Energy simulations of residential building using a dynamic energy-balanced software

M. Fedorczak-Cisak, A. Kowalska-Koczwara, A. Romańska-Zapała

Abstract — The aim of this study is to investigate whether, by using commonly available insulation materials it is possible to achieve building parameters as:

- low energy demand,
- for passive building.

The article presents the results of analyzes of selected building designed in accordance with the Technical Conditions in relation to the Standard NF15 and NF40 which are Polish passive building design guidelines. The study analyzed opportunities to reduce energy requirements of the building and this study also attempts to optimal selection of design elements of the building due to the energy requirements using computational simulation tool which is the program Design Builder. External partitions due to the number of layers, the thickness of layers and air tightness of enclosure were adopted as the decision variables. The scope of work includes energy analysis of existing residential house, built in the 80s.

***Keywords*—**energy-efficient buildings, dynamic energy models, tightness of buildings, parametric optimization.

MCBE - MALOPOLSKA'S CENTER OF ENERGY EFFICIENT CONSTRUCTIONS – 2012

This investment is an innovative unit of Cracow University of Technology, whose aim is to establish a partnership network of cooperation between science and business. Such cooperation enables scientists and entrepreneurs to develop and implement new technologies in the field of energy efficient construction.

Malopolska's Centre of Energy-Efficient Construction unit of Cracow University of Technology - Project "SPIN - Model transfer of innovation in Malopolska" realized by the Human Capital Operational Programme, Priority VIII: Regional human resources, Measure 8.2. Transfer of knowledge, Sub 8.2.1. Support for cooperation zone of science and Enterprises. The aim of the project is to increase the intensity of knowledge transfer and exploit the potential of universities by companies in Malopolska. In this study Design Builder software was used (that has been purchased under this project).

M. Fedorczak-Cisak is with the Małopolskim Laboratorium Budownictwa Energooszczędnego Wydziału Inżynierii Lądowej na Politechnice Krakowskiej, Polska, (corresponding author to provide phone: 0048-12-628-30-62; fax: 0048-12-628-30-61; e-mail: mfedorczak-cisak@pk.edu.pl).

A. Kowalska-Koczwara is with the Cracow University of Technology, Cracow, Warszawska 24 St., 31-155, Poland (corresponding author phone: +48126282121; fax: +48126282340; e-mail: akowalska@pk.edu.pl).

A. Romańska-Zapała pracuje w Małopolskim Laboratorium Budownictwa Energooszczędnego Wydziału Inżynierii Lądowej na Politechnice Krakowskiej, Polska, (corresponding author to provide phone: 0048-12-628-30-62;fax: 0048-12-628-30-61; e-mail: a.romanska@pk.edu.pl).

I. Introduction

NOWADYS the function that buildings perform is not only shelter, security and convenience, but equally important is how they influence on our environment (see for example [1], [2], [3]). In response to the growing awareness and concern about the environment in Poland and in Europe gaining popularity energy-efficient and passive constructions. This is not caused only by lower energy consumption or non-renewable resources consumption such as coal, oil and gas, but also the construction shall be equal to reduced CO_2 emissions compared with traditional construction whilst ensuring better indoor environment quality for humans. Energy efficient building, despite higher investment costs, minimizes expenses related to the use of the building, so the overall balance of costs from the point of view of users, it is more advantageous financially.

Along with the growing demands for energy savings in the building, the energy for exploitation of buildings is minimizing and has become one of the main topics of analysis and research.

Important parameters for evaluation of energy efficiency of the building is an indicator of seasonal heating demand for heating and air-tightness of the building. As a result of careful selection of these parameters for example by computer simulations the energy consumption and indirectly reduction of CO_2 emissions of the selected building could be improved.

The indicator seasonal heating demand is a very important element for evaluating the energy consumption of the building.

Estimated data for the average multi-family buildings in Poland, seasonal heat demand depending on the year, are as follows:

- in buildings built before the entry into force of PN-82 / B-02020 (ie. before approx. 1985). - approx. 250-280 kWh / (m2a)w budynkach wzniesionych zgodnie z wymaganiami PN-82/B-02020 (tj. po ok. 1985r.) – ok. 220 kWh/(m2a)
- in buildings built in accordance with the requirements of PN-91 / B-02020 (ie. after approx. 1995). - Approx. 160 kWh / (m2a)
- in buildings built in accordance with the requirements of 1997 (ie. after approx. 1999). - approx. 120-140 kWh / (m2a).

The Regulation of the Minister of Transport, Construction and Maritime Economy was signed on 5^{th} July 2013. This regulation changes the ordinance on technical conditions to be met by buildings and their location (Journal of Laws of 2013., Pos. 926) [4]. The regulation came into force on January 1st

2014. It contains a new "technical conditions to be met by buildings and their location". The regulation changes the existing requirements of thermal insulation of the building envelope, and exacerbating value of the indicator for primary energy demand of the building. These parameters will be much stricter until 2021.

