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Dual-purpose model of energy consumption-construction cost to evaluate the construction methods of the outer shell of residential buildings: A real case study

Ahmad Madadi[1*], Masoud Barati[1], Rasoul Baharloo[1], Omid Solgi[2]

[1]*Department of Industrial Management, University of Islamic Azad, Science and Research, Najafabad branch, Esfahan, Iran*

[2]*School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran*

a.madadi@haierasa.ir, barati_masoud@yahoo.com, rasoul.baharloo@gmail.com, omidsolg72@gmail.com

Abstract

The outer shell is the primary protection of the building against adverse weather conditions and determines the heat exchange rate to the environment. Evaluating and optimizing the outer shell design of residential buildings due to multiple and conflicting criteria such as energy consumption, costs, and environmental impacts is a multi-objective challenge. In this paper, a bi-objective model is presented to evaluate different methods of constructing the outer shell of residential buildings to reduce energy consumption at the lowest possible cost significantly. So that, minimizing the heat transfer from the outer shell as a function of the energy target and minimizing the cost of fabricating the components of the outer shell as a function of the cost and the augmented epsilon constraint method are used to solve the model and determine Pareto's solutions. The results show that by determining the appropriate thickness and density of the walls and the appropriate ratio of walls' permeable surface while spending reasonable costs, it is possible to reduce required energy for cooling and heating the house.

Keywords: Residential building, outer shell, multi-objective optimization, energy consumption, construction cost, augmented ε-constraint

1-Introduction

Saving energy is one of today world's challenges. The share of buildings in global energy consumption is significant (National Building Regulations of Iran). Residential and commercial buildings are responsible for consuming more than 39% of the world's energy and emitting more than 38% of greenhouse gases (U.S. Department of Energy (2009)). More than 52% of energy in residential buildings is spent on cooling, heating, and ventilation (energy used at the source). Exterior shell as the interface between the interior space and the building environment (including walls, ceilings, and openings) reduces energy consumption and greenhouse gas emission in various ways, including shell design, wall and ceiling insulation, and window placement. The outer shell of the building, as a thermal interface, can be very effective in determining the internal temperature and the amount of energy required to maintain thermal comfort. Minimizing heat transfer through the building shell effectively reduces the energy required for heating and cooling and the natural light hours of the building. Different approaches with different efficiencies and effects can be unlike according to the desired climate. In addition, the decision-makers must have multiple factors such as environmental, economic, and energy for maximum efficiency for maximum efficiency.

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*Corresponding author
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There are two solutions: simulation techniques and multi-objective optimization; in this study, multi-objective optimization has been used. Simulation is an imitation of a real system or process over time. Energy simulation is the demonstration and reconstruction of a building's energy processes, which can help identify the optimal energy efficiency measures according to the builder's specifications.

Peng, Huang, Liu, and Huang (2015), evaluated the energy performance of Zero Carbon cells using energy simulation techniques and data measurements and examined the reasons for the difference between the simulation results in Energy Plus software and the actual results. They also considered the costs of purchasing, installing, and implementing the various technologies used but did not consider the wall life cycle. Delgarm, Sajadi, and Kowsary (2016) integrated a multi-objective and single-objective particle swarm optimization (MOPSO) algorithm with the Energy Plus building simulation software to achieve a set of Pareto solutions to improve building energy performance. Evaluating various combinations of energy efficiency measures and renewable energies in an integrated framework is necessary to find economical options for Zero Energy Buildings (ZEBs) per the Energy performance Directive. Hamdy, Hasan, and Siren (2013) investigated various external shell parameters of the building, heat recovery units, cooling and heating systems, and the capacity of the photovoltaic system through a three-stage optimization and used them in a case study in Finland. Ho, Chang, Wei, and Wang (2014) presented a multi-object linear programming model and a two-phase fuzzy algorithm for energy efficiency and the use of renewable energy in schools and developed two objective functions to maximize return on investment and maximize photovoltaic energy and solar heat generation. Motawa, Elsheikh, and Diab (2021). This study develops a multi-objective genetic algorithm to achieve higher energy efficiency in low life-cycle cost (LCC) in residential buildings and increasing thermal comfort conditions for Egypt's three main climates (the Mediterranean, semi-arid and arid). Design variables include exterior wall type, roof type, window-to-wall ratio (WWR), building direction, HVAC system setting point, and HVAC performance program. In addition, the durable materials available in Egypt are intended for building cladding alternatives such as limestone and expanded polyurethane. Optimal solutions in all climates have successfully balanced energy reduction and LCC in this study. Gamayunova, Petrichenko, and Mottaeva (2020), When there is a library of standard projects, they no longer need additional expertise, which significantly reduces the cost and construction time of the facility; accordingly, the cost per square meter is reduced. To reduce construction costs, some developers currently use enclosed structures made of materials with high thermal conductivity, thereby reducing the energy efficiency of buildings and structures. For example, in this paper, 1-447 series houses were applied to calculate the technical heat of enclosed structures, and the optimal insulation position option is determined. This paper aims to establish artificial neural networks (ANNs) to evaluate and predict the impact of communication factors on the cost of rework in construction projects. Twelve parameters that were affecting the communication were identified and evaluated. Also, the level of reconstruction costs in 18 construction projects was calculated. (Trach, Trach, & Lendo-Siwicka, 2021), used a two-layer feed-forward ANN with a sigmoid transfer function in the hidden layer and a linear transfer function in the output layer. The network input layer contains 12 neurons, while the hidden layer contains ten neurons and one output neuron. The Levenberg-Marquardt algorithm showed optimal results of mean squared error and correlation. The proposed model is applicable by project management as an integrated decision support tool to reduce the number of renovations and consumption of energy and resource in construction projects. Li, Wang, Wang, Hu, and Sun (2021), Analysis of factors stirring energy consumption is vital to save and reduce consumption in residential buildings. Research in this area lacks the analysis of multiple interactions and has not solved high energy consumption. Therefore, this article first identifies various factors affecting energy consumption, including meteorology, architecture, residents, equipment, and energy consumption behavior. Then, the system dynamics theory is used to build a system dynamics (SD) model of energy consumption in older residential buildings to show these factors' effect on energy consumption. Li et al. (2021) discovered the best energy-saving renovation design for older residential buildings based on the SD model and data from northwest China and with the help of scenario simulation. Also, the results show that the interaction between multiple factors is the leading cause of high energy consumption in older residential buildings, which can be greatly reduced by a comprehensive renovation program to improve the building's thermal insulation performance and improve energy usage.

