Improvement of the energy performance of elementary school Ćele kula in Niš by applying passive solar design systems

POBOLJŠANJE ENERGETSKIH PERFORMANSI OSNOVNE ŠKOLE ĆELE KULA U NIŠU PRIMENOM SISTEMA PASIVNOG SOLARNOG DIZAJNA

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Introduction

- **The need for primary energy** has almost tripled in the past 30 years
- **It is possible to make the necessary adaptations of the existing construction fund** because of the great potential for energy savings
- **The current state of energy efficiency in Serbia in the field of public buildings** gives a lot of opportunities for improvement and energy savings
- **The lack of reliable information related to the technical characteristics of the buildings,** the way they are used, poor information and motivation of their users for improving energy efficiency makes current situation complicated

Introduction

- **The aim of this study** is to develop and determine the optimal model of energy rehabilitation in the process of comprehensive revitalization of existing facilities of primary schools by implementing passive solar design strategies, as well as their application in local climatic conditions
- In addition to the **literature review**, **modeling method based on computer simulation of the existing building** of primary school has been used

Passive solar improvement measures

- **Passive solar design is based on spontaneous natural processes that do not use expensive technological solutions and mechanical systems for their functioning**
- **Almost all developed countries have more or less extensive solar energy development programs**. Some even have solar energy commissions, the highest ranks, equal to the commissions for nuclear energy
- Passive solar design is extremely important and is defined as: "**Systems that collect, store and redistribute solar energy without the use of mechanical systems**"

Passive solar improvement measures

- **Awareness of the importance of improving energy performance** is known to the general public, and the main question is **how much isolation is sufficient and whether there are some systems that would provide internal comfort without additional energy consumption**
- **Passive use of solar energy is the basic and cheapest way to use energy from the environment**

Double skin facades

- The **Double skin façade (DSF)** is a system of building consisting of two skins, or facades, placed in such a way that air flows in the intermediate cavity. The ventilation of the cavity can be natural, fan supported or mechanical.
- **The behavior of the double skin façade is directly related to orientation and climatic conditions**, and in general, it can be said that the greater the sun's radiation and the surrounding air temperature, the greater the final energy savings in the open ventilated facades
- **The application of the double skin facade** system is proved to be justified for the climatic conditions of Serbia

Trombe wall

- A **Trombe wall (TW)** is a passive solar building design where a wall is built on the winter sun side of a building with a glass external layer and a high heat capacity internal layer separated by a layer of air.
- **Trombe wall** is proven to be an appropriate solution for passive use of energy for the current ecological and energy crisis
- **Any materials that have a high thermal capacity can be used in the Trombe wall**. The high degree of heat accumulation has concrete, stone, earth, but also water, so they are most suitable for making such heating elements
- The use of double instead of single glazing for the Trombe wall system not only reduces thermal losses in winter but also improves passive cooling in summer

Green roof

- **A green roof (GR) or living roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems**
- **The higher the ratio of the roof surface to the surface of the entire building envelope, the greater the potential energy losses**
- Compared to conventional roofs (CR), **green roofs improve building performance and reduce energy consumption for heating the building**
- Sailor developed the physical model of the energy balance of the green roof and integrated it into the energy building simulation program - EnergyPlus (**EcoRoof**)
- **This model of green roof enables the use of energy modeling to study the design options for green roofs, including the thermal properties and depth of the substrate, as well as the vegetation characteristic (types of plants, supstrat height and leaf area index - LAI).** It is obvious that this method of simulating green roofs can significantly contribute in further information and decision-making related to the design of green roofs

