

The influence of building zones with different dynamic properties on the building energy performance

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Abstract. The paper presents an analysis of the energy performance of single-family buildings with two zones differing in dynamic properties. The procedure currently applied for determining the energy performance distinguishes several cases in which a division into separate calculation zones is required, whereas none of them sanctions dissimilarities of dynamic properties between parts of buildings. In order to determine the differences resulting from the separation into zones, e.g. the ground floor with a heavy structure and a lightweight usable attic, the monthly balance method was used as legally binding for establishing energy performance of buildings. Heat demand for heating and cooling a building was determined. The results obtained for a building treated as one zone and divided into two zones were compared. The analysis was carried out in a variant manner, i.e. assuming varying internal thermal capacity, usable space, surface of glazed partitions, and air exchange rate, for 59 locations in Poland. It was shown that, under assumption of the same useful area of upper and lower storey, in cases taken into consideration the maximal difference in energy demand for heating only is 5.41% (Nowy Sącz), but in cooling can reach as much as 46.75% (Zakopane).

1. Introduction

The principles of determining the energy performance of buildings currently in force in Poland are based on the PN-EN ISO 13790: 2009 standard [6] which specifies conditions for dividing a building into calculation zones. Generally, the partitioning of a building into thermal zones is required in several independent cases:

- set-point temperatures for heating or cooling of spaces differ by more than 4 K,
- spaces are serviced by different heating systems and different cooling systems (if any),
- less than 80% of the floor area is serviced by the same ventilation system, and
- the ventilation air flow relative to the floor area differs by more than four times in 80% of the floor area or doors are not likely to be opened frequently between spaces.

Among the above listed conditions, no special case is distinguished where a building consists of parts with different dynamic properties.

The dynamic properties of a building are influenced by, among others, internal thermal capacity. Internal heat capacity (or: thermal mass) is a heat capacity of building materials, which has an effects on fluctuation of the internal temperature [3].

This property enables storage a heat in building construction to reduce peak heating or cooling loads [2, 4] as well as energy needs [1, 9].



2. Mathematical model

The demand for useful heat for heating and cooling in each of the two assumed zones as well as in the entire building was determined using the monthly balance method according to the formula provided in PN-EN ISO 13790: 2009 [6]. In Poland, this algorithm is required to determine energy performance of a building [8]. Climate statistics published on the website of the Ministry of Investment and Development [5] were used in the calculations.

If the energy assessment takes account only of the building construction, i.e. without heating and cooling systems, then the building energy performance can be expressed by an indicator of the annual useful energy demand (EU_H) for heating and cooling (EU_C). This indicator is determined on the basis of the annual useful demand for heating (Q_H) and conditioned floor area of the space (A_f):

$$EU_{H,x} = \frac{Q_{H,x}}{A_{f,x}}, \text{ kWh m}^{-2} \text{ K}^{-1} \quad (1)$$

The additional subscript x is 1 for the first floor zone, 2 for the second floor zone, and B for the whole building treated as one conditioned zone.

Similarly, on the basis of the annual useful heat demand for cooling (Q_C), the annual useful heat demand indicator for cooling was determined as:

$$EU_{C,x} = \frac{Q_{C,x}}{A_{f,x}}, \text{ kWh m}^{-2} \text{ K}^{-1} \quad (2)$$

To evaluate the influence of different internal heat capacities on the energy efficiency of the building, the indicators were compared:

- for heating $EU_{H,Tot} = \frac{Q_{H,1}+Q_{H,2}}{A_{f,B}}$ and $EU_{H,B}$,
- for cooling $EU_{C,Tot} = \frac{Q_{C,1}+Q_{C,2}}{A_{f,B}}$ and $EU_{C,B}$.

