Modeling and Control Electric and Heating Sources in a Building Using MPC

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Abstract- Saving energy in various sections of the building and improving productivity in the face of energy crisis and environmental pollution can be one of the main challenges in the world and our country. In this paper, based on the necessity of controlling and minimizing energy consumption by considering the maximum optimal temperature conditions in different areas of the building, a control method based on the predictive controller is used, which takes into account the effects of the time of use for sources. The predictive controller predicts the optimal control input for future moments according to the definition of the cost function based on the ambient temperature error and the weighted expression of the control input. In this paper, the issue of optimization is thoroughly studied, evaluated, and simulated. The temperature change model in buildings and the proposed control scheme are implemented in MATLAB software and the system is simulated using the building environment. The simulation is performed under several different scenarios of time of use and conditions to show the performance of the proposed design. Based on the results of the proposed control method, the accuracy and performance of the model in different scenarios of building conditions are acceptable.

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

1. Introduction

performance and control of heating and air conditioning systems (HVAC) is a breakthrough in the energy management industry and there have been several approaches in this area. Having an accurate model of the building is crucial for designing advanced HVAC systems. The system consists of a heat exchanger, a chiller, which supplies cooled water to the heat exchanger, an air fan with a rotating system, a heat chamber, connecting ducts, and air components. In practice, the HVAC system controls the temperature and humidity ratio as follows;

1) Fresh air is injected into the system and combined with a certain ratio of circulating air in the air mixer. The combined air in the mixer enters the heat exchanger and is ventilated there.
2) The ventilated air leaves the heat exchanger and this air is prepared to enter the heating chamber, which is called injected air.
3) The injected air enters the temperature chamber where the thermal (humidity) loads that are circulating in the system and the tangible loads (actual heat) are balanced.
4) Finally, air flows into the heating chamber through a fan. A percentage of this air is put back into the circulation cycle and the rest of the air is taken out of the system.

Control inputs for an HVAC system can be air velocity, system power consumption (according to operating voltage and current), air vent percentage, or air circulation velocity. The purpose of this system is to achieve the desired temperature loaded by residents. One of the challenges of the building temperature change model is to consider the effects of resident presence in the building environment. The presence or absence of a person in the area can lead to decreasing or increasing effects of temperature in the area. Opening and closing doors and windows or changes in the desired temperature are some of the effects that the model of

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temperature changes in the area is affected by the presence of a person in the area. Paying more attention to the human dimension in energy use has several potential benefits, including increased comfort, health, and productivity for building occupants and efficient energy management [1]. In most studies, HVAC systems have been modeled taking into account changes in temperature, humidity, and turbulence. On the other hand, extensive articles and research have been conducted in the field of temperature control of HVAC systems. In [2, 3], the airflow is significant due to the convection between the heat zones through the inlet doors and can have a direct effect on the temperature of the zone, because it leads to heat transfer between the zones [4-6]. In [7] and [8], a feedback linearization controller is designed and the adjacent areas also indirectly affect each other by transferring heat through the areas separated by the wall. Information about occupancy (presence of residents) in buildings has a great impact on energy consumption as well as the quality of the indoor environment [9]. Many studies show that approximately 40% of the energy consumed in buildings can be saved with occupancy information [9]. For example, energy consumption can be reduced by turning off lighting systems during off-peak hours and adjusting the air damper opening or air conditioning based on occupancy information. By collecting data in four real buildings, the authors found a linear relationship between occupancy and total electricity consumption. They also found an effective way to estimate electricity consumption per person. Researchers at [11] have designed an occupancy detection software and confirmed that approximately 10% of energy can be saved by conducting an office experiment. They turn off lights and air conditioners to save energy in uninhabited areas. The authors in [12] proposed a demand-based control strategy based on learning despite occupancy analysis, and they found that with effective occupancy information, 20% of energy could be saved. They used a rule-based control method to adjust the cooling temperature of each area based on the presence of individuals. In addition, as an important input for air conditioning and lighting systems, occupation information can not only optimize energy consumption but also have the potential to improve environmental conditions [13]. The authors in [14] considered that thermal comfort depends on many factors such as room temperature, relative humidity (RH), airflow rate, residents 'clothing, and residents' activity status .Various research efforts have been presented to overcome the many challenges of designing a satisfactory HVAC control method. One of the main approaches is to use model prediction control (MPC) methods. The predictive control model includes the optimization of a cost function that minimizes system performance based on certain criteria and meets the limits of control input. A comprehensive data of the features and benefits of MPC can be found in [15], which consider these approaches to controlling the temperature of the area affected by neighboring areas [16].