Published regulation is a consequence of the implementation of art. 4 to 8 of the Directive of the European Parliament and the EU Council of 19 May 2010 on the energy performance of buildings (recast) (Dz. U. EU L 153, 18.06.2010, p. 13) [5].

The role of the member states is to establish rules that will define the energy standards of the building and its components whereas the three fundamental aspects: technical, economic and financial, that is, the cost-effectiveness of the solutions.

The purpose of Directive 2010/31/EU is the use of economically reasonable improvement energy performance of buildings as a result of lower heat demand for heating, cooling, domestic hot water and lighting, through the use of appropriate materials (with good thermal insulation parameters λ [W/mK]), the technology performance of heating system and tap water and mounting techniques with a responsible and thoughtful use of selected power sources.

II. Building design using dynamic energy simulations

Computer simulations of the building allow to make a decision that will be able to optimize the architectural design and installation, which leads to a reduction in energy demand and allows for ensuring adequate internal environmental conditions. Building energy simulations, also called the energy modeling of the building, it is the use of software to predict energy consumption of the building. Building Energy Modeling is the practice of assessing energy consumption of the building through simulations using a lot of of energy-related elements. Programs for simulation energy performance are powerful tools for studying energy efficiency and thermal comfort throughout the life cycle of the building. Most programs for thermal simulations consist of calculation tool based on simple input and output text file.

There are many programs for dynamic energy simulation based on specific, simplifying assumptions. It is important to be aware of these assumptions and be able to decide whether they are justified and which may influence on the results of the simulation. For example, the weather data are adopted on the basis of measurements from previous seasons and based on them future external thermal loads are assumed. Another assumption is that the temperature in the room is spatially uniform. This is a good foundation for not so high spaces, but not so good for larger rooms where the temperature varies depending on the height of the storey.

There are two main elements in energy design programs: calculations tool and graphical interface. Calculation tool uses input files of a particular form taken from the geometry model. Compared to other graphical interface design architecture, the energy modeling programs are very weak. This tool defines simple architecture and reads only the simple geometry. This is one of the main reasons for difficulties in communication between architecture design and designing using energy programs.

Computer simulations presented in this article are based on DesingBuilder software.

A method of modeling of buildings is the formation of blocks which are the basic elements used to create the model in DesingBuilder program. There are three types of elements that could be added to the building model:

- Building Blocks - constitute the outer shell of model or part of model, they can be divided inwardly to form a series of zones. The finished house consists of a set of construction elements, which may include external walls, roofs and floor tiles.
- Outline Blocks - are used to help to create a more complex geometry. They are created and edited in exactly the same way as main element, but is only created a 3D shape without related building components such as walls, floors, roofs, etc.
- Component Blocks - are used to create visual elements, an external area and shading of structures that zones do not contain.

In DesignBuilder program there are three types of HVAC systems:

- Simple - suitable for use in the initial design phase, heating / cooling system is modeled by a calculation algorithms of basic load.
- Compact - can be useful when modeling in EnergyPlus. They allow for modeling of HVAC systems in some detail, without necessarily been drawn air flow network and coping with complexity of control systems and connection nodes. The compact HVAC is an intermediate between simple and detailed model HVAC options.
- Detailed - DesignBuilder system models are connected by a placing several predefined installation schematic diagrams, which are then combined to form a complete system.

In this study was used DesignBuilder software capabilities to perform residential building model and simulate the four selected variants of external partitions. The influence of external partition structures and tightness of the building on its energy consumption was also investigated.

III. Description of analyzed building

The object subjected to analysis is an existing residential building located in Tarnow. Single-family home design dates from the year 1979. The building was built in the years 80s-90s using economic method. Over the years, changes were made in the body of the building, and used expanded polystyrene insulation with a thickness of 10cm (with λ = 0.035 [W / mK]).

General design data

Usable area: 107,57 m^2

Building area: 88,63 m^2

Cubature: 718 m^3

General characteristics of the building:

Residential detached house – one-storey building with a garage in the basement. Designed in traditional construction.

<u>Construction-material data:</u>

- Concrete continous footings
- Basement walls - concrete, faced with brick inside / thickness equal 12cm
- Ground floor and upper floors walls made of brick and cinderblock MAX on cement and lime mortar
- Internal dividing walls made of full and hollow bricks
- Slabs over the basement and floors are ceramics FERT type.
- Envelope Roof - covering: galvanized sheet steel
  wooden structure
  warming of the floor – Suprema
- lintels, balconies, stairs, cornice - reinforced concrete
- Waterproofing - a double roofing felt on glue situated on continuous footings and under ground floor slab.
- Ridge height: 8,3 m
- Roof angle: 40 °

<u>Finishing works</u>

- Floors - residential rooms - wooden floor, cork; in the hall, kitchen, bathrooms - terracotta.
- Plasters - cement and lime.

