INNOVATIONS – SUSTAINABILITY – MODERNITY – OPENNESS
ENERGY

edited by
Dorota Anna Krawczyk
Iwona Skoczko
Ewa Szatyłowicz

SERIES OF MONOGRAPHS

VOLUME 40

Bialystok 2020

FACULTY OF CIVIL ENGINEERING
AND ENVIRONMENTAL SCIENCES
BIALYSTOK UNIVERSITY
OF TECHNOLOGY

ASSOCIATION
OF SANITARY ENGINEERS
AND TECHNICIANS

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Printing House of Bialystok University of Technology
Bialystok 2020

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Technical editing, binding:
Printing House of Bialystok University of Technology

e-ISBN 978-83-66391-29-1 **DOI 10.24427/978-83-66391-29-1**

Faculty of Civil Engineering and Environmental Sciences
Bialystok University of Technology
45E, Wiejska Street
15-351 Bialystok
www.wb.pb.edu.pl

Association of Sanitary Engineers
and Technicians in Bialystok
2, M. C. Skłodowskiej Street
15-950 Bialystok
www.pzits.bialystok.pl

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Authors

Prof. Frida Bazzocchi – University of Florence, Faculty of Engineering, DICEA Department of Civil and Environmental Engineering

Research fellow Cecilia Ciacci, PhD – University of Florence, Faculty of Engineering, DICEA Department of Civil and Environmental Engineering

Assoc. Prof. Katarzyna Gładyszewska-Fiedoruk, PhD, Eng. – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Assoc. Prof. Dorota Anna Krawczyk, PhD, Eng. – Bialystok University of Technology, Faculty of Civil and Environmental Sciences

Assoc. Prof. Vincenzo Di Naso – University of Florence, Faculty of Engi-neering, DICEA Department of Civil and Environmental Engineering

Andrii Pushchinskyi, MSc Eng – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Monika Šadauskaitė – Kaunas University of Technology Gymnasium

Assoc. Prof. Jolanta Šadauskienė, PhD, Eng. – Kaunas University of Technology, Faculty of Civil Engineering and Architecture

Ewa Szatyłowicz, PhD, Eng. – Białystok University of Technology, Department of Technology in Environmental Sciences

Sebastian Szatyłowicz, MSc Eng. – Białystok University of Technology, Department of Technology in Environmental Sciences

Rokas Tamašauskas – JSC “Planuotojai” Lithuania

Bernadetta Wądołowska, MSc Eng. – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Anna Justyna Werner-Juszczuk, PhD, Eng – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Agata Witkowska, MSc Eng. – Bialystok University of Technology, Faculty of Civil and Environmental Sciences

Preface

Nowadays, issues connected with a reduction of energy consumption in the development of systems using renewable energy consumption are crucial in both scientific studies and industrial use.

In this book we show results of the analysis of different energy sources in single family houses. Advantages and disadvantages of systems with heat pumps, solar collectors and gas boilers, depending on their location, are discussed. Pros and cons were analysed from technical, ecological and financial sides. Moreover, the possibility to design installations using a modern BIM technology is presented in the example of a ventilation system. Another chapter shows different solutions regarding external walls dedicated for carbon zero kindergartens in Italy. Then, the influence of the primary energy factor of hydropower plants on the energy performance of buildings is discussed. Finally, legal aspects of air protection, in the context of air pollutants from fuels in Europe are presented.

Dorota Anna Krawczyk, Editor

Białystok, July 2020

Analysis of energy costs in a single family house with gas boiler for a heating system and solar collectors in a domestic hot water system

Keywords: renewable energy sources, solar collectors, DHW, heating

Abstract

Solar collectors are commonly used in domestic hot water (DHW) systems in different types of buildings. In this paper we conducted the analysis for a single family house located in two countries: Poland (Warsaw) and Spain (Madrid). Various factors like national rules, climatic conditions, investment costs or fuel and electricity prices were taken into consideration. We took into account flat-plate and vacuum pipe collectors to select the best solution. The results show that the use of solar collectors in Poland and Spain is economically justified.
Moreover we analyzed heat loses and annual operating costs of the heating installation for both buildings and they were found to be at a similar level, due to high fuel prices in Spain.

Introduction

Global Climate Report for Annual 2019 [1] shows climate changes are much faster recently. Temperature increase is caused by the use of fossil fuels for energy production, thus leading to much research focus on alternatives to traditional fossil fuels. Issues connected with renewable energy sources were discussed in [2, 3]. It is worth noting that low-carbon investments significantly reduce environmental pollution and lead to improved quality of life. Energy produced from renewable sources contributes to the growth of innovation and expansion of the labor market. In 2018 renewable energy sources in the EU produced about 30.7% of final gross electrical energy, 19.5% of energy for heating, ventilation and air conditioning (HVAC) as well as 7.6% of energy used in the transport sector. In the case of heating the main source was biomass (80%) while solar collectors, heat pumps and biogas systems increase their share continuously. Moreover increase of wind and photovoltaic systems (PV) is observed [4].

Efficiency of a solar collector system installed in public buildings in Poland, Spain and Lithuania were analyzed by Krawczyk et al. [5]. Results showed that energy transfer from the system in Cordoba was three times higher than in Bialystok (respectively 990.5 kWh/m^2 of collector and 336.2 kWh/m^2 of collector), while in Kaunas, obtained value was 464.5 kWh/m^2 of collector, so 38% higher than in Poland. Annual energy gathered from one collector in Cordoba (2030.62 kWh) was nearly equal to energy possible to obtain from the system with three collectors in Bialystok (2067.63 kWh) and two collectors in Kaunas (1904.32 kWh)

Kolendo and Krawczyk [6] analyzed issues associated with the planning of solar installations with flat and vacuum solar collectors mounted on the roofs of the single-family buildings. During the analysis GIS&T technology, multi-criteria decision support as well as detailed spatial data obtained by modern remote sensing techniques including airborne laser scanning were used. The results of the research showed high utility of the proposed methods in the field of spatial and economic assessment of the use of solar collectors in the single-family housing sector.

Fieducik [7] analyzed the operating parameters and the thermal efficiency of a solar air collector in northern Poland. Various applications of solar air collectors were discussed. Solar air collectors can be used for heating, ventilating and drying indoor premises and for heating water.

Olczak et al. [8] studied installations with flat and evacuated tube collectors and found that the use of evacuated tube solar collectors showed much better solar energy productivity than flat plate collectors for the absorber area. Higher heat solar gains (by 7.9%) were also observed in the case of the gross collector area.

Kowalczyk-Juśko and Roczeń [9] presented results of research on the efficiency of the solar collector system in south-eastern Poland. The installation was most effective in the period from March to October, which significantly reduces the cost of water heating. In the coldest month (December) the system delivered only 7 kWh, while in the warmest month (July) the installation produced 336 kWh.

Siuta-Olcha et al. [10] conducted research on the energy performance of an evacuated solar collector in Lublin (Poland). The solar irradiation per month in July was found as 80 kWh/m^2, while in August – 112.8 kWh/m^2. The average thermal gain was found to be in July 163 W/m^2 and in August 145 W/m^2. The average monthly energy efficiencies of the solar collector in July and August were estimated for 45.3% and 32.9%, respectively.

The aim of this chapter is a comparison of heating and hot water systems in the same house located in Poland and Spain.

Methodology

A single family house with two storeys and compact form was analyzed [Fig. 1, 2].

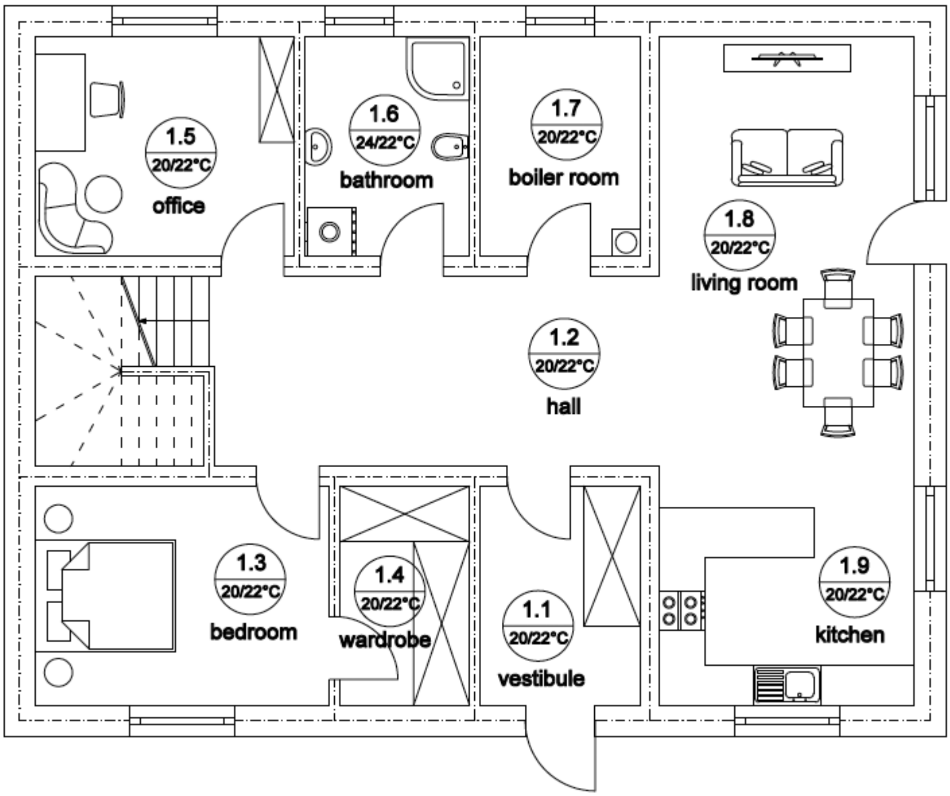


Fig. 1. Ground floor
Source: [based on 11]

The analysis consisted of comparing the total design heat losses, demand for usable energy, investment outlays and annual operating costs of installations with a gas boiler for heating the building and solar collectors for domestic hot water preparation. Solar collectors were considered in two cases: flat plate and vacuum pipe.

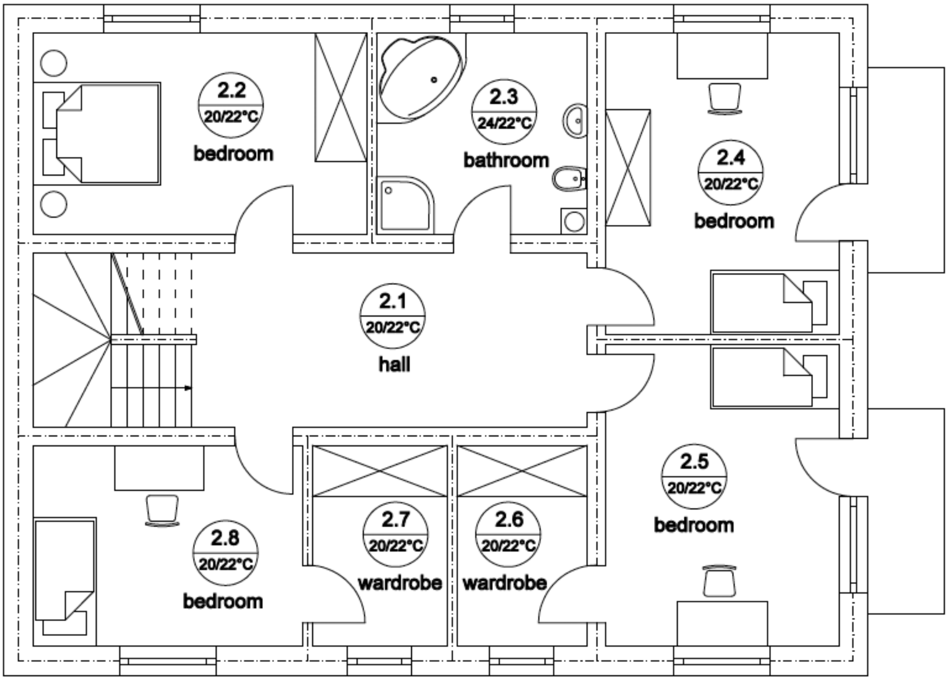


Fig. 2. First floor

Source: [based on 11]

Coefficients heat transfer through building partitions were adopted as the maximum acceptable in Poland, but also meeting the requirements in Spain. All used materials meet currently applicable technical requirements and quality standards.

The calculations were conducted for two building locations: Madrid in Spain and Warsaw in Poland. Both of these two locations are in the average climatic zone. Main parameters for Madrid and Warsaw are shown in Table 1.

Table 1. Data for heat loss calculation and solar collectors selection

Location	Warsaw	Madrid
Climate zone	III	D3
Design outdoor temperature	–20°C	–3,7°
Average annual outdoor temperature	7,6°C	14,5°C
Annual daily solar radiation in collector	39 kWh/m^2	62 kWh/m^2
Annual monthly solar radiation in collector	1185 kWh/m^2	1887 kWh/m^2
Tilt angle	42°	34°

Source: [based on 11]

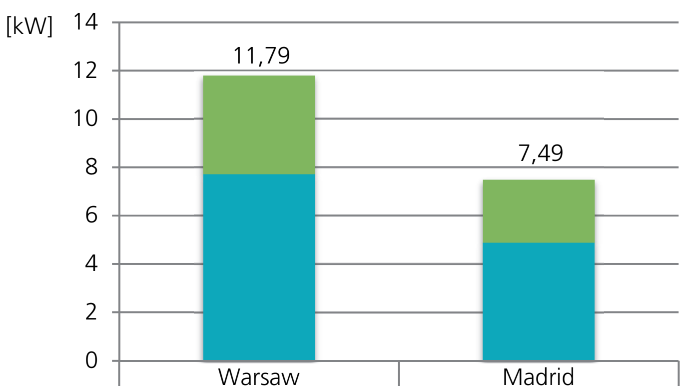
Thermal energy for heating the building is supplied by means of a water, two-pipe, central heating system in a horizontal, tee, closed system. The heat source is a condensing gas boiler located in the boiler room on the ground floor. The heating medium flow and return temperature is 70°C and 50°C, respectively.

The design values of outdoor temperature and the average annual outdoor temperature for calculating heat loss in the building were adopted in accordance with Table 1. The design indoor temperature value for the building located in Poland was assumed to be 24°C in bathrooms and 20°C in other rooms [12]. For a building located in Spain, a design indoor temperature of 22°C was assumed for all rooms [13]. The demand for thermal power for domestic hot water preparation was calculated on the basis of [14]. According to [15] in Poland the unit daily consumption of hot water by a resident is 65 dm^3/person·day, while in Spain according to [16] is 28 dm^3/person·day. In Poland, according to the guidelines [17], the cold water temperature should be 10°C [17], in Spain 13°C [16].

The selection of solar collectors (flat-plate and vacuum pipe) was based on the tools prepared as a part of the VIPSKILLS project [18].

Calculations and Results

Based on the calculated total design heat loss [Fig. 3] the building's heat source was selected – condensing gas boiler. On the basis of heat losses in individual rooms, steel panel radiator and bathroom radiators were selected. Based on the calculated demand for DHW hot water tank and solar collectors in two variants: flat-plate and vacuum pipe were selected.



	Warsaw	Madrid
ventilation heat loss	4,07	2,60
penetration heat loss	7,72	4,89

Fig. 3. Total design heat loss for building located in Poland and Spain
Source: [based on 11]

On the basis of catalogue cards and manufacturers' price list, investment outlays for heating and DHW installations were estimated. The investment outlays included labour, indirect costs and costs of preparing technical documentation. The results are shown in Table 2.

Table 2. Investment outlays for heating and DHW installations in Poland and Spain

	Warsaw	Madrid
	Price [Euro]	
Gas boiler + Flat-plate collectors	12 884	9 683
Gas boiler + Vacuum pipe collectors	16 501	10 372

Source: [based on 11]

To estimate the annual operating costs of the installations, firstly the usable energy demand for heating the building and hot water preparation was calculated. The results of the calculation are show in Figure 4.

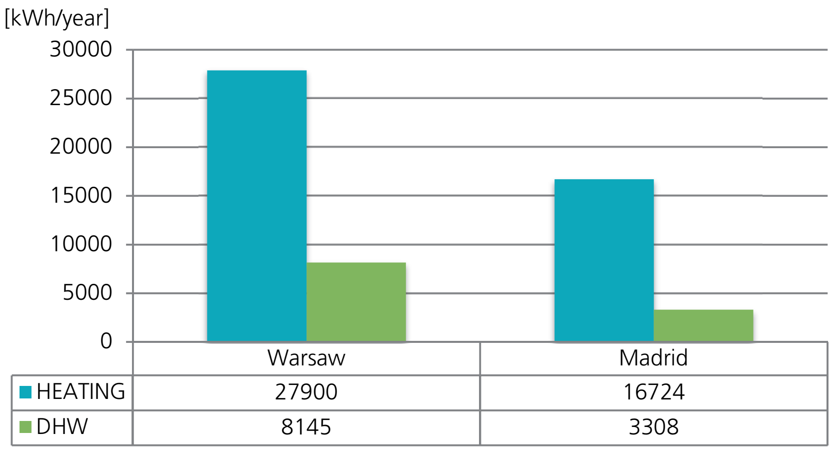


Fig. 4. Demand for usable energy for heating and DHW preparation in Poland and Spain
Source: [based on 11]

Table 2. Annual operating costs of heating and DHW preparation in Poland and Spain

	Warsaw	Madrid
	Price [Euro]	
Heating the building	1 233	1 245
DHW preparation	1 136	816

Source: [based on 11]

Based on the calculated demand for usable energy for both installations annual operating costs were estimated [Table 2]. The unit price of fuel (gas) in Poland was 0.04 Euro/kWh, while in Spain 0.07 Euro/kWh. For DHW preparation a unit price of electricity in Poland of 0.14 Euro/kWh was assumed, while in Spain 0.25 Euro/kWh [19].

Conclusions

The calculations made and the results obtained show that greater overall design heat losses will occur in a building located in Poland. This is due to the fact that the design outdoor temperature in Warsaw is much lower than the design outdoor temperature in Madrid. Assuming a design value for the indoor temperature at a similar level, a greater difference between the indoor temperature and the outdoor temperature intensifies the heat exchange process, which results in greater heat loss through penetration.

