Info-communication system for monitoring and control of heat supply to buildings and premises

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Abstract. The article considers the control of heat supply to individual premises in the modes of switching premise temperature during the day in order to optimize the supply of heat energy and save energy resources. The author considers theoretical and practical works of other teams and authors on this problematic. The article states thermal processes do not adequately account for inertia. The author proposes an approach to solving this problem based on the application of a simple mathematical model considering the heat capacity of the premises, the temperature of the external environment, and the heat transfer coefficient from the premises to the external environment. The paper proposes modeling in the premise heating mode and in the air-conditioning mode. The transition process from the stationary state to the operating state, as defined by SanPin rules, takes approximately 1.5 hours. The character of the transition process is exponential. The author conducted experimental studies in the educational laboratory of the university on the installation containing temperature sensors, a heater, air conditioner, microcontroller, server and relay based on a smart socket. They also developed the software. The air conditioning mode focused on the stages of turning on the air conditioner (cooling down), going to steady-state, and heating (turning on the air conditioner). The experimental dependencies agree well with the theoretical ones. The influence of solar radiation explains a slight discrepancy on the thermal regime of the premise. The article suggests viable options for improving the method: considering heat emissions because of the presence of people, electrical equipment operation, solar and wind loads.

1 Introduction

Indoor climate parameters such as temperature, humidity, illumination, carbon dioxide concentration and others have a significant influence on the comfort of the premise and performing the occupants.

Many companies have developed climate control systems to control and maintain the set conditions in a premise. These companies control or operate their climate control systems manually or based on the principle of negative feedback. This leads to a decrease in efficiency for these systems and neglects the thermal processes occurring in the building. Such systems may not have sufficient power to control the microclimate in a premise.

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2 Research methodology

In order to eliminate the disadvantages described above, it is suggested to use a system based on a mathematical model for certain parameters of the premise microclimate. With the help of this system it is possible to predict the reaction of the premise to certain types of influence from microclimate control devices, such as heater, air conditioner (for heat), ventilation. Application of mathematical model will allow to adjust microclimate parameters more accurately, to switch off microclimate control devices when there are no people in the premise, and vice versa to bring the premise to the required state by the time people come to the premise.

Let's consider the works devoted to heat supply control of separate premises. Modelling thermal processes can optimize control systems for heating premises. The following works are devoted to the solution of these problems.

The monograph [1] gives an analysis of the existing control structure of a cogeneration district heating system, the results of modelling and full-scale experiments of control systems of a number of industrial and civil objects are given. The premise fails to consider the inertia of thermal processes.

In the dissertation work [2] based on models of separate elements of a heat supply system the model of a heat supply system with a remote autonomous source of thermal energy is developed; two models of a heat supply system with an integrated autonomous source of thermal energy, isolated and combined with a heated premise, are developed and proposed; methods of optimal control of the developed models of heat supply systems of a premise are considered. In this work, at the modelling level, an attempt is made to take into account the inertia of thermal processes in the premise. The procedure itself is cumbersome and does not give practical realizations, such characteristic as effective heat capacity of a premise is not used.

Some companies carry out practical realization of temperature control.

The company Xiaomi has developments by smart home, such as motion sensors, IP-cameras, humidifiers, etc. [3]. One of the main parameters of microclimate is the temperature of air in the premise. Thermostats are used for its regulation. Temperature regulation is carried out by thermostats manually, according to a schedule, or according to the principle of negative feedback.

Siemens thermostats are the most advanced of the considered ones, but they cannot be referred to the budget segment. Usually, it is a system of several devices, but it can control climate control devices directly through an inbuilt relay. An example is the smart thermostat RDS110.R

The SIEMENS RDS 110 climate control station is designed to control heating applications in private houses, flats, office buildings, etc. [5] It supports control of the following equipment: gas boiler, radiator with valve, radiator with pump, electric floor heating, fan with electric heater, floor heating with valve, floor heating with pump, electric heater, electric boiler.

A common disadvantage of the above systems is that they do not take into account the inertia of thermal processes in the premises.