The figures below summarizes the plans of individual storeys with taking into account the surface area and the cross-section of the building chosen for analysis.

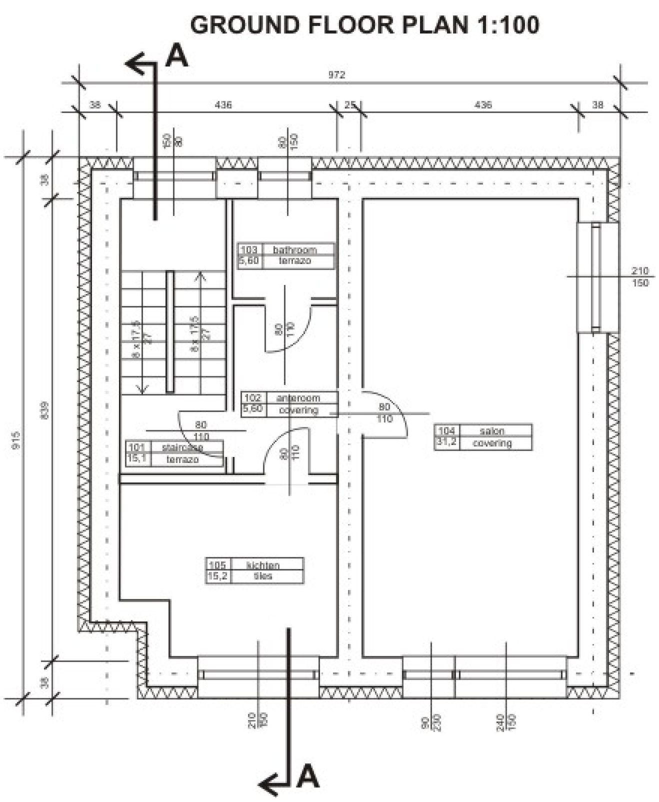

Fig. 1. Ground floor plan

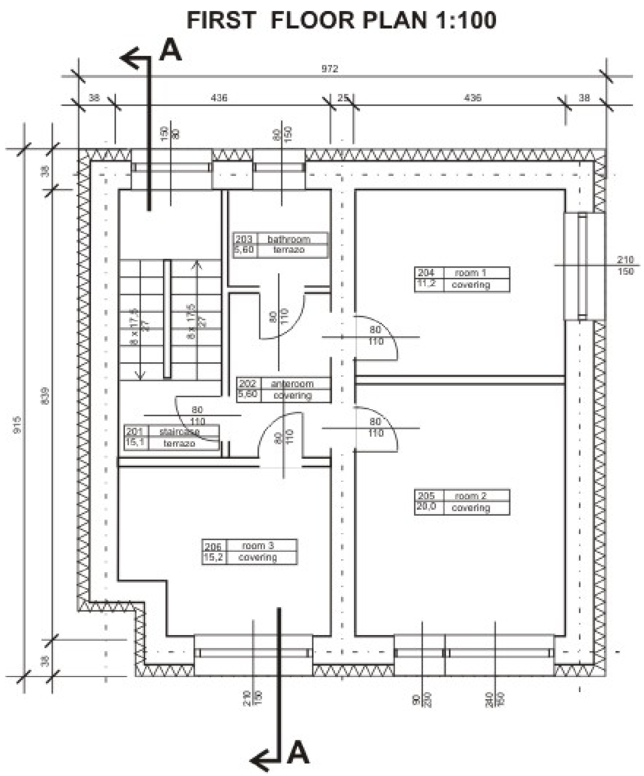

Fig. 2. First floor plan

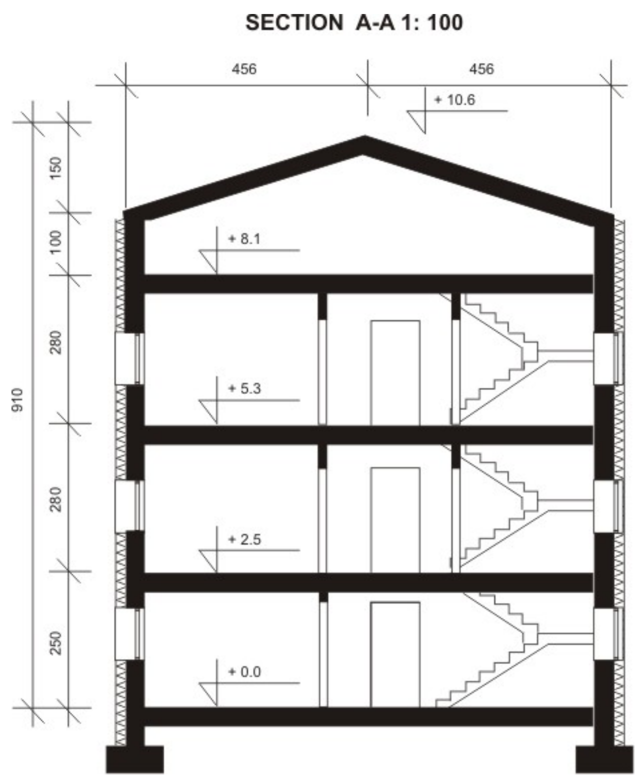

Fig. 3. Cross-section of the building

IV. Modelling and Energy Simulations of Buildings on Chosen Building Example

Basic data are given before creating a model. These data concern on:

- Location - determines the geographic location and weather data for all buildings on this site,
- Standards, legislation and building regulations in the given region.

The figures below illustrate the boundary conditions introduced to the program DesignBuilder.

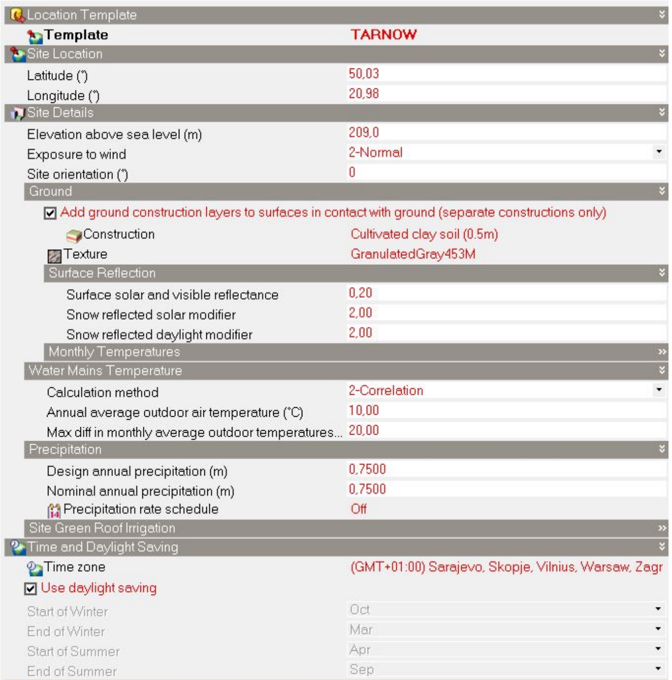

Fig.4. Boundary conditions of the model

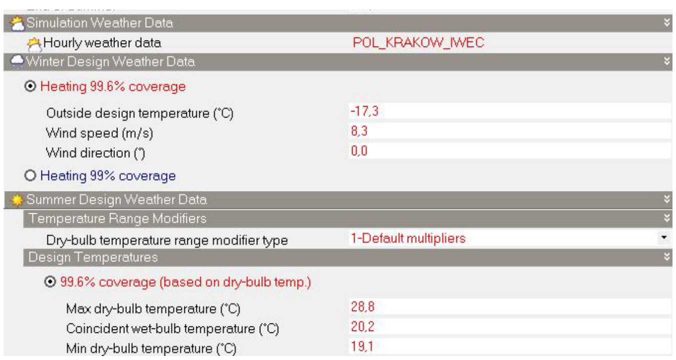

Fig. 5. Designed weather data

Data taken for analysis:
Heat transfer coefficient:
U_g= 1,0 W/m2K, - coefficient U for glass window
U_f = 1,8 W/m2K - coefficient U for window frame (see [6]).
Light transmission Lt = 80%,
The total transmission coefficient of solar energy g = 62%.

HVAC simple modeling system was selected for designing, due to the lack of complex systems such as heat pump systems, air conditioning or ventilation with heat recovery.

The HVAC system selected in the design is based on a template "Hot water radiator heating, nat vent." which means :

- heating system using coal boiler of the central heating (efficiency ratio equal 0.85%).
- natural ventilation; 3 ac / h - the amount of ventilation air (fresh air),
- DHW system - gas heater 100l volume; (efficiency ratio equal 0.85%).

The figures below illustrate the visualization of modeled building.