Considering the demand for usable energy for heating a building and preparing hot water, in both cases higher values occur in the case of a building located in Warsaw. With regard to heating, it mainly depends on the number of degree days of the heating season, which is 3944 for a building in Warsaw, and 2931 for a building in Madrid [20]. The overall design heat loss as well as the design indoor and outdoor temperature also have an impact on such a large discrepancy in the energy demand for heating the building depending on the location. In the case of demand for usable energy for DHW preparation the difference in demand is primarily due to the amount of water consumed per year by the inhabitant, as well as the difference between the temperature of the cold water flowing into the installation. In Poland, the assumed water consumption is more than twice as high as the consumption in Spain.

Both in the case of gas boiler installations with flat-plate collectors and installations with vacuum pipe collectors, higher investment outlays will be incurred in the case of a building located in Poland. This is mainly due to the expenditure incurred for the purchase of a gas boiler and radiators, as well as a larger number of solar collectors compared to a building located in Spain.

Comparing installations with flat-plate collectors and vacuum pipe collectors, higher outlays in both Warsaw and Madrid will be incurred for vacuum pipe collectors. In this case, a particularly large difference is noticeable for a building located in Poland. This is largely due to the larger number of collectors adopted, as well as the higher purchase prices for this type of installation. In terms of energy, the solar installation based on flat collectors is much more efficient in the summer (spring, summer) than an installation with vacuum collectors. However, the solar installation based on vacuum collectors is more efficient in winter (autumn, winter). Therefore, if the consumption of hot water in summer will be higher than in winter, it is worth using a system with flat collectors. However, if the consumption of hot water in summer is comparable to that in winter, a better solution in terms of energy will be installation with vacuum collectors.

Comparing the annual operating costs of installations, they are also higher for a building located in Warsaw. The annual cost of heating a building with a gas boiler does not differ particularly depending on the location, despite the fact that the demand for heating energy for the building in Poland was much higher. This is due to the difference in price for 1kWh of gas consumption. In Spain, the gas price is 0.03 Euro/kWh higher than in Poland. The same applies to the annual operating costs of domestic hot water installations. In Warsaw, they are slightly higher than in Madrid, despite the fact that the demand for energy for locations in Poland was about 60% higher. This is also due to the difference in the price for electricity, which is almost twice as high in Spain than in Poland.

Based on the results obtained, it can be concluded that in economic terms the use of solar collectors is more advantageous in Spain than in Poland. This is mainly due to climatic conditions, which are very important in this type of installation. A much larger number of hours with the sun per year means that solar collectors and solar installations achieve higher efficiency, which means that the system generates lower energy consumption and lower costs. It is also worth noting that the prices of traditional fuels in Spain are very high. Therefore, investing in renewable energy sources is becoming the best alternative.

In Poland, investment outlays and annual operating costs are higher than in Spain, but this does not mean that the solar installation in our climatic conditions is unprofitable. Appropriate design of the installation and correct operation mean that the one-off costs of purchasing solar collectors pay for themselves as a result of the savings obtained by reducing the use of traditional fuels.

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Air-source heat pumps in a single family house – a case study

Keywords: heat pumps, heating, cooling, heat sources, renewable energy

Abstract

Heat pumps are used in the heating and air conditioning sector. These devices mantain thermal comfort in an economical and ecological way, meeting the requirements of the European Union in the field of renewable energy.

The purpose of this work is to compare systems with an air-source heat pump in a single-family house in Poland and Spain. For the analysis a single-family residential building was selected and its location in two cities with different climatic conditions, in Poland and Spain was taken into account. On the basis of calculations, heat losses and gains were estimated, and the energy demand for heating was found to be about 40% higher in Wroclaw than in Cordoba. On the other hand Energy demand for cooling was determined as 31% higher in Cordoba. Total investment costs were found to be twice as high in Poland, whereas the total annual maintaining costs of using an air-source heat pump were comparable and only 3% difference was calculated.

Introduction

Observing the changes in the heating industry taking place in recent years, it can be seen that the energy needs of people are constantly growing. Nowadays 85% of energy for heating and cooling in Europe is obtained from coal, gas, oil products or electricity. It means, that only 15% is produced from the renewable energies [1, 2]. Using fossil fuels results in the release of harmful substances into the environment. The most common pollutants are sulfur dioxide, carbon monoxide and dioxide, nitrogen oxides, as well as solid products – volatile ashes, chemical metals, soot and slag. Air pollution has a negative impact on the health of all living organisms and changes in the deterioration of soil and water properties and the formation of acid rain. Pollutans are also potentially affecting the greenhouse effect and support corrosion of metal structures, land deformation or changes in soil and groundwater reaction [3, 4]. Thus, lately, renewable energy sources that do not case such environmental demage become more and more common. In line with European Union Policy, all Member States should promote energy efficiency at individual levels of the national economy, as well as gradually tighten the regulations regarding heating systems. Currently, heating and cooling accounts for around 50% of total energy consumpion in Europe, which means that this sector has a significant role in acheiving long-term energy security. The European Union tries to help the Member States to increase energy efficiency of buildings, reduce the cost of heating and cooling and – in results – maximise the use of renewable energy sources by implementing the projects, which are developed and funded by the European Commision [2]. All of the factors mentioned above encourages people to increasingly use alternative sources of energy or try to modernise existing heating systems to the extent that they are the least harmful to the environment [1].

Swardt and Mayer [5] compared the performance of a reversible ground-source heat pump coupled to a municipality water reticulation system, with a conventional air-source heat pump for space cooling and heating. Results obtained from measurements and simulations indicated that the utilization of municipality water recirculation systems as a heat source/sink was a viable method.

Dongellini at al. [6] presented the results of a numerical simulation of a heating and cooling system based on a reversible air-to-water electric heat pump and electric resistances as back-up. Their results showed, that in Italy in the Northern and Middle regions, where the heating loads are larger than the cooling loads, the best annual performances are reached by selecting multi-compressor heat pumps (MCHPs) or inverter-driven heat pumps (IDHPs) sized to cover partially the heating peak load with a bivalent temperature of the order of 0-2°C.

Tabatabaei at al. [7] analyzed a house in Iran supplied by different energy sources.

Kelly et al. [8] studied a resiential sector in Ireland. They found that, for large numbers of households, representing almost all types of heating systems, from a societal perspective, there was a likely move to Air Source Heat Pumps (ASHP) technology when considering the annualized capital and running costs.

Vocale at al. [9] investigated the effect of the outdoor air temperature and relative humidity on the performance of an air heat pump system in Italy. They analyzed a frost formation process and found that the outdoor air conditions played an important role in determining the amount of defrost cycles; however the frost formation was mainly affected by the relative humidity. Moreover they noted that the hourly COP may be reduced by up to 20%, depending on outdoor conditions.

Gajewski et al. [10] focused on carbon dioxide emissions and investment costs in installations with heat pumps in Poland. It was found that air-to-water heat pump had higher operating costs and higher CO_2 emissions. The ground-source heat pump working in a closed-loop had lower operating costs, but higher CO_2 emissions than the gas boiler system. Finally, the water heat pump had the lowest operating costs and CO_2 emissions of all the systems studied.

In this chapter we analized the investment and operating costs of the air-source heat pump for a single family house located in Poland and Spain.

Heat pumps

The example of one of the most dynamically developing renewable energy technologies are heat pumps. They are practical heating and air-conditioning devices, which are generally used to supply low-temperature central heating installations or, by reverse operations cycle, to cooling the individual rooms in the building. They provide exceptionally high efficiency compared with conventional fuels combustion. Heat pumps carry heat from low temperature surroundings to a higher temperature building and their work is based on the second law of thermodynamics, according to which the heat flow always takes place from a body with a higher temperature, to a body with a lower temperature. This fact is a serious problem, when using low-temperature energy resources that occur naturally in the environment [1, 11, 12, 13]. Reverse direction of heat flow is possibile, but external power must be provided to the circuit, which in turn is ensured by heat pumps. Although heat pumps require potentially expensive electricity to operate, the majority of the necessary energy is renewable and drawn from the environment. Compared to the popular condensing boilers, heat pumps are able to reduce primary energy consumption by 15 to 50%. What is more, while combining high efficiency with potentially clean electricity, the global CO_2 emissions could be reduced even by 8% [13].

The basic criteria for the division of heat pumps is the type of lower heat source according to which the pumps are generally divided into: air, ground or water.

In terms of driving force and operating principle, heat pumps can be divided into three basic types:

- absorption (with termal drive),
- [thermoelectric (with electric drive),
- compressor (with mechanical drive).

Among compressor heat pumps, six main types are destinguished: air-to-water, air-to-air, water-to-water, ground-to-water, brine-to-water and direct evaporation-to-water. The first part of the name indicates the type of lower heat source, while the second part is the type of medium in the upper heat source.

The basic elements of compressor heat pumps are the evaporator, condenser, compressor and expansion valve. A typical heating system using heat pumps consist of three circuits: lower heat source circuit, upper heat source circuit and thermodynamic circuit. The lower heat source circuit is connected to the thermodynamic circuit by means of an evaporator, while the upper heat source circuit is connected with the thermodynamic circuit by condenser [3, 14, 15, 16].

In the installation with air-to-water heat pump, heat is exacted from air by evaporating a refrigerant, which is contained in a closed circuit. The diagram of the air compressor heat pump operation is shown in Figure 1 below.

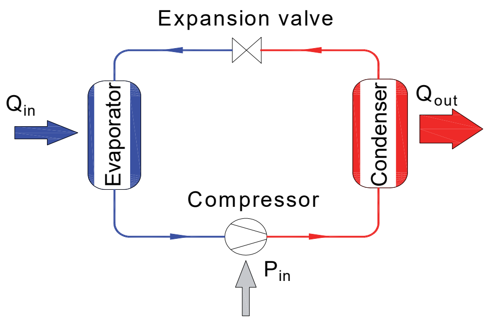

Fig. 1. The energy flow in a heat pump system
Source: [12]

At the beginning, the refrigerant is guided to a compressor, where its pressure and temperature increases as a results of compression. Next, compressed gas is fed to the condenser, where it is changing to the liquid phase and the energy is transferred to the water circulating in a heating system. When the installation of the upper heat source receives heat from the condenser, the expansion valve opens and slowly expands the condensed medium. The expanded refrigerant goes to the evaporator, where it evaporates as a results of temperature rising. Next, the cycle repeats. It is important that the refrigerant can be condensed at technically possibile pressure and has a low evaporation temperature. Summarizing, the heat pump operation principle consist of four processes:

- compression,
- condensation,
- expansion,
- evaporation [12, 17].

The quality of devices, for example heat pumps, is understood as a ratio of achieved effects to incurred losses and is referred as efficiency. The basic indicator for determining the energy efficiency of heat pumps is COP (Coefficient of Performance), which is calculated by the following formula (1):

$$COP = \frac{Q_h}{P}\,[-] \tag{1}$$

where:
Q_h – heating capacity [W],
P – electricity consumed by the compressor and other associate devices [W].

Another indicator, characterizing the operation of a heat pump in heating mode is the Seasonal Coefficient of Performance – SCOP. It determines the ratio of obtained energy to external energy throughout the entire heating season, taking into account real operating parameters, internal temperatures in heated rooms, climatic conditions, as well as standby periods and operating conditions for the device. In Europe, there are different formulas for calculating the SCOP coefficient, depending on the climate zone. There is cold zone (in which Poland is located), a warm zone (e.g. Portugal and Spain) and a moderate zone (Belgium, the Netherlands).

The indicator characterizing the operation of refrigeration and air-conditioning devices or heat pumps in cooling mode is the EER (Energy Efficiency Ratio) factor. EER is calculated by the formula below:

$$EER = \frac{Q_c}{P}\,[-] \tag{2}$$

where:
Q_c – cooling capacity [W],
P – electricity consumed by the compressor and other associate devices [W].

Similarly to the coefficient COP, the measure of the annual energy efficiency of heat a pump operating in cooling mode is Seasonal Energy Efficiency Ratio (SEER) [13, 18].

Methodology

A single-family house was analysed. The main assumtions were as:

- 5 habitants,
- 2 storeys (Fig. 2),
- heating area approx. 175 m^2,
- cubic capacity of the building approx. 475 m^3,
- ACH: 4 air exchange per hour.

Heat coefficients of the building envelope meet all law and construction requirements for both Polish (Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 5 lipca 2016 r. [19]) and Spanish (Documento Basico HE Ahorro de Energia [20]) conditions. „U" values are shown in the Table 1.

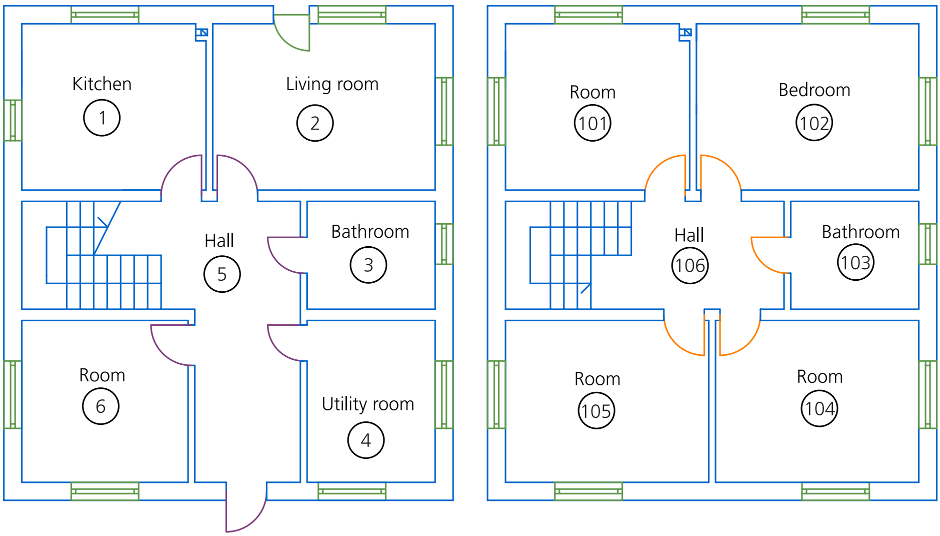

Fig. 2. Ground and first floor of the single-family house

Source: own study

Tab. 1. Heat coefficnets „U"

Type of building envelope	"U" [W/m²K]
Floor on the ground	0,25
External wall	0,23
Internal wall	0,9-1,0
Floor between storeys	0,50
Floor of unheated attic	0,18
Windows	1,10
Internal doors	2,50
External doors	1,50

Source: own study

Characteristic of the climate

Two locations were considered:

- Cordoba (zone B4 in Spain),
- Wroclaw (zone II in Poland).

Parameters of outdoor air in Poland and Spain, as well as design parameters of the indoor air were established based on [20, 21, 22, 23, 24]. Design outdoor temperature was set as:

- 26,3°C in Poland and 36,8°C in Spain for cooling season,
- –18°C in Poland and –0,3°C in Spain for heating season.

The indoor temperature was established as:

- 22°C in Poland and 24°C in Spain for cooling season,
- 20°C in Poland and 22°C in Spain for heating season.

Characteristic of the energy source

The energy source for HVAC system was a reversible air to water heat pump, working in a monovalent system. The schematic of such equipment is presented in Fig. 3.

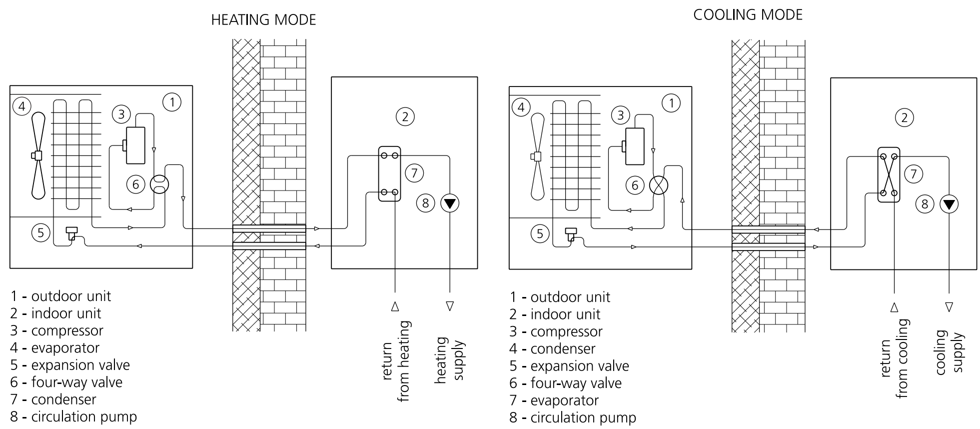

Fig. 3. Operation schematic of a reversible air heat pump
Source: own study based on [25]

Results

The calculations were conducted using Purmo OZC 6.7 Basic Sankom software. The results of design heat losses are presented in the Figure 4.

The design heat losses by transmission in case of Cordoba were estimated for 4782 W and it was about 43% less than in case of Wroclaw. The design heat losses by ventilation differed by 42% (3445 W versus 2008 W) while total heat losses were found as 11841 W in Wroclaw and 6790 W in Cordoba. The reason of such a difference in the obtained results was mainly the location of building in different climate zones with a significant difference in temperatures.

Heat gains for all rooms and design cool load were estimated using Vipskills Project tool [26].