On the top of that, this study helps engineers and policymakers identify the effective factors in energy consumption and create the best energy-saving renovation plan for older residential buildings. Albertini, Gomes, Grondona, and Caetano (2021), This article investigates the inefficiency during the construction of the building concerning some environmental aspects such as waste generation, water consumption, and energy. A data envelopment analysis (DEA) model was used to define the technical efficiency levels of each construction site, taking into account input and output data to compare results. Tobit model was also used to scrutinize the effects of qualitative aspects on the calculated efficiency. The average efficiency was set at 83.5, and out of 16 construction sites, five were 100% efficient. The results showed that building construction standards harm environmental performance. Araújo, Almeida, Bragança, and Barbosa (2016) considered investment costs by presenting a computational method, and decision-maker expectations were included in energy approach selection process. Diakaki et al. (2010) considered various approaches in the two categories related to building shells and cooling, heating, and ventilation systems according to criteria, including energy consumption, carbon dioxide emissions, and initial investment cost. Also, Karmellos, Kiprakis, and Mavrotas (2015) considered two new models, one for new buildings and another for renovating the existing buildings, lighting systems, appliances, and renewable energy sources. Designers determine the values of design parameters by relying on experience or simulation. Experience may lead to incorrect responses because they do not cover all predictable conditions, and complex interactions do not reflect different parameters. Simulation is time-consuming and cannot explore a large design space. In this study of Kaya, Çolak, and Terzi (2019), an MCDM procedure stands on two approaches that are advised to assess endless energy substitutes for Turkey. Interval type-2 fuzzy AHP process is applied to choose the measurements of decision criteria, and hesitant fuzzy TOPSIS procedure is covered to rank endless energy substitutes. A real case operation has been shown by dint of adept evaluations to show the relevancy of the suggested model. Furthermore, a susceptibility inquiry has been made to asset the impressions of main criteria weights in prioritizing. Beltrán and Martínez-Gómez (2019) analyzed the choosing of PCM for construction wallboards and roofs by correlation between multi-criteria decision methods (MCDM) and Building Energy Simulations (BES). For this reason, a reference universal social habitat designed in Ecuador to shed four people in a 36 m2 space has been chosen for this study. The MCDM, TOPSIS, and VIKOR are applied to prioritize PCM substitutes, considering diverse material choosing criteria. Besides, BES is also carried out. The results found dissemblance between the MCDM and BES, showing the influence that the environment variables play to evaluate the performance of PCM properly. Then, two new models, one for new buildings and the other for the renovation of existing buildings, also considered the presentation and lighting systems, electrical appliances, and renewable energy sources. Three phases are done to optimize pattern variables connected to the all building plants arrangement, considering diverse energy, amenity, economic, and environmental function indicators. The innovation and experimental significance subsist in ensuring a decisive pattern optimization by considering a domain of elements and goals as widespread as ever before. Regarding the literature review, innovations that distinguish this research from other studies mentioned above are summarized as follows:

- Designers determine the values of design parameters based on experience or simulation. Experience may lead to incorrect answers because they do not cover all predictable conditions and do not reflect the complex interactions of various parameters. Simulation is also time-consuming and cannot explore an ample design space. This paper seeks to provide a mathematical model to choose from among the various strategies for building the outer shell components of a building, the best of which is to minimize energy consumption by reducing heat loss and minimizing investment costs. Attempts are made to consider using the area during the evaluation process, and also the variables and model parameters' values are defined in such a way as to reduce dependency on the plan and house design details.

