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Research of Combined Building-Energy Systems

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ABSTRACT : *Combined building-energy systems represent alternative solutions for transposition of the requirements of Directive 2018/844/EU amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, which introduced a new concept into our legal system - nearly Zero Energy Building (nZEB). According to this directive, all new buildings approved after 2020 must meet the nZEB criteria. For new buildings in which public authorities reside or are owned by them, the period is even two years shorter, i.e. it is valid from 01.01.2019. In addition to tightening the requirements for thermal-technical properties of building envelope structures, which are to reduce the energy intensity of buildings, required is also increased use of renewable energy sources (RES) and a reduction of emissions of greenhouse gases,*
especially CO_2.

KEYWORDS : *Building structures with an internal energy source, active thermal protection, thermal barrier, solar roof, solar absorbers, large-capacity and small-capacity heat storage, ground heat storage, ground heat exchanger, solar energy, geothermic energy, ambient energy, recuperation ventilation.*

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I. INTRODUCTION

Energy systems built into one of the building structures that serve to capture solar energy, geothermic energy, and ambient energy, or which have the function of end elements of heating, cooling, and ventilation system, we generally call combined building-energy systems.

Among combined building-energy systems we include solar roofs with built-in pipe absorbers, building structures with active thermal protection (ATO) - active heat transfer control, which have a multifunctional purpose – a thermal barrier, low-temperature heating, high-temperature cooling, recuperation and accumulation of heat, solar and ambient energy collection, large-capacity heat storage (ground heat accumulators built simultaneously in the foundation slab of the building), or heat exchangers used for recuperative ventilation of buildings built into the foundation slabs and wall structures.

The research of combined building-energy systems at the Department of Building Services, Faculty of Civil Engineering, Slovak University of Technology in Bratislava has been carried out continuously since 2005. Within five research projects (responsible researcher: Kalús, D.) HZ 04-309-05, HZ 04-310- 05, HZ 04-142-07 (research and experimental measurements took place in the years 2005 to 2007), [12], HZ PG73/2011 (research and experimental measurements took place in the years 2011 to 2013), [13,] and HZ PR10/2015 (research and experimental measurements have been carried out since 2015), [15,] two experimental houses IDA I. and EB2020, a mobile laboratory designed for measuring and optimizing a compact heat station using renewable heat sources, were designed and built by the research team at our workplace, and also a research of a fragment of a perimeter wall with built-in active thermal protection was carried out in the climatic chamber of the Faculty of Civil Engineering STU in Bratislava, Slovak Republic [14].

Significant contribution to the research was provided by doctoral students Ing. Martin Cvíčela, Ph.D. [12], (supervisor: Kalús, D.), Ing. Peter Janik, PhD. [13], (supervisor: Kalús, D.) and Ing. Martin Šimko, PhD. [14], (supervisor: Kalús, D.), who described the results of the research in their dissertations. At present experimental measurements in the mobile laboratory are performed by doctoral student Ing. Matej Kubica, [15], (supervisor: Kalús, D.).

II. CURRENT STATE OF TECHNICAL SOLUTIONS

2.1 Large-area high-temperature heating and low-temperature cooling

In the current state of technical solutions, known are building structures of low-energy and energy-passive buildings, in which as standard large-area low-temperature energy heating systems as well as large-area high-temperature cooling systems are used, such as wall, ceiling, and floor systems, Fig. 1.

Fig.1. Large area low temperature heating and high temperature cooling systems [34]

2.2 Thermal active building structures

Known are thermal active building structures (TABS), which are suitable for both low-energy and energy-passive buildings, Fig. 2. These systems use thermally activated mass of concrete structures. This is a hybrid system that is used for heating during the heating season and for cooling during the summer. Pipe systems are directly embedded into the poured concrete core of a wall or ceiling. This energy system is characterized by very low differences between wall surface temperatures and indoor air temperature. The exchange of heat or cold takes place mainly by radiation; only a small part of the heat (cold) is spread by convection. Used as heat or cold sources are standard sources, in particular reversible heat pumps.

Fig.2. Thermal activate building structures [34]

2.3 Systems with active thermal protection

Also known are active thermal protection (ATP) wall energy systems with one or two thermal barriers, as described, for example, in patent SK 284 751, Fig. 3, [2]. This is a wall energy system ISOMAX originating from Luxembourg (author: Krecké Edmond D.; Beaufort; LU), which, like TABS systems, uses thermal active material. In the sense of the technical solution presented in the patent SK 284 751 [2], ATP is applied in two ways. During its operation, this system uses heat obtained from solar radiation, which is stored in heat storages, to actively reduce heat loss through enveloping structures. During the heating season, water is supplied to the pipes from the ground heat storage tank; the average temperature of the heating water is in the range of 15°C to 20°C. Cold water from the ground pipe register is used for cooling in the summer. Unlike TABS, this system does not only use a concrete core, Fig. 5, [2], but it can also use wall storage core made of any material with high heat storage properties, Fig. 4, or both methods can be applied, Fig. 6, [2].

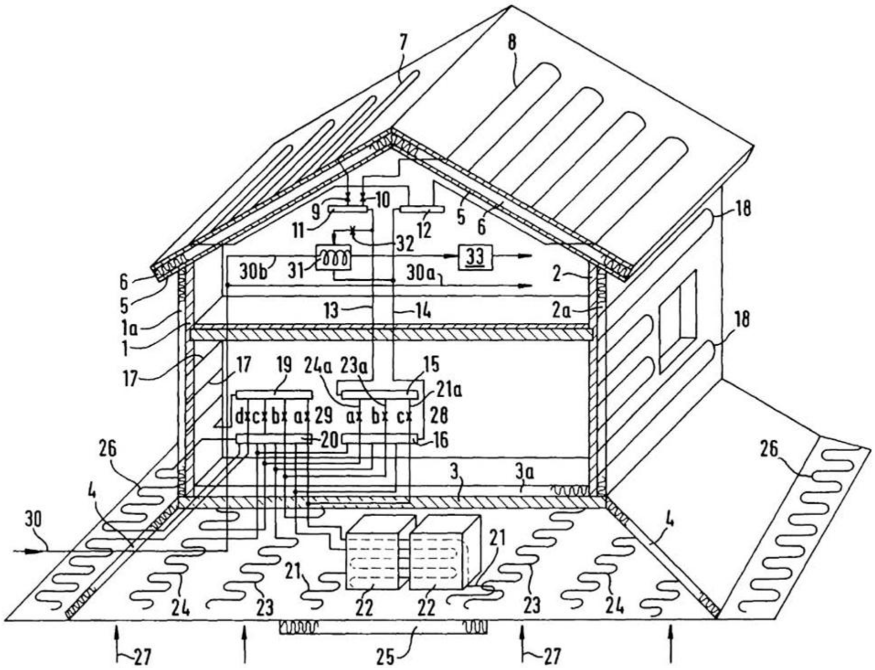

Fig.3. Patented building-energy system ISOMAX in the sense of patent SK 284 751 [2]

The first method of implementation is the application to the building's enveloping structures, where for the purposes of distribution of low-temperature heat transfer medium a pipe system is attached to the perimeter wall of an existing building, which is then covered with leveling plaster, thermal insulation is glued on and all layers of surface facade plaster are applied. This application is possible for new constructions but also for thermal insulation of already existing buildings, Fig. 4, [2], [12], [27], [28].