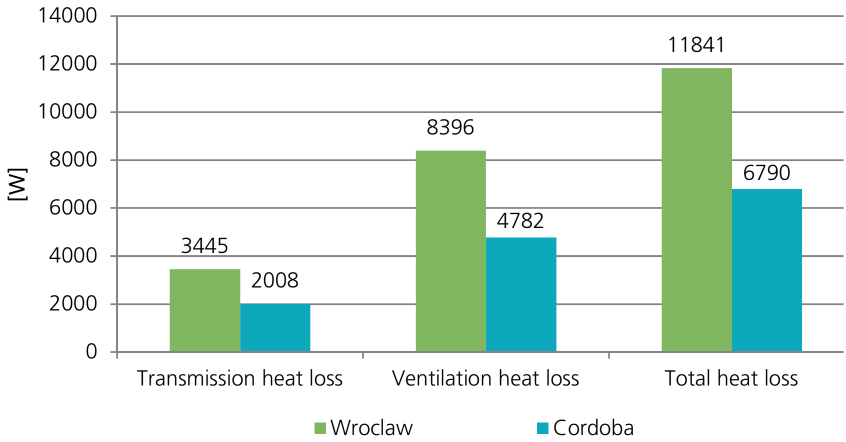

Fig. 4. Comparison of design heat losses in Poland and Spain
Source: own study

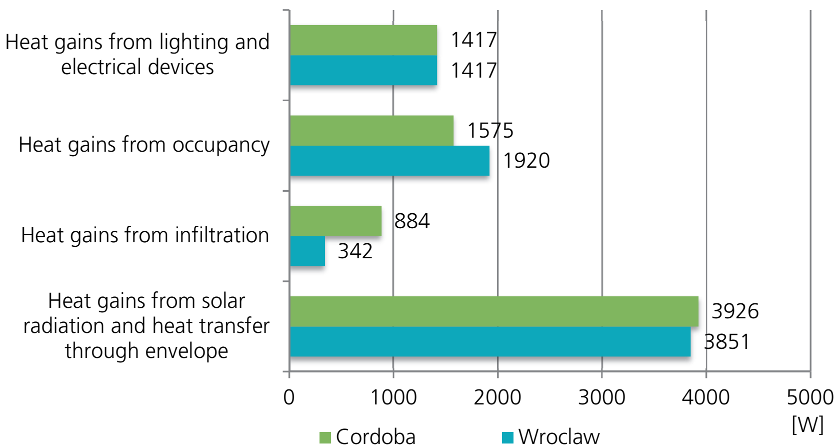

Fig. 5. Comparison of design heat gains in Poland and Spain
Source: own study

Heat gains from insulation and through building partitions was 3851 W for a house located in Wroclaw and it amounted to about 2% lower than in the case of Cordoba. The difference in the value of the obtained results was caused by the different geographical latitude of the analyzed cities, which in turn had a significant impact on the degree of solar absorption and the angle of sunlight incidence. In the case of Wroclaw heat gains due to infiltration reached 342 W, which was about 61% lower than in Cordoba. This difference was maliny caused by various values of the difference between the temperature of the internal and external air, which in Wroclaw was much lower. Heat gains from people were determined based on PN-B-02025:2001 [27] standard in Poland and Table 3 in [28], used for calculations and design in Spain. In the case of Cordoba, they amounted to 1575 W, which was about 22% lower than in Wroclaw. Due to the fact, that heat gains from lighting and electrical devices depended only on the number, type and power of devices installed in the building, equal values were achieved in both cases. The total value of heat gains for the building located in Cordoba was 7802 W, i.e. about 3,5% less than in Wroclaw. Comparison of heat gains in Poland and Spain is presented in Figure 5.

Based on the results of the total design heat losses and gains, and the number of degree days of heating and cooling season [29], the design heat and cool loads were determined. The calculation results are summarized in the table (Tab. 2) below.

Tab. 2. Design heat and cool load

Location	Design heat load [kWh/year]	Design cool load [kWh/year]
Wroclaw	26 943	5 884
Cordoba	16 245	8 541

Source: own study

Analyzing the values presented above, it can be estimated that the amount of demand for usable energy for heating, determined for a building located in Cordoba was 16245 kWh/year and was as much as 40% lower than in the case of Wroclaw. In the case of Cordoba, the value of demand for usable energy for cooling reached 8541 kWh/year, i.e. 31% more than for a building located in Wroclaw.

Based on the above values, reversible air-source heat pumps split type from Dimplex, model LAK 9IMR for cooling and heating of the building were selected. The following table (Tab. 3) compares the installation parameters with the heat pump in Poland and Spain.

Tab. 3. Parameters of the installation with a heat pump

Parameter	Wroclaw	Cordoba
Heating		
Outdoor temperature	–7°C	7°C
Heating water temperature	45°C	45°C
Heating power	6,43 kW	6,85 kW
COP	2,24	3,35

Parameter	Wroclaw	Cordoba
Cooling		
Outdoor temperature	+27°C	+35°C
Cooling water temperature	18°C	18°C
Cooling power	8,7 kW	9,0 kW
EER	4,2	3,4
Number of selected pumps	**1**	**2**

Source: own study

Based on the Dimplex price list and own calculations, investment expenditures covering the purchase of heat pumps and their installation as well as preparation of project documentation was estimated. In the case of Wroclaw, the cost of purchasing heat pumps was 44009 zl gross, while the amount of labor and preparation of the project documentation – 15787 zl. Therefore, the total cost was **59796 zl** gross.

Considering the building located in Cordoba, the purchase price of the heat pump was 22005 zl, while assembly and preparation of the project – 8394 zl. In the case of Spain, the total expenditures reached **30399 zl** gross, which was about 49% lower than in Poland.

The estimated costs of operating heat pumps in Poland and Spain were determined based on the price of electricity [30] and the demand for usable and final energy for heating and cooling the building, as well as the values of COP and EER coefficients. A graphic comparison of the obtained results is shown in Figure 5.

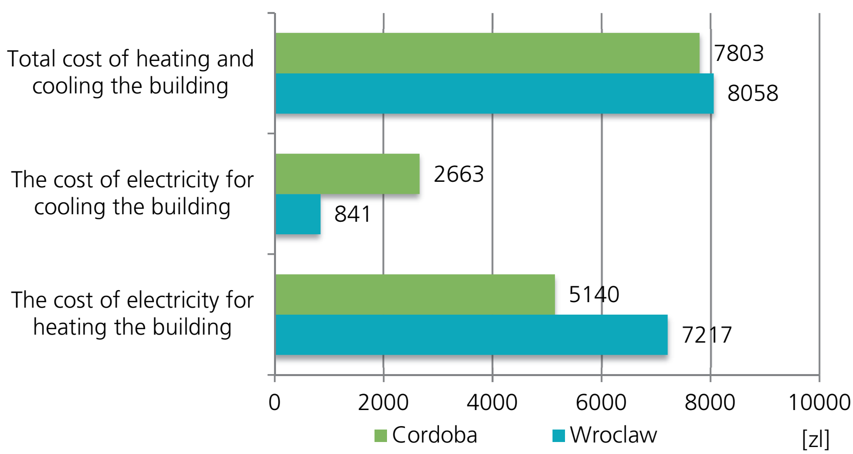

Fig. 6. Comparison of operating costs of heating and cooling the building

Source: own study

Electical energy cost for heating of a building in Cordoba was 5140 zl, thus 29% less than in Wroclaw (7217 zl). On the other hand cost of electricity for cooling was 68% higher in Spain (2663 zl). These facts resulted in only 3% difference in total annual electricity costs (8058 zl) in Wroclaw and 7803 zl in Cordoba.

Conclusions

The results show that the air heat pump for heating and cooling a single family residential building, both in economic and energy therms is a more efficient solution for Spanish conditions. Total investment costs were found about 44% lower in Cordoba (38202 zl versus 67854 zl), while operating costs were estimated on a similar level. However it is worth noting that air heat pumps are a renewable energy source and allow pollutant emission reduction in a place of energy generation. Assistance programmes that allow reductions in owners own cost contribution would contribute to wider usage of heat pumps in Poland.

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Designing installations in bim technology on the example of a ventilation system

Keywords: Building Information Modeling, BIM, ventilation system

Abstract

The advantages and disadvantages of the BIM design system for creating indoor installations are presented using the example of ventilation installation.

In this work, one of the most effective systems has been designed for a school complex in Lviv region, Ukraine. The ventilation system was designed with the help of BIM technology in the Autodesk Revit software. After creating the 3D model of the ventilation system, aerodynamic calculations were performed and ventilation equipment selected.

Introduction

BIM (Building Information Modeling) is a concept that completely changes the approach to design, implementation of investments and building management [8]. BIM is defined as tools, processes and technologies that are supported by digital documentation [2], [20], [37]. BIM enables continuous and immediate access to current information about the project and all costs at various stages of the facility construction [4] and throughout its entire life cycle, from design to demolition [10], [20], [39].

BIM supports the process of integrated energy design, due to the fact that in one place the data about all construction elements (building envelope, internal building partitions) and mechanical equipment (HVAC, electric installations, automation) are gathered. When taking into account climatic conditions (weather data, solar radiation), human factors, energy cost, thanks to BIM it is possible to carry out complex and detailed energy modelling of building [17], [29], [46]. Thus, BIM supports the process of designing energy efficient and passive buildings, in line with the concept of sustainable construction [46] and indirectly helps reduce building energy consumption [12], [18].

Because of the huge potential, BIM has been introduced by most commercial CAD software companies, including Autodesk Revit, ArchiCAD and Allplan [25].

The benefits of using BIM technology can be divided into operational, managerial, organizational and strategic [45].

BIM technology gives the opportunity to test various installation variants in the virtual world in order to select the optimal one. BIM also applies to the energy analysis of building, determination of energy demand and consumption [17], and testing of various energy consumption patterns [8].

BIM allows for the development of consistent and good-quality project documentation (together with all internal installations) [32], estimation of investment costs, inventory of materials and scheduling of works, and later facility management [2], [28]. BIM facilitates cooperation between the architect, constructor and designers of all internal installations [19], [21], [35]. By working on one virtual building model, designers get information on the operation of other branches on an ongoing basis, what improves communication, shortens designing time and increases the efficiency of the investment process [22], [26], [30], [32]. The risk of errors in documentation is reduced, e.g. on building plans and sections [14], [26], [39]. There is no need to transfer projects between individual offices and adapt file formats and software versions to those used by other designers. Designers of installations and constructors can start designing much earlier than in the case of traditional projects, without waiting for the architects to finish work on the plans of the building.

BIM has functions for automatic collision detection, which allows quick adaptation of the design to other installations and building structure [19].

Thanks to the 3D building visualization, cooperation with the investor is improved, who is informed in a transparent and accessible way about the engineering solutions used [39]. The investor, therefore, can more rapidly influence designers' decisions, choose optimal technological solutions, and thus affect the final shape of the investment.

The advantages of BIM technology include efficient costing correcting itself when changes in concept and automatic generation of documentation based on the modeled body of the building [7], [43], [44]. Sketches of the building plan, cross-sections, axonometry, elevations, legends or diagrams can be easily generated. Thanks to the change module, after each change in the project, the documentation is generated again, without the need for time consuming corrections in each drawing [4], [34], which is extremely important for large investments.

BIM also facilitates investment management during its construction, i.a. by controlling the quality of works performed, compliance of works performed with the project and schedule [2], [45]. It reduces the time of construction and its costs by minimizing the risk of collision of installations and building construction [21], [37]. Through appropriate applications, BIM allows comparison of the actual state of the building with the project, what improves communication between contractors, designers and the investor. BIM facilitates making changes to the project during its construction, thanks to ongoing verification of their impact on the building's structural elements and its installations.

The great potential of BIM technology lies in the building management in the post-construction lifecycle. BIM can be used in building inspection and quality control prior to its operation [12]. In addition, BIM enables the assessment of energy consumption in post-construction lifecycle, which can translate into better energy management by building users and a reduction in energy consumption [42].

BIM technology is becoming increasingly popular all over the world, as evidenced by hundreds of articles published in the last several years [41]. It is used successfully in the Scandinavian countries, the USA and Great Britain [11]. The development of BIM technology is observed in Australia and Singapore [36]. In Poland, BIM technology is very often used by constructors [5], [6], [23], less often by architects [3], [13]. Unfortunately, it is not widely used by installation designers and contractors. In Poland, most HVAC installation projects are still being created in CAD programs. These are projects in the form of 2D drawings. Rarely, internal installation designs are created in the three-dimensional form. The 3D model is mainly used by architects.

The implementation of BIM technology, or rather the way of thinking, is associated with many difficulties. The main reasons for the reluctant implementation of the BIM system include the cost of software, computers and the cost of training employees [1], [21]. An important issue is also the unwillingness to learn new technologies and the lack of knowledge about the benefits associated with their use [27]. Unfortunately, in Poland, the internal installation design system clearly distinguishes three groups of designers. The first group consists of designers of heating systems, sometimes able to develop building ventilation systems. The second group are designers of water and sewage systems. The third group consists of designers of electrical installations and broadly understood as IT and telecommunications installations. There is a small group of designers and most often contractors at the same time, dealing with building automation. This division means that the building is not designed as a whole, but as a collection of many installations, often designed without careful analysis of the others. BIM technology enables the cooperation of all designers and execution of a coherent project of the building, on which all installations will be located [15].

In Poland, the interest in the use of BIM has been increasing in the last few years [11], but much effort should still be put into popularizing this technology in the construction industry. It is necessary to change the system of engineering training [33]. The lack of properly trained personnel is a brake in the development and implementation of BIM technology in our country. In the Polish education system, there is still a lack of cooperation between students of design fields: construction, sanitary engineering, electrical and IT. Actions should be taken that will enable students of these fields to jointly design buildings, and thus learn to solve problems together and choose optimal technologies. An example of skillful implementation of BIM technology in education is Lithuania and Ukraine, where students acquire practical skills in using this software.

One of the installations designed in BIM technology is a ventilation installation [16] with fire protection elements. The article presents a design of a ventilation installation made with Autodesk Revit program.

Example of mechanical ventilation installation design – building description

The design of the ventilation system was carried out at the school complex in Novoyavorovsk, Lviv region, Ukraine, with the following parameters:

- building area: 4909 m^2,
- usable floor area: 6310 m^2,
- volume: 19 000 m^3,
- number of teaching rooms: 41,
- number of students: 945.

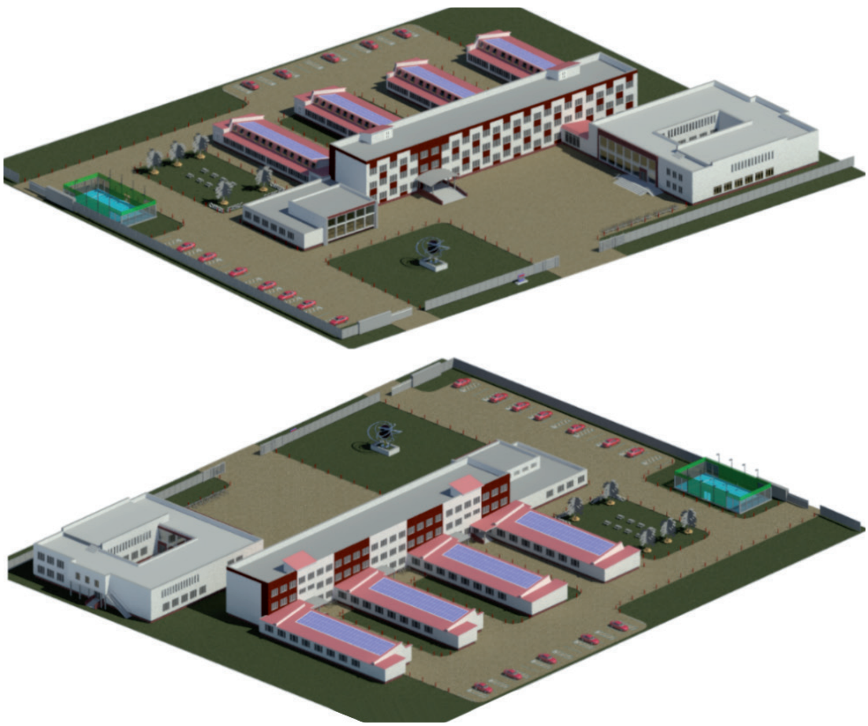

Fig. 1. School complex, Lviv region, Ukraine. Project made in BIM technology (made by A. Pushchinskyi)
Source: [31]

Figure 1 presents a three-dimensional architectural and structural model of the building made in BIM technology, using the Autodesk Revit program.

Description of the ventilation system

Knowing the function of individual rooms in the building and their loads (number of people), the heating and cooling loads of individual building zones were calculated in the program. Based on the results, two supply and exhaust air handling units with a rotary heat recovery exchanger have been designed for classroom ventilation. An exhaust system has been designed in the sanitary and storage rooms.

The ventilation system was distributed in the program on a building model containing other installations in order to eliminate collisions of ventilation ducts and water and sewage installations. It was also necessary to provide the electrical connections for all designed devices.

In the version of the program that was used, it was necessary to calculate the air flows in each room, set the number of supply and exhaust grates and to distribute the ventilation ducts of the supply and exhaust installation as well as the cables to all ducts (Figure 2). Installation regulation is provided by means of channel dampers, dampers in plenum boxes of diffusers and by means of ventilation valve settings.

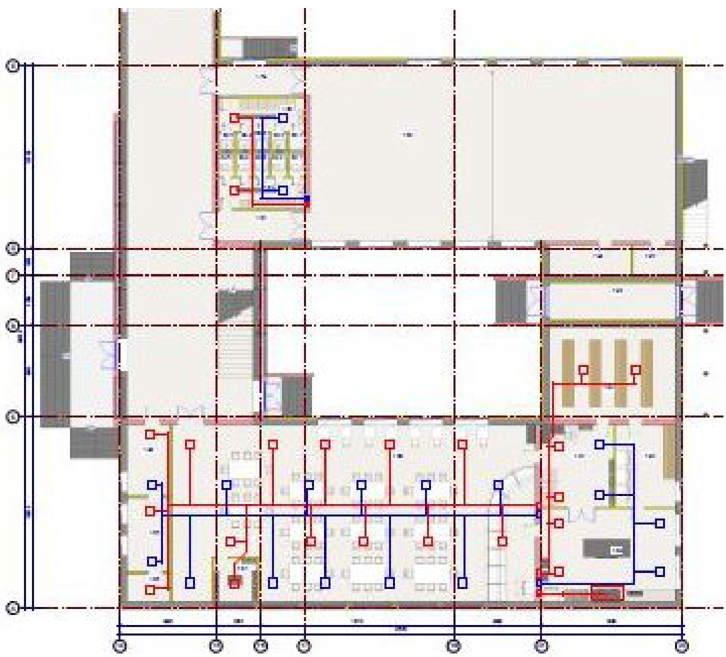

Fig. 2. Layout of the ventilation system in a part of the building (made by A. Pushchinskyi)
Source: [31]

The air inlets and outlets are connected by ventilation ducts that can be done using the automatic program functions or by the designer him/herself. The dimensions of the ducts had to be selected both with hydraulic requirements, such as air velocity in the ducts, as well as the ducts material. Fittings for connecting individual elements of the installation were also selected. Ventilation ducts in the program are marked with different colors depending on the function performed (Figure 2 and 3).

