Heat Delivered to the Premises by the Heating System, and the Actual Amount of Heat Needed to Heat the Premises

Paweł Michnikowski

Institute of Environmental Engineering, Lodz University of Technology, 90-924 Lodz, Al. Politechniki 6, Poland

Abstract: ***The article presents current implementation of the 2012 European Parliament Directive on energy efficiency for the heat cost allocation in multi-apartment buildings, into regulations of various Member States of the European Union. Technical arrangements have been defined, in accordance with rules of social conduct, for proper division of the heat delivered to particular apartments of the building in Poland. Criteria for the building selection have been specified to analyse the relation between measured heat consumption & individual fees for real heat consumption. Buildings were selected according to the specified criteria. Indication of heat cost allocators mounted on radiators was used to determine the energy supplied from the heating system to individual premises. The indications of allocators from 290 premises located in 9 buildings were analyzed, over 5 billing periods. Collected rich statistical material allowed the determination of correlation coefficients and determination of the dependence of the amount of energy supplied by the heating system of the building on the heat necessary to heat individual premises. Following extensive statistical material, heat cost allocation was evaluated in reference to meet the user's expectations for fair billing.***

Keywords: heat consumption, energy for space heating, heat cost allocation

Nomenclature:

$A/_V$	-	building compactness, in m^{-1},
$\phi_{u,c}$	-	area related heat demand for the case conditions (calculated), in W/m^2,
$\phi_{u,r}$	-	area related heat demand for actual unit internal temperatures (calculated), in W/m^2,
$\Delta A/V /_{A/V}$	-	building compactness relative deviation, in %,
$\Delta\phi_{u,c} /_{\phi_{u,c}}$	-	relative deviation of area related heat demand for the case conditions, in %,
cv_u	-	consumption value (displayed reading value rated by rating factors), in $-/m^2$,
Q_u	-	area related heat consumption (measured), in GJ/m^2,
$\theta_{i,av}$	-	average unit internal temperature determined by the allocators (measured indirectly), in ^0C,
$\theta_{i,p}$	-	designed apartment internal temperature, in ^0C,
$\theta_{e,av}$	-	average external temperature of the settlement period (measured), in ^0C,
$\theta_{e,c}$	-	climatic zone external temperature for the case conditions, in ^0C,
τ	-	heating season length (measured), in h.

1. Introduction

The heat cost allocation (**I**ndividual **M**etering and **B**illing) of the multi-apartment buildings, based on the heat consumption of individual units, is a part of energy efficiency strategy in the household sector. That is why the Energy Efficiency Directive imposes a law to settle heating costs on the basis of actual heat consumption. The Directive 2012/27/UE (EED) in clause 9, item 3, titled "Metering" introduces the legal duty for all EU countries, valid from December 31, 2016, to install meters for heating or cooling energy usage or hot water supplied to each apartment in multi-apartment and multi-functional buildings; but in case the application of individual meters is technically or economically not viable, consumption of heating energy shall be measured by means of heat cost allocators installed on the radiators [1]. Next Directive 2018/2002/UE (EED-18) does not change the regulation quoted above [2].

Despite the 2012 EED concerning energy efficiency requiring Member States to adjust their local regulations on space & water heating to actual energy consumption, only 16 out of the 28 countries have implemented rules at national levels. Three countries - Malta, Poland and Great Britain - have introduced only the general rules. Nine countries, that is, Spain, Portugal, Ireland, Greece, Cyprus, Luxemburg, Belgium, Sweden and Finland have not implemented the above mentioned regulations at all. In case of two countries where the EED is not yet implemented to the native law, the reasons of that are well known. Mainly, there is lack of economic efficiency during heat cost allocation - in Finland [4], Sweden [5] and Poland [6].

Among the countries which have implemented the legal duty of metering, there are some that defined conditions to achieve fair cost allocation. The conditions in question include correction factors concerning apartment location in the building as well as maximum/minimum limits of heating costs. More information about the correction factors can be found in the following publications [7], [8], [9]. Corrective factors concerning apartment location are applied in Bulgaria, Romania, Denmark, Hungary, Slovenia, Slovakia, the Czech Republic, Latvia, Estonia, France and the Netherlands [3]. Three countries employ feasible limits of heating costs. In the Czech Republic, e.g., the minimum heating costs per unit square area cannot be lower than 80% of the building average heating cost per unit square area whereas and the maximum costs cannot exceed 200% of that cost [10]. In Slovenia, the values are 40% and 300% respectively [11]. In Hungary, the maximum heating cost is referred to the share of costs allocated to individual units & the limit is 250% of the building average cost [12].

In Romania, despite that EED has been implemented to their national regulations, heat cost allocation is carried out with considerable difficulties. Only 500 thousand out of 3 million apartments are equipped with heat cost allocators. The Romania regulations require heating energy fixed cost level to assure minimum internal temperature of 18 ^{0}C [13].

The paper is an attempt to respond to the following questions:

- Why not all of the EU-countries have introduced the regulations of the EED concerning heat cost allocation in multi-apartment buildings?
- Why some countries applied them selectively?
- Why even the 16 countries which fully implemented the EED regulations provided additional conditions, corrections or limitations which significantly modify procedures of heat cost allocation in multi-apartment buildings.
- Why heat cost allocation based on heat mater readings in Housing Cooperatives frequently becomes a source of conflict? [14]

2. Critical evaluation of existing methods for heat cost allocation

The amount of heating costs should be related to the quantity of consumed energy for space heating the apartment, up to the real temperature in the given apartment. This requirement is a part of the mentioned above Directive and the legal regulations govern the issues of the heat costs allocation in Poland [15]. If a method of apartments' heat costs allocation secures the high coefficient of linear correlation between the indicated costs and energy consumption for a purpose of these apartments heating such settlement should be considered as correct and fair one.

Are the methods applied in the Poland securing the sufficient correlation of the heating costs and the real heat consumption? It is a priori assumed that the costs indicated by the permitted in EED methods, based on the indications coming from the apartment heat-meters or the allocators installed on the radiators, are proportional to the heat consumption. But recently, this assumption is questioned in the publications, where the problems connected to the heat cost allocations in the apartments in the multi-apartment buildings, are described in a qualitative way. The problems described in the listed above publications are as follows: an adverse impact of heat transfer between the separate apartments, lack of heat gain registration if they come from the pipe installation or the diverse energy consumption of the apartments depending on their position in the building (correction factors). Despite the above examples of problems associated with heat cost allocation, using of IMC in multi-apartment buildings provides an efficient way of energy saving.

Below is a review of selected literature sources describing the above issues.

Pakanen et. al. [16] used ARMAX modeling to dynamically establish the flow of heat between hotel rooms with variable residence profiles. Their model also included the influence of such factors as: insolation, gains from internal sources, and variable ventilation conditions. In their overview of heating cost allocation methods. Siggelsten [17] proposed a rational method of correcting apartment heating cost allocation in order to remedy the errors associated with heat transfer through walls. As stated by Gafsi et. al. [18] in extreme cases as much as 90% of the energy required to heat an apartment is transferred through internal walls and is not registered. Yao et al. [19] point to the impossibility of quantitatively describing the phenomenon of heat transfer through the walls of adjacent apartments.