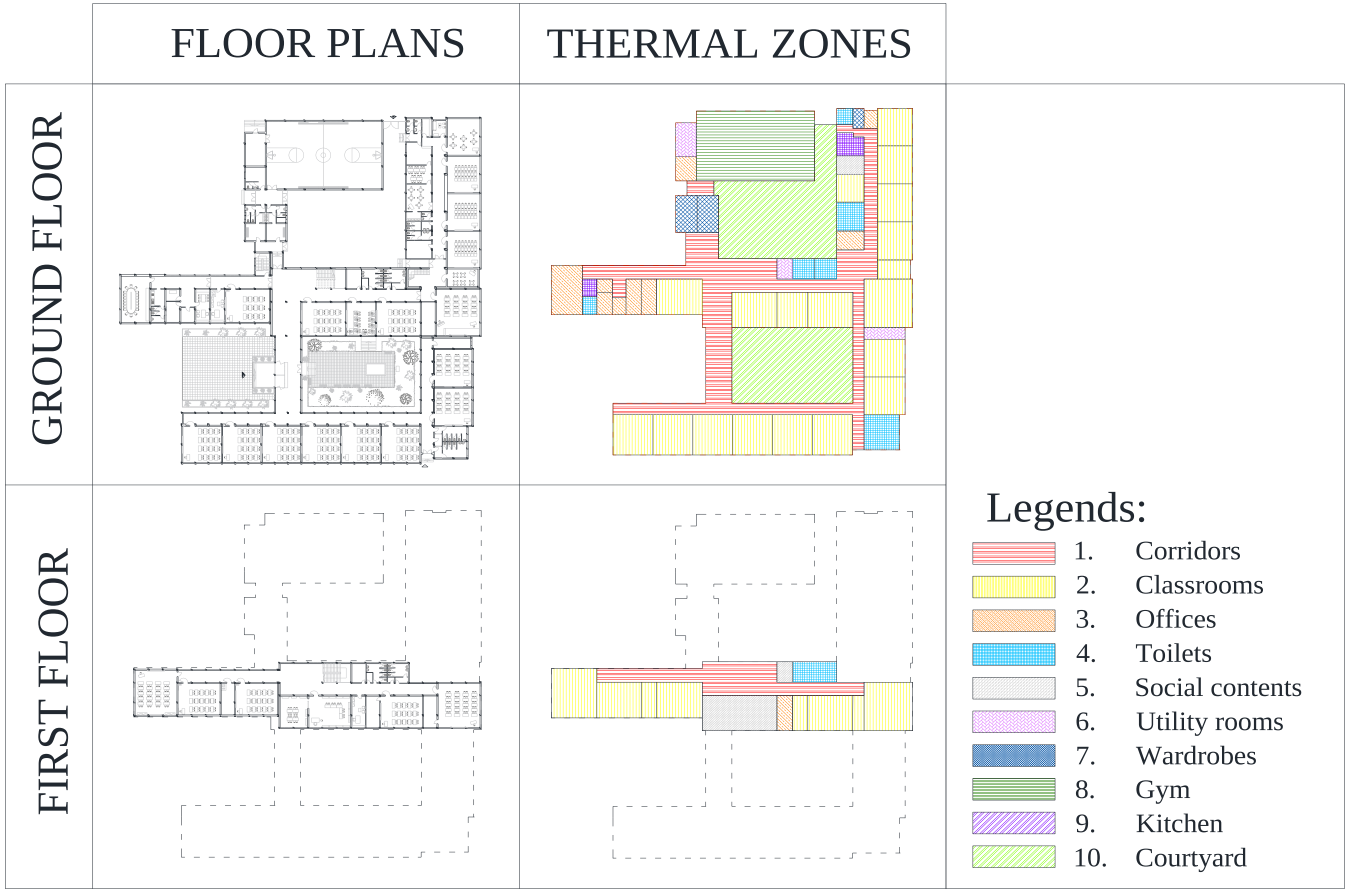
Case study analysis and implementation of passive solar design strategies

- **The largest number of existing educational buildings on the territory of southeastern Serbia is obsolete in terms of energy efficiency**
- Based on the case study of the representative Primary school in the city of Niš, the following steps were undertaken:
  - Identification of a representative example of the elementary school building in the city of Niš and a brief presentation of its technical characteristics,
  - Definition of the possible levels of energy efficiency improvement by applying passive design principles

Structure of the existing thermal envelope - prior to energy performance improvement

- **Elements of the envelope structure of existing primary school Ćele** kula do not meet the regulations in terms of maximum permissible values of thermal transmittance coefficients (for walls and bottom floor Umax=0.3 $Wm^{-2}K^{-1}$, for a flat roof Umax=0.15 $Wm^{-2}K^{-1}$, for the glazed part of the façade Umax=1.5 $Wm^{-2}K^{-1}$). The structure of the building is made of the following materials (inside to outside):
  - **Default Exterior walls:** mortar 1,5cm thick, brick 25cm thick, elasticated polystyrene 5cm thick and Finishing Mortar 2,5cm thick. Thermal transmittance coefficient U=1,072 $Wm^{-2}K^{-1}$.
  - **Default Flat roof:** mortar 2cm thick, hollow clay block for interfloor and attic construction – MONTA 16cm thick reinforced concrete 4cm thick, layer for inclination 5cm thick, vapor dam 0,5cm thick, elasticated polystyrene 10cm thick, PVC soft foil 0,01 cm thick, bitumen roofing paper 1,3cm thick, dry sand 4cm thick, dry gravel 2,5cm thick. Thermal transmittance coefficient U=0,306 $Wm^{-2}K^{-1}$.
  - **Default Floor:** Granite ceramics 1,5cm thick, elasticated polystyrene 8cm thick, reinforced concrete 10cm thick. Thermal transmittance coefficient U=0,380 $Wm^{-2}K^{-1}$.
  - **Default Windows:** The windows on the building are made of PVC, with double glazing and air between the glass panes (4-12-4), with no screens or rolling shutters. U-Factor 1,9 $Wm^{-2}K^{-1}$, Solar Heat Gain Coefficient 0,63