The Revit program enables a three-dimensional preview of a ventilation system, thanks to which it is possible to assess the correctness of adopted solutions and detect collisions with building structural elements and other installations (Figure 3). This is the advantage of this type of modeling over 2D design in which the collision-free arrangement of ventilation ducts is difficult and time consuming.

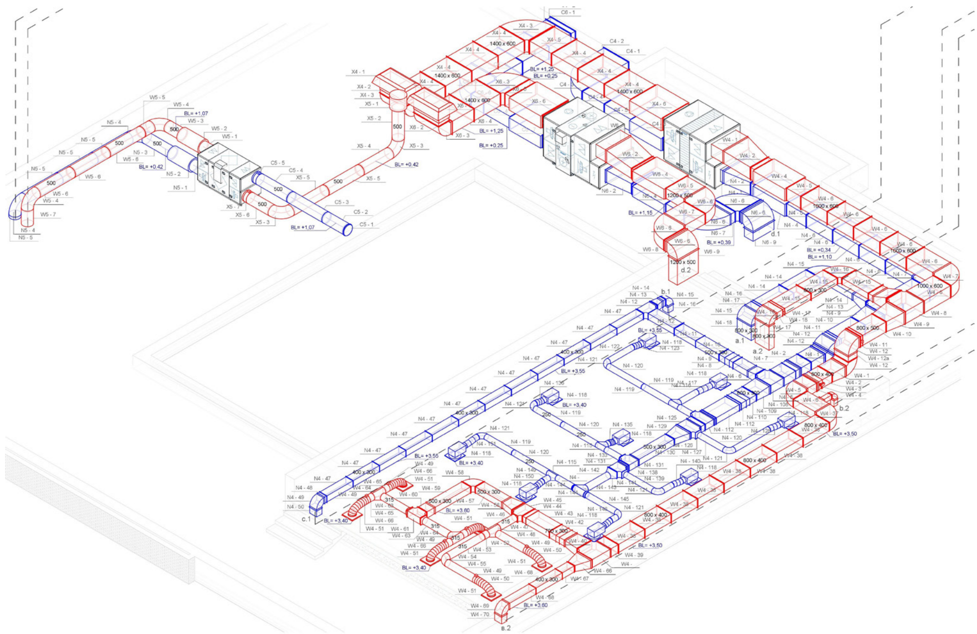

Fig. 3. Designed ventilation system (made by A. Pushchinskyi)
Source: [31]

In the classrooms, a system of variable ventilation efficiency was designed taking into account the number of people in the room and reduction of ventilation efficiency outside school hours. The amount of air supplied to the classrooms is controlled by indoor air quality sensors which significantly reduces operating costs.

Up to 1000 m^3/h of air is blown into each classroom and is removed up to 800 m^3/h. Excess air flows through the noise suppression grille installed above the entrance door to the classroom to communication rooms, from where it is removed by means of ventilation units above the roof of the building (Figure 4). If the windows in the classroom are opened, the ventilation system for the classroom is cut off. When presence sensors indicate no activity, the amount of air is reduced to a minimum, i.e. 200 m^3/h supply air and 0 m^3/h exhaust air.

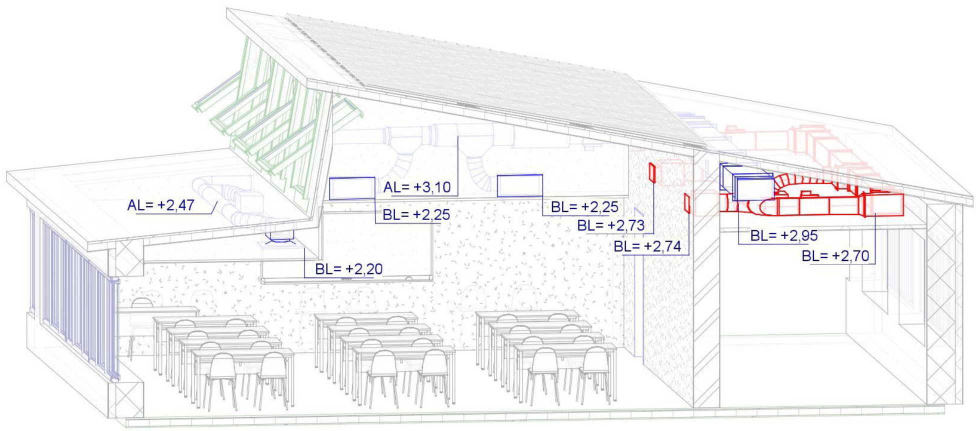

Fig. 4. Cross section of the classroom (made by A. Pushchinskyi)
Source: [31]

Air transfer from classrooms to the corridor is possible by using the flow grates. The whole system is connected to the superior building management system.

In the corridors, a system equipped with dampers with servomotors was used, working with a constant output. This system works with systems in classrooms in which the amount of air is continuously adjusted. System control devices are located at individual control panels.

To design a fire protection ventilation system, the building is divided into ventilation zones (Figure 5).

In the places of passage of the ventilation system through the fire separation partitions, fire dampers or fire valves are designed.

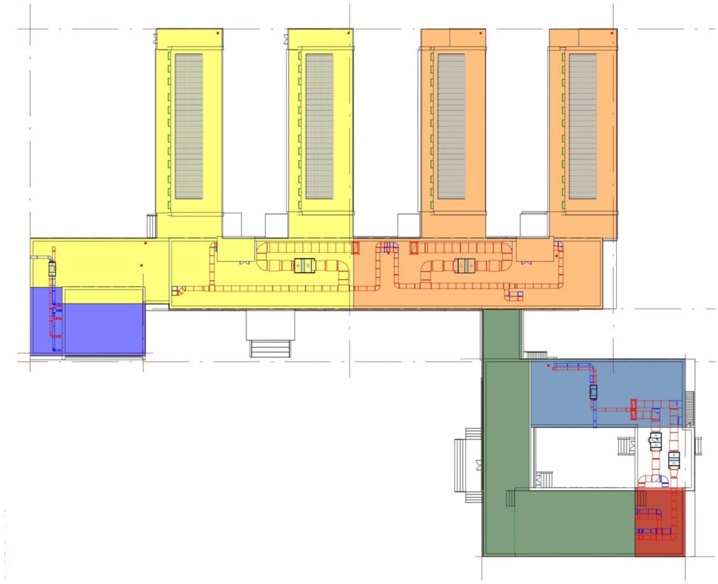

Fig. 5. Ventilation zones in the building (made by A. Pushchinskyi)
Source: [31]

After the project was completed, project documentation was generated covering sketches of the building plan, cross-sections of the building, axonometry of the ventilation system, list of installation elements.

Summary

BIM technology is the next step in the design process development. In the last few years one can observe the increment of requirements to the quality of projects and the shortening time for preparing the documentation. At the same time, the designed objects become more and more technologically advanced, equipped with numerous installations, whose operation should be correlated with each other. For this reason there is a strong need by design offices to look for new tools to improve the design process. Due to climate changes and the pursuit of sustainable construction, designing passive and low-energy buildings become a necessity. This requires the use of technologies that enable advanced energy analysis with multiple data from a variety of sources. BIM technology offers complex designing of building and possibility of analyzing many variants of construction, mechanical equipment, energy consumption. At the same time it offers shortening of design time, collision elimination, efficient costing and automatically created documentation. It improves communication between all members of the investment process, i.e. investor, architect, constructor and installation designers as well as contractors. Due to numerous advantages, BIM technology is becoming a valuable alternative to the traditional design process and its use seems inevitable. The implementation of each new technology is a time-consuming process, that requires knowledge and experience. In Poland BIM technology requires above all a change in the engineering training system [15], so that in the future they can use this technology, popularize it and thus be competitive in the dynamically developing construction market [26].

Acknowledgments
The study has been executed with resources of the W/WBiIŚ/4/19 statutory work financed by the Ministry of Science and Higher Education in Poland.

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External wall technological solutions for carbon zero kindergartens in Italy

Keywords: external envelope, carbon-zero, sensitivity analysis, kindergartens, sustainability

Abstract

For the construction of a carbon zero kindergartens, it is necessary to choose a proper technological solution for the external wall and the material to be used for the insulation layer in the early stages of the design process. Furthermore, in the context of "2030 climate & energy framework" and "2050 low-carbon economy", from the beginning of the building design, it is fundamental to try to identify the elements that significantly influence energy performance to reduce building energy needs. The main aim of the presented study is to analyse five different technological solutions for an external wall combined with four different materials for the insulation layer. The solutions will be used in a new typological model for a kindergarten and analysed and compared with respect to both environmental impact and energy performance. Results point out that all the technological solutions proposed are valid alternatives to build a carbon-zero kindergarten in Italy. Furthermore, for completeness, a sensitivity analysis was carried out to understand the influence on energy demand of different factors such as, for instance, the type of wall technological solution, the thickness of insulation for wall and roof and the type of solar shading considering different climate zones in Italy.

Introduction

Thermal building performance is connected to 3 major topics: firstly, the building physics, which is regulated precisely to the building envelope, then the micro-climate of the environment of the building and, finally, to the inter-nal hygro-thermal comfort [1]. The choice of the technological solution for the external envelope, and related building structure, is one of the passive strate-gies that influences the energy performance of a building, since it regulates the energy flow between the inside and outside [2] due to the difference of the internal air temperature and external one. Consequently, it controls the amount of the dispersions during the winter season as well as the benefit of solar gains.

In literature, the studies concerning the technological solution to be utilised for the external wall mainly concern the evaluation of the dynamic thermal properties of the material typology used for the insulation layer and its thick-ness [2-4]. The optimization of the insulation thickness is performed by evalu-ating different features separately or simultaneously: namely, energy, envi-ronmental, and economic. Consequently, the following parameters are usually considered: the energy needs for heating and cooling, respectively (kWh/m^2a) [5-7], the global warming power for the evaluation of CO_2 emissions (kgCO_2/m^2a) [5, 6, 8], the total cost (the sum of energy cost, insulation material cost, and the cost in terms of CO_2) [5, 8] related to the payback period [9].

The choice of the structure and technological solution for the external envelope is not the only necessary step to be dealt with by designers starting a project. At the same time, during the preliminary phase of the design process it is equally fundamental to understand which parameters related to the building external envelope mostly affect the energy needs. This is necessary to adopt immediately, in the early stages of the design and during the related decision-making process, all the measures and architectural choices that efficiently re-duce the building energy needs. It is fundamental according to recent a Euro-pean Directive and Italian legislation about energy savings in buildings and environmental impact reduction, since buildings are responsible for 36% of energy consumption and 39% of CO_2 emissions.

One of the methods used to identify these parameters is the sensitivity analysis. Used since 1970 [10], this method can be helpful to the designer to establish the contribution of each of the design features that can be parameterized (input) in relation to the building primary energy demand (output). Many studies in literature applying this methodology with respect to energy needs concern office buildings [11, 12] and homes. For instance, Hemsath et al. [13] study the influence of the shape of the building and the relation of two dimen-sions of the floor with respect to the energy needs according to different cli-mate conditions, performing 2 different types of sensitivity analysis (definition of sensitivity index and Morris global sensitivity analysis). They state that gen-erally the choice of the shape affects energy consumption more than the choice of technological solution for the external envelope. Smith et al. [14] consider the roof solar absorptance, the air exchange rates and the sub-roof R-value for the analysis with respect to energy needs for heating and cooling. These pa-rameters affect the energy balance of the examined building as they greatly affect the value of dispersions and internal gains. Heiselberg et al. [15] per-formed a global sensitivity analysis by varying 21 parameters within a fixed range considering a multi-storey office building. For this building type the re-sults show that lighting control of artificial lighting and the air change rate through mechanical ventilation are the factors that mostly influenced the ener-gy demand. Finally

Harkouss et al. [16] after finding the best combination of strategies in order to achieve a Nearly Zero Energy Building (nZEB) and opti-mizing each considered variable (external walls and roof insulation thickness, windows glazing type, cooling and heating setpoints and window-to-wall ratio – WWR), performed the sensitivity analysis to validate the results.

The main aim of the presented study is firstly to analyse and compare five different technological solutions for the external wall with five different typologies of load-bearing layer combined with four different load-bearing structures (reinforced concrete, steel, platform frame, and cross laminated timber (XLAM)) and considering four different materials for the external insulation layer (wood fibre, sintered expanded polystyrene, rock wool, and glass wool). Secondly, for the sake of completeness, to perform one-at-a-time step sensitivity analysis in order to identify which are the factors, always related to the building envelope, that mostly influence kindergartens energy performance considering different Italian climate zones (E-D-B).

Method and input data

For the first type of the analyses, the minimum thickness of insulation to be used for the five different technological solutions was initially defined in order to comply with the minimum thermal transmittance (U measured in W/m^2K) required for the reference building [17]. Then, the dynamic thermal properties of the external wall were calculated and, according to the four dif-ferent materials considered for the insulation layer, the thickness of the insula-tion was increased or kept the same in order to obtain a periodic thermal transmittance (Y_{IE} measured in [W/m^2K]) less than 0.10 W/m^2K, as required by current energy regulation, and a time shift (φ measured in [hours]) possibly equal to 8 h. Later, a parametric analysis was carried out by varying – with a step of 0.02 m – the thickness of each insulation typology for each technologi-cal solution for the external wall in a range within the minimum required by the regulation and a maximum of 0.24 m, considered as the maximum thick-ness achievable from a constructive point of view. For each solution, the ener-gy consumption for heating and cooling (kWh/m^2a) was calculated through an energy simulation in a dynamic regime with an hourly time step. Finally, the environmental impact was defined in terms of CO_2 ($kgCO_2/m^2a$) both for the construction and operational phase.

For energy simulations, a typological model for the kindergarten with a compact shape and internal courtyard (model I1) was considered [18]. It was developed on a single ground floor (with a gross surface area equal to approximately 1050 m^2), with an aspect ratio equal to 0.53 m^{-1} (Figure 1). This model was configured in a previous stage of the research with two others characterised by linear shape respectively with three (model I2) (Figure 2) and six classrooms (model I3) (Figure 3) [18].

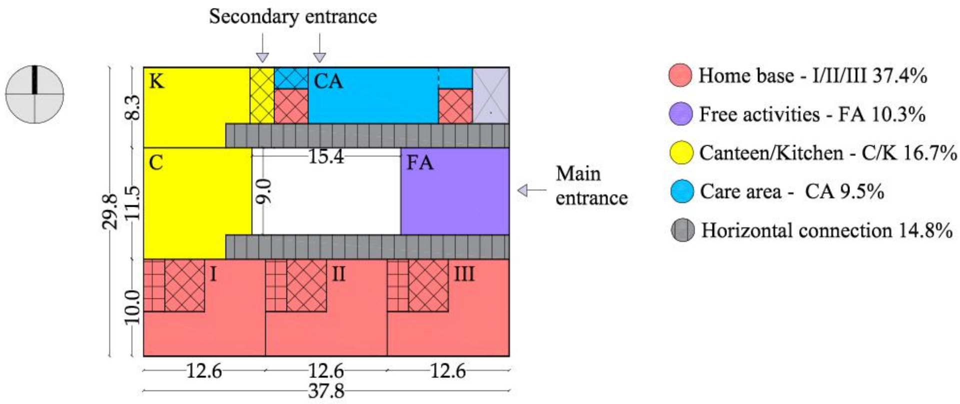


Fig. 1. Model I1 for kindergarten. In the figure the building's main dimensions and the functional units' distribution with respective percentages are showed.

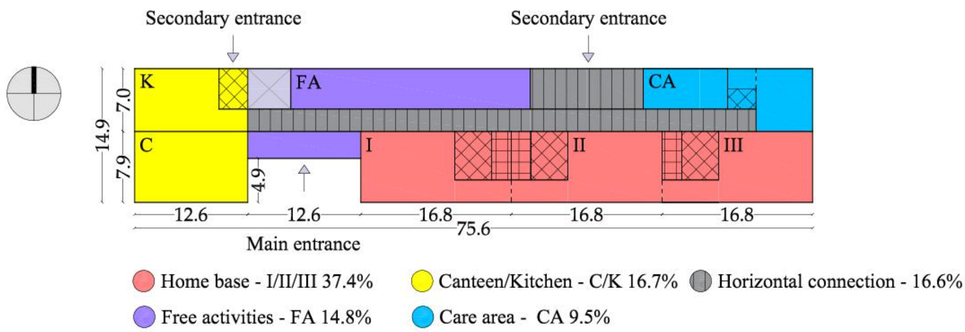


Fig. 2. Model I2 for kindergarten. In the figure the building's main dimensions and the functional units' distribution with respective percentages are showed.

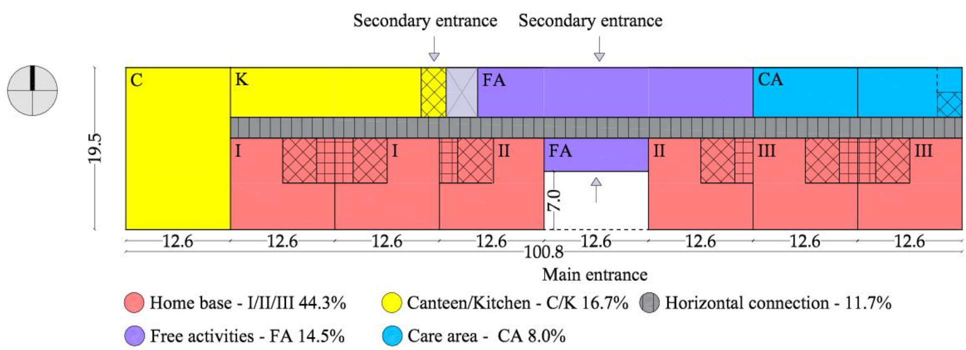


Fig. 3. Model I3 for kindergarten. In the figure the building's main dimensions and the functional units' distribution with respective percentages are showed.