Ling et al. [20] describe the influence of the location of an apartment within a building on the costs of heating. In the case of heat cost allocators, heat gains from pipes supplying heat to radiators constitute another source of errors.

The legislation concerning heating cost allocation in Switzerland [21] requires the inclusion of heat from pipes in individual apartment heating costs. German recommendations require you to check each heat costs allocation to determine whether the heat emission from the internal piping in the building affects the accuracy of the distribution of heating costs [22]. Zoellner et. al. [23] describe the phenomenon of heat retrieval from pipes in a quantitative manner.

Despite some critical opinions about the methods used to divide heating costs into individual premises of a multi-family building, there are many publications confirming the positive impact of IMC on the rational use of energy for space heating. According to Slijpcevic et. al. [24] the transition to individual metering in Croatia resulted in significant energy savings averaged from 20 to 35%. However, low heat energy prices in cities with a dominant share of heat energy consumption did not ensure a positive net present value of investment for all buildings.

Cholewa et. al. [25] presents the results of experimental research conducted during 17 heating seasons (from1997/1998 to 2013/2014) in a multifamily building located in Poland, divided in the two parts: R with the heat cost allocators, L without allocators. The energy consumption in part R of the building was on average 26.6% and 30.5% lower than in part L for the period before and after thermal renovation of external walls of the building, respectively.

Teres-Zubiaga et. al. [26] shows that individual metering and charging has brought a reduction of normalized energy consumption of 15-20% during the first two years after implementing it, and simple payback periods are around 10 years. These results confirm that individual metering and charging affects directly on user behaviour encouraging inhabitants to change their habits to reduce their energy consumption, and this effect is significant even in European temperate climates.

There is no, in the technical literature, results of the researches focused on the quantitative analysis of an influence of the individual elements disturbing the correct division of the heating costs. That gap can be filled by the analysis of relationship between the heat costs allocation based on the present methods and the real heat consumption. The article contributes an insight onto the relationship between heat cost allocators indications & individual heat consumption for apartments.

Why so important problems haven't been addressed, yet? It can be only assumed that one of the reasons for that is a lack of the reliable data regarding the energy consumption for the apartment's space heating up to the level of the internal temperature and for the real conditions of the ventilation. The only available data are theoretical (analytical) ones, related to the heat demand for the heating purpose as a forecast of building's behaviour in the certain meteorological conditions. They are designated based on the commercial software, knowing the quality of partitions, layout of the apartments and designed internal temperatures and nominal ventilation conditions and so called: a computational external temperature during the heating season. Utilisation of the above prognosis to determine real heat consumption of a particular unit for a given calculation period, that is, for a known outside temperature, given unit inside temperatures & real ventilation intensity, becomes feasible if we possess actual calculation data for a large number of units & several calculation periods.

In such a case the average values of these operation parameters of the apartments: the temperature and ventilation may coincide with the designed parameters or vary from them only a little. Data from readings of the devices e.g.: heat meters or allocators from a huge number of apartments, located in a similar position in the building, allow for appointment of the average values of energy consumption, which can be compared with the analytical values of heat demands for the design conditions.

This paper is an attempt to answer the question from the previous paragraph: in what way the modern methods of heat cost allocation, based on the allocators readings, are meeting the basic requirements of the fair settlement, consistent with the real energy consumption.

3. Collection & Analysis of the Test Material

3.1. Method of the test material selection.

To achieve the goal stated above a selection of the research material must be conducted – in this case, choice of buildings to be analysed. This may be executed in the following way:

- Select one apartment building with all radiators equipped with heat cost allocators,
- Select a couple of the similar buildings located next to each other, calculated in the same billing period.

To find fully metered multi-apartment buildings is the major difficulty in Poland. Most buildings in which individual heat cost allocation is implemented, based on allocator readings, are not equipped with allocators in bathrooms or kitchens. The argument for not installing allocators in bathrooms is the risk of moisture to appear when users try to save energy in excess there.

Nine buildings out of 40 were selected – all located close to each other, with the same settlement period & the following criteria met:

- Same insulation parameters,
- Similar compactness factor,
- Similar demand for heat/ per area unit.

Fig. 1 illustrates building location. Table 1 presents building partition heat transfer coefficient, the same for all 9 appointed buildings. Table 2 provides building serial numbers, their heated areas, individual heat demands for the calculation conditions of II climatic zone (city Nowy Tomyśl west of Poland), $\theta_{e,o}$= -18°C and the number of apartments in each building.

Additionally, the column 6 presents relative deviation of the compactness factor average value *A/V*, while column 7, relative deviation of the unit, calculated heat demand for the nine analysed buildings. Table 3 presents the operation parameters of the buildings i.e. the area-related consumer values cv_u (taking into account the radiators rating factors), area-related heat consumption Q_u and the weighted average of internal temperatures in the apartments $\theta_{i,av}$ for 5 settlement periods. Area-related heat consumption Q_u is the ratio between the total heat consumption of the building for the space heating (measured in building input) & the building heating surface. Last line in Table 3 provides the average values of consecutive parameters. Table 4 presents the date of the settlement periods, a length of heating seasons and average external (outdoor) temperatures. Total number of the apartments in the analysed buildings amounts to 290 to the utility units (premises). All radiators in the chosen buildings are equipped in the heat cost allocators. Space heating internal system (pipes) is located at the top of walls. The buildings have 5 floors, from 1 to 3 staircases and similar layout of premises. All buildings are supplied with heat from the municipal heating network through dual-purpose individual thermal nodes equipped with measuring and billing systems. It means that it is possible to define heat consumption for space and domestic hot water heating.

Relative deviations mean values for the parameters given in Table 3 are shown in Table 5. The term relative deviation is understood as the fraction in which the numerator shows the difference between the current value and the average of the parameter, and the denominator of the average (in percent).For example, for area-related heat consumption Q_u the dependence for to the relative deviation is:

$$\frac{\Delta Q_u}{Q_u} = \frac{Q_{u,k} - Q_{u,av}}{Q_{u,av}} 100\% \qquad (1)$$

where:

$Q_{u,k}$ - area related heat consumption in *k* – apartment, in GJ/m^2,

$Q_{u,av}$ - average area-related heat consumption, in GJ/m^2, described by the dependence:

$$Q_{u,av} = \sum_{k=1}^{9} Q_{u,k} \qquad (2)$$

Last line of Table 5 provides average values of the deviations.

3.2. Research results

It has already been mentioned that there is a lack of an analysis regarding the relationship between allocator indications and real heat consumption for space heating of individual apartments in a muti-apartment building. If there is a strong relationship between the two parameters we should be able to evaluate whether heat consumption billing based on allocator readings corresponds to actual heat consumption. Comparative database selection presenting real heat consumption values for space heating, providing apartment internal temperatures and ventilation levels demanded by the user, seems to be one of the reason why such analyses do not exist. Houselord or building administrator posses data of heat consumption values for the whole apartment building. There is no data concerning individual apartments. Energy consumption audit performed for the building should provide prognosis data for the heat demand of particular apartments. These data concern designed performance parameters - inside temperature, ventilation and calculated external temperature.

