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Towards Smart Building: Exploring of Indoor Microclimate Comfort Level Thermal Processes

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Abstract Modern requirements to reduce the consumption of energy resources while maintaining comfortable conditions for people in residential, public and administrative buildings pose the task of developing new approaches to assessing the comfort of the microclimate. Currently used methods for assessing the comfort of the microclimate do not take into account the specific hazards characteristic of non-industrial premises, and for this reason, the introduction of energy-saving measures may lead to a violation of the comfort conditions in the premises of buildings. In this regard, the development of methods and methods to take into account the impact of energy-saving measures on the microclimate is an urgent task.

This research paper is devoted to solving the urgent problem – energy efficiency of buildings. We explore mathematical model of indoor microclimate thermal processes, parameters that affect to indoor microclimate, comfort microclimate serving, and represent simulation results of the developed mathematical model of thermal processes. Also, we explore how to control heating, ventilation and air conditioning equipments considering indoor and outdoor temperature and humidity level, and the problem , how to keep stable indoor comfort temperature and humidity

Keywords: HVAC System, Indoor Microclimate, Thermal Process.

1 Introduction

Individuals spend most their time in an indoor environment and comfort is one of the most important issues with respect to staying indoors. Environmental quality of an interior environment is directly dependent on its organization and content [1]. Therefore, the task of maintaining a comfortable environment is extremely important for health, good spirit, and human activity [2]. Several parameters can be adjusted to achieve comfort in a room—air temperature, humidity, air quality, speed of movement of air throughout the room, oxygen content in the air, ionization of air, and noise level [3-6]. A deviation of the aforementioned parameters could result in the deterioration of the normal state of an individual. This can lead to the disruption of thermal balance as well as result in a negative impact on health and productivity [7].

Energy saving has become an urgent problem for the whole world in recent decades. The solution of this problem is connected not only with improving the environment, but also with ensuring the energy security of individual States [8]. At the same time, for countries with limited reserves of fuel resources, energy security means reducing the economy's dependence on fuel imports, and for resource - producing countries, it consists in ensuring growing domestic demand for energy resources through more efficient use of the energy that is already produced, rather than by increasing fuel production and building new sources of heat and electricity [9].

Since a significant potential for energy saving is the modernization of building enclosing structures, it is most appropriate to introduce energy-saving measures that increase the thermal protection characteristics of the walls, Windows and floors of the building. Insulation and sealing of buildings by applying thermal insulation or replacing individual elements of enclosing structures naturally leads to a reduction in heat losses and, as a result, a decrease in the required amount of heat for heating [10]. However, as a rule, in buildings with natural ventilation, the hygienic conditions of people's stay deteriorate due to changes in the microclimate parameters [11]. Therefore, when solving the problem of increasing the efficiency of the use of fuel and energy resources, it is necessary to take into account the level of comfort of premises.

Thus, a comfortable dwelling can be achieved when the temperature, humidity, and air flow rates are known.

This paper considers mathematical model of the thermal process, indoor microclimate thermal balance, heat balance on indoor microclimate, and temperature control parameters' correlation in the next section. After, in the simulation results section, we demonstration experimental environment and simulation results. Also, the experiment results in this paper were conducted taking into consideration the comfort data of the premises, given based on international European standards and recommendations ISO 7730 [12].

2 Literature review

When performing the task of designing a smart home, an important aspect is the development of an effective heating, ventilation and air conditioning (HVAC) control system [13], which is aimed at maintaining comfortable microclimatic parameters while ensuring the highest possible level of energy savings.

Over the years, simulations and experiments have developed strategies to find an acceptable balance between residential comfort and low energy consumption. So, some models took into account the air temperature and the availability of clothing, while others focused on factors such as, for example, a draft [14]. As this area has been studied and smart home management systems have developed, there have been needs for more efficient maintenance of comfortable temperature, ventilation, and air conditioning parameters in building design [15-18].

In [19], models of providing comfortable indoor microclimate conditions were considered, taking into account the conditions for minimizing energy costs. as part of the article, it was found that all models can be divided into three classes as "white box" models, "black box" models, and "gray box" models, which are hybrid.

Analysis of the literature on this issue allowed us to form four principles that determine the policy of energy saving:

1. Energy Resources are of great importance both for improving the quality of life of citizens, and for ensuring energy security and independence of the country.

2. Energy resources must have all the characteristics of a commodity, since they can be created, sold, purchased, and otherwise participate in commodity-money relations.

