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Design, Project, and Realization of a Prototype of an Energy-efficient Prefabricated House IDA I. using Renewable Energy Sources

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Abstract

In this paper, we describe our experience with the design, project, and implementation of a prototype of an energy-efficient prefabricated house IDA I. using renewable energy sources (RES). This prototype is the result of our research in the field of energy (solar) roofs, ground heat storages, and active thermal protection. The client of the applied research, the owner of the prefabricated plant, has purchased the license for the patented ISOMAX system. Experience from the implementation of buildings according to this system shows the high potential using of RES but also the shortcomings caused by the variable, unstable, hardly predictable solar and geothermic energy stored in ground heat storages. The production of panels ISOMAX in the lost form from expanded polystyrene was too complicated, time-consuming, and often showed problems from a static point of view. Our research aimed to design an innovative, original, and reliable mode of operation for the IDA I. prefabricated house prototype under development, which in synergy with the building management system, will optimize the mode of operation of all heat/cooling sources and energy systems. Another task was to innovate the design of the envelope panel with active thermal protection, eliminate the shortcomings of the technical design of the ISOMAX panel, and adapt as many components as possible to prefabrication. The prototype of the energy-efficient prefabricated house IDA I. using RES represents an innovative energy-secure and self-sufficient construction option compared to buildings with fossil fuel-based heating/cooling sources.

Keywords

combined building-energy systems (CBES), renewable energy sources (RES), energy (solar) roof (ESR), ground heat storage (GHS), peak heat source, panels with integrated thermal barrier, ground heat recovery, air heat exchanger, cooling circuits

1 Introduction

Based on the requirement of practice, in 2005 the company AQUA IDA Slovakia, s. r. o. (currently Paneláreň Vrakuňa, a. s.) - the owner of the license for the patented building technology with the name and trademark ®ISOMAX, author: KRECKÉ [1], (hereafter referred to as the "ISOMAX system" or "ISOMAX"), commissioned a request for applied research focused on the design, project, and management of the realization of a prototype of the energy-saving prefabricated panel house IDA I. with the utilization of renewable energy sources (RES).

The ISOMAX system has been implemented on many experimental and real buildings around the world. In addition to Slovakia, there are implementations in Poland, Germany, Austria, Switzerland, Japan, Luxembourg, the Netherlands, Puerto Rico, Saudi Arabia, the USA, and elsewhere. More detailed information about the system and implementations can be obtained from the website [1].

Following the work contract HZ 04-309-05 (responsible researcher: Kalús, D.) [2], between the customer and the Department of Building Services of the Faculty of Civil Engineering of the STU in Bratislava, this prefabricated house was developed, designed, and implemented in 2005–2006. The house currently serves as an administrative building of the joint-stock company Paneláreň Vrakuňa.

The subject of our long-term research since about 2003/04 is the development and innovation of combined building-energy systems using RES. The building technology ISOMAX inspired us. This system uses only the solar energy captured by the energy roof, which it stores in long-term ground heat storage under or near the building.

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Heat losses/gains are eliminated by a thermal barrier-pipes embedded in the building envelope that use heat from the ground heat storage or ground cold from the building surroundings.

It is clear from the implementation of buildings under this system that a stable peak heat/cooling source is also needed so that energy systems are not dependent on variable, unstable, hard-to-predict solar and geothermic energy stored in ground heat storages. For these reasons, our research aimed to address the identified shortcomings of this perspective system and to ensure the reliable, cost-effective, and convenient operation of the building's individual energy systems using as much renewable energy as possible.

The novelty of our technical solution described in this paper lies in the innovation of the original mode of operation of the ISOMAX system. We add heat sources, including other system components that, in synergy with the building control system, optimize the mode of operation in the IDA I prototype prefabricated house. This solution offer variations of energy-secure and reliable technical building solutions compared to buildings with fossil-fuel-based heat/cooling sources.

We have also innovated the construction of the perimeter panel with active thermal protection and eliminated the shortcomings of the technical solution of the ISOMAX panel. We also adapted to prefabrication the maximum number of components used in the construction of the prototype of the prefabricated house IDA I.

2 Analysis of the energy potential of the prototype prefabricated house IDA I. in comparison with a conventional house

The energy balance and standard assessment of the prototype of the IDA I. prefabricated house are in accordance with the standard requirements valid in 2005 when the object was designed. The specific area of the building $A_b = 324.6$ m^2, the built volume $V_b = 971.9$ m^3, and the average height of the building $k_v = 3.0$ m. The total heated area is $A_H = 253.58$ m^2 and the heated volume $V_H = 659.31$ m^3 [2].

Table 1 shows the climatic data of the building site necessary for the energy balance of the building [2]

The thermal-technical properties of the proposed building structures are with the following heat transfer coefficients:

- perimeter walls U = 0.120 W/(m^{2}K),
- floor U = 0.180 W/(m^{2}K),
- roof U = 0.085 W/(m^{2}K),
- windows and doors U = 1.000 W/(m^{2}K).

Table 1 Climatic data of the building site [2]

S. n.	Climatic data	Value	Physical unit
1	Calculated exterior temperature	-11	°C
2	Calculated interior temperature	20	°C
3	Air exchange intensity	0.5	1/h
4	Height above sea level	142	m n.m.
5	Temperature region	1	-
6	Wind region	2	-
7	Number of heating days	206	day
8	Average annual exterior temperature	9.9	°C
9	The average outdoor temperature during the heating season	4	°C
10	The interior temperature during attenuation	15	°C

Heat losses through ventilation in the prototype prefabricated house IDA I. are eliminated using heat recovery with an expected efficiency of 85%. The designed heat input of the heating system according to STN EN 12831 is 4.5 kW. The results of the heat input and specific heat losses of the building for the classic alternative house and the prototype prefabricated house IDA I. can be seen in Table 2 [2].

Based on the above results, we can conclude that the prototype of the prefabricated house IDA I. has 2.37 times lower heat losses than a classical building meeting the requirements for thermal properties of building structures in terms of STN EN 73 0540 valid in 2005 when it was designed. Table 3 shows the evaluation of the heat demand for heating the classical family house and the prototype of the prefabricated house IDA I according to the criteria valid in 2005 in the sense of STN EN 73 0540. The heat demand for heating is Q_h = 18,274.98 kWh/(m^{2}yr) for a classical family house and Q_h = 4,839.786 kWh/(m^{2}yr) for the prototype of the prefabricated house IDA I. The heat demand for heating the prototype of the prefabricated house IDA I. is 3.78 times lower than that of a classical family house. The time of design and construction in 2005–2006 met the requirements for the thermo-technical properties of building structures in terms of the standard STN EN 73 0540 [3].

In Table 4, we present the results of the calculation of the energy performance of the buildings with the determination of energy classes for heating, hot water preparation, total energy demand, and primary energy for a classical family house with a gas condensing boiler heat source and low-temperature large-area heating and for the prototype of the prefabricated house IDA I. with the combined

Table 2 Design heat input according to STN EN 12831 and specific heat losses of the building (Note: the project was based on standard requirements from the 2005 to 2006 construction period) [2]

S.n.	Energy balance data of the building:	Value	Physical unit
1	Average heat transfer coefficient for a classic family house (valid in 2005)	0.43	W/(m^2.K)
2	Average heat transfer coefficient for the prototype of a prefabricated house IDA I.	0.21	W/(m^2.K)
3	Heat loss through ventilation for a classic family house without recuperation	3,640	W
4	Ventilation heat loss for the prototype of a prefabricated house IDA I. (heat recovery = 85%)	910	W
5	Designed heat input for a classic family house, STN EN 12 831	10,650	W
6	Designed heat input for prototype of a prefabricated house IDA I., STN EN 12 831	4,500	W
7	Specific heat loss of the built-up area of a classic family house	10.96	W/m^3
8	Specific heat loss of the built-up area for the prototype of a prefabricated house IDA I.	4.63	W/m^3
9	Specific heat loss of the heated space of a classic family house	16.15	W/m^3
10	Specific heat loss of the heated space for the prototype of a prefabricated house IDA I.	6.83	W/m^3
11	Specific heat loss per specific area for heating a classic family house	32.81	W/m^2
12	Specific heat loss per specific area for heating for the prototype of a prefabricated house IDA I.	13.86	W/m^2
13	Specific heat loss per heated area for the heating of a classic family house	42.00	W/m^2
14	Specific heat loss per heated area for the heating of the prototype prefabricated house IDA I.	17.75	W/m^2

building-energy system described in the previous sections, with an assumed total utilization of solar and geothermic energy of about 40 % [2, 4].