- It attempts to take into account the use of the intended space during the evaluation process.

- Also, the variables and model parameters' values are defined in a way that the reliance on details in home plan and design is reduced

- Deploying the augmented ε-constraint method ensures optimal strong Pareto solutions and prevents the weak ones.
- Finally, to assess the impact and usefulness of the proposed method, a case study was considered on the provision and manufacturing of telecommunication satellite components (flight), and valuable managerial outcomes were extracted.

This article is as follows: The next section presents the Statement of the Problem and the mathematical model used. Section 3 describes the method of increasing the ε-constraint to solve the multi-objective optimization model. Section 4 is a case study, and finally, conclusions and future research strategies are presented in section 5.

2-Defining the problem and mathematical model

The proposed bi-objective optimization model includes minimizing the outer shell manufacturing cost and minimizing the heat transfer from the outer shell. The elongation of the building is in the east-west direction due to the desert climate of Yazd. The usage of all building spaces is divided into two groups: "Adjacent to controlled space" and "Adjacent to Outdoor space." Types of costs and heat transfer coefficients per square meter are extracted from the price list of buildings 1395 and topic 19 of engineering systems (National Building Regulations of Iran, 2010).

Table 1. Definitions

Index	Definition
i	Types of proximity: outdoor space($\boldsymbol{i = 2}$), controlled space($\boldsymbol{i = 1}$)
j	Types of walls
r	Types of roofs
f	Types of floors
g	Types of translucent walls
d	Types of doors

Table 2. Parameters of the model

Parameters	Definition
(m^2)A_i^{wall}	Area of walls adjacent to controlled/ external spaces
(m^2)A^{roof}	Roof area
(m^2)A_i^{floor}	Floor area adjacent to controlled / outdoor space
(m^2)A^{glass}	Area of translucent wall surfaces
(m^2)A^{door}	Area of doors
(m^2)A^{total}	Total area of infrastructure
(m^2)A^{SW}	The total area of the east and west walls has a translucent wall
(m^2)A^{NC}	Area of walls adjacent to outdoor space
$t_{out}(°K)$	Outdoor design temperature

Table 2. Continued

Parameters	Definition
$t_{int}(°K)$	Indoor design temperature
Δt_i	The difference between outdoor temperature and controlled/ outdoor space
$U_{ij}^{wall}(W/(m^2.K))$	Coefficient of heat transfer of wall type j in the vicinity of controlled/external space
$U_r^{roof}(W/(m^2.K))$	Roof Heat transfer coefficient of type r
$U_{if}^{floor}(W/(m^2.K))$	Floor heat transfer coefficient type f in the vicinity of the controlled/external space
$U_g^{glass}(W/(m^2.K))$	Transmission wall heat transfer coefficient type *g*
$U_d^{door}(W/(m^2.K))$	Door heat transfer coefficient type *d*
(Rial)$Budjet$	Maximum budget available for external shell
per	Ratio of translucent wall surfaces to floor level
$C_{ij}^{wall}(W/(m^2.K))$	Cost of construction of type *j* wall in the vicinity of controlled/ external space
$C_r^{roof}(W/(m^2.K))$	Cost of construction of roof type *r*
$C_{if}^{floor}(W/(m^2.K))$	Cost of construction of type *f* floor in the vicinity of controlled/ external space
$C_g^{glass}(W/(m^2.K))$	Cost of preparation and installation of translucent wall type *g*
$C_d^{door}(W/(m^2.K))$	Cost of preparation and installation of type *d* door

The problem includes the building shell's decision variables, which are the type of door, window, wall, roof, and floor with different layers of materials and thermal conductivity coefficients and different thicknesses. These parameters are extracted from the publication of the National Planning and Budget Organization (Publications of the Management and Planning Organization of the country), and suitable Yazd climate cases with Expert opinion were selected. Twenty-three types of walls, which according to experts, are more common in Yazd climate and have more applications, are used.

$$X_{ij}^{wall} = \begin{cases} 1 \; if\ the\ wall\ of\ i\ of\ type\ j\ has\ been\ selected \\ 0 \quad otherwise \end{cases}, \quad j=1\ldots,23 \tag{1}$$

9 types of concrete roofs were extracted, the details of which vary according to the thickness and materials of the layers.

$$X_r^{roof} = \begin{cases} 1 \quad if\ the\ ceiling\ of\ type\ r\ has\ been\ selected \\ 0 \quad ,otherwise \end{cases}, \quad r=1\ldots,9. \tag{2}$$