3. In the twenty-first century, non-traditional and renewable energy sources will be actively used.

4. Priority in the selection and implementation of energy-saving measures will be given to solutions that are effective not only in technical or economic terms, but also at the same time contribute to improving the microclimate of premises [20].

Thus, the implementation of energy-saving measures in buildings should be carried out taking into account the comfortable stay of a person in them. Currently, the most common method for determining the comfort of the microclimate is the measurement and evaluation of individual components of the temperature and humidity regime of the room: temperature, mobility, relative humidity, as well as the characteristics of thermal radiation [21]. A significant disadvantage of this approach is the neglect of the mutual influence of microclimate parameters on each other. To improve the accuracy of determining the comfort of the microclimate, it is necessary to develop a comprehensive indicator that takes into account the maximum possible number of parameters and their mutual influence.

3 Mathematical model

3.1 Heat Balance Equation On Indoor Environment

All Thermal processes of heated space are a series of interconnected heat exchange sub-processes and heat transfer between the elements of the system include: indoor air, building fence, internal content, heaters, ventilation system [22]. These elements interact with each other and with the environment by means of heat and mass transfer. On the fence of air and heat exchange element boundaries is carried out by convection and by radiation. Also, the heat is transferred by convection from the radiators to the internal air space [23]. The heat from the inner to the outer surface of the enclosure is passed through heat transfer. Also on the basis of heat transfer processes are carried out through the facilities of energy partitioning. In addition to thermal processes and should be considered as mass transfer processes due to the need for room ventilation [24-27].

Thus, the heated building can be displayed on a graph G = {X, U}, where X - the set of vertices, each of which is xk (k = 1, n) corresponds to the internal air space of the k-th building and U - a plurality of edges , each of which corresponds to the heat or material flow between adjacent rooms. We should also highlight the vertex of x0, representing the ambient air.

Each vertex of the graph xk may have thermodynamic parameters of air (Vk, Tk) - the volume and temperature respectively. Uij each edge corresponds to a vector (Hij, cij, ρij ,Fij, λii), where, Hi – thickness, cij – specific heat, ρij - density, Fij – surface, λij - fencing the thermal conductivity between the elements of the structure of i and j.

In addition to these system parameters defining the purely thermal processes, you must also enter the parameters responsible for the mass transfer associated with the ventilation of premises and the possible exchange of air masses between the rooms. As this parameter can be viewed obliquely symmetric matrix Gij (i, j = 0, n) - weight air flow between the i-th and j-th element.

Each edge of the structural graph uii symbolizes the heat flow j qii the element xi to xj element. In turn, the heat flow qii determined by the laws of heat transfer, in accordance with which in the fence between the i-th and j-th rooms Tii(x,t) unsteady temperature field is formed, where x∈ [0, Hii] linear coordinate perpendicular to the surfaces of the fence. The specified temperature field described by the differential equation of heat conduction

$$\frac{\partial T_{ij}}{\partial t} = a_{ij}\frac{\partial^2 T_{ij}}{\partial x^2} \quad (1)$$

where $a_{ij} = \frac{\lambda_{ij}}{c_{ij}\rho_{ij}}$ – coefficient of thermal conductivity.

At the boundaries of the fence x = 0 and x=Hij temperature satisfies the boundary conditions of the 3rd kind, whereby the convective heat flux from the air to the fence is the heat flow inside the enclosure, i.e.

$$\alpha\left(T_i - T_{ij}(x,t)\right)_{x=0} = -\lambda_{ij}\left(\frac{\partial T_{ij}(x,t)}{\partial x}\right)_{x=0} \quad (2)$$

$$\alpha\left(T_{ij}(x,t)-T_j\right)_{x=H_{ij}} = -\lambda_{ij}\left(\frac{\partial T_{ij}(x,t)}{\partial x}\right)_{x=H_{ij}} \quad (3)$$

where α – the convective heat transfer coefficient.

In turn, the temperature Ti of each structural element can be determined based on the heat balance equation has the following form

$$c_v \rho_B V_i \frac{dT_i}{dt} = \alpha \sum_{\substack{j=0 \\ j\neq i}}^{n} F_{ij}\left(T_{ij}(0,t)-T_i\right)$$
$$+ c_0 \sum_{\substack{j=0 \\ j\neq i}}^{n} G_{ij}\left(T_j - T_i\right) + \alpha F_{ai}\left(T_{ai} - T_i\right) + Q_i(t) \quad (4)$$

Where cv, cp - specific isochoric and isobaric heat capacity of air, ρ_a – the density of air, F_{ai} and T_{ai}– the surface area and the temperature of the internal battery, the i-th filling the room, Qi(t) - the heat flux due to supply heat from heaters.