According to the above, increasing the efficiency of these systems can reduce energy and also improve the desired temperature conditions for residents. Recent advances in sensors, electronic knowledge, control, and communications have motivated much research to design and optimize HVAC control. 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 software and based on 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

The heat and power heating system, which uses a micro-turbine (MT) as the actuator, can provide electrical energy and use the return heat to provide the heating needs of buildings at the time [10]. The model of heat and power heating system can be expressed as follows:

$$Q_{CHP}(t) = \frac{P_{CHP}(t)\left(1-\eta_{CHP}-\eta_{l}\right)}{\eta_{CHP}} \tag{1}$$

$$V_{CHP}(t) = \frac{P_{CHP}(t)\Delta t}{\eta_{CHP} * LHV_{NG}} \tag{2}$$

$$C_{CHP} = \sum_{t=1}^{24} P_{NG} * V_{CHP}(t) \tag{3}$$

Where Q_{CHP} ‘$V_{CHP}$and C_{CHP} are the heating power generation capacity of CHP based on the coefficient of MT and electricity generation from CHP, the volume of gas consumed, and the cost per unit of gas consumed during the period of use respectively. P_{chp} ‘η_{CHP} ‘η_{l} ‘LHV_{NG} ‘P_{NG} ‘V_{CHP} are defined as electrical power generation capacity of CHP, MT efficiency, CHP heat dissipation rate, minimum natural gas heating amount, gas consumption cost, and gas volume used, respectively. Natural gas consumption at any time is calculated by the CHP in (1) through natural gas consumption volume, MT efficiency, and electricity generation at that time. Results (2) are used together with the price of natural gas to achieve the CHP fuel cost (C_{CHP}) for one day in (3). The boiler system coordinates the heat and power system to satisfy the TL demand of the building. In (4), using the thermal efficiency of GB and the heat of the boiler, the heat generation power is obtained from GB. Finally, with the results (5) as well as the unit price of fuel, the daily cost of GB in (6) is calculated.

$$Q_{GB}(t) = R_{GB} * \eta_{GB} \tag{4}$$

$$V_{GB}(t) = \frac{Q_{CHP}(t)\Delta t}{\eta_{CHP} * LHV_{NG}} \tag{5}$$

$$C_{GB} = \sum_{t=1}^{24} P_{NG} * V_{GB}(t) \tag{6}$$

Equations (4) - (6) are used to calculate the cost of daily GB operations based on the amount of consumption; where Q_{GB} ، $V_{GB}$and$C_{GB}$are defined as the amount of heat produced by the boiler, the volume of gas consumed, and the cost of gas consumption of the boiler, respectively. The parameters R_{GB} ، η_{GB} ،$P_{NG}$and V_{GB} are the relative heating of the boiler, the boiler efficiency, the gas consumption cost, and the volume of the boiler gas consumption, respectively. The room is a perimeter with a rectangular plan that is 20 meters long, 10 meters wide, and 3 meters high. There are two windows in the room, which are 1.2 meters long and 1.5 meters wide. The structure of the room considered for the optimization problem is shown in Fig 1.