The results of the energy analysis show that the prototype of the prefabricated house IDA I. with a combined building-energy system using RES already in the period of construction (2005 to 2006) met the requirements for buildings with nearly Zero Energy Building and showed a high potential for reducing CO_2 emissions compared to conventional heat sources using natural gas, up to 90% [2].

3 The project and implementation of the prototype prefabricated house IDA I.

In the following section, we present the project and implementation of the prototype of the prefabricated house IDA I. using RES as the achieved results of the synthesis of knowledge obtained by scientific analysis of technical solutions in the field of combined building-energy systems and their transformation in the solution of the set objectives.

3.1 Project and realization - construction and disposition of the building

The prototype of the prefabricated house IDA I. was built on the premises of the factory Paneláreň Vrakuňa, a. s., Bratislava, Slovakia, Fig. 1. It is a two-story building with a ground floor and an attic. It was designed as an administrative building [2].

The building is structurally designed as a prefabricated longitudinal load-bearing system with load-bearing perimeter walls and one central wall made of reinforced concrete panels. The roof is gabled with a ridge parallel to the front façade. The ground floor is laid out with an entrance hall with a staircase, offices, and a bathroom. The attic consists of a hall, offices, and a bathroom.

Table 3 Specific heat demand for heating of a conventional family house and the prototype of the prefabricated house IDA I. (STN EN 73 0540, requirements from 2005) [2, 3]

<table>
<tr><td colspan="4">Specific heat demand E_1, E_2</td><td></td></tr>
<tr><td colspan="2">E_1</td><td colspan="2">E_2</td><td></td></tr>
<tr><td>Classic family house</td><td>Prototype of prefabricated house IDA I.</td><td>Classic family house</td><td>Prototype of prefabricated house IDA I.</td><td rowspan="4">BSF building shape factor</td></tr>
<tr><td>kWh/(m^{3}year)</td><td>kWh/(m^{2}year)</td><td></td><td></td></tr>
<tr><td>18.77</td><td>4.97</td><td>56.3</td><td>14.91</td></tr>
<tr><td colspan="4">Standard-specific heat demand</td></tr>
<tr><td colspan="2">$E_{1,N}$</td><td colspan="2">$E_{2,N}$</td><td>-</td></tr>
<tr><td colspan="2">kWh/(m^{3}year)</td><td colspan="2">kWh/(m^{2}year)</td><td></td></tr>
<tr><td colspan="2">28.1</td><td colspan="2">78.6</td><td>0.69</td></tr>
</table>

Table 4 Results of the calculation of the energy performance of the buildings for the conventional house and the IDA I prototype prefabricated house [2, 4]

Line number	Quantity	Heat/energy demand-classic house kWh/(m²yr)	Energy class according to Decree No. 35/2020 Coll.	Heat/energy demand-prototype prefabricated house IDA I. kWh/(m²yr)	Energy class according to Decree No. 35/2020 Coll.	Heat/energy savings in kWh/(m²yr)	**Potential savings in %**
1	Heat demand for heating	56.3		14.9		41.4	73.5%
	Energy demand:						
2	for heating	59.2	B (44-86)	15.0	A (≤ 43)	44.2	74.7%
3	for hot water preparation	20.3	B (13-24)	11.0	A (≤ 12)	9.3	45.7%
4	for cooling/ventilation	for family houses we do not evaluate					
5	for lighting	for family houses we do not evaluate					
6	**Total energy demand kWh/(m²yr)**	79.4	B (56-110)	26.0	A (≤ 55)	53.5	67.3%
7	**Primary energy kWh/(m²yr)**	88.6	A1 (55-108)	**19.4**	**A0 (≤ 54)**	69.2	78.1%
8	**CO_2 emissions**	**17.4**		**1.7**		**15.7**	**90.3%**
	Deductible thermal and electrical energy:						
9	Solar thermal			14.6			
10	Solar photovoltaic						
11	Cogeneration						
12	Thermal energy from other renewable source						

The layout and construction solution is shown in the project documentation and photo documentation in Figs. 2–9 [2].

The foundation strips and foundation slab are designed from B-15 concrete reinforced with welded steel mesh.

Figs. 5 and 6 show photo documentation of the ground floor and attic assembly using reinforced concrete panels. The truss is a wooden gambrel. The shape of the roof is gable with a pitch of 39º, Fig. 7. The roof covering is designed from dark-colored concrete tiles to ensure maximum accumulation and absorption of solar energy.

Once the mortar had cured, all walls with integrated energetic-active elements were insulated with a contact insulation system on both sides. This is a method of creating wall systems with active thermal protection in the function of a thermal barrier and a large capacity heat/cool storage, Figs. 8 and 9.

3.2 Project and realization - energy systems solution

The source of heat for heating, domestic hot water pretreatment, and ventilation for the IDA I. panel house prototype is an energy (solar) roof.

The energy (solar) roof (ESR) is made of PP plastic pipes 20 × 2 or 16 × 2 with a circuit length of 100 to 120 m. The individual circuits are connected to the energy system in the attic space using a distributor and collector. Fig. 10 shows a view of the implementation of the ESR circuits. Fig. 11 is a cross-section of the ESR showing the location of the solar absorber and the thermal barrier [2].

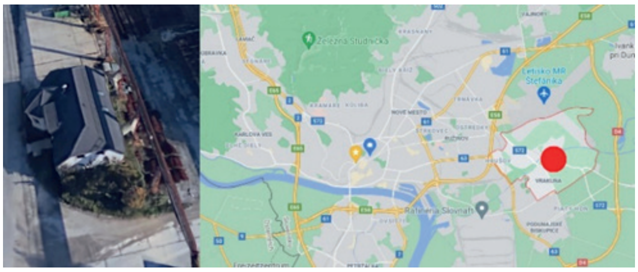

Fig. 1 Location of the prototype of the prefabricated house IDA I. within Bratislava, Slovak Republic (Google Maps)

The solar energy captured by the ESR is stored in three zones with different temperatures in the ground heat storage (GHS). Two temperature zones with lower temperatures are located under the base slab, Fig. 12, and Fig. 13. The central temperature zone is created directly in the base slab, where the excess heat from the heating water storage tank is also stored directly from the fireplace heat exchanger. The GHS circuits are formed by 20 × 2 PP tubes with lengths from 120 to 200 m [2].

The principle design of the thermal insulation of the ground heat storage tank is shown in Fig. 14. Heat losses/gains are eliminated by a thermal barrier integrated into the external walls and roof structure, Fig. 11 and Fig. 15. The heating of the IDA I prototype prefabricated house is using low-temperature radiant floor heating, Fig. 16. The circuits of the energy systems are supplied with a heat transfer medium for heating or cooling by the building control system. The distributor and collector for all heat/cooling sources and energy systems, the building control system, control valves, expansion tanks, pumps, and the heating water storage tank are in the space under the staircase, Fig. 17 [2].