10 types of foam were extracted, the details of which vary according to the thickness and materials of the layers.

$$X_{if}^{floor} = \begin{cases} 1 \quad if\ the\ i\ floor\ type\ of\ f\ has\ been\ selected \\ 0 \quad ,otherwise \end{cases}, \quad f=1,\ldots,10. \tag{3}$$

Two types of windows with single-pane glass and double-pane glass filled with air were selected.

$$X_g^{glass} = \begin{cases} 1, if\ the\ window\ of\ type\ g\ has\ been\ selected \\ 0, otherwise \end{cases}, \quad g=1,2. \tag{4}$$

There are two types of wooden and metal doors:

$$X_d^{door} = \begin{cases} 1, if\ the\ door\ of\ type\ d\ has\ been\ selected \\ 0, otherwise \end{cases}, \quad d=1,2. \tag{5}$$

The model is allowed to choose a type of wall, ceiling, floor, window, and door which is presented in relations (Management and Planning Organization of the country, Publications of the Management and Planning Organization of the country, Publications of the Management and Planning Organization of the country and New York: McGraw-Hill).

2-1- Objective functions

Equation (9) is an objective function trying to minimizing energy consumption. One must calculate the amount of heat transfer through all its external surfaces to check the amount of energy lost/received through the external surfaces of the building. Equation (6) is used to calculate the amount of heat lost/taken from the outer shell such as windows, walls, ceilings, and floors (Askaripoor, Shirali, Yarahmadi, & Kazemi, 2016; Bergman, Incropera, DeWitt, & Lavine, 2011; Lienhard & John, 2005).

$$Q = U.A\,.(T_o - T_i) \tag{6}$$

Q is the amount of energy lost / taken from a surface of area A. T_o is the outside air temperature and T_i is the indoor air temperature. U, the total thermal conductivity of the surface is obtained from equation (7):

$$U = \frac{1}{1/h_o + \sum_{i=1}^{n} R_i + 1/h_i} \tag{7}$$

R_i the thermal resistance of each wall layer is obtained from equation (8):

$$R_i = \frac{x_i}{k_i} \tag{8}$$

K is the thermal conductivity of the materials, X is the thickness of the materials, and R is the thermal resistance of the materials. Also, "h" is the coefficient of thermal conductivity through the convection flow. The value of "h" varies depending on the air flow velocity and the material type of external texture. The energy objective function and the building's outer shell manufacturing cost are presented in equations (9) and (9). The cost in the objective function is the investment cost.

2-2- Constraints

According to the rules of the engineering system organization of the country (National Building Regulations of Iran, 2010), the levels of the building's translucent walls are equal to a minimum of 1/8 and a maximum of 1/5 floor levels. Equations (15) to (18) are used to determine the percentage of transmittance. Equation (19) introduces budget constraints.

$$\text{Min}\, g_1(x) = \left\{\sum_{i,j}\left(X_{ij}^{wall} * U_{ij}^{wall} * A_i^{wall} * \Delta t_i^{wall}\right) + \sum_{i,f}\left(X_{if}^{floor} * U_{if}^{floor} * A_i^{floor} * \Delta t_i^{floor}\right) + \sum_r\left(X_r^{roof} * U_r^{roof} * A^{roof} * \left|t_{out}(°K) - t_{int}(°K)\right|\right) + \sum_g\left(X_g^{glass} * U_g^{glass} * A^{glass} * \left|t_{out}(°K) - t_{int}(°K)\right|\right) + \sum_d\left(X_d^{door} * U_d^{door} * A^{door} * \left|t_{out}(°K) - t_{int}(°K)\right|\right)\right\}$$

$$\text{Min}\, g_2(x) = \left\{\sum_{i,j}\left(X_{ij}^{wall} . C_{ij}^{wall} . A_z^{wall}\right) + \sum_{i,f}\left(X_{if}^{floor} . C_{if}^{floor} . A^{floor}\right) + \sum_r\left(X_r^{roof} . C_r^{roof} . A^{roof}\right) + \sum_g\left(X_g^{glass} . C_g^{glass} . A^{glass}\right) + \sum_d\left(X_d^{door} . C_d^{door} . A^{door}\right)\right\} \quad (9)$$