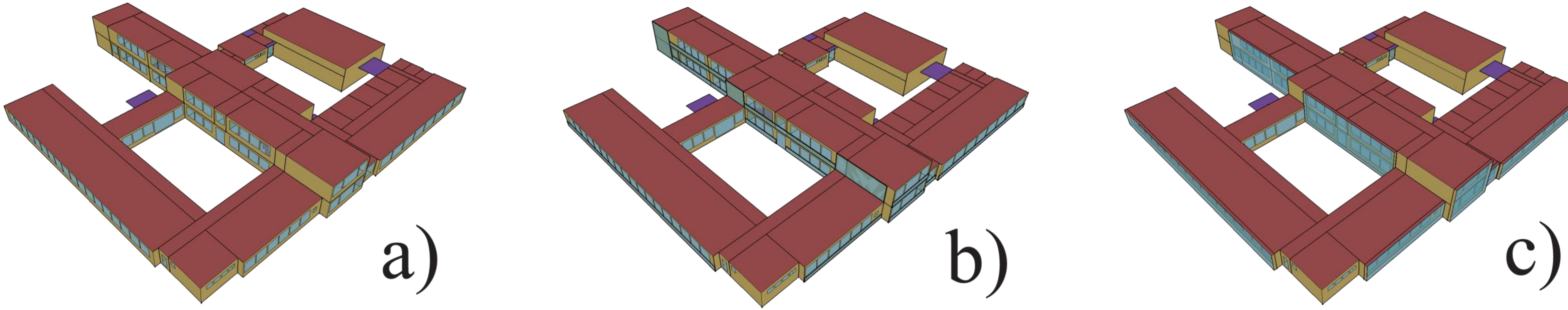
Simulation



Modeled floor plans and thermal zones of primary school Ćele kula are shown.

As we can see on this figure, ground floor and first floor plan are divided into different thermal zones based on space types

Simulation



Appearance of 3D models of Primary school: a) Basic model; b) Model with implemented Trombe Wall on parapet walls; c) Model with implemented Double skin facade

Simulation

- The simulations were conducted for a **run period of one school year** (the months of July and August were not taken into account).
- **The largest heat losses occur through the building envelope**. In the performed simulations, we start from the assumption that constant internal temperature is maintained in each zone (in the winter mode - 20°C, in the summer mode 26°C). **An ideal HVAC system** (the IdealLoadsAirSystem) has been adopted to provide thermal comfort in the modified thermal zones, enabling each zone to deliver the energy required in a given moment
- **The internal gains are determined by the number of students and teachers and electrical equipments**
- **For various space types different number of people are defined, as well as adequate degree of their activity and their presence during the day**

Parametric simulation and optimization of the working model

- **Energy rehabilitation was carried out by intervention on transparent and non-transparent surfaces of the thermal envelope**. In general, the intervention for the purpose of energy performance improvement is based on correcting the existing values of the coefficient of heat transfer U (W/m^2K) of the analyzed elements of the thermal building shell on the prescribed rules
- **Simulations were conducted using software packages SketchUp and EnergyPlus**

Parametric simulation and optimization of the working model

- The analysis includes seven variant solutions for rehabilitation according to the principle, method and scope of intervention:

  Variant I: Basic model of the existing Primary school Ćele kula in Niš.

  Variant II: Energy performance improvement is done by increasing the thickness of the thermal insulation layer of the building elements of the corresponding non-transparent part of the thermal envelope to satisfy the conditions ≤ U_{max} (W/m^2K) for the existing building, while the transparent part of the envelope corrects the prescribed value of the heat transfer coefficient U_{max}=1,5 W/m^2K.

  Variant III: Variant II, as well as the implementation of green instead of a conventional roof.