Fig.4. Application of the ISOMAX system in the sense of patent SK 284 751 on the exterior surface of perimeter walls of a building [2], [12], [27], [28]

The second method is by means of load-bearing panels in the form of lost formwork (mostly polystyrene) in which active thermal protection is placed and usually their interior is filled with a cast concrete mixture only after installation on the construction site. In the next stage, the concrete must harden and reach the required strength (approximately 28 days). Such construction technology is the so-called *"wet construction process"*. This is only applied in new buildings, Fig. 5 and Fig. 6, [2], [12], [27], [28].

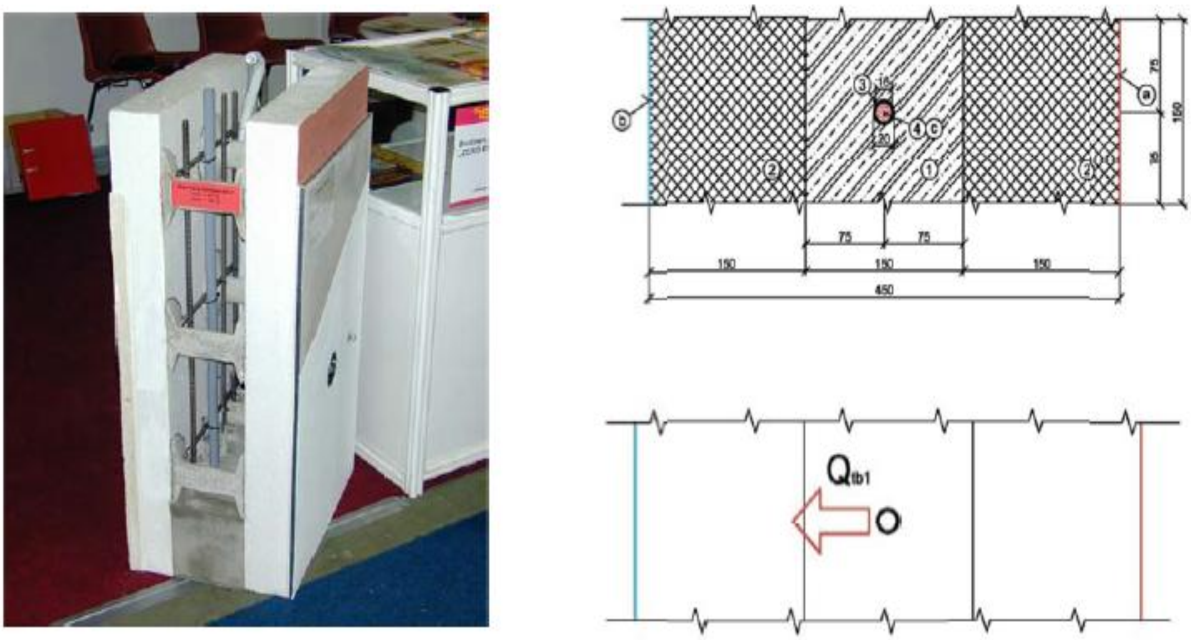

Fig.5. Single-pipe wall energy system ISOMAX in the sense of patent SK 284 751 [2], [12], [27], [28]

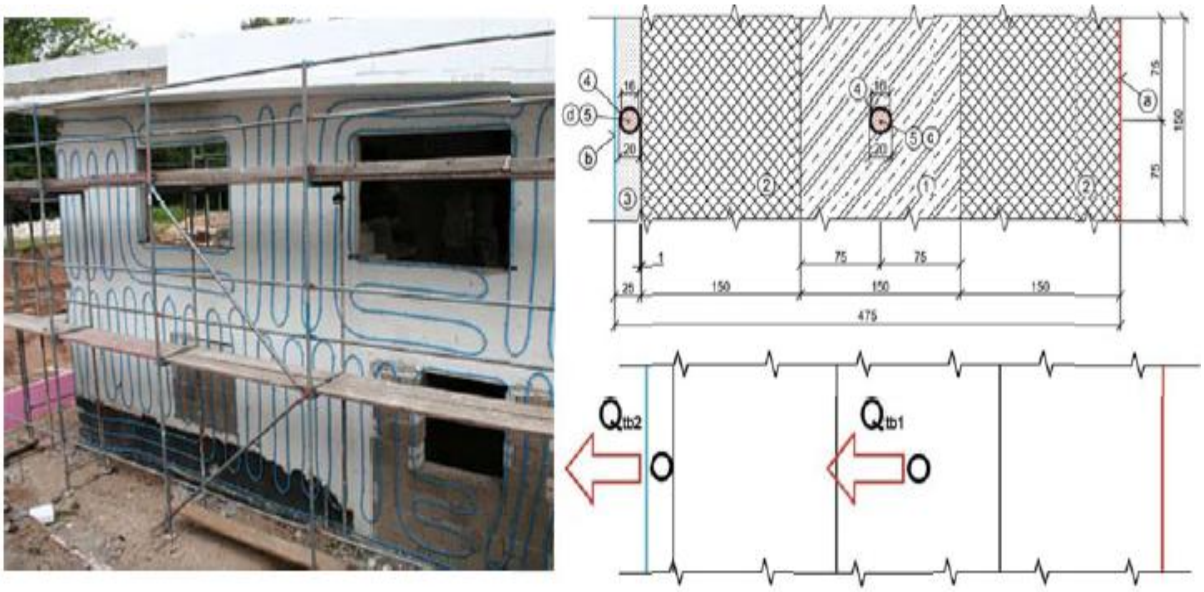

Fig.6. Two-pipe wall energy system ISOMAX in the sense of patent SK 284 751 [2], [12], [27], [28]

Since the temperature barrier in the outer walls is considerably slow in connection with temperature regulation, it is supplemented by a "fast" component in the form of the also patented ISOMAX ventilation device (patent specification SK 284 751), the so-called "pipe in a pipe" countercurrent device. Exhaust air is supplied to the outer, larger pipe and fresh air to the smaller, inner pipe, Fig. 7, [2].