For these types of study, the energy simulations were carried out considering the city of Florence located in climate zone D, as Italian regulation establishes. Florence is characterised by 1415 heating degrees days (HDD) and a temperate climate with warm summer season and cold and humid winter (Cfd for Köppen-Geiger classification).

The technological solutions for the external wall, related to suitable structural systems, are the following:

- Solution 1: reinforced concrete frame structure, with load bearing layer in lightweight bricks (0.30 m), external insulation (0.02 m), and a false wall constituted by a double plasterboard panel (0.015 m) and rock wool insulation layer (0.05) to ensure the right acoustic insulation required by regulation.
- Solution 2: steel frame structure, external wall made of dry solution with cement board external panel (0.0125 m), waterproofing sheet (0.0018 m), insulation layer (0.08), plasterboard panel (0.015 m), and false wall, as in Solution 1.
- Solution 3: steel frame structure, load bearing layer in aerated autoclaved concrete blocks (0.30 m), and false wall, as in Solution 1.
- Solution 4: wooden platform frame structure, external insulation (0.02 m) applied on a single oriented strand board (OSB) (0.02 m), internal insulation layer (0.06), waterproofing sheet (0.0018 m), single OSB panel (0.02 m), and false wall, as in Solution 1.
- Solution 5: XLAM wooden structure, external insulation applied on XLAM wall (0.04 m), and false wall as in Solution 1.

In the results (Table 3), solutions 1-5 refer to a thickness of insulation equal to the minimum required by regulation, while solutions 1A–5A have a thickness such as to obtain the right dynamic thermal transmittance value and a proper time shift.

In order to perform the energy simulation these technological solutions for the roof layer are adopted:

- Solution 1: made with a brick slab (0.32 m) completed with slope screed (minimum 0.05 m), vapour barrier with polypropylene protective felt and 0.00045 m polyethylene-copolymer film, wood fibre insulation, bituminous waterproofing sheet with double reinforcement (0.005 m) and 0.05 m gravel layer.
- Solution 2-3: constituted of a corrugated sheet slab (0.0015 m thick and 0.053 m high) with a 0.045 m collaborating slab, slope screed (minimum 0.05 m), vapour barrier with polypropylene protective felt and 0.00045 m polyethylene-copolymer film, wood fibre insulation, bituminous waterproofing sheet with double reinforcement (0.005 m) and 0.05 m gravel layer.

- Solution 4: made with a platform frame structure with a single OSB panel of 0.02 m, vapour barrier with protective polypropylene felt and polyethylene-copolymer film (0.00045 m), wood fibre insulation, wood cement panel (0.022 m), bituminous waterproofing sheet with double reinforcement (0.005 m) and gravel layer of 0.05 m.
- Solution 5: made of a wooden structure with XLAM panel of 0.13 m, vapour barrier with polypropylene protective felt and polyethylene-copolymer film (0.00045 m), wood fibre insulation (low density – 0.04 m), wood fibre insulation (high density), wood cement panel (0.022 m), bituminous waterproofing sheet with double reinforcement (0.005 m) and 0.05 m gravel layer.

Moreover, in order to evaluate the influence of some parameters related to the external envelope on the models primary energy demand, a one-a-at-time step sensitivity analysis was perfomed. This is the simplest method to be able to make this evaluation and to quantify in percentage the impact of every variable examined.

The study was performed by considering one typological model as a reference model and by varying each factor within a specific range, keeping the remaining fixed. The variations concern the following parameters: shape of the building, different types of structure and technological solutions (sol. 1-2-4), thermal transmittance for the façade and roof, green roof technological solution, WWR for each orientation, solar shading type for South orientation and the use of solar shading system for East and West orientation. To be thorough, the analysis was also carried out in relation to the final energy consumption for heating and cooling as the influence of individual parameters could change with respect to the reference season. In order to show the results of the sensitivity analysis, the sensitivity index has not been defined [15] but the variation in percentage of each individual parameter was calculated with respect to the model considered as the reference model. This was necessary because not only numerical factors which vary in a precise range have been analysed, but also building features as shown in Table 1.

Tab. 1. Range of the considered parameters for on-a-time step sensitivity analysis

N.	Parameter	Range
1	Shape	2 types (model I2 and I3)
2	Type of structure	4 types (sol. 1 – 2 – 4)
3	Façade thermal transmittance (E)	0.239 W/m^2K – 0.104 W/m^2K
	Façade thermal transmittance (D)	0.275 W/m^2K – 0.104 W/m^2K
	Façade thermal transmittance (B)	0.145 W/m^2K – 0.104 W/m^2K
4	Roof thermal transmittance (E)	0.219 W/m^2K – 0.106 W/m^2K
	Roof thermal transmittance (D)	0.249 W/m^2K – 0.120 W/m^2K
	Roof thermal transmittance (B)	0.340 W/m^2K – 0.177 W/m^2K

N.	Parameter	Range
5	Green roof technological solution	use it – not use it
6	South WWR	33%; 50%; 76%
7	East WWR	17%; 29%; 36%
8	West WWR	17%; 23%; 29%
9	Type of solar shading (South)	4 types (9.1-9.2-9.3-9.4)
10	Vertical solar shadings	West – East orientation

The sensitivity analysis was carried out considering 3 different cities (Bolzano, Florence, Palermo) belonging to three different climate zones in Italy (E-D-C). Bolzano is characterised by 2791 HDD and a continental climate with cold winter (Dfb for Köppen-Geiger classification). While Palermo has 751 HDD and temperate Mediteranean climate with droughty summer (Cfa for Köppen-Geiger classification).

As a reference model for the analysis, model I1 is considered. The solution 5 is used as the structure and technological solution for the external envelope considering a wood fibre insulation layer.

To make clearer the performed variations, some details are needed:

- The first variation concerns the shape of the building. By comparison, the two other kindergarten configurations are considered. The model I2 is characterised by a gross surface area equal approximately to 1060 m^2 with aspect ratio equal to 0.51 m^{-1}. While model I2 is developed on approximately 1630 m^2 of gross surface area with an aspect ratio equal to 0.41 m^{-1}. The shape of the building is related to the external envelope since the changing of the aspect ratio value leads to a variation of dispersing surface of the envelope.
- The second variation deals with the type of structure and wall technological solution used. The other four solutions (sol. 1 – 2 – 4) are considered as an alternative for one of the reference models.Solution 3 is not considered in this analysis because in this case the thermal transmittance is not comparable due to the lower thermal conductivity of the autoclaved aerated concrete blocks.
- The fifth variation involves the use of the green roof technological solution and the following parameters are assumed (Table 2) [19] [20].

Tab. 2. Simulation set up for green roof technological solution

Parameter	Unit	Value
Conductivity of dry soil	W/mK	0.20
Density of dry soil	Kg/m^3	1020
Specific heat of dry soil	J/kgK	1093
Saturation volumetric moisture content of the soil	–	0.13
Thermal absorptance	–	0.96

Parameter	Unit	Value
Solar absorptance	–	0.85
Height of plants	m	0.10
Leaf Area Index (LAI)	m^2/m^2	3.00
Leaf reflectivity	–	0.19
Leaf emissivity	–	0.97
Minimum stomatal resistance	$mmol/m^2s$	120
Maximum volumetric moisture content	–	0.5
Minimum residual volumetric content	–	0.01
Initial volumetric moisture content	–	0.15

- The variations from 6 to 8 concern the WWR. The variation of WWR is considered for each orientation except for the North façade where it is maintained equal to the minimum value required by Italian legislation in order to satisfy health-hygiene standards and to avoid an increase in dispersions and consequently an increase in heating energy consumption. The maximum WWR is equal to that which can be achieved within the functional unit and setting as a limit for height corresponding to a suspended ceiling inside rooms.
- The ninth and tenth variations deal with the type of solar shading system and it is necessary to consider separately the different orientations. For South orientation four different solutions are varied: internal blinds with horizontal slats with high reflection and control on solar radiation equal to 120 W/m^2 – 9.1, combination of 2 m overhang and internal blinds with horizontal slats with high reflection and control on solar radiation equal to 120 W/m^2 – 9.2, horizontal louvres – 9.3, external with horizontal slats with high reflection and control on solar radiation equal to 120 W/m^2 – 9.4). Instead, for East and West orientation the possible use of vertical solar shadings is evaluated.

All the energy simulations in the dynamic regime with an hourly time-step, related to both analyses, were carried out with Design Builder. The following parameters relating to each thermal zone are considered: occupancy (per-son/m^2) according to UNI (Italian National Agency of unification) 10339 (June 1995 – Appendix A) [21], minimum air change rate refers to the same legisla-tion (June 1995 – Table 3) [21] and, finally, internal gains in line with UNI/TS (UNI/Technical specification) 11300-1 (October 2014 – Table 17) [22]. Con-cerning the level of illuminance UNI EN (UNI European Standard) 12464-1 [23] was considered. The lighting efficiency was considered equal to 120 lm/W with the use of LED lights. Lighting control is applied with a maximum allowed discomfort glare index (DGI) equal to 22.

As far as the system is concerned, the first analysis deals with a wall technological solution, a heat pump for heating (coefficient of performance COP=3.6) and for cooling (energy efficiency ratio EER=3.2) is considered and a controlled mechanical ventilation system with sensitive heat recovery with efficiency equal to 65% is used. By contrast, in the second study involving sensitivity analysis, a gas condensing boiler with 90% efficiency for heating and a heat pump for cooling (energy efficiency ratio EER=2.5) are considered and a controlled mechanical ventilation system with sensitive heat recovery with efficiency equal to 65% is adopted.

Results and discussion

Table 3 shows the dynamic thermal transmittance (Y_{IE} measured in [W/m^2K]) and the time shift (φ measured in [hours]) and the thickness of insulation (t measured in [m]) of the five technological solutions analyzed with respect to each insulation material considered. It is possible to notice immediately that the two options (1-5 and 1A–5A) corresponded for most solutions.

Tab. 3. Dynamic thermal characteristics of different types of technological solutions

<table>
<tr><th></th><th colspan="3">Wood Fiber</th><th colspan="3">EPS</th><th colspan="3">Mineral Wool</th><th colspan="3">Glass Wool</th></tr>
<tr><th>Sol</th><th>Y_{IE}</th><th>Φ</th><th>t</th><th>Y_{IE}</th><th>φ</th><th>t</th><th>Y_{IE}</th><th>φ</th><th>t</th><th>Y_{IE}</th><th>φ</th><th>t</th></tr>
<tr><td>1</td><td rowspan="2">0.009</td><td rowspan="2">18.47</td><td rowspan="2">0.02</td><td rowspan="2">0.009</td><td rowspan="2">18.31</td><td rowspan="2">0.02</td><td rowspan="2">0.009</td><td rowspan="2">18.36</td><td rowspan="2">0.02</td><td rowspan="2">0.008</td><td rowspan="2">18.37</td><td rowspan="2">0.02</td></tr>
<tr><td>1A</td></tr>
<tr><td>2</td><td>0.207</td><td>4.69</td><td>0.08</td><td>0.216</td><td>2.23</td><td>0.08</td><td>0.239</td><td>2.80</td><td>0.08</td><td>0.236</td><td>2.75</td><td>0.08</td></tr>
<tr><td>2A</td><td>0.087</td><td>8.14</td><td>0.14</td><td>0.095</td><td>8.10</td><td>0.32</td><td>0.058</td><td>8.27</td><td>0.24</td><td>0.059</td><td>8.08</td><td>0.24</td></tr>
<tr><td>3</td><td rowspan="2">0.018</td><td rowspan="2">15.89</td><td rowspan="2">–</td><td rowspan="2">0.018</td><td rowspan="2">15.89</td><td rowspan="2">–</td><td rowspan="2">0.018</td><td rowspan="2">15.89</td><td rowspan="2">–</td><td rowspan="2">0.018</td><td rowspan="2">15.89</td><td rowspan="2">–</td></tr>
<tr><td>3A</td></tr>
<tr><td>4</td><td rowspan="2">0.05</td><td rowspan="2">11.88</td><td rowspan="2">0.04</td><td>0.101</td><td>9.19</td><td>0.04</td><td rowspan="2">0.099</td><td rowspan="2">9.33</td><td rowspan="2">0.04</td><td rowspan="2">0.099</td><td rowspan="2">9.18</td><td rowspan="2">0.04</td></tr>
<tr><td>4A</td><td>0.079</td><td>9.76</td><td>0.06</td></tr>
<tr><td>5</td><td rowspan="2">0.02</td><td rowspan="2">14.36</td><td rowspan="2">0.04</td><td rowspan="2">0.02</td><td rowspan="2">13.82</td><td rowspan="2">0.04</td><td rowspan="2">0.02</td><td rowspan="2">13.94</td><td rowspan="2">0.04</td><td rowspan="2">0.02</td><td rowspan="2">13.95</td><td rowspan="2">0.04</td></tr>
<tr><td>5A</td></tr>
</table>

It is possible to state that the change of the insulation material mainly affected the solutions that had less mass surface: Solution 2 ($60\ kg/m^3 < M_s < 70\ kg/m^3$) and Solution 4 ($107\ kg/m^3 < M_s < 115\ kg/m^3$). For instance, when using EPS (sintered expanded polystyrene) insulation (density $\rho = 35\ kg/m^3$) for Solution 2, 0.32 m is needed to ensure a time shift greater than 8 h. Consequently, for climate zones with particularly hot summers, it is advisable to use a technological solution with high surface mass in order to ensure proper internal comfort conditions, especially during the summer season, or a solution with lower mass surface but combined with an insulation material with higher density: for instance, wood fiber (density ρ = 160 kg/m^3). The following graphs (Figures 4 and 5) illustrate the trend of energy needs, respectively, for heating and cooling with respect to the variation of insulation thickness for each technological solution.

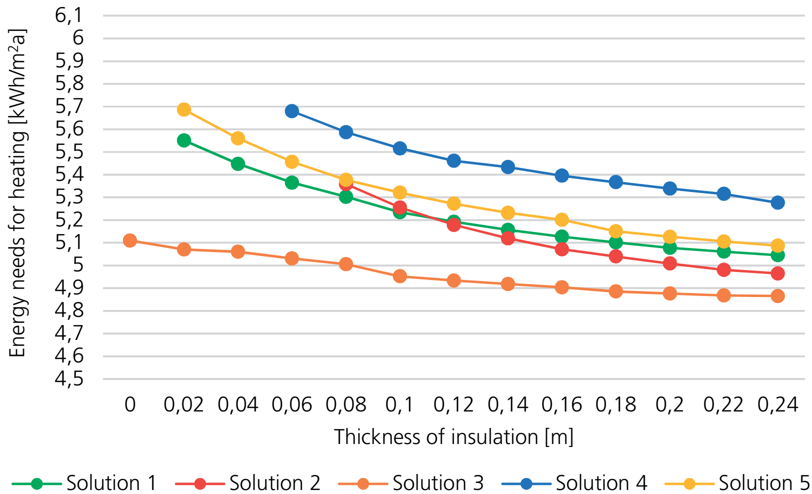


Fig. 4. Energy needs for heating for different types of technological solutions.

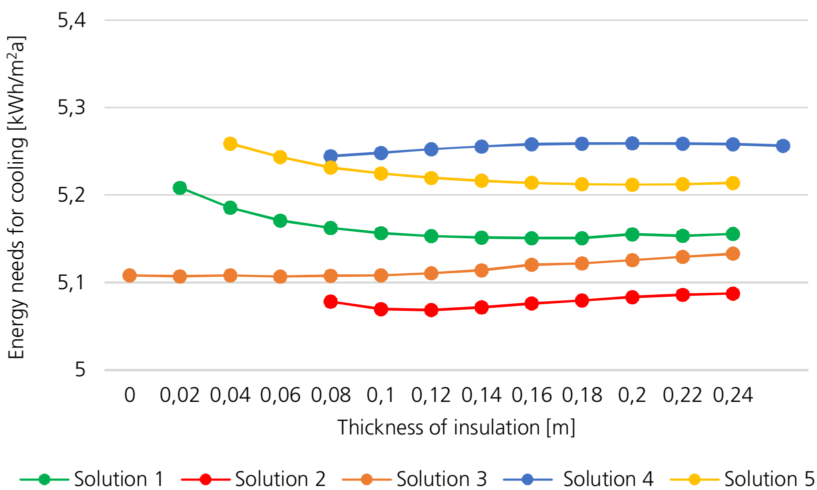


Fig. 5 Energy needs for cooling for different types of technological solutions.

The trend of consumptions was the same for each insulation material considered, as they were characterized by similar thermal conductivities. The analysis was performed only for the city of Florence because the trend of this curve of consumptions is the same for all the Italian climate zones. In accordance with the literature, the results obtained showed that the variation of the thickness of insulation mainly influenced the energy needs for heating. In addition, the effect on the energy needs was higher for lower insulation thickness (<0.14 m). As for cooling, the increase in insulation did not lead to a significant reduction in energy needs. For the solutions with lower mass surface, the increase in insulation thickness led to a proportional rise in energy needs for cooling (solution 2).

However, the following graph (Figure 6) shows the CO_2 emissions trend exclusively due to the construction of the building with respect to the insulation layer variation (wood fiber and EPS) for technological solutions 1 and 4. These were the worst and the best solutions, respectively, when considering the environmental impact. The emissions during the operational phase were null because a heat pump powered by photovoltaic panels installed on the roof was considered for the building, and they met 100% of the electricity energy needs of the building. For both options, the increase in emissions was proportional to the rise in insulation thickness, even if the solutions with EPS were characterized by a greater slope than wood fiber ones. The graph shows that the analyzed technological solutions were characterized by similar environmental impacts. As a matter of fact, the global warming power (GWP) changed within a range of 7 $kgCO_2$ and 11.5 $kgCO_2$, considering the minimum insulation thickness required by current Italian regulation.