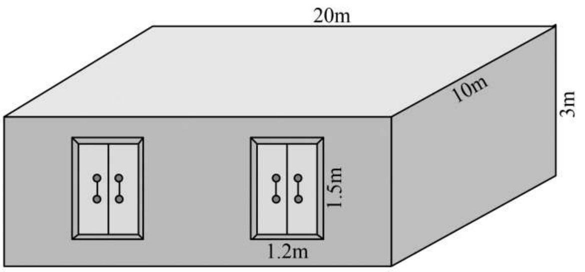

Fig.1. Structure of the building model

Visual comfort, thermal comfort, and favorable air and proper ventilation in the interior of the building are the three basic factors that determine the environmental conditions of a building. The indoor lighting index and the visual comfort index are indicated by indoor lighting, which varies within an acceptable range set by users. can be expressed as follows [10]:

$$E(t) = \frac{n.P_E(t).\varphi.U.M}{A} \tag{7}$$

$$D_1(t) = 1 - \left(\frac{E(t) - E_{SET}}{E_{SET}}\right)^2 \tag{8}$$

Where n ،P_E ،φ ،U ،MandAare considered the number of lamps, lamp power, lamp luminous flux, lamp consumption coefficient, lamp Utilization coefficient, and the area below the lighting, respectively. E_{SET} and D_1 (t) indicate the desired amount of brightness and visual comfort at time t. One of the most important issues in the satisfaction and desirability of the room for the residents is the issue of temperature and its changes. This section introduces the model of temperature changes. Indoor temperature is shown in (9):

$$T_{room}(t) = T_{room}(t-1) + \frac{\frac{T_{out}(t) - T_{room}(t-1)}{R_{eq}} - Q(t)}{M_{air}C_p} \tag{9}$$

$$R_{eq} = \frac{R_{wall}R_{window}}{R_{wall} + R_{window}} \tag{10}$$

Where, T_{room}, T_{out}, Q, $M_{air,}$ and C_p are defined as the indoor temperature of the room, the temperature outside the room, the heat generated for the room, the specific heat capacity of the air, and the mass of the air in the room (calculated by the density and volume of the air in the room). R_{eq} is Room temperature resistance. $R_{wall}$and R_{window} are the temperature resistance of the wall and the window of the room, respectively. The cost function for this model is considered based on the error of building room temperatures. The indoor air temperature index is defined as follows:

$$D_2(t) = 1 - \left(\frac{T_{room} - T_{SET}}{T_{SET}}\right)^2 \tag{11}$$

T_{SET} is the desired temperature of the room. As the value of D_2 achieves 1, the room temperature value has reached the desired value. The goal is to maintain a certain amount of comfort within a reasonable range in different building conditions, and the overall comfort level can be expressed in (12):

$$D = \sum_{t=1}^{24} [\alpha D_1(t) + \beta D_2(t) + \gamma D_3(t)] \tag{12}$$

Where D_3 is the cost of energy gas consumption of boiler and CHP sources, and electrical grid, and D represents the total convenience in optimization, among which α, β, γ are adjusted by and must α + β + γ = 1. In multi-objective optimization problems, the optimization objectives are often in conflict with each other parameter.

3. MPC control method

In this section by designing the model predictive control structure for the model, control the temperature of the building rooms to achieve the desired values with minimum costs. The process of the predictive control method is shown in Fig. 2.

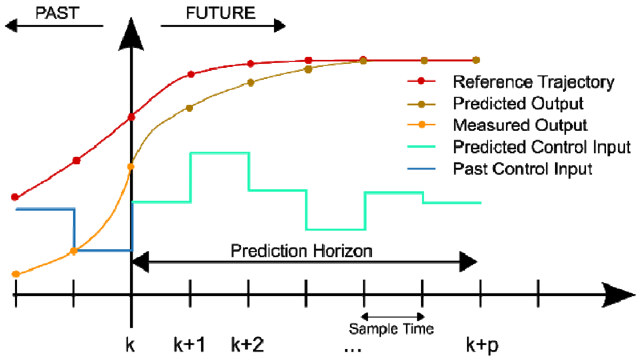

Fig. 2. MPC controller performance.

