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# RESEARCH OF METHODS OF ENERGY EFFICIENCY MANAGEMENT IN THE "SMART HOUSE" SYSTEM

*The research of methods of energy efficiency management in the "Smart Home" system is carried out in the work. For researchers and practitioners, the problem of monitoring, estimating and reducing energy consumption by homes is an urgent task. According to the results of research, the method of determining user preferences has been improved, which has allowed to achieve more efficient use of energy. The method has also been further developed, which provides the ability to determine the number of people in the room and helps control oxygen levels.*

*Key words: smart home, energy efficiency, occupant-centric controls, residential buildings, HVAC, software and hardware, smart home management model.*

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# ДОСЛІДЖЕННЯ МЕТОДІВ УПРАВЛІННЯ ЕНЕРГОЕФЕКТИВНІСТЮ В СИСТЕМІ «РОЗУМНИЙ БУДИНОК»

*В роботі проведено дослідження методів управління енергоефективністю в системі «Розумний будинок». Для дослідників і практиків проблема моніторингу, оцінки та зниження споживання енергії будинками є актуальною задачею. За результатами проведених досліджень удосконалено метод визначення вподобань користувача, що дозволило досягти більш ефективного використання енергоносіїв. Також набув подальшого розвитку метод, за допомогою якого забезпечується можливість визначення кількості осіб в приміщенні та допомагає контролювати рівень кисню.*

*Ключові слова: розумний будинок, енергоефективність, елементи керування, орієнтовані на мешканців, житлові будинки, ОВК, програмно-апаратний засіб, модель управління розумним будинком.*

## Introduction

Analysis of the research topic showed that many researchers consider ordinary apartment buildings (partly private houses) and do not consider commercial and industrial buildings, do not take into account the benefits and requirements for the level of comfort of different users. The considered methods of determining the occupancy of the premises will not allow to effectively predict the transfer of the user to other areas of the premises, which negatively affects the operation of the HVAC system and increase energy efficiency of the "Smart Home" system [1]. They also do not pay attention to the high cost of sensors to detect the presence and number of inhabitants in the controlled space of the room, which is quite relevant against the background of the crisis in the country [2]. The considered works use powerful hardware, which has high energy consumption and high cost, which does not allow to compete with ready-made analogues [3].

Therefore, it is necessary to use appropriate localization methods to distinguish between different occupants of apartments and offices, which are used by many people, and apply their benefits. An additional analysis of employment behavior (data processing) was then conducted, consisting of three stages to determine important employment characteristics, such as the number of residents present, periods of absence and presence, and other random changes in the profile of residents.

Typical meteorological data on the weather in the city are used to model the energy characteristics of the building. In Khmelnytsky warm and humid summers and cold winters. The room has five zones: north, east, center, south and west. In all areas except the central, the wall attached to the outer part has a window-to-wall ratio of 0.4. Ceiling height in all areas is 2.7 meters. Each node represents an area with similar environmental parameters (such as temperature, lighting and air velocity), such as a separate area or one of the layers of the wall. Heat is transferred between nodes by convection, conductivity or radiation.

## Basics of the method of energy efficiency management in the "Smart Home" system

In order to achieve the goals of minimizing energy consumption in the building, as well as the hours of discomfort of residents, it is necessary to develop and invest in the optimization algorithm a detailed model of energy simulation of the house.

Since the functioning of building systems is highly dependent on the presence of residents, the integrated model should choose the most optimized parameters of building systems based on information about the dynamic occupation of space.

Using local control of building systems, the simulated space should be divided into several zones to assign appropriate dynamic information about the employment of each zone. Zoning is used to account for the effect:

1. Different activities performed in each zone.
2. Different number of HVAC terminals, as will be discussed in the next section.

3. Different orientation of the facade for the perimeter of the zones.

Knowing the location of a particular resident, the corresponding HVAC terminal and the corresponding light are regulated by local management strategies.

In this study, the proposed methodology includes two main modules: a multi-purpose modeling-based optimization module and a fill-in module, as shown in Figure 1.

