Heat transfer between heated, partially heated and non-heated residential units in buildings

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Abstract Space heating cost allocation according to actual consumption can be one possible motivating factor for saving energy in residential and other buildings. As a consequence of the exclusion of a certain number of users in collective housing units from the central heating supply system in the city of Skopje, the problem of heating cost allocation and collection of the fixed part of the heat energy payment has arisen. The subject of the analysis in this study was the heat transfer in buildings, with the main focus on the issue of heat transfer rate between residential units with different internal temperatures, such as from heated to unheated or partly heated apartments in collective building objects. The purpose of the analysis was to assess the mutual energy interaction between the completely or partially excluded apartments from the central heating system and the adjacent apartments connected to the central heating system. This is done by simulating the thermal characteristics of typical buildings that are representatives of new (insulated) and old (un-insulated) buildings. For the simulation purposes, the external average daily and monthly temperatures were obtained based on the perennial outdoor temperatures measured in Skopje and additional series of input data that are characteristic for the city were used. For the value of the internal temperature in the dwellings the value for the standard internal design temperatures are predefined. As results of the simulation, values were obtained for the annual heat gains (in kWh/year) and the specific heat gains (in kWh/m²/year) of the excluded apartments from the system of central heating through the enclosures (internal walls, ceiling and floor) of the adjacent apartments that are connected to the system for central heating and vertical hot water pipelines for an isolated and non-isolated buildings. In order to obtain a clearer picture, in the study are considered different configurations and positions of apartments in the building. As an indicator for each considered apartment, the ratio of the received thermal energy of the disconnected apartment to the required energy for its heating is calculated. Based on the obtained results, appropriate conclusions were drawn regarding the reduction of the necessary energy for heating of the excluded apartments, as a consequence of the thermal gains through the walls of the neighboring apartments that are connected to the heating system.

Keywords: energy, district heating system, heat transfer, building, heating cost allocation, energy efficiency
1. Introduction

Continuous population growth in major urban areas, as well as the rising demand and expectations for better and more comfortable living and working conditions, result in higher energy demand i.e. higher energy consumption. The use of energy efficient solutions, technologies and heating equipment in households, public institutions, service sector and companies is a step forward towards reducing energy consumption and harmful impact on the environment. Heating of living space has always had the largest share in the total household energy consumption.

Selection of optimal heating system i.e. heat source for buildings in larger urban areas, should be carefully done, considering the influence of a number of factors from both energy and environmental aspects. Every larger living urban area should have an organizational structure devoted to energy planning - energy urbanism, participating in the developing, supervising and decision making for implementation of heating systems in new buildings, considering the influence of the heating systems on the city/country power system and environment. The results from series of surveys and studies [1] indicate that from economic and environmental aspects, district heating is an optimal solution for buildings heat energy supply. District heating or cooling with central energy supply units gives access to several fuel types making district heating production very flexible. This increases both the security of supply and the production efficiency. Should one unit break down there are alternatives available and at any given time the district energy company may choose the cheapest fuel.

District heating system also increases safety, due to the absence of combustion systems at the final users of thermal energy.

Individual heating solutions only allow one specific type of fuel, e.g. coal, oil or natural gas. For the end user, this means that the heating bill is fully financially exposed to price increases of a specific fuel. With district heating, it is possible to take advantage of the free market forces driving price changes on different types of fuel. District heating also makes it possible to meet other of society’s preferences and goals, e.g. independence from import of fuel and CO₂ targets. In short, it is much simpler to change fuel from, e.g. natural gas at one central place than having to change boilers in thousands of individual houses. With large district heating systems, it is possible to make that change almost from day-to-day [2]. Utilization of highly efficient cogeneration with district heating systems can greatly increase energy efficiency and reduce the CO₂ emissions of the energy sector. Currently, only 13% of the European heat supply is covered by district heating systems, which makes the potential for increasing this share significant, especially in urban areas which are characterized by high heat demand densities [3].