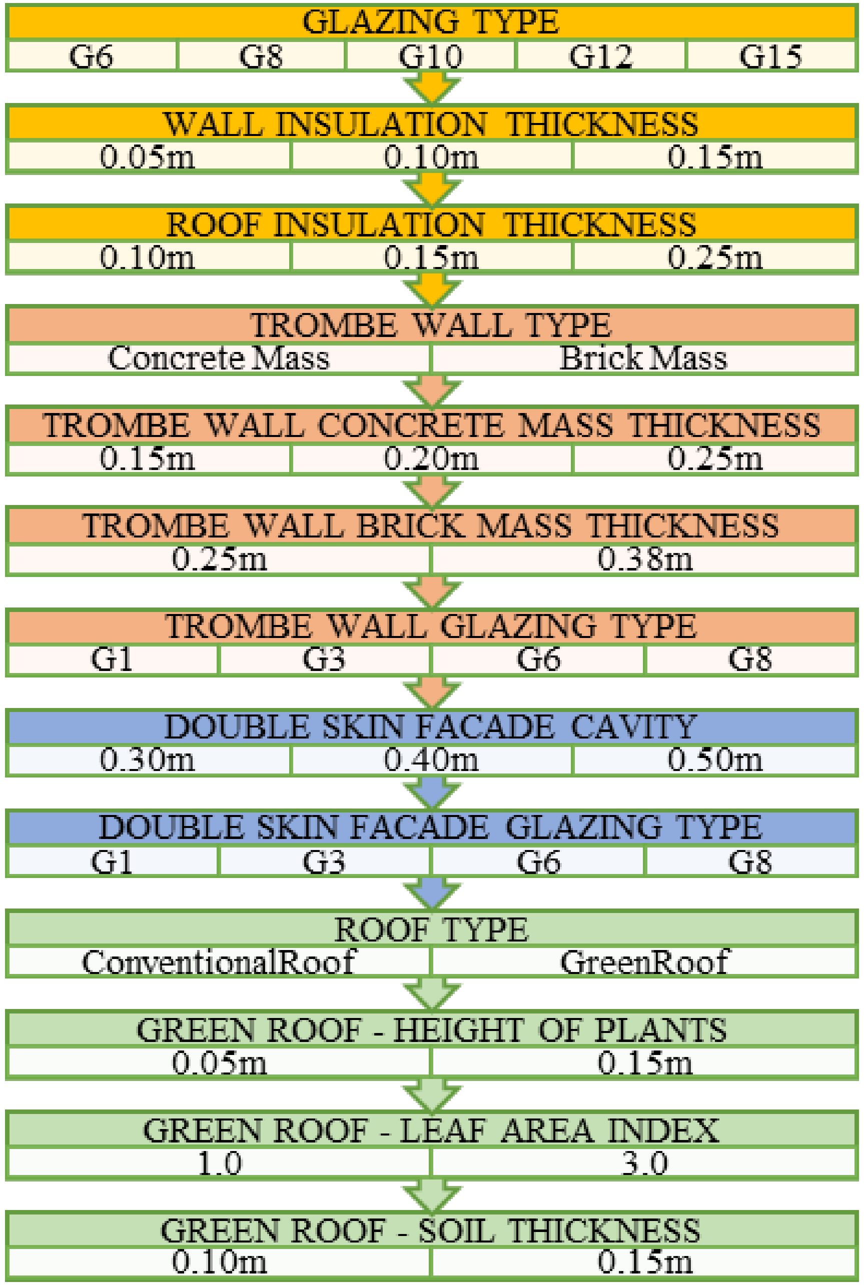
  Variant IV: Variant II with the implementation of the Trombe wall in the parapet of the walls of predominantly south-oriented classrooms

  Variant V: Variant IV, as well as the implementation of green instead of a conventional roof.

  Variant VI: Variant II with the implementation of Double skin facade.

  Variant VII: Variant , as well as the implementation of green instead of a conventional roof

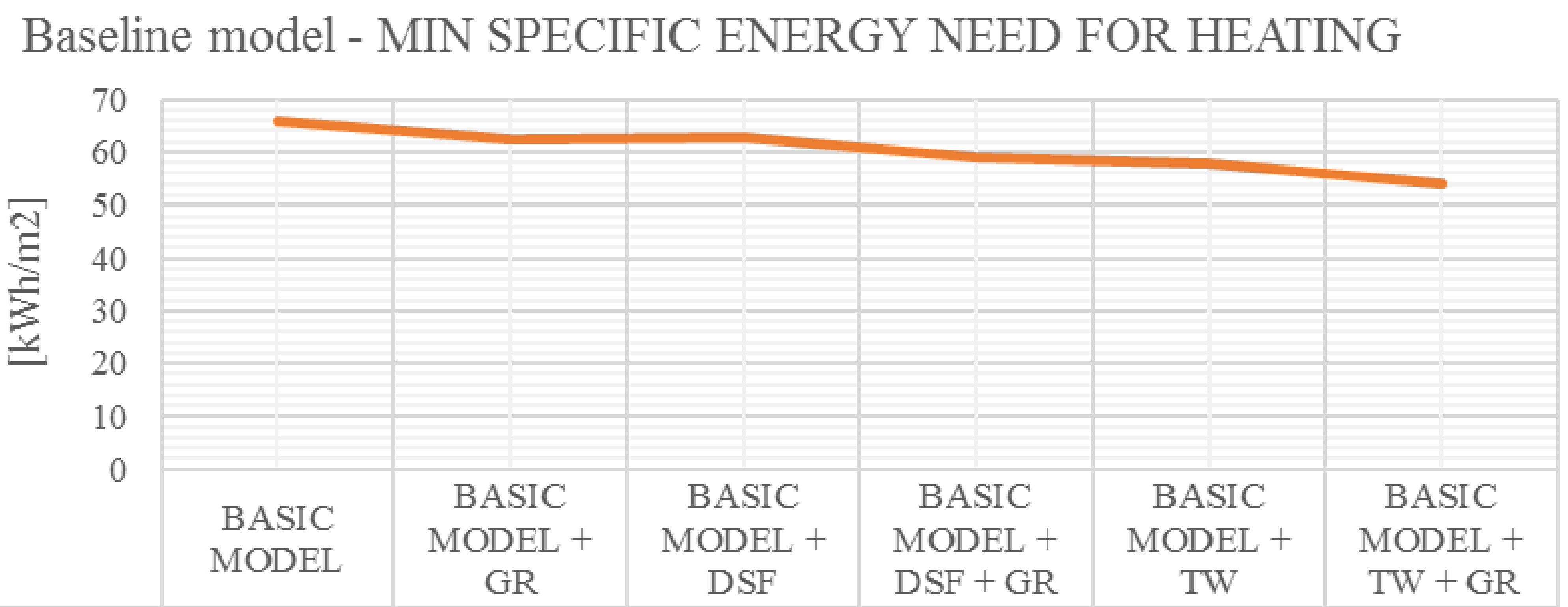
Parametric simulation and optimization of the working model – **PARAMETRIC TREE**



