# ICT for Smart and Energy-Efficient Buildings

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*Abstract:* - The article examines the application of new technologies and ICT for the construction of intelligent and energy-efficient buildings. The state of the housing stock in Bulgaria is presented. The idea of using solar tiles both as a roof and as a photovoltaic source of electrical energy is substantiated. Other elements of the smart home management system are also described. The construction of a thermal energy storage system using phase change materials is given, as well as a thermometer for the blind, facilitating the life of visually impaired people at home.

*Key-Words:* - ICT, solar roof tiles, renewable energy, smart home, phase change materials, energy efficiency, thermometer for the blind.

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## 1 Introduction

The European Intelligent Building Group (EIBG), the Japan Institute of Intelligent Buildings (JIIB), the Chinese standard GB/T50314–2000, and others offer different definitions of intelligent buildings. EIBG offers a performance-based definition. EIBG considers smart buildings to be those designed to provide their users with the most efficient environment and for the building to use and manage resources as efficiently as possible to minimize appliance and installation costs. Service-based definitions describe smart buildings in terms of the services and/or quality provided by the buildings. JIIB provides a service-based definition: a smart building has the functions of communication, office automation, and automation at the service of its occupants and is convenient for smart activities. The definition of smart buildings is described by directly addressing the technologies and technology systems that buildings must incorporate. GB/T50314–2000 offers a solution for smart buildings. It states that intelligent buildings provide building automation, office systems, and communication networks and optimally integrate structures, systems, services, and management, providing the building with high efficiency, comfort, convenience, and safety for the occupants, [1], [2], [3], [4], [5].

## 2 Residential Buildings in Bulgaria

According to data from the National Sociological Institute, there are about 4,000,000 homes in Bulgaria, with approximately 66% of them located in cities. Depending on the type of construction, the largest percentage are brick buildings (about 80% with beams or reinforced concrete slab), followed by adobe, stone, and reinforced concrete construction. In the cities, the percentage of panel and reinforced concrete buildings is the largest (approximately 12%), the rest includes mainly low-rise buildings. Predominant for the country and low-rise dwellings are pitched roofs, using ceramic, concrete, bituminous, or metal tiles for covering. Once installed, roof tiles have no function other than weather protection. With the advent of solar panels as an alternative energy supply option, the question arises of including the roof tiles and the entire roof structure in an independent home power supply system, reducing the costs of heating, air conditioning, and other daily energy needs by supplying "green" energy, [6], [7].

According to data from the Ministries of Economy, Energy, and Tourism, the potential of solar radiation on the territory of Bulgaria is significant. The average annual duration of insolation is about 2150 hours with annual total radiation ranging from 1400 to 1600 kWH/m2 and represents about 49% of the maximum possible insolation. There are relative differences in the intensity of sunshine by region, and in terms of territory, Bulgaria can be divided into four sunny zones: Central-East, North-East, South-East, and South-West.

According to data from the same sources, 77% of the country's territory is occupied by the forest fund and arable land, as well as by territories protected by law such as nature reserves, military bases, etc., from which it is assumed that about 3% of the territory of the country can theoretically be used for photovoltaic energy. This makes the option of installing rooftop solar systems for home use even more attractive.

## 3 Smart and Energy Efficient Homes

In recent years, more and more private properties and residential buildings have acquired solar panels, aiming at a more ecological way of life and minimizing electricity costs (the average return on investment is 7-8 years). The end user faces three options for handling energy: The energy from the photovoltaic installation is to be used entirely for own use; Sale of part or all of the energy produced, which in turn requires significant costs of connecting to the electricity grid and a mixed option where part of the energy is used and the rest is sold. With the introduction of smart home technologies and the "Internet of Things" concept, it becomes possible to manage and distribute the energy produced from renewable sources in the home, as well as its storage through special batteries, [8].

Renewable energy systems capture solar energy using photovoltaic cells; also known as photovoltaic panels. The electricity generated by the photovoltaic panels partially covers the on-site needs, and the grid provides additional electricity if needed. Typically, the load on the roof structure from the photovoltaic plant is about 20 kg/m2, and the power reaches up to 5 kW. Some buildings do not have the possibility for this type of installation and their implementation is technically impossible due to the inability of the roof structure to withstand additional load, inappropriate orientation of the building, height limitations of the additional photovoltaic structure, etc. [5].

The solar tiles provide a suitable solution to these and other problems. Through their configuration, the offered systems built with solar tiles perfect the capture of solar energy and its distribution in the electrical network, simultaneously performing the function of a roof.

