and Quetta, respectively. Karachi recorded the highest heat flux rate for April. The heat flux rate ranges from 26–17 W/m² without insulation and 12–8 W/m² with polyurethane insulation for Karachi. Lahore recorded the highest heat flux rate for May. The heat flux rate ranges from 29–23 W/m² without insulation and 15–11 W/m² with polyurethane insulation for Lahore. Peshawar recorded the highest heat flux rate for June. The heat flux rate ranges from 29–23 W/m² without insulation and 14–11 W/m² with polyurethane insulation for Peshawar. Islamabad recorded the highest heat flux rate for May and June. The heat flux rate ranges from 28–22 W/m² without insulation and 13–10 W/m² with polyurethane insulation for Islamabad. Quetta recorded the highest heat flux rate for July. The heat flux rate ranges from 24–21 W/m² without insulation and 11–9 W/m² with polyurethane insulation for Quetta. It is clear from the results that applying insulation has drastically reduced the heat flux rate per area for the selected cities.

4.3 Energy Consumption and Savings

Figure 7 shows the Energy consumption by conventional AC for the selected cities without polyurethane insulation. Lahore recorded highest energy consumption for the selected months followed by Peshawar and Karachi. Electricity consumption of 2180 kWh was recorded for June in Lahore. Lowest consumption was recorded for Quetta compared to all other selected cities due to lower mean monthly ambient tempertures as shown in figure 2. For Peshawar, Karachi, Quetta, and Islamabad highest consumption was reported in the month of July (1990 kWh), May (1806 kWh), July (1447 kWh) and June (1715 kWh) respectively.

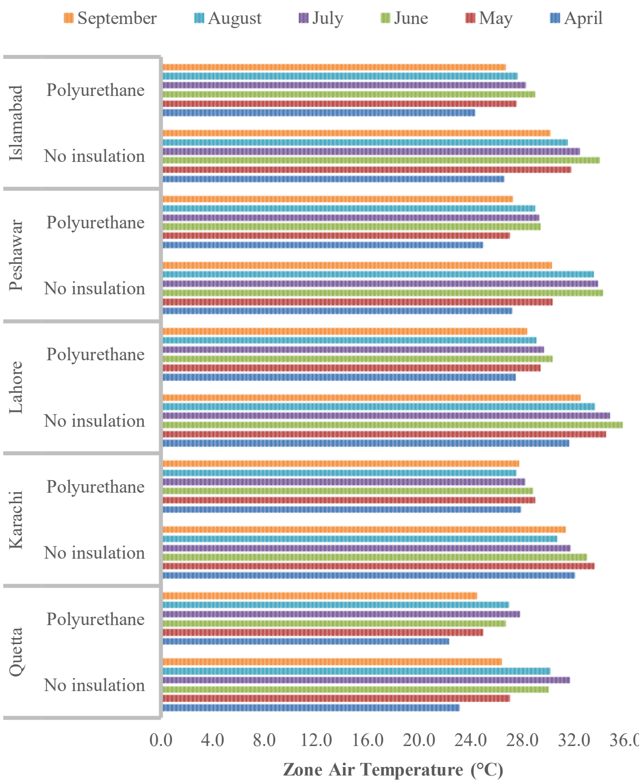
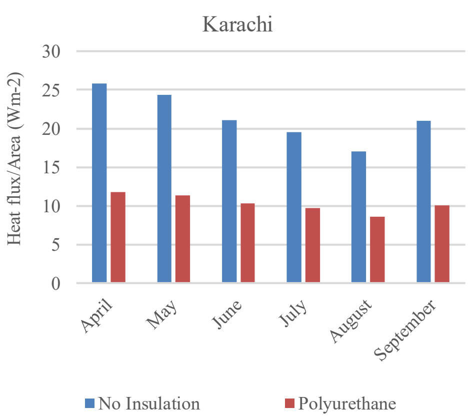
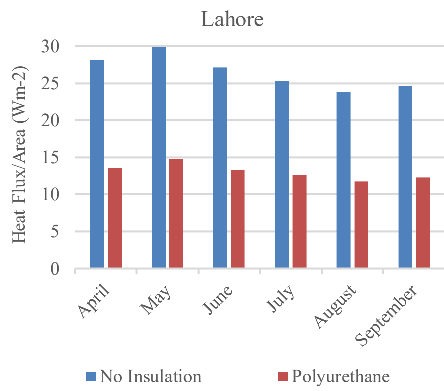