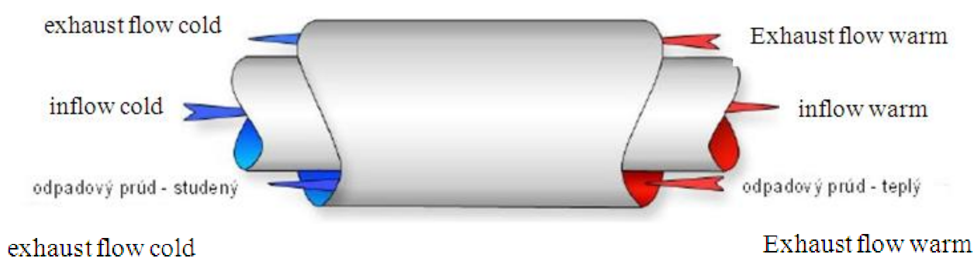

Fig.7. ISOMAX "pipe in a pipe" countercurrent device [2], [27], [28]

The piping system laid outside the building in the ground passes under the foundation plate into the ground heat storage tank under the building and is laid there, if possible in the peripheral part of the storage tank in the length of 40-45m. Fresh air is supplied from outside the building and exhaust air is also removed there. The pipes are made of flexible interlocking wound stainless stripe with a wall thickness of 0.12 - 0.15 mm, which have ribs on the outside for better heat transfer. In the fresh air pipe, a dew point may not be reached on the wall surface and condensation may form. The pipes are therefore laid in the ground with a drop of 0.5% and it is necessary to pay attention to draining the condensate. Calculations for sizing of ventilation pipes can be performed using dynamic simulation programs. Due to the large range of limit values, such as soil condition, climatic conditions, etc., large fluctuations in calculations can be expected. The input parameters for these calculations are, inter alia, the specific gravity of the soil, the specific heat capacity, the thermal conductivity and the water content of the soil. The flow velocity should be between 1.0 - 1.4 m/s. With an air exchange rate of 0.4 - 0.8/h, air volume flows of up to 500 m3/h are created in the usual living areas of family houses, [2], [27], [28].

For pre-heating of hot water, it is recommended to use a special tank, a so-called core tank under the foundation slab. This is an earth body insulated on all sides by a 10 cm layer of pressure-resistant insulator, into which hose lines are laid with a heat transfer medium temperature of more than 35°C. The volume of the core tank should be approximately 20 - 30 m3 per 1 housing unit. The core tank is supposed to be placed in an area with a minimum static load, i.e., not under the load-bearing walls if possible. If this is not possible, the soil in the area of the core tank must be compacted accordingly. The structural designer decides on the appropriate compaction. In contrast to a central respectively an edge hot water storage tank, heat transfer medium lines are fed directly into the storage tank to heat the core storage tank. At least 3 bm of hot water line must be available per 1 m3. A meaningful and economical implementation is shown in Fig. 8. A reinforcing mesh to which hose lines are connected is laid on all sides of the insulated space of the core tank. Finally, the core tank is filled with soil.

If a core tank is to be located in a space with static load and the soil in the core tank must be compacted, it is recommended to use one or more finished wall prefabricates with a thickness of approx. 10-12 cm, in which all pipelines are located, [2], [27], [28].

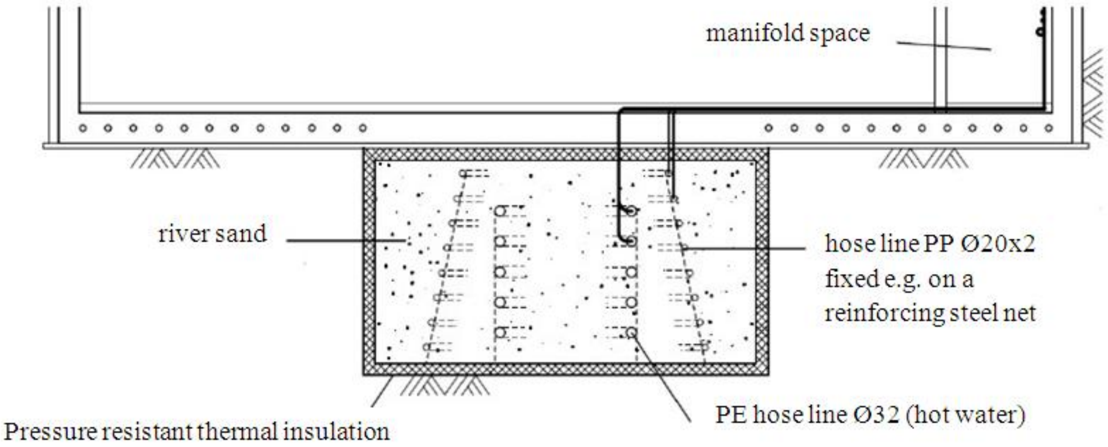

Fig.8. Core storage under a floor board [2], [27], [28]

III. DEFINING THE RESEARCH SUBJECT MATTER

The ISOMAX system described in the patent document SK 284 751 seems to be a very promising idea for the construction of buildings with nearly zero energy need using renewable energy sources, but on the other hand it has an unresolved mode of operation, from which the following shortcomings results.

The only source of heat is solar and geothermic energy. Solar energy is absorbed through a solar roof. This source causes unstable and insufficient absorption of solar radiation, it is usable in the summer and partly in the transitional period with sufficient heating of the heat transfer medium, i.e. at a temperature higher than the temperature in the long-term heat storage in the ground (ground heat storage). Geothermic energy is captured in the ground storage to an extent negligible for heating needs. **The ISOMAX system captures these energies only for direct use in the so-called thermal barrier without increasing energy efficiency e.g. by means of a heat pump or solar collectors.** The amount of energy is difficult to determine exactly due to the large number of unstable physical parameters influencing the capture of solar radiation. The captured energy is only applied to charge the long-term storage tank. The source is difficult to regulate and cannot cover sudden requirements for increasing the energy supply and cannot cover the year-round need for energy for heating, hot water, or ventilation. For example, the design of sources with the ISOMAX system is done only empirically - by estimation. **From the realizations so far, it is clear that a peak heat source is also needed.**

Heat accumulation with the ISOMAX system takes place only into the long-term earth storage tank, it is unstable, uneven. Most earth storage tanks are constructed with an open surface at the bottom part, which causes uncontrollable and immeasurable leakage of accumulated heat. The efficiency of such a storage tank is several times lower than the efficiency of a closed, insulated heat storage tank. The amount of stored energy and the length of charge of the ground tank at a certain capacity is difficult to calculate due to a large number of changing physical parameters, such as ground moisture, its composition, groundwater level, and its vertical movement and the like. Available for heating is always only such temperature of the heat transfer medium as is the average temperature of the long-term earth storage tank and the ISOMAX system cannot increase it in any way. The temperature of the heat transfer medium cannot be changed other than through the absorption of solar radiation. Calculation and design is done only by empirical - estimation method.