Consumption values registered by the allocators (displayed reading value multiplied by radiator rating factor) depend on the amount of the apartment thermal energy losses through heat transfer and ventilation, for the apartment internal temperature. Due to subjective conditions of the apartment operation an objective forecasted for heat demand will considerably vary from reality. If we provide a large number of readings for comparable apartments similarly located in buildings, with the same heat loss unit values, then average value of these measurements should enable us to objectively evaluate heat consumption. Average values of multiple readings concerning similarly located apartments allow to compare heat consumption real values with computer calculation data based on theoretical analyses.

Fig. 2 presents relationships between heat consumption values registered by allocators & heat values demanded for the apartments in 9 analysed buildings, for the time period from October 1, 2013 to September 30, 2014. Along the x-axis area-related heat demand dependent on the apartment location in the building is indicated; the y-axis shows allocators area-related displayed reading value rated by rating factors. The determination coefficient, R^2 amounts to 0.092 and its square root, which is the correlation coefficient, is equal to 0.303. The same diagram presents, in addition, designed heat consumption values reduced by correction factors. Trend line should be parallel to the x-axis. But as is not in this case it means that the reducing factors insufficiently correct increased heat consumption associated with adverse apartment location. The following diagrams present the same relationships for the billing periods below:

- from 01.10.2014 to 30.09.2015 (fig. 3a),
- from 01.10.2015 to 30.09.2016 (fig. 3b),
- from 01.10.2016 to 30.09.2017 (fig. 3c),
- from 01.10.2017 to 30.09.2018 (fig. 3d).

For the settlement period of October 1, 2015 - September 30, 2016 (fig. 3b), correction factors improved the increased apartment heat consumption caused by adverse location in the building, as the trend line is almost parallel to the x-axis

The x-axis in figures 2 and 3 present the theoretical, area-related heat demand for calculation conditions i.e. the external temperature -18^{0}C and the designed internal temperature of the heated apartments. But how would the correlation coefficients change if the x-axis presented heat demand values for real average inside temperatures in the apartments, determined by special allocators equipped with a function the average internal temperature registration [9]**Error! Reference source not found.**? Allocations, which in addition to the standard displayed reading allows you to determine the average, from the billing period, internal (indoor) temperature in the room at a distance of 1.5 m from the radiator and a height of 0.75 m. In order to designate area-related heat demand in the billing period for a k – apartment, the following equation was applied:

$$\phi_{u,r,k} = \phi_{u,c,k} \frac{\theta_{i,av,k} - \theta_{e,av}}{\theta_{i,p} - \theta_{e,c}} \quad (3)$$

where:

- $\phi_{u,r,k}$ - area-related heat demand in k – apartment for real internal temperature, in W/m^2,
- $\phi_{u,c,k}$ - area-related heat demand in k – apartment for calculation conditions, in W/m^2,
- $\theta_{i,av,k}$ - average internal temperature in k - apartment designated by the allocators, in ^{0}C.

Fig. 4 presents correlations between area-related consumption values of allocators and the area-related heat demand for the real average internal temperatures of the apartments in the period of 01.10.2017 - 30.09.2018.

Comparing results for the buildings, in case of building number 12, the average deviation of the allocator individual readings exceeds even 20% (Tab. 5).

For particular settlement periods, buildings with the deviation of individual allocator consumption values or individual heat demand (tab. 5) exceeding 10% were eliminated. As a result, the analysis for the particular settlement periods considered:

- 2013/2014 – 200 apartments,
- 2014/2015 – 130 apartments
- 2015/2016 – 100 apartments,
- 2016/2017 – 190 apartments,
- 2017/2018 – 230 apartments.

Table 5 presents buildings taken into account for each calculation period.

The results of the analysis for all billing periods are given in Table 6. The correlation and determination coefficients are presented there for three analysed variants:

a) Area-related allocator consumption values dependent on the heat demand for calculation conditions,
b) Area-related allocator consumption values dependent on heat demand values for real average apartment internal temperatures,
c) Area-related allocator consumption values dependent on the heat demand values for real average apartment internal temperature, excluding the buildings with the

deviations area-related consumption values or heat demands exceeding 10% (Tab. 5).

Real temperatures considerably influence heat demand on individual allocator consumption values (table 6, line B). Elimination of some of the buildings from the analysis does not change much. It is clearly visible when comparing variants B and C from Table 6. This comparison shows that the maximum correlation coefficient amounts to 0.561 (variant C, 2016/2017 period). Is the value relevant? What is the value of the border correlation factor to be considered significant for 190 measurements?

The following formula for the statistic value should be transformed to arrive at an answer [32]:

$$t = \frac{R}{\sqrt{1-R^2}}\sqrt{n-2} \qquad (4)$$

where:
R- correlation coefficient from a sample,
n- *n* - elements sample

After the conversion, we receive a border value of the correlation coefficient for the *n* - element sample and selected critical value t_{krit} , for a defined confidence level, from Student's *t* - distribution:

$$R_{\lim} = \frac{t_{krit}}{\sqrt{t_{krit} + n - 2}} \qquad (5)$$

For a level of confidence α = 0.05 and n - 2 = 188 degrees of freedom, the critical value t_{krit} amounts to 1.96. Solving the above equation (5), we arrive at 0.139 for the border value of the correlation coefficient for which it is significant. Such a small border value results from large sample size. The question is whether it is reliable to evaluate heat consumption billing based on allocator consumption values for the correlation coefficient of dependency power, valued from 0.4 to 0.56 and it is done in a way corresponding to energy used for space heating.

As it is shown in the latter part of this paper, application of determination coefficients is a better tool for that purpose. The determination coefficient, R^2, is a measure the percentage of changeability of a dependent variable (result) is explained by means of an independent variable (reason) [32]. The allocator's consumption values are the dependent variable for the analysis conducted in this paper. The determination coefficient defines the percentage of their dependency on the independent variable, i.e., the heat demand. Table 6 confirms that in the best option (variant C, 2016/2017 time period) only 31.5% of the allocator readings depend on the heat demand for real temperatures, which is, on energy consumption for the space heating purpose. Most of the readings, 68.5%, depend on other factors. The results are even worse for earlier settlement periods, which clearly indicates that billing based on the allocator consumption values does not correspond to real energy consumption for space heating.

3.4. Case of incomplete metered buildings

The analyses conducted in the previous chapter refer to 9 buildings where all radiators were equipped with the electronic allocators. The result of the analyses is an observation that it exists the average power of dependency between allocator's consumption values in the apartments and heat consumption for the space heating.