The obtained values of the indicators were used to determine:

- the relative difference between annual useful energy demand indicators for heating:

$$\delta EU_H = \frac{EU_{H,Tot} - EU_{H,B}}{EU_{H,B}}, \% \quad (3)$$

- the relative difference between annual useful energy demand indicators for cooling:

$$\delta EU_C = \frac{EU_{C,Tot} - EU_{C,B}}{EU_{C,B}}, \% \quad (4)$$

- the relative root mean square of the annual useful energy demand for heating:

$$dRMS_H = \sqrt{\frac{(Q_{H,B} - Q_{H,1})^2 + (Q_{H,B} - Q_{H,2})^2}{2}} / Q_{H,B}, \% \quad (5)$$

- the relative root mean square of the annual useful energy demand for cooling:

$$dRMS_C = \sqrt{\frac{(Q_{C,B} - Q_{C,1})^2 + (Q_{C,B} - Q_{C,2})^2}{2}} / Q_{C,B}, \% \quad (6)$$

3. Case study

The impact of different dynamic properties of two zones on the value of the annual energy demand indicator for heating and cooling of a building was analysed by performing a number of variant calculations. The assumed data are provided in Table 1.

Maximum values that indicate differences in the energy performance of the analysed building due to different dynamic properties of the two zones are provided in tables 2 ÷ 3.

Due to specific metrological data, the maximum values the relative difference in heating mode occur in Nowy Sącz (Table 2), and in cooling mode occur in Zakopane (Table 3).

The analysis of the mathematical model applied leads to a general conclusion that the largest differences in the energy performance of a building, as described by the useful heat demand indicator for heating, will occur in the case of:

- the largest internal thermal heat capacity of the first storey and the lowest internal heat capacity of the second storey,
- the height standard of thermal insulation of external partitions,
- the lowest air change rate,
- the smallest conditioned space, and
- large heat gains, especially from solar radiation.

Similarly, while the useful heat demand indicator for cooling is evaluated the largest differences of the indicators can be expected when:

- the largest internal thermal heat capacity of the first storey and the lowest internal heat capacity of the second storey,
- the highest standard of thermal insulation of external partitions,
- the highest air change rate,
- the smallest conditioned space, and
- large heat gains, especially from solar radiation.

However, the calculations performed indicate how large these differences can be. For example, in the case shown in Table 2, the actual useful heat demand for heating, determined as the sum of the demand in each zone, is more than twice as high as that calculated for the entire building.

Table 1. Dataset for calculations.

Description	Specification and variants
Location	59 weather stations [5]
Shape of the building	Cuboid
Net height of a storey	2.80 m
Conditioned (e.g. usable) space of one storey (in brackets: the whole building)	50 (100) m ² ; 75 (150) m ² ; 100 (200) m ²
Internal heat capacity of the upper storey per conditioned area ($C_{mu,2}$)	260,000 J K ⁻¹ m ⁻² ; 370,000 J K ⁻¹ m ⁻² ; 400,000 J K ⁻¹ m ⁻²
Internal heat capacity of the lower storey per conditioned area ($C_{mu,1}$)	500,000 J K ⁻¹ m ⁻² ; 600,000 J K ⁻¹ m ⁻²
Area of external partitions facing S and N	25% larger than the surface of external partitions facing E and W
Area of the glazed external partitions	The minimum variant: 1/8 of the conditioned (used) area The intermediate variant: the arithmetic mean of the minimum and maximum variants The maximum variant: the total surface of external partitions
Set-point temperature for space heating	20.0 °C
Set-point temperature for space cooling	24.0 °C
Air exchange rate	0.5 h ⁻¹ ; 1.5 h ⁻¹ ; 3.0 h ⁻¹
Thermal insulation standard	The 2002, 2008, 2017, and 2021 requirements [7]

Across Poland, the relative differences in annual useful energy demand indicators for heating (δEU_H) vary between 5.41% (Nowy Sącz) and 1.82% (Suwałki) (Figure 1). The main data for Nowy Sącz location are included in Table 2. It is worth noting that these relative differences are always positive, which means that the useful heat demand for heating calculated to assess the energy performance of a building with two zones differing in dynamic properties is lower than the actual one.