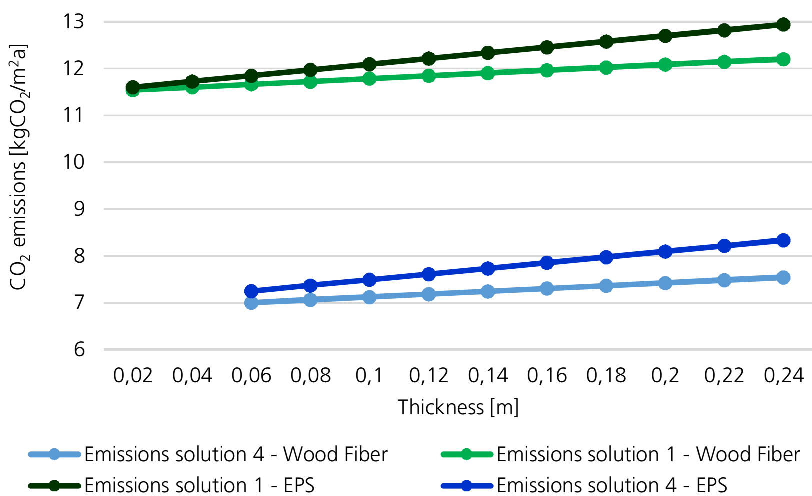
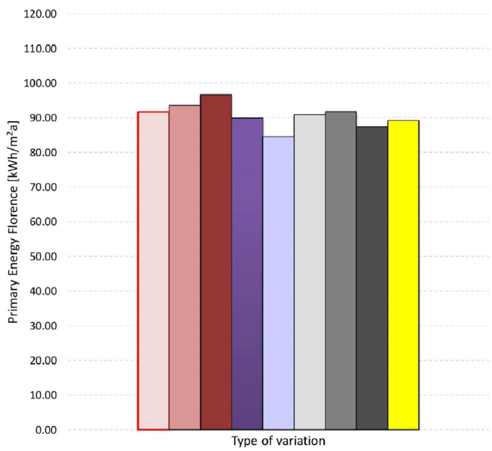
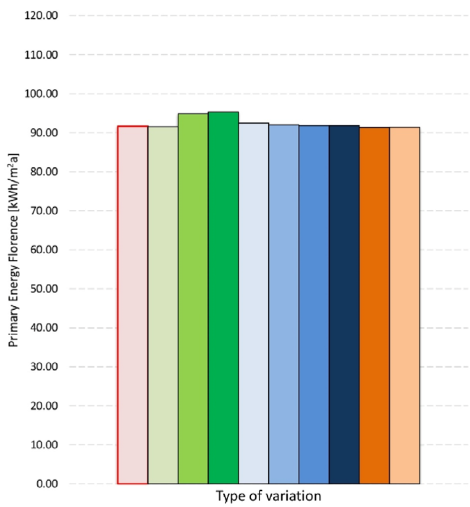


Fig. 6. CO_2 emissions of technological solutions 1 and 4.



Type of variation		
Parameter	Range	
Reference building		
Shape	Model I2	
	Model I3	
Façade thermal transmittance	0.275 W/m²K – **0.104 W/m²K**	
Roof thermal transmittance	0.249 W/m²K – **0.120 W/m²K**	
Type of structure	Solution 4	
	Solution 2	
	Solution 1	
Green roof technological solution	**use it** – not use it	

Fig. 7. Primary energy demand for Florence with respect to shape, insulaton, structure and green roof – table 1.



Type of variation		
Parameter	Range	
Reference building		
South WWR	33%; 50%; **76%**	
East WWR	17%; 29%; **36%**	
West WWR	17%; 23%; **29%**	
Type of solar shading (South)	Overhang of 2 m + internal blind with solar control	
	Internal blind with solar control	
	Horizontal louvres	
	External blind with solar control	
Vertical solar shadings	East orientation	
	West orientation	

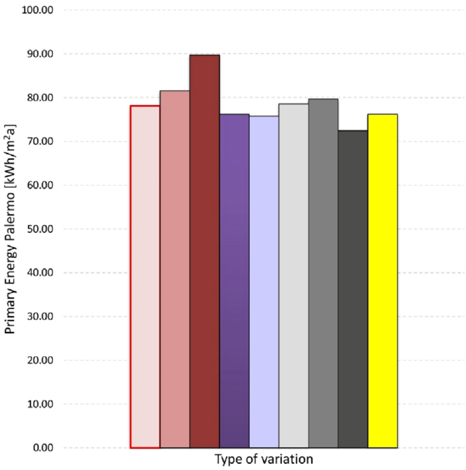
Fig. 8. Primary energy demand for Florence with respect to WWR and horizontal and vertical solar shadings – table 1.

As far as sensitivity analysis related to building envelope is concerned, figures 7 and 8 are related to the city of Florence and they show the results by relating the final energy consumption [kWh/m^{2}K] of the reference model with the final energy consumption of the model obtained by assuming different variations (Table 1). For the construction of graphs for each variable the minimum or maximum value was considered depending on how the single parameter affects the energy needs. Given the wide range of variables, as already explained, the value assumed (minimum or maximum) has been defined compatibly with the geometry of the building or with exclusively technological features. The goal is to establish how the maximum variation of each individual parameter changes in percentage the primary energy demand with respect to the corresponding value of the building taken as a reference. Obviously, it is necessary to point out that the results of the sensitivity analysis listed below are strictly linked to functional bands and units' distribution, orientation, intended use and occupancy level of the analysed building.

Figures 7-8 illustrate that for the city of Florence the shape with internal courtyard (model I1), that is considered as the reference model for the sensitivity analysis performed, has the better energy performance with respect to primary energy demand. Between the best model I1 and the worst there is a difference of about 5 kWh/m^{2}a. Despite that, the shape with a predominant linear development with 6 classrooms (model I3) achieves a saving of final energy demand for heating (~ 30%) compared to compact shape with internal courtyard (model I1). This is related to the shape of the building plan that has a predominant horizontal development with the main direction along East-West axis. This permits the exploitation of solar gains and to reduce demand for heating while causing, at the same time, a noticeable increase (> 40%) in demand for cooling. With respect to the demand for cooling the model I2 leads to a decrease in final energy of about 7% compared with the reference model. In relation to the characteristics of the building, as can be seen from the graphs (Figures 5 and 6), the choice of the type of structure and consequently the identification of the solution for the technological systems for the external envelope are the variables that mainly affect the primary energy demand. The use of double OSB panel (solution 4), leads to an increase in final energy consumption for cooling equal to about 10%. This is mainly related to the reason that this external wall does not have enough thermal mass and related periodic thermal transmittance to ensure a proper decrement factor and time shift of the thermal wave considering a minimum thickness of insulation to meet the thermal transmittance required by Italian regulation. The external wall solution with double OSB panel (solution 4) is characterized by: decrement factor f_D=0.27 [–], time shift φ=10.81 h and periodic thermal transmittance Y_{ie}=0.068 W/m^{2}K in according to UNI EN ISO (UNI EN International Organization for Standardization) 13786 [24]. These values are definitely worse than those that are possible to be obtained by adopting the solution with XLAM panel (solution 5). Solution 1 shows a better behaviour of above-mentioned values than the reference solution (solution 5).

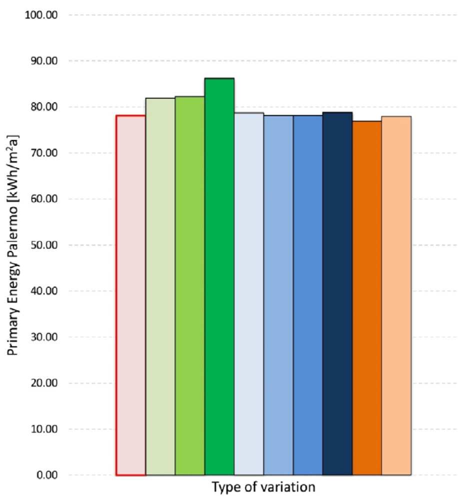
The increase in thickness of insulation on the roof floor significantly affects the primary energy needs compared to the same increase in thickness of external wall insulation (~ 8.5%). The upper limit set for both is the thickness of insulation that achieves a thermal transmittance equal to half of that required by current legislation for reference building.

The use of green roof technological solution for a roof floor primarily leads to a decrease in energy needs for cooling (8%) but generally to a small decrease in primary energy consumption equal to approximately 2.70%. The green roof allows a lower surface temperature to be obtained because it absorbs lower solar energy than traditional solutions and it enables more control of the building internal temperature by minimizing the energy needs for cooling [24].



Type of variation	
Parameter	Range
Reference building	
Shape	Model I2
	Model I3
Façade thermal transmittance	0.145 W/m^2K – **0.104 W/m^2K**
Roof thermal transmittance	0.340 W/m^2K – **0.177 W/m^2K**
Type of structure	Solution 4
	Solution 2
	Solution 1
Green roof technological solution	**use it** – not use it

Fig. 9. Primary energy demand for Palermo with respect to shape, insulaton, structure and green roof – table 1.



Type of variation	
Parameter	Range
Reference building	
South WWR	33%; 50%; **76%**
East WWR	17%; 29%; **36%**
West WWR	17%; 23%; **29%**
Type of solar shading (South)	Overhang of 2 m + internal blind with solar control
	Internal blind with solar control
	Horizontal louvres
	External blind with solar control
Vertical solar shadings	East orientation
	West orientation

Fig. 10. Primary energy demand for Palermo with respect to WWR and horizontal and vertical solar shadings – table 1.

For Florence the increase in WWR for South orientation leads to a benefit in terms of final energy demand for heating while for East and West orientation the increase in WWR negatively affects the energy balance but not significantly for a climate zone characterized by a climate with cold winter. Furthermore, for a building characterized by this internal functional distribution (Figure 1) the use of solar shadings for eastern and western façades does not remarkably influence the primary energy demand. This result is mainly related to the reason that in the model there are not windows in these orientations for classrooms that are the functional units with higher occupancy density during teaching time.

As regard the city of Palermo figures 9 and 10 concern the results of the sensitivity analysis performed.

For the city of Palermo, the model I1 is the one that ensures the minimum primary energy demand and the difference with the model I3 is noticeable (~ 13%).

In detail, it is possible to point out that as for climate zone D, the choice of the type of structure and the connected technological solution for the external wall are the parameters that mainly affect the final energy demand of the building, even if in a lower measure with respect to the shape.

The wooden structure with double OSB panel (solution 4) leads to an increase in primary energy demand equal to about 2% for a city with a mild climate where the demand for cooling is prevalent with respect to the demand for heating. With respect to the final energy for cooling solution 4 causes a rise in final energy needs for cooling equal to about 10% compared to the reference model (solution 5).

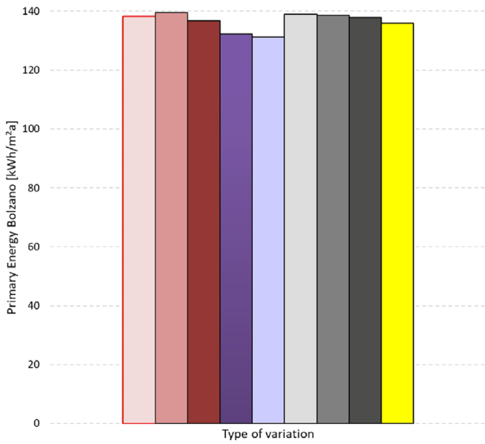
The use of the green roof technological solution does not cause a remarkable advantage in terms of primary energy demand (< 2%).

In contrast to climate zone D, for climate zone B the increase in WWR in each orientation negatively influences the energy needs. For instance, for Palermo, the increase in WWR for East façade leads to a corresponding increase of 9% of primary energy demand even though it is calculated according to windows for areas with lower occupation during teaching time.

Finally, the figures 11 and 12 show the results for the city of Bolzano.

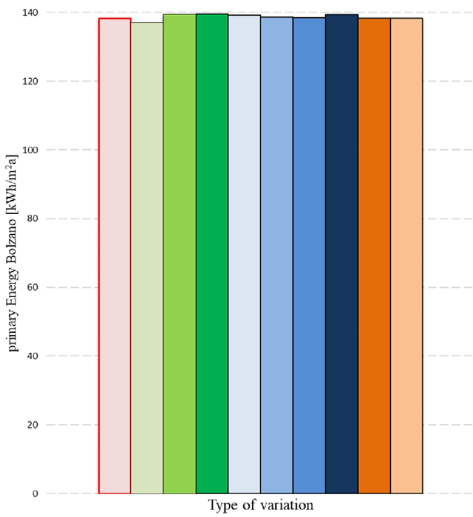
As far as the city of Bolzano is concerned, the more significant results are related to the variation of the shape and the thickness of insulation for wall and roof.

By contrast to the other climate zones considered, the model I3 has the better energy performance compared to the reference model (model I1). This is due to the building linear shape and prevalent South orientation that ensures the solar gains exploitation during winter season in a city where the demand for heating most affect the energy balance.



Type of variation		
Parameter	Range	
Reference building		
Shape	Model I2	
	Model I3	
Façade thermal transmittance	0.239 W/m²K – **0.104 W/m²K**	
Roof thermal transmittance	0.219 W/m²K – **0.106 W/m²K**	
Type of structure	Solution 4	
	Solution 2	
	Solution 1	
Green roof technological solution	**use it** – not use it	

Fig. 11. Primary energy demand for Bolzano with respect to shape, insulaton, structure and green roof – table 1.



Type of variation		
Parameter	Range	
Reference building		
South WWR	33%; 50%; **76%**	
East WWR	17%; 29%; **36%**	
West WWR	17%; 23%; **29%**	
Type of solar shading (South)	Overhang of 2 m + internal blind with solar control	
	Internal blind with solar control	
	Horizontal louvres	
	External blind with solar control	
Vertical solar shadings	East orientation	
	West orientation	

Fig. 12. Primary energy demand for Bolzano with respect to WWR and horizontal and vertical solar shadings – table 1.

The increase in the thickness of insulation for the facades result in a noticeable decrease in primary energy demand equal approximately to 4.5%. The same applies to the roof with 5.4%.

While for climate zones D and B the type of structure and technological solution influence the primary energy demand, on the contrary for climate zone E there is a slight difference between the different type of solutions analysed.

Finally, with respect to WWR variation a low decrease (~ 1%) happens with a South WWR equal to 76%.

The use of a green roof technological solution does not cause a significant benefit in terms of primary energy demand (~ 1.7%).

As expected for this climate zone the insulation of the building envelope is the parameter that most affects the primary energy demand.

Since it was not possible to calculate the sensitivity index for each single variation (Table 1), table 4 shows the variation in percentage of primary energy demand for the city of Florence, Palermo and Bolzano with respect to the model considered as reference model (model I1). The negative values state the decrease in percentage in primary energy demand obtained by varying the corresponding parameters (Table 1) with respect to the reference model.

Tab. 4. Results in percentage of sensitivity analysis

N	Parameter	Florence	Palermo	Bolzano
1	Shape	2.00%; 5.00%	4.30%; 13%	0.9%; –1%
2	Type of structure	~0%; ~0%; –5%	0.5%; 2%; –8%	0.5%; 0.3%; –0.3%
3	Façade thermal transmittance (E)	–	–	–4.5%
	Façade thermal transmittance (D)	–2.00%	–	–
	Façade thickness of insulation (B)	–	–2.50%	–
4	Roof thermal transmittance (E)	–	–	–5.4%
	Roof thermal transmittance (D)	–8.50%	–	–
	Roof thermal transmittance (B)	–	–3.00%	–
5	Green roof technological solution	–2.70	–1.70%	–1.7%
6	South WWR	<1%; <1%; –0.1%	1.40%; 2.60%; 4.60%	–0.3%; –0.5%; –0.8
7	East WWR	1.70%; 2.60%; 3.40%	4.40%; 7.50%; 9.30%	<1%; <1%; 0.9%
8	West WWR	1.80%; 2.50%; 3.40%	2.80%; 3.40%; 5.00%	<1%; <1%; 0.8%
9	Type of solar shading (South)	<1%; <1%; <1%; 1.40%	<1%; <1%; <1%; 1%	<1%; 0.7%; <1%; 0.9%
10	Vertical solar shadings	–0.2%; –0.3%	–0.2%; –1.50%	<1%; <1%

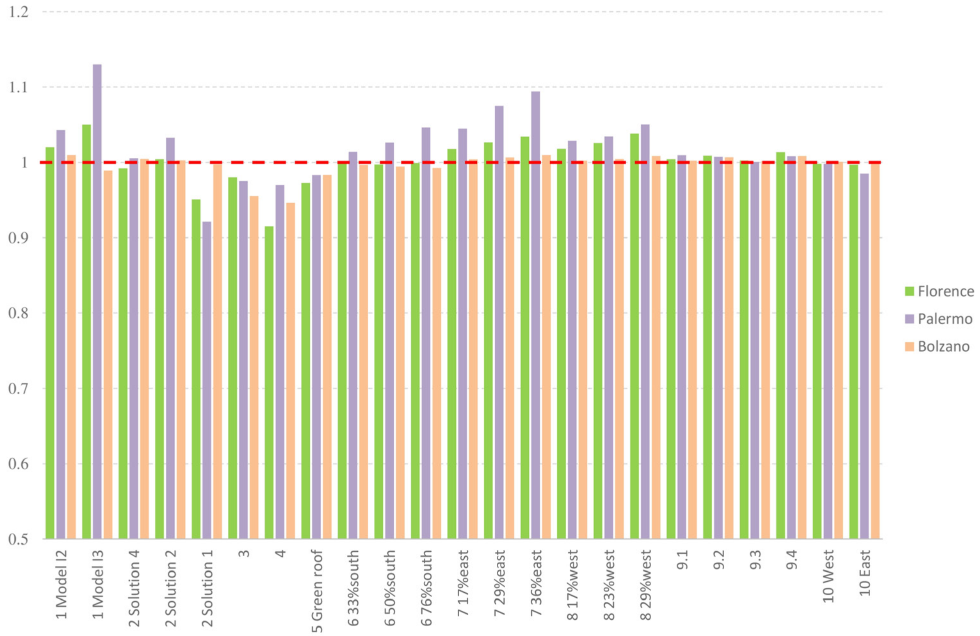


Fig. 13. Results of the sensitivity analysis for the cities of Florence, Palermo and Bolzano. The values are normalized with respect to model I1.

Summary

In conclusion, if the technological solutions for the external walls meet the Italian law requirements in terms of thermal transmittance and dynamic thermal transmittance, it is possible to use each one of the recommended insulation materials that are valid options for the construction of zero emissions kindergartens in Italy indiscriminately. All the analyzed technological solutions for the external wall allow a good energy performance to be obtained (primary energy demand equal to about 24 kWh/m^{2}a) and low CO_2 emissions for construction (within 7 kgCO_2 and 11.5 kgCO_2) with the aim of a carbon-free economy by 2050. This is valid for each type of proposed insulation material that ensures a thermal transmittance for the external envelope equal to about 0.28 W/m^{2}K.