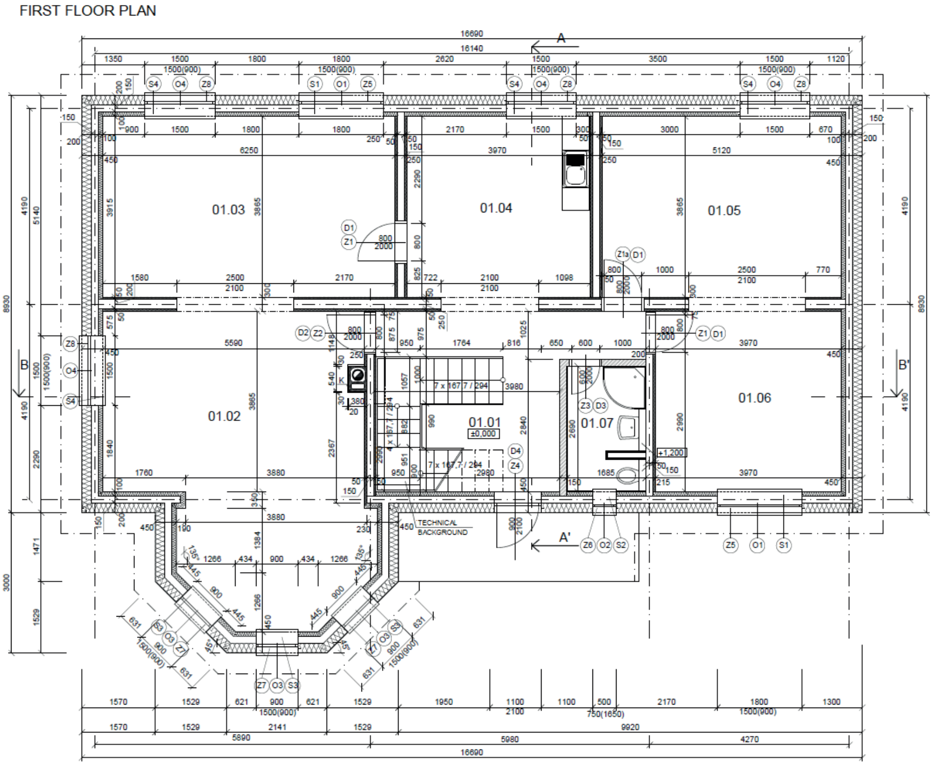

Fig. 2 Prototype of prefabricated house IDA I. - floor plan of the first floor [2]

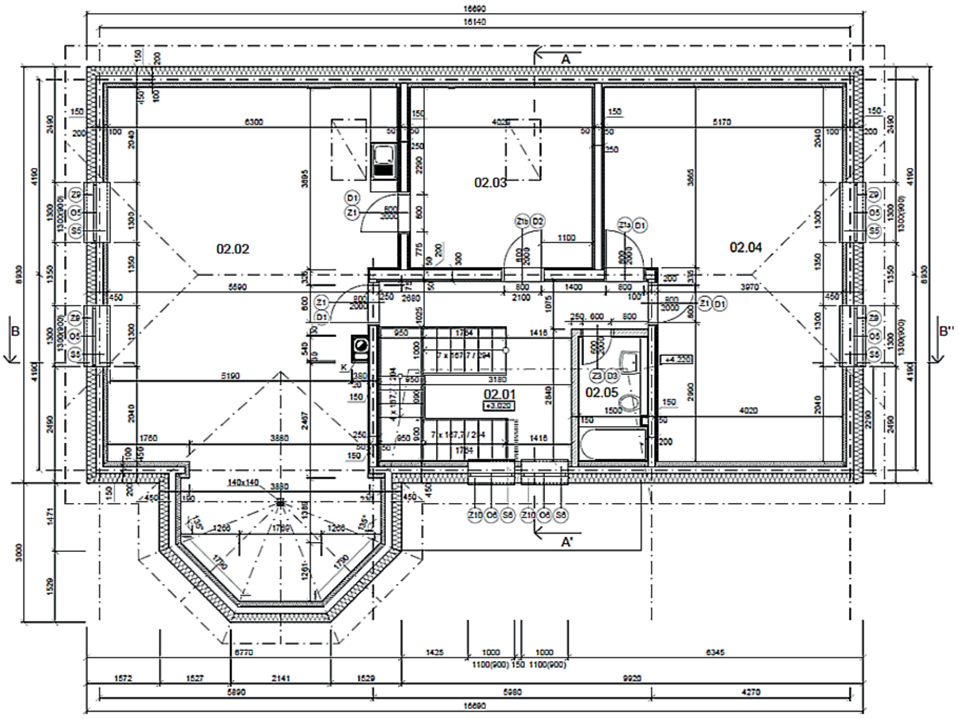

Fig. 3 Prototype of prefabricated house IDA I. - floor plan of the second floor [2]

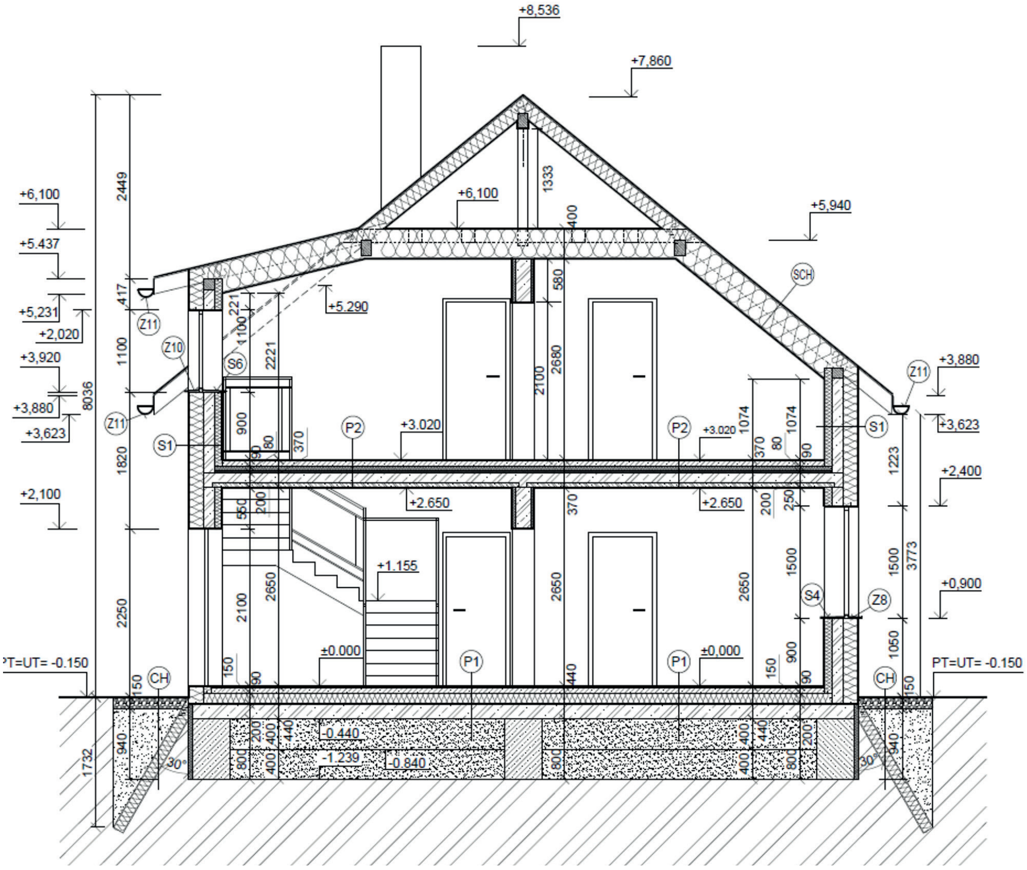

Fig. 4 Prototype of prefabricated house IDA I. - cross section A-A' [2]

Fig. 5 View of the completed assembly of the ground floor (Photo archive: Kalús, D.) [2]

Fig. 6 View of the attic assembly (Photo archive: Kalús, D.) [2]

The individual circuits of the energy systems are interconnected with the energy roof, the ground heat storage tank, the peak heat source, the heating water storage tank that the supply of the necessary energy for heating is possible at any time and from any heat source. A fireplace with a hot-water heat exchanger with an output of 18 kW (12/6 kW) is designed as a peak heat source. The heating water storage tank is designed as a combined (vessel within a vessel) with a water volume of 750 l for heating and 180 l for hot water. An integrated 6 kW electric insert can also be used to heat hot water. The thermal barrier circuits are also connected to liquid circuits stored in the ground outside the building, which are mainly used for passive cooling [2].