Results and discussion

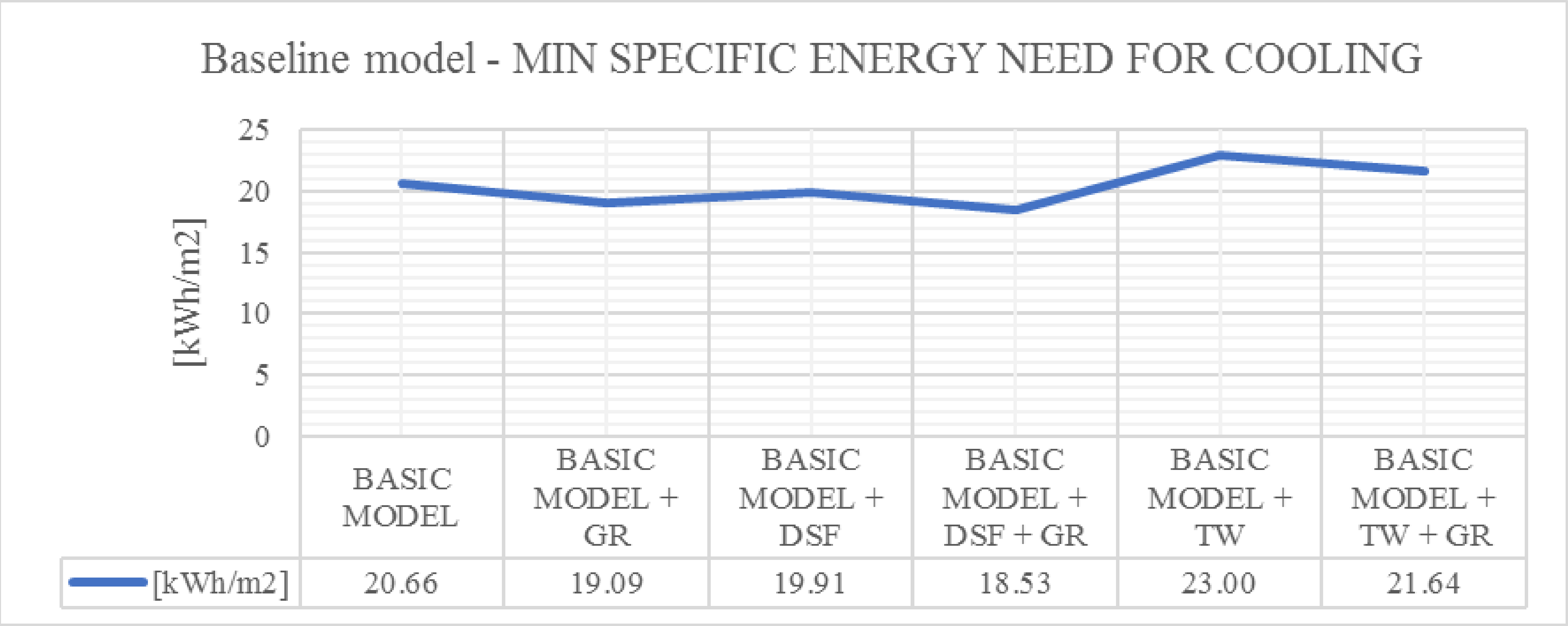
- **Implementation of passive solar design strategies can lead to significant savings**
- It is also shown **the possibility of implementing a green roof, double skin facade or trombe wall, as well as their combination on the existing model without improving its performance in any other way**
- **Following graphs show the least specific energy needs for heating and cooling for the basic and retrofitted model variants**

