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Analysis of Energy Supply Solutions of Dwelling Buildings

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Abstract **– Individual heating consumption for dwelling buildings has an important part in Latvia's energy balance. Increasing energy efficiency and reducing primary energy in the household sector can play a role in national energy targets. This paper analyses three different heating systems which focus on a pellet boiler and solar collector combined system. The performance of existing solar collectors is analysed and the solar collector system performance ratio is determined. Costs including investments, fuel and maintenance have been analysed and a comparison between systems is made using the indicator – costs per produced energy. Results show that the performance of the solar collector system should be increased or investments should decrease to meet the cost effectiveness of other analysed heating systems.**

Keywords **– Cost analysis; individual heating; pellet boiler; solar collector performance; water heat pump**

Nomenclature	
COP	Coefficient of Performance
WHP	Water heat pump
EU	European Union
DH	District heating
IH	Individual heating

1. INTRODUCTION

185 countries across the world have ratified the Paris agreement and undertaken responsibilities "holding the increase in the global average temperature to well below 2 ºC above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 ºC above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" [1]. To fulfil the Paris agreement and to limit climate change, the EU has adopted several documents containing aims and actions in energy production, energy efficiency and other fields.

The EU has decided to decrease greenhouse gas emissions by 2030 at least for 40 % compared to 1990. In 2030, the renewable share in EU must be 27 % or greater and energy

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efficiency must be improved by 27 %. To reach these aims, EU member states have to adopt national energy and climate plans for the period of 2021–2030 containing a description of the national energy system, national climate policy and national policy framework regarding the Energy Union [2]–[4].

Latvia's National Energy and Climate Plan has been submitted to the European Commission for consideration. The plan contains renewable energy usage and energy efficiency measures in the household sector. The plan states that new policy should be adopted for supporting renewable energy usage, efficient heating energy production implementation and refurbishment of multi-storey dwelling buildings [5].

Household sector share of end-use energy consumption in Latvia is 29.9 % [5]. 83.4 % of end-use energy consumption in the household sector is used for heating and hot water preparation [6]. 74.2 % of dwelling houses are multi-apartment buildings and 57.3 % are receiving heat energy from district heating [6]. There is no specific statistical data how many multi-apartment buildings have individual heating, but according to previous statements it could reach 15–20 %. As there is a big potential in district heating, there have been several national funding programs for increasing energy efficiency. Nonetheless, looking to solutions in terms of energy efficiency for individual heating should not be forgotten as it is necessary to find possible solutions for energy efficient individual heating in multi-apartment buildings. Yoon et al. [7] have made a survey to find out whether people prefer individual heating or district heating. The survey was carried out in a region where DH system is available. The results show, that respondents highly prefer a DH system.

Fraga et al. have carried out a comparative analysis for multi-family buildings to determine the potential of different heat sources used by heat pump systems [8]. The results of analysing seasonal performance factor for heat pump show that groundwater has the highest performance factor. The same results apply for system performance. Zou et al. have studied the real case operation of phase change material system using energy saving performance assessment in multi-storey buildings [9]. The results show, that the main issues are connected with design and operation mismatch, which is due to limited knowledge of maintenance staff, material quality and inefficient operation. Forzano et al. studied solar collectors for air heating integrated in the building façade [10]. Authors introduce a simulation model and a whole building prototype. The results show that remarkable savings of primary energy were achieved as well as a significant increase of indoor thermal comfort. Authors state that their proposed system has a higher economic benefit in cold weather zones, where system is connected to heating, ventilation and air condition systems. Wang et al. have made an application of a multi-functional, solar-heat pump system in residential buildings [11]. The system can be used for heating, cooling and hot water supply. The results show, that average efficiency in heating mode were 37 % and 55 % in water heating mode. However, significant role of energy performance in building is tied with its design as Albatayneh et al. state [12].

