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Optimize electrical energy cost of air conditioning considering to different wall characteristics

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ABSTRACT

The purpose of this study is to optimize the electrical energy cost (EC) of air conditioning (AC) with consideration of different wall characteristics. The type of wall characteristics is based on the varying composition of the wall. For example: Styrofoam, soil, calcium carbonate and iron. There are three kinds of wall that have been evaluated to design an economical building. To fulfill the goal of this research, a cooling model of building has been designed to optimize the electrical EC of the AC considering to temperature room. Under numerical optimization the electrical EC can be computed by considering thermal conductivity (K) and outside temperature (Tout). Consequently, the electrical EC for Building-1, Building-2, and Building-3 can be reduced to IDR 25,000, IDR 23,000, and IDR 20,000, respectively. In addition, this model is tested considering the value of Tout in Barru South Sulawesi-Indonesia during the entire day of July 17th, 2021 in dry session with geographical coordinates are 4° 24′ 20″ South, 119° 36’ 23” East and Latitude −4.436417.

1. Introduction

According to Refs. [1–3] one of the main drivers of electricity demand is the rate of population expansion. Population growth is causing a rise in demand for air conditioning (AC). One of the primary factors of rising global electricity demand is the increased use of AC [4]. Applying AC to stay cool in residential homes already accounts for around 30%–40% during the summer season [5]. The main concern in regard to the use of AC is not only for the billing payments but also the cost of providing new power plants and the cost to the environment. Author in Ref. [6] reveals that Indonesia is the second-largest consumer and uses 66% more energy than Thailand. Although Indonesia's electrification ratio is more than 98%, hot countries in some regions still do not use AC to keep rooms/buildings comfortable. For example, Barru in South Sulawesi, Indonesia has a higher temperature during the dry season. This is because the cost of installation, maintenance and paying electricity bills is a higher. Therefore, there is an urgent need for policy action to improve cooling efficiency in order to reduce investment debt, cut emissions and minimize costs for consumers.

Author in Refs. [7–9] illustrates how AC usage contributes considerably to peak demand in residential buildings. In the United Kingdom, the residential electricity demand is estimated at 30% of the total electricity consumption and 50% of the national electricity peak demand [10]. In KSA, the electricity consumption due to the installed AC systems in residential homes is estimated to be more than 65% [11]. In some industrialized countries, such as Australia, Canada, France, Japan, Netherlands, Sweden, Switzerland and Spain, residential homes spent 35%–42% more electricity when consumers installed the AC [12]. In China, residential electricity consumption during summer season generates more than 40%, only for the AC demand [13]. In Egypt, the AC systems consumed 56% of the total energy output of buildings [14]. The AC issues have become particularly sensitive in both developing and advanced countries. Growing demand for AC is one of the most critical points in energy issues for some countries. Consequently, energy conservation for residential buildings must be paid more attention due to the large proportion in global energy use and potential saving for the AC in particular.

According to Refs. [15–18] thermal insulation is an essential factor in minimizing the energy consumption for residential building. Ref [19]

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Nomenclature:

Abbreviations

AC	Air conditioning
C_aCO_3	Calcium Carbonate
EC	Energy Cost
EMS	Energy management system
IDR	Indonesian Rupiah
kWh	Kilo Watt Hour
KSA	King Saud Arabia
Matlab	Matrix Laboratory
PCM	Phase change material
PDLC	Polymer-Dispersed Liquid Crystal
VC	Varying composition
SISs	Switchable insulation system
SPD	Suspended particle device
UK	United Kingdom

Symbols

A	Total area (m^2)
B	Heat Transmission (W)
H	Heat Capacity of the Room (J/^{o}C)
K	Thermal conductivity (W/m.C)
L	Wall thickness (m)
P	Electricity Price (IDR/kWh)
Q	Heat Transfer Coefficient
Rc	W/m^{2o}C
S	Resistance conduction (C.m^2/W)
Tin	Electricity power (kW)
T_{out}	Inside Temperature (^{o}C)
To	Outside Temperature (^{o}C)
Ts	Initial temperature (^{o}C)
T_{max}	The starting temperature (^{o}C)
T_{min}	Maximum temperature (^{o}C)
W	Minimum temperature (^{o}C)
X	Watt
Y	Duration Time
ΔT	Binary Variable (0 or 1) Temperature gradient

investigates that wall material has a high potential effectiveness in reducing the effect of overheating a building. Author in Refs. [20,21] explained that a wall has a major impact on lowering the electrical EC of the building. The important aspects impacting the electrical EC linked to the AC is the buildings' wall material. Wall envelope design is an advanced approach to realize cost savings potential for the AC. Consequently, selection of appropriate material for walls can be applied to minimize the electrical EC of the AC. In addition, an innovative material selection to produce a wall is required to diminish the electrical EC for the AC and keep the room comfortable.

Generally, examples of materials that have been used to manufacture walls include wood, brick and CLC brick. Author in Ref. [22] investigates wood material selections for the manufacture of school buildings. Ref [23] applied PCM integrated brick material to create a wall in cooling management for residential houses. Ref [24] assesses the physical and mechanical qualities of CLC bricks due to their increased popularity in the construction market over the last decade. In addition, certain studies have discussed some materials that have been applied to achieve building energy savings (see Table 1). However, even though some references were examined, none of these studies specifically developed an innovative material to create walls which can be applied to reduce the electrical EC for AC, considering both K and Tout.

In addition, the electricity peak demand occurred when the user operate the AC at the same time during hot days. Refs [25–27] said the electricity use increased during hot days because of the AC. The Tout increased to a high or extreme level as consumers operated their AC at the same time. Usually, the consumer switched on the AC to a cooler level to keep rooms comfortable. Consequently, it needed more power to operate it. In contrast, when the Tout decreased to a basic level then the AC were only operated by less power. Therefore, it is required to optimize the electrical EC for the AC based on the Tout.

To bridge the research gap, this paper's goal was to create an economic-building to decrease the EC of the AC considering different wall characteristics. There are two major contributions discussed in this paper. Firstly, compute Tin and EC of the AC considering the K. Secondly, compute Tin and EC of the AC considering the K and Tout.