It would be reasonable to conduct the similar analysis for the buildings where the metering is not complete e.g.: allocator missing on one of the radiators in the apartment. Within the housing development where the 9 analysed buildings are located, there are also 3 buildings with apartments not equipped with allocators in the bathrooms. Apartment owners disagreed to install heat meters there due to the risk of the excessive moisture coming from the bathrooms. The buildings in question belonged to the same billing period and had the same parameters for the building partitions, as given in Tab. 1. The buildings included 135 apartments. Heat demand calculation for each apartment varied from 43 to 47 W/m^2. Table 7 presents operation data for the buildings.

Comparing average values from Table 7 and Table 3 it can be noticed that for the three buildings with incomplete metering, area-related allocator readings decrease about 27% (column 2,5,8,11,14) whereas when compared to buildings with complete metering, area-related heat consumption registered by heat meters of thermal nodes increases by 42% on average (column 3,6,9,12,15). Additionally, the average operation temperature rises above 22^{0}C.

Decrease of the area-related allocator consumption values is a result of lack of readings from allocators in the bathrooms, on one hand, & lower readings from the allocators in adjacent rooms, on the other hand, additionally heated by bathroom radiators. Increase of the area-related heat consumption is due to dismantling the valve thermostatic heads on the radiators in the bathrooms or exchanging radiators for bigger ones. Residents mistakenly consider free the heat from the bathroom radiators as a part of fixed costs. Lack of allocators in the bathrooms is completely unreasonable. It leads to the situation before the individual heat cost allocation was introduced. For such conditions, proposed method of heat cost allocation, based on incomplete metering, does not favour energy saving by apartment residents and it is inconsistent with the requirements of the Energy Law [19].

Tab. 8 presents the correlation and determination coefficients for the relation between the area-related allocators' consumption values and heat demand values for the real internal temperatures of the apartments in three buildings with incomplete metering (variant B).

A value of correlation coefficient R_{krit}, above which it is essential for the level of confidence α = 0.05 and k - 2 = 133 degree of freedom - equals 0.169. It is not achieved for any of the analysed settlement periods, which means that there is no correlation, at all. As far as the correlation coefficient, R^2 is concerned, the highest value for the 2014/2015 season is 0.026, which means that the allocator's consumption values are determined by the change of heat consumption only in the value of 2.6%.

Fig. 5 presents the diagram of the relationship between the area-related: allocator consumption values and the heat demand values for the real average internal temperatures in the apartments located in three buildings with incomplete metering for a period of time: 2014/2015.

3.4. Discussion of the results

This paper presents the analysis of the relationship between the area-related: allocator's consumption values and heat consumption for the purpose of space heating. Nine buildings & 5 billing periods were selected for the research purpose. The buildings were chosen on the basis of the following criteria:

- Complete metering i.e. all radiators equipped with heat costs allocators,
- The same building envelopes and similar individual values of the heat demand (±2%),
- Similar building location and the same billing period,
- Similar individual heat consumption values, allocator's consumption values and average internal temperature.

Average heat demand values for large statistic samples, apartments similarly located in the buildings & real average internal temperatures, were used as the representative values of heat consumption for space heating. The internal temperatures were registered by means of the special heat costs allocators [9].

Results of the analysis of the relationship between area-related: allocator's consumption values and heat demand for actual average internal temperatures of the apartments are presented in Tab. 6. The correlation coefficients, although statistically significant, present moderate power of dependency (max. value of 0.561). The determination coefficient seems a more reliable parameter to assess whether the allocator consumption values allow correct billing of the energy used for apartment heating. It specifies what part of the readings refers to heat consumption. In the most favourable variant C, for the 2016/2017 period, only 31.5% of the readings depended on energy consumption for heating. It means that as much as 68.5% of the fee was due to other factors. Such a result confirms billing of heat consumption corresponds to actual usage to a limited extend.

For buildings with incomplete metering, the relationship between area-related: allocator readings & heat consumption looks even worse. The analysis presented in this paper was conducted for three buildings (with 135 apartments) in which bathroom radiators were not equipped with allocators. Building partitions were identical - both there as well as in the other 9 buildings with complete metering. The analysis shows that in comparison with the group of completely metered buildings, the individual allocator readings dropped by 27%, whereas the heat consumption registered by heat meters in building thermal nodes increased by 42%. The result may be a premise to consider the fee allocation method based on incomplete metering as inconsistent with paragraph 45a, clause 9 of the Energy Law on stimulation of the users' energy saving behaviour [19].

The correlation coefficient of the allocator's consumption values and the heat consumption - for the most favourable variant & 2014/215 period of time (Tab. 6) - amounts to 0.16 and is statistically insignificant. For the same period of time, the determination coefficient equals to 0.026, which means that individual allocator readings were determined by the change of heat consumption only to the extent of 2.6%.

4. Conclusions

The analysis conducted in this paper proves that the method based on allocator readings installed in the apartments on all radiators does not provide correct fees for the energy purchased for space heating; billing does not correspond to real heat consumption. In case of incomplete metering, e.g., no allocators in the bathrooms, there is not any correlation between billing and heat consumption; in addition, the method does not persuade residents to save energy for heating.

As long as building owners or managers apply in Poland methods based only on allocator readings to determine heat costs of individual apartments, they must be aware that the measuring methods are not consistent with the valid law and that they do not fulfil the basic expectation of the users – a fair heat allocation.

References

[1] European Parliament, Directive 2012/27/EU, 2012.
[2] European Parliament, Directive 2018/2002/EU, 2018.
[3] L. Castellazzi, Analysis of Member States' Rules for Allocating Heating, Cooling and Hot Water Costs in Multi-apartment/Purpose Buildings Supplied from Collective Systems (2017) JRP Technical Report, doi: 10.2760/40665.
[4] Energy Efficiency Act (1429/2014), as issued 30.12.2014 (MNE(2015)50503), *Energiatehokkuuslaki* ['Energy Efficiency Act'], https://www.finlex.fi/fi/laki/ajantasa/2014/20141429.
[5] S. Siggelsten, Heat cost allocation in energy efficient multi-apartment buildings, Cogent Engineering 5/2018.
[6] Implementation of Articles 9 – 11 of Directive 2012/27/UE in Poland http://mbic.eu/fileadmin/mbic/rce-warsaw/10-komar_and_jeziorowska.pdf.
[7] L. Gao, X. Fang, Study on comprehensive correction factors of northern residential buildings, Gas Heat 25 (2005) 23–26.
[8] H. Ren, B. Hao, J. Qi, Influence of position diversity on the heat consumption and heat fees in the same floor, Build. Energy Effic. 36 (2008) 1–4.
[9] J. Ling, Q. Li, J. Xing, The influence of apartment location on household space heating consumption in multi-apartment buildings, Energy Build. 103 (2015) 185-197.
[10] https://www.zakonyprolidi.cz/cs/2015-269.
[11] http://www/pisrs.si/Pis.web/pregledPredpisa?id=PRAV12408.
[12] Government Decree No. 157/2005. (VIII. 15.) of the Government Implementing Act XVIII of 2005 on District Heat Supply (https://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=a0500157.kor).
[13] Presentation of Mr Eadu Opaina (Federation of Owners' Association) at the MBIC workshop in Warsaw on 14/11/2016 http://mbic.eu/fileadmin/mbic/rce-warsaw/07-opaina.pdf.