As shown in Fig .2, at the current moment k, the sample P data output of the modelis received and process Past inputs are achieved by the predicted model and solve the optimization problem of a sequence of future inputs by minimizing the MPC objective function. The problem of minimizing the cost function in terms of system error and minimizing control effort is Q is defined as follows:

$$J(k)\colon \min \sum_{j=1}^{P} \lambda \|D(K+j)\|^2 + R \sum_{j=1}^{M} \|Q(k+j-1)\|^2 \tag{13}$$

where $r\,(k), \lambda, M,$ and R represent the desired value of temperature, weight coefficient for system error, control horizon, and weight coefficient for control input, respectively, of the input weight coefficient. The solution of this problem is solved by using Riccati equations and using linear feedback structure.

4. Simulation

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 (1) [11].

Table 1. Building model parameters [11]

Parameter	value	Parameter	value
N	20	M_{air3}	**650**
φ	5000	C_{p1}	**1000.4**
U	0.8	LHV	**9.78**
M	0.8	P_{NG}	**2.2**
V_{co2}	0.000056	$\alpha.\beta.\gamma$	**1.3**
P	1.2	μ	**1.2**
A	200	V	**600**
M_{air1}	723	C_{p2}	**900.4**
M_{air2}	700	C_{p3}	**500.4**
$P_{EX\text{-}min}$	0	$P_{EX\text{-}max}$	**30**
$P_{CHP\text{-}min}$	0	$P_{CHP\text{-}max}$	**65**
$Q_{GB\text{-}min}$	0	$Q_{GB\text{-}max}$	**100**
$Q_{TES\text{-}min}$	0	$Q_{TES\text{-}max}$	**5**

Fig .3 shows the TOU diagram intended for the building, which shows the cost weight coefficient of energy sources.

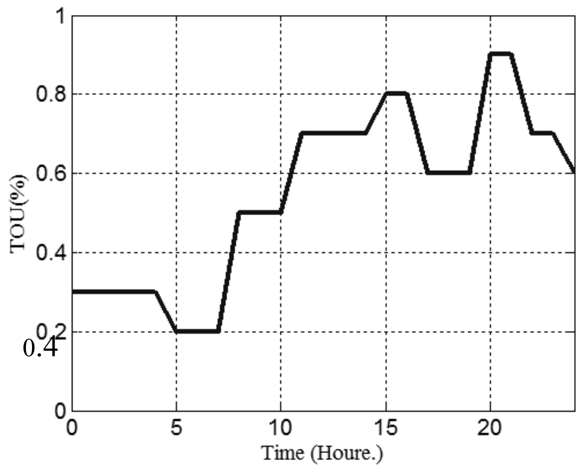

Fig. 3. TOU for the building.

In this simulation, the desired values for lighting temperature equal to 320 lux and 25 ° C, respectively. The simulation is done during 24 hours and results are shown in Figs .4 to 10 which indicate the amount of brightness, boiler thermal power, grid electrical power, CHP electric power, CO_2 concentration, the temperature of the first room, the heat output of the first room, the temperature of the second room, the heating power of the second room, the temperature of the third room and the heating power of the third room, respectively.