2. Methods

2.1. *An explanation of the issue*

Residential electrical energy use has been rising rapidly as a result of the AC load. The majority of energy used in residential homes is for maintenance and comfort. Walls have a big effect on keeping a space comfortable and can reduce electricity bills over time by saving energy on the AC. To construct a new model of wall, some techniques have been used. But none of the earlier research used an innovative material to create a building wall. The suggested model develops an innovative CLC brick to build walls. Soil, Styrofoam, C_aCO_3, iron, are among the components. Soil and Styrofoam were chosen as the primary and bonding components to create an innovative CLC brick since they are readily available and inexpensive. Additionally, Styrofoam may shield the environment from waste Styrofoam contamination. Styrofoam has a high level of thermal resistance, such as: 1.07 m^oK/W, according to the result of experiment. Furthermore, Styrofoam garbage makes a significant contribution to the harmful waste that can directly or indirectly impact water sources. This research, optimizing the electrical energy costs of the AC, considered three kinds of different wall characteristics.

2.2. *Varying composition of wall*

To optimize the electrical energy cost of building, there were three kinds of different wall characteristics considered. These were based on the varying compositions to create a wall. Table 2 (below) illustrates the varying composition for each different wall.

Table Iillustrated the kind of materials required to make an inventive CLC brick. Only 5% of Styrofoam, 94% of soil, 5% of iron, and 5% of C_aCO_3 are used in the VC-1. On the other hand, the percentages of Styrofoam, soil, C_aCO_3, and iron in the materials used to make an inventive CLC brick of VC-3 were: 15%, 83.6%, 0.7%, and 0.7%, respectively.

2.3. *Wall design and building model*

Figs. 1 and 2 below show a wall design and a building model, respectively. The inventive CLC brick produced a wall design. A model of a single room that might represent an entire apartment building was created. The size of this single room model is 5 m long, 5 m wide, and 3.5 m high. In the modelling phase, the entire building envelope is simulated and connected to the AC and ventilation system. To make things easier, the heat transfer interaction between the interior and exterior temperatures caused by convection and radiation as well as cooling load was not taken into account when calculating the room temperature inside the enclosure. In this study, the heat transfer was

Table 1
State of the art.

References number	Aims of research	Methods	Results
[28]	Investigates the potential energy saving based on the cool paint modification in University of California, Davis Campus	Cool paint simulation	Energy saving of around $45,000 can be achieved annually
[29]	Analyze the effect of exterior walls to conserve energy in green buildings	Thermal insulation optimization method	The study's findings suggested that this technique is useful for preserving heat and preventing cold
[30]	The goal of this study was to enhance latent heat usage by separating the PCM into two layers and altering their location and melting temperature	Optimization under PCM scenarios	The results showed that two PCM layers resulted in larger yearly energy savings (17.2%) than a single PCM layer (16.8%).
[31]	The goal of this research is to increase unstable thermal performance in non-air-conditioned buildings while lowering energy expenditures in air-conditioned buildings.	The cost-saving potential of air conditioning for various wall envelopes has been calculated using unstable thermal transmittance obtained using the admittance approach.	In comparison to all tested building materials for AC structures, this design gives the largest annual EC reductions (1.71 $/m2 at 2 m/s), the highest life cycle cost savings (18.32 $/m2 at 2 m/s), and the shortest payback period (4.03 years at 2 m/s).
[32]	Investigated multi-layer wall to increase its thermal performance on reducing the cost of AC of building.	The PCM and thermal insulating materials methods while AC is being used both constantly and intermittently.	Intermittent AC use can reduce energy use by 46.69–64.73% compared to the AC continuous operation.
[33]	Reviewed PCM as a potential solution to decreased the EC for AC.	Integration PCM based thermal energy storage technology.	According to the estimated potential benefits there would be at least a 1.8% gain in performance, at least a 5% energy savings, and at least a 30% decrease in CO2 emissions if PCMs were integrated into air conditioners.
[34]	This study aims to create a multi-objective best building envelope and AC system energy performance decision model.	Optimum decision-making model for the energy performance of the building envelope and the cooling system.	The proposed method can reduce construction costs and carbon dioxide emissions when the building envelope and AC system are completed.
[35]	The proposed research is to alleviate load on the AC system through retrofitting a PCM embedded pin fin heat exchanger into an air-conditioning system in three hot climate zone in India, such as Jaisalmer, Kolkata, and Delhi.	Retrofitting a phase change material method	The use of the PCM integrated heat exchanger saves up to 4.7% of energy in Delhi, 2% in Kolkata, and 2.75% in Jaisalmer. The findings show that such PCM thermal storage has the ability to reduce peak energy demands of buildings in the face of many environmental and health concerns.
[36]	Thermal evaluations were performed in cardinal and intercardinal orientations to assess solar heat gains, building thermal loads, and daylight infiltration through stained windows for various coloured architectural antique stained glasses in two temperature zones of India (New-Delhi and Tiruchirappalli).	A numerical model used for the thermo-economic investigation was tested by design builder simulations.	The most cost-effective stained glass was olive-green, with savings of 13.02$/m2, carbon emission reductions of 0.89 tCO2/year, and sufficient daylight ingress to prevent artificial daylighting.
[37]	The experimental characterisation and numerical analysis of a scale model in combination with a smart window in a hot desert climate in Saudi Arabia were discussed in this work.	PDLC glazing system.	The results show that Saudi Arabia's energy consumption decreased and visual comfort was achieved with the system's PDLC glass.
[38]	The suggested study examined the overall energy use and switchable SPD smart window as a component of the glazing integration of an adaptable structure designed to consume less energy in a hot desert environment.	Controlled switchable SPD glazing.	The results of the simulation demonstrated that, with the exception of the northern orientation, switchable SPD smart windows (in the automated and off modes) achieved a promising decrease of net energy by up to 58% in comparison to double-glazing low emissivity.

Table 2
Varying composition.

Wall	Varying composition			
	Styrofoam (%)	Soil (%)	CaCo3 (%)	Iron (%)
1	5	94	0.5	0.5
2	10	88.8	0.6	0.6
3	15	83.6	0.7	0.7

conducted only to consider the conduction process.

2.4. Heat transfer and cooling model of building

In this study, a composite wall comprises a number of layers with different properties (see Fig. 3). The kind of wall characteristics are according to the amount of its material composition. Consequently, a number series or parallel thermal resistance arises due to the different layers of materials. The heat transfer rate is associated with difference in temperature and thermal resistance can be computed by the following

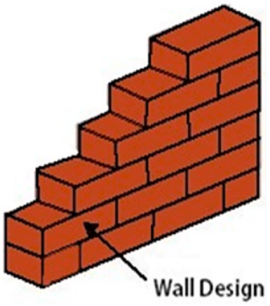

Fig. 1. Wall design.