The smallest yearly useful heat demand indicator for heating is observed in Nowy Sącz ($EU_{H,B} = 42.99 \text{ kWh m}^{-2} \text{ a}^{-1}$). In that case the largest relative change of δEU_H (5.41%) is present (Figure 2). The highest yearly useful heat demand indicator for heating is noticed in Suwałki ($EU_{H,B} = 138.35 \text{ kWh m}^{-2} \text{ a}^{-1}$), but a relative change δEU_C is equal 1.82%, when the absolute difference is $2.52 \text{ kWh m}^{-2} \text{ a}^{-1}$. The relative root mean square of the annual useful energy demand for heating varies from 48.15% (Nowy Sącz) to 49.18% (Suwałki) (Figure 2).

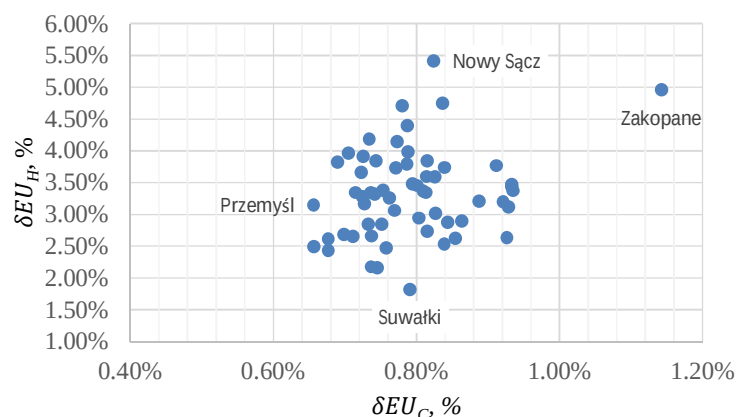


Figure 1. Maximal values of the relative difference between annual useful energy demand indicators for heating and the corresponding values in cooling mode.

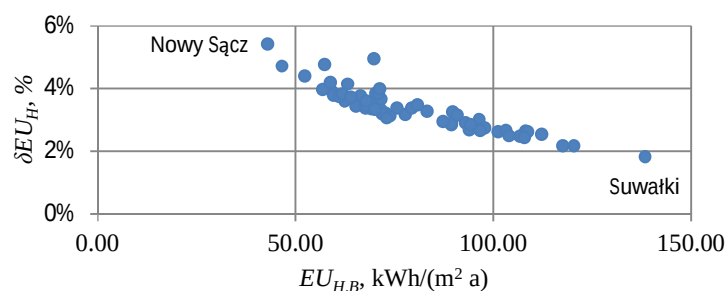


Figure 2. Relative difference between annual useful energy demand indicators for heating in relation to annual useful energy demand indicator for heating.