$$\sum_j X_{ij}^{wall} = 1 \;\; \forall i = 1,2 \quad (10)$$

$$\sum_f X_{if}^{floor} = 1 \;, \forall\, i = 1,2. \quad (11)$$

$$\sum_r X_r^{roof} = 1. \quad (12)$$

$$\sum_g X_g^{glass} = 1. \quad (13)$$

$$\sum_d X_d^{door} = 1. \quad (14)$$

$$\frac{1}{8} \leq per \leq \frac{1}{5} \quad (15)$$

$$A^{glass} = per * A^{total} \quad (16)$$

$$A_1^{wall} = A^{SW} - A^{glass} \quad (17)$$

$$A_2^{wall} = A^{NC} \quad (18)$$

$$\sum_{i,j}\left(X_{ij}^{wall} * C_{ij}^{wall} * A_z^{wall}\right) + \sum_{i,f}\left(X_{if}^{floor} * C_{if}^{floor} * A_i^{floor}\right) + \sum_r\left(X_r^{roof} * C_r^{roof} * A^{roof}\right) + \sum_g\left(X_g^{glass} * C_g^{glass} * A^{glass}\right) + \sum_d\left(X_d^{door} * C_d^{door} * A^{door}\right) \leq budget \quad (19)$$

$$per, A_i^{wall}, A^{glass} \geq 0 \quad (20)$$

$$X_{ij}^{wall}, X_{if}^{floor}, X_{r}^{roof}, X_{g}^{glass}, X_{d}^{door} \in \{0,1\} \quad (21)$$

2-3-Augmented ε-constraint method

In solving a multi-objective problem, we seek the methods that produce Pareto solutions. In this context, Hwang and Masud (2012) classified the multi-objective mathematical models into three sections (1) priori, (2) interactive, and (3) posterior. In the posterior approach, weights of functions should be determined before the resolution process, which is a tough task (Mavrotas, 2009). In interactive approaches, the decision-maker aims at achieving the desire solutions interactively (Chowdhury & Quaddus, 2015). The main weakness of this approach is that it cannot provide an image of Pareto solution set and only focuses on the decision maker's desired solutions, and the remaining efficient ones will be eliminated. In prior methods, a set of Pareto solutions will first be determined, and if these solutions are not appropriate for it, some other will be generated. According to the above-mention discussion, we will use the third method in this article. The ε-constraint method is one of famous posterior methods used to find optimal Pareto solutions for multi-objective problems. In this method, an objective function will be optimized, and the remained one will be added as constraints as shown below:

$$M\text{in } f_1(x) \quad (22)$$

$$f_q(x) \le r_q \;; \forall\; q = 2..., q \quad (23)$$

$$x \in X \quad (24)$$

Where x is the decision variable's vector, X is a feasible available, $f_1(x), f_2(x), ..., f_q(x)$ are the objective functions that must be minimized. By parametric changes on the right of the objective functions, being in the constraints, Pareto's solution will be obtained (Azadeh, Rezaei-Malek, Evazabadian, & Sheikhalishahi, 2015). To end this, the range of each ε must first be earned. For this, the pay table is created by optimizing the $(q-1)$ objective function which is in the constraints. Then, the values of ε are obtained by spilling, the obtained ranges of n_q interval as follows (Esmaili, Amjady, & Shayanfar, 2011):

$$rangrp = f_q^{\max} - f_q^{\min} \;;\; \varepsilon_p^l = f_q^{\max} - (rangr_p)/n_q * k \;;\; \forall p \ne 1, k = 0,1, n_q = 1 \quad (25)$$

Where, f_q^{max} and f_q^{min} are the maximum and minimum values of the objective function of q. However, as pointed out by Mavrotas (2009), the general form of the ε-constraint method does not guarantee an efficient solution to the vector ε. To prevent this problem, a developed version of this method will be used, which is called the augmented ε-constraint method. By deploying the ε-constraint method, the following model can be obtained:

$$\begin{aligned} & min\ \theta_1\ \ f_1(x) - rangr_{q1} * \delta * (\beta_2\ \ jl_2 / (rangr_2) + \beta_3 jl_3 / (rangr_3) + ... + \beta_q jl_q / (rangr_q) \\ & + ... + \beta_q jl_p / (rangr_q)) \\ & S.t. \\ & f_q(x) + \beta jl_q = r_{(q)} \ \ \forall q = 2..., q \quad (26) \\ & x \in X ; jl_q \in R^+ \end{aligned}$$

Where, δ is a very small number (between 10^{-6} and 10^{-3}), β_q has priority value over the objective function of q^{th}, and jl_p is the shortage of variable of the relevant constraint. Note that the complementary term of $\beta_q \frac{jl_q}{rangr_q}$ will ensure that only the efficient solution is obtained for the vector ε.

3-Case study analysis

In order to evaluate the model, we used it for a two-story residential building in Yazd, a new texture area with a total area of 250 square meters.