Heat transfer by the ISOMAX system is performed only to the heat barrier and serves only to reduce heat losses. The temperature of the heat transfer medium is limited by the temperature in the ground heat storage tank or in the cooling circuit and fluctuates according to the current temperature in these storage tanks and cannot respond to sudden weather changes or indoor climate change needs by higher or lower temperatures than available in storage tanks. Due to the fact that it is not possible to supply a heat transfer medium with a constant temperature to the thermal barrier throughout the entire period - this changes the heat transfer through the building structure and its thermal resistance. It is clear from the previous realizations that the thermal barrier constructed in this way cannot cover the heat losses of the building all year round.

The only source of cold for the ISOMAX system is the ground cold storage tank at non-freezing depth. The temperature of the coolant depends on the changing temperature of the soil, is limited and fluctuates, and cannot respond to sudden changes in weather and needs with a colder substance than is available in the ground tank. The ISOMAX system only solves preheating of hot water up to max. temperature of 35 ^{0}C and only in summer when there is enough sunlight. The temperature of the ventilation air in the ISOMAX system fluctuates and depends on the temperature in the ground heat storage and in the ground cooling circuit and it is not possible to adjust it to temperatures different from those in the ground heat storage.

IV. RESEARCH OBJECTIVES

The aim of research in the field of combined building-energy systems is to solve the defined shortcomings so that:

a) **heat/cold sources for energy systems - heating, hot water preparation, ventilation, and cooling were stable, independent of variable and unpredictable solar and geothermic energy accumulated in large-capacity, especially in ground heat storage,**
b) **the requirements for buildings with nearly zero energy demand have been met,**
c) **RES are used as much as possible and the best possible accumulation of heat/cold from these sources is ensured,**
d) **the implementation of active thermal protection has been simplified,**
e) **the advantages of contact thermal insulation system have been economically effectively combined with energy systems - thermal barrier, heating, cooling, heat accumulation and recuperation, capture of solar and ambient energy and use of recuperative ventilation - in multifunctional building-energy constructions of buildings,**
f) **a compact heat station with a separate control system was designed to regulate, measure, and optimize the energy demand in the building,**
g) **a reliable exact calculation methodology was developed for the design, calculation, selection, and assessment of all components of the combined building and energy systems of a building.**

V. DESCRIPTION OF RESEARCH PROJECTS

5.1 Research project - type panel house IDA I.

Based on the request of the limited liability company AQUA IDA Slovakia, s.r.o. (formerly a concrete panel manufacturer in Bratislava - Vrakuna), in accordance with the research project HZ 04-309-05, the Department of Building Services, Faculty of Civil Engineering, STU in Bratislava in 2005-2006 designed and implemented a type panel house IDA I., which currently serves as an administrative building for the company, (responsible researcher: Kalús, D.), [7]. Subsequently, on the basis of research projects HZ 04-310-05 and HZ 04-142-07, the Department of Building Services, Faculty of Civil Engineering, STU in Bratislava in the years 2006 to 2007 carried out measurements of heat-comfort state in this building (responsible researcher: Kalús), [8], [9].

Since the production of panels in the form of lost formwork, in accordance with patent SK 284 751 did not work, was too complicated and lengthy, the investor decided that reinforced concrete perimeter panels will be produced without thermal insulation so that tubular coils of active thermal protection (ATO) are in the central structure of the panels on steel reinforcement, Fig. 10, and thermal insulation from the outer and inner side of the perimeter walls will be applied additionally only after the completion of the initial structural construction stage (foundations, walls, roof).

Apart from the foundations, the ground heat storage, the ground heat exchanger, the roof structure with a solar energy roof, Fig.9, the structural and energy components of the type panel house IDA I were industrially manufactured in the panel shop as common parts for panel production, Fig.10.

a) the solar energy roof **b)** the ground heat exchanger

Fig.9. Solar energy roof and ground heat storage built into and under the foundation slab of a type panel house IDA I. (photo archive: Kalús, D.) [7, 8, 9]

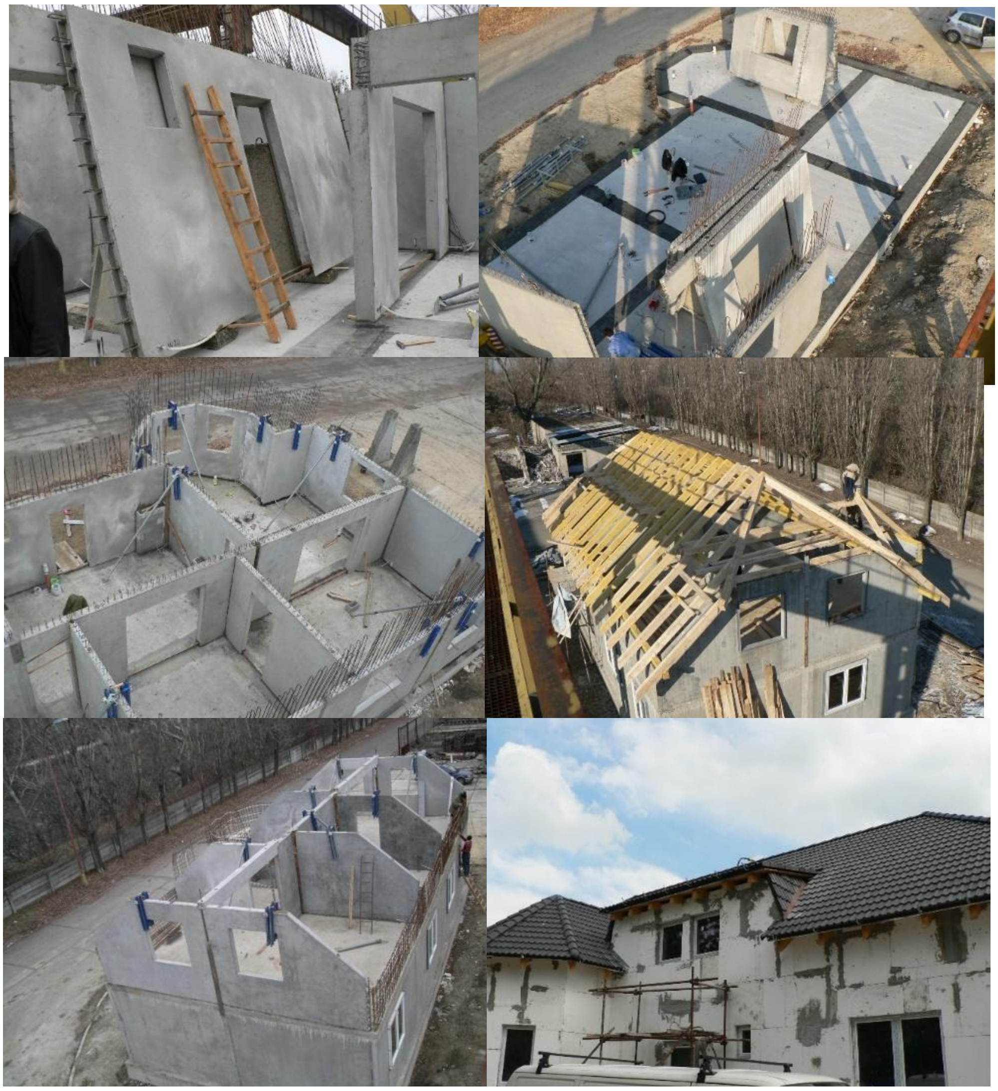

Fig.10. **Photographs from the assembly of type panel house IDA I. (photo archive: Kalús, D.) [7, 8, 9]**