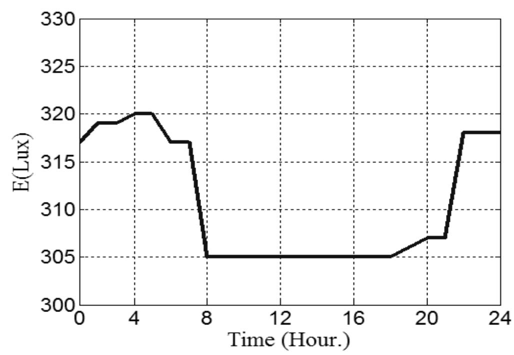

Fig. 4. Parameter of room Lighting

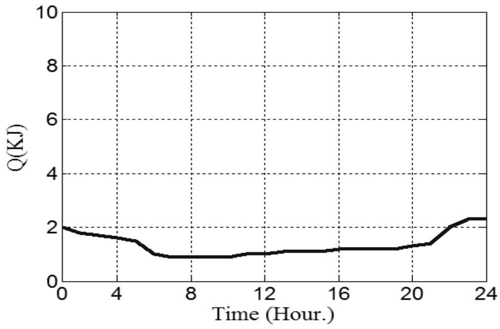

Fig.5. Thermal power of GB

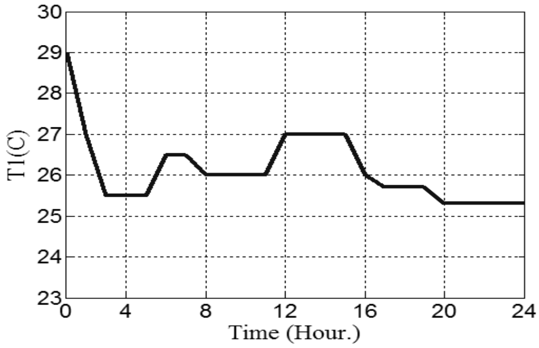

Fig.8. Temperature of the first room

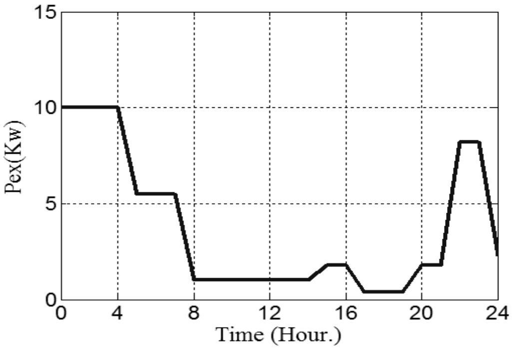

Fig. 6. Transmission line electrical power

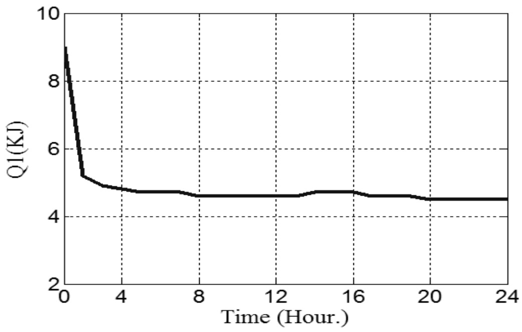

Fig.9. The heat power of the first room

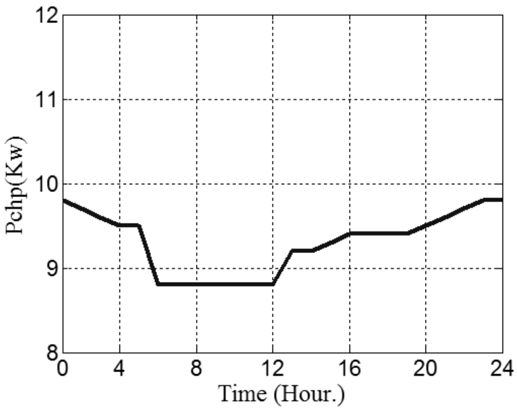

Fig. 7. Electrical power of CHP

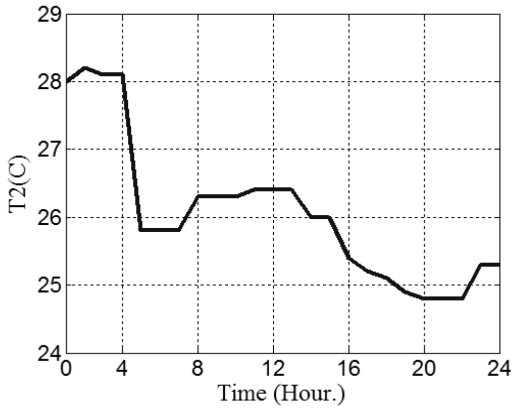

Fig.10. Temperature of the second room

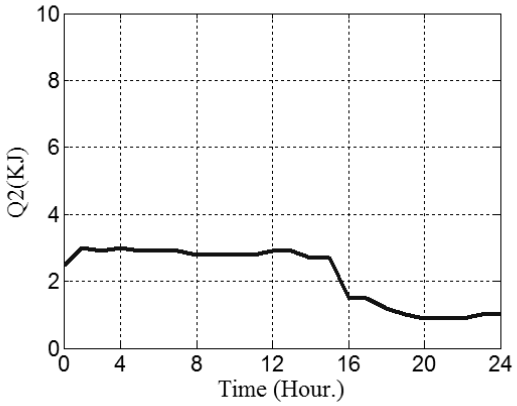

Fig.11. Thermal power second room

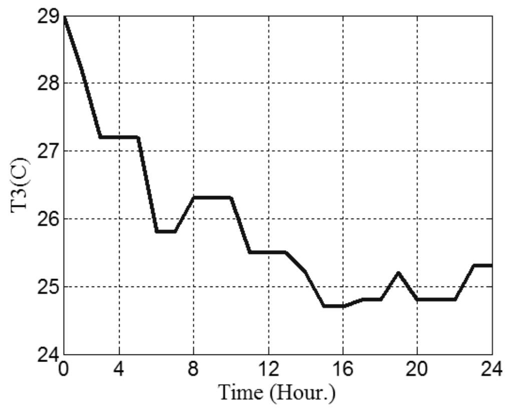

Fig.12. Temperature of the third room

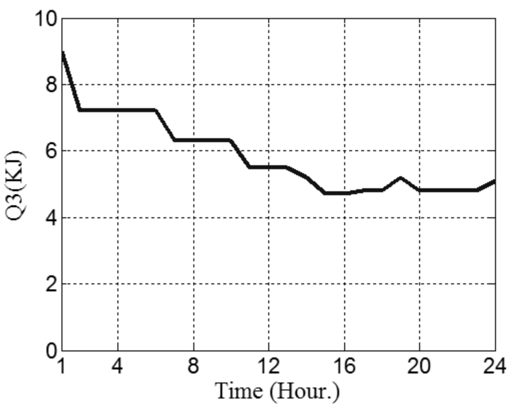

Fig.13. Third room thermal power

As shown in Fig .4, the brightness has a maximum brightness at 2 to 8 hours and is close to the desired value. it is clear at 8 to 18 hours because of the high temperature outside the rooms, the amount of thermal power by GB is minimal(Fig .5). As shown in Fig .6, 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.As shown in Figs .8 to 13, the changes in rooms temperature are very small. Fig 14 shows the cost function of D which includes three indexes D_1 (lighting), D_2 (costs), and D_3 (temperature).