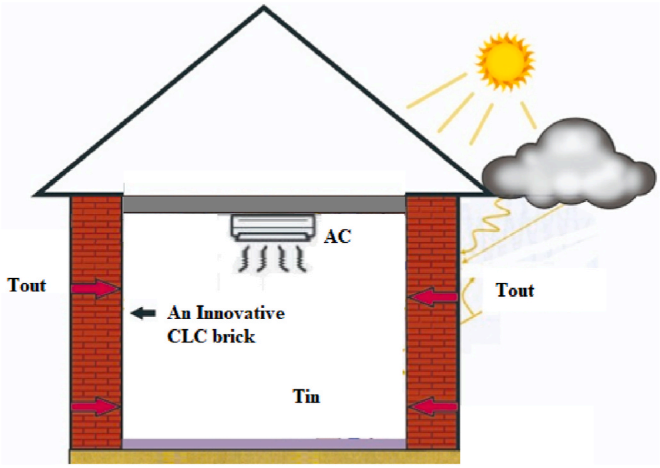

Fig. 2. Model of building.

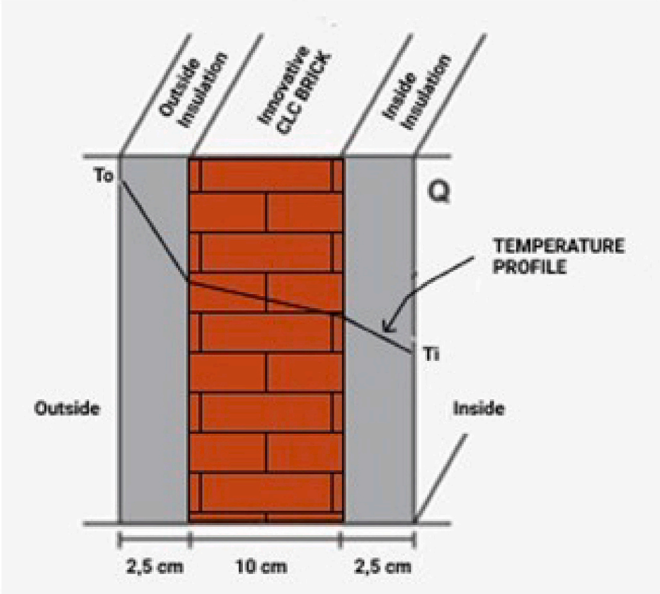

Fig. 3. The composition of a wall.

equation [39].

$$Q = \frac{\Delta T}{\sum R_c} \tag{1}$$

$$R_c = \frac{L}{K.A} \tag{2}$$

In addition, the temperature distribution of the wall for three kinds of buildings can be calculated based on the following equation [40]:

$$T_{(x,y)} = \frac{4\,T_1}{\pi} \sum_{1}^{\infty} \frac{\sin\left[(2n-1)\frac{\pi x}{X_1}\right]}{(2n-1)} \; \frac{\sinh\left[(2n-1)\frac{\pi y}{X_1}\right]}{\sinh\left[(2n-1)\frac{\pi Y_1}{X_1}\right]} \tag{3}$$

To manage the Tin and determine the EC of the building's AC, a cooling model for the building has been established. The control system manages the Tin for the user and finds a lowest EC. Under numerical optimization, the effect of K and Tout of building to Tin and EC have been evaluated. Consequently, the Tin can be comfortable for the consumer and the minimum EC can be achieved. In analysis, Ansys fluent analysis is applied to define the Tin, EC and displays the result in the same plot. Fig. 4 (below) indicates the kind of cooling model of the building.

2.5. Electrical energy consumption

The following equations (4) and (5) illustrate the minimum energy consumption of a residential building:

$$EC\left(t\right) = \int_{t=1}^{t=n} \left[(S(t).\,P\left(t\right) X\left(t\right) Y\left(t\right)\right)\, dt\Big] \tag{4}$$

Subject to constraints:

$$\frac{dT}{dt} = \frac{Q.\;A\,.\,(T_O(t) - Tin(t))}{H} - \frac{B.\,Y(t)}{H} \tag{5}$$

The kind characteristics of wall and building for those three bricks were illustrated in the following parameters: Q of third building, namely 1.2 W/m^{2o}C, 1.1 W/m^{2o}C and 0.85 W/m^{2o}C for building-1, 2 and 3, respectively. A of building-1, 2 and 3 is equal to 25 m^2. B for building-1, 2 and 3 is 450 W. L for building-1, 2 and 3 is equal to 0.15 m. X for building-1, 2 and 3 is 10 h. Permitted T maximum and minimum were 24 °C and 20 °C, respectively; the Tout was 33 °C; S for third building is 900 W; P is IDR/kWh 1352.

To compute the minimum EC, the AC was turned on and turned off according to Tin. The AC was turned ON when the AC reached the permitted maximum temperature. In contrast, the AC was turned OFF if the AC dropped to the maximum permitted temperature. In this study, outside room temperature and characteristics of building were considered to calculate the minimum EC. Fig. 5 shows the temperature on hot days in Barru, South Sulawesi-Indonesia, where the Tout was used to support this model (below). The geographical coordinates are 4° 24′ 20″ South, 119° 36’ 23” East and Latitude −4.436417.

Fig. 5 shows an illustration of Tout in Barru during the entire day of July 17th, 2021 in dry session. Fig. 5 indicates that the lowest Tout basically conducted before 11:00 in the morning and after 16:00 in the

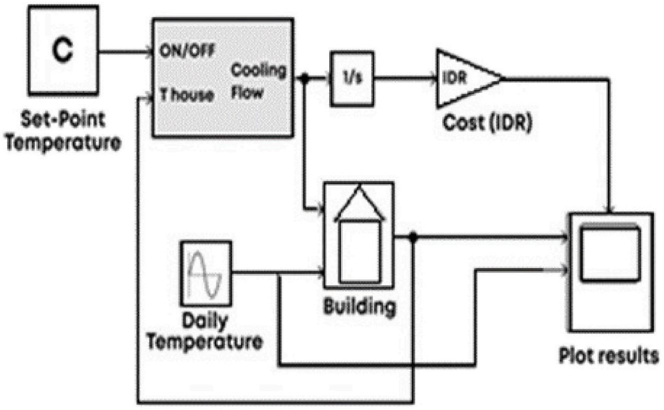

Fig. 4. Cooling Model of building.