Advantages of the type panel house IDA I .:

- unification of panels, fast mass production, fast assembly of a building without significant technological intermissions,
- high potential for the use of RES or waste heat,
- storage capacity of envelope structures to accumulate heat/cold – thermal barrier - active control of heat transfer through building structures,
- use of the self-regulatory effect of large-area radiant systems and TABS systems,
- application of a peak heat source and a small-capacity heating water storage tank eliminates instability and dependence of energy systems on variable and difficult to predict solar and geothermic energy accumulated in a large-capacity, especially in ground heat storage.

Disadvantages of the type panel house IDA I .:

- production of combined building-energy components with ATO is more time-consuming compared to conventional components of prefabricated production due to the fastening of pipe coils to reinforcement and compaction of concrete around the pipes,
- the need for technological breaks due to the hardening time of concrete (28 days),
- in the event of a leak from pipes in the panels, the repair is very demanding and the panel loses its energy function,
- the contact thermal insulation system can be realized only by gluing, anchoring could damage the pipe system in the panels,

- application of the IDA I. type panel solution in the sense of the patent solution SK 284 751 - ISOMAX, thermal insulation of the interior and exterior side of the perimeter walls limits the function of the combined building-energy system with ATO only to the function of a thermal barrier,
- The implementation of recuperation ventilation by a ground heat exchanger (pipe in pipe), as well as its subsequent maintenance or disinfection, also appears to be complicated and cost intensiv.

The type panel house IDA I. is a building which, thanks to the application of combined construction and energy systems, has a high potential to use RES to a large extent and in accordance with Directive 2018/844 / EU to meet the requirements for *nearly Zero Energy Buildings*. Based on the conducted research, it is possible to recommend the production of panels with integrated active thermal protection and thermal insulation exclusively from the exterior in a unified way directly in the production. With such a modification, we obtain a multifunctional combined building-energy system, namely: large-area radiant low-temperature heating/high-temperature cooling, a thermal barrier and the accumulation of heat and cold in the mass making up the static part of the panels. We also avoid complications and time loss for subsequent thermal insulation of the building.

5.2 Research project - experimental house EB2020

The research project HZ PG73 / 2011 solved by a team of researchers from the Department of Building services, Faculty of Civil Engineering STU in Bratislava, Slovak Republic, in 2011-2013 focused on experimental measurements, analysis and determination of optimal use of RES for prototype family house EB2020 for nearly Zero Energy Buildings (responsible researcher: Kalús, D.), [10], namely to:

- experimental measurements and evaluation of energy roof operation,
- experimental measurements and evaluation of the operation of the ground heat storage,
- experimental measurements and evaluation of active thermal protection operation.

The experimental family house is located 17 km from Bratislava, Slovak Republic, at an altitude of 128 m above sea level, in the village of Tomášov with a number of houses of about 700. It has two floors, a specific area of 187.4 m2, built-up volume of 590 m3, average construction height of 3.15 m Fig. 11.

The perimeter structure consists of internal plaster, aerated concrete block (375 mm, λ = 0.104 W / m.K), adhesive mortar, facade polystyrene (100 mm, λ = 0.035 W / m.K) and external plaster. The ATP is formed by a plastic pipe between the aerated concrete masonry and the facade polystyrene and in the roof structure, Fig. 12.

In Fig. 12 shows the temperature distribution in the perimeter structure without the use of ATP and with an average heat transfer medium temperature in the layer of 14 ° C and 20 ° C (at an outdoor temperature of -11 ° C). In the construction without ATP, the surface temperature will be 18.7 ° C and the temperature between the aerated concrete block and the thermal insulation will be 2.5 ° C. When installing an ATP with a temperature in its location layer of 14 ° C, the surface temperature will be 19.6 ° C.

Fig.11. View of the experimental house EB2020 (Photo archive: Kalús) [10, 13]

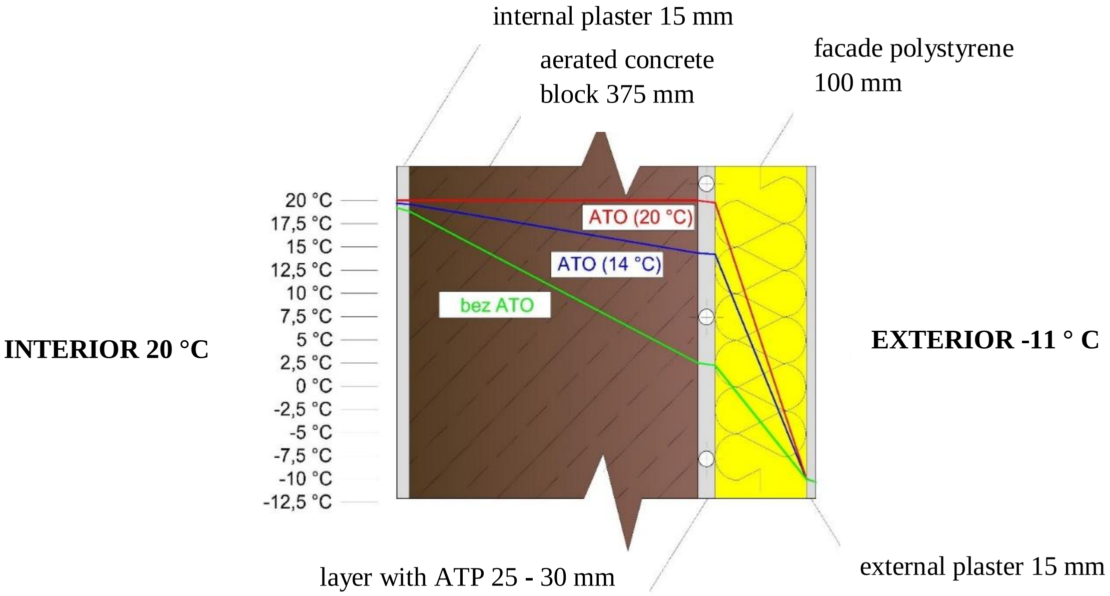

Fig.12. Sectional representation of a perimeter structure with temperature distribution without the use of ATP and with an average heat transfer medium temperature in the ATO layer of 14 ° C and 20 ° C [10, 13]

The source of heat is an energy roof formed by a plastic pipe placed under the roof covering in circuits: 3 x 100 m, fireplace insert and gas boiler. In addition to the combined storage tank (V = 575 l for central heating and 180 l for DHW), the heat is stored in the ground storage tank, which is formed by a plastic pipe in the base plate in the following circuits: 5 x 100 m.