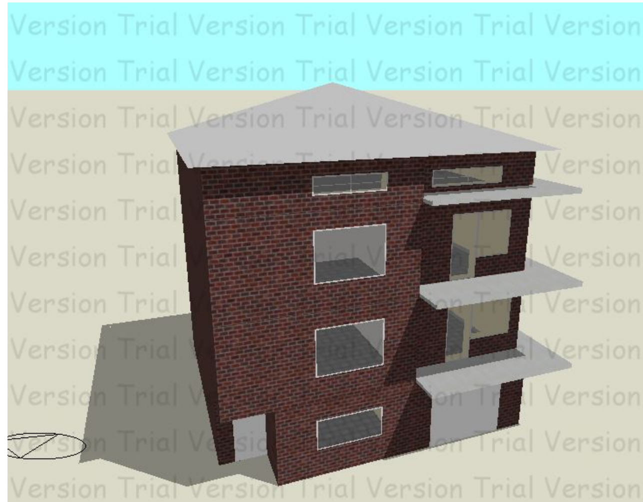

Fig. 6. Visualization of building model

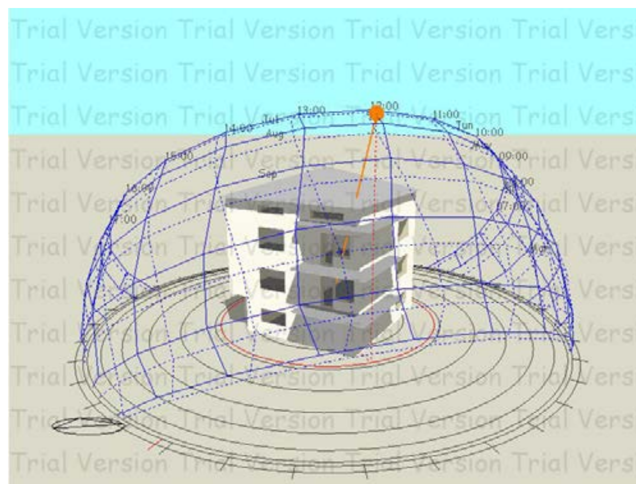

Fig. 7. Visualization of the building withstaging path of the sun

The path of the sun in relation to the location of the building has an impact on the analysis and was included in the model (Fig. 7).

Four variants of the model have been analyzed:

- Option I - variant design - a wall with air gap (see fig. 8)

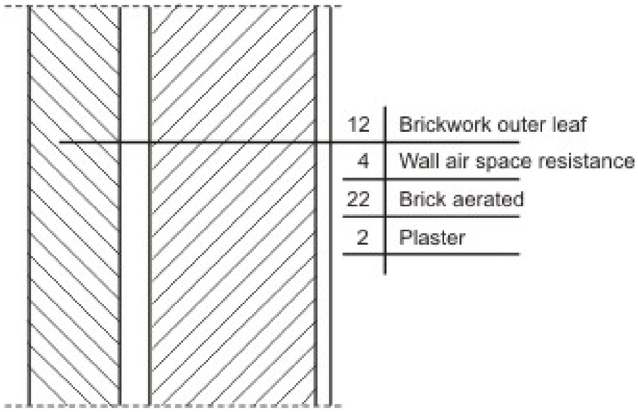

Fig. 8. Cavity wall without insulation

- Option 2 – the existing situation - cavity wall with air gap + 10cm Styrofoam insulation (see. Fig. 9)

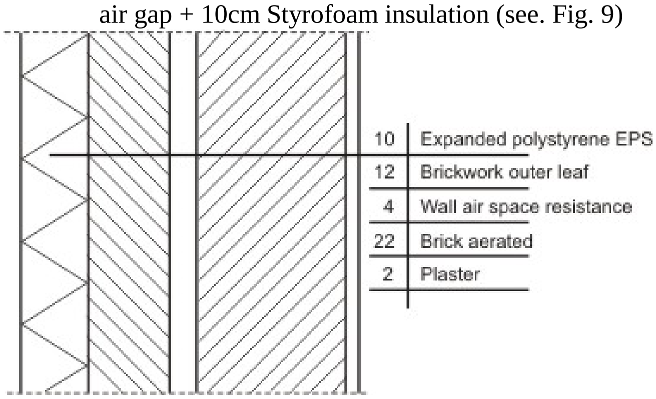

Fig. 9. Cavity wall with 10cm thermal insulation

- Option 3 - cavity wall with air gap + 20cm Styrofoam insulation (see. Fig. 10)

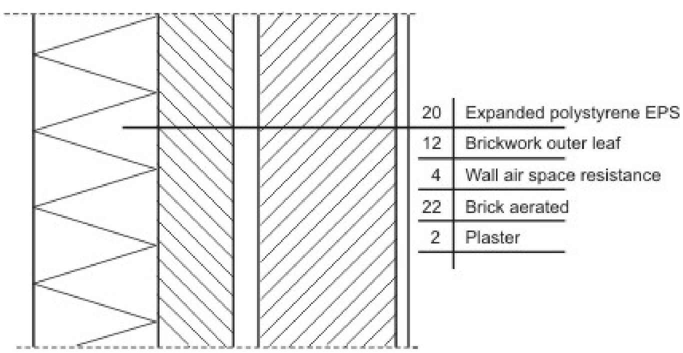

Fig. 10. cavity wall with air gap + 20cm Styrofoam insulation

- Option 4 - cavity wall with air gap + 30cm of insulation (see. Fig. 11)

