Energy Consumption Control with Zero Energy Approach for a Building Model

Rasoul Moradimehr[1], Esmaeil Alibeiki[2*], SeyyedMostafa Ghadami[3]

Abstract–- Based on the study of the theoretical foundations of the research, it is determined that so far there is no detailed study on heating and cooling energy related to zero-energy buildings in the recent research based on energy waste in buildings. Therefore, in this article, by simulating commercial buildings and simulating the correct materials and strategies in the heating and cooling system, as well as investigating the insulation of buildings, we will study the effect of zero-energy building materials on energy wastage to model the temperature variations in building and control to achieve desire value.This article, taking into account the effects of heat transfer through building walls, the energy consumption model, and by genetic algorithm model predictive control (MPC) methodoptimizes the indoor temperature of the building. For this purpose, the genetic algorithm is used to determine the best control input in the form of building heating. The simulation of this process has been done in MATLAB software and the method of modeling heat loss and temperature change outputs shows that the proposed method has a good performance. The maximum of overshoot of the temperature is %4 and the cost function of GA algorithm is 165 based of minimum control effort and temperature error.

Keywords: Building energy management, Energy consumption, Genetic method.

1. Introduction

Trust Zero energy building refers to buildings that have zero annual energy consumption and do not produce carbon pollutants. In today's world, due to the limited resources of fossil fuels, buildings, industries, and other organizations have moved towards the use of other energies available on earth such as solar, wind, biological, and water energy [1]. The idea and principle of zero net energy consumption have attracted a lot of attention because the use of renewable energy is a means and a solution to eliminate pollutants and greenhouse gases. Today, projects related to the principles of "zero energy" have become very practical and popular due to the increase in the cost of fossil fuels and their destructive effects on the environment and weather conditions and disrupting the ecological balance [2].The access of developing countries to all kinds of new energy sources is of fundamental importance for their economic development, and new research has shown that there is a direct relationship between the level of development of a country and its energy consumption. Considering the limited reserves of fossil energy and the increase in the level of energy consumption in the current world, it is no longer possible to rely on the existing sources of energy, energy plays a very important role in the development of human civilization [3]. Because energy consumption in the building sector accounts for the highest amount of consumption in the world. The global effort to reduce pollution, as well as the reduction of global energy resources and the fact that buildings account for a large share of primary energy consumption in the world, led research to a new definition of buildings called zero energy buildings**.**In [4] the concept of green building is considered as the optimal use of energy and water saving. The building information modeling approach has been used to analyze green building concepts. Green building parameters are defined in the Leadership in Energy and Environmental Design rating system. A parametric model of the building of the case study has been developed on the platform of View software based on the original drawings and details. Then the same model has been implemented by providing insulation measures. The intensity of energy consumption of both models is calculated and analyzed [5]. The results

1 Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran. Email: Rasoulmoradimehr@gmail.com
2* Corresponding Author : Department of Computer Engineering, Aliabad katoul Branch, Islamic Azad University, Aliabad Katoul, Iran. Email:esmail_alibeiki@aliabadiau.ac.ir
3 Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran. Email: ghadami@aliabadiau.ac.ir
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of the study indicate that if better measures and decisions are taken in the design phase, there is a potential to save energy to some extent. Energy has been saved by 28% and water by approximately 32%.

Rating systems for sustainable or green buildings have been developed in many countries. The Green Building Index is a rating system developed in Malaysia that consists of six main criteria [6]. Evaluation of materials and energy resources is one of the main criteria that requires the quantification of building materials to calculate the cost of materials and give points and evaluation. Normally, the evaluation process is done manually, which is a time-consuming and error-prone process. Building Information Modeling technology provides a new possibility to extract material values instantly from a model that can support the assessment process. Therefore, this research aims to develop an integration method that integrates the material values extracted from BIM with developed templates and scripts to form automatic evaluation results [7]. Strengthening the thermal performance of the building envelope is very important to ensure adequate thermal comfort inside the building, to minimize the amount of cooling load, and as a result to reduce the overall energy consumption of the building [8]. The process of retrofitting the existing building envelope includes the design team's selection of the best building materials and components based on various design variables and predefined design goals. Worldwide, a global heat transfer value metric has been developed and used to evaluate heat transfer through building envelopes. However, its use requires addressing many design variables and a lot of information, which makes the design decision-making process time-consuming and complicated [8]. The results show that the developed system provides a valuable design decision support system for retrofitting the thermal performance of the building envelope while considering the cost of retrofitting. In addition, this system shows an improved level of automation in terms of data management compared to conventional methods.