[14] http://mbic.eu/fileadmin/mbic/rce-warsaw/08-michnikowski.pdf.
[15] The Act of 10 April 1997 - Energy Law in Poland.
[16] J. Pakanen, S. Karjalainen, Estimating static heat flow in buildings for energy allocation systems, Energy and Buildings, 38/2006, s. 1044–1052.
[17] S. Siggelsten, Reallocation of heating costs due to heat transfer between adjacent apartments, Energy and Buildings 75 (2014) 256-263.
[18] A. Gafsi, G. Lefebvre, Stolen heating or cooling energy evaluation in collective buildings using model inversion techniques, Energy and Buildings, 35/2003, s. 293-303.
[19] Y. Yao, S. Liu, Z. Lian, Key technologies on heating/cooling cost allocation in multifamily housing, Energy and Buildings 40 (2008) 689–696.
[20] L. Liu, L. Fu, Y. Jiang, S. Guo, Major issues and solutions in the heat-metering reform in China, Renewable and Sustainable Energy Reviews, 15/2011, s. 673-680.
[21] Handbuch zur verbrauchsabhaengiegen Heiz- and Warmwasserkostenabrechnung VHKA, Bundesamt fuer Energie Bern 2004.
[22] VDI 2007, Energy consumption accounting for the building services – Method for the consideration of heat loss through Pipes, March 2009, Beuth Verlag Duesseldorf.
[23] G. Zoellner, W. D. Geisenheimer, Bedeutung der Rohrwaermeabgabe fuer die verbrauchsabhaengige Abrechung, HLH 6 (2002).
[24] S. Slijepcevic, D. Mikulic, K. Horvat, Evaluation of the Cost-Effectiveness of the Installation of Heat-Cost Allocations in Multifamily Buildings in Croatia.
[25] T. Cholewa, A. Siuta-Olcha, Long term experimental evaluation of the influence of heat cost allocators on energy consumption in multifamily building, Energy and Buildings 104 (2015) 122-130.
[26] J. Teres-Zubiaga, E. Perez-Iribarren, I. Gonzalez-Pina, J.M.Sala, Effects of individual metering and charging of heating and domestic hot water on energy consumption of buildings in temperatur climates, Energy Conversion and Management (171) 2018, 491-506.
[27] C. Łucyk, Settling heating costs in multi-family buildings - model tests (in Polish), Rynek Ciepła REC 2010, Materiały i studia, Kaprint Lublin 2010.
[28] P. Michnikowski, E. Szczechowiak, Determination of heat load released by a radiator by an electronic heating cost allocator, Archives of Thermodynamics, 30/2009, No 2. s. 15–36.
[29] P. Michnikowski, Analytical and measurement method for determining energy consumption for heating premises in multi-family buildings (in Polish), Rozprawy nr 468, Wydawnictwo Politechniki Poznańskiej, Poznań 2012.
[30] P. Michnikowski, Energy consumption for heating premises in a multi-family building (in Polish), Rynek Energii, 5/2012, s. 81-86.
[31] P. Michnikowski, E. Szczechowiak, Settlement of heating costs for premises depending on the actual energy consumption for heating in multi-family buildings (in Polish), Rynek Energii, 6/2013, s. 63-70.
[32] J. Greń, Mathematical statistics - Models and tasks (in Polish), PWM, Warszawa 1984
[33] EN834:2012, Heat cost allocators for the determination of consumption of room heating radiators – Appliances with electrical energy supply.
[34] P. Michnikowski, Allocation of heating costs with consideration to energy transfer from adjacent apartments, Energy and Buildings 139 (2017) 224-231.

Table 1: Partition insulation parameters in the buildings

cover and external curtain walls	U=0.259 W/(m^{2}K)
internal load bearing walls	U=1.055 W/(m^{2}K)
internal partition walls	U=2.205 W/(m^{2}K)
basement slab ceiling	U=0.886 W/(m^{2}K)
slab/roof ceiling	U=0.210 W/(m^{2}K)
window frames/carpentry (average)	U=2.000 W/(m^{2}K)

Table 2: Comparison of buildings

Order number	Area m^2	Compactness *A/V*	Heat demand $\phi_{u.c}$ W/m^2	Number of apartments	Relative deviation $\Delta(A/V)/A/V$ %	Relative deviation $\Delta\phi_{u.c}/\phi_{u.c}$ %
1	2	3	4	5	6	7
8	1442	0.400	44.25	30	5.45	1.89
12	1442	0.400	44.25	30	5.45	1.89
13	2503.5	0.350	43.14	40	7.73	0.67
17	1442	0.400	44.25	30	5.45	1.89
33	1887	0.380	42.96	30	0.17	1.08
39	1887	0.380	42.96	30	0.17	1.08
47	1887	0.380	42.96	30	0.17	1.08
49	2243	0.370	43.76	40	2.46	0.76
51	1887	0.380	42.96	30	0.17	1.08
Σ	16620.5			290		

Table 3: Operation data of the buildings for 5 billing periods

no.	2013/2014			2014/2015			2015/2016			2016/2017			2017/2018		
	cv_u -/m^2	Q_u GJ/m^2	$\Theta_{i.av}$ °C	cv_u -/m^2	Q_u GJ/m^2	$\Theta_{i.av}$ °C	cv_u -/m^2	Q_u GJ/m^2	$\Theta_{i.av}$ °C	cv_u -/m^2	Q_u GJ/m^2	$\Theta_{i.av}$ °C	cv_u -/m^2	Q_u GJ/m^2	$\Theta_{i.av}$ °C
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
8	68.20	0.226	20.46	72.50	0.268	20.37	77.30	0.258	20.69	100.20	0.302	20.76	90.90	0.277	20.66
12	77.20	0.261	19.92	88.40	0.269	20.38	90.30	0.270	20.56	106.20	0.292	20.39	98.60	0.261	19.98
13	58.50	0.222	20.26	64.30	0.214	20.36	69.10	0.236	20.43	88.20	0.261	20.36	88.20	0.242	20.84
17	68.40	0.253	20.84	80.20	0.240	20.88	92.10	0.253	21.15	106.90	0.321	20.94	102.80	0.264	20.86
33	70.30	0.268	20.66	82.10	0.279	20.98	89.50	0.273	20.95	104.70	0.314	20.84	93.60	0.273	21.05

39	63.30	0.217	20.72	62.20	0.222	20.13	74.70	0.227	20.71	99.50	0.272	20.87	94.20	0.266	20.69
47	67.60	0.268	20.78	74.40	0.257	20.86	80.99	0.268	20.43	94.60	0.303	20.75	91.50	0.276	20.85
49	63.90	0.266	20.56	73.90	0.253	20.68	79.70	0.284	20.87	93.40	0.238	20.55	85.40	0.281	20.69
51	54.90	0.255	20.48	63.50	0.231	20.56	66.40	0.258	20.36	82.60	0.287	20.59	78.70	0.265	20.64
Av	65.06	0.248	20.52	72.62	0.246	20.57	79.07	0.258	20.67	96.37	0.284	20.66	90.82	0.267	20.72