Active thermal protection in a given building consists of plastic pipes between aerated concrete masonry (375 mm) and facade polystyrene (100 mm) and in the roof structure in the perimeter: 20 x 100 m. With the help of ATP it is possible to reduce heat losses in the building through opaque constructions, to heat the building and to cool it in summer.

The source of cold is the cooling circuits, which are located at a non-freezing depth in the ground around the foundation strips of the building. They are formed by circuits of plastic pipes: 20 x 100 m.

Heating in the building is also possible by underfloor heating on both floors. An air handling unit with heat recovery is also installed. Photographs of energy systems of the experimental house EB2020 are in Fig.13.

Fig.13. Photographs of energy systems of the experimental house EB2020 [10, 13]

Combined building-energy systems with applied active thermal protection with the use of solar energy with long-term heat accumulation can be more efficient than conventional construction with conventional heating systems only with the right design and proper operation. Theoretical calculations, experimental measurements and analysis have identified important facts that need to be taken into account in the calculation, design, assessment and planning of buildings with combined building and energy systems, as well as the need for further research in this area, as these technical solutions have a high the potential to make significant use of RES and, in accordance with Directive 2018/844 / EU, to meet the requirements for nearly zero energy buildings "nearly Zero Energy Building (nZEB)".

Several system optimizations and recommendations for further research can be suggested:

- The application of an energy roof requires lower investment costs than conventional solar collectors, but experimental measurements have shown that the energy gain and the achieved temperatures of the working substance at the outlet are significantly lower. For higher efficiency, it is worth considering installing a dark roofing and installing more circuits with a suitable division according to the sides of the world. This may be the subject of further research.
- For theoretical calculations of energy roof it is necessary to know the radiation of solar radiation in hourly averages for a specific slope - it is suitable to install a solar radiation meter on the roof and connect to a measuring and recording control panel, or to install a flat solar collector with a given roof slope for direct comparison of heat and outlet temperatures.
- For a more detailed evaluation of the energy roof, it is advisable to install a compact heat meter on the primary side as well - in front of the plate heat exchanger (already performed).
- The use of an energy roof for low-temperature heating or the supply of active thermal protection can only be realized with a suitable heat storage solution. When preparing hot water, the energy roof can only be used for preheating. It is appropriate to consider its use in the operation of heat pumps, where in the summer it could serve as a heat exchanger in the preparation of hot water or in pool management.

- Whenever possible, supply the ATP directly from the energy roof without heat accumulation, consider using an energy roof to preheat hot water.
- In summer, the ATP was used as a wall cooling from July to September, with the inlet temperature to the ATP set at 20 ° C and the return temperature ranging from 20 to 23.5 ° C. The supply was carried out from cooling circuits, which are located in the ground around the foundations of the building - a passive cooling system. The soil temperature has warmed up here and another low-temperature storage tank has been created - it is appropriate to consider its use for the supply of ATP in the transitional and winter periods. The cooling circuits are directly connected to the ATP.
- With large-area wall cooling, a separate cooling source is not required if the wall is designed correctly. The thermal conductivity of the material in front of the ATP tubes and the material in which the tubes are located should be as high as possible, this is a necessary condition for optimal operation ATP.
- The use of ATO as a wall heating and cooling function is of practical importance only for building structures which have a high storage capacity on the interior side in front of the ATP pipes, ie a suitable bulk density, thermal conductivity and thermal capacity. Given the construction in the family house, where the experimental measurements took place, heating with ATP is very limited and economically inefficient. By wall cooling, it is practically possible to cover only the heat load through non-transparent constructions. For the use of ATP in the function of wall heating and cooling, it is recommended to design structures with suitable accumulation, e.g. reinforced concrete with a suitable thickness of thermal insulation from the exterior.
- Building structures that have a high thermal resistance in front of the ATP pipes are not suitable for the wall heating and wall cooling function. The ATP system offered on the market, where the pipes are installed in a reinforced concrete structure, which is provided with thermal insulation on the interior and exterior side (ISOMAX system - self-supporting panels), cannot ensure year-round thermal comfort at normal temperature gradients of low-temperature heating and high-temperature cooling. At higher temperature gradients in the heating function, operation is energy and economically inefficient. With such constructions, it is necessary to design a heating system.
- Heat accumulation in a common base plate is disadvantageous - it is advisable to consider heat accumulation in deep drillings, or to apply large-capacity water tanks.
- In experimental measurements in the EB2020 experimental house in the heating period, the air temperature on the 2nd floor was often lower by more than 1 K compared to the air temperature on the 1st floor. Underfloor heating on the 1st floor and 2nd floor is connected via one circulation pump. . It is advisable to design two separate branches for each floor, just because there is a ground heat storage under the 1st floor.
- It is necessary to perform further measurements of heating operations with setting the attenuation of the indoor air temperature. It is advisable to perform operation measurements only with underfloor heating, then only with active thermal protection and then in combined use with different temperatures. During experimental measurements in less than two heating seasons, it was not physically possible to perform further measurements, while the comfort of the inhabitants had to be taken into account.

The combined building and energy system consisting of the use of solar energy by the energy roof, long-term heat accumulation in the ground storage and active thermal protection was comprehensively evaluated on the basis of calculations and experimental measurements. This is probably the first object in Slovakia with such a system, where long-term measurements took place. To date, no independent (non-commercial) research is known from domestic or foreign sources with published output, based on long-term measurements of all components of this system from heat recovery, through accumulation to ATP supply. Outputs for the further development of the scientific field and for technical and social practice were defined.

5.3 Research project – mobile laboratory

Based on the research project HZ PR10 / 2015 by a team of researchers from the Department of HVAC, the Faculty of Civil Engineering STU in Bratislava (responsible researcher: Kalús, D.) and the utility model no. 5749 "Method of operation of the combined construction-energy system of buildings and equipment" registered in the Gazette of the Industrial Property Office of the Slovak Republic No .: 5/2011 in Banská Bystrica, April 2011 (author of the utility model: Kalús, D.), was designed and manufactured by REGULTHERM, s.r.o. Slovak Republic a functional mobile laboratory and a developed series of mathematical-physical models of compact energy equipment for the use of RES in energy-active buildings, [6].