The construction industry is known for producing a large amount of carbon emissions, and this, along with the huge costs of buildings during their life cycle, seriously affects its environmental and economic sustainability. The fact that the decrease of the former causes the increase of the latter is a very important problem that aggravates the situation [9]. Finding a solution with the lowest carbon emissions at a given cost is an urgent problem to be solved. In response, this paper presents a method for integrating life cycle carbon emissions and life cycle costs of buildings to assess life cycle carbon emission intensity based on BIM technology. Through a public building in China as a case study, the feasibility of the method has been confirmed, and the key stages of the carbon emission of the building are analyzed using software, and the conversion of materials with high carbon emissions to low carbon emissions is investigated. Is. The proposed methodology and framework provide solutions and ideas for achieving optimal cost-effectiveness with low carbon emissions throughout the building life cycle, facilitating the assessment of carbon emissions in the decision-making and design stages, achieving optimization of carbon emissions and building costs, and increasing the sustainability of the building life cycle [10].

According to the investigations, correct modeling of temperature changes based on the amount of losses and energy consumption for building heating is very important to control the temperature of the indoor environment. In the reviewed articles, the modeling topics are mostly on the sources of energy supply, taking into account insulation and non-loss of energy. While energy loss can occur in different ways in the building, this article deals with the heating resistance of walls based on materials. Based on the investigated data for a simulated building sample, the output of the indoor temperature of the feedback building is taken and to adjust the temperature to achieve the desired temperature, the controller part is designed based on the predictive model control optimized with the genetic algorithm. Therefore, the motivation and innovation of this article can be considered in improving the modeling method by considering the effects of temperature loss and control in an optimal way.The rest of the paper is organized as follows. In the second section, the model of the building energy sources is presented. In the third section, the proposed adaptive MPC controller is designed. In the fourth section, the building model is simulated in MATLAB and Energy Plus software, and based on the results, the performance of the method is evaluated. In the fifth section, according to the evaluations performed, the conclusion of the paper is explained.

2. Model of Consumption

As we know, whenever there is a temperature difference between two bodies, heat is lost from the hotter body to the colder body. This heat transfer may be done by one of the three methods of conduction, displacement or convection, and radiation, in this research, due to the insignificant influence of other parameters, the category of conduction is discussed.

In the method of conducting heat transfer, which takes place due to the temperature difference of different surfaces of an object or two adjacent objects, thermal energy is transferred from hotter molecules to colder molecules, and there is little movement in the molecules and particles of the object or objects. does not have. Transferred heat is a quantity that depends on the temperature difference between adjacent surfaces, the type of constituent materials, and the cross-sectional area of the object. In a one-dimensional state and in stable conditions where we assume most heat transfer materials in air conditioning problems are of this type, the heat transferred per unit time due to conduction is obtained from (1) [11]:

$$Q = -\frac{kAdt}{dx} \quad (1)$$

This law is known as Fourier's law.

To investigate the conduction heat transfer in a simple wall, consider Figure 1. Assume that T1 < T2 and T, then heat flows from level 2 to level 1. In this way, according to relation (1), we will have:

$$Q = -\frac{kA(T_{S2}-T_{S1})}{x} \quad (2)$$

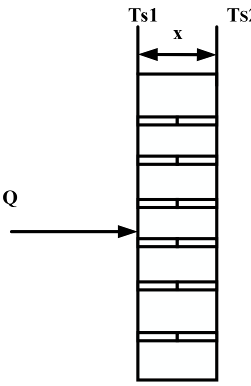

Fig. 1. Investigation of conductive heat transfer in a simple wall

This relationship is written as follows:

$$Q = -\frac{A(T_{S2}-T_{S1})}{R} \quad (3)$$

$$R = \frac{x}{k} \quad (4)$$

In this relation, R is the thermal resistance of the wall. To check heat transfer from composite walls, the procedure is the same. Suppose. A wall according to the rough shape consists of three layers with different thicknesses and coefficients of thermal conductivity [12-15].