In order to be able to control the microclimate in the premise (in a particular case, the thermal regime), it is necessary to know the reaction of the premise to certain types of effects (both external environment and internal sources of heating/cooling). It is possible to estimate the response of the premise to certain types of influence by means of a known mathematical model. The mathematical model of the thermal balance of the premise can be used as such a model [6, 7].

In a simplified form, this mathematical model can be represented as follows:

$$C \cdot \frac{dT}{dt} = (P_{heater} + P_{add}) - G \cdot (T_{pr} - T_{external}) \tag{1}$$

where:

based on capacity of the premise [W/°C],

$\frac{dT}{dt}$ - rate of change (derivative of) temperature [°C/sec],

P_{heater} - power of the premise heater [W], sets the duty stationary mode, does not participate in the control,

P_{add}- power of additional heating source [W], which provides temperature control,

G - heat transfer coefficient to the external environment [W/°C],

T_{pr}- current premise temperature [°C],

$T_{external}$- external temperature [°C].

This mathematical mod consider premise as an object capable of accumulating and storing energy, changing the amount of stored energy because of external and internal sources of influence (heating, heat exchange, etc.).

In the process of changing the temperature of the premise, there comes when the powers of all sources of influence are balanced, and the premise enters the so-called stationary mode. Then the response of the premise to the addition of an alternative source of influence will be described by the expression [8].

$$\mathrm{C} \cdot \frac{dT}{dt} = P_{add} - G \cdot (T_{pr} - T_{st}) \tag{2}$$

To carry out the modelling, the ordinary differential equation (2) was solved in Octave software using one-step explicit Runge-Kutta methods of 4th and 5th order.

The modelling was performed for the following scenario: the premise has a steady-state steady-state condition at a tempeconsider. The time interval is divided into 2 sections: section 1 is modelling with active air conditioning system, section 2 is modelling after the air conditioner is switched off. The heat capacity of the premise, heat transfer coefficient and air conditioner power remain unchanged except for the second time interval when the air conditioner power is equal to zero. The result of the simulation is shown in Fig. 1

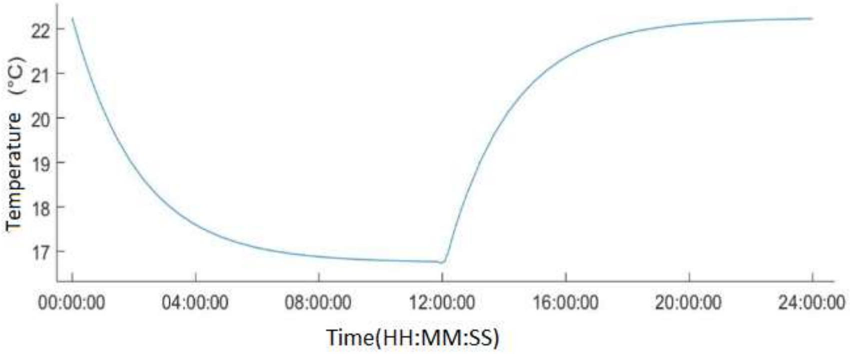

Fig. 1. Temperature vs. time graph when the air conditioner is switched on and off.

As seen in Fig. 1, the graph of temperature change with time has an exponential character. Predictability of temperature change dependence on time allows to know how much time it will take to bring the premise to the required state at the parameters.

Let's simulate the following situation: a training laboratory is in a steady-state stationary mode at a temperature of 25.75 °C. While students are in it, the air temperature should meet the general sanitary and hygienic requirements for the air of the working area be approximately equal to 23 °C [9]. Then, it will take some time to bring the teaching laboratory to the required state, which can be found by modelling (Fig. 2).