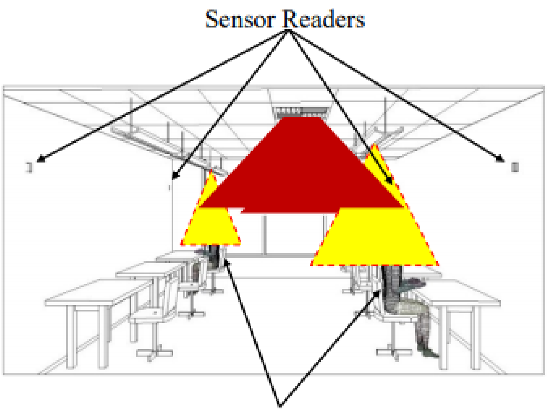


**Fig. 1. Local control strategy with population monitoring**

The occupancy module is used to determine specific dynamic profiles of residents based on their presence data, as shown in Figures 2 - 4. The main advantages of having dynamic occupancy profiles [4], which reveal the information of residents about his / her location and model of space use, are:

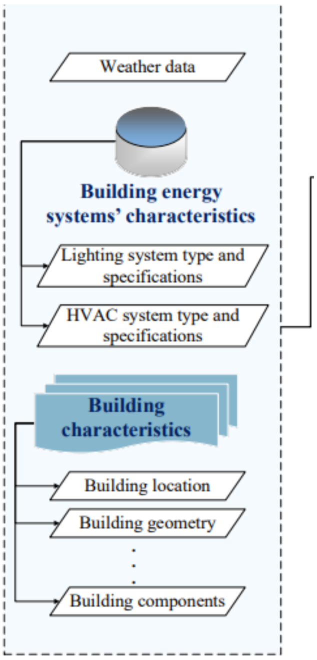


**Fig. 2. The main modules of the framework**

1. Unlike models that rely on averaging the behavior or schedules of different residents, dynamic occupancy profiles can cover the diversity of behavior of different residents, which is a very important factor in open planning offices.

**2.** Real-time monitoring and decision-making are the closest ways to imitate the real behavior of residents and their interaction with the energy-consuming systems of the building [5]. Dynamic occupancy profiles allow you to distinguish between schedules and habits of different residents.

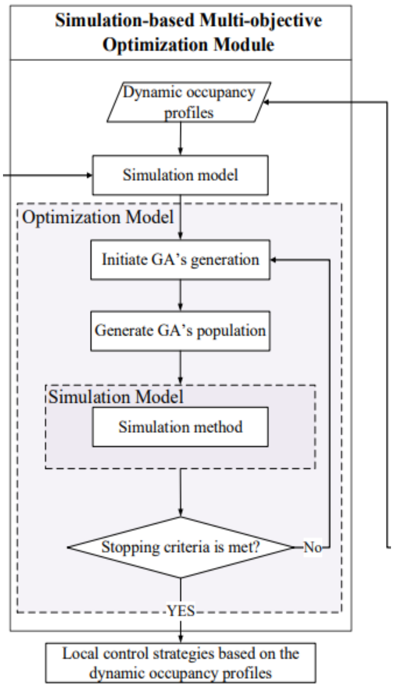


**Fig. 3. The main modules of the framework**

These profiles can be used to effectively apply the personal preferences of residents.

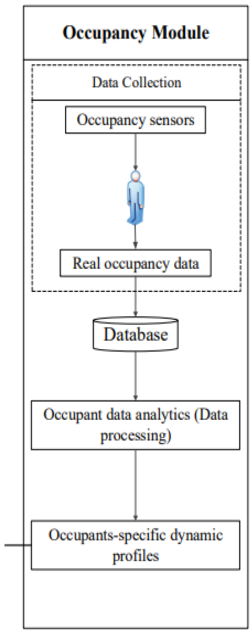


**Fig. 4. The main modules of the framework**

### Experimental studies of the method of energy efficiency management in the "Smart Home" system

In each zone, four environmental parameters of artificial lighting, natural light, room temperature and ventilation rate are automatically monitored every hour [6]. Each zone is equipped with a variable air volume system (VAV), which provides heating, cooling and ventilation. During idle hours, energy management and integrated zone control are based on SOOP energy consumption [7]. The objective function of the SOOP method consists only of the term energy costs. For each zone, the total energy consumption (E_total) per hour is the sum of the energy consumption of artificial lighting, cooler, boiler and fan (1):

$$E_{total} = E_{lighting} + E_{cooler} + E_{boiler} + E_{fan}. \quad (1)$$

The term energy consumption in the target function of the SOOP method is the product of the price of electricity or gas and the associated hourly energy consumption. Fixed tariffs of UAH 1.68 / kWh and UAH 6.99 per m3 are accepted as prices for electricity and gas in Ukraine [8]. For each hour of simulation, the term energy consumption in the objective function is (2):

$$\text{energy cost} = \left[\text{ElecPrice}\,.\sum_{z=1}^{5} E_z^{\text{electricity}} + \text{GasPrice}\,.\sum_{z=1}^{5} E_z^{\text{gas}}\right], \quad (2)$$

E is the consumption of electronic energy in kWh; z- number of the zone (room);
ElecPrice, GasPrice are the prices for electricity and natural gas.