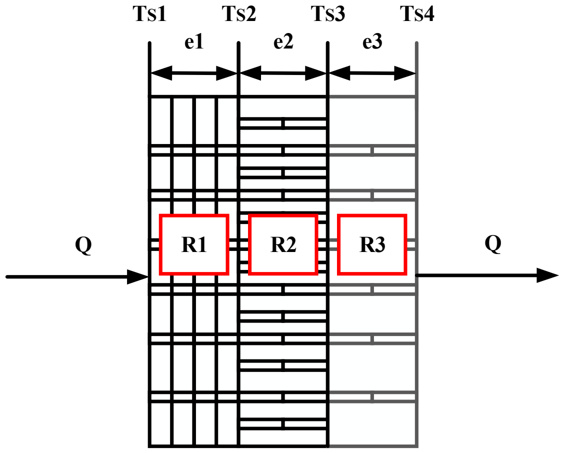

Fig. 2. Investigating conductive heat transfer in a three-layer wall

In the steady state where a constant heat flow passes through the wall, it can be written:

$$Q_1 = -\frac{k_1A(T_{S1}-T_{S2})}{e1} \quad (5)$$

$$Q_2 = -\frac{k_2A(T_{S2}-T_{S3})}{e2} \quad (6)$$

$$Q_3 = -\frac{k_3A(T_{S3}-T_{S4})}{e3} \quad (7)$$

Using the relation (3), the above relations will be as follows:

$$Q_1 = -\frac{A(T_{S1}-T_{S2})}{R1} \quad (8)$$

$$Q_2 = -\frac{A(T_{S2}-T_{S3})}{R2} \quad (9)$$

$$Q_3 = -\frac{A(T_{S3}-T_{S4})}{R3} \quad (10)$$

After averaging the sides of the above relations, we will have:

$$Q_1R_1 = A(T_{s1} - T_{s2}) \quad (11)$$

$$Q_2R_2 = A(T_{s2} - T_{s3}) \quad (12)$$

$$Q_3R_3 = A(T_{s3} - T_{s4}) \quad (13)$$

which we have in the above relations:

$$R_t = R_1 + R_2 + R_3 \quad (14)$$

This method can be easily extended to multiple layers and in this case, after finding the resistance of different layers, we add them together, and then heat can be transferred from equation (14) knowing the temperature of the initial and final surfaces. obtained the

$$Q = -\frac{A(T_{S1}-T_n)}{R_t} \quad (15)$$

In this relation, T is the temperature of the first surface of the first layer, T_nd is the temperature of the last surface of the nth layer, and R is the sum of all thermal resistances. The relation (15) is usually written as follows:

$$Q = U.A(T_{s1} - T_n) = U.A.\Delta T \quad (16)$$

In this relationship, U is the overall heat transfer coefficient of the wall and is obtained from the following relationship:

$$U = \frac{1}{R_t} = \frac{1}{\sum_{i=1}^{i=n} R_i} \quad (17)$$

When calculating the value of R or U, the resistance of these layers should also be considered. We denote the thermal conductivity of the air layers with h, and hi and ho represent the thermal conductivity coefficients of the air layers inside and outside the building, respectively. For air layers, the value of thermal resistance is defined as the reciprocal of thermal conductivity coefficients.

$$R_i = \frac{1}{h_i}.R_o = \frac{1}{h_o} \quad (18)$$

As a result, the relationship (17) can be written as follows:

$$U = \frac{1}{R_t} = \frac{1}{\sum_{i=1}^{i=n} R_i} = \frac{1}{\left(\frac{1}{h_i}\right)+R_1+R_2+\cdots+R_n+\left(\frac{1}{h_o}\right)} \quad (19)$$

3. Optimum Control Method

In this paper, the issue of control temperature is thoroughly evaluated and simulated based on the MPC method. The temperature change model in buildings and the Genetic algorithm model predictive control are simulated in MATLAB software. The simulation is performed under several different scenarios and conditions to show the performance of the proposed design.The problem of minimizing the cost function based on system error (E) and control effort (Q) is defined as follows:

$$J(k)\text{: min} \sum_{j=1}^{P} \lambda \|T(K+j) - r(k)\|^2 + R_u \sum_{j=1}^{M_u} \|Q(k+j-1)\|^2 \quad (20)$$

where$r(k), \lambda, M_u$, and $R_u$represent the desired value of temperature, weight coefficient for system error, control horizon, and weight coefficient for control law, respectively. The solution of this problem is solved by using Riccati equations and using linear feedback structure. The use of a genetic optimization algorithm has led to the selection of appropriate coefficients for weighting coefficients in the MPC controller. These coefficients are performed by minimizing the cost function of obtaining new data at each sampling rate with three methods elite selection, intersection, and mutation. The simulation was performed with 50 initial populations in 200 repetitions and the results are shown in Table (1) which leads to the minimization of the cost function in terms of slip levels. The cost function to reduce the error of the model outputs to the desired value (e) despite reducing the control effort (u) to reduce energy consumption is considered as follows:

$$J = \int e^2 + u^2 \, dt \quad (21)$$

In the genetic algorithm, from the 3 methods of an elite child, mutation, and crossover, the data of each iteration is generated, and considering the value of the lower cost function in each step, some data are deleted and finally, the best problem-solving parameters are obtained in its output. are brought The particle swarm algorithm is set by taking into account the search limits in specific intervals and the corresponding cost function is calculated and then at each stage with a specific speed based on the cost functions obtained from each parameter, towards the most optimal Data are moving forward.