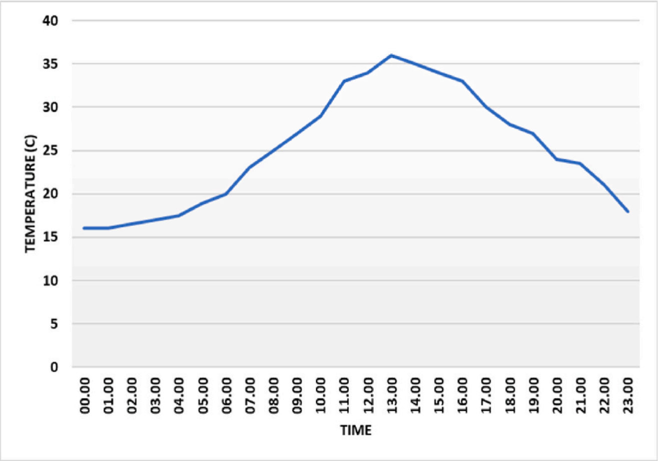

Fig. 5. Outside Temperature data of July 17th' 2021.

afternoon. The Tout increased to a high level, namely 32 °C starting from 10:30 to 16:00 in the middle of the day. Moreover, the extreme Tout was computed between 12:00 and 14:00 in the middle of the day, above 34 °C. In this study, the hot days are recognized when the Tout is more than 32 °C. Therefore, the hot days were identified from 11:00 to 16:00 when the Tout $\geq$ 33 °C.

Fig. 6 depicts the flow chart of the proposed technique for achieving the research goal.

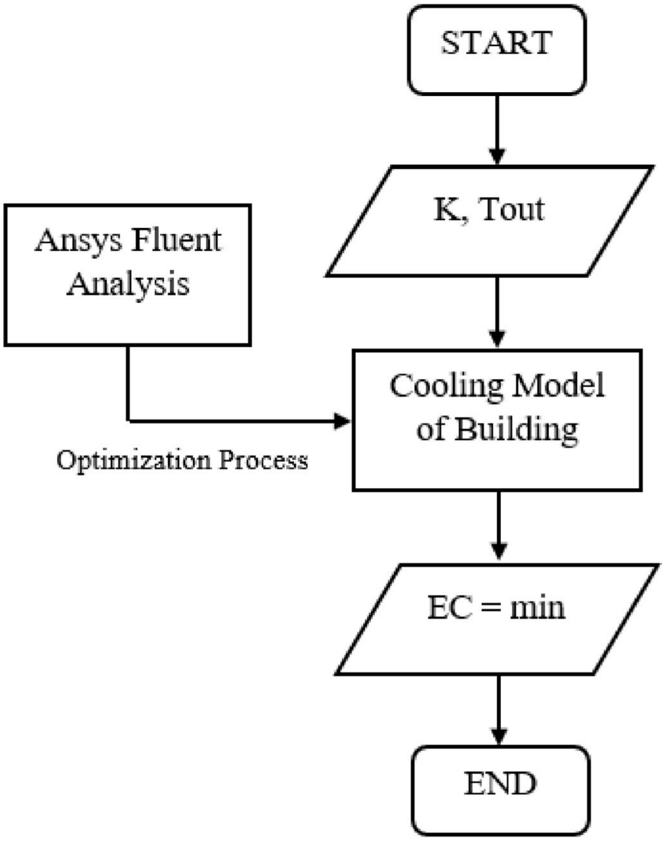

Fig. 6. Flow chart of the proposed method.

3. Numerical result

3.1. Temperature distribution of the wall

Figs. 6–8 below illustrates the temperature distribution of the wall. Due to the different varying compositions, the temperature distribution for every type was not similar. These Figures below illustrated the plot of temperature distribution due to the conduction process of the wall. The length and width of the wall is divided into 10 and 15 segments. The point temperature for every segment is defined by adding k terms from the Fourier series. The heat transfer occurs through this material by conduction from outside to inside temperature. The temperature distribution in this material can be determined by equation (3).

Figs. 7–9 below illustrates that due to the characteristic material of every kind of wall then the distribution temperature was not similar. The different result of temperature distribution at each point is due to the effect of Styrofoam composition in particular, as Styrofoam has a high thermal resistance. Combined with other materials such as soil, C_aCO_3 and iron, the temperature distribution of the walls was not identical for every type. Consequently, the temperature distribution at each point for type-3 was slowly increased in comparison to other types. In contrast, due to the quantity of Styrofoam composition then the temperature distribution for type-1 increased more quickly than other types.

3.2. Case 1: Tin and EC of building considering to K

Equations (4) and (5) were applied to define Tin and EC of the AC. Figs. 10–12 illustrates the result of optimization Tin and EC of the AC for every kind of building. The Tin was defined based on the K. To optimize the EC and maintain comfort for Tin, the Tmin and Tmax permitted temperatures were 21.2 °C and 25 °C. When the Tin's temperature reached the upper limit allowed, the control system turned on the AC. In contrast, the AC switched off once the Tin dropped to the minimum permitted temperature. This continued until the time to operate the AC had expired.

The outcome of optimization shows that the Tin and the EC of the AC for every kind of building were not similar. The thermal resistance for every building was not identical Due to the wall's construction in materials. The thermal resistance of building-1 was lower than other buildings. To run the AC, the control system requires additional electricity power. In contrast, thermal resistance of building-3 was higher than other buildings. The control system needs less power to operate the AC. Consequently, the EC can be minimized to be IDR 28,000; IDR

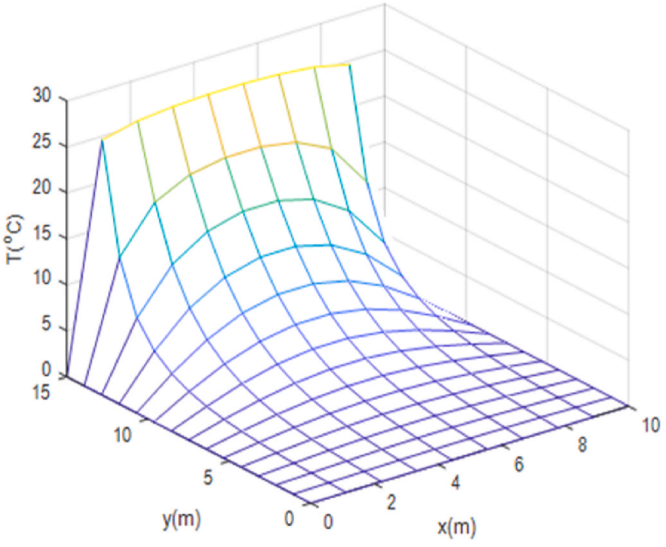

Fig. 7. The Q of wall (type-1).