Table 4: Billing period data

Order no.	Billing period	Length of heating season τ, h	External temperature $\Theta_{e.av}$, °C
1	01.10.2013 – 30.09.2014	5688	5.14
2	01.10.2014 – 30.09.2015	5400	5.00
4	01.10.2015 – 30.09.2016	5400	4.80
4	01.10.2016 – 30.09.2017	5520	4.30
5	01.10.2017 – 30.09.2018	5520	4.60

Table 5: Relative deviation of the parameters given in tab. 3 (the buildings taken for analysis were shaded in blue)

No	2013/2014			2014/2015			2015/2016			2016/2017			2017/2018		
	$\Delta cv_u/cv_u$	$\Delta Q_u/Q_u$	$\Delta\Theta_i/\Theta_i$	$\Delta cv_u/cv_u$	$\Delta Q_u/Q_u$	$\Delta\Theta_i/\Theta_i$	$\Delta cv_u/cv_u$	$\Delta Q_u/Q_u$	$\Delta\Theta_i/\Theta_i$	$\Delta cv_u/cv_u$	$\Delta Q_u/Q_u$	$\Delta\Theta_i/\Theta_i$	$\Delta cv_u/cv_u$	$\Delta Q_u/Q_u$	$\Delta\Theta_i/\Theta_i$
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
8	4.83	8.86	0.29	0.16	8.91	0.99	2.24	0.02	0.10	3.97	6.21	0.50	0.09	3.91	0.27
12	18.66	5.25	2.93	21.74	9.32	0.95	14.20	4.63	0.53	9.92	2.70	1.29	8.57	2.09	3.56
13	9.87	9.48	1.27	11.45	13.03	1.04	12.61	8.66	1.15	8.48	8.21	1.43	2.88	9.22	0.60
17	5.13	2.02	1.56	9.44	2.47	1.48	16.48	1.96	2.33	10.92	12.90	1.37	13.20	0.97	0.69
33	8.05	8.07	0.68	13.06	13.38	1.97	13.19	5.75	1.36	8.64	9,73	0.89	3.07	2.41	1.61
39	2.71	12.49	0.97	14.34	9.78	2.16	5.53	12.03	0.20	3.24	4.34	1.04	3.73	0.21	0.13
47	3.90	8.07	1.27	2.46	4.44	1.39	2.43	3.78	1.15	1.84	6.56	0.45	0.75	3.54	0.64
49	1.78	7.27	0.19	1.77	2.81	0.51	0.79	10.21	0.97	3.09	16.30	0.51	5.96	5.41	0.13
51	15.62	2.83	0.20	12.55	6.13	0.07	16.03	0.17	1.49	14.29	0.94	0.32	13.34	0.59	0.37
Av	7.68	7.53	0.99	9.59	7.97	1.16	9.08	5.72	1.04	7.05	7.86	0.87	5.51	3.49	0.81

Table 6: Correlation and determination coefficients for the analysed variants and settlement periods

Variant	2013/2014		2014/2015		2015/2016		2016/2017		2017/2018	
	R	R^2	R	R^2	R	R^2	R	R^2	R	R^2
A	0.303	0.092	0.282	0.079	0.265	0.070	0.344	0.118	0.398	0.158
B	0.455	0.207	0.459	0.211	0.454	0.206	0.519	0.270	0.548	0.300
C	0.487	0.237	0.496	0.246	0.412	0.170	0.561	0.315	0.548	0.300

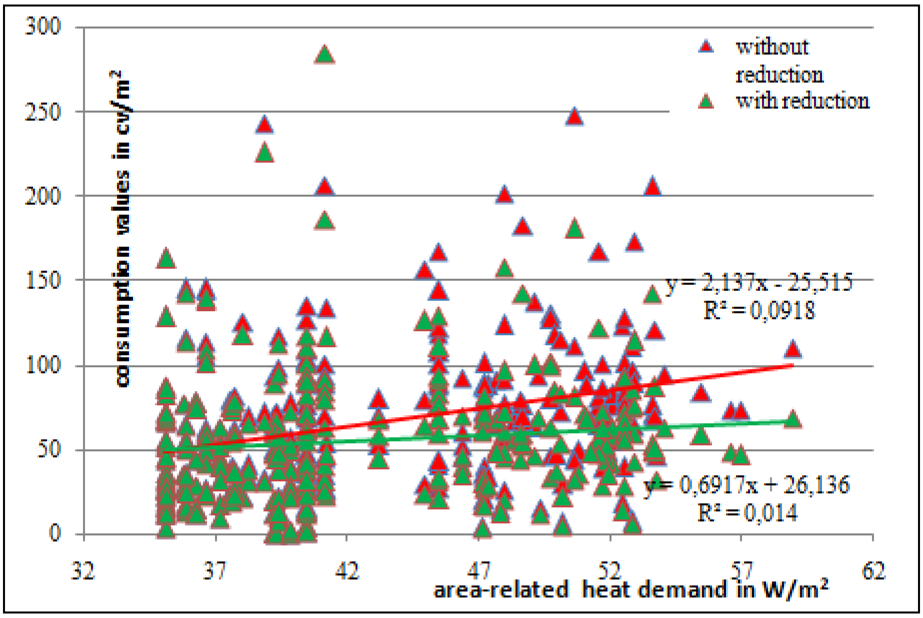
Table 7: Operation data of the buildings without complete metering

No.	2013/2014			2014/2015			2015/2016			2016/2017			2017/2018		
	cv_u -/m²	Q_u GJ/m²	$\Theta_{i.av}$ °C	cv_u -/m²	Q_u GJ/m²	$\Theta_{i.av}$ °C	cv_u -/m²	Q_u GJ/m²	$\Theta_{i.av}$ °C	cv_u -/m²	Q_u GJ/m²	$\Theta_{i.av}$ °C	cv_u -/m²	Q_u GJ/m²	$\Theta_{i.av}$ °C
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
21	41.45	0.380	22.37	52.75	0.367	22.45	59.78	0.361	22.41	74.74	0.414	22.47	63.29	0.372	22.44
22	42.03	0.346	22.33	49.20	0.337	22.41	51.47	0.358	22.36	58.07	0.384	22.40	55.13	0.361	22.45
23	49.40	0.382	21.12	61.46	0.342	22.12	63.66	0.371	22.18	81.60	0.397	22.12	80.90	0.365	22.07
Av	44.26	0.369	21.95	54.44	0.349	22.33	58.31	0.363	22.32	71.48	0.398	22.33	66.38	0.366	22.32

Table 8: Correlation and determination coefficients of the buildings with incomplete metering