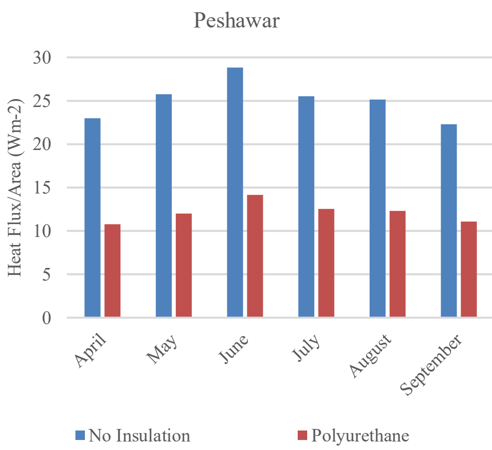
Fig. 5. Mean monthly zone air temperature



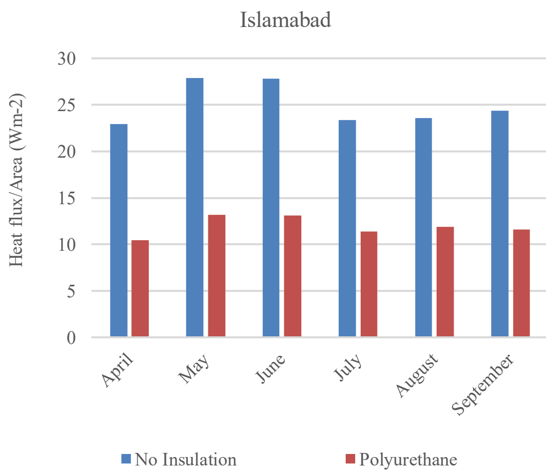
(a)



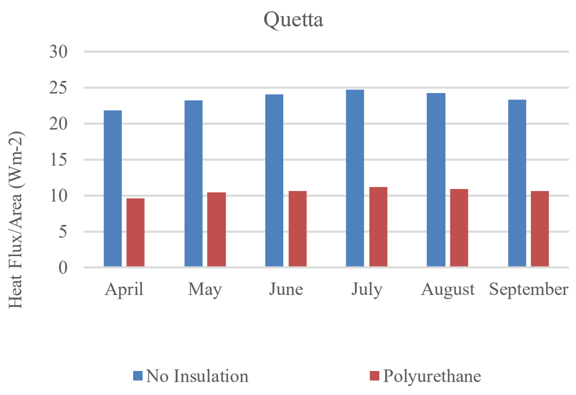
(b)



(c)



(d)



(e)

Fig. 6. (a) – (e). Mean monthly Heat flux rate for Karachi, Lahore, Peshawar, Islamabad and Quetta

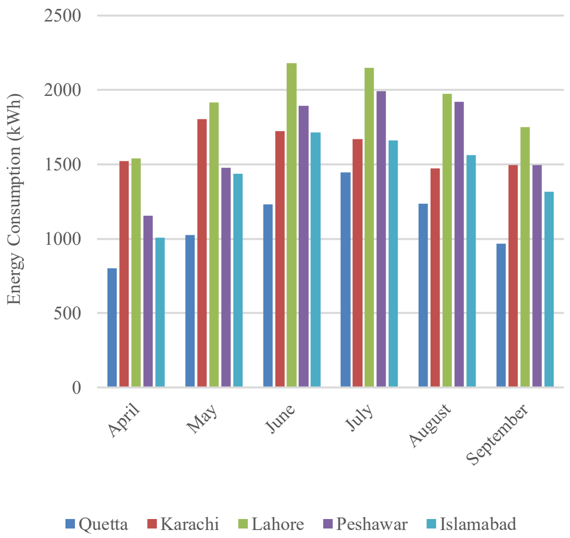


Fig. 7. Energy consumption by conventional AC without insulation

Figure 8 illustrates the electricity consumption for the selected cities using conventional AC and polyurethane insulation. The implementation of insulation has significantly decreased energy consumption, as evident from the comparison of energy usage in Figures 7 and 8. A reduction of nearly 48-57% in consumption is observed with the use of polyurethane insulation. The highest monthly reduction of 56.9% is noted for the month of May in Islamabad, followed by Lahore with a 56.1% reduction during the same month.