As far as sensitivity analysis is concerned the performed simulations point out that the variation of different external envelope features implies an influence on building primary energy demand in all examined climate zones that cannot be ignored to design carbon zero schools. The choices made already in the preliminary phase of the design process in relation to strategies and techniques to be used in the building will significantly affect the energy performance of the building and the environmental impact.

In conclusion, as the analysis shows, for what concerns the choice of the proper technological solution for the opaque external envelope for both Florence (climate zone D) and Palermo (climate zone B) the periodic thermal transmittance (Y_{IE} < 0.1 W/m^{2}K) is essential to reduce the building primary energy demand. By contrast, for the city of Bolzano (climate zone E) the change of the type of structure does not lead to a significant benefit or disadvantage in terms of building energy performance.

Furthermore, for all climate zones the increase in thickness of insulation for a roof floor leads to a sensible decrease in primary energy demand. For climate zone D, where the energy contribution for heating is prevalent, an increase of thickness of insulation for external wall results in a corresponding decrease in the related energy needs equal respectively to 2% and 8.5%. The same happens for climate zone E where the decreases are respectively of 4% and 5.4%.

Moreover, as regards Florence, the implementation of WWR equal to 76% for southern façade affects the final energy demand for heating of approximately 5%. As far as Bolzano is concerned this decrease in demand for heating is equal to about 2 kWh/m^{2}a.

Instead, to reduce the energy consumption due to cooling a technological solution for roof floor with green roof can be used. For climate zone B, the parameter that mainly affects the primary energy demand is the WWR. Table 4 shows that for the city of Palermo to reduce primary energy demand, primarily linked to the energy needs for cooling, it is necessary to minimize windows and to maintain the WWR required by health-hygiene Italian standards.

For all climate zones the use of solar shadings for East and West façade does not cause a significant variation of primary energy demand, such as the variation of type of solar shading used for South orientation.

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Evaluation of the influence of the primary energy factor of hydropower plants in the methodology for assessing the energy performance of buildings

Keywords: Primary energy; renewable energy; hydropower; energy efficiency

Abstract

There is currently no common or standardized procedure for certification of the energy performance of buildings, as each EU Member State takes into account the specificities of its own construction sector when implementing the provisions of Directive 2010/31/EU. This usually depends on two features: the purpose of the building and the climate. Therefore, the purpose of this paper is to evaluate the influence of the hydropower primary energy factor for assessing the energy performance of buildings. For this purpose, non-renewable primary energy factor values were analyzed regarding actual energy production and consumption data from 19 Lithuanian hydroelectric plants. The results of the studies show that the average value of the non-renewable primary energy factor of hydropower plants is 0.059.

Introduction

Recently, the EU construction sector focuses on sustainable energy use and production. The EU has adopted a new climate and energy framework which includes delivering a minimum 27% share of renewable energy consumption by 2030 [1]. Taking into account the different climatic conditions and building traditions in EU countries, Member States commit themselves to develop national targets, increasing the number of buildings of this type, defining primary energy demand, that is needed for heating, cooling, ventilation and hot water preparation and a using of renewable energy sources in new buildings [2-7].

Lithuania has also adopted a revised National Energy Independence Strategy [8] 2018. The strategy envisages four main directions of Lithuania's energy policy: energy security, development of green energy, energy efficiency, competitiveness and innovation. Over the last few years, support for renewable energy has grown steadily at both national and European level. Therefore, in 2016 renewable energy sources accounted for 25.6% of total final energy consumption and 16.7% of total electricity consumption in Lithuania, mainly due to wind, hydropower and biomass. At the end of 2016, wind energy was the largest single technology, accounting for more than 63% of installed capacity, and hydropower and solar are the other main renewable energy sources, accounting for 15.8% and 9% respectively in the current structure. renewable electricity generation capacity. The share of local energy sources (local oil, peat, wood, geothermal, wind, solar and hydropower, as well as chemical process energy) in the country's primary energy balance was 24.7% and the share of renewable energy sources in the local energy balance was 80.6%. The contribution of hydropower to the absolute value varies depending on climatic conditions, with slight changes and amounts to 3.3% [9].

One of the parameters of renewable energy sources is the primary energy factor [10,11]. The primary energy factor $f_{P,tot}$ is a sum of renewable energy factor $f_{P,ren}$ and non-renewable factor $f_{Pn,ren}$. Renewable energy must account for a major proportion of the energy consumed in a building. Accordingly, the renewable primary energy factor $f_{P,ren}$ is equal to 1 according EN 15603 167 [10]. Meanwhile, the part of the energy from a non-renewable energy source is not known clearly, because the $f_{P,nren}$ depends on the additional energy consumed in the conversion device, which normally uses additional non-renewable energy, such as electrical energy generated from a common grid [11].

This is a very important part of the evaluation of primary energy from hydropower plants. As an ancient technology, hydropower is being challenged by climate change and other environmental concerns [12]. Water availability has different temporal and spatial fluctuations in different locations and water availability fluctuations indirectly and directly affect the different electricity generating technologies [13].

The analyzed literature did not give sufficient information about calculation of value of non-renewable factor. Only with sufficiently accurate data on hydropower renewable ($f_{P,ren}$) and non-renewable ($f_{P,nren}$) primary factors can the amount of renewable and non-renewable primary energy consumed in a building be objectively calculated.

Therefore the aim of this article is to calculate value of non-renewable factors for hydropower plants in Lithuania.

Methods

Data for the investigation (for the period 2007-2014) were collected from 19 hydropower plants operating in Lithuania [14], with the total capacity (107.3 MW) accounting for 79.2% of the total hydropower capacity in the country. The data were collected by interviewing hydropower plants owners/operators and by analyzing the reports of electricity transmission system operators in Lithuania

(Table 1). The main characteristics of the investigated hydropower plants was total installed power capacity, produced electrical energy and consumed electrical energy.

Table 1. The main characteristics of the studied hydroelectric power plants

N_o of hydropower plants	Installed power, MW	Produced energy, MWh	Consumed energy, MWh
1	100.800	324731	3646
2	2.914	12798.5	38.4
3	0.600	2921.4	52.6
4	0.360	1840.1	33.1
5	0.350	929.1	20.9
6	0.320	1430.6	23.3
7	0.300	1412.0	25.4
8	0.264	1028.1	18.5
9	0.264	1094.7	19.7
10	0.260	1174.5	21.1
11	0.260	1383.5	23.5
12	0.110	591.5	0.5
13	0.110	355.4	0.6
14	0.100	307.2	5.5
15	0.090	135.7	2.2
16	0.055	378.1	6.8
17	0.050	168.9	3.4
18	0.045	7.8	0.2
19	0.045	86.6	0.4

The value of the primary non-renewable energy factor $f_{P,nren}$ of hydropower plants was calculated using the methodology described in EN 15603 [10], where included is an energy calculation framework specifying how to define the various energy flows and how to establish the energy boundaries in the building. The total the total primary energy factor was calculated from Equation 1:

$$f_{P,tot} = f_{P,nren} + f_{P,ren} \quad (1)$$

where:

$f_{P,tot}$ – the total primary energy factor, kW·h;
$f_{P,nren}$ – the non-renewable primary energy factor, kW·h;
$f_{P,ren}$ – the renewable primary energy factor, kW·h.

It is assumed that all the energy supplied to the building is attributable to renewable energy because it is made from renewable hydropower plants energy. Accordingly, the renewable primary energy factor $f_{P,ren}$ is equal 1.

The value of the primary non-renewable energy factor $f_{P,nren}$ produced by hydropower plants is given by the formula (Equation 2):

$$f_{P,nren} = \frac{E_{a,nren}}{E_{b,ren}}; \tag{2}$$

where:

$E_{a,nren}$ – the amount of additionally consumed non-renewable energy (from the electrical grid) regarding the produced electricity of the hydropower plants, designed to supply into the building, kWh/year;

$E_{b,ren}$ – the amount of electrical energy, which is produced in hydropower plants and supplied into the building, kWh/year.

Geographical conditions of hydropower plants in Lithuania

The prospects for the use of hydropower depend on natural and geographical conditions. There are about 29.900 rivers and streams longer than 0.25 km in Lithuania – their total length is 63.7 thousand km. The number of rivers and streams longer than 3 km was calculated very accurately – 4418. There are 816 rivers longer than 10 km (3%) and 17 longer than 100 km.

As Lithuania is in the zone of excess moisture, its river network is dense (average density 0.99 km/km^2). In the central lowlands this density is one of the highest (1.45 km/km^2) and in the south-eastern plain one of the lowest (0.45 km/km^2). Due to the flat surface of the country, the slopes of the rivers are small, the water flow is slow, the beds are meandering (Šalčia, Kiauna, Merkys and Grūda are the most meandering). Most rivers are not very watery: only 155 average annual discharges exceed 1 m^3/s, of which 15 rivers exceed 10 m^3/s, and only two – 100 m^3/s. The highest flow is in the lower reaches of the Nemunas – 616 m^3/s.

Lithuania's hydropower resources are not large, and their efficient use is highly dependent on the hydrological and topographic conditions of the river. The relative energy capacity of Lithuanian rivers is incomparable with that of mountainous countries, which is 4 to 40 times higher (Fig. 1).

The largest hydroelectric power plant in the territory of Lithuania is located near the river Nemunas, where 100.8 MW power is installed. In Lithuania, except for the Nemunas and Neris rivers, it is possible to build only small hydroelectric power plants with a capacity of less than 10 MW (Fig. 2.). The contribution of small hydropower is about 1-1.5%. The reason is their low capacity, which is mostly limited by the relatively low heights of the river falls and the large areas of the formed pond. A similar percentage of electricity from total electricity generation is accounted for by EU small hydroelectric plants – 1.6% [15].

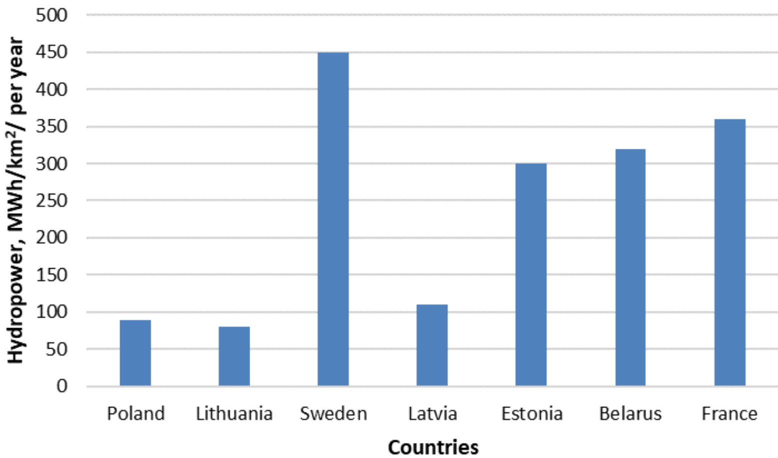

Fig. 1. Hydropower per 1 km² of the country area.
Source: [15].

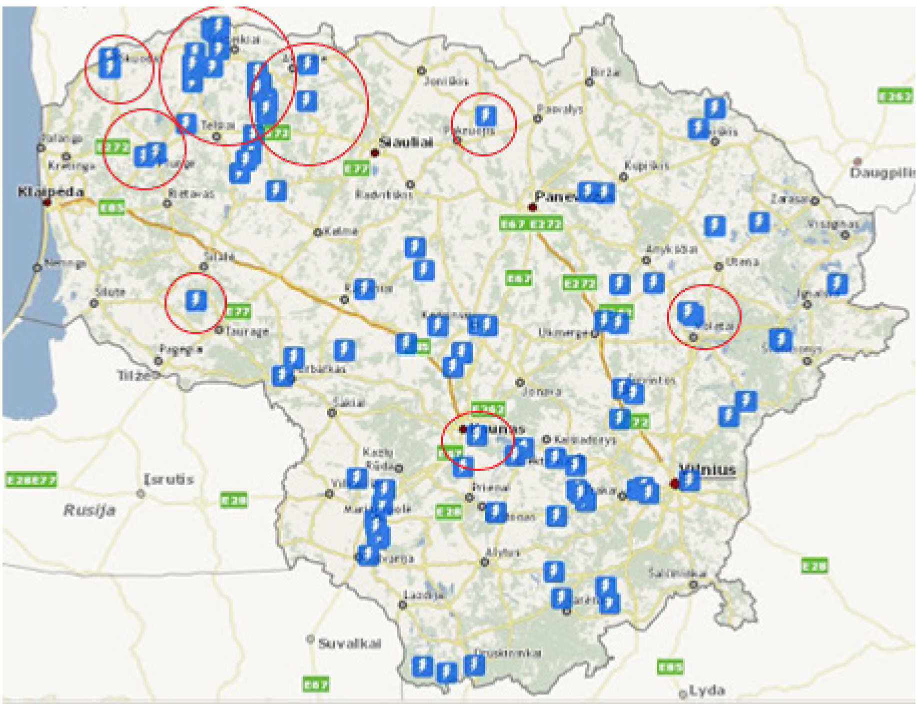

Fig. 2. The map of the small Lithuanian hydroelectric power plant (red area shows the investigated hydropower plants in this work)
Source: [15]

Results and discussion

The calculated values of the $f_{P,nren}$ factors of the analyzed hydropower plants are presented in Fig 3.

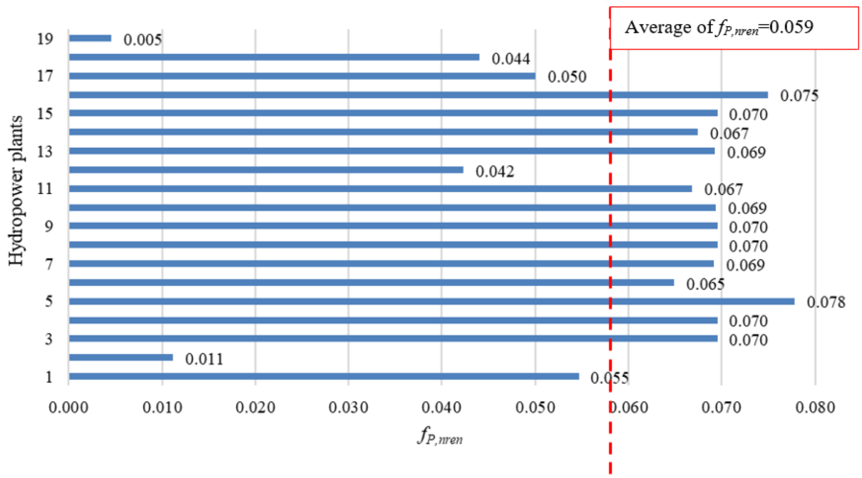

Fig. 3. Average annual values of $f_{P,nren}$ of hydropower plants in Lithuania.

Calculation results show that the average annual value of $f_{P,nern}$ ranges from 0.005 to 0.078. The lowest value was 0.005 and the highest value was 0.078. The $f_{P,enrn}$ value of hydropower plants operated in Lithuania is 0.059.

Analyzing produced and consumed distribution of electricity quantities by months, it was found that there is a direct relationship between these parameters. The average annual amount of energy used by hydroelectric power plants for its own use (for maintenance of a hydropower plant) is up to 1.24% of the total amount of electricity produced. The amount of electricity consumed is not constant and varies dynamically with the time of year, usually during the warm season less than the cold. Correspondingly, it can average 1.60% in winter and 1.06% – in summer.

The primary energy factor values of the hydropower plants $f_{P,nern}$ determined in this work were used to revise the methodology of assessment of energy performance of buildings in the Lithuanian Technical Regulation STR 2.01.09:2005 [16]. The mentioned standard provides the value of non-renewable primary energy factor $f_{P,nern}$ was 0.500. However, the $f_{P,nern}$ value set in this work is 0.059. The difference is 9 times. On the basis of these studies, the method of assessing the energy performance of buildings due to non-renewable primary energy factor when energy is produced from hydroelectric power plants are used was adjusted.

Analyzing the distribution of amount of produced and consumed electricity by the above hydroelectric power plants by months, the results show (Fig. 4) that there is a direct relationship between the amount of electricity produced and consumed in hydroelectric power plants. The average annual amount of energy used in hydropower plants for own use is up to 1.24% of the total amount of electricity produced. The amount of electricity consumed is not constant and changes dynamically depending on the time of year, usually during the warm season it is lower than during the cold season. Accordingly, it can reach 1.60% on average in winter and 1.06% in summer.

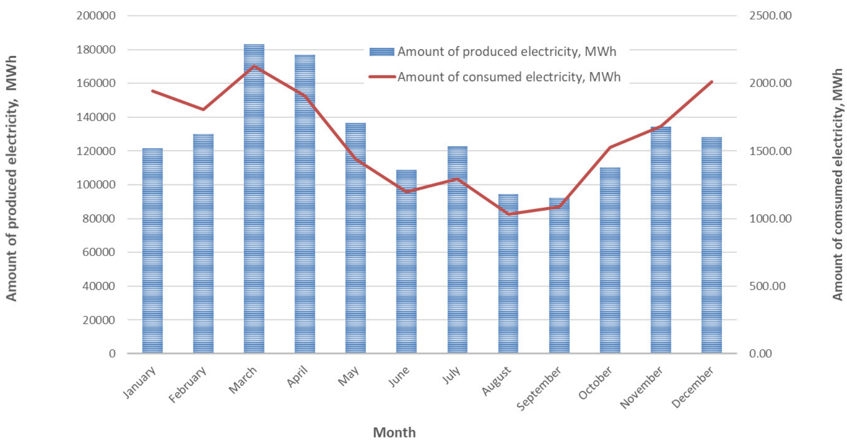

Fig. 4. The distribution of amount of produced and consumed electricity by the above hydroelectric power plants by months.

As the amount of electricity consumed varies regarding a month compared to the amount of electricity produced regarding the month, this causes changes in the monthly values of the non-renewable primary energy factor, which are presented in Figure 5. The results show, the average annual value of the $f_{P,nren}$ factor for hydropower plants is 0.059 (marked with a dotted line). The monthly values of the $f_{P,nren}$ factor range from 0.053 to 0.068, the lowest values were 0.053-0.054 in the April-August period, and the highest values were 0.067-0.068 in the December-January respectively.