Results and discussion

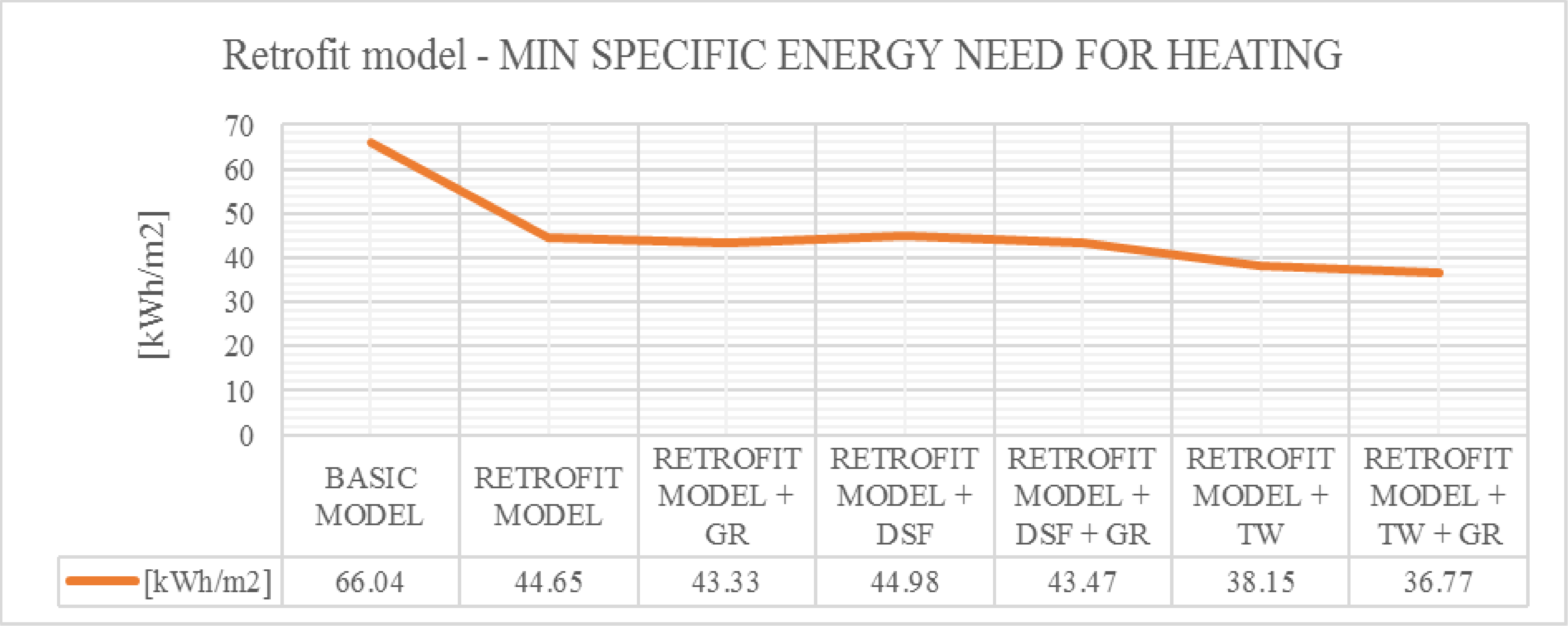


	BASIC MODEL	BASIC MODEL + GR	BASIC MODEL + DSF	BASIC MODEL + DSF + GR	BASIC MODEL + TW	BASIC MODEL + TW + GR
[kWh/m2]	66.04	62.62	62.92	59.11	57.87	54.25