Fig. 7 View of the realization of the wooden truss (Photo archive: Kalús, D.) [2]

Fig. 8 Additional wall insulation also on the inside - the mass of the building walls, including the interior walls, serves as a large-capacity heat/cooling reservoir (Photo archive: Kalús, D.) [2]

Fig. 9 View of the implementation of the insulation of the perimeter panels (Photo archive: Kalús, D.) [2]

Fig. 10 View of the implementation of the energy roof. (Photo archive: Kalús, D.) [2]

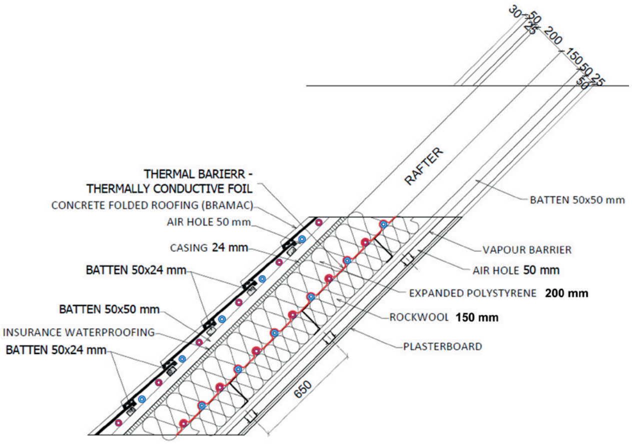

Fig. 11 Prototype of the prefabricated house IDA I. - detail composition of ESR

Heat recovery ventilation is provided by a counter-current heat recovery heat exchanger of the pipe-in-pipe type (ISOMAX system). It is made of stainless steel with an antimicrobial surface, inner pipe DN 180, and outer pipe DN 250. The piping is located outside the building at a depth of 2 m below ground level, 40 m in length, and directly under the building in the ground heat storage tank at a depth of 1.0 m below the floor, also 40 m in length, Figs. 18 and 19 [2].

In contrast to the ISOMAX system, we have designed a heat exchanger installed to the internal supply air duct to heat or cool the air, thus ensuring the desired supply air temperature even during extreme outdoor conditions.

Fig. 12 Prototype of the prefabricated house IDA I. - view of the ground heat storage under the foundation slab (Photo archive: Kalús, D.) [2]

The heating water storage tank supplies the heat required to heat the ventilation air. The cold required to cool the ventilation air is supplied from ground cooling circuits - pipes laid at a depth of approx. 2 m below ground level outside the building [2].

Cooling of the building is provided by a ground cooling circuit a piping system of PP pipes 20 × 2 stored at a depth of 2 m below ground level outside the building with a length of 3 × 200 m, Fig. 20. This cooling system is connected to the thermal barrier circuits in the external perimeter walls and the heat exchanger in the ventilation air cooling duct via a distributor and collector [2].

The domestic hot water preparation is carried out in two phases. First, it is preheated from a temperature of approximately 10 °C to approximately 25 to 30 °C in a ground heat storage (GHS) tank, Fig. 21. It is then reheated to the desired temperature of 55 to 60 °C in a triple-valve heating water storage tank with an integrated hot water storage tank using solar energy, electricity, or heating water heated in a hot water exchanger in the fireplace [2].

After the implementation of all the energy systems, pressure and leakage tests at maximum operating overpressure, hydraulic regulation of the individual branches, adjustment of the operating values of the control devices, etc. were carried out. The thermal barrier circuits were also hydraulically regulated. The layout of the individual energy distribution lines in the ground source heat store can be seen in Fig. 22 [2].

4 Results and discussion

The applied research aimed to design an innovative, original, and reliable mode of operation for the developed prototype of the prefabricated house IDA I. In synergy with the building management system optimizes the mode of

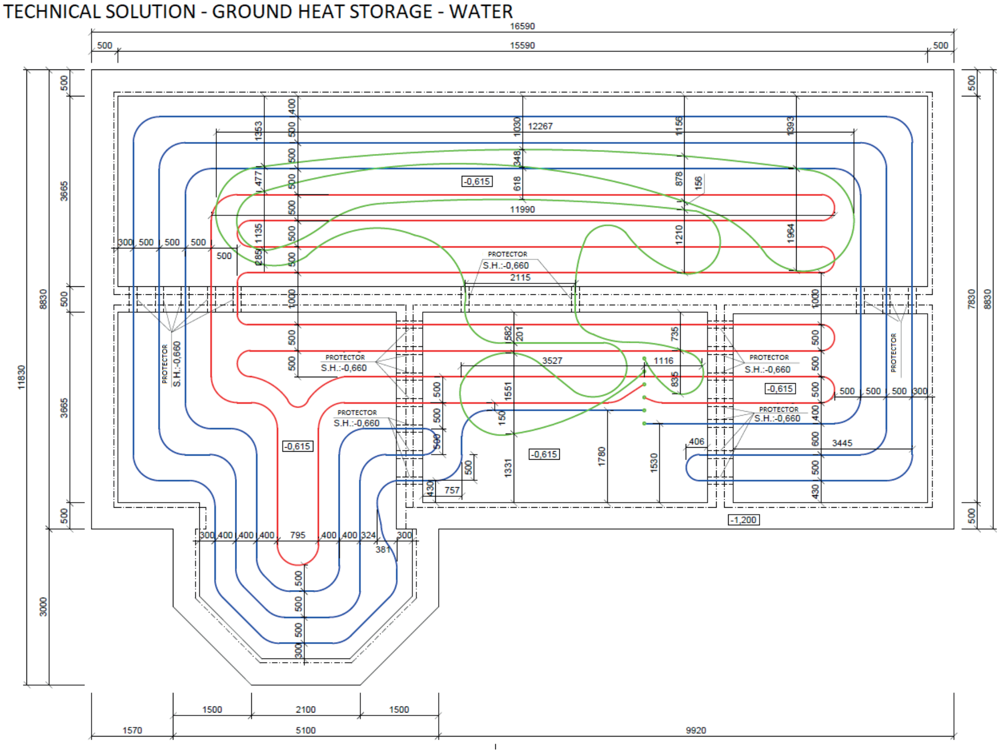

Fig. 13 View of the ground heat storage under the foundation slab. The pipes marked in red and blue are circuits for the accumulation of captured heat from the energy roof, the pipes marked in green are used for preheating hot water [2]

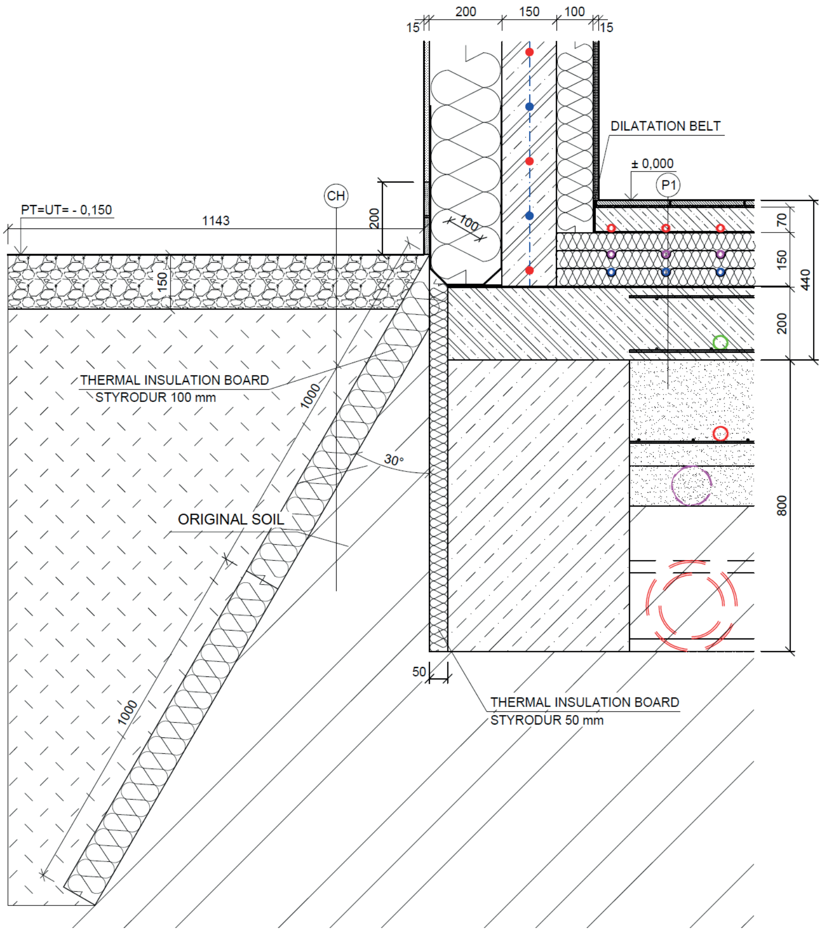

Fig. 14 Detail of the construction solution of the ground heat storage thermal insulation [2]