Several authors have focused on heating in Latvia, however mostly district heating systems have been analysed. Ziemele et al. have established a system dynamics model for 4th generation district heating implementation in Latvia [13]. Soloha et al. have analysed the case study of solar energy use in district heating in Latvia [14]. Polikarpova and Rosa have studied energy reduction through introduction of energy management systems in a district heating company [15]. Zandeckis et al. have analysed the optimization possibilities of pellet boiler in multi-storey residential building [16].

As Kuznecova et al. state in their paper, households in Latvia are one of the main energy consumers. The main part of consumption is for the purposes of heating and hot water.

Authors state heating systems from that household sector emits the great amount of pollutants and obligations have to be set to increase energy efficiency and decrease emissions [17].

2. METHODOLOGY

To find the most suitable way to secure individual heating in a multi-apartment building, three different buildings with different heating systems were analysed. The first building has a natural gas boiler, the second building has a combined pellet boiler- heat pump system and the third building has a combined pellet boiler-solar collector system. The third building before and after renovations is pictured in Fig. 1. This building has four storeys with 30 flats total. A container-type heating system with pellet boiler is set up on the right side of the building. Three sections with seven solar collectors are installed on the roof.

(a) (b)

Fig. 1. Building 3: a) before renovation; b) after renovation.

In Table 1, the main building characteristics are shown. Buildings 1 and 3 were renovated in 2011, but Building 2 was renovated in 2014. In terms of heated area, Buildings 2 and 3 are similar; the heated area of Building 1 is almost twice as big as the other two. The heating systems of buildings 1 and 3 provide heating and hot water, whereas the heating system of Building 2 is not used for hot water preparation.

TABLE 1. CHARACTERISTICS OF BUILDINGS

	Building 1	**Building 2**	**Building 3**
Year of renovation	2011	2014	2011
Heating system	Natural gas boiler	Pellet boiler and water heat pump	Pellet boiler and solar collectors
Heated area, m^2	3 526	1 934	1 671
Heat consumption MWh/year	366.9	171.8	199.7
Investments in heating system, EUR	71 395	55 340	51 524

The efficiency of each heating system is calculated. To determine the efficiency of the natural gas boiler, annual heat consumption is divided by natural gas consumption converted into MWh by using the calorific value shown in Table 3. The efficiency for both pellet boilers is calculated similar to the natural gas boiler by dividing annual produced heat energy with annual pellet consumption converted into MWh. The efficiency for the water heat pump is expressed in coefficient of performance (COP), which is a ratio between energy usage (electricity) and produced useful energy (heat). The efficiency of the solar collector system is calculated dividing annual produced energy per m^2 with available solar energy per m^2.

The next thing to calculate is annual expenses which are the sum of investments per years of operation, maintenance costs and fuel costs. For all heating systems, the years of operation are 15 years. Other assumptions for the heating systems as well as specifications are provided in Table 2.

TABLE 2. CHARACTERISTICS OF BUILDINGS

	Natural gas boiler	**Pellet boiler and water heat pump**		**Pellet boiler and solar collectors**	
Installation year	2010	2018	2011	2011	2011
Heating system	*Buderus Logamax*	*NBE RTB*	*Stiebel Eltron WPF*	*GD-Turbo*	*TS*300
Capacity, kW	2·100	50	2·16.9	100	29
Maintenance costs, EUR/year	500	100	150	100	150
Efficiency, %	87.7	93.4	COP 3.1	82.9	–

After calculating total annual expenses, expenses per produced energy (EUR/MWh) are calculated for each heating system to compare them with another.

An enhanced study is made for Building 3 to determine the potential of the combined pellet boiler and solar collector system. Energy produced by solar collectors is compared with the monthly available solar energy in terms of kWh per m^2. The solar collector system performance ratio is calculated by dividing monthly produced energy and monthly available solar energy. Assumptions made in the calculations are shown in Table 3.