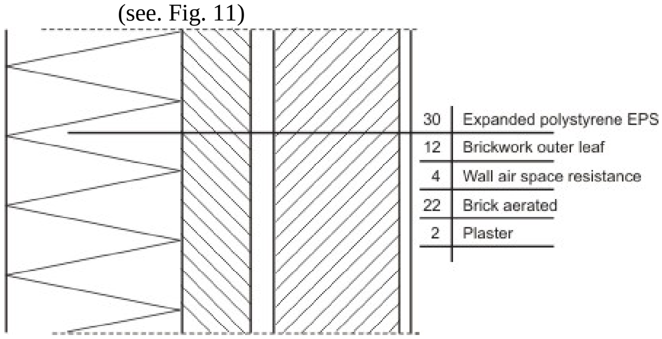

Fig. 11. Cavity wall with 30cm thermal insulation

V. Analysis results

The calculation of designed heating are conducted in order to determine the size of heating equipment to meet the required conditions for internal temperatures to the weather - the coldest winter, which can occur in a given location. In the statement profits from solar heating and internal gains such as: lighting, electrical equipment, heat exhausted from users are not considered. Wind speed and direction were adopted by design data. The calculations include heat conduction and convection between the zones of different temperatures.

The simulation calculates the heating capacity required to maintain the set temperature in each zone, and displays the total loss of heat divided into:

- Glazing
- Walls
- Floors
- roof
- Departed outer
- The internal natural ventilation (ie heat losses to other colder adjacent rooms and the vents, windows, doors, openings).

The total loss of heat in each zone are multiplied by a safety factor of 1,2. It provides additional heat required in the building to bring the required temperature in a relatively short period of preheating and allows you to be sure that comfortable conditions are maintained in all, including the most extreme winter conditions. In the test case, the coefficient is smaller than in the case of public buildings where buildings are not used by the weekend. Then we must be sure that the installation is large enough to heat the building shortly after a cold start in the winter on Monday morning when the building cooled during the weekend. In the case of a residential building such situations doesn't take place, because during the week there are not large differences in energy demand.

Tightness is a leak, air permeability, related to the infiltration of cold / hot air into the building and / or loss of the heated / cooled air from the inside by means of splits, cracks, pinholes, etc.. In the building material.

The loss of cooled / heated air through the "uncontrolled ventilation" influence on the energy consumption of the building. This loss will cause the need for additional energy to re-heating or re-cooling of the air. It also influence on the comfort level of residents of the building. Therefore it is important to carefully and conscientiously make connections and transitions.

Assessment of tightness of the building is carried out at 50 Pa pressure difference between the internal pressure of the building and the external atmospheric pressure. PN-EN 13829: 2002 [7] provides for the examination method of measuring the pressure with ventilator.

Requirements for tightness - n50 value - are defined in the "Regulation of the Minister of Infrastructure ', Acts Of 2002 No. 75, item. 690, on the technical requirements to be met by buildings and their location [8]. However, Polish legislation does not impose the obligation to perform leak testing of buildings - they are only recommended.

The maximum values of air changes are as follows:

- buildings with gravitational ventilation: n50 ≤ 3.0 [1 / h]
- buildings with mechanical ventilation: n50 ≤ 1.5 [1 / h]
- passive buildings, energy-saving: n50 ≤ 0.6 [1 / h].

Passive and energy-efficient buildings must meet the condition of air change n50 ≤ 0.6. The air ventilation in passive houses should be provided through heat recovery units.

Because the tightness of the building has a significant impact on energy demand, examined building will be analyzed with taking into account this parameter. Depending on the variants of the outer layer air change at a pressure of 50 Pa will be also varied.

The first value is five air exchanges. It was chosen on the basis of similar buildings constructed in the 80s. The tightness and accuracy in these years was not particularly important aspect, which values N50 can range from 4 [1 / h] to 10 [1 / h]. The value of n50 ≤ 5.0 [1 / h] is the maximum value that can be assumed in DesignBuilder program. In the simulations were also analyzed three air exchanges, this is the number of air exchanges that should satisfy buildings with gravitational ventilation and the requirements for passive buildings - 0.6 [1 / h].

Table 1. Matrix simulation variants [9]

	U [W/m2K]	n50 [1/h]		
V1- without insulation	0,84	5.0	3.0	0.6
V2 - 10 cm of insulation	0,24	5.0	3.0	0.6
V3 - 20 cm of insulation	0,14	5.0	3.0	0.6
V4 - 30 cm of insulation	0,10	5.0	3.0	0.6

Thanks to simulations in an easy way, it is possible to compare different solutions. On the basis of statements it can be concluded that the problem of leakage, which is usually overlooked is extremely important. Only improving the U-value in order to obtain better performance of the building, without proper tightness, we will not achieve the planned savings in the use of building. Leaks translate directly into increased demand for heating energy.