4. Simulation

In this section, the proposed method for building energy management is simulated using MATLAB and Energy Plus software. For simulation, a room was considered as follows:

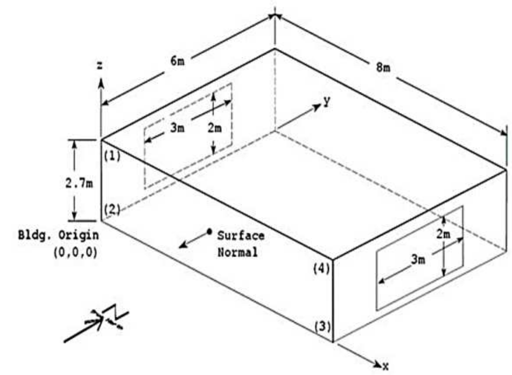

Fig. 3. Simulation and data of walls and windows

The simulation and the data related to the walls and the size of the windows are entered in the software as shown above. All parameters that have used in simulation is shown inAppendix A.The use of 0.5-inch glass wool insulation in the wall with a brick facade reduces the heat load of the building by 15.8% and by increasing the thickness to 1 inch, this percentage increases to 23%. Increasing the insulation thickness from 1.5 inches to 2 inches and from 2 inches to 2.5 inches only causes a 3% reduction in heating load.The effect of insulation of external walls on consumption,the amount of thermal load, annual consumption, and the natural gas heat load (for the cold months of the year) of the entire building is shown in Figures (4)-(7).