TABLE 3. ASSUMPTIONS FOR CALCULATIONS

Calorific value of wood pellets	4.92 kWh/kg
Calorific value of natural gas	10.59 kWh/m^3
Costs of natural gas	0.448 EUR/kWh
Costs of wood pellets	160 EUR/t
Costs of electricity	140 EUR/MWh

3. RESULTS

Costs per produced energy were calculated and are shown in Fig. 1. The lowest costs were for Building 1, where a natural gas boiler was used for heat supply. Total cost using the natural gas boiler is 47.7 EUR/MWh. The second lowest costs were calculated for the combined pellet boiler and solar collector system – 55.84 EUR/MWh. The combined pellet boiler and WHP system costs 63.6 EUR/MWh. In this combined system, the pellet boiler is used as a secondary heat source and energy produced by WHP constitutes 70 %. Fig. 3 illustrates that energy produced by WHP costs 65 EUR/MWh.

In case of Building 1, the cost of fuel makes up 70 % of the total costs, but investments for the heating system installation make up 27.2 %. In case of Building 2, the fuel part from total cost is lower at 64 %, but the investment part makes 33.7 % of the total costs. This can be explained with higher costs for WHP installation. The cost of wood pellets is 27.4 EUR/MWh produced and this makes 67 % from total costs, but the investment part constitutes 30.8 %. A relatively large amount of investments was made for the solar collector system.

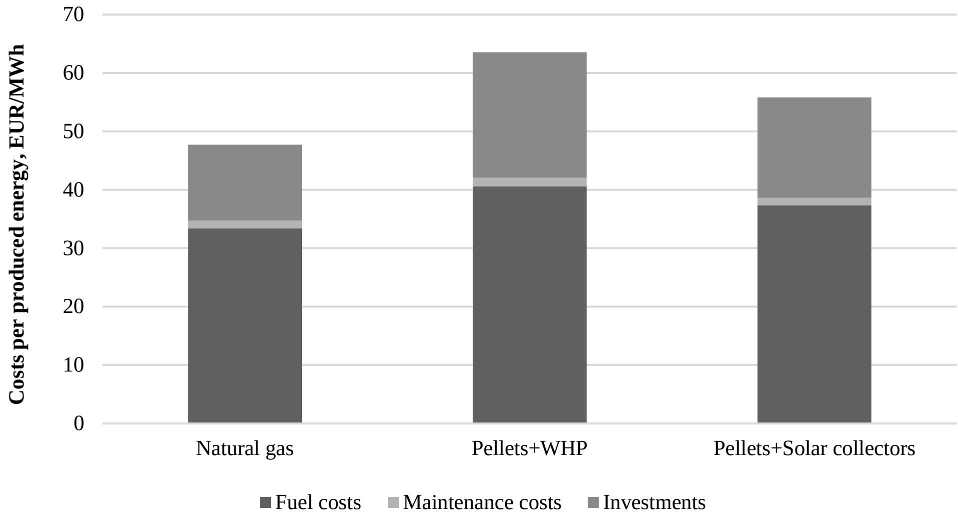

Fig. 2. Calculated costs per energy production.

To determine the potential of the combined pellet boiler and solar collector heating system, the ratio between annual produced energy per m^2 (obtained from measured data) and annual available solar energy per m^2 [6] was calculated. And the results are shown in Fig. 3. In the winter, solar radiation varies from 10–50 kWh/m^2 per month, but in the summer it mostly varies from 160–200 kWh/m^2 per month. The produced amount of heat in the winter is 1–15 kWh/m^2 per month, but in the summer it varies from 30–50 kWh/m^2 per month.

Calculated ratio averaging previous four years on monthly scale is – 0.21. This specific system is using 21 % of annual received solar energy. Several aspects can have an influence on this ratio, however this is how the system has been operated. Considering the amount of produced energy by solar collectors and investments, it was calculated that the annually averaged costs per produced energy amounted to 234 EUR/MWh. To understand the scale of required increase of solar collector system performance ratio and decrease of investments, Fig. 4 was developed.

Five different investment costs per kW were used, from which 827.6 EUR/kW is the current situation, and is used to determine the point at which solar collector system performance ratio meets other heating systems. By analysing the established graph, it can be stated that the solar collector system performance ratio should reach 0.32 and investments should decrease to 300 EUR/kW to meet the costs of other systems. The current situation in the Solar collector market shows that the quality of solar collectors is increasing and different solar collectors reach efficiency up to 50 %, which allows to use solar energy more efficiently and produce much more energy per 1 m^2. At the same time, the cost of solar collectors has decreased significantly in the last ten years, which affects the investment costs and repayment time.