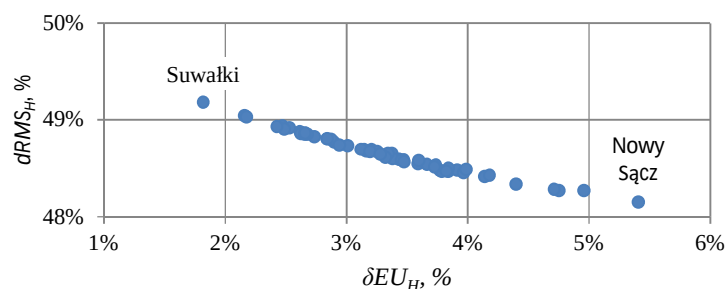


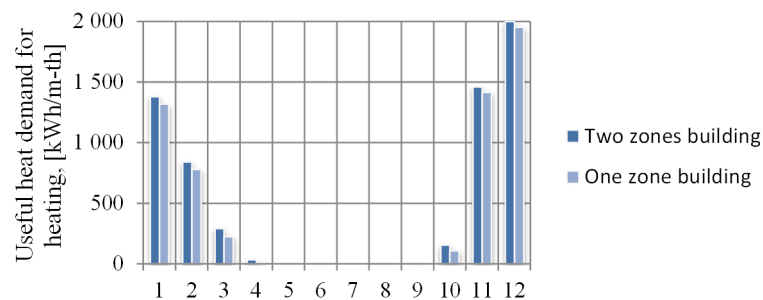
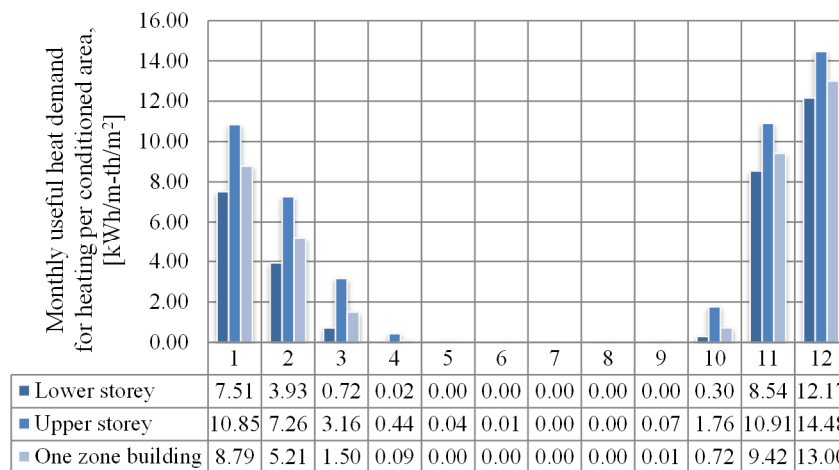
Figure 3. Relative root mean square of the annual useful energy demand for heating in relation to relative difference between annual useful energy demand indicator.

Monthly changes of the useful heat demand for heating for the Nowy Sącz location are presented in Figure 4. The monthly useful heat demand for heating of the two zones building is higher than one zone building. Due to the heat solar gains in January the useful heat demand is lower than in December.

A comparison of monthly heat demand for heating per conditioned area (Figure 5) shows that heating is noticed in the lower storey in 7 months, in the upper story in 10 months, while in the entire building it is equal 8 months.

Table 2. Main data for the chosen case for the heating mode of a building located in Nowy Sącz.

Results	Variant description
$EU_{H,1} = 27.32 \text{ kWh m}^{-2} \text{ a}^{-1}$	$C_{mu,1} = 600,000 \text{ J K}^{-1} \text{ m}^{-2}$
$EU_{H,2} = 43.95 \text{ kWh m}^{-2} \text{ a}^{-1}$	$C_{mu,2} = 260,000 \text{ J K}^{-1} \text{ m}^{-2}$
$EU_{H,Tot} = 71.27 \text{ kWh m}^{-2} \text{ a}^{-1}$	The 2017 thermal insulation standard
$EU_{H,B} = 33.13 \text{ kWh m}^{-2} \text{ a}^{-1}$	$A_{f,B}: 150.00 \text{ m}^2$
$dRMS_H = 49,89\%$	Air exchange rate: 0.5 h^{-1}
$\delta EU_H = 5.41\%$	Share of window surfaces in the total area of external partitions: N – 0%, S – maximum, W – maximum, E – maximum

**Figure 4.** Monthly useful heat demand for heating for the Nowy Sącz location.**Figure 5.** Monthly heat demand for heating per conditioned area for the Nowy Sącz location.

In the cooling mode, the largest differences occur in the case of:

- the largest internal thermal capacity of the first storey and the lowest internal heat capacity of the second storey,
- the worst standard of thermal insulation of external partitions,
- the largest air change rate,
- the smallest conditioned space, and
- the largest heat gains, especially from solar radiation.

Across Poland, the relative differences in annual useful energy demand indicators for cooling (δEU_C) vary between 46.75% (Zakopane) and 12.93% (Krosno) (Figure 6).