Nevertheless, it should be noted that considered only from the individual perspective, the main driving factor for choosing district heating instead of individual heating is the delivered heat price. The price of thermal energy in district heating system is dependent on series of factors such as: fuel price, efficiency of the heat production facilities, heating capacity, grid size, heat demand, heat density, etc. A lower heat demand will decrease the heat density of the system, which, in turn, increases the relative heat loss in the pipes. In addition, it simultaneously means that the fixed costs are shared between fewer energy users and the price per MWh therefore will be higher. It is interesting to be mentioned that, besides physically existing feasible quantity of heat density from the existing and future planned building stock, uncertainty in the final heat price arises from the prediction of the buildings/apartments that will be connected to the district heating system, which is in mutual relation with price of heat. Another indirect factor affecting the final heat price is the method of heat cost allocation (heat metering), especially in multi-apartment buildings. It is necessary to take into account a number of key criteria in the heat cost allocation process in order to make it as equitable as possible. In the EU directive 2012/27/EU there is a decree of heat cost allocation in multi-apartment buildings. The purpose of the directive is to increase the energy efficiency within the European Union and to achieve the objective of saving 20% of the Union’s primary energy consumption by 2020 [4]. Individual metering for heating has been a topic since the entrance of central (district) heating systems in the larger European cities in the 1920s [5]. The subject of the analysis in this study was the heat transfer in
buildings, with the main focus on the issue of heat transfer between residential units with different internal temperatures, such as from heated to unheated or partly heated apartments in collective building objects.

2. Background analysis

In Skopje most of heat energy customers are connected to one common heat meter located in the heating substation of the building. These are the buildings built before 2001 in which the piping did not provide possibility for central individual metering of heat energy for each apartment. Although in the new buildings the heating installation provides possibility for installation of heat meter, majority of the buildings still have only one central heat meter, and the heating bills consist of a fixed part in function of the installed thermal capacity of the heating element and variable part that represents the apartment consumed heating energy, obtained by dividing the total consumed heating energy (measured by the central heat meter) with the total building area, multiplied with the apartment area. Problems arise as a consequence of the exclusion of a certain number of users in multi-apartment buildings from the central heating supply system for heating, since there is problem with the allocation and collection of the fixed part of the heat supply fee. Therefore, the aim of this study is providing contribution toward the research of the heat transfer in the buildings, with emphasis on the internal heat transfer, quantifying the heat transfer from heated to unheated and partly heated apartments in collective building, as function of building energy performance, indoor temperature set point, apartment location relative to heated and unheated apartments, all for the climate data characteristic for the city of Skopje. This is done by simulating the thermal characteristics of typical buildings that are representatives of new (isolated) and old (non-isolated) buildings.

A number of problems arise in the heat cost allocation process in the multi-apartment buildings. The amount of heat supplied to a certain apartment, is not the same as the amount of heat consumed in the apartment due to heat flows between the apartments and heat losses in the surrounding. Considering that the indoor partitions, i.e. the walls between adjacent apartments lack thermal insulation, heat flows easily between the adjacent apartments and rooms with different indoor air temperatures. There are a number of scientific papers which analyze this effect [6], where the heat that flows from one to another apartment is defined as "stolen heat". The obtained results in [7] show that comfort temperature in the apartment with fewer outer walls can be almost completely ensured by the heat from the adjacent apartments. The results from the computer simulation with a relatively small apartment surrounded with adjacent apartments with the exception of one side only, have shown the possibility to gain more than 95% of the needed heat from the adjacent apartments [8].

3. Methodology

3.1. Overview of the modelling approach

The energy modeling software Design Builder is used as a modeling tool for the analysis of the heat transfer between the heated and unheated apartments, i.e. for defining the thermal performance and interactions between the surfaces of the adjacent apartments in the multi apartment building. This software, as a subroutine for energy calculations, uses the integrated "Energy +" program, which represents software for energy simulations of objects, developed in 2001 by the US Department of Energy (DOE). The software has a modular structure code based on simulation programs BLAST (Building Loads and System Thermodynamics) and DOE-2. This software enables the analysis of multi-zone objects as well as their energy systems.