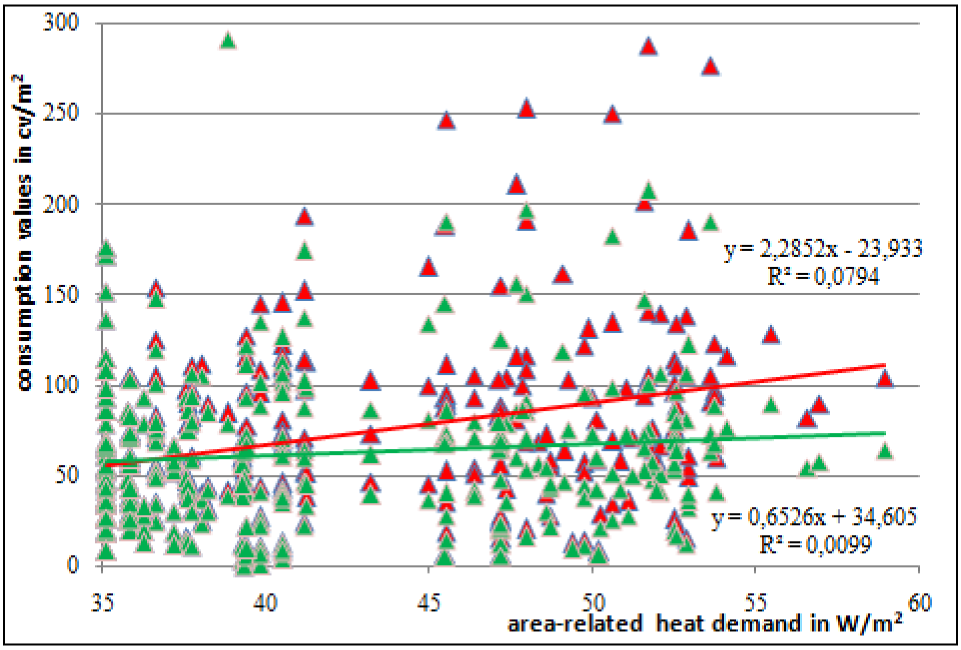
Variant	2013/2014		2014/2015		2015/2016		2016/2017		2017/2018	
	R	R^2	R	R^2	R	R^2	R	R^2	R	R^2
B	0.104	0.011	0.160	0.026	0.148	0.022	0.143	0.021	0.154	0.024

Figure 1: Location of selected buildings

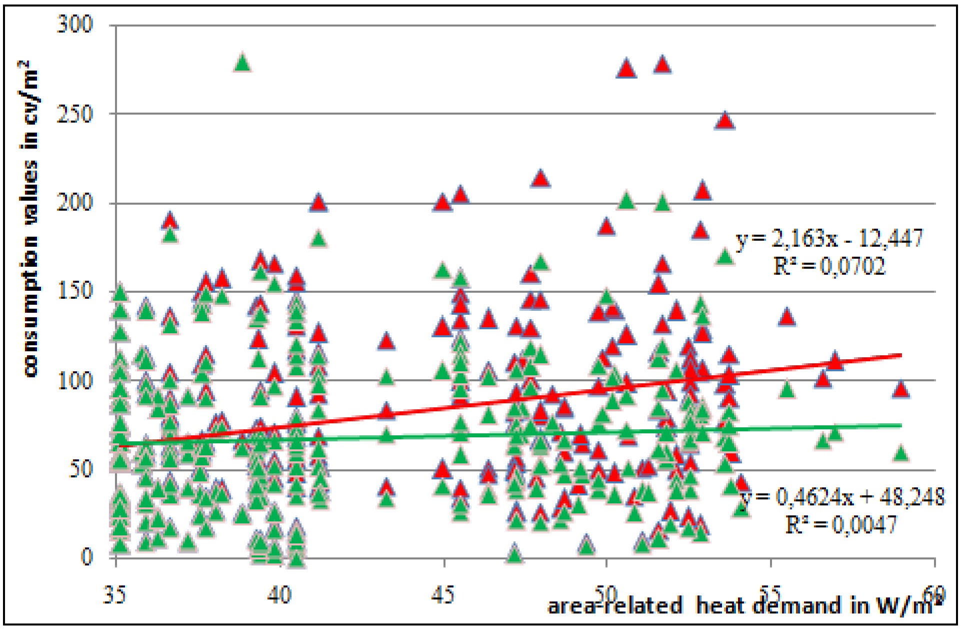


a)

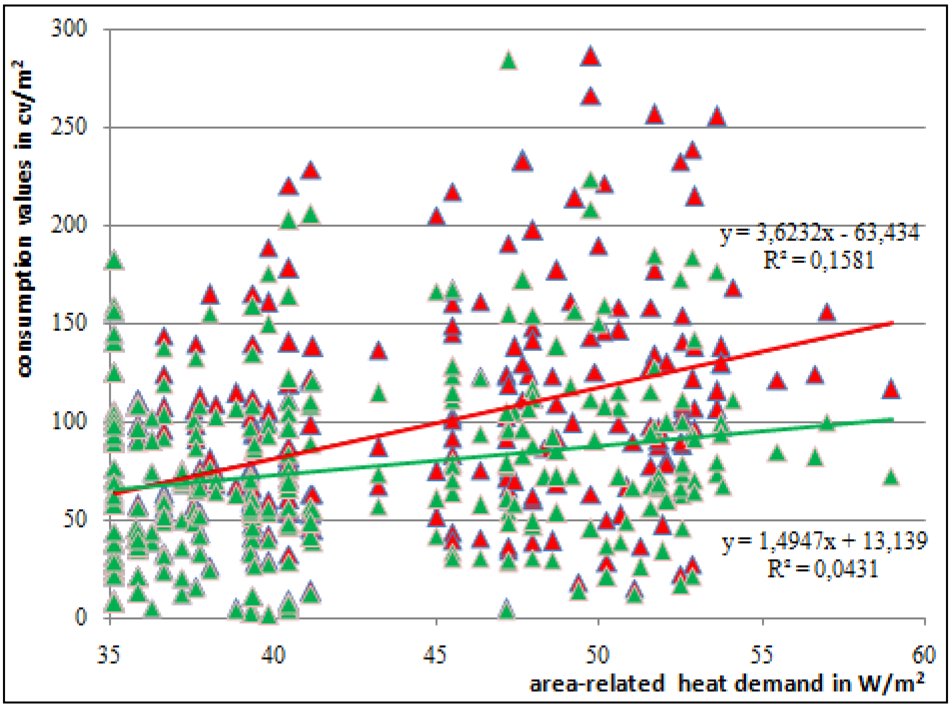
Figure 2: A plot of allocator area-related: readings & heat demand for the settlement period of October 1, 2013 & September 30, 2014


300
250
200
150
100
50
0
35
40
45
50
55
60
consumption values in cv/m²
area-related heat demand in W/m²
y = 2,2852x - 23,933
R² = 0,0794
y = 0,6526x + 34,605
R² = 0,0099

b)