The smallest yearly useful heat demand indicator for cooling is observed in Zakopane ($EU_{C,B} = 1.39 \text{ kWh m}^{-2} \text{ a}^{-1}$), then a small change of the absolute value causes a largest relative change of δEU_C (48.75%) (Figure 7). The highest yearly useful heat demand indicator for cooling is noticed in Krosno ($EU_{C,B} = 5.89 \text{ kWh m}^{-2} \text{ a}^{-1}$), but a relative change δEU_C is equal 12.93%, when the absolute difference is $0.76 \text{ kWh m}^{-2} \text{ a}^{-1}$.

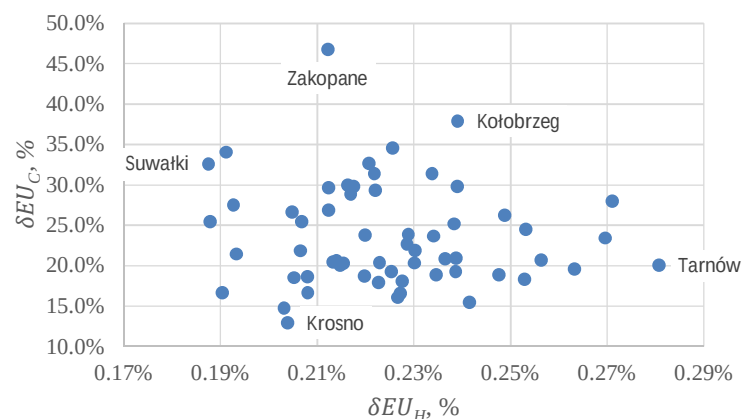


Figure 6. Maximal values of the relative difference between annual useful energy demand indicators for cooling and the corresponding values in heating mode.

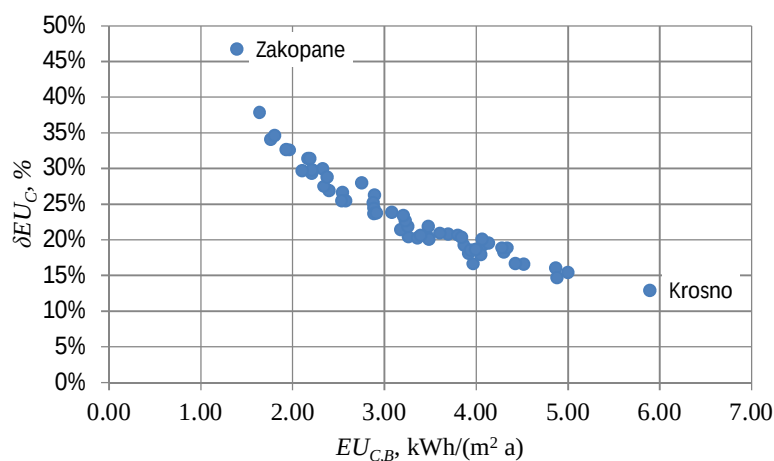


Figure 7. Relative difference between annual useful energy demand indicators for cooling in relation to annual useful energy demand indicator for cooling.

In the extreme case at the Zakopane location, the useful heat demand indicator for cooling calculated as the sum of relevant indicators determined in the zones is 46.75% of the indicator characterizing the entire building (Table 3).

Monthly changes of the useful heat demand for cooling for the Zakopane location is presented in Figure 9. The sum of the useful energy demand for cooling of two zones exceeds analogical value calculated for one zone.

In Zakopane (Figure 10) lower storey requires cooling for 6 months, while for upper storey cooling is needed for the whole year. The entire building needs cooling in eight months.