Information in each level are obtained and are in mutual interaction along the hierarchical structure. Values, schedules, activities are assigned to each level, which can also be replicated for other levels of the area (for example, if the interior wall design is defined, it can be taken for all surfaces in an object defined as interior walls). Basic input data in the software package for energy analysis of objects are: geometry, orientation and physical characteristics of materials for transparent and non-transparent elements (walls, windows, doors). The physical model of the reference object, with all its thermophysical features, is graphically defined within the software, after which it is further applied as
a subject of numerical simulations for determining and quantifying the heat transfer. The simulations based on the prepared model consider the influence of solar radiation, i.e. energy gain due to solar radiation, as well as the thermal mass of the surfaces, which includes the thermal inertia of the surfaces of each thermal zone in the building. The solar energy gains are defined according to the building transparent surfaces orientation, as presented in Figure 1.

Figure 1. Visual presentation of the referent building position and the Sun path

Within the software model, the building is generally divided into three main parts: (1) Zone, (2) System and (3) Plant (source of heating / cooling energy). Since the simulations in the software are integrated, the calculations regarding these three parts are conducted simultaneously. The entire system consists of several modules that have mutual interaction. The analysis takes into account that the thermal processes in the building are in function of a number of external factors, contributing to the intense dynamic behavior of the heat and mass transfer systems. In order to define the behavior of the systems, a numerical model of the considered object is defined, which aims to cover the processes of heat transfer and the thermal mass inside and outside the object. In addition, time-dependent functions for the transfer of heat into a series of structural / building elements from the wrapper of the object are also defined. Changes in the heat flux across a boundary surface represent a signal that is transmitted through the considered element (material). The heat resistance and heat capacity of the building materials influence the signal transmission, causing its weakening and phase shift. Dynamic characteristics of massive components cannot be defined through the concepts of a stationary state. It should be emphasized that walls with the same value of the heat transfer coefficients (in W/m²K), but made of different materials, have a different influence on the overall dynamics of the heating / cooling systems. An example of this can be the use of an isolated massive wall as an accumulator of solar or thermal energy. Also, the thermal capacity of the walls has an impact on the phase shift of the heating needs, which is the result of the possibility of accumulating the heat energy.

In the present model, the analyzed apartments in the building are defined as thermal zones, which interact with each other and with the environment. The thermal zone is defined by the volume of air with an uniform temperature and all surfaces that cover the defined volume of air. The zones are bounded by exterior and interior walls, ceilings, floors, roofs, windows or doors. Each of these elements / surfaces is composed of several layers of different materials. The building is divided into zones as activity areas, one for each activity. The end result of the zoning process should be a set of zones that are distinguished from all others in contact with it by differences in one or more of: the activity attached to it, the HVAC system which serves it, the lighting system which serves it, the access to daylight (through windows or roof-lights). The base cell of the zone is the constructive element (walls, windows, etc.), which in the model is defined by a set of parameters such as: thermo physical characteristics of the material, size, structure and orientation of the construction element. The next level of the model development is defining the simulation boundary conditions, by which are defined zone mutual interactions, i.e. heat transfer between elements, zones and the external environment. The simulation model is defined by a set of parameters for the entire simulation period, such as: the layout and the number of people present in the building (and zones if
the object is divided), values for the metabolite degree depending on the activity, the values for heat gains due to radiation and convection of lighting and other electrical equipment, as well as the manner or schedule of usage, etc.