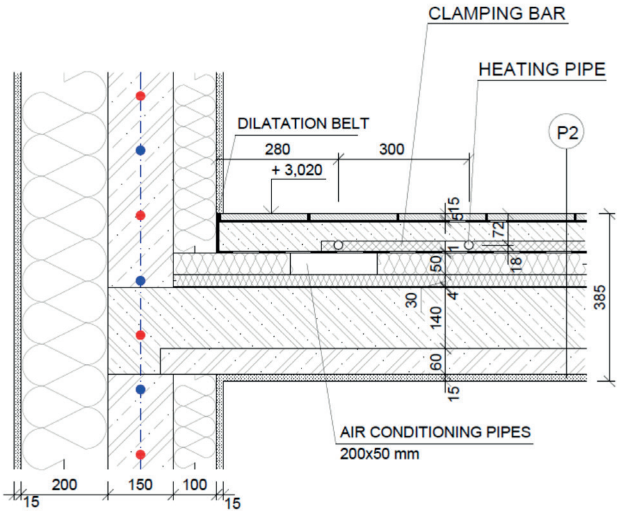

Fig. 15 Detail of the location of the floor heating pipes and the thermal barrier [2]

operation of all heat/cooling sources and energy systems. Another task was to innovate the design of the envelope panel with active thermal protection, eliminate the shortcomings of the technical solution of the ISOMAX panel, and adapt as many components as possible to the prefabrication.

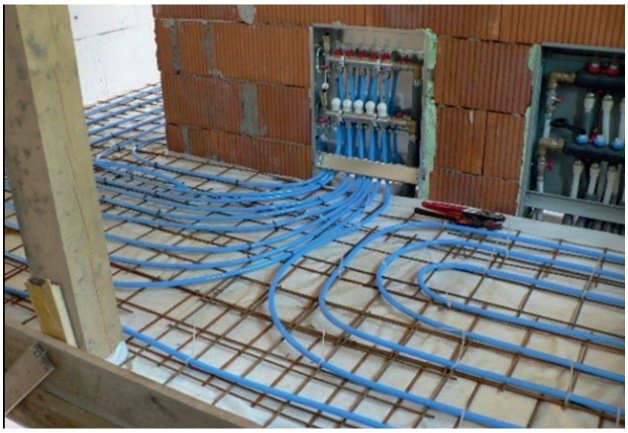

Fig. 16 View of the distributor and collector of the underfloor heating (Photo archive: Kalús, D.) [2]

4.1 Variants of complex functional wiring schemes

The analysis of the implemented buildings with the ISOMAX system has shown that a stable peak heat/cooling source is also needed. The energy systems (heating, cooling, domestic hot water, and ventilation) are not dependent on variable, unstable, hardly predictable solar and geothermic energy stored in large-capacity heat

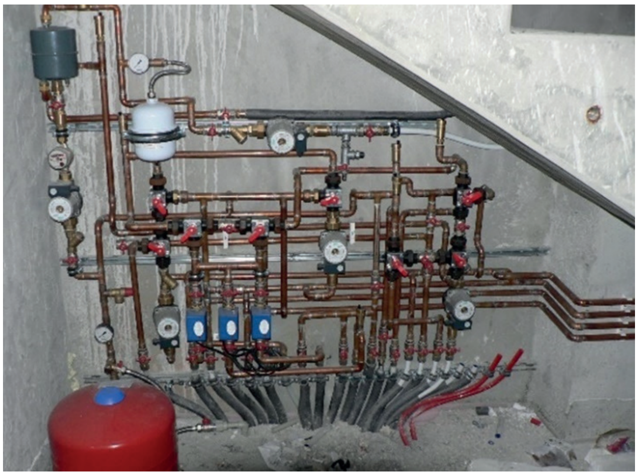

Fig. 17 View of the complex connection of the combined building-energy system (Photo archive: Kalús, D.) [2]

Fig. 18 Fabrication of the stainless-steel pipe-in-pipe heat exchanger on site (Photo archive: Kalús, D.) [2]

storage, especially in the GHS and ground cooling circuits. To ensure reliable, economical, and comfortable operation of the individual energy systems of the building, we have modernized this original method and developed examples of the implementation of technically innovative solutions for the mode of operation and variants of complex functional measurement and control schemes for the interconnection of all energy systems, which, in synergy with the building control system, optimize the mode of operation in buildings using combined building-energy systems.