The mobile laboratory is currently researching, measuring and optimizing the compact heating unit of the new S.M.A.R.T. type within the dissertation Ing. Mateja Kubica (supervisor: Kalús, D.). Self-monitoring, analysis and reporting technology or S.M.A.R.T. is a monitoring system of technological equipment that detects and sends reports on various reliability indicators in an effort to predict failures. The new compact thermal unit of the intelligent type is a technological device with a control unit that can monitor, analyze, detect and predict faults, ensure communication and cooperation of technological components of the compact thermal unit with each other, but also with external devices using specially developed software for this purpose. remote control.

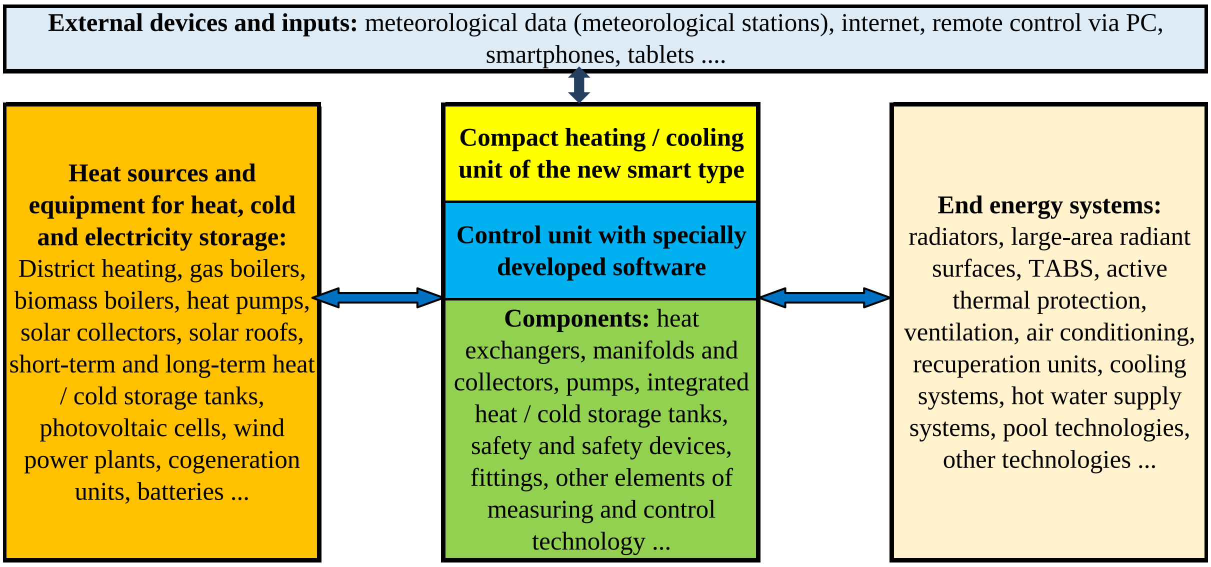

Fig.14. Principle diagram of a compact heat unit of a new SMART type [6, 15]

Fig.15. Mobile laboratory - optimizer and simulator of compact heating / cooling units [6, 15]

Our research is focused on the development of compact heating / cooling units using renewable energy sources, wiring diagrams, method of measurement and regulation, possible production process and their future applications. One interesting innovation will be the performance diagnostics of the entire system connected to the compact station - which will bring better control accuracy and it will be possible to integrate this invention into existing heating / cooling systems.

The laboratory includes vacuum solar collectors, photovoltaic panels, an air-to-water heat pump with the option of producing heat or cold, and a heat recovery ventilation unit and a DHW tank with electric heating. Remote access allows you to monitor and set actual and desired quantities according to the needs of the measurements performed. The software records measured states at five minutes intervals. The software can create various time graphs with temperature, humidity, consumption or battery charge status. If necessary, we can export all values to another calculation program.

Fig.16. View at the energetical and measuring equipment of a mobile laboratory [6, 15]

VI. CONCLUSION

Type panel house IDA I.: Based on the conducted research, it is possible to recommend the production of panels with integrated active thermal protection and thermal insulation exclusively from the exterior in a unified way directly in the production. With such a modification, we obtain a multifunctional combined building-energy system, namely: large-area radiant low-temperature heating/high-temperature cooling, a thermal barrier and the accumulation of heat and cold in the mass making up the static part of the panels. We also avoid complications and time loss for subsequent thermal insulation of the building.

Experimental house EB2020: Experimental measurements - energy roof measurements found real temperatures at the outlet of the energy roof and the heat that can be obtained. In the case of a underground storage tank, the measured heat was stored and removed from the storage tank and the efficiency was evaluated. At ATP, the parameters of operations at different temperatures in the ATP pipeline were measured. Experimental measurements can serve as a basis for similar measurements, e.g. energy roofs with another upper part of the structure, underground heat accumulators under the foundation slab of the building, or ATP applications in other building structures, also as a base for designers.

Mobile laboratory - optimizer and simulator of compact heating / cooling units: Pre-installed and pre-programmed ultrasonic heat meters make it possible to create new ways of acquiring data and to compare design and actual conditions. Two sets of ultrasonic heat meters are installed in the compact unit. The power pack can detect instantaneous power and the amount of energy stored in the heat and cold store. The set of heat meters recognizes the installed capacity of heating systems. The measurement and control system is crucial for the proper functioning of the heating system. In addition to the qualitative and quantitative way of adjusting the power, the progressive measurement and control systems can also adjust the pressure conditions in the heating system. In addition to adjusting the operating characteristics of the system, the measurement and control system provides protection against damage to heating systems. Measurement and control monitors and sends feedback so that the software is updated in time for the next action. As a result, we can evaluate the very favorable conditions for developing and selling a new renewable energy facility and addressing the complex production, preparation and distribution of heat for family houses and small apartment buildings. There are currently technically simpler devices on the market that make good sense of compact stations due to their current advantages, such as fast and high quality assembly, pre-production and calibration in the production, control and flushing of the finest parts. The European Union's ecological focus also contributes to increasing sympathy for the prepared facility. Last but not least, the end of the economic crisis in the European Union and the high number of users of the target group will also be beneficial.

In the area of combined construction and energy systems, research and optimization of suitable solutions continues, which have been transformed into one European patent and three utility models [3, 4, 5, 6].

REFERENCES

[1]. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

[2]. KRECKÉ E. D .: PATENT SK 284 751: *Energetické zariadenie budov.* [Energy equipment of buildings.] Date of effectiveness of the patent: 3.11.2005. In: Vestník ÚPV SR č .: 11/2005, 10 p.