Climate data is another important parameter that directly affects the merit of the simulation results. In the DesignBuilder software tool, EnergyPlus format hourly weather data has been used to define external conditions during simulations. Each location has a separate file describing the external temperature, solar radiation, atmospheric conditions etc. for every hour of the year at that location. They are set at specific time intervals, i.e. they are defined on the basis of statistical methods, shown through a reference climate year that contains a series of data such as: external (ambient temperature), wind speed, solar radiation, relative humidity, etc. Climate data from the Meteonorm data aggregator is used in the Design Builder software package. Also, parameters that have a significant influence on the merit of the results obtained are the values for the simulation step. For example, if the simulation has a time step greater than the time constant of the process being analyzed then it is not possible to display the dynamic behavior of the process.

3.2. Modelling a reference multi apartment building
3.2.1. Selection of a reference building
In general, there are great variations in the building sector in every town regarding the construction type, layout, size, arrangement of the apartments, number of apartments etc, but each building must be built in accordance with the construction law valid during its the construction period. For that reason, it is very difficult to define the optimal reference building for the energy calculations. In order to achieve the basic goal of this analysis, a building with a three level floor is selected as reference building for the city of Skopje. The ground floor is located above the basement premises, the first and second floor are considered as any characteristic floor. The roof is considered as a sloping roof with a standard elevation and a slope above the second floor. The hallways in the building are taken so that a corridor connection can be reached with the staircase and exit part of the building. Referent building with the corresponding size and layout of the apartments is presented in Figure 2.

![Figure 2. Model of the referent multi apartment building with apartments of 60 m²](image)

The arrangement of the apartments in the building is presumed in such a manner with the intention chosen for the building to contain neighboring apartments limited by compartments with an external wall (wall to outside space), internal wall (barrier between the apartments), internal wall to the hallway (barrier to the hallway) towards the roof and neighboring apartment, and under the basement premises and the neighboring apartment. In the simulation model for the need of the heat transfer analysis an apartment it has been selected an apartment with a referent heating surface of 60 m², which is in line with the usual offer of apartments in a new residential areas in the last few years (which corresponds to the purchasing power and the wishes of the buyers). According to the [9], the existing average residential area in the urban part of Skopje is 69 m². If the unheated area (terraces, corridors, etc.) is deducted from total surface, it can be concluded that the adopted heating surface in the model fully corresponds to the actual condition. Construction physics, regarding the thermo-physical
properties of materials for the building elements, such as heat transfer coefficients, has been harmonized with the [10]. Due to the need of obtaining a relevant energy image, it has been accepted that all apartments in the building are of the same living area. The total height of the rooms in the buildings is taken as a standard height of 2.6 m. The size and number of windows in each apartment, depending on the area of the apartment (building), are adopted to provide sufficient light according to the standards for residential buildings.

### 3.2.2. Operating schedule of the central heating system in the simulation model

According to the Network rules for distribution of thermal energy, in accordance with the Energy Regulatory Commission of the Republic of Macedonia, the Directorate for distribution of heat, and Distribution of heat Balkan Energy DOOEL Skopje [11], the heating season starts at 15 October and ends at 15 April. Operation period of the central heating system is considered to be between (6 ÷ 22), keeping operational temperature of 20°C.

The term unheated apartment, refers to an apartment which is disconnected from the district heating system has its own individual heating system (or it is not heated) and is subject to the analysis of the heat transfer (heat gain) from the adjacent apartments that are connected to the district heating system.

### 3.2.3. Referent multi apartment building thermal characteristics

Energy characteristics and performance of the buildings are defined by the thermo-physical properties of the construction elements, internal heat gains and required level of thermal comfort. Thermophysical characteristics of building elements are determined with the heat transfer coefficients. The values of the heat transfer rates for the modeled referent building surfaces are presented in Table 1.

| Table 1. Heat transfer coefficient for building elements |
|----------------------------------------------------------|
| Heat transfer coefficient | U (W/m²K) | BUILDING |
|                           |          | ISOLATED | UNINSULATED |
| Internal partition (wall) | 1.5      | 1.5      |
| Internal partition (unheated area) | 0.6      | 1.2      |
| Floor above unheated space | 0.33     | 1.7      |
| Floor between heated spaces | 1.6      | 1.6      |
| Roof | 0.25 | 2.7 |
| Window | 1.8 | 2.5 |