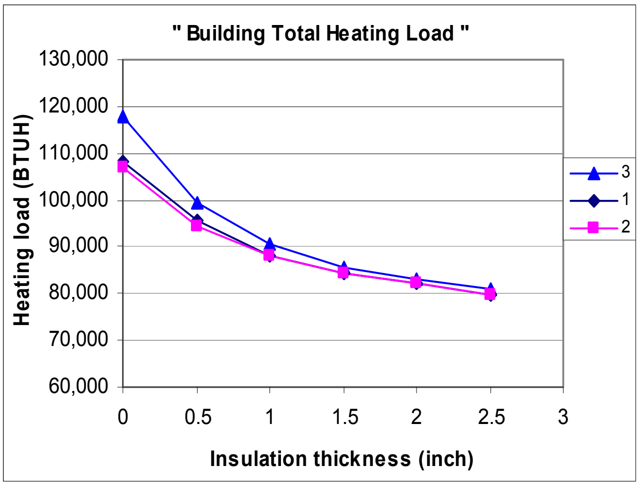

Fig. 4. The effect of insulation of external walls on consumption

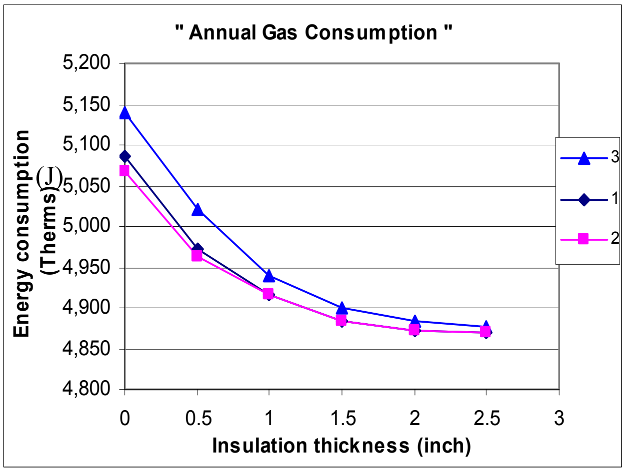

Fig. 5. The effect of insulation of external walls on the amount of thermal load

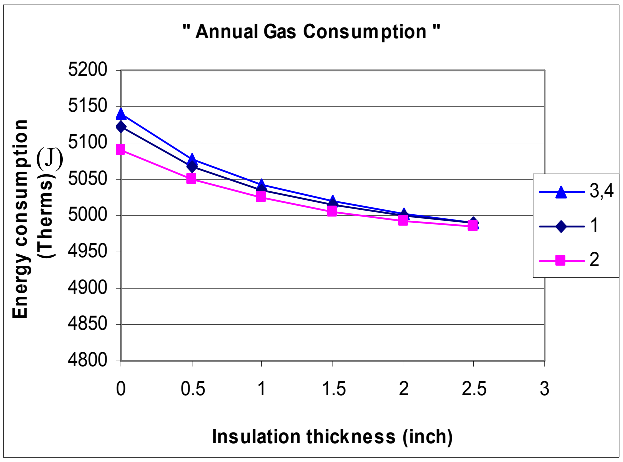

Fig. 6. The effect of external roof insulation on annual consumption

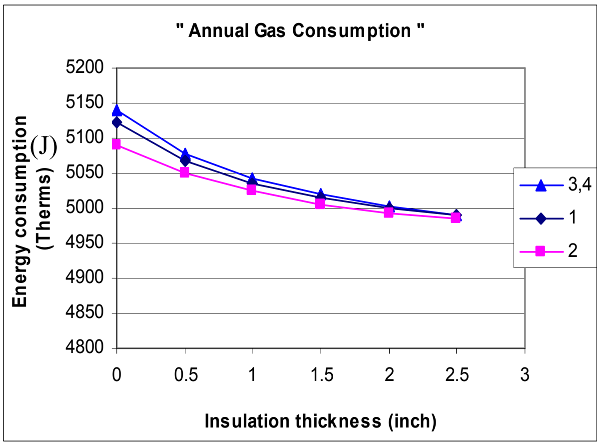

Fig. 7. The effect of external roof insulation on the natural gas heat load (for the cold months of the year) of the entire building

If the insulation thickness increases more than 2 inches, the thermal loads will change less. Also, with the thickness of 0.5-inch insulation, the amount of energy consumption is reduced by 2.3%. By increasing the insulation thickness to 1 inch, this percentage reaches 4%, that is, compared to the previous state (0.5 inches), energy consumption is reduced by 1.6% [7]. By increasing the thickness of the insulation from 2 inches to 2.5 inches, the amount of energy consumption decreases by only 0.14%, therefore, by increasing the thickness of the insulation more than 2 inches, the energy consumption does not change significantly. As a result, from a limit of insulation thickness, the reduction of thermal load and energy consumption goes through a slower process, which is clear from the behavior of the curves in Figures 6 and 7.

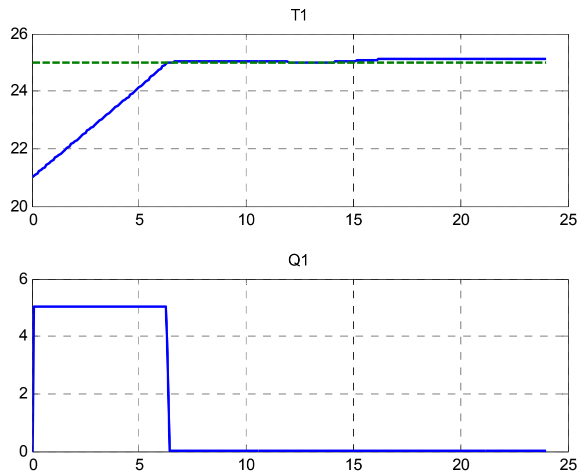

Fig. 8. Room temperature changes using the genetic optimization method

As an example, for a wall with a brick facade, the annual reduction in natural gas consumption due to the insulation of external walls with a thickness of 2 inches is equal to 5%. Diagrams 6 and 7 show that with proper insulation of the roof, the amount of heat loss and energy consumption can be reduced to an acceptable level for all four types of roofs. The behavior of these curves is similar to the behavior of the curves related to the insulation part of the external walls, and from one insulation thickness onwards, the heat load and energy consumption decrease at a slow rate. This behavior of the curves shows the fact that the insulation of the external walls of the building up to a certain thickness will have a significant effect on reducing heat losses and saving energy consumption, and from that point on these effects will be less and the discussion of its cost and economics will become more prominent. Based on the results shown in Figure 8, the use of the genetic algorithm due to the presence of energy loss in the building, the controller of temperature changes has led to the optimization of the control input value and has reached a temperature of 25 degrees Celsius.In this section, the proposed method for building energy management is simulated using MATLAB software. The parameters used in the MPC problem are shown in Table (2) [11]. In this table,P_{EX} is the input electrical power of the building.