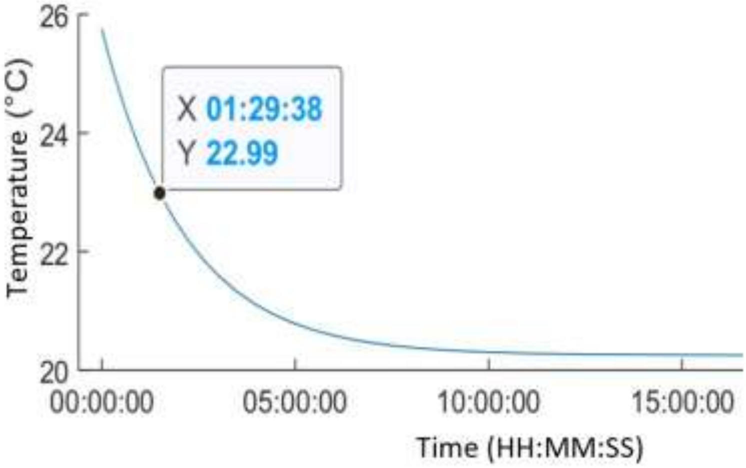

Fig. 2. Modelling the premise response after the air conditioner is switched on.

According to Fig. 2, it will take about 1.5 hours for the premise to reach the desired temperature. Knowing this time, it is possible to bring the premise to the set temperature by switching on the air conditioner before the students arrive for an hour and a half (the time interval found), and then maintaining a constant temperature in the premise within 0.5-1℃ by periodically switching on or off the air conditioner.

To control the microclimate of the premise, it is proposed to use the mathematical model of the heat balance of the premise (2).

Based on the heat capacity of the premise, we can find the other parameters of the premise from the experimental curve shown in Fig. 3.

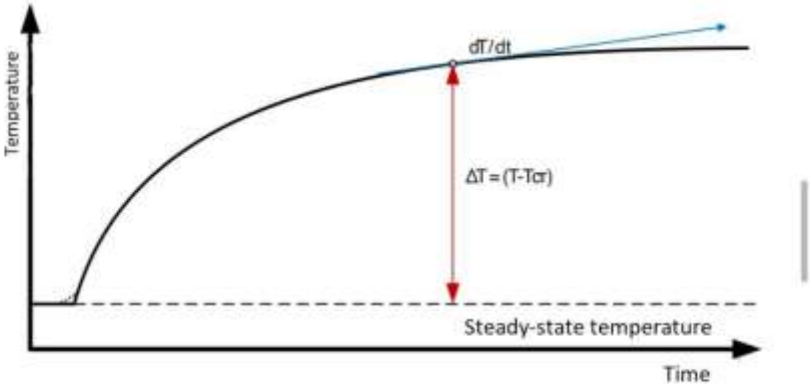

Fig. 3. An example of an experimental curve.

Based on the modeling results, it is possible to regulate the microclimate parameters (Fig. 4) by turning on the heating source or air conditioner a few hours before the arrival in the room (time intervals t_0 - t_1), then maintaining the desired temperature as long as people are in the room (time intervals t_1 - t_2), and turning off the heating sources after people leave in order to save energy (time interval after t_2).

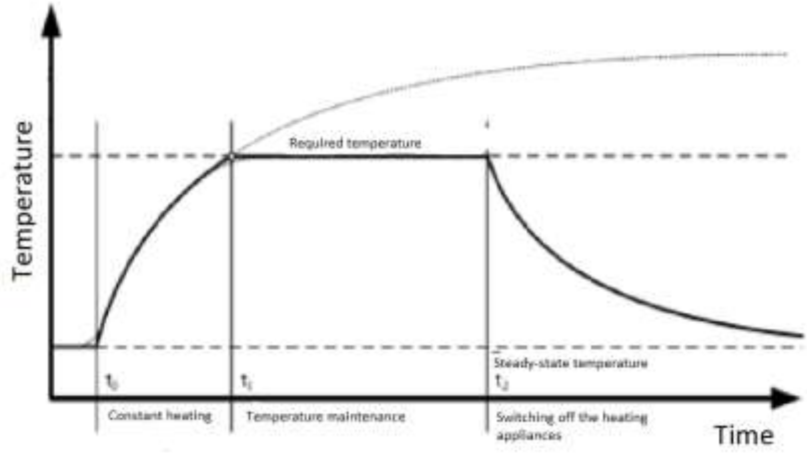

Fig. 4. Example of temperature control using an algorithm based on a mathematical model when heating a premise to a set temperature.