The selected heat transfer coefficients (U values) for the construction structures of the older buildings envelope (hereinafter referred to as "uninsulated building") were selected so as to comply with the most used structures of the characteristic compartments of the existing buildings in the City of Skopje. The other values for the characteristic parameters required for the simulation i.e. calculation of the building energy performance are presented in Table 2.

| Table 2. Internal heat gains for the apartment model |
|-----------------------------------------------------|
| Input parameter | Unit | Isolated | Uninsulated |
|-----------------|------|----------|-------------|
| Occupancy       | people/m² | 0.05   | 0.05        |
| Metabolic activity | met | 0.9     | 0.9         |
| Computer equipment heat gain | W/m² | 5     | 5           |
| Lightning       | W/m² | 5     | 5           |
| Air infiltration | 1/h | 0.5    | 0.9         |

### 3.2.4. Heat gains from pipe risers

In buildings with a heating system with pipe riser-main distribution lines (supply and return), it is necessary to determine the heat gain from pipe risers passing through the apartments. The total heat
gain from the pipe risers in the apartment depends on the pipe diameter, number of pipes, pipe material, hot water temperature in the supply and return pipework and the indoor temperature in the premises. The values of these characteristic parameters used in the calculations are given in Table 3.

### Table 3. Input calculation parameters for pipe risers heat transfer

| Value | Description |
|-------|-------------|
| DN 25 | Most used pipe material and avg. size |
| 3     | One bedroom apartment (40 m²) |
| 4     | Two bedroom apartment (60 m²) |
| 5     | Three bedroom apartment (80 m²) |
| 40÷80 °C | Variable |
| 16, 18, 20 °C | Variable |
| 2.6 m | Height of apartment room |

The supply and return temperatures of the hot water in the pipe risers are assumed as annual average supply/return temperatures obtained from the district heating company (BEG – Skopje). The values used in the model are: for the supply line 55°C and for the return line 47°C (Table 4). The heat gain from the pipe risers can be determined either by calculation or by using nomograms with heat loss data given by the manufacturer. The calculation method is based on well-known expressions for determination of heat losses for pipes, considering the heating system operation of 2100 ÷ 2300 h/annually. As for the second method for determining the heat gain from pipe risers in the apartments, in the present analysis are data from the Technical Manual VSH Xpres, VSH Fittings BV, Hilversum, The Netherlands, for determining the line heat gain along the pipe, for the same temperatures as presented in the calculation method (Table 4).

### Table 4. Parameters values for calculation of heat gains per pair pipe risers per year

| Description                          | Unit   | Value  |
|--------------------------------------|--------|--------|
| Supply/return water temperature      | t_w°C  | 47     |
| Ambient air temperature (indoor)     | t_v°C  | 20     |
| Length of pipe risers                | L m    | 2.6    |
| Total heat transfer coefficient      | K W/mK | 0.51   |
| Specific heat power per pipe riser   | Q W    | 35.59  |
| Annual heat gain per pipe riser      | Z kWh/ann. | 74.75 |

The results obtained by the two methods are very close to each other and therefore the following values are used: one-bedroom apartment (40 m²) with 3 pipe risers heat gains are 520 kWh/year, two-bedroom apartment (60 m²) with 4 pipe risers 690 kWh/year and for three-bedroom apartment (80 m²) with 5 pipe risers 870 kWh/year.