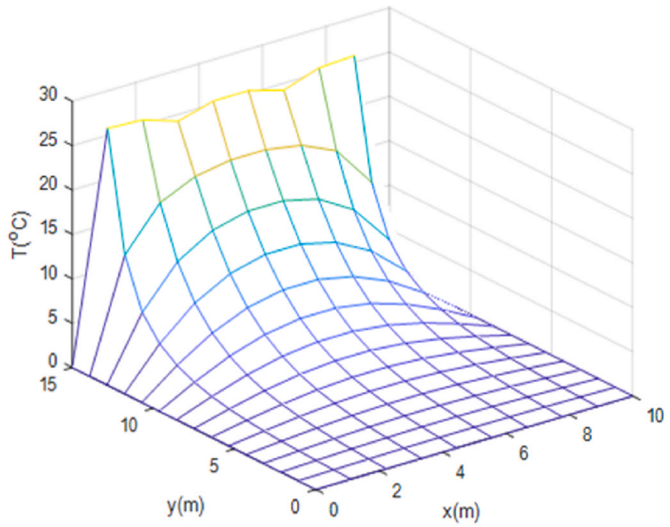

Fig. 8. The Q of wall (type-2).

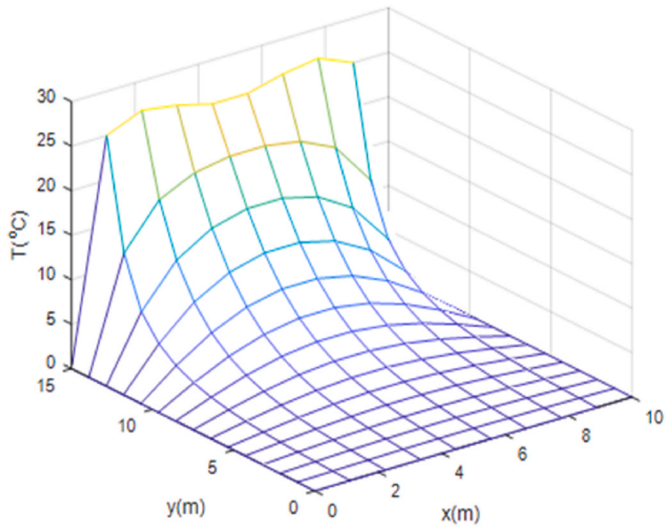

Fig. 9. The Q of wall (type-3).

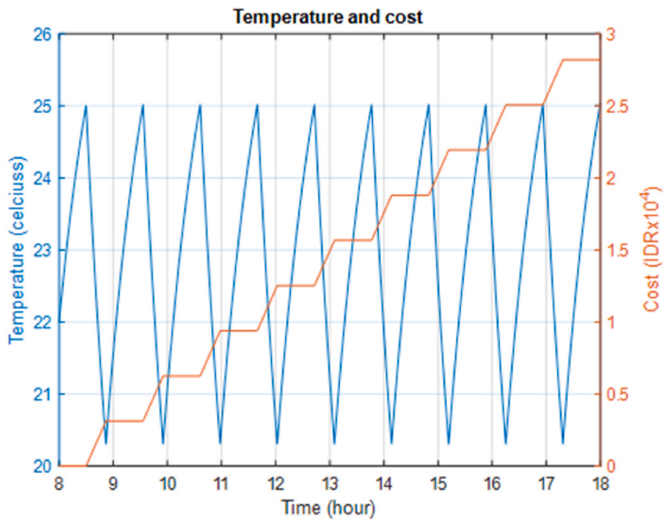

Fig. 10. Result of Optimization building-1.

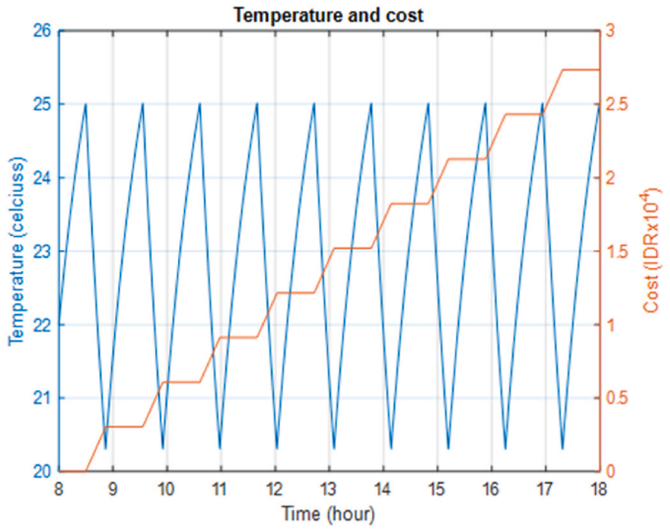

Fig. 11. Result of Optimization building-2.

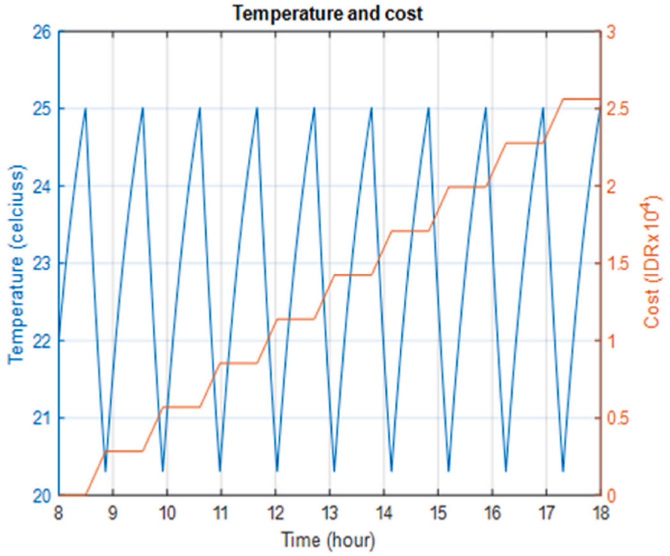

Fig. 12. Result of Optimization building-3.

27,500 and IDR 26,000 for building-1, building-2 and building-3, respectively.