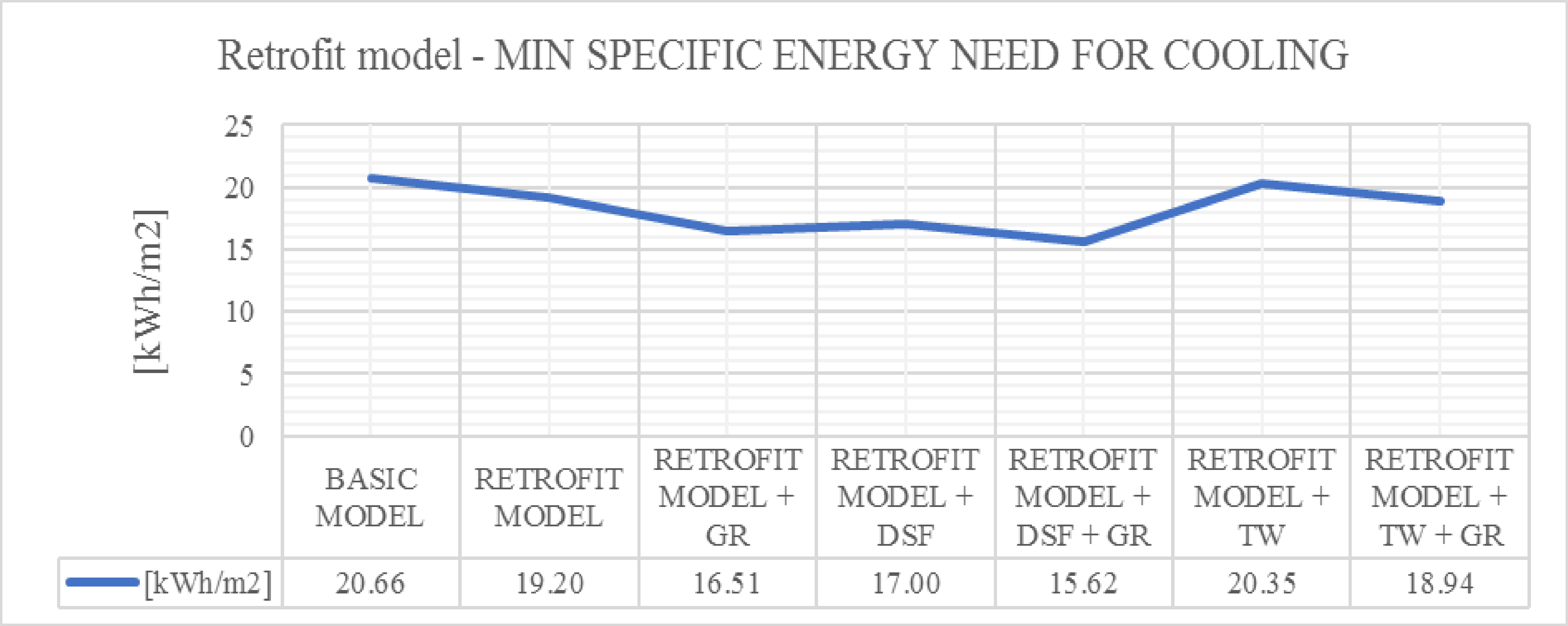
Results and discussion



Results and discussion



Results and discussion



Results

SIMULATION NUMBER	COMMENT	WALL_THICK [m]	WALL_INS_THICK [m]	ROOF_INS_THICK [m]	GLAZ_TYPE	TW_GLAZ_TYPE	TW_TYPE	TW_CONCRETE_THICK	DSF_GLAZ_TYPE	DSF_CAVITY [m]	ROOF_TYPE	HOP [m]	LAI	SOIL_THICK [m]	SPEC. HEAT. ENERGY [kWh/m2]	SPEC. COOL. ENERGY [kWh/m2]	SAVINGS - HEATING[%]	SAVINGS - COOLING[%]
1	BASIC MODEL	0.25	0.05	0.1	G6g	-	-	-	-	-	CR	-	-	-	66.04	20.66	0.00%	0.00%
10	RETROFIT MODEL	0.25	0.05	0.15	G15g	-	-	-	-	-	CR	-	-	-	56.21	18.13	14.88%	12.26%
44	RETROFIT MODEL	0.25	0.15	0.25	G12g	-	-	-	-	-	CR	-	-	-	45.90	23.52	30.50%	-13.81%
45	RETROFIT MODEL	0.25	0.15	0.25	G15g	-	-	-	-	-	CR	-	-	-	44.65	19.20	32.40%	7.09%
46	BASIC + GR	0.25	0.05	0.1	G6g	-	-	-	-	-	GR	0.05	1	0.1	62.97	20.81	4.66%	-0.70%
47	BASIC + GR	0.25	0.05	0.1	G6g	-	-	-	-	-	GR	0.05	1	0.15	62.62	20.73	5.18%	-0.32%
52	BASIC + GR	0.25	0.05	0.1	G6g	-	-	-	-	-	GR	0.15	3	0.1	63.68	19.11	3.57%	7.51%
53	BASIC + GR	0.25	0.05	0.1	G6g	-	-	-	-	-	GR	0.15	3	0.15	63.37	19.09	4.04%	7.60%
85	RETROFIT + GR	0.25	0.05	0.1	G15g	-	-	-	-	-	GR	0.15	3	0.15	56.45	16.51	14.53%	20.07%
390	RETROFIT + GR	0.25	0.15	0.25	G12g	-	-	-	-	-	GR	0.05	1	0.1	44.64	23.63	32.41%	-14.36%
399	RETROFIT + GR	0.25	0.15	0.25	G15g	-	-	-	-	-	GR	0.05	1	0.15	43.33	19.24	34.40%	6.89%
406	BASIC + DSF	0.25	0.05	0.1	G6g	-	-	-	G1g	0.3	CR	-	-	-	63.38	22.11	4.04%	-6.99%
411	BASIC + DSF	0.25	0.05	0.1	G6g	-	-	-	G3g	0.5	CR	-	-	-	64.11	20.47	2.93%	0.94%
414	BASIC + DSF	0.25	0.05	0.1	G6g	-	-	-	G6g	0.5	CR	-	-	-	64.07	19.91	2.98%	3.65%
415	BASIC + DSF	0.25	0.05	0.1	G6g	-	-	-	G8g	0.3	CR	-	-	-	62.92	20.62	4.73%	0.19%
922	RETROFIT + DSF	0.25	0.15	0.25	G12g	-	-	-	G1g	0.3	CR	-	-	-	45.98	23.03	30.39%	-11.48%
934	RETROFIT + DSF	0.25	0.15	0.25	G15g	-	-	-	G1g	0.3	CR	-	-	-	44.98	19.19	31.89%	7.14%
942	RETROFIT + DSF	0.25	0.15	0.25	G15g	-	-	-	G6g	0.5	CR	-	-	-	46.44	17.00	29.68%	17.72%
946	BASIC + DSF + GR	0.25	0.05	0.1	G6g	-	-	-	G1g	0.3	GR	0.05	1	0.1	59.91	22.65	9.28%	-9.61%
992	BASIC + DSF + GR	0.25	0.05	0.1	G6g	-	-	-	G3g	0.5	GR	0.15	3	0.1	61.46	19.10	6.93%	7.56%
1017	BASIC + DSF + GR	0.25	0.05	0.1	G6g	-	-	-	G6g	0.5	GR	0.15	3	0.15	61.13	18.53	7.44%	10.32%
1019	BASIC + DSF + GR	0.25	0.05	0.1	G6g	-	-	-	G8g	0.3	GR	0.05	1	0.15	59.11	21.05	10.50%	-1.88%
4114	RETROFIT + DSF + GR	0.25	0.15	0.1	G12g	-	-	-	G1g	0.3	GR	0.05	1	0.1	48.24	23.49	26.96%	-13.71%
4281	RETROFIT + DSF + GR	0.25	0.15	0.1	G15g	-	-	-	G6g	0.5	GR	0.15	3	0.15	49.24	15.62	25.45%	24.41%
5171	RETROFIT + DSF + GR	0.25	0.15	0.25	G15g	-	-	-	G1g	0.3	GR	0.05	1	0.15	43.47	19.41	34.18%	6.06%
5266	BASIC + TW	0.25	0.05	0.1	G6g	G1g	TWbrickIN	-	-	-	CR	-	-	-	57.87	23.34	12.37%	-12.98%