### 3.3. Parametrical analysis for heat transfer between adjacent apartments

Parametrical analysis has been conducted on two energy performance scenarios, “isolated” and “nonisolated”, for the same physical model of the referent multi-apartment building, previously defined with data given in Tables 1 and 2. The aim of the analysis was to determine and quantify the parameters affecting the heat transfer rate and the amount of heat exchanged between the apartments. The results are obtained by energy simulations on the referent building model (developed in Design Builderas previously explained), showing that the annual heating energy for “isolated” building is 152325 kWh/ann. and the specific heating energy is 58.6 kWh/m²god, while the annual heating energy for “uninsulated” building is 283192 kWh/ann. and the specific heating energy in that case is 109 kWh/m²god.
In order to determine and clarify the heat transfer interaction between adjacent apartments, a number of cases have been considered both for “isolated” and “non-isolated” building, taking into consideration the following:

- Location/layout of the unheated apartment in the building. This analysis is performed in order to quantify the impact of the position of the unheated apartments on the amount of heat gains from the adjacent apartments supplied with heat from district heating system, regarding the mutual position of the apartments in the building.
- Location and layout of the unheated apartment, taking into account heat gains from the pipe risers.
- Heating schedule, which differs from the schedule of heating in the district heating system. Occasional shutdown of the individual heating system in apartments is most often done due to energy savings, because of absence of tenants in the apartment. On the other hand, the heating interruption is a saving for the apartment under consideration, but a distortion of the heat image in the adjacent dwellings, that is, additional heat loss from the apartments connected to the district heating. The modified heating schedule for the apartments with individual heating system is assumed as follows: in working days 15-22 h and in weekends 6-22 h.
- Partially heated apartments. In many cases, only part of the living area is heated for the reasons of energy saving or just because of the lack of need for heating the whole area of the apartment. During the analysis, apartments were considered with only one half of the living area heated, most often it is the living space, meaning that it is heated to the standard internal design temperature of 20°C, while the other part is not heated at all. Heat gains from pipe risers have been also taken into account.
- Heat gains to the apartment with indoor air temperature of 18°C from adjacent apartments with indoor air temperature (22°C, 24°C). Most often the indoor air temperature in the apartments connected on the district heating network, is higher than the standard design temperature (20°C) and ranges from 22°C to 24°C. On the other hand, often the internal temperature in the apartment that has individual heating system is maintained at 18°C, in order to save energy.

4. Results and discussions

A number of results were obtained with the conducted simulations based on the above described scenarios and the reference multi-apartment building model ("isolated" and "non-isolated"), prepared using the Designer Builder software package [1]. The output results for heat transfer between adjacent apartments are obtained and presented in the study [1], separately for each of the internal partitions (internal walls, ceiling, floor), for series of different predefined conditions. Regarding the above defined scenarios, some of the obtained results are presented in Tables 5 to 8.

| Floor      | Without pipe risers | With pipe risers | Isolated | Uninsulated | Isolated | Uninsulated |
|------------|----------------------|------------------|----------|-------------|----------|-------------|
| Ground floor | 35±45 %             | 30±45 %          | 50±60 %  | 40±50 %     |
| I Floor    | 25±40 %             | 30±45 %          | 40±60 %  | 40±55 %     |
| II Floor   | 55±65 %             | 40±50 %          | 70±80 %  | 50±60 %     |
| Total      | 25±65 %             | 30±50 %          | 40±80 %  | 40±60 %     |

Table 5. Share of the heat gains regarding total required annual heating energy for unheated apartment adjacent to apartments connected to district heating, without and with heat from pipe risers

| Floor      | Isolated | Unisolated |
|------------|----------|------------|

Table 6. Heat gains to total required annual heating energy for apartment with individual heating system, operating in working days from 15-22 h and weekends 6-22 h
The results indicate that apartments with individual heating systems with indoor temperatures lower for 1°C regarding the indoor temperature of the adjacent apartments, have heat gains of about 250 kWh/year. In the case of the building without isolation the heat gains are 380 kWh/year for each 1°C difference.

### 5. Conclusion

The purpose of the analysis is to assess and quantify the heat transfer between apartments connected to the district heating system and apartments with individual heating system in a multi-apartment building. This is performed by simulating the thermal performance of a model of referent building in two main scenarios: (1) energy efficient building (isolated, with low energy consumption for heating) and (2) old, energy inefficient building (non-isolated, with high heat energy consumption).