Table 2. Building model parameters [11]

Parameter	**value**	**unit**	**Parameter**	**value**	**unit**
N	20	-	LHV	9.78	m^3
φ	5000	lm	P_{NG}	2.2	$
U	0.8	-	α, β, γ	1.3	-
M	0.8	-	μ	1.2	
V_{co2}	0.000056	m^3	V	600	m^3
P	1.2	W	C_p	900.4	$\frac{j}{kg.C^{\circ}}$
A	200	m^2	$P_{EX\text{-}max}$	30	Kw
M_{air}	723	Kg	$P_{CHP\text{-}max}$	65	Kw
$P_{EX\text{-}min}$	0	Kw	$Q_{GB\text{-}max}$	100	Kw
$P_{CHP\text{-}min}$	0	Kw	$Q_{GB\text{-}min}$	0	Kw

Figure (9) shows the energy consumption of an operator in the building in a day is defined as TOU[1]. TOU diagram intended for the building, which shows the cost-weight coefficient of energy sources.

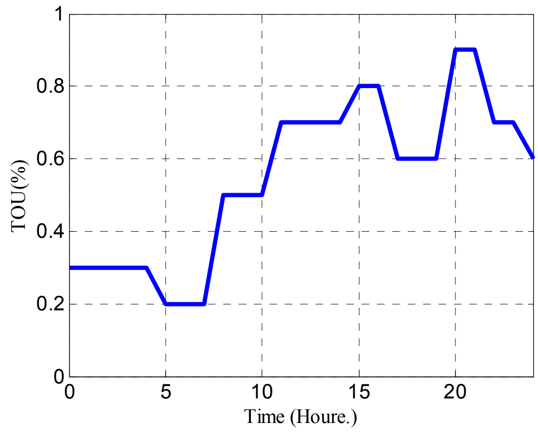

Fig. 9.TOU for the building.

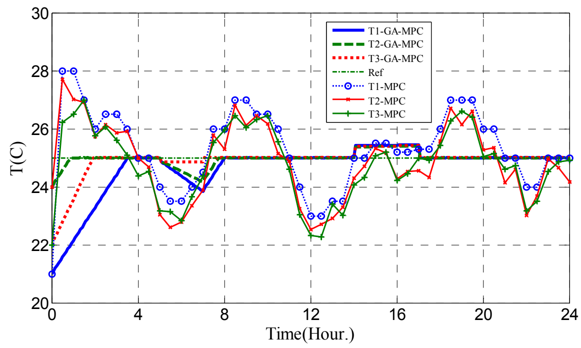

Fig. 10. The temperature of the room with MPC and optimized MPC based on GA(GA -MPC)

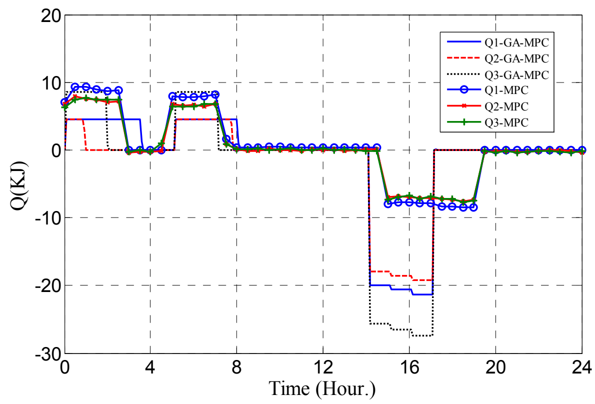

Fig. 11. The heat power of the room with MPC and optimized MPC based on GA (GA -MPC)

According to the energy supplied by the energy consumption management system, Figure (10) shows the evaluation results of the proposed method in comparison

[1]Time of use

with temperature control by conventional predictive control (MPC) method. The results show that the GA-MPC method has reached the desired temperature in a shorter time and has much less oscillation than the MPC method. In these figures, different effects of occupancy on the room are considered as a variable disturbance. The proposed method behaves as a robust controller in comparison with the conventional method. The maximum overshoot of GA_MPC in different conditions equals 4% and the maximum of overshoot conventional MPC is 8%. This indicates the optimal performance of GA in the MPC control structure.As shown in Figure (11), the power consumption is based on the TOU, in the times when the TOU is in minimum value, the power consumption of the line is maximized and is compensated by the electric power of the solar cell and CHP sources. The result of the algorithm is shown in Table 3. The best cost function by 100 iterations of the proposed method in comparison with MPC method has a better performance during the 24 hours.

Table.3 The proposed method in comparison with MPC method resultsduring the 24 hours.

Method	*Cost Function*	*Max. Overshoot*
GA-MPC	165	%4
MPC	182	%8

The optimum values of cost function variables are shown in figures (10) and (11) that are temperature and heat of the room in the building.