The energy performance calculations for buildings assume that the value of the non-renewable primary energy factor is a constant. If these calculations took into account the fact that the value of these factors changes over the years, the results of the energy performance assessment of buildings would be more accurate.

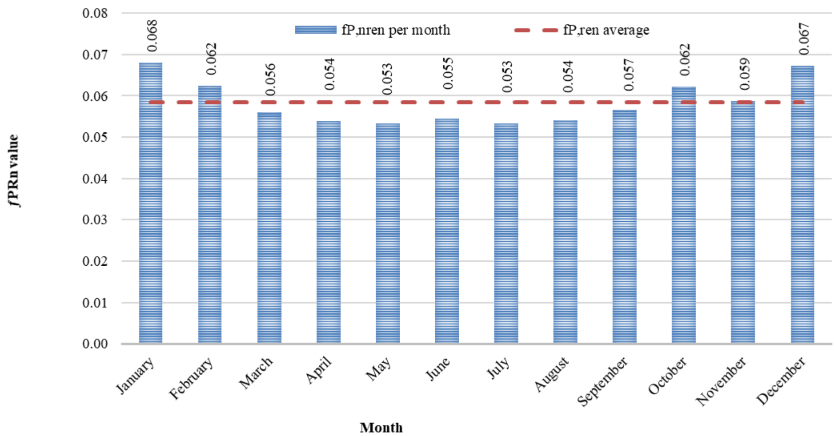

Fig. 5. The monthly values of the non-renewable primary energy factor.

Analyzing the provided values of non-renewable primary energy factor in the current Construction Technical Regulation of the Republic of Lithuania [16], a significant difference is observed with the values of Primary energy factor set in this work (Table 2.)

Table 2. Comparison of values of primary energy factors (fP,nren, fP,ren, fP,tot) in hydropower plants

Primary energy factors	The values of primary energy factors	
	The values set in this work	The value according to STR 2.01.09:2005 [16]
$f_{P,nren}$	0.059	0.500
$f_{P,ren}$	1.000	1.000
$f_{P,tot}$	1.059	1.500

The values presented in Table 2 show that the average non-renewable primary energy factor of Lithuanian hydropower plants is equal to 0.059 and is 9 times lower than indicated in STR 2.01.09:2005 [16].

Conclusions

This is a detailed study of the hydropower plants of Lithuania shows, that the average non-renewable primary energy factor of Lithuanian hydropower plants is equal to 0.059. The results of the research will help to evaluate energy efficiency more precisely of buildings in Lithuania.

The average annual amount of energy used in hydropower plants for own use is up to 1.24% of the total amount of electricity produced.

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Legal aspects of air protection in Poland and Europe

Keywords: air protection, law, Poland, Europe, air pollution

Abstract

The issue of air protection is a topic discussed in many scientific publications. How much air people breathe also largely depends on themselves. Therefore, there is a need for legal regulation as well as other instruments, such as people's awareness for the state of air in Poland to systematically improve. Despite the reduction in pollutant emissions, air quality is still not good enough. The European Environment Agency estimates that several hundred thousand people die prematurely every year due to air pollution in Europe. The norms and standards imposed by legal instruments play a huge role in improving the air quality. These guidelines are based on scientific evidence of the health effects of air pollution, and standards, which are in most cases legally binding, must consider technical feasibility and the costs and benefits of a compliance. The paper analyzes the most important legal regulations concerning the air protection in Poland and Europe, concerning emission of pollutants into the air as a result of burning the solid fuels and in the transport sector.

Introduction

Air is an element of the environment, the specificity and nature of which determine the priority of protection, as it is necessary for the life of all living creatures. Its necessity, combined with the limitation of the possibility of applying individual protection strategies, forces the necessity to take institutionalized actions, including legal ones. Despite a number of legal acts, regulations and standards that have brought significant effects in the form of improving the air quality, air pollution is still the most serious threat to human life and health [5]. It is estimated that about 400,000 of EU residents die prematurely because of these air pollutants. It also significantly reduces the quality of life, leading to serious diseases of respiratory and circulatory systems, is associated with the occurrence of diseases of the nervous system, diabetes, atherosclerosis and pregnancy complications [3, 14]. The impact of air pollution on the condition of ecosystems is also significantly negative.

The issues of air protection are very broad, which results in a wide range, multi threaded nature and interdependence of activities and research, including technical, economic, social and legal spheres. This is reflected in the design of the air protection legal model, which covers many levels, the most important of which are: international law, European Union law and national law [4].

The main two directions of legal air protection are: immission protection, i.e. establishing general air quality standards and developing sanitation plans, and emission protection, which includes protection against pollution by counteracting and controlling emissions [1]. In the field of emission protection, the following groups of regulations can be distinguished: establishing national limit values for total emissions, requirements for the principles of emissions from indicated industrial installations, principles of emissions by a specific type of installation and limiting the use of certain harmful substances (e.g. halons, freons) [3].

This paper presents the most important legal regulations concerning the air protection in Poland and Europe, referring to the emission of pollutants into the air as a result of the combustion of solid fuels and in the transport sector. The norms of the immission of particular pollutants in the atmosphere were also presented.

Legislation in Europe

In the European Union (EU), the first air quality strategies and measures were implemented in the 1970s. These steps helped to reduce the amount of pollutants released into the air, and the levels of air pollutant emissions from the most important emission sources, which include transport, industry and power generation, are now regulated and are generally declining. The setting of legally binding and non-binding limits on airborne emissions of pollutants in the air within the EU is evidence of an improvement in this regard. The European Union has legally established standards for the emission of particulate matter of various sizes, sulfur dioxide, nitrogen oxides, ozone, heavy metals and other air pollutants that may have an adverse impact on the environment and human health [8].

The key legal acts setting the emission limits in Europe include Clean Air For Europe (CAFE) directive of 2008 on air quality and cleaner air for Europe (2008/50/EC) and the framework directive of 1996 on the assessment and management of ambient quality air (96/62/EC). In addition, the most important legal acts in the EU regarding air protection include: Commission Implementing Decision 2011/850/EC of December 12, 2011, laying down the rules for the application of Directives 2004/107/EC and 2008/50/EC of the European Parliament and of the Council regarding the system of mutual exchange of information and reports on ambient air quality, Directive 2010/75/EC of the European Parliament of November 24, 2010, on industrial emissions (integrated pollution prevention and control), Directive 2001/81/EC of the European Parliament and of the Council of October 23, 2001, on national emission thresholds for certain types of air pollutants and the 2001/80/EC Directive of 2001 on the limitation of certain pollutants into the air from large combustion plants (LCP) [6].

Transport emissions are regulated by a number of emission standards and fuel standards, which consider the 1998 Directive relating to the quality of petrol and diesel fuels (98/70/EC) and standards of transport emissions, known as the Euro standards. Euro 5 and 6 standards apply to emissions from light duty vehicles, including cars, vans and commercial vehicles. The introduction of the subsequent Euro 7 emission standard will certainly contribute to the combustion of less fuel. The CAFE Directive introduced detailed guidelines for conducting the measurements and defined permissible levels of pollutants. The most important elements of air protection included in the CAFE Directive relate primarily to the hazards associated with dusts suspended in the atmosphere and the effects of their presence. In addition, the Directive established thresholds, limit values and target values, which enabled the assessment of individual ranges of air pollution indicators. Table 1 presents the limit values for basic air pollutants such as: nitrogen dioxide, ozone, sulfur dioxide, PM10 dust, PM2.5 dust and the maximum annual number of exceedances according to the CAFE Directive and WHO guidelines.

Table 1. Permissible levels of air pollutants according to the CAFE Directive and recommended by the World Health Organization (WHO) [EEA 2016; 2008/50 /EC]

Pollution factor	Interval	Guidelines WHO (μg/m^3)	Limit values in the EU Air Quality Directive (μg/m^3)	Number of times in a year when EU standards can be exceeded
NO_2	1 year	40	40	–
	1 hour	200	200	18
O_3	8 hours	100	120	25
PM_{10}	1 year	20	40	–
	24 hours	50	50	35
$PM_{2,5}$	1 year	10	25	–
	24 hours	25	–	–
SO_2	24 hours	20	125	3
	1 hour	–	350	24
	10 minutes	500	–	–

The air quality guidelines are based on scientific evidence about the health effects of air pollution, and standards, which are in most cases legally binding, must consider technical feasibility as well as costs and benefits of compliance.

The World Health Organization (WHO) recognizes PM2.5 as the most harmful air pollutant, therefore WHO guidelines include a short-term value for PM2.5, but the ambient air quality Directive does not provide such a value. This means that the EU standard is only based on an annual average, and high and harmful PM2.5 emissions of domestic heating in winter are compensated by low levels in summer. The annual limit values set out in the ambient air quality Directive (25 $\mu g/m^3$) are more than twice the value set in the WHO guidelines (10 $\mu g/m^3$).

A crucial legal act concerning the air protection in the EU is Directive (EU) 2015/2193 of the European Parliament and of the Council of November 25, 2015, on the limitation of emissions of certain pollutants into the air from medium combustion plants (the MCP Directive) sets out emission standards into the air: sulfur dioxide, nitrogen oxide and dioxide (expressed as nitrogen dioxide) and dust – for medium combustion sources (so-called MCP – Medium Combustion Plant), i.e. those with a nominal thermal power equal to or greater than 1 MW and less than 50 MW. The Directive introduced an obligation to include these sources in a permit or registration system and mandatory emission monitoring and introduced requirements for the operation of emission reduction devices. Since January 1, 2020, only boilers that meet the Ecodesign Directive of the European Parliament can be installed in the European Union. Table 2 shows the emission standards for low-power boilers according to Ecodesign.

Table 2. Emission standards for heating boilers according to Ecodesign

Fuel	Emission limits, GWE			
	Mg/m³ przy 10% O2*¹			
	CO	OGC*²	pył	NOx
Manual loading				
Biofuel	700	30	60	200
Fossil fuel	700	30	60	350
Automatic loading				
Biofuel	500	20	40	200
Fossil fuel	500	20	40	350

* 1 relative to dry exhaust gas, 0°C, 1013 hPa
* 2 content of organic bound carbon (volatile organic compounds)

In addition to the new emission standards, Ecodesign also introduces the concept of seasonal energy efficiency, which defines the average useful efficiency between nominal and reduced power. Up to now, the main focus has been on nominal output, although most of the time, the boiler usually operates with reduced output. By averaging these values, the assessment of energy efficiency becomes more authoritative. The Ecodesign mark on the boiler ensures that the appliance will meet the emission requirements even when it is not operating at its nominal output. According to the new regulations, for boilers above 20 kW, the seasonal energy efficiency should be at least 77%, and for boilers below 20 kW, it should be at least 75%. In comparison, traditional older generation backfill boilers have an efficiency of 60-80%. Thanks to the seasonal energy efficiency index, we can be sure that lowering the boiler output will not result in an unfavourable reduction of its efficiency.

Legislation in Poland

The air protection legislation in Poland is implemented through relevant legal acts. The acts relating to the assessment of air quality define the air monitoring systems, the scope and method of air quality testing, define the minimum number of stations as well as methods and criteria of assessment:

- The Act of April 27, 2001, Environmental Protection Law (Journal of Laws 2001, No. 62, item 627);
- Act of October 3, 2008, on the provision of information on the environment and its protection, public participation in environmental protection and on environmental impact assessments (Journal of Laws 2008, No. 199, item 1227);
- Ordinance of the Minister of Environment of August 24, 2012, on the levels of certain substances in the air (Journal of Laws 2012, No. 0, item 1031);
- Ordinance of the Minister of the Environment of June 6, 2018, on the scope and the method of providing information on air pollution (Journal of Laws 2018, item 1120);
- Ordinance of the Minister of the Environment of June 8, 2018, on the assessment of the levels of substances in the air (Journal of Laws 2018, item 1119);
- Ordinance of the Minister of the Environment of October 8, 2019, amending the ordinance on the levels of certain substances in the air (Journal of Laws 2019, item 1931).

Limit values, target values, short-term goals for ozone, alert and information levels and the exposure concentration thresholds for some pollutants in the air are regulated by the Regulation of the Minister of the Environment of August 24, 2012, on the levels of certain substances in the air (Journal of Laws 2012, item 1031). Table 3 presents the permissible levels of air pollution in the criterion of health protection.

Table 3. Permissible levels of air pollutants in the criterion of health protection (Journal of Laws No. 2012, item 1031; OJ 2019 item 1931)

Substance	Averaging period of measurement results	Acceptable level of the substance in air [μg/m³]	Permissible frequency of exceeding the permissible level in a calendar year	Information levels	Alarm levels
Nitrogen dioxide	calendar year	40	–	–	–
	1 hour	200	18 times	–	400**
Sulphur dioxide	24 hours	125	3 times	–	
	1 hour	350	24 times	–	500**
Particulate matter PM10	calendar year	40	–	–	–
	24 hours	50	35 times	100	150
Carbon monoxide	8 hours	10000	–	–	–
Particulate matter PM2,5	calendar year	25	–	–	–
Particulate matter PM2,5*	calendar year	20	–	–	–

* acceptable level specified for the so-called phase II with a deadline of 01/01/2020, the standard will be subject to verification by the European Commission;
** value present for three consecutive hours at measuring points representing air quality.

The situation of dust and gas emissions into the air as a result of the combustion of solid fuels (excluding the industry sector) is of the greatest importance for the reduced air quality. The above indication means that direct cause of the so-called low emission is heating work in the housing sector [12].

Therefore, in addition to the provisions on air quality assessment, legislation on emission standards for the combustion of solid fuels is essential. The quality of coal burned in households has a significant impact on the phenomenon of low emissions, and the improvement of air quality in Poland over the past few years has become a priority for many local governments. Amendment to the Environmental Protection Law Act of 2015 [Journal of Laws 2015, item 1593] gave local governments the opportunity to introduce the anti-smog resolutions [7].

At the beginning of 2018, seven voivodeships (Lesser Poland, Silesia, Opole, Greater Poland, Łódź, Mazovia and Lower Silesia) took advantage of this privilege [13]. These resolutions, apart from the combustion of brown coal, some fine coal, flotation-concentrates and wet biomass, also prohibit burning of sludge. Limiting the combustion of low-quality fuels may contribute to reduce the level of pollutants in the air [10]. The first to adopt the anti-smog resolution was the Lesser Poland Voivodeship Seym. Councilors have passed regulations to protect the air quality, which have appliedin the area of the Municipality of Kraków since September 1, 2019. According to them, the combustion of coal and wood will be completely prohibited in boilers, stoves and fireplaces. As early as July 1, 2017, it was not possible to burn low-quality coal and wood with a moisture content of more than 20% in the area of the Municipality of Kraków [11].

In addition, in Poland, in the last 10 years, Low Emission Elimination Programs (PONE) have been established in cities and municipalities, for which one of the main assumptions is the reduction of solid fuels in heating systems and the elimination of existing, ineffective heat sources. This goal is to be achieved by introducing ecological, energy-saving heating devices. The harmful emissions are related to the combustion of solid fuels of hard coal, brown coal, flotation-concentrate and coal sludge in low-power boilers used to generate the heat for heating purposes in residential buildings [2].

When discussing the air protection legislation in Poland, the National Air Protection Program (KPOP) should be also mentioned. It is a strategic document setting out the goals and directions of activities that should be included in air protection programs at the central, regional and local levels to improve the air quality in Poland to a state that does not cause any negative health effects. The task of the National Air Protection Program is to improve the quality of life of residents, protect their life and health, considering the principles of environmental protection, and achieve permissible levels of particulate matter and other harmful substances [8]. The aforementioned directions of activities with the KPOP, which should be compliant with the European Union legislation, include [8]:

- establishing the Partnership for the improvement of air quality, which will enable the strengthening of the position of air quality in strategic documents;
- creation of such regulations that affect the fulfillment of activities aimed at improving air quality;
- development of technologies influencing the state of air;
- extension of structures related to low emission control and financial mechanisms influencing air quality;
- growing people's awareness of air quality.

Summary

The poor condition of the natural environment, with particular emphasis on low quality of the ambient air, has been confirmed and thoroughly described by a series of professionally conducted studies. The fact of highly polluted air poses a particular threat not only to the comfort of life, but above all, to human health. The spectrum of exposure of a human being to the influence of harmful dusts and gases may lead to the development of serious disorders and multi-organ diseases.

Air protection in Poland is implemented to a large extent by local government units. The statutory delegation in this respect is specified in the Act of April 27, 2001 – Environmental Protection Law – in which the competence to adopt air protection programs, the so-called anti-smog resolutions or adopting short-term action plans, has been established. Permissible levels of particulate matter will be systematically tightened in the coming years. Therefore, it is necessary to implement effective legal instruments that will ensure adequate air quality standards. The implementation of measures for air protection must be rational and adjusted to technical capabilities and economic potential of citizens. Air pollution is not a problem of a particular region, but of the entire country, and the effects affect not only the present, but also many future generations.

Legislative activities in the field of reduction of pollution emissions from the municipal and commercial sector stimulate the demand in Poland for high quality heating equipment meeting certain standards. Current users of boilers for solid fuels will have to consider alternative ways of supplying buildings with heat, such as: liquid and gas fuels, renewable energy sources, connection to the heating system. In order to continue using the cheapest heating method in operation, the user will have to bear higher investment costs than before, related to the purchase of a heating boiler made according to the latest technologies and adaptation of the chimney system to it. New legal regulations force manufacturers operating in the boiler industry to constantly improve the technology and introduce changes to the boiler design. The obligation to carry out certification tests of the boiler before it is placed on the market and sold is an additional financial burden on the company [9].

Summarizing the above considerations, it should be remembered that in both Polish and European legal systems, we have a very extensive catalog of legal sources related to the issues of air protection. Despite so many legal norms and introduced restrictions, the problem of low emission air pollution accumulation is still huge, and even alarming. When adopting the appropriate legal regulations and creating new legal "tools", the legislator should be aware of the specificity, infrastructure, resources, financial and technical possibilities the country possesses.

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