3.3. *Case 2: Tin and EC of building considering to K and Tout*

Equations (4) and (5) are used to compute the Tin and EC of the building considering the K and Tout. In this study, the Tmin and Tmax permitted temperatures were 21.2 °C and 25 °C. The time to operate the AC operated from 08:00 to 18:00. Comparable to the earlier approach, the AC was turned on if the Tin reached the Tmax permitted temperature and switched off when the Tin dropped to Tmin permitted temperature. However, to optimize the EC and keep the room comfortable, considering K and Tout then the pattern of Tin for every kind of building is different. Due to the Tout being increased in the middle of the day then the Tin dropped to a low level, under 24 °C. The cycling temperature range during hot days is 21.2 °C–23.8 °C, as illustrated in Figs. 13–15.

Based on the result of optimization, the Tin decreased to low level starting from 11:00 until 16:00. Due to the different wall characteristics, the times to switch the AC on and off were not the same for every type of building. For example, the AC was switched on at 11:00 and switched off

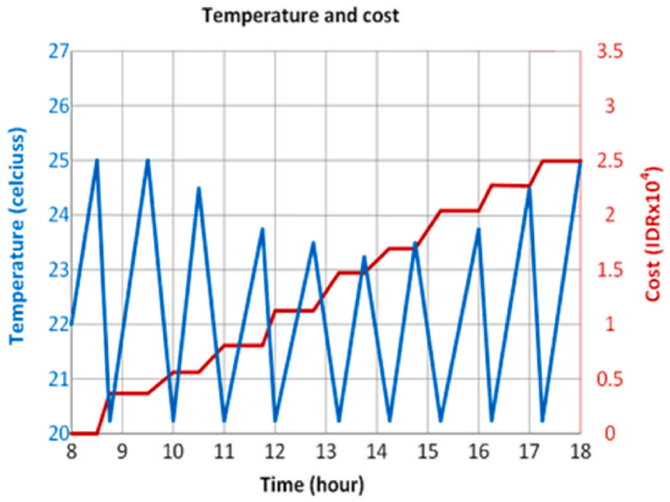

Fig. 13. Result of Optimization building-1.

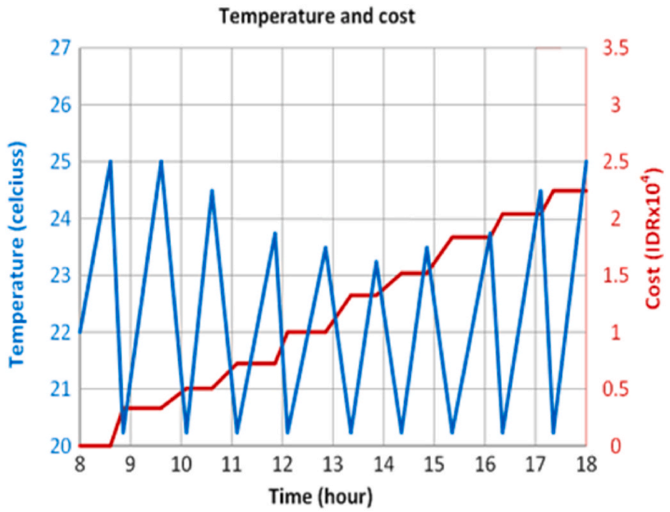

Fig. 14. Result of Optimization building-2.

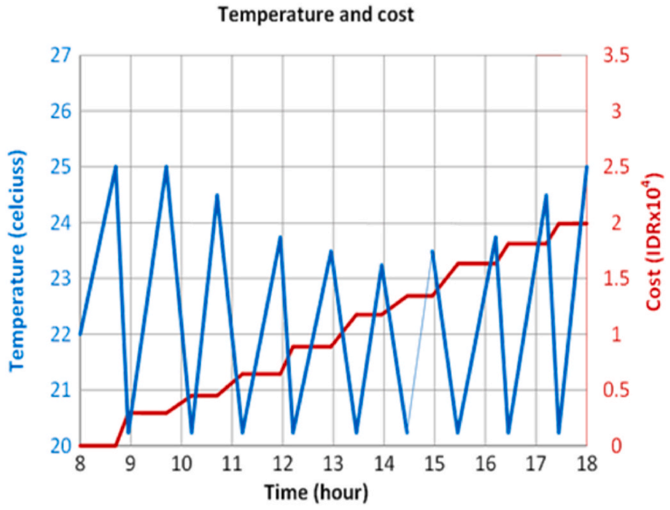

Fig. 15. Result of Optimization building-3.

at 11:40 for building-1. The AC was turned on at 11.05 and switched off at 11:50 for building-2, while the AC switched on at 11:15 and switched off at 11:58 for building-3. In addition, the form of the cycling temperature is not only based on the K but also depends on the fluctuation of Tout. The control mechanism turned on the AC to decrease the Tin when the Tout was raised to a high level. In contrast, as the Tout dropped to a lower level, the Tin rose to the highest temperature allowed. Therefore, the EC can be decreased to be IDR 25,000; IDR 23,000 and IDR 20,000 for every building-1, building-2 and building-3, respectively.

3.4. The electrical energy cost of building

Fig. 16 (below) illustrates the EC of the AC considering to K.

The optimization result indicated that the EC for the AC for every building was variable. The EC of building-1, building-2 and building-3 were IDR 28,000, IDR 27,500 and IDR 26,000. The EC of building-1 was more expensive than other buildings because the thermal wall resistance of building-1 was lower than building-2 and building-3. The amount of Styrofoam as a bonding material was only 5% for building-1. In contrast, the amounts of Styrofoam for building-2 and building-3 were 10% and 15%, respectively. This specifies that the material of Styrofoam to create a building wall has noteworthy impact in minimizing the EC of the AC.

Fig. 17 (below) illustrates the EC of the AC considering both K and Tout.

As illustrated in Fig. 17 the EC of the AC for building-1, building-2 and building-3 were IDR 25,000; IDR 23,000 and IDR 20,000. The thermal resistance of building-3 was higher, the EC of the AC was inexpensive than building-1 and building-2. This is due to the building's material mix, which included using more Styrofoam than the other structures. The Styrofoam has a high thermal resistance to maintain inside room temperature and to obstruct heat transfer speed from external to interior walls. In addition, Tout has a direct substantial effect in computing the EC of the AC for every kind of building. According to Tout, The Tin was controlled by the system to turned on and off. The time to switch it on during hot days was only brief. As a result, the AC only requires less power to keep the room comfortable.