Analysis is performed for series of different boundary conditions, obtaining numerous values for heat gains/losses (in kWh/year) and specific heat gains/losses (kWh/m²god) between the adjacent apartments with individual heating system and district heating system through their border surfaces (inner walls, ceiling and floor).

In all analyzed cases, the apartments with individual heating system in multi apartment building have heat gains through internal partitions - walls, ceiling and floor from the adjacent apartments connected to the district heating system and also significant heat gains from pipe risers in cases where they are passing through these apartments. It must be noted that the heat losses from the apartments connected
to the district heating system to the ones with individual heating can be defined as “stolen heat”, since those apartments are billed for a quantity of heat not used. Also, it must be noted that installation of individual heat meters on each apartment connected to district heating system, will not solve these issues, since again it will not distinct for the heat energy transferred to the adjacent apartment(s) with individual heating.

It must be mentioned that from thermodynamic aspect, there is the possibility for case where heat is transferred from the apartment(s) with individual heating to the adjacent apartment(s) connected to district heating system. However, considering that the apartments with individual heating system have the possibility to control the heating system operation time and temperature, it enables them with the possibility to manage the system operation, providing them with the opportunity to use significant heat gains from the adjacent apartment(s) and also from pipe risers from the district heating system. In a completely different category belongs the case when the apartment has no heating system or it is used occasionally for the weekends. Then, the adjacent apartments have significant heat losses and therefore higher heating bills. In this study, an analysis was conducted regarding the indoor temperature during a heating season for an unheated apartment with all adjacent apartments connected to the district heating system, and results revealed that the average indoor temperature during the heating season in that case can be up to 16.5°C. Therefore, it is recommended that in multi apartment buildings, either all apartments to be connected to the district heating network or all to have individual heating system. Observed from a broader perspective, heating in large urban areas should be organized and controlled i.e. centralized, but under economically acceptable conditions for the users, aiming to protect the environment.

6. References
[1] Tashevski D., Filkoski R., Armenski S., Shesho I., Dimitrovski D., Dimitrov D., 2016, A study for determination of techno-economically optimal and environmentally sustainable heating structure in the city of Skopje, financed by Balkan Energy Group, Faculty of Mechanical Engineering, Skopje
[2] Martin B. Petersen et. al., District Energy, Energy Efficiency for Urban Areas, Version 1.0 Danish Energy Agency, February 2016
[3] Connolly, D.; Lund, H. Mathiesen, B.V.; Werner, S. Möller, B. Persson, U. Boermans, T. Trier, D. Østergaard, P.A. Nielsen, S. Heat roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. Energy Policy 2014, 65, 475–489
[4] European Parliament, Directive 2012/27/EU, Official Journal of the European Union, 2012
[5] S. Siggelsten, B. Hansson, Incentives for individual metering and charging, Journal of Facilities Management 8 (4) (2010) 299–307
[6] Liu L, Fu L, Jiang Y, Guo S. Major issues and solutions in the heat-metering reform in China. Renewable and Sustainable Energy Reviews 2011;15(1):673–680. [5] Gafsi A, Lefebvre G. Stolen heating or cooling energy evaluation in collective buildings using model inversion techniques. Energy and Buildings 2003;35(3):293–303
[7] Pakanen J, Karjalainen S. Estimating static heat flows in buildings for energy allocation systems. Energy and Buildings 2006;38(9):1044–1052
[8] G. Andersson, Kv.Jankowitz– Individual heat measurement and impact heating transition between apartments, Bengt Dahlgren AB, project no. 50-8351101, Göteborg, 2001
[9] Statistical Review Industry and Energy, Energy Consumption in Households for 2014, State Statistical Office of RM, 2015
[10] Rulebook on energy efficiency, Official Journal of R. Macedonia, No.94/13, Skopje, 2013
[11] Official Gazette of the Republic of Macedonia" No. 73/14