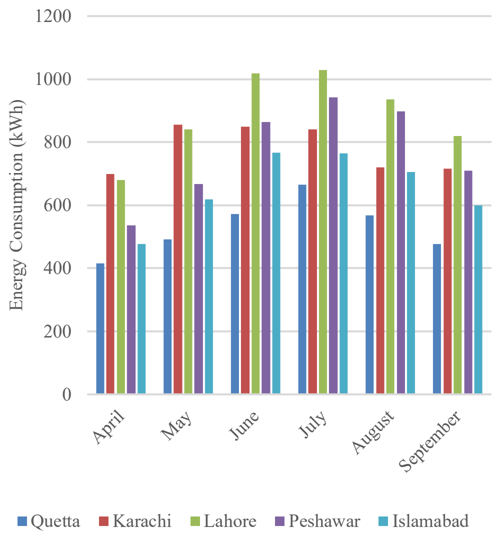


Fig. 8. Energy consumption by conventional AC with insulation

Figure 9 and 10 displays the energy consumption by VRF AC without insulation and with applying insulation respectively. The energy consumption for Karachi increased from April to May and after that declined till August, and then slightly increased in September while for Quetta consumption increased till July and after that declined till September. No such usual energy consumption trend was seen for Peshawar. Using VRF AC has reduced the energy consumption by 39–48 % as compared to conventional AC.