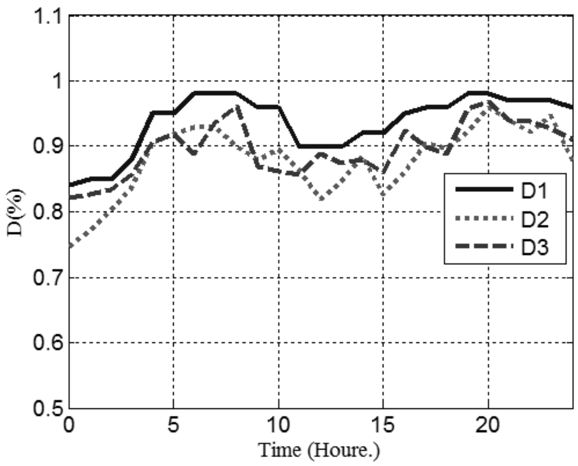

Fig.14. Cost function of D

Based on Fig 14, the cost function D_1, changes in the simulation interval of 24 hours to achieve the desired value, so is close to the unit value at 6 to 8 hours and 19 to 21 hours. parameters D_2 and D_3, has an increasing trend during the day, and at 16 to 22 hours are close to the desired value and the desired value D_3 is close to 1 at 20 hours that is a suitable condition for building by attention to minimize costs.

5. Conclusion

With population growth and increasing energy consumption in recent years, a large number of researchers and companies active in the field of building contracts are looking to provide effective ways to reduce energy consumption in buildings. in this paper, based on the need to optimize and minimize energy consumptionand the maximum environmental conditionsfor the building, the optimization method based on the predictive controller is used. According to the simulation results, by solving the problem of MPC, reducing costs, and achieving the desired values of building environmental conditions, the energy variables have been controlled during the day.

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