The algorithm is to calculate the time it takes for the climate control device to bring the room to the set temperature (time intervals t_0 - t_1),) and to calculate the active state time in the temperature maintenance mode (time intervals t_1 - t_2).

Similarly, this algorithm is implemented for refrigeration and air conditioning systems. The main difference will be that the graph of temperature dependence on time will be inverted along the Y axis (Fig. 5).

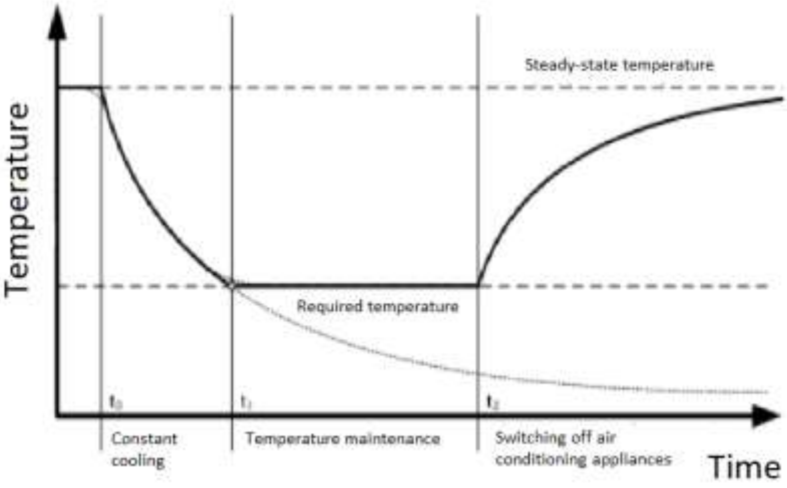

Fig. 5. Example of temperature control using an algorithm based on a mathematical model when cooling a premise to a set temperature.

It is possible to use this mathematical model for both downward and upward temperature control.

This control algorithm is applicable to both cooling and heating systems. Also, with the help of this mathematical model, based on the known heat capacity of the premise, it is possible to determine the effective capacity of heating/air conditioning devices. It can also be used to conclude whether the capacity is sufficient to obtain the required temperature under the current conditions.

The considered examples of climate control systems use at best a PID-regulator [10], negative feedback, or have no control algorithm at all, switching on and off the climate control devices at the user's command.

To implement the control algorithm using a mathematical model, it is necessary to have a controllable climate control device (heater or air conditioner), a control device (server or microcontroller) with sufficient computing power. Also, it is necessary to know the parameters of the premise: constant (such as volume or total heat capacity) and current (temperature in the premise at the moment).

A microclimate control system can be represented by three devices: a microclimate sensing device, a control device and a device for influencing the microclimate parameters.

The microclimate reading device is a sensor or a set of sensors placed throughout the premise. The control device can be a server, microcontroller or other device with the possibility of programming to set the algorithm. The device of influence on the microclimate parameters can be a device that changes the microclimate parameters according to the known dependence. It should be a device that can be adjusted or switched on/off. For example, a heater/air conditioner connected to the 220V network via a relay. Functional scheme of such a system is shown in Fig.6.

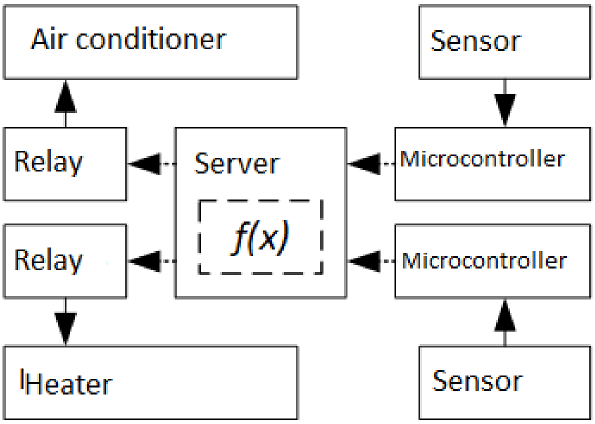

Fig. 6. Functional diagram of the microclimate control system.