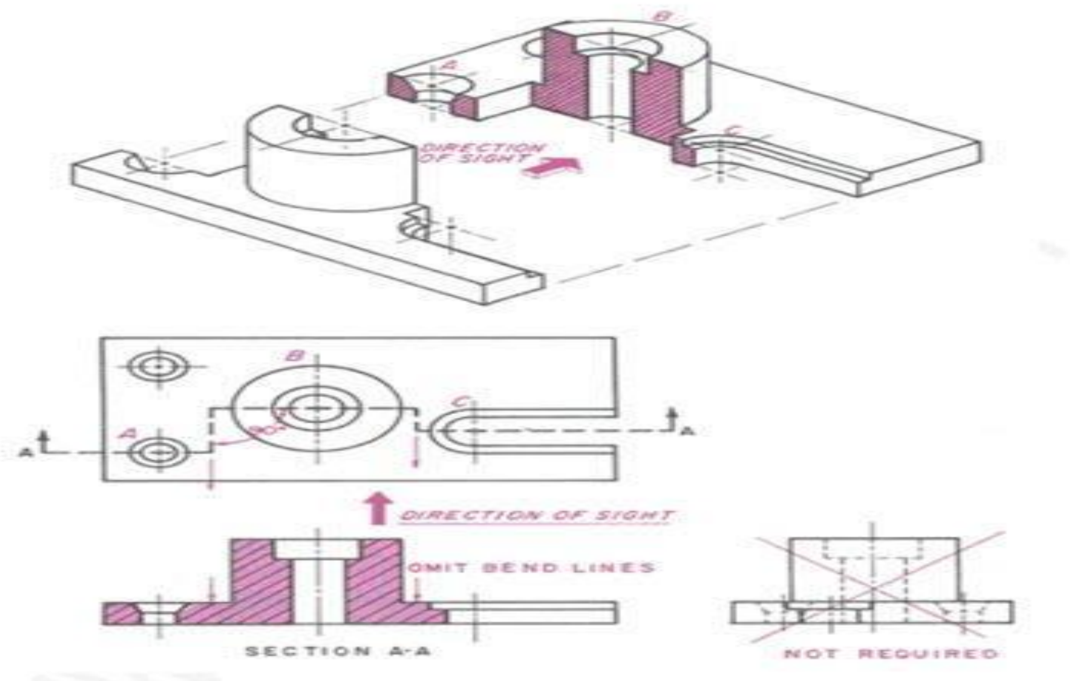

Fig 1. Top view of the building under study

The model was executed and coded by a Sony notebook computer in GAMS software. All calculations of heat transfer coefficients of walls, ceilings, and floors were performed through equations (6) to (8) using the values approved in section 19 of the Engineering system organization (National Building Regulations of Iran, 2010) in the Excel environment. Information on heat transfer coefficients and construction costs of the options building external shell components are presented in table 2. Table 5 summarizes the model parameters, construction costs, and door types' heat transfer coefficient. According to the values of the above parameters and other parameters related to the area obtained according to the study plan, the two-objective model was implemented in GAMS environment. The best value of the energy target function was 6,039.134 for 0.125, and the best value of the cost function was 341,073,900 Rials for 0.195. The results related to the decision variables are shown in table 7: construction cost and heat transfer coefficient of different types of translucent walls.

Table 3. Cost of construction and heat transmission coefficient in various walls				
Heat transmission coefficient in adjacent to controlled space	Heat transmission coefficient in adjacent to outer space	Cost of construction in adjacent to uncontrolled space	Cost of construction in adjacent to outer space	Kinds of wall (*j*)
0.037927	*M*	371200	[1]*M*	1
0.038535	*M*	1004900	*M*	2
M	0.038535	*M*	1178400	3
0.038132	*M*	1871100	*M*	4
0.038353	*M*	544700	*M*	5
M	0.038325	*M*	2256900	6
M	0.038287	*M*	2306533	7
0.038348	*M*	1648300	*M*	8
M	0.038296	*M*	2009500	9
M	0.038522	*M*	2067500	10
M	0.03388	*M*	569700	11
0.038613	*M*	1222100	*M*	12
0.038229	*M*	1354000	*M*	13
M	0.038377	*M*	1875900	14
M	0.038429	*M*	1840300	15
M	0.038017	*M*	2008500	16
M	0.037982	*M*	1795600	17
M	0.037761	*M*	1591400	18
M	0.037322	*M*	1453600	19
M	0.038427	*M*	2341750	20
M	0.028511	*M*	1724800	21
M	0.029153	*M*	2040300	22
M	0.028904	*M*	1742800	23

[1] M indicates a big positive number

Table 4. Cost of construction and heat transmission of various ceilings

Heat transmission coefficient	Cost of construction	Kinds of ceiling (r)
0.03746885	1927800	1
0.01848083	648300	2
0.03667156	1874800	3
0.02563466	2234800	4
0.03664096	2355800	5
0.03671735	2295800	6
0.03753714	880300	7
0.02603515	1782900	8
0.01826570	1428800	9