The system of equations (1) and (4) need to be supplemented by a system of differential equations describing the thermal processes in the internal battery, consisting of various production equipment, furniture and other space filling:

$$c_i \frac{dT_{ai}}{dt} = \alpha F_{ai}\left(T_i - T_{ai}\right) \quad (5)$$

where c_i – capacity of heat accumulators.

Thus, the mathematical model of thermal processes of building to be heated is a system of n (n-1)/2 differential equations in partial derivatives of the form (1) with the boundary conditions (2), (3), and a system of 2n ordinary differential thermal balance equations (4), (5). For the integration of the system (1), (4), (5) it is necessary to set the initial conditions for the temperature Ti (i = 1,n) and for the initial distribution of temperature fields Tij (x, 0), as well as the laws of the heat Qi(t) and Mass Transfer Gij(t). The result of the integration will function Ti(t) - changes in air temperature.

The above-formulated problem is a problem analysis and provides an answer to the question how will change the room temperature depending on the outdoor environment temperature changes and heat input from heaters of indoor environment. This problem can be solved by numerical methods or finite element based on the asymptotic expansions of the one-dimensional temperature field [28].

Additional systems and technologies are required for heating or cooling in buildings in which a thermal system is not naturally in equilibrium. It is necessary for the net heating energy to be provided by a heating system. The heating system experiences losses when heat is produced from a primary energy source. The total heating energy demand of a building corresponds to the sum of heating energy and heating equipment losses.

4 Simulation results and discussion

The microclimate in the workplace is determined by the air temperature, relative humidity, air velocity, and the intensity of radiation from heated surfaces. The optimal parameters of the microclimate is a combination of temperature, relative humidity and air velocity, which in long-term and systematic exposure does not cause variations in the human condition. High air temperature in the premises, while maintaining the other parameters causes fatigue working, body overheating and sweating a lot. Low temperatures can cause local and general cooling of the body and cause colds.

The experiments were conducted at the Artificial Intelligent and Smart City laboratory in Gachon University. In the laboratory space, an area of 3×6 m2 with a height of 2.5 m on one of the outer walls included six work areas separated by translucent partition walls (with a height 1.5 m) with personal computers. Figure 2 illustrates the plan of the laboratory.

Furthermore, as shown by field studies, the humidified air flowed in the duct and over obstacles (e.g., silencers, etc.). There were significant losses due to moisture condensation on solid surfaces. Thus, a power saving humidification process is necessary to determine the minimum amount of normal air and water supply wherein the relative humidity of indoor air was given. For this purpose, a numerical simulation of the spatial distribution of relative humidity in the room was initially conducted through corresponding field experiments.

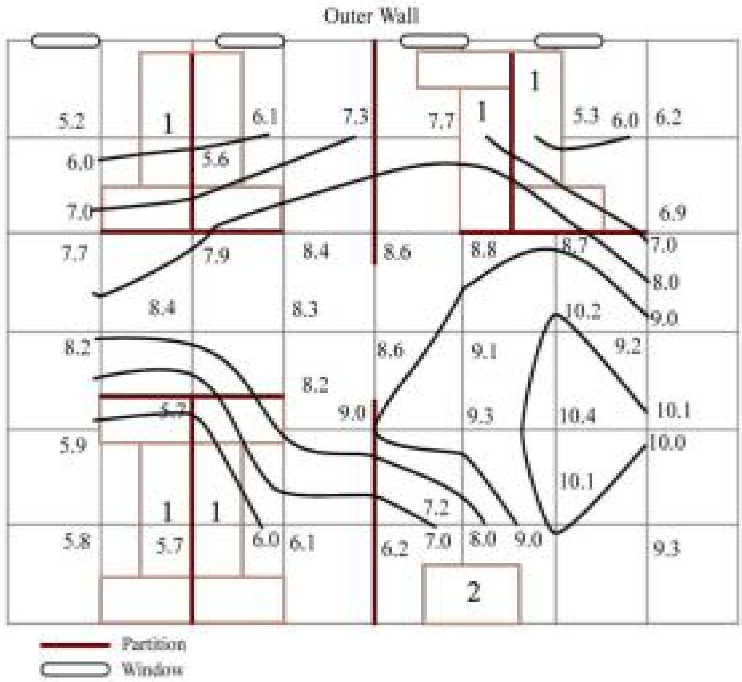

Figure 2. Experimental Dependence Of Air Temperature And The Contour Temperature To Time