3 Results of the study

To verify the validity of the mathematical model approach, an experimental study was carried out under conditions similar to the modelling.

The elements of the experimental setup selected are:

-A DS18B20 digital temperature sensor providing temperature measurement in Celsius with an accuracy of 9 to 12 bits.

-Air conditioner or heater connected through relay to the server by the server;

- Relay - Sonoff S20 smart socket with WiFi connect because of use of controller;
- Server for storage and processing OpenHAB.

The methodology of the experiment was to recreate the modelled scenario and compare the theoretical and experimental curves. Thus, for this case, using a timer, the air conditioner was switched on for the first 12 hours of the experiment and switched off all the remaining time. The obtained data are presented in Fig. 7.

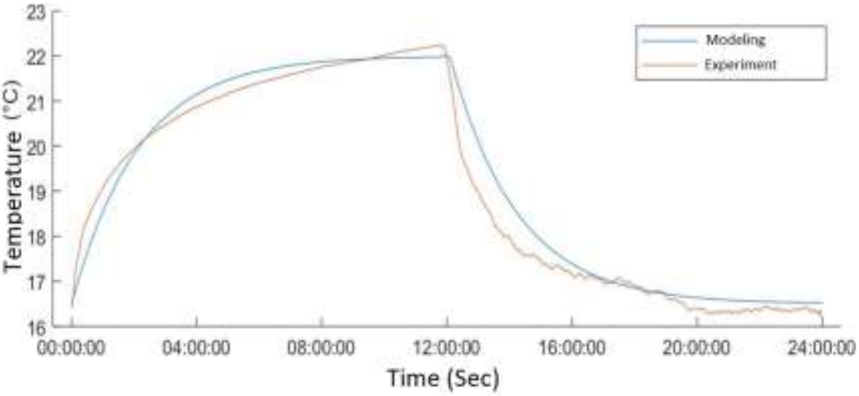

Fig. 7. Comparison of modelling and experimental results.

Both curves have an exponential character and are approximately the same, with insignificant discrepancies. These discrepancies are due to the fact that the modelling does not take into account the transient nature of the heating of the premise by solar radiation. Finally, the experimental curve continues to rise after 12 hours. However, the theoretical curve indicates the beginning of the steady-state regime.

In addition, the time from the moment the air conditioner is switched on until the desired temperature is reached is 1 hour and 20 minutes. This value coincides with that obtained by modelling. The error in the time's calculation needed to cool the premise may be due to the averaging of the total heat energy coming from outside during the day, while the start of the experiment was at a time of low solar radiation, causing the premise to respond to cooling faster than calculated. To eliminate this error, it is necessary to take into account the change in temperature of the street air and the amount of incoming solar energy during the day.

Mathematical modelling also allows us to estimate the energy saved by switching the thermal mode of the premise from working mode to standby mode. Thus, with an average ambient temperature of 5 ºC, a premise temperature of 17 ºC in standby mode and 23 ºC in work mode, and a working day of 8 hours, the thermal energy saving will be approximately 15%.

4 Conclusions

The conducted work shows the prospects of application of mathematical modelling to the processes of heat supply control of individual premises. Taking into account the inertia of thermal processes (heat capacity of the space) allows to determine the time of transition processes from one stationary state to another with sufficient accuracy. In this case, the consumption of thermal energy required to maintain the necessary mode of people's work is reduced. Since the working day lasts 8-10 hours, energy savings can reach 15-20%. Additional savings are also possible at weekends.

This system has good scalability as it is possible to connect additional sensors to existing microcontrollers and add new microcontrollers as required. As the data transmission is wireless, there is no need to link each sensor to the server.

The development of our proposed method assumes that the mathematical model takes into account the following factors: heat generation from people, electrical equipment (including computers), solar energy and the influence of wind load.

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