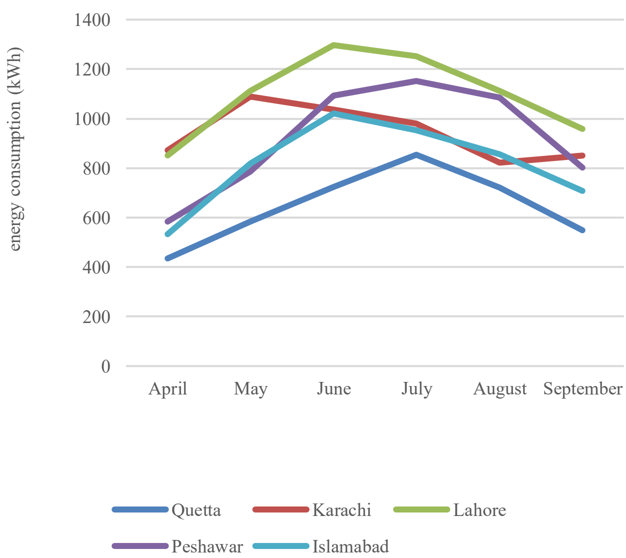


Fig. 9. Energy consumption by VRF AC without insulation

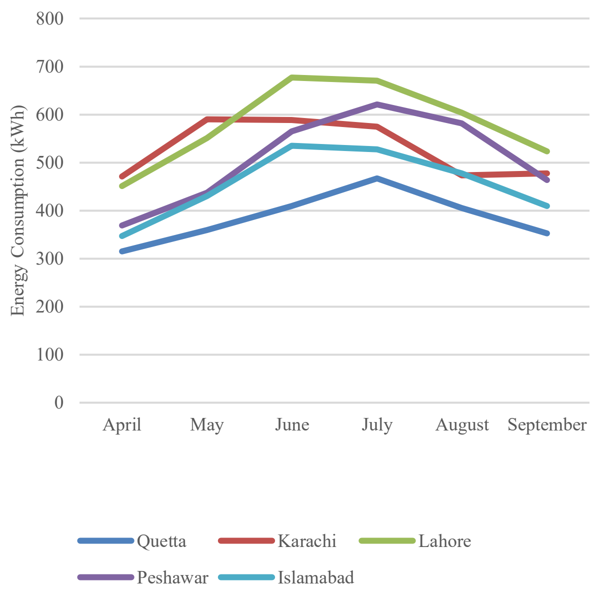


Fig. 10. Energy consumption by VRF AC with insulation

Figure 11 shows the energy saving with insulation for the selected cities. Highest saving is reported for Lahore in the month of June amounting to 1162 kWh while for Peshawar in the month of July amounting to 1048 kWh. For Karachi highest monthly saving of 951 kWh is recorded for the month of May. Figure 12 shows the monthly energy savings with VRF air conditioner for the selected cities and figure 13 shows the energy savings with VRF and building insulation combined. It is clear from the figure that combination of VRF and insulation proved to be the highest energy saving option. Graph trends represented in figure 12 and 13 are almost similar. Highest energy saving of 895 kWh with VRF air conditioner is reported for Lahore in the month of July. By adding insulation with VRF 1503 kWh energy saving is recorded for Lahore in the month of June. The energy saving is increased by 5–26 % by replacing conventional air conditioner with VRF AC without insulation and by 32–70 % by applying insulation with VRF AC as compared to VRF AC without insulation.

4.4 Annual Energy Cost Savings

The annual energy cost savings can be computed from the equation (1)

$$\text{Annual Energy Cost Saving} = [\Sigma\{\text{Energy consumed by base case} - \text{Energy consumed by case (x)}\}] \times \text{Cost of per unit energy in (Rs/kWh)} \quad (1)$$

Assumptions:

Cost of electricity = 25.26 (Rs/kWh)

Inflation rate = 10%

Set point Temperature = 25 °C

Figure 14 shows the annual energy cost saving for each case for selected cities. The combined system of VRF and insulation recorded the highest cost saving followed by building insulation alone. With insulation annual saving of Rs 88695, Rs 126553, Rs 156183, Rs 134181 and Rs 120339 is reported for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively. With VRF annual saving of Rs 71569, Rs 102025, Rs 124279, Rs 111801 and Rs 96089 is recorded for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively. Annual energy cost saving of Rs 110949, Rs 164493, Rs 202737, Rs 174092 and Rs 150726 is achieved for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively with insulation and VRF.