There are many factors that determine the accuracy of the use model, including the identity of the occupants, the length of stay of the occupants, their location in different areas of the building, and their preferences [9].

New RTLSs can provide location and duration of presence, while benefits data can be collected through a simple survey. The fill module is used to define dynamic profiles related to residents [10].

The main advantages are:

1) dynamic employment profiles can cover the diversity of behavior of different residents, which is a very important factor in open planning offices;

2) real-time monitoring and decision-making that arise as a result are the closest ways to imitate the real behavior of residents and their interaction with energy-intensive building systems.

These profiles can be used to effectively apply the personal preferences of residents [11].

The operation of the proposed MOOP (Proposed Case) method and the SOOP (Base Case) method [12] on the thermal comfort of residents is compared.

The temperatures in the room of one-hour simulations in January and July, selected according to the proposed and base case, are compared (Fig. 5).

Optimal Pareto solutions are generated by changing the productivity factor ($ / h) [13].

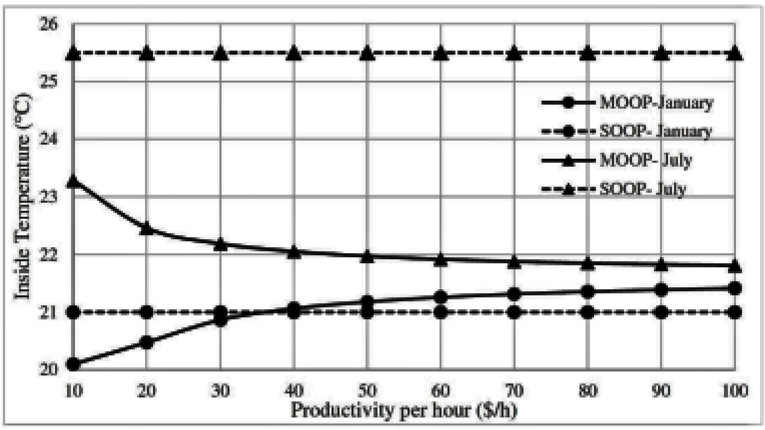


**Fig 5. Indoor temperatures (ºC), selected according to the proposed case and the basic option in the eastern zone**

In all three zones and for both external weather conditions with an increase in productivity per hour ($ / h) of residents, the average monthly room temperature moves to the maximum comfortable temperature (21.7 ºC). As collective productivity increases, the relative importance of residents 'productivity in terms of electricity costs increases, so the method reduces the relative loss of residents' productivity by approaching the maximum comfortable temperature. Here, the average monthly room temperature (ºC) is chosen to assess thermal comfort. An alternative approach is to demonstrate the frequency distribution of thermal sensory voices and to calculate the number of hours during which thermal sensory voices are in the comfort range. This approach is convenient when thermal comfort indicators such as the PMV index and the PPD index [14] are used to indicate the voices of thermal sensation.

## Conclusions

Analysis of the research topic showed that many researchers consider common apartment buildings, do not take into account the preferences and requirements for the level of comfort of different users. The main contributions of this study are:

1) development of a method for obtaining information on population with different time steps from the collected RTLS employment data. This method can capture the different levels of resolution required to apply intelligent local government strategies;

2) development of a new adaptive probabilistic model of employment forecasting on the basis of the received information on employment;

3) development of time-dependent inhomogeneous filling model.

The proposed forecasting model is an adaptive model that evolves and improves over time.

The availability of a occupancy profile forecast for each resident leads to the development of a occupancy level forecast at the zone level.

The forecasting model can accurately estimate the location of residents during most data collection periods during the day. The high accuracy (86% and 68% on average for lighting and air conditioning and ventilation control, respectively) of forecasting employment models also indicates acceptable efficiency of the forecasting model.

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