5438	RETROFIT + TW	0.25	0.15	0.25	G12g	G1g	TWbrickIN	-	-	-	CR	-	-	-	39.65	26.53	39.96%	-28.41%
5442	RETROFIT + TW	0.25	0.15	0.25	G15g	G1g	TWbrickIN	-	-	-	CR	-	-	-	38.15	21.91	42.24%	-6.03%
5454	BASIC + TW	0.25	0.05	0.1	G6g	G6g	TWconcreteIN	0.25	-	-	CR	-	-	-	59.80	23.00	9.46%	-11.32%
5455	BASIC + TW	0.25	0.05	0.1	G6g	G8g	TWconcreteIN	0.15	-	-	CR	-	-	-	59.89	23.10	9.32%	-11.80%
5502	RETROFIT + TW	0.25	0.05	0.1	G15g	G6g	TWconcreteIN	0.25	-	-	CR	-	-	-	52.70	20.35	20.21%	1.50%
5986	BASIC + TW + GR	0.25	0.05	0.1	G6g	G1g	TWbrickIN	-	-	-	GR	0.05	1	0.1	54.57	23.90	17.37%	-15.69%
5987	BASIC + TW + GR	0.25	0.05	0.1	G6g	G1g	TWbrickIN	-	-	-	GR	0.05	1	0.15	54.25	23.80	17.85%	-15.20%
7042	RETROFIT + TW + GR	0.25	0.15	0.1	G12g	G1g	TWbrickIN	-	-	-	GR	0.05	1	0.1	41.74	26.94	36.80%	-30.38%
7395	RETROFIT + TW + GR	0.25	0.15	0.25	G15g	G1g	TWbrickIN	-	-	-	GR	0.05	1	0.15	36.77	22.17	44.32%	-7.31%
7497	BASIC + TW + GR	0.25	0.05	0.1	G6g	G6g	TWconcreteIN	0.25	-	-	GR	0.15	3	0.15	56.90	21.64	13.85%	-4.74%
7504	BASIC + TW + GR	0.25	0.05	0.1	G6g	G8g	TWconcreteIN	0.15	-	-	GR	0.15	3	0.1	57.27	21.75	13.28%	-5.26%
7881	RETROFIT + TW + GR	0.25	0.05	0.1	G15g	G6g	TWconcreteIN	0.25	-	-	GR	0.15	3	0.15	49.76	18.94	24.66%	8.32%

Conclusions

- **The goal of sustainability is to provide safe and sufficient energy supply while at the same time reducing the negative impact on the environment**
- **Reconstruction and re-use of buildings** is an important component in order to achieve the best possible results in improving the energy efficiency of the existing construction fund
- **The results of the performed simulations indicate a clear linear dependence of the heat loss effects across the building envelope**;
- **The observable trend of reducing energy consumption shows an obvious non-linearity**, which indicates the justification of doing such research in order to find the most optimal strategies for achieving the best results.

Conclusions

- **All results of this study were obtained for ideal simulation conditions**. Aggravating circumstances, which are inevitable in the actual conditions of exploitation of the building (negligence of the building user, reduction in the performance of applied materials over the years, etc.), are not taken into account
- **The practical applicability of the obtained results** is reflected in the establishment of methodological and systematic framework for the management of energy performance improvement measures in the process of comprehensive revitalization of primary schools
- **Increasing the energy efficiency of buildings does not always have to be based on monetary investments**, but also by conscientious and responsible behavior

THANK YOU!