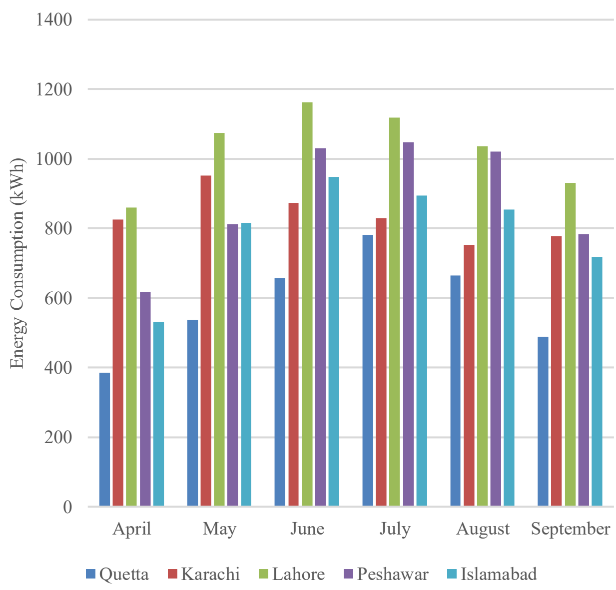


Fig. 11. Energy Saving with insulation

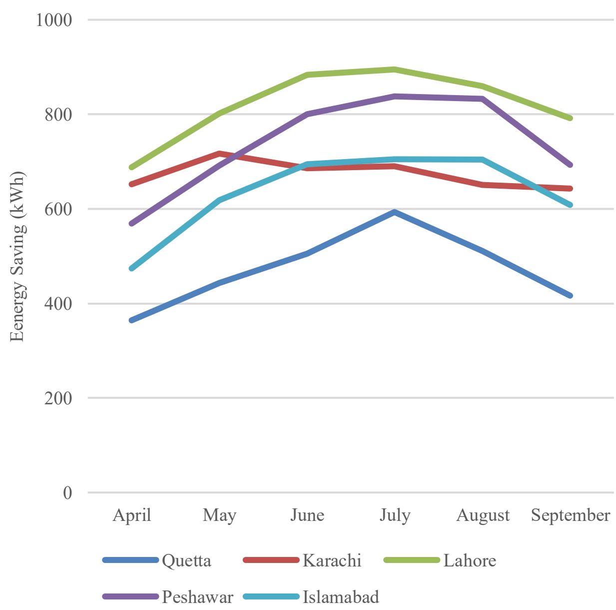


Fig. 12. Energy Saving with VRF AC

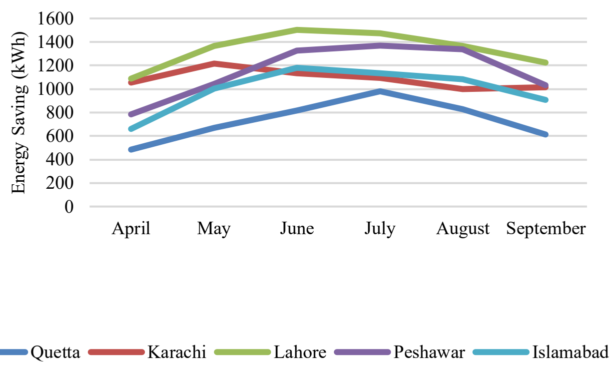


Fig. 13. Energy Saving with VRF AC and insulation

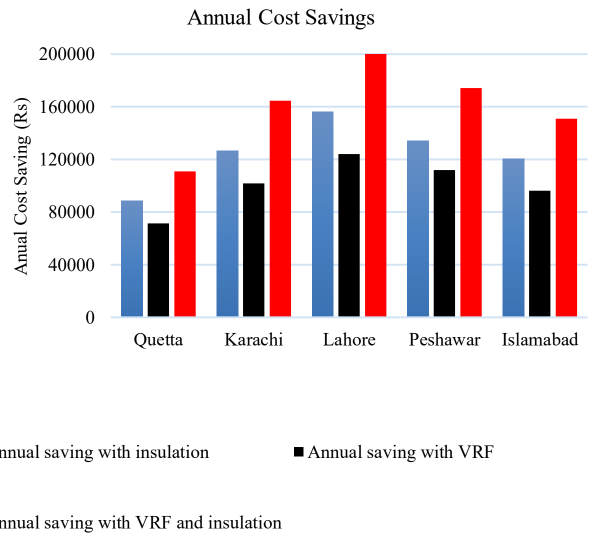


Fig. 14. Comparative analysis of annual cost savings using three strategies for five major cities

4.5 Payback Analysis

In order to confirm the financial viability of the discussed cases, a simple payback is calculated for each case. The Payback Period is the number of years or months needed to capitalize on solely the Net Annual Savings to recover the initial investment (Initial Cost).

The Payback Period is computed by using the equation below:

$$\text{Payback Period (PB} = (\textit{Cost of Airconditioner} + \textit{Cost of Insulation Material} + \textit{Cost of Installation}) \,/\, \textit{Annual energy cost saving} \quad (2)$$

Figure 15 shows the payback period (in months) for each case in selected cities. The lowest payback period is calculated for the combined VRF and insulation, while the longest payback is recorded for the VRF air conditioner alone. A slight difference is noted between the payback periods of insulation alone and the combined system. The payback period ranges from 28–60, 19–42, 16–35, 18–39, and 21–45 months for Quetta, Karachi, Lahore, Peshawar, and Islamabad, respectively. The lowest payback period of 16 months is achieved for Lahore with the combined VRF and insulation. Similarly, for Peshawar, Karachi, Islamabad, and Quetta, the shortest payback periods of 18 months, 19 months, 21 months, and 28 months are recorded, respectively, with the combined VRF and insulation. The longest payback period of 60 months is reported for Quetta with the VRF air conditioner. From the graph, it is clear that insulation is a more financially viable option compared to the VRF air conditioner.