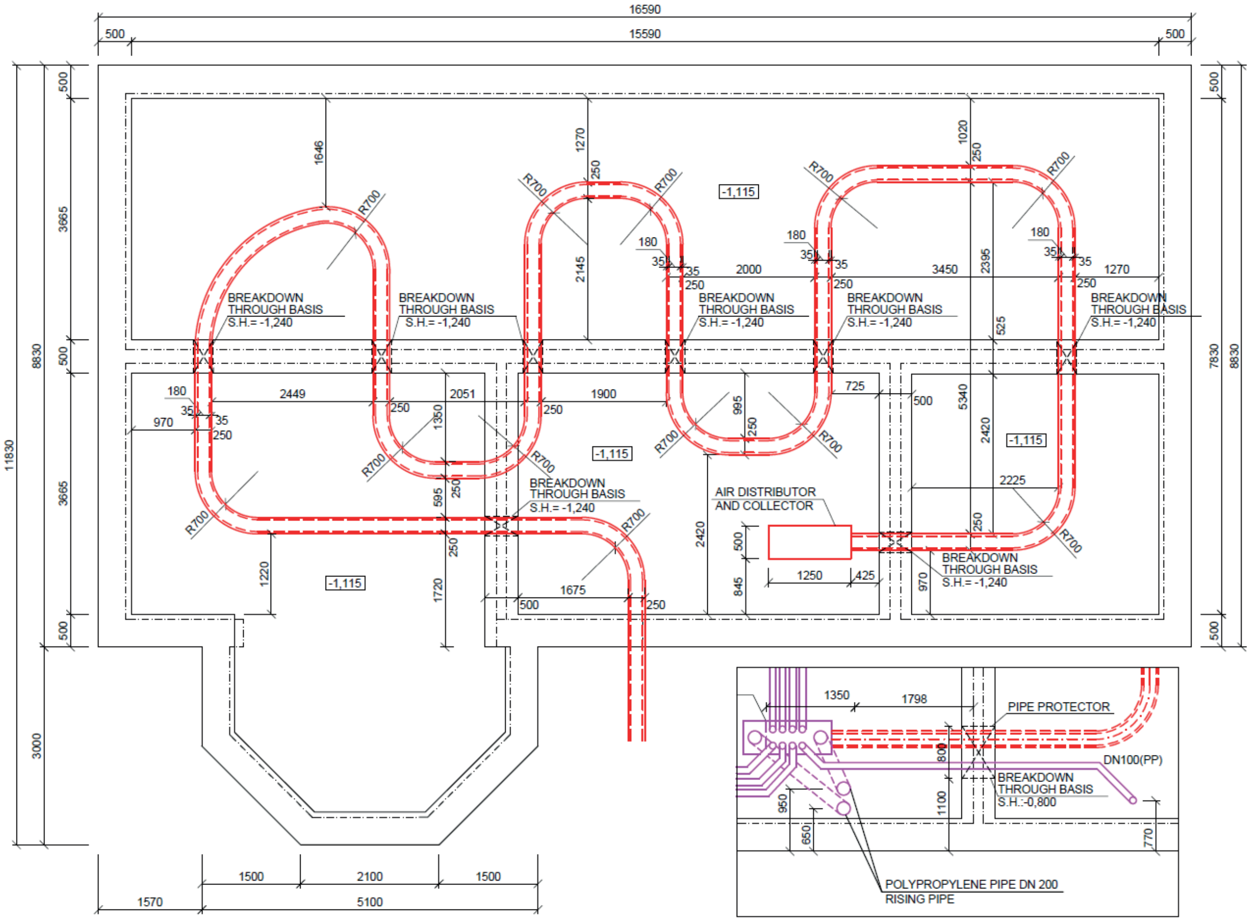

Fig. 19 Design of the heat recovery heat exchanger pipe-in-pipe under the building [2]

Fig. 20 Excavation for cooling circuits and heat recovery heat exchanger pipe-in-pipe with forced ventilation - outside the building at a depth of 2 m (Photo archive: Kalús, D.) [2]

Fig. 21 Installation of piping system for preheating hot water (Photo archive: Kalús, D.) [2]

In the development of the design of the functional variants of the combined building-energy systems for the prototype of the prefabricated house IDA I, we have relied on the analysis of research studies of scientists from all over the world, we give only a few references [5–22].

In the variant technical solutions, we have added a peak heat/cooling source, a short-term heat/cooling storage, the possibility of using an air handling unit with heat recovery or adding a water/air heat exchanger to heat and cool the ventilation air, the addition of a photovoltaic system, a wind turbine, the possibility of using waste heat, and the addition of terminal elements for the heating, cooling, and ventilation systems. We have designed and defined the method of operation in different modes for the different energy systems. The principle diagram on which we based the development of the different variants of the functional wiring diagrams is shown in Fig. 23. Variant solutions are analyzed in detail in utility model SK 5749 Y1 [23].

In Section 3.2 we described the energy solution of the prototype prefabricated house IDA I, and Fig. 24 shows a simplified diagram of the heat/cooling sources and energy systems. Fig. 25 shows a variant of the comprehensive functional wiring diagram of a combined building-energy system, which includes alternative solutions for peak heat sources such as a heat pump and a fossil-fuel boiler.

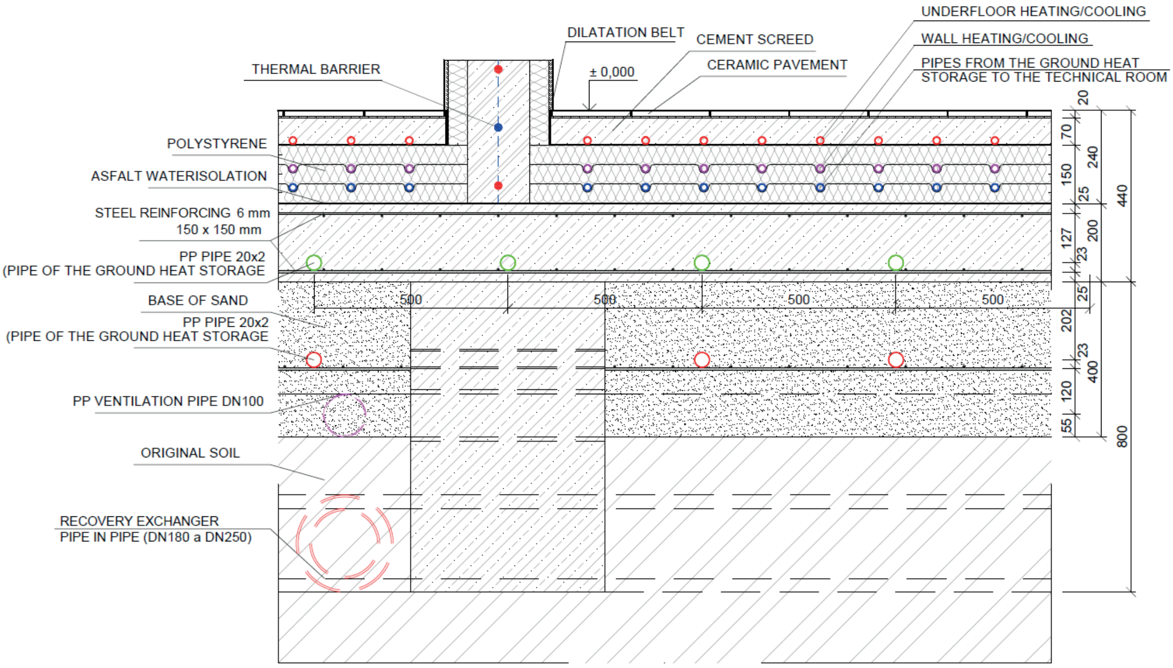

Fig. 22 Detail of the layout of the piping systems in the ground source heat storage tank (under the base plate and in the base plate) [2]

Fig. 25 is the result of long-term research showing variant solutions applicable to RES buildings, which is part of the utility model SK 5749 Y1 [23].

4.2 Innovation of thermal barrier panels

We published a detailed description of the research and development of an innovative panel with embedded energy-active elements in the function of a thermal barrier [24]. In this section, we summarize the most important results of our research.

The laborious and lengthy production of ISOMAX panels, which requires a gradual implementation of the site-concreting, appears to be disadvantageous and impractical. Another problem is the complication of the even placement of the tubes in the center of the load-bearing reinforced concrete wall and the compaction of the cast-in-place concrete itself. The lost formwork cannot be poured over the entire height of the wall, resulting in cracks and misalignment of the individual concrete layers along the height of the wall. After analysis with the structural engineer and technologist, we proposed to remedy these problems by prefabricating the individual panels in the prefabrication plant using vibrating tables and applying the finished panels to the building structure, Fig. 26 [24].

Fig. 23 Variants of power equipment cooperation in different modes of operation. (The legend to the figures is given in the caption in Fig. 25)

The design of the innovative panel with a thermal barrier was subjected to energy analysis, and in terms of the requirements for reducing the energy demand for heating, we proposed its structural solution with thermal insulation of expanded polystyrene on the inside with a thickness of 100 mm and on the outside with a thickness of 200 mm.