An innovative idea is the construction of a roof system (solar tiles) for energy-efficient construction and energy storage (Figure 1). Its adoption enables efficient and reliable roof constructions, reducing electricity costs and providing "green" energy, with the possibility of integration into technological "smart home" systems (SHS's) and building management systems (BMS) as well as storage of the harvested energy (Figure 2), [9].

Fig. 1: Solar tiles


Fig. 2: Schematic diagram of a smart home

It fits perfectly with the goals for zero harmful emissions and zero external energy consumption by 2050, as well as buildings. It is also part of the future smart energy grids, including diversification of electrical energy sources.

In this way, some of the peaks in consumption will be smoothed out by shifting to periods with less network load. It reduces the need for more expensive and polluting conventional power at times of peak load or large imbalance. This leads to a reduction in costs for the system and reduces CO2 emissions, which within the framework of the ETS (European Emissions Trading Scheme) has not only ecological but also economic significance. Losses from network transmission are also reduced. Possible benefits for the consumer are a reduction in the cost of energy; for the provider, reducing costs and improving network stability; for society, it reduces environmental pollution, [5], [9].

The innovativeness of the proposed solution consists in the use of solar tiles (for example solar photovoltaic tiles with a power of 80 W or more and a large operating temperature range: from -40 to +85 degrees Celsius), through the creation of a complete smart system for energy management, which will not only record the energy produced, consumed or given away by the household but will be able to learn itself and make a decision based on the machine learning concept and user habits about whether it should store or give away the energy produced. A similar product, which combines in itself a set of solar tiles for the production of electrical energy, and operational and control units, managed remotely via the Internet using a self-learning software system, can be classified as an innovation, not only in Bulgaria but also at the European level.

# 4 Additional Elements in The System

## 4.1 The Temperature Controller for Types of Solar Collectors

The temperature controller for types of solar collectors allows for achieving maximum efficiency when using similar types of systems, focusing on:
- Optimization and quality of the collected data during operational work of the solar collector,
- Predictability of processes, through the implementation of intelligent algorithms based on the weather forecast and collected data on external temperature and cloudiness,
- Construction of intelligent control of the Smart IoT type, which will allow the remote monitoring of the system and its adjustment through an Internet connection and user applications,
- Optimization of the heat exchange processes between the solar collector and the expansion vessel, based on developed additional algorithms for control and modulation of the pump circulation group of the system,
- Reducing the possibility of overheating or damage to the solar collector in case of excessive sunlight,
- Development of a smart, self-learning algorithm for controlling solar collectors based on their geographic location and heating intensity.

## 4.2 The Controller for the Management of Heating-Cooling

The controller for the management of heating-cooling fluid systems is designed for the management of heating and cooling systems with fluid circulation. Based on the world's energy reserves and current gas and resource crises, more and more people are paying close attention to the optimization of their heating and cooling systems, trying to achieve better efficiency. In this regard, as one of the most effective technologies used, systems using the circulation of water or other fluids with a moderate temperature, which is largely known as the so-called water floor systems, are increasingly gaining ground. These systems achieve their efficiency by circulating a fluid with a moderate temperature in the range of 10 – 30 degrees Celsius. The possibilities for achieving maximum efficiency in the use of such type of systems focus on the following several aspects:
- Carrying out research and experiments to determine the optimal temperature of the circulating fluid to achieve maximum heating efficiency, with minimum energy consumption,
- Creation of a thermostatic controller to manage the circulation process (water temperature, circulation speed, operating time), based on real-time temperature and humidity readings,
- Creation of possibilities for simultaneous control of several heating circuits, using separate wireless sensors,
- Implementation of IoT (Internet of Things) technology to allow the controller to be monitored and controlled remotely through an Internet connection and mobile applications,
- Development of a smart algorithm to control the heating and cooling process, matching the temperature and humidity in the room with those outside and eliminating the formation of condensation.

Heating buildings with solar energy significantly reduces the use of non-renewable energy sources and alleviates the degree of environmental and air pollution. A so-called "combined solar system" is a heating system that supplies heat for domestic hot water and space heating in a building using two energy sources - solar energy and any other auxiliary heat source to solve the problems of solar energy instability and insufficient heat storage, [5], [10].