4. Conclusion

The optimization of electrical EC for the AC for various wall features is discussed in this study. The findings of the optimization showed that

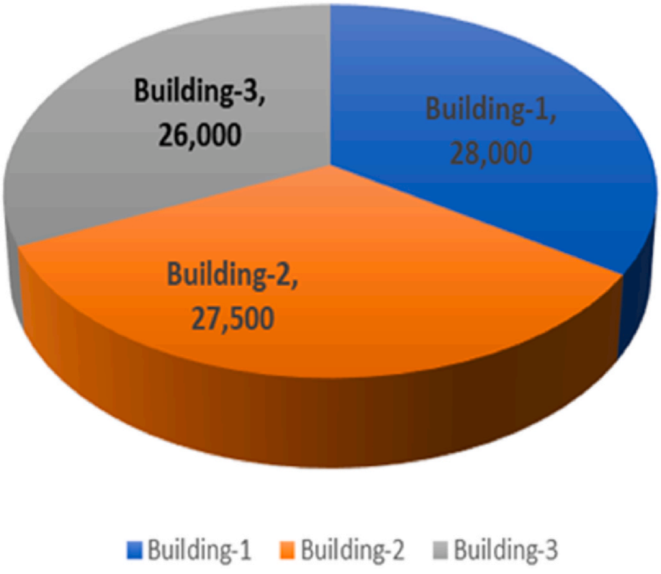

Fig. 16. The Electrical energy cost considering to K.

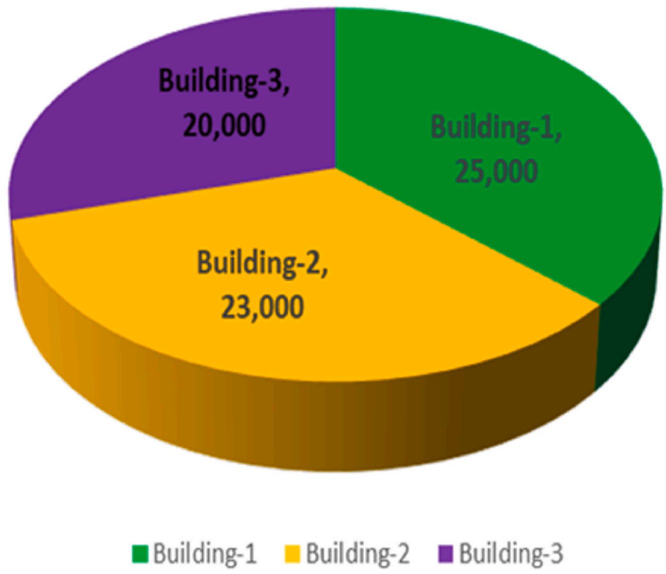

Fig. 17. The Electrical energy cost considering both K and Tout.

the K of wall and Tout's directly affect EC of the AC minimization. Based on the optimization results, if considering only to K the EC can be minimized to IDR 28,000, IDR 27,500 and IDR 26,000 for building-1, 2, 3 respectively. Thermal wall resistance of building-3 was higher than building- 1 and 2. In addition, when the optimization process considers both K and Tout, the EC can be minimized to IDR 25,000, IDR 23,000, and IDR 20,000 for Buildings 1, 2, and 3, respectively. Due to the effect of K and Tout, the control system only needs a brief period to switch on the AC during hot days. The amount of Styrofoam as a bonding material for buildings 1, 2 and 3 were 5%, 10% and 15%, respectively. Consequently, thermal wall resistance of building-1 was lower than building-2 and building-3.

Authorship contributions

Conception and design of study: Marwan Marwan, Jamal Jamal, Abdul Hamid, Nasir Nasir; Mustarum Musaruddin; Acquisition of data: Nur Alam La Nafie, Andi Gunawan, Syamsuddin Syamsuddin, Bustamin Abdul Razak; analysis and/or interpretation of data: Marwan Marwan, Jamal Jamal, Abdul Hamid, Nasir Nasir; Drafting the manuscript: Marwan Marwan, Nur Alam La Nafie, Andi Gunawan, Syamsuddin Syamsuddin; revising the manuscript critically for important intellectual content: Marwan Marwan, Bustamin Abdul Razak, Jamal Jamal, Nasir Nasir, Abdul Hamid, Mustarum Musaruddin.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