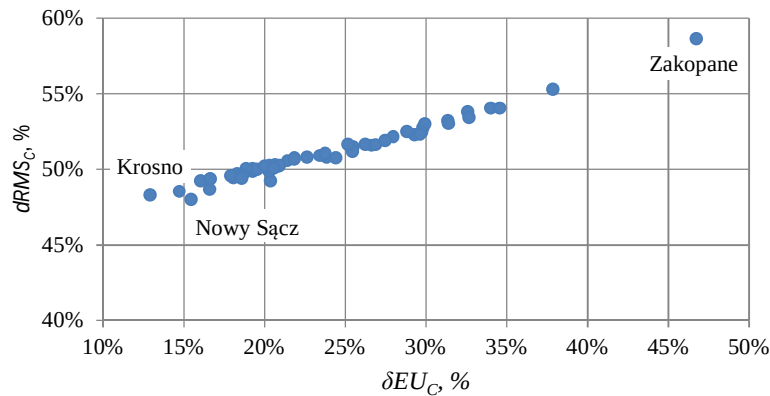


Figure 8. Relative root mean square of the annual useful energy demand for cooling in relation to relative difference between annual useful energy demand indicator.

Table 3. Main data for the chosen case for the cooling mode of a building located in Zakopane.

Results	Variant description
$EU_{C,1} = 0.59 \text{ kWh m}^{-2} \text{ a}^{-1}$	$C_{mu,1} = 600,000 \text{ J K}^{-1} \text{ m}^{-2}$
$EU_{C,2} = 3.50 \text{ kWh m}^{-2} \text{ a}^{-1}$	$C_{mu,2} = 260,000 \text{ J K}^{-1} \text{ m}^{-2}$
$EU_{C,Tot} = 2.04 \text{ kWh m}^{-2} \text{ a}^{-1}$	The 2021 thermal insulation standard
$EU_{C,B} = 1.39 \text{ kWh m}^{-2} \text{ a}^{-1}$	$A_{f,B}: 100 \text{ m}^2$
$\delta EU_C = 46.75\%$	Air exchange rate: 3.0 h^{-1}
	Share of window surfaces in the total area of external partitions: N – 0%, S – minimum, W – minimum, E – minimum

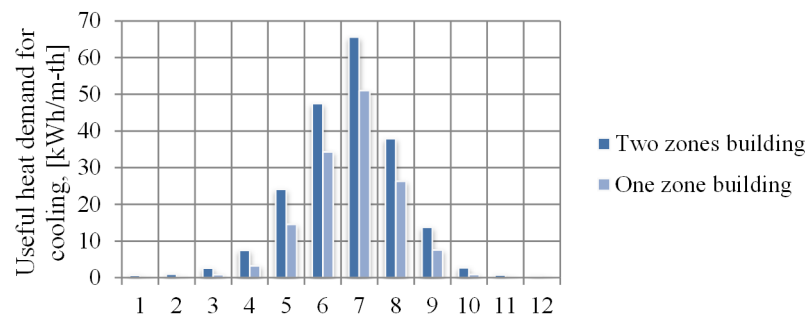


Figure 9. Monthly useful heat demand for cooling for the Zakopane location.

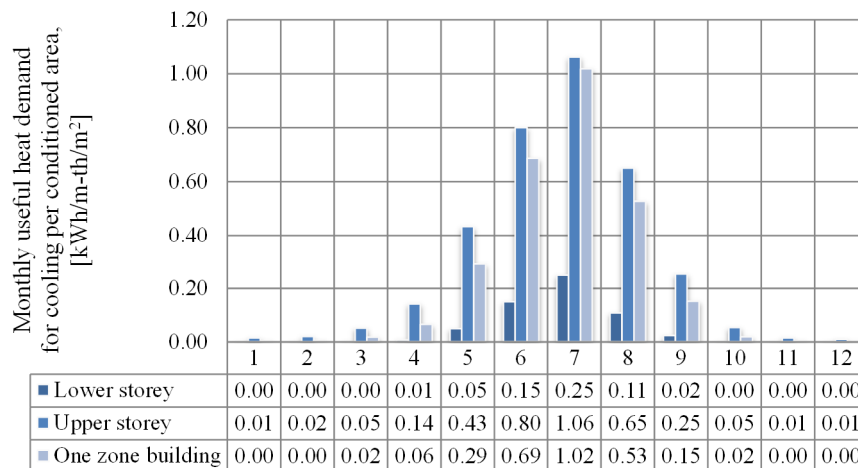


Figure 10. Monthly heat demand for cooling per conditioned area for the Zakopane location.