5. Conclusion

The simulation of building energy consumption is an efficient tool that can consider the complex interactions of the building with the external environment and internal systems, and therefore it can be considered the only useful technique related to energy saving in the building sector. The use of simulation to estimate the amount of energy consumption is important in the sense that it enables the amount of savings made by applying the determining parameters in the energy consumption of the building, On the other hand, in the simulation methods, all the physical factors required for the energy analysis of the building are considered and The heating and cooling needs of the building are accurately calculated, suitable equipment is selected for heating and cooling, whose capacity meets the building's heating and cooling needs. By simulating the systems defining their type and defining the weather characteristics, it is possible to give a complete report on the amount of fuel and electricity consumption in different seasons, and by simulating new building materials, we can discuss their impact on building energy and the results. They can be compared with each other. In this software, you can check all the devices in the building, from a light bulb, water pump, refrigerator, etc., and even the angle of the building can be defined as a commercial building. You can fully simulate and discuss new methods of zero-energy buildings compared to traditional buildings.

AppendixA:

The parameters of simulation that are used in the software like basic initializationand geographical parameters of the building are made as follows:

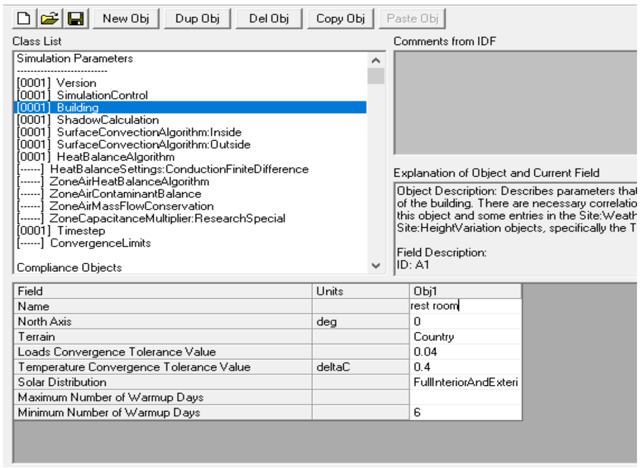

Figure (1): The parameters of introducing the software version and room name

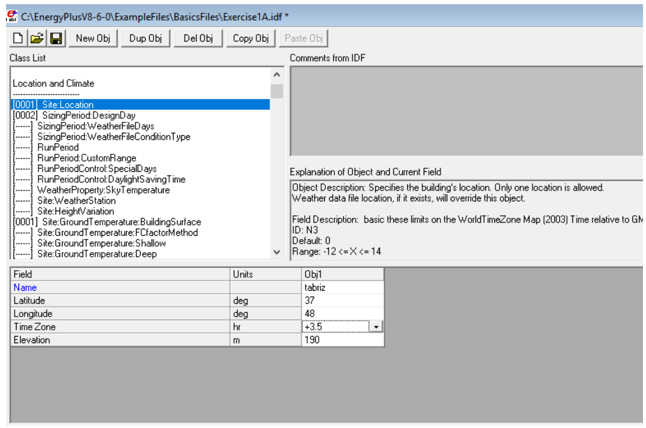

Figure (2): Geographical parameters of the building

This simulation is defined for two seasons, winter and summer, each for three months as shown in the figure:

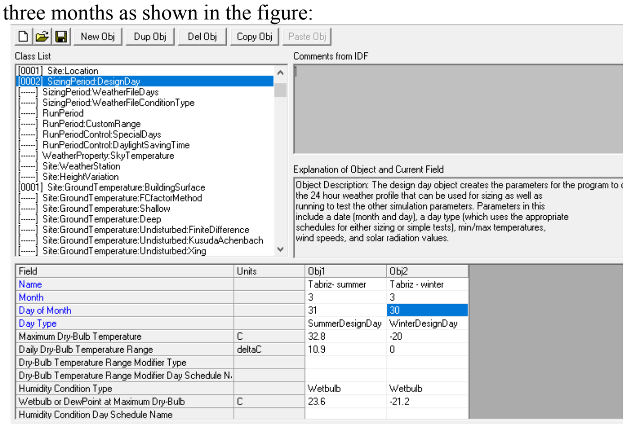

Figure (3): seasonal parameters

The parameters of building windows

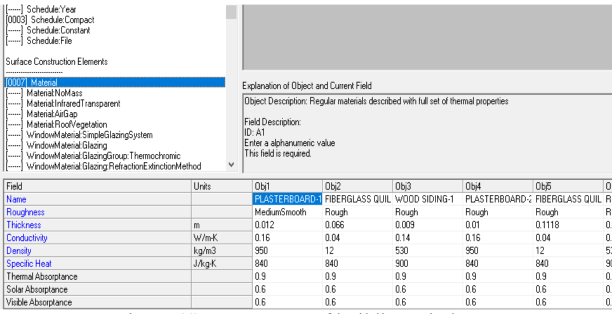
Figure (4): Parameters of building windows