[3]. KALÚS, D .: EUROPEAN PATENT EP 2 572 057 B1: *Heat insulating panel with active regulation of heat transition.* Date of publication and mention of the grant of the patent: 15.10.2014 In: Bulletin 2014/42 European Patent Office, international application number: PCT/SK2011/000004, international publication number: WO 2011/146025 (24.11.2011 Gazette 2011/47), 67 p.

[4]. KALÚS, D .: UTILITY MODEL SK 5725 Y1 (UTILITY MODEL): *Tepelnoizolačný panel pre systémy s aktívnym riadením prechodu tepla.* [Thermal insulation panel for systems with active heat transfer control.] Date of entry into force of the utility model: 25.2.2011 In: Vestník ÚPV SR No .: 4/2011, 63 p.

[5]. KALÚS, D .: UTILITY MODEL SK 5729 Y1 (UTILITY MODEL): *Samonosný tepelnoizolačný panel pre systémy s aktívnym riadením prechodu tepla.* [Self-supporting thermal insulation panel for systems with active heat transfer control.] Date of entry into force of the utility model: 28.2.2011 In: Vestník ÚPV SR No .: 4/2011, 32 p.

[6]. KALÚS, D .: UTILITY MODEL SK 5749 Y1 (UTILITY MODEL): *Spôsob prevádzky kombinovaného stavebno-energetického systému budov a zariadenie.* [Method of operation of a combined construction-energy system of buildings and equipment.] Date of entry into force of the utility model: 1.4.2011 In: Vestník ÚPV SR No .: 5/2011, 23 p.

[7]. KALÚS, D. et al .: Research Project HZ 04-309-05 - Design of a passive house using solar and geothermic energy. K-TZB SvF STU Bratislava, 2006.

[8]. KALÚS, D. et al .: Research Project HZ 04-310-05 - Assessment of thermal comfort state in an experimental house. K-TZB SvF STU Bratislava, 2006.

[9]. KALÚS, D. et al .: Research Project HZ 04-142-07 - Assessment of thermal comfort state in an experimental house. K-TZB SvF STU Bratislava, 2007.

[10]. KALÚS, D. et al .: Research Project HZ PG73/2011 - Experimental measurements, analysis, and determination of the optimal rate of use of renewable energy sources on a prototype of a family house EB2020 with nearly zero energy demand. K-TZB SvF STU Bratislava, 2011-2013.

[11]. KALÚS, D. et al .: Research Project HZ PR10/2015 - Analysis of energy, economic, environmental aspects and experimental measurements of compact equipment of energy systems for the application of renewable energy sources. K-TZB SvF STU Bratislava, 2015.

[12]. CVÍČELA, M .: Analysis of wall energy systems. Dissertation. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2011, 119 pp., SVF-13422-17675.

[13]. JANÍK, P .: Optimization of energy systems with long-term heat accumulation. Dissertation. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2013, 185 pp., SvF-13422-16657.

[14]. ŠIMKO, M .: Energy efficiency in buildings with systems with active thermal protection. Dissertation. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2017, 152 pp., SvF-13422-49350.

[15]. KUBICA, M .: Measurement and optimization of a compact heat station using renewable heat sources. Written part of the dissertation exam. Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Slovak Republic 2019.

[16]. ŠIMKO, M. - KRAJČÍK, M. - ŠIKULA, O. - ŠIMKO, P. - KALÚS, D .: Insulation panels for active control of heat transfer in walls operated as space heating or as a thermal barrier: Numerical simulations and experiments. In: Energy and buildings. Vol. 158, (2018), p. 135-146. ISSN 0378-7788 (2018: 4.495 - IF, Q1 - JCR Best Q, 1.934 - SJR, Q1 - SJR Best Q).

[17]. KALÚS, D. - ŠIMKO, M. - GALVÁNEKOVÁ, M .: *Intelligent facade system with active thermal protection.* In: Stuttgart: Scholars' Press (October 24, 2014), 56 p., ISBN-10: 9783639665246, ISBN-13: 978-3639665246, ASIN: 3639665244.

[18]. Q Zhu, X Xu, J Gao, F Xiao: *A semi - Dynamic simplified therm model of active pipe embedded building envelope based on frequency finite difference method.* In: International Journal of Thermal Sciences, 2015 - Elsevier, Vol. 88, pg. 170-179, 2015.

[19]. KRZACZEKA, M., KOWALCZUK, Z .: *Thermal Barrier as a technique of indirect heating and cooling for residential buildings.* In: An international journal devoted to investigations of energy use and efficiency in buildings - Energy and Buildings, 2011 - Elsevier, Vol. 43, pg. 823-837, 2011.

[20]. BABIAK, J. - OLESEN, B.W. - PETRÁŠ, D .: *Low temperature heating and high temperature cooling.* REHVA, Guidebook no 7, 2007, ISBN (s): 2960046862, p. 115.

[21]. KRAJČÍK, M. - PETRÁŠ, D. - SKALÍKOVÁ, I. *Energy evaluation of buildings.* Bratislava: SPEKTRUM STU, 2019. ISBN 978-80-227-4903-9.

[22]. CHMÚRNY, I. *Tepelná ochrana budov. Tepelnotechnické vlastnosti stavebných konštrukcií a budov.* [Thermal protection of buildings.] Bratislava: Jaga, 2003. ISBN 80-889-0527-3.

[23]. KURČOVÁ, M. - KOUDELKOVÁ, D .: *Vykurovanie* [Heating.] Bratislava: SPEKTRUM STU, 2020. ISBN 978-80-227-5002-8.

[24]. STN 730540-2 + Z1 + Z2: 2019 *Tepelná ochrana budov. Tepelnotechnické vlastnosti stavebných konštrukcií a budov.* [Thermal protection of buildings. Thermal technical properties of building structures and buildings.] Part 2: Functional requirements. Consolidated text

[25]. STN EN 12831: 2019 *Energetická hospodárnosť budov. Metóda výpočtu projektovaného tepelného príkonu.* [Energy performance of buildings. Method of calculation of projected heat input.] Part 1: Heat input, Module M3-3

[26]. STN 06 0892 - *Ústredné sálavé vykurovanie so zabetónovanými rúrkami.* [Central radiant heating with concreted pipes.]

[27]. www.isomax-terrasol.eu

[28]. ISOMAX. http://www.isomax.sk

[29]. www.rieder.at

[30]. www.po.opole.pl. TU in Opole (2013)

[31]. http://www.eng.pw.edu.pl TU in Warsaw (2013)

[32]. http://www.stavebne-forum.sk/en/article/18284/

[33]. https://www.uponor.sk

[34]. https://www.rehau.com

Assist. Prof. Ing. Daniel Kalús, et. al. "Research of Combined Building-Energy Systems."*American Journal of Engineering Research (AJER)*, vol. 10(2), 2021, pp. 31-45.