300
250
200
150
100
50
0
35
40
45
50
55
60
consumption values in cv/m²
area-related heat demand in W/m²
y = 2,163x - 12,447
R² = 0,0702
y = 0,4624x + 48,248
R² = 0,0047

c)



d)

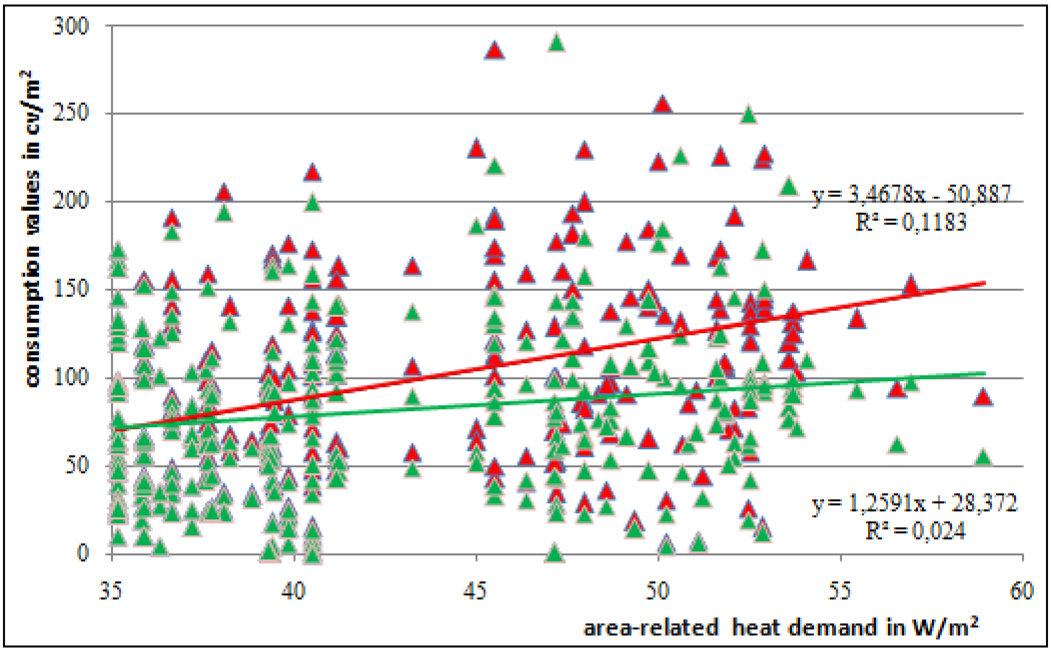


Figure 3: A plot of allocator area-related: readings & heat demand for the following settlement periods : a) 01.10.2014 – 30.09.2015, b) 01.10.2015 – 30.09.2016, c) 01.10.2016 – 30.09.2017, d) 01.10.2017 – 30.09.2018

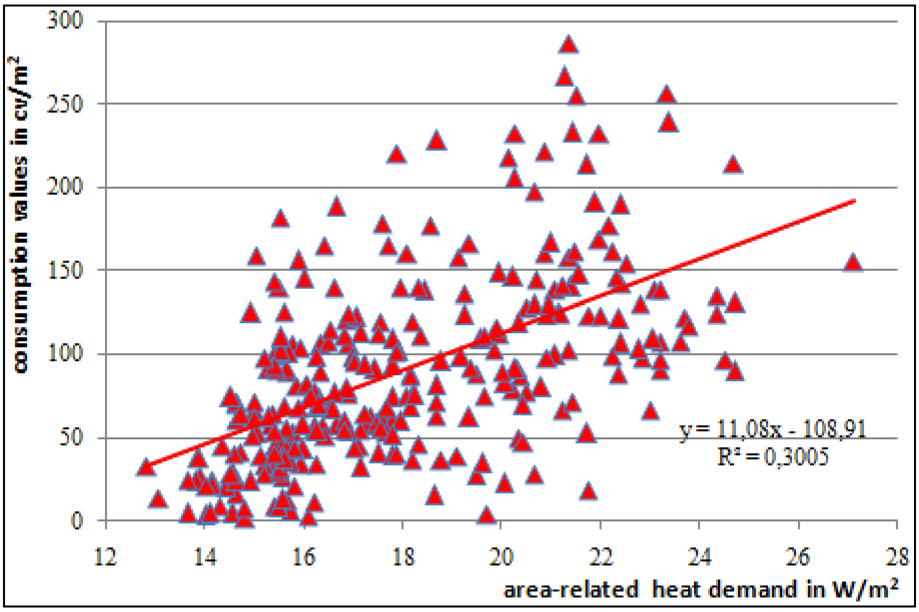


Figure 4: A plot of the allocator individual readings & heat demand values for the apartment actual average internal temperatures & the settlement period from 01.10.2017 to 30.09.2018

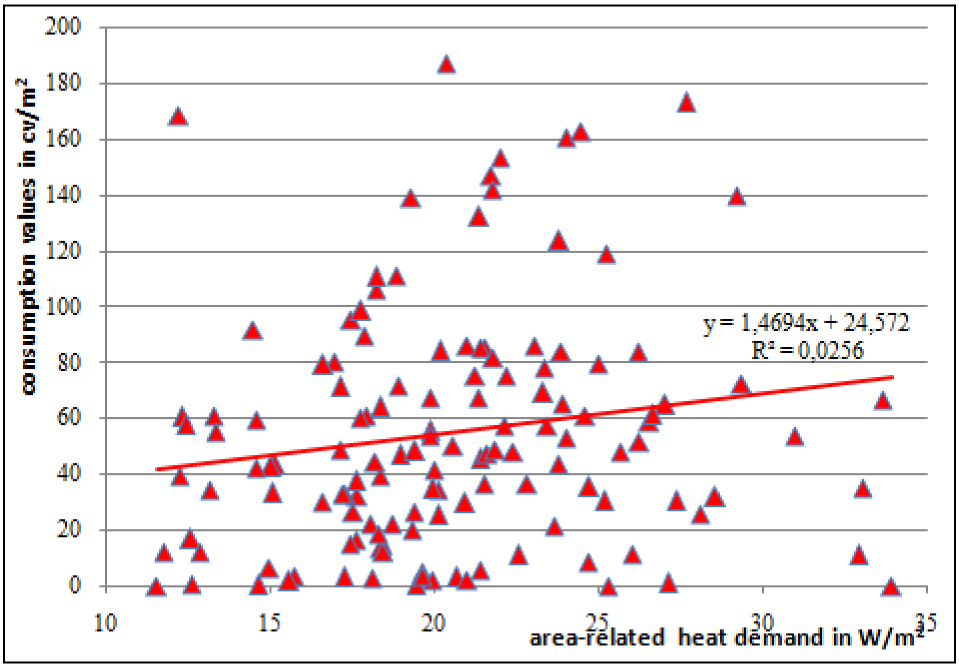


Figure 5: Relationship between the area-related: allocator consumption values and the heat demand values of the buildings with incomplete metering in 2014/ 2015