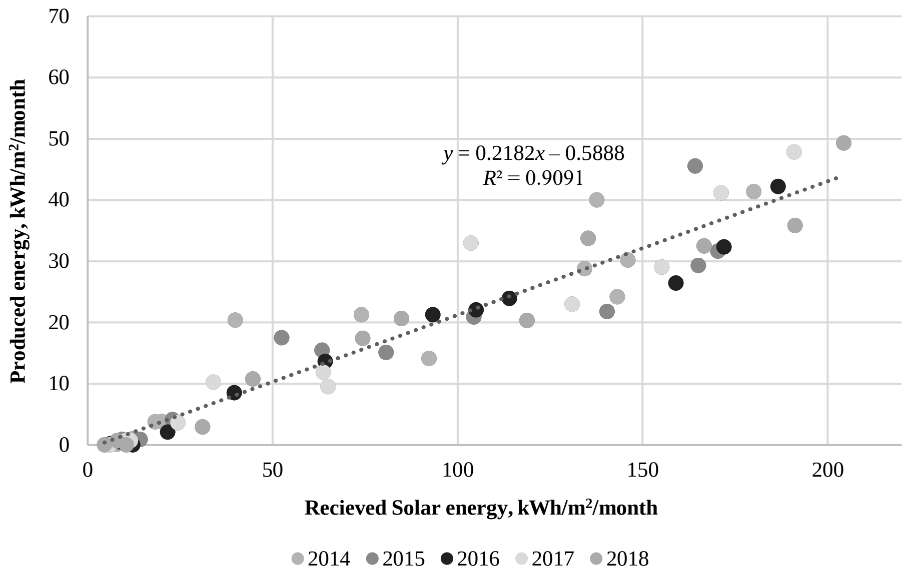

Fig. 3. Calculated solar collector system performance ratio.

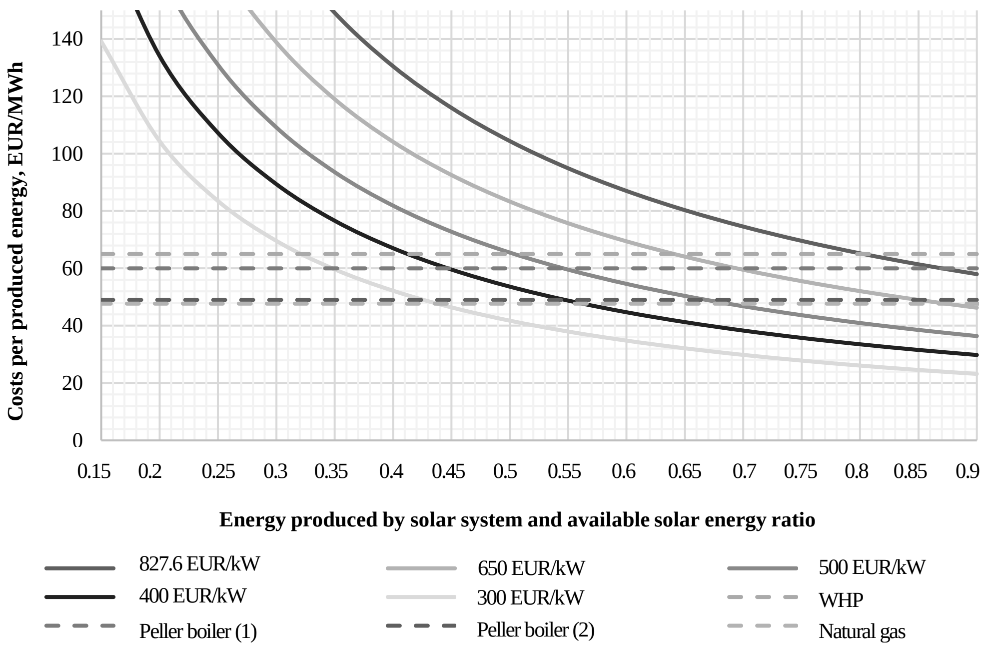

Fig. 4. Comparison of different heating systems and solar collector system.