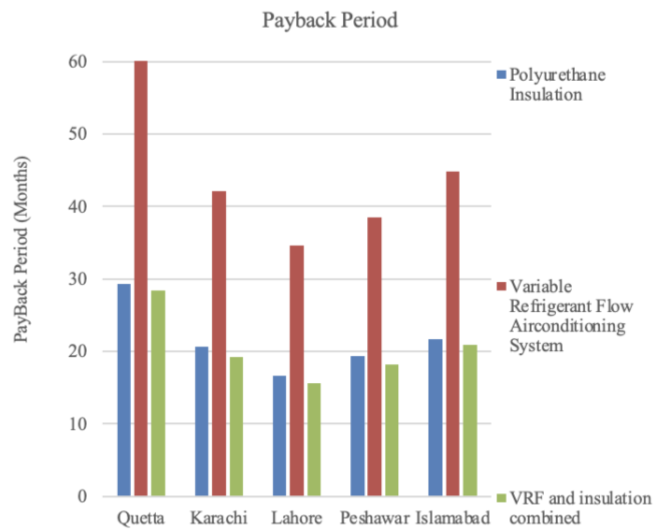


Fig. 15. Comparative analysis of Payback Period for selected cities using three strategies

4.6 Impact of increasing electricity tariff and investment cost on the Payback period

Figure 16 shows the impact of increasing electricity tariff on the payback period of each case for the selected cities. The electricity tariff is increased from 5 – 15 % in three stages with an increment of 5 %. Minor fluctuation is recorded in payback period for polyurethane insulation and combined installation of VRF air conditioner and insulation. The VRF air conditioner without insulation recorded more changes in the PBP as compared to other two cases with Islamabad registering steepest decline in PBP. For Islamabad at 5 % increase in tariff, the calculated PBP is 43 months which is reduced to 16 months at 15 % tariff rate increase resulting in lowest payback recorded with VRF air conditioner alone. Quetta remained the longest PBP claiming location for all the discussed cases. With combined installation of VRF air conditioner and polyurethane insulation the PBP ranges from 27–25, 18–17, 15–14, 17–16 and 20–18 months for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively.

Figure 17 shows the impact of increasing investment and energy tariff cost on the payback period of each case for the selected cities. The investment cost is increased from 20–60 % in three stages with strep increment of 20% while electricity tariff is increased from 5–15 %. At 5% tariff rate increase the PBP at increasing investment rate ranges from 33 – 92, 22 – 64, 18–53, 21–59 and 24–68 months for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively. At 10% tariff rate increase the PBP at increasing investment rate ranges from 31–88, 21–61, 17–50, 20–56 and 23–65 months for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively while At 15% tariff rate increase the PBP ranges from 30–84, 20–59, 16–48, 19–54 and 22–62 months for Quetta, Karachi, Lahore, Peshawar and Islamabad respectively. Lowest PBP of 16 months is recorded for Lahore at 15 % tariff and 20% investment cost increase with combined installation of insulation and VRF air conditioner while longest PBP of 92 months is reported for Quetta at 5 % tariff and 60% investment cost increase with VRF air conditioner.