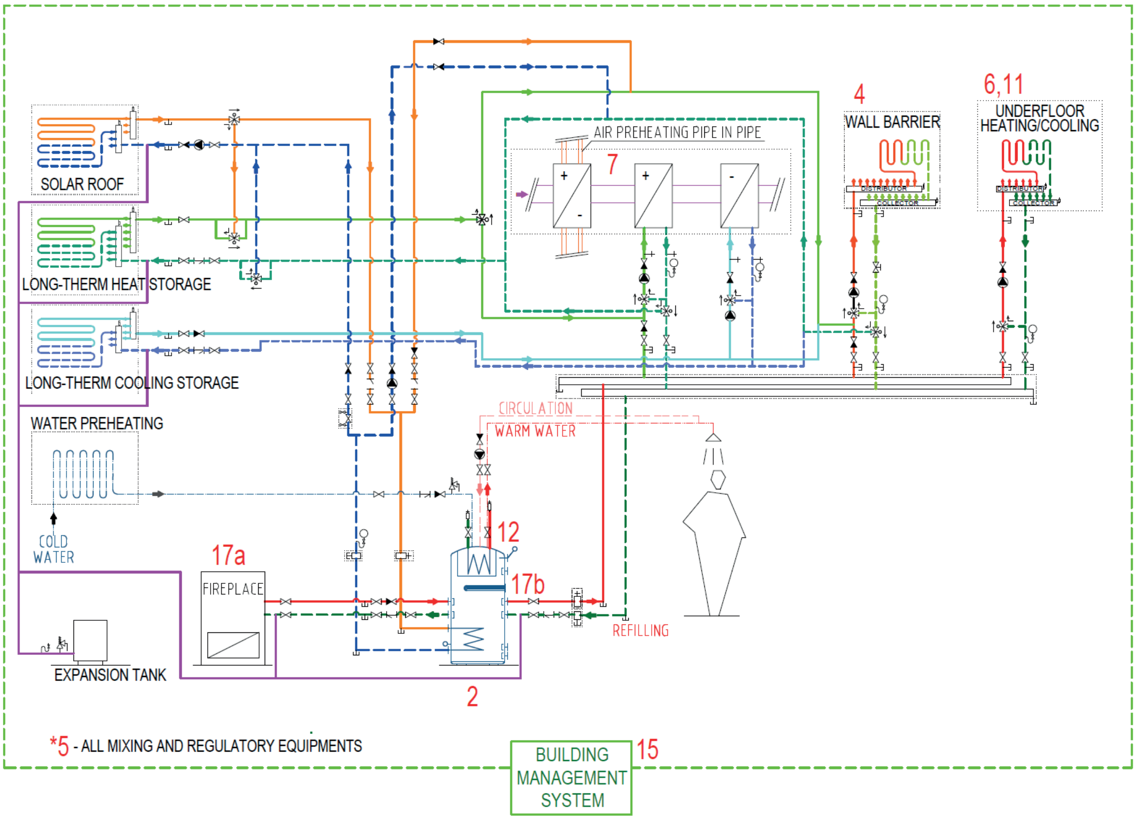

Fig. 24 Simplified wiring diagram of the technical solution of the energy systems of the IDA I. prefabricated house prototype. (The legend of the figures is given in the caption in Fig. 25) [2]

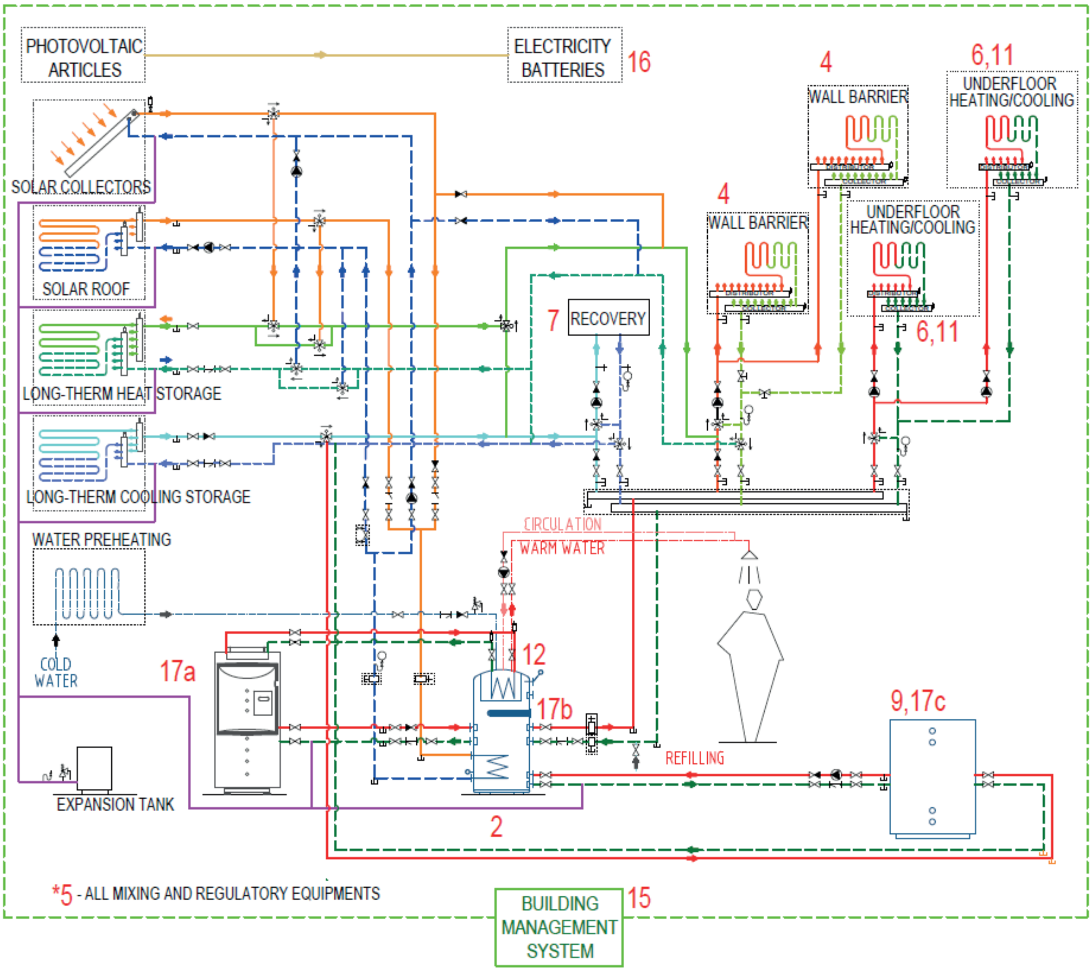

Fig. 25 Comprehensive functional wiring diagram of a combined building-energy system, which includes alternative solutions for peak heat sources such as a heat pump and a fossil-fuel boiler [2]

1 - solar absorber (energy roof, solar collector, etc.), 2 - short-term heat storage, 3 - long-term heat storage, 4 - active thermal protection circuits (building structure with an internal heat source), 5 - mixing and control equipment, 6 - low-temperature heating circuits, 7 - heat recovery ventilation equipment, 8 - cooling circuits located in the ground outside the building, 9 - peak cooling source, 10 - short-term cold storage, 11 - high-temperature cooling circuits, 12 - waste heat from the drainage system, 13 - waste heat from the technological process, 14 - electricity generation equipment (photovoltaics, wind power plant, etc.), 15 - building control system, 16 - batteries for storing the generated electricity, and others, 17 - top heat source

Fig. 26 A view of the beginning of the installation of panels with integrated energy-active elements in the function of a thermal barrier [2]

The central static part of the panel, consisting of reinforced concrete with integrated PP-20/2 tubes at an axial distance of 100 to 250 mm apart, remained unchanged with a thickness of 150 mm [24].

Fig. 27 shows the isotherms characterizing the heat transfer through the ISOMAX panel structure and our proposed panel structure during the heating period (winter). The heat savings/loss of these structures is expressed by the area between the isotherms. The area above the isotherms when heated to a thermal barrier temperature equal to the interior temperature of 20 °C expresses the energy-saving potential [24].

The technical design of the envelope panels with integrated energy-active elements in the central load-bearing part of the structure, insulated on both sides, performs the

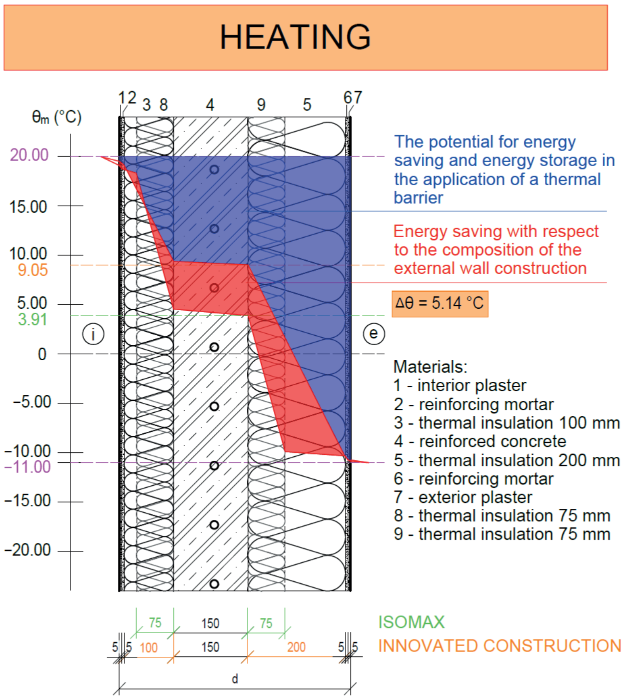

Fig. 27 Energy saving potential of the ISOMAX panel and the upgraded panel design in the heating period.
θ_m - the temperature between the load-bearing layer and the thermal insulation layer of the building structure, $\Delta\theta$ - temperature difference, *i* - interior, *e* - exterior

function of a large-capacity heat/cooling storage in addition to the function of a thermal barrier. The accumulated heat/cool significantly influences the heat/cool transfer through the building structure. When implementing this type of panel, it is important that the load-bearing part is thermally well conductive and forms a uniform thermal layer = thermal barrier, while at the same time having the highest possible heat/cold storage capacity. A modernized envelope panel design with a greater thickness of thermal insulation, especially on the outside, is justified and important from energy, economic and environmental point of view [24].