In the case under examination system of mechanical ventilation and infiltration dominates the greatest heat loss as shown in Fig. 12.

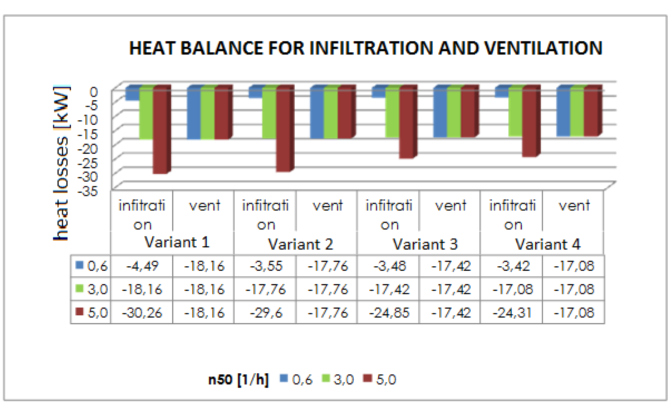

Fig. 12. Summary of energy losses through infiltration for all variants

Ensure better tightness of the building has a direct impact on its final energy demand. This relationship is shown in Figure 13, which were included to compare the results of simulation variants.

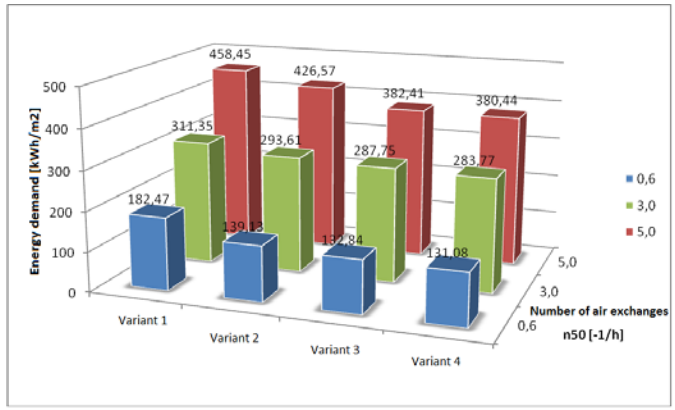

Fig. 13. Final energy demand - comparative summary results of simulation variants

The characteristics of energy-efficient construction is low power consumption while ensuring better indoor environment for humans. As a result, for considered four different variants with an increase airtightness of the building envelopes, there was also observed a reduction of CO_2 production. Suitable variants are shown in Fig. 14.

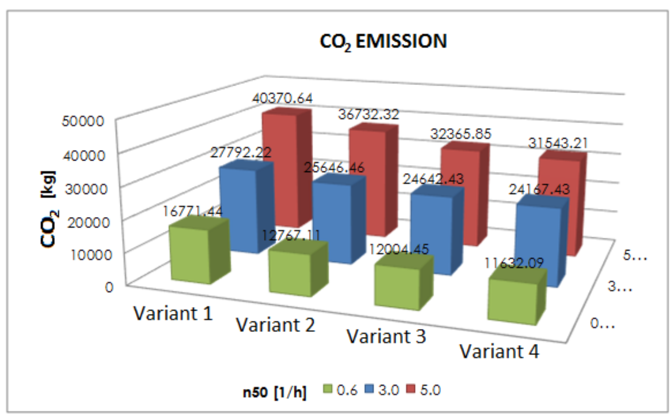

Fig. 14. CO_2 emissions, summary of simulation variants

When calculating annual energy consumption for heating for all examined variants of the outer shell of the building there was observed a decrease of energy consumption with an increase in air tightness of the building envelope. In shown in Fig. 15 graph can be observed large differences in energy consumption for air exchange n50 = 0.6 [1 / h], and N50 = 5 [1 / h]. For variants W2 and W4 biggest differences were observed.

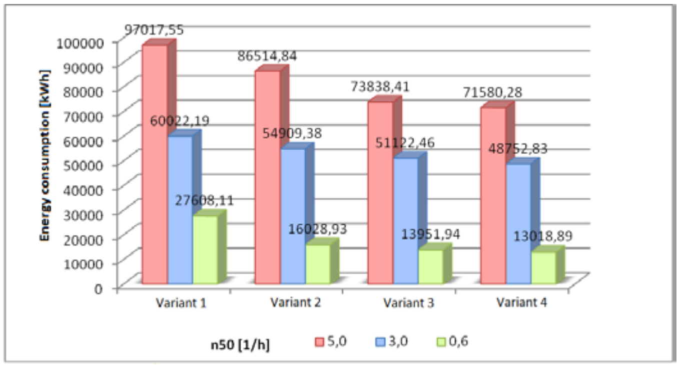

Fig. 15. Annual energy consumption for heating - comparative summary

VI. Conclusion

The tool, which are energy simulations, meets our expectations and growing needs for rapid analysis. However, this is still a new field, complicated and may cause difficulties in use. You have to understand the limitations of the software, their complexity, as well as a wealth of knowledge about the processes of energy in buildings. The main value of the simulation is to compare different solutions rather than absolute energy consumption prediction.