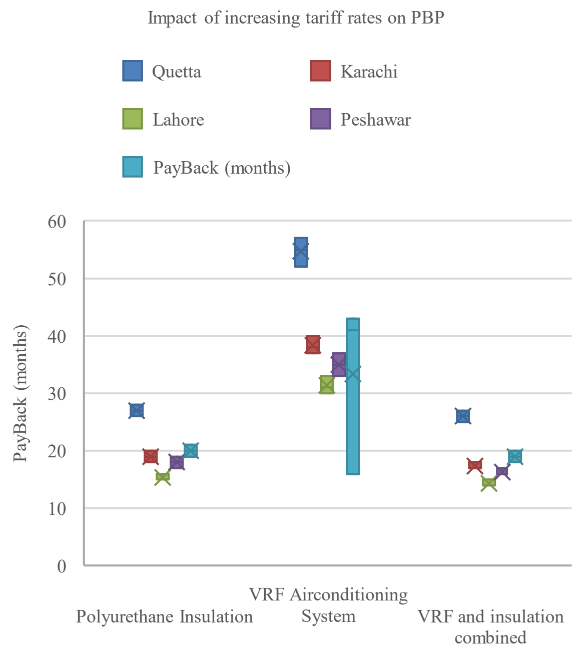


Fig. 16. Parametric analysis on PBP for varying tariff rates across major cities

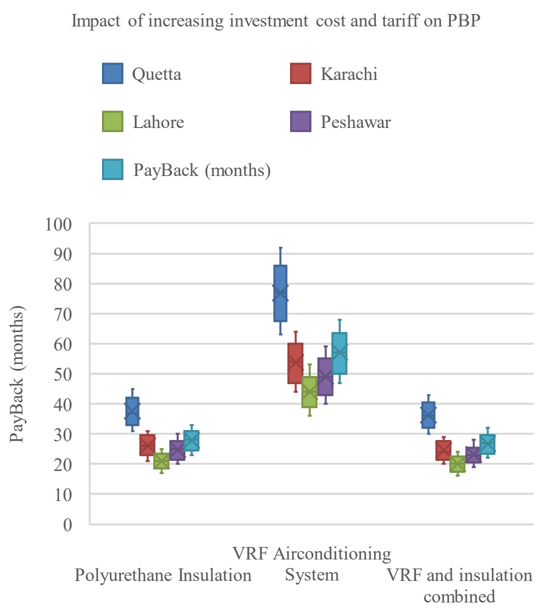


Fig. 17. Parametric analysis on PBP for varying investment costs across major

5. Conclusion

The main objective of this research is to investigate and compare the influence of applying building insulation and replacing conventional CAC air conditioners with efficient VRF air conditioners on the energy-saving potential for major cities in Pakistan. To achieve this, a single-zone building model is created in SketchUp, which is then imported into Energy Plus software to simulate the model and determine the energy consumption trends of different cases in the selected cities. The simulation results illustrate that applying polyurethane insulation reduces the peak zone air temperature by up to 28%. The heat flux rate ranges from 29-21 W/m² without insulation and 15-8 W/m² with polyurethane insulation for the selected cities. The lowest energy consumption was recorded in Quetta compared to all other selected cities. A reduction in consumption of almost 48 to 57% is noted with the application of polyurethane insulation, while using a VRF AC has decreased energy consumption by 39 to 48% compared to conventional AC in the selected cities. The combined system of VRF and insulation offers the highest cost savings and investment recovery, followed by polyurethane insulation alone. Polyurethane insulation has the quickest payback period throughout the range of application situations and the lowest payback period overall (about 15–28 months), as it repays the investment more quickly than any other option. When considered alone, the VRF Air Conditioning System is the least economically appealing option due to its longest payback period, which ranges from 32 - 55 months. When a VRF air conditioning system and insulation are combined, the VRF system will pay for itself much more quickly than if it were applied separately (between 18 and 28 months). Accordingly, the combined investment in VRF and polyurethane insulation offers the best balance of energy saving and investment recovery better than either the VRF system alone or the polyurethane insulation alone. Future research can examine the integration of alternative energy sources like solar PV and wind energy with VRF-insulated building concept.

Acknowledgement

In conducting the present work the authors acknowledge the cooperation and Research assistance by the Department of Mechanical Engineering, Mehran University of Engineering and Technology.

References

[1] Jeon, J., Lee, J. H., Seo, J., Jeong, S. G., & Kim, S. (2013). Application of PCM thermal energy storage system to reduce building energy consumption. Journal of thermal analysis and calorimetry, 111, 279-288. doi: https://doi.org/10.1007/s10973-012-2291-9

[2] Saha, S., Ruslan, A. R. M., Monjur Morshed, A. K. M., & Hasanuzzaman, M. (2021). Global prospects and challenges of latent heat thermal energy storage: A review. Clean Technologies and Environmental Policy, 23, 531-559. doi: https://doi.org/10.1007/s10098-020-01997-7

[3] Berardi, U. (2017). A cross-country comparison of the building energy consumptions and their trends. Resources, Conservation and Recycling, 123, 230-241. doi: https://doi.org/10.1016/j.resconrec.2016.03.014

[4] Harish, V. S. K. V., & Kumar, A. (2016). A review on modeling and simulation of building energy systems. Renewable and sustainable energy reviews, 56, 1272-1292. doi: https://doi.org/10.1016/j.rser.2015.12.040

[5] Allen, K., Connelly, K., Rutherford, P., & Wu, Y. (2017). Smart windows—Dynamic control of building energy performance. Energy and Buildings, 139, 535-546. doi: https://doi.org/10.1016/j.enbuild.2016.12.093

[6] Li, D. H. W., Lam, J. C., & Wong, S. L. (2002). Daylighting and its implications to overall thermal transfer value (OTTV) determinations. Energy, 27(11), 991-1008. doi: https://doi.org/10.1016/S0360-5442(02)00067-1

[7] Xue, Z., & Jiang, Y. (2004). Energy consumption and energy saving potential analysis for large-scale public buildings in Beijing. Heating Ventilating & Air Conditioning, 34(9), 8-10.