[1] A.H. Almasoud, H.M. Gandayh, Future of solar energy in Saudi Arabia, Journal of King Saud University-Engineering Science 27 (2015) 153–157.
[2] M. Salah, , M., G.Abo-Khalil, A., R.P. Praveen, Wind speed characteristics and energy potential for selected sites in Saudi Arabia, Journal of King Saud University - Engineering Sciences 33 (2021) 119–128.
[3] A. Nazir, A.K. Shaikh, A.S. Shah, A. Khalil, Forecasting energy consumption demand of customers in smart grid using Temporal Fusion Transformer (TFT), Results in Engineering 17 (2023), 100888.
[4] Z.A. Barkhordar, S. Habibzadeh, N. Alizadeh, Deriving electricity consumption patterns using a decomposition approach, Results in Engineering 16 (2022), 100628.
[5] Z. Zhang, P. Zhang, Y. Zhao, X. Chen, Z. Zong, K. Wu, J. Zhou, Survey-based air-conditioning demand response for critical peak reduction considering residential consumption behaviors, Energy Rep. 6 (2020) 3303–3315.
[6] M.A. Mcneil, N. Karali, V. Letschert, Forecasting Indonesia's Electricity Load through 2030 and Peak Demand Reductions from Appliance and Lighting Efficiency, vol. 49, Energy for Sustainable Development, 2019, pp. 65–77.
[7] J. Park, T. Kim, C.-S. Lee, Development of thermal comfort-based controller and potential reduction of the cooling energy consumption of a residential building in Kuwait, Energies 12 (2019) 1–22.
[8] R. Opoku, I.A. Edwin, A.Agyarko, K., Energy efficiency and cost saving opportunities in public and commercial buildings in developing countries – the case of air-conditioners in Ghana, J. Clean. Prod. 230 (2019) 937–944.
[9] G.D.N.P. Leite, F. Weschenfelde, A. Maurícioaraújo, Á.a.V. Ochoa, N.D.F.P. Neto, Andreakraj, An economic analysis of the integration between air-conditioning and solar photovoltaic systems, Energy Convers. Manag. 185 (2019) 836–849.
[10] A. Satre-Meloy, M. Diakonova, P. Grünewald, Cluster analysis and prediction of residential peak demand profiles using occupant activity data, Appl. Energy 260 (2020), 114246.
[11] M. Krarti, N. Howarth, Transitioning to high efficiency air conditioning in Saudi Arabia: a benefit cost analysis for residential buildings, J. Build. Eng. 31 (2020), 1011457.
[12] T. Randazzo, E.D. Cian, N.Mistry, M., Air conditioning and electricity expenditure: the role of climate in temperate countries, Econ. Modell. 90 (2020) 273–287.
[13] H. Xu, L. Cheng, N. Qi, X. Zhou, Peak shaving potential analysis of distributed load virtual power plants, Energy Rep. 6 (2020) 515–525.
[14] I. El-Darwish, M. Gomaa, Retrofitting strategy for building envelopes to achieve energy efficiency, Alex. Eng. J. 56 (2017) 579–589.
[15] S. Eyupoglu, U. Sanver, Conference of Russian Young Researchers in Electrical and Electronic Engineering Moscow and, in: Characteristics of Building Thermal Insulation, 2018, pp. 1–5. St. Petersburg, Russia.
[16] A.N. Saleh, A.A. Attar, O.K. Ahmed, S.S. Mustafa, Improving the thermal insulation and mechanical properties of concrete using Nano-SiO2, Results in Engineering 12 (2021), 100303.
[17] I. Mawardi, S. Aprilia, M. Faisal, Ikramullah, S. Rizal, An investigation of thermal conductivity and sound absorption from binderless panels made of oil palm wood as bio-insulation materials, Results in Engineering 13 (2022), 100319.
[18] S. Abu Dabous, T. Ibrahim, S. Shareef, E. Mushtaha, I. Alsyouf, Sustainable façade cladding selection for buildings in hot climates based on thermal performance and energy consumption, Results in Engineering 16 (2022), 100643.
[19] A. Staszczuk, T. Kuczyński, The impact of wall and roof material on the summer thermal performance of building in a temperate climate, Energy 228 (2021), 120482.
[20] T. Kisilewicz, On the role of external walls in the reduction of energy demand and the mitigation of human thermal discomfort, Sustainability 11 (2019) 1–20.
[21] A. Almuwailhi, O. Zeitoun, Investigating the Cooling of Solar Photovoltaic Modules under the Conditions of Riyadh, Journal of King Saud University - Engineering Sciences, 2021, pp. 1–10.
[22] D.K. Blasco, N. Saukkonen, T. Korhonen, T. Lainea, R. Muilu-Mäkelä, Wood material selection in school building procurement – a multi-case analysis in Finnish municipalities, J. Clean. Prod. 1 (2021), 129474.
[23] C.Rai, A., Energy performance of phase change materials integrated into brick masonry walls for cooling load management in residential buildings, Build. Environ. 199 (2021), 107930.
[24] A. Bhosale, , P.Zade, N., P. Sarkar, R. Davis, Mechanical and physical properties of cellular lightweight concrete block masonry, Construct. Build. Mater. 248 (2020), 118621.
[25] K.O. Lee, A.Medina, M., Using phase change materials for residential air conditioning peak demand reduction and energy conservation in coastal and transitional climates in the State of California, Energy Build. 116 (2016) 69–77.
[26] D. Cheng, W. Zhang, K. Wang, Hierarchical reserve allocation with air conditioning loads considering lock time using Benders decomposition, Int. J. Electr. Power Energy Syst. 110 (2019) 293–308.
[27] I. Staffell, S. Pfenninger, The increasing impact of weather on electricity supply and demand, Energy 145 (2018) 65–78.
[28] C. Celniker, S. Chen, A. Meier, R. Levinson, Targeting Buildings for Energy-Saving Cool-Wall Retrofits: a Case Study at the University of California, vol. 249, Energy and Buildings, Davis, 2021, 111014.

[29] L. Zhang, Analysis of Energy Saving Effect of Green Building Exterior Wall Structure Based on ANSYS Simulation Analysis, vol. 23, Environmental Technology & Innovation, 2021, 101673.

[30] M. Arıcı, F. Bilgin, M. Krajcik, S. Nizetic, H. Karabay, Energy saving and CO2 reduction potential of external building walls containing two layers of phase change material, Energy 252 (2022), 124010.

[31] S. Saboor, A. Chelliah, K.K. Gorantla, K.-H. Kim, S.H. Lee, Z.H. Shon, R.J.C. Brown, Strategic design of wall envelopes for the enhancement of building thermal performance at reduced air-conditioning costs, Environ. Res. 193 (2021), 110577.

[32] X. Geng, J. Wang, Y. Gao, X. Meng, Location combination optimization of thermal insulation material and phase-change material in multi-layer walls under air-conditioning continuous and intermittent operation, J. Energy Storage 44 (2021), 103449.

[33] A. Takudzwa Muzhanje, M.A. Hassan, H. Hassan, Phase change material based thermal energy storage applications for air conditioning: review, Appl. Therm. Eng. 214 (2022), 118832.

[34] Y.-H. Lin, M.-D. Lin, K.-T. Tsai, M.-J. Deng, H. Ishii, Multi-objective optimization design of green building envelopes and air conditioning systems for energy conservation and CO2 emission reduction, Sustain. Cities Soc. 64 (2021), 102555.

[35] R. Kumar Sharma, S. Yagnamurthy, D. Rakshit, Energy analysis of a phase change material embedded heat exchanger for air conditioning load reduction in different Indian climatic zones, Sustain. Energy Technol. Assessments 53 (2022), 102776.

[36] S. Shaik, V.R. Maduru, G. Kirankumar, M. Arıcı, A. Ghosh, K.J. Kontoleon, A. Afzal, Space-age energy saving, carbon emission mitigation and color rendering perspective of architectural antique stained glass windows, Energy 259 (2022), 124898.

[37] A. Mesloub, A. Ghosh, L. Kolsi, M. Alshenaifi, Polymer-Dispersed Liquid Crystal (PDLC) smart switchable windows for less-energy hungry buildings and visual comfort in hot desert climate, J. Build. Eng. 59 (2022), 105101.

[38] A. Mesloub, A. Ghosh, M. Touahmia, G.A. Albaqawy, B.M. Alsolami, A. Ahriz, Assessment of the overall energy performance of an SPD smart window in a hot desert climate, Energy 252 (2022), 124073.

[39] M. Ghassemi, A. Shahidian, *Nano And Bio Heat Transfer And Fluid Flow*. Biosystems Heat and Mass Transfer, Elsevier, 2017.

[40] E. Kreyszig, Advanced Engineering Mathematics, 10 ed, John Wiley & Sons, New York, 1993.