Our design of the envelope panel exhibits approximately 2.6 times lower specific heat loss from the thermal barrier to the exterior at a mean heat transfer fluid temperature of 20 °C than the ISOMAX system wall [24].

The parametric study and energy analysis show that, for example, an average temperature of θ_{TB} (°C) = +15 °C in the thermal barrier layer of upgraded panel design during heating represents the equivalent thermal resistance Requivalent ((m^{2}K)/W) or the equivalent heat transfer coefficient Uequivalent (W/(m^{2}K)) of the panel - as would be achieved with a 500 mm thick external thermal insulation. By analogy, this can be applied to the cooling period, where the mean temperature θ_{TB} (°C) = +27 °C in the thermal barrier layer, for a design indoor temperature of +26 °C and an outdoor temperature of +32 °C, for this panel design represents an external thermal insulation thickness of 500 mm [24].

4.3 Innovation of a forced ventilation method

The use of geothermic energy for an ISOMAX (pipe-in-pipe) air heat exchanger without a peak heat or cold source is uncertain, unstable, and difficult to predict, which is influenced by several factors (change in outdoor temperatures, groundwater level fluctuations, different soil composition, etc.). For this reason, we propose to install a water/air heat exchanger in the distributor chamber and a collector of the ground heat recovery air exchanger, which will heat or cool the supply air to the rooms of the building according to the actual requirements, Fig. 28.

Fig. 28 shows the chamber of the air distributor and air collector for ventilation with heat recovery with an installed water/air exchanger. No additional air handling unit was used. The heat/cold exchange occurs between the supply and extracts air and the soil in which the pipe-in-pipe heat exchanger is located, Fig. 29. The movement of incoming and outgoing air is provided by fans. Superheating or aftercooling of the supply air is provided by a water heater/cooler located in the air distributor and air collector chamber. The heat source is a hot-water fireplace, an accumulation tank of heating water, or a solar roof. The source of cold is well water.

This exchanger can alternatively be installed in the ductwork. In terms of heat exchange between the ductwork and the adjacent soil, we propose to use spacer rings in the pipe-in-pipe ventilation system to ensure uniform airflow around the entire internal ductwork, Fig. 29(b).

5 Conclusions

The novelty of our research described in this study lies in the innovation of the original ISOMAX system operation mode in different modes for different energy systems. We have added peak heat/cooling sources, including other system components that work in conjunction with the building control system to optimize the mode of operation in the IDA I prototype prefabricated building. The energy systems we have designed represent variants of energy-safe and reliable technical building solutions compared to buildings with fossil fuel-based heat/cooling sources. We have proposed and defined innovative and original variants of the method of operation of combined building-energy sources of heat/cooling and energy systems, for which we

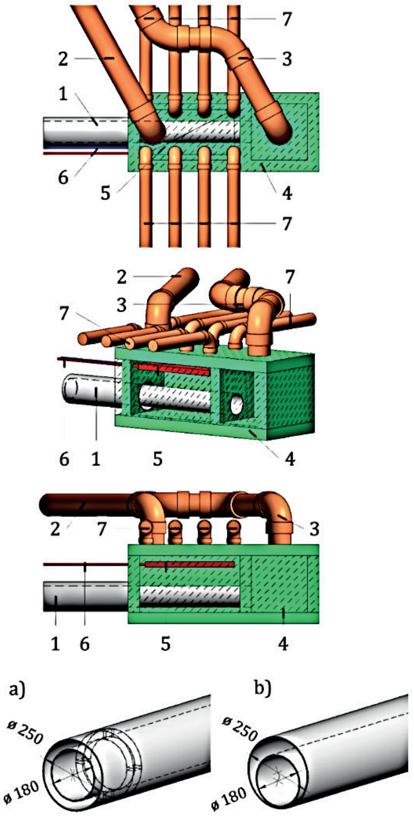

Fig. 28 Chamber of pooled air distributor and air collector for ventilation with heat recovery with installed water/air exchanger. 1 - heat recovery heat exchanger pipe-in-pipe, 2 - supply of treated air to the building, 3 - air exhaust from the building, 4 - chamber of the distributor and collector of ventilation air, 5 - liquid heat exchanger of water-air type, 6 - supply and return of the heat transfer medium, 7 - supply pipes of treated air on the first floor.

have created variants of wiring diagrams. We have innovated the construction of the perimeter panel with active thermal protection and the method of ventilation with heat recovery in the pipe-in-pipe heat exchanger. Partial results of our research have been published in several scientific articles and are also part of three utility models (UM SK 5749 Y1 [23], UM SK 5729 Y1 [25], UM SK 5725 Y1 [26]) and one European patent (EP 2 572 057 B1 [27]).

The objectives of our further research are to:

1. Develop further design variants of thermal insulation envelope panels with integrated energy-active elements.
2. Develop a methodology for the installation of envelope panels with ATP.
3. Implement selected types of perimeter thermal insulation panels with integrated energy-active elements on a laboratory building.
4. Apply the proposed calculation methodology, selection, and assessment for selected combined building-energy systems using RES in buildings.

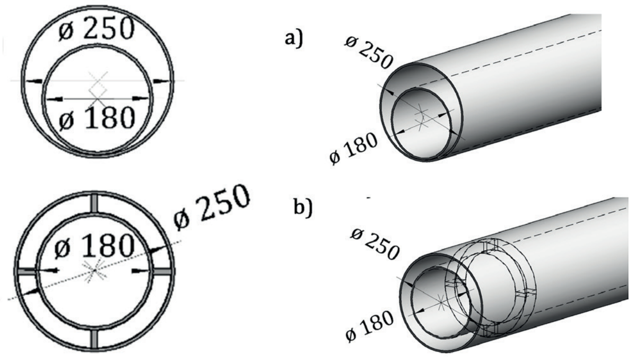

Fig. 29 Installation view of a pipe-in-pipe heat recovery air exchanger a) ISOMAX solution, b) Innovative solution with spacer rings

5. Conduct experimental measurements of selected types of building envelope thermal insulation panels with integrated energy-active elements using RES as part of a laboratory building object in different operating modes.
6. Measure usable energy of selected types of thermal insulation panels with integrated energy-active elements using RES in the application of active thermal protection in the functions of thermal barriers, cooling, and preparation of TV or heating water.
7. Measure the efficiency of selected types of thermal insulation panels with integrated energy-active elements using RES in the application of active thermal protection for the elimination of overheating of the envelope and the interior depending on the intensity of solar radiation, shading, and the outdoor temperature.
8. Develop software for designing, calculating, and assessing envelope thermal insulation panels with integrated RES-using active elements.
9. Develop a methodology for applying building envelope thermal insulation panels with integrated RES energy components in a building information modeling (BIM) model.
10. Ensure the automated transfer of the proposed database of envelope thermal insulation panels with integrated energy-active elements using RES to the BIM model.
11. Verify the proposed solution on a concrete building project created in the BIM model.

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