# 5 Thermal Energy Storage

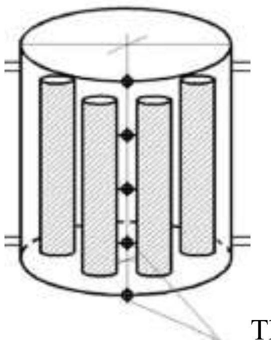
Thermal energy storage systems can store heat or cold to be used later under different conditions such as temperature, location, or power. These systems are divided into three types: sensible heat storage systems (sensation heat), latent heat storage systems, and thermo-chemical heat storage systems.
Thermal energy storage tanks used in heating and air conditioning systems have become more

widespread in recent years, with stratified tanks gaining in popularity, [11].

Knowledge of the melting and freezing characteristics of phase change materials, their ability to undergo thermal cycling, and their compatibility with building materials is essential for evaluating the short- and long-term performance of latent heat storage systems. A typical heat storage system is a water storage vessel in which encapsulated tubes (pipes) filled with phase change material are installed (Figure 3), [12].

Phase-change materials (PCM) used for heat storage are chemical substances that undergo a solid-to-liquid transition at temperatures in the desired heating and cooling range. During the transition process, the material absorbs energy as it goes from solid to liquid and releases energy as it returns from liquid to solid. A typical example of PCM is storage vessels with types of special paraffin (Figure 4), [13].

Paraffin is a hydrocarbon belonging to the group of organic PCMs. The advantages of using organic PCMs for thermal energy storage are low degree of supercooling, chemical and thermal stability, and non-corrosive. The special paraffin used as PCM are a mixture of mainly straight-chain n-alkanes CH3–(CH2)–CH3. The temperature range for the transition from solid to liquid phase and vice versa is from 36-38 $^0$C to 66-68 $^0$C depending on the type of paraffin.



Thermal sensors

Fig. 3: Structure of an accumulator vessel with PCM

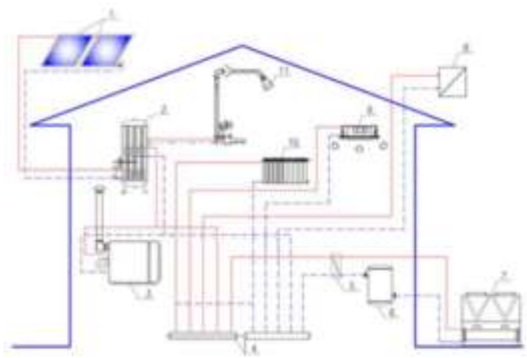


Fig. 4: Vessel with PCM in a building heating installation

## 6 Facilities for the Visually Impaired

People with visual impairments (not to be confused with reduced vision in the elderly) usually have heightened other senses - for example, a greater sensitivity to touch. They can sense small bumps on the flat surfaces of objects. This is what the Braille alphabet is based on, where symbols are represented by a combination of small dots. This possibility can also be used in the construction of some household appliances for people with visual impairments.

The patented tactile thermometer for the visually impaired is a bimetallic spiral (2) attached at one end (3) to a base (1). The other end (4) of the spiral (2), as the temperature increases, with its tip (5) successively raises the lower end (9) of the buttons (8). When the temperature decreases, the spiral (2) shrinks back, and the buttons (8) are retracted into their sockets (6) by return springs (7). A visually impaired user can find out the temperature of an appliance by feeling how many of the buttons (8) are raised by touching the top edge (10) of the buttons (8). The tactile thermometer is intended for installation on a boiler, stove, radiator, etc., for the convenience of a blind user living in a smart home (Figure 5), [14].

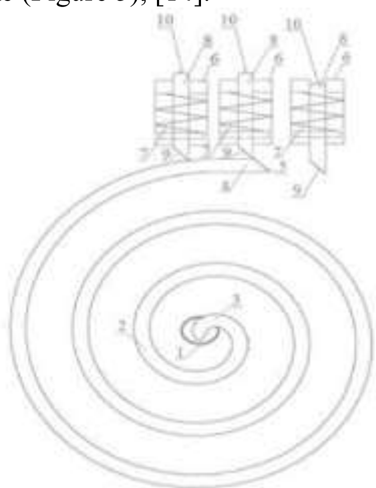


Fig. 5: Tactile thermometer for the blind

## 7 Conclusion

Smart homes with the application of ICT increase the quality of life of residents, reduce building maintenance costs, and provide additional services. The installation of additional systems for the production, storage, and distribution of electrical and thermal energy provides further advantages of a smart home. The presence in the home of orientation and control devices designed for disadvantaged people is another factor in expanding the circle of users of such a home. All the elements of a smart building with ICT technologies can also be applied to farm buildings, for example, to premises for growing plants and animals in agriculture, [15], [16], [17].

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**Conflict of Interest**

The authors have no conflicts of interest to declare.