Table 5. Cost of construction and heat transmission of various floors

Heat transmission coefficient in adjacent to uncontrolled space	Heat transmission coefficient in touch with earth	Cost of construction	Kinds of ceiling (*f*)
0.0313776196	0.0313776196	2016956	1
0.031447927	0.031447927	1778600	2
0.032047371	0.032047371	527200	3
0.032047371	0.032047371	527200	4
0.031533504	0.031533504	1396000	5
0.031419971	0.031419971	1197356	6
0.031482626	0.031482626	1459500	7
0.031649683	0.031649683	2251200	8
0.031710905	0.031710905	1946600	9
0.031821106	0.031821106	1380600	10

Table 6. Cost of construction and heat transmission of various doors

Heat transmission coefficient	Cost of installation and preparation	Kinds of doors (d)
3.5	70000	1
5.8	58000	2

Table 7. Cost of construction and heat transmission of various transparent walls

Heat transmission coefficient	Cost of installation and preparation	Kinds of transparent walls (*g*)
5.8	280500	1
2.4	387500	2

Table 8. Quantities of decision variables

Decision variable	Quantity
X_{11}^{wall}	1
X_{21}^{wall}	1
X_{11}^{floor}	1
X_{21}^{floor}	1
X_{2}^{roof}	1
X_{2}^{glass}	1
X_{1}^{door}	1
A^{glass}	26.25$\boldsymbol{m^2}$
A_{1}^{wall}	332.89$\boldsymbol{m^2}$

Figure 2 shows the relation between heat analyses of the outer shell of the building for different values of indoor comfort temperature as a Pareto solution diagram obtained by the Epsilon method. As it turns out, the sensitivity of the objective functions to each other is very low, and, in exchange for changing the steps of the upper limit of the epsilon constraint, the objective function value is negligible, since according to equation (8), the thermal resistance of each component is directly related to its thickness, and the model is looking for high-thickness walls, which are traditional walls and do not have insulating materials and cost less. It is necessary to pay much attention to the walls to achieve the highest energy efficiency because those are important in two ways: first, they have the largest area of the outer shell, and second, their thickness is effective both in terms of useful space inside the building and heat transfer. It is expected that we will achieve better results if the density of the walls is taken into account in prioritizing their selection. One of the things that should be considered in a house designing initial phase in terms of heat transfer is the ratio of light transmitters and the choice of material of walls. One of the proposed model's features is investigating the effects of the ratio different values on heat transfer and energy consumption. Figure 3 shows Pareto's problem-solving diagram of the sensitivity analysis of energy objective function values (g_1 (x)) for different amounts of PER (ratio of transmittance to floor surface). It can be seen that there is a direct relationship between the ratio of permeable surfaces and the amount of heat passing through the walls. As the permeable surfaces' ratio increases, the amount of heat passing through the walls increases, and vice versa; therefore, in design initial phase, measures such as utilizing multi-glazed windows' capabilities should be considered to reduce heat loss. It is also important to mention that in determining the level of light transmitters, the effect of the dimensions and elongation of the light transmitters on the natural light hours of the house should be considered.

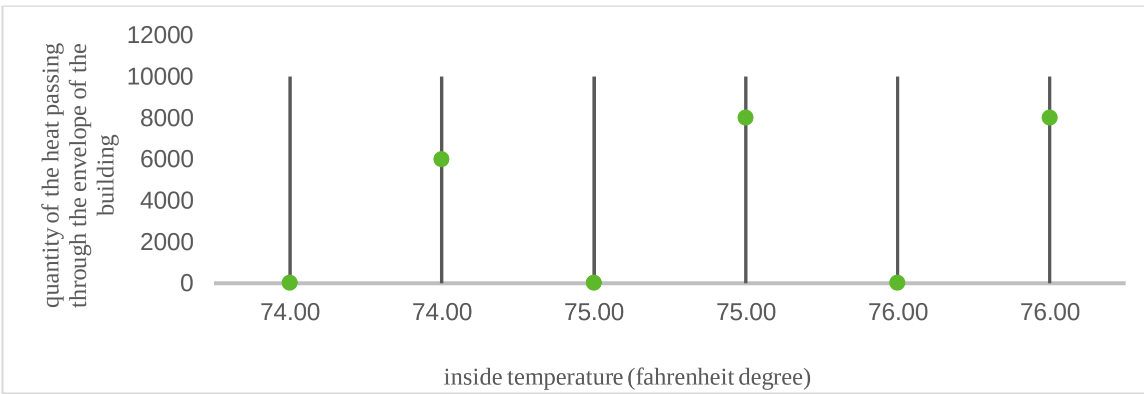

Fig 2. Heat analysis passing through the outer shell of the building for different values of indoor comfort temperature

Figure 3 shows the Pareto solution for sensitivity analysis for energy objective function values per various values of PER (the ratio of the lightning surfaces to the floor surface). There is a direct relationship between the lightning surfaces ratio and the amount of heat passing through the walls. The higher the proportion of the lightning surfaces, the higher the amount of heat passing through the walls, and vice versa. Therefore, in the initial design phase, measures such as the use of multi-shielded glasses should be considered to reduce heat dissipation. It is also important to note that in determining the lightning surfaces, the impact of the dimensions and elongation of the lightning surfaces on the natural light hours of the home should be taken into account.