The room provided fresh air supply through the three dimension 400x400mm windows. The experimental studies indicated that at an outside temperature below $T_{outdoor}$ (-5 °C) during heating and ventilation operations, the air temperature significantly exceeded the critical temperature, and the relative humidity was in the range of 5-10%. The low relative humidity primarily negatively affected the respiratory organs. Furthermore, humid air is a poor conductor of static electricity. This contributed to the accumulation of humid air on the surface, and this exceeded the performance of the electromagnetic field with respect to the remote control at the workplace with PC and led to failure of the electronic equipment. Humidification units were installed to ensure standardized relative humidity values in the installation of central air conditioning. Nevertheless, the generation of vapor or fine water required significant energy costs.

In the study, the results indicated the minimum amount of moisture in the supply air by which it was possible to determine the rated value of relative humidity of internal air. Experiment for the temperature dependence of the room and finding the circuit parameters experiment was conducted. The essence of the experiment was as follows. Temperature sensors were placed on the walls and ceilings in several places, so that you can then get the average integral factor associated with the thermal capacity of walls and ceilings. Simultaneously, the sensors were placed in the air, and the coolant in the external environment. The temperature data were taken at intervals of one minute, and these data can be averaged over the population, which was mentioned earlier.

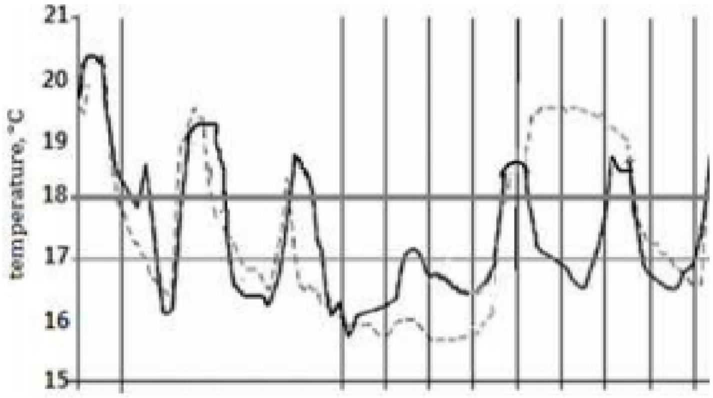

Figure 3. Average Internal Air Temperature Change (Dotted Line Means Actual Temperature Change. Full Line Means Math Model Calculated Temperature Change)

During two weeks we explored average internal air temperature and comparison with math model calculated data was provided. Figure 3 illustrates the comparison of measured data with the math model calculated data. The foregoing comparison proves adequacy of the mathematical model. The numerical simulation results shown in Figure 4 include temperature field distribution in the horizontal plane data distance of 1.500 m from the room floor.

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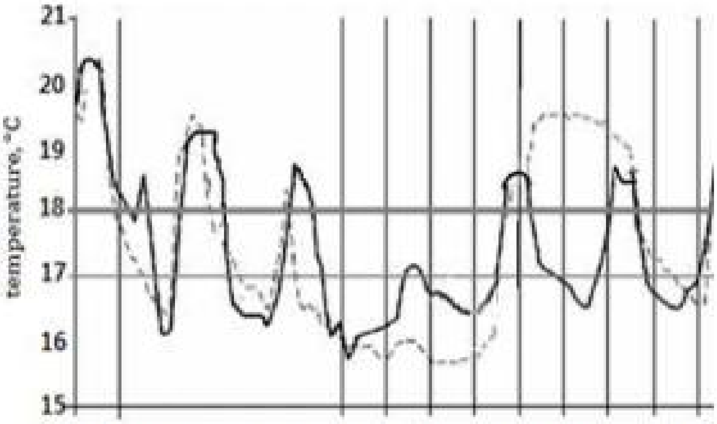

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5 Conclusion

Thermal processes are building a set of interrelated heat and mass exchange processes arising in different areas of the building. A mathematical model of these processes, based on the classical methods of thermal physics, is of little use to solve the heating process automation tasks. Proposed and justified in the structure of the mathematical model of the thermal building process in the form of a finite-dimensional linear system of differential equations paves the way for effective adaptation of the entire spectrum of modern methods of analysis and synthesis of automatic control systems for heating processes.

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