[8] Galvin, R. (2010). Thermal upgrades of existing homes in Germany: The building code, subsidies, and economic efficiency. Energy and Buildings, 42(6), 834-844. doi: https://doi.org/10.1016/j.enbuild.2009.12.004

[9] Creyts, J. C. (2007). Reducing US greenhouse gas emissions: how much at what cost?: US Greenhouse Gas Abatement Mapping Initiative. McKinsey & Company.

[10] Kumar, Dileep, et al. "Comparative analysis of building insulation material properties and performance." Renewable and Sustainable Energy Reviews 131 (2020): 110038. doi: https://doi.org/10.1016/j.rser.2020.110038

[11] Aditya, Lisa, et al. "A review on insulation materials for energy conservation in buildings." Renewable and sustainable energy reviews 73 (2017): 1352-1365. doi: https://doi.org/10.1016/j.rser.2017.02.034

[12] Lee, Junghun, et al. "Impact of external insulation and internal thermal density upon energy consumption of buildings in a temperate climate with four distinct seasons." Renewable and Sustainable Energy Reviews 75 (2017): 1081-1088. doi: https://doi.org/10.1016/j.rser.2016.11.087

[13] Akram, M. Washim, et al. "Global technological advancement and challenges of glazed window, facade system and vertical greenery-based energy savings in buildings: A comprehensive review." Energy and Built Environment 4.2 (2023): 206-226.. doi: https://doi.org/10.1016/j.enbenv.2021.11.003

[14] Shaikh, Hamza, et al. "The impact of the wall insulation material and variable refrigerant flow system on building energy consumption and cost." Journal of Mechanical Engineering and Sciences (2023): 9383-9394. doi: https://doi.org/10.15282/jmes.17.1.2023.8.0742

[15] Ascione, Fabrizio, et al. "Building envelope design: Multi-objective optimization to minimize energy consumption, global cost and thermal discomfort. Application to different Italian climatic zones." Energy 174 (2019): 359-374. doi: https://doi.org/10.1016/j.energy.2019.02.182

[16] Farghali, Mohamed, et al. "Strategies to save energy in the context of the energy crisis: a review." Environmental Chemistry Letters 21.4 (2023): 2003-2039. doi: https://doi.org/10.1007/s10311-023-01591-5

[17] Heidari, A., & Olivieri, F. (2023). Energy Efficiency in Dome Structures: An Examination of Thermal Performance in Iranian Architecture. Buildings, 13(9), 2171. doi: https://doi.org/10.3390/buildings13092171

[18] Farghali, Mohamed, et al. "Strategies to save energy in the context of the energy crisis: a review." Environmental Chemistry Letters 21.4 (2023): 2003-2039. doi: https://doi.org/10.1007/s10311-023-01591-5

[19] Yurtseven, M. Berker, et al. "An experimental investigation of energy saving potentials for room type variable-speed air conditioners in public offices: A case study from Istanbul." Energy and buildings 68 (2014): 165-171. doi: https://doi.org/10.1016/j.enbuild.2013.09.020

[20] Atallah, G., & Tarlochan, F. (2021). Comparison between variable and constant refrigerant flow air conditioning systems in arid climate: Life cycle cost analysis and energy savings. Sustainability, 13(18), 10374. doi: https://doi.org/10.3390/su131810374

[21] Kim, D., Cox, S. J., Cho, H., & Im, P. (2017). Evaluation of energy savings potential of variable refrigerant flow (VRF) from variable air volume (VAV) in the US climate locations. Energy Reports, 3, 85-93. doi: https://doi.org/10.1016/j.egyr.2017.05.002

[22] Aynur, T. N. (2010). Variable refrigerant flow systems: A review. Energy and Buildings, 42(7), 1106-1112. doi: https://doi.org/10.1016/j.enbuild.2010.01.024