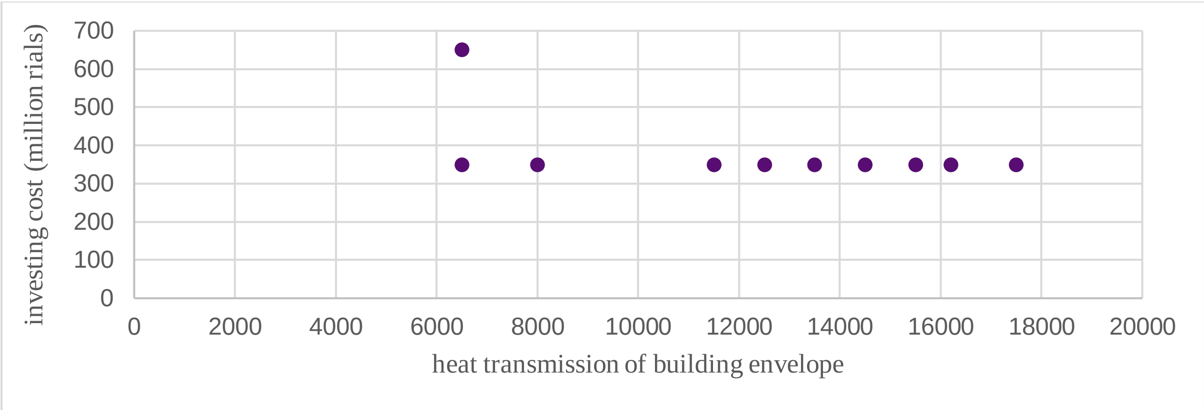

Fig 3. Diagram of the pareto`s responses of the problem

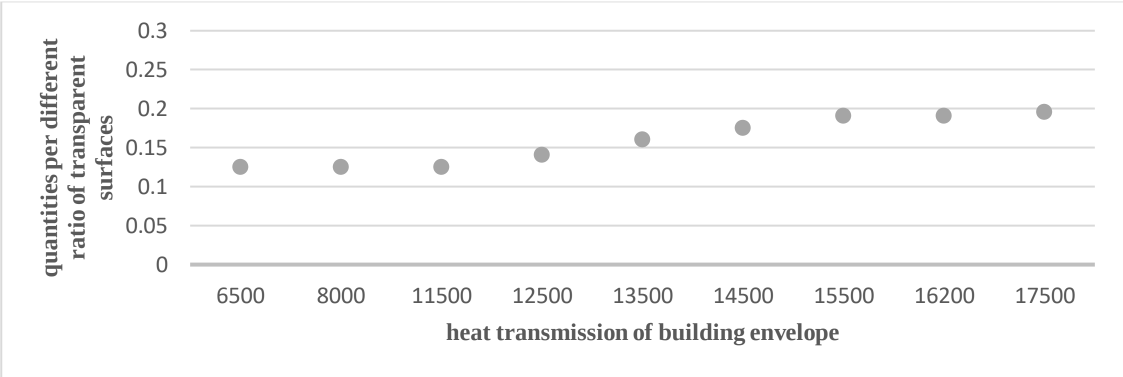

Fig 4. Heat transmission of building development per different ratio of transparent surfaces

4-Conclusion

Heat transfer through building's different walls is an essential issue in building energy consumption. In this study, the proposed bi-objective model can be provided to building designers, which will also be a handy tool for determining the energy required for cooling and heating equipment and lighting system. According to the descriptions, the minimization of heat transferred from the envelope is considered the energy objective function, and minimizing the cost of executing the envelope components is considered the cost target function. Meanwhile, the augmented ε-constraint method is used to ensure the optimal strong Pareto solutions and prevent the weak ones for the proposed bi-objective model. The results indicate that by determining the proper thickness and density of the walls and the proper ratio for transitional walls' surfaces while minimizing the cost, the energy minimization required for cooling and heating becomes possible. The proposed bi-object model can be provided to building designers. It is also a valuable tool in determining the energy required for cooling and heating equipment and lighting systems. The ability to evaluate the results through translucent surfaces is an important feature of the model, which in addition to affecting the amount of heat passing through the walls, also affects the time required for natural light into the house. To evaluate the proposed model efficiency, the results of model's utilization for this case building were compared with the reference heat transfer standard of Iranian buildings. The results of the proposed model of this study are approximately 22 percent of the Iranian standard. Several research methods can be recommended to enrich future research. For example, considering a multi-source strategy for risk reduction can be interesting for the proposed model. Also, future research may be aimed at proposing the exact solution procedure such as the benders algorithm to solve it.

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