Based on the analysis of simulation it can be concluded that only by meeting requirements for building envelope, without heat recovery and renewable energy sources, it is not possible to satisfy the NF40 and NF15 [10] conditions.

The heat losses caused by lack of tightness of the partitions (see Fig. 12) have a significant impact on energy demand of buildings, they may even increase it to 50%, what can be seen on Fig. 15. Improving the U-values for the building envelope without improving the tightness will not bring significant results in energy savings for heating (see Fig. 12). In addition, uncontrolled air infiltration can reduce indoor environmental quality, causing unpleasant for residents, local drafts. The penetration of the hot moist air may lead to an interlayer condensation that may cause decreased of durability of the envelope.

Increasing the air tightness of the building, while improving the value of factor U of external partitions, as shown in Figure 14, results in a reduction in CO_2 production.

Computer simulations are very helpful in the design of energy efficient buildings and the selection of the parameters of external partitions used in the design. An important factor directly influencing on energy consumption and CO2 emissions is tightness, and so in energy efficient building design process, special attention must be paid to the elimination of the so-called "uncontrolled ventilation" [11].

References

[1] T. Law: "The Future of Thermal Comfort in an Energy-Constrained World", ISBN 978-3-319-00148-7
[2] K. Parsons: "Human Thermal Environments", ISBN 978-1-4665-9599-6
[3] I. Dincer, A. Midilli., H. Kucuk-"Progress in Exergy, Energy, and the Environment", ISBN 978-3-319-04680-8
[4] Regulation of the Minister of Transport, Construction and Maritime Economy amending the regulation on technical conditions to be met by buildings and their location (Journal of Laws of 2013., Pos. 926)
[5] European Parliament and Council 2010/31 / EU of 19 May 2010. On the energy performance of buildings (recast)
[6] A. Dylla " Thermal physics of buildings in practice" PWN.
[7] PN-EN 13829:2002 provides for the examination method of measuring the pressure with a fan.
[8] "Regulation of the Minister of Infrastructure ', Journal of Laws Of 2002 No. 75, item. 690, on the technical requirements to be met by buildings and their location
[9] Standard PN-EN ISO 6946 "Building components and building elements. Thermal resistance and thermal heat transfer. The method of calculation"
[10] Requirements for programs NF15 NF40 the National Fund for Environmental Protection file:///C:/Users/mcbe/Downloads/wytyczne_do_pp%20(2).pdf
[11] Fergus N, Humphreys M. "Adaptive Thermal Comfort"

Dr Malgorzata Fedorczak-Cisak
Director of the Malopolska's Center of Energy-Efficient Construction. A graduate of the Cracow University of Technology. Represents the scientific field of building physics and energy efficient construction. Expert actively participating in the meetings of the advisory and opinion of the representatives of the Malopolska Regional Government, the effect of which is to develop the provisions of the Malopolska Region strategy and long-term development of the Malopolska take into account the development of measures to improve energy efficiency especially in the area of construction. Expert working actively in the work to implement EU Directives, inter alia, for the development and implementation of the definition of near zero energy buildings in Poland. She is a member of the Polish Committee for Standardization, the Association of Energy Auditors and expert appointed to evaluate international projects related to the area of energy saving measures.

Dr Alicja Kowalska-Koczwara
V-ce Director of Instittute of Structural Mechanics at the Faculty of Civil Engimeering, Cracow University of Technology. She is currently conducting research on influence of vibrations on human body and on humans residing in buildings. Expert working actively in the work to implement Polish standard "Evaluation of vibrations influence on people in buildings". She takes part in many expert opinions on the dynamic effects on buildings and on people in buildings. The main directions of interest are dynamic influences of paraseismic origin.

Dr Anna Romanska-Zapala
Anna Romanska-Zapala dealing with the issues of intelligent building. Participated in creating Laboratory of Integrated Control Systems at the Department of Electrical and Computer Engineering and the Malopolska Laboratory of Energy Efficient Building at the Faculty of Civil Engineering, , Cracow University of Technology. She is currently conducting research on the influence of integrated systems for comfort and energy efficiency issues related to various types of buildings. Anna Romanska-Zapala also conducts interdisciplinary team research on the impact of noise and vibration stimuli on human psycho-physiological parameters. In particular, looking for opportunities to use these stimuli in the rehabilitation of osteoporosis, cardiovascular diseases and respiratory diseases.