Wall parameters

The walls were defined according to the proposed figure as follows:

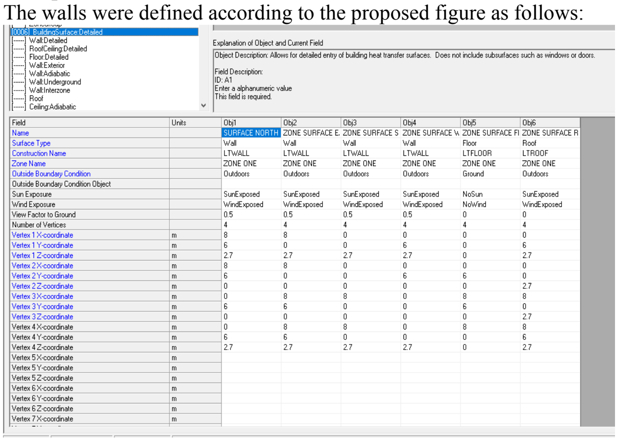
Figure (5): The parameters of the walls

Temperature parameters

In this section, to set the assumed temperature in summer and winter, the temperature of the cooling and heating system is set to 20 degrees Celsius, For the definition in the software, it is done as follows:

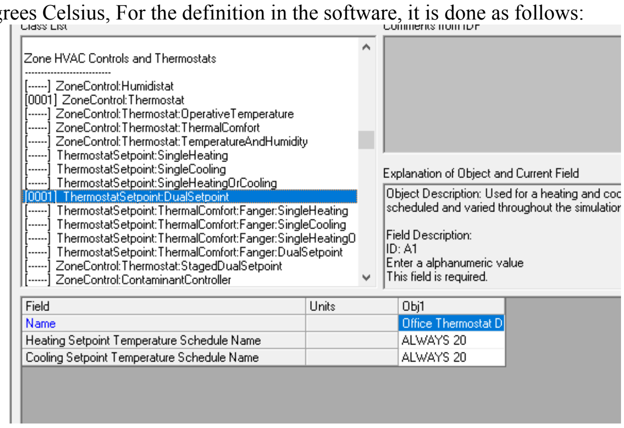

Figure (6): Temperature parameters

The capabilities and limitations of the cooling and heating system installed in the desired room are as follows:

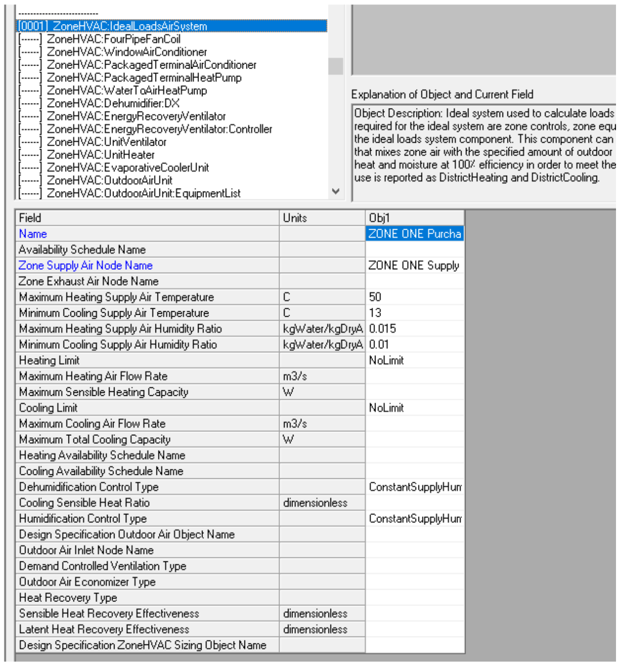

Figure (7): The ability and limitations of the cooling and heating system installed in the room

The simulation of this structure was done completely and without errors in the program, The report of the program indicates the absence of errors during the simulation:

Heat losses in the building mainly take place in the following ways:

1- Heat losses from the walls of the building, including the walls, doors, windows, floor and roof of the building

2- Thermal losses as a result of cold air entering the building.

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