4. Conclusions

Different energy characteristics of the distinguished building zones result not only from different dynamic properties but also from a different thermal insulation of external partitions, for example between the roof and the ceiling above the unheated basement or ground floor.

In buildings with a lower thermal insulation standard, a smaller influence of the internal thermal capacity on the differences in the energy performance indicators is observed than in the case of very well insulated buildings.

Generally in the Polish climatic conditions, in the case of the same useful area of upper and lower storey, the influence of internal heat capacity on useful heat indicator for heating can be omitted, because the relative difference of that do not excide 5.41% (Nowy Sącz), and in absolute value is a maximum of $3.46 \text{ kWh m}^{-2} \text{ K}^{-1}$ (Zakopane).

The relative root square mean in the heating mode varies between 48.15% (Nowy Sącz) and 49.91% (Suwałki) (Figure 2), and in cooling mode changes from 47.99% (Nowy Sącz) to 58.64% (Zakopane) (Figure 8), and the analysed effect of internal heat capacity is more important in the cooling mode.

Disregarding the division into two zones due to the different dynamic properties slightly improves the value of the building assessment indicator.

In heating mode the division into two zone due a to different internal heat capacity can be omitted because of a neglected effect on the useful heat demand indicator (maximum: 5.41%). In cooling mode that effect can be neglected because of the small absolute value (maximum: $3.46 \text{ kWh m}^{-2} \text{ K}^{-1}$), even if the relative difference between useful heat demand indicator is equal to 46.75%. However, noticeable differences appear in the number of months influencing the value of heat demand for heating and cooling.

It can be expected that in the case of a building with two zones differing significantly in terms of conditioned area the division into zones should be introduced due to their different dynamic properties.

References

- [1] Aste N., Angelotti A., Buzzetti M. 2009 The influence of the external walls thermal inertia on the energy performance of well insulated buildings *Energ Buildings* **41** pp 1181–1187
- [2] Balaras C.A. 1996 The role of thermal mass on the cooling load of buildings. An overview of computational methods *Energ Buildings* **24** pp 1-10
- [3] Haase M., Andresen I. 2007 Thermal Mass Concepts. State of the art. SINTEF Report No. SBF BK A07030
- [4] Kosny J., Petrie T., Gawin D. Childs P., Desjarlais A., Christian J. 2006 Thermal Mass -Energy Savings Potential in Residential Buildings. (https://www.researchgate.net/publication/268411404_Thermal_Mass_-Energy_Savings_Potential_in_Residential_Buildings)
- [5] Ministry of Investment and Development. Data for energy calculations of buildings, in Polish (<http://www.mir.gov.pl/strony/zadania/budownictwo/charakterystyka-energetyczna-budynkow/dane-do-obliczen-energetycznych-budynkow-1/>)
- [6] PN-EN ISO 13790:2009 Energy performance of buildings -- Calculation of energy use for space heating and cooling, in Polish
- [7] Regulation of the Minister of Infrastructure of 12 April 2002 on technical specifications for buildings and their location. Journal of Laws 2015, Item 1422, consolidated text, amended in Journal of Laws 2017, Item 2285, in Polish
- [8] Regulation of the Minister of Infrastructure and Development of 27 February 2015 on the methodology for calculating the energy performance of the building or part of the building and the preparation and design of energy performance certificates. Journal of Laws 2015, Item 376, amended in Journal of Laws 2017 Item 1100, in Polish
- [9] Reilly A. Kinnane O. 2017 The impact of thermal mass on building energy consumption, *Appl Energ* **198** pp 108-121