However, annually averaged data have been used in this graph, but as it is known, solar collectors are producing much more energy in the summer, which is why monthly data are analysed.

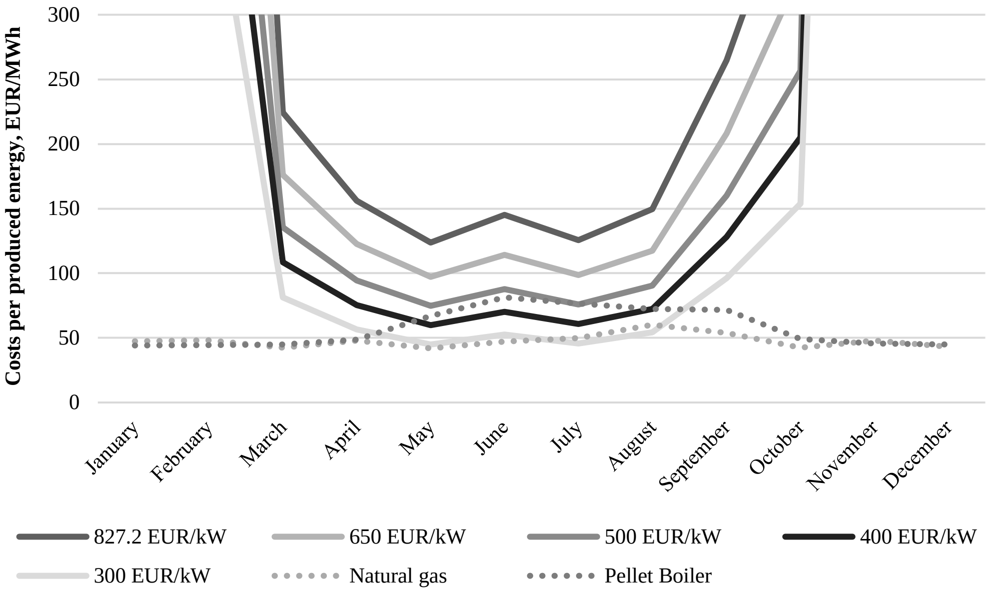

Fig. 5. Costs per produced energy based on monthly data.

Fig. 5 shows that in the summer, when the amount of available solar energy is higher, costs of the solar collector system decrease significantly and by reducing investments to 500 EUR/kW – meet the costs of the pellet boiler in the summer season.

4. DISCUSSION AND CONCLUSIONS

As it is stated in the results section, the natural gas boiler has the lowest costs per produced energy, however not everywhere is the natural gas grid close enough to use it as a solution. Emissions produced by the natural gas boiler have not been taken into account in this analysis and adjustments to the CO_2 tax can increase total costs of the natural gas operation.

The water heat pump system combined with the pellet boiler shows higher costs than the other two heating systems, however, this solution is more flexible. One energy source can be used over another in accordance with the price of energy source and performance due to climate conditions.

The cost of the combined pellet boiler and solar collector system per produced energy was 55.8 EUR/MWh, however solar energy played a negligible part at only 3.4 % of total produced energy. The performance ratio of the solar collector system is 0.21 annually. To meet the costs per produced energy of other energy systems, required investments in solar collectors should decrease and their efficiency should increase.

Calculations are based on three specific buildings and the results should not be generalized. Each situation, when the heating system is considered, requires individual analysis of surrounding infrastructure, maintenance possibilities and other important aspects

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REFERENCES

[1] UNFCCC. Conference of the Parties (COP). Adoption Of The Paris Agreement. Presented at the Conference of the Parties COP 21, Paris, France, 2015. Adopt. Paris Agreement. Propos. by Pres 2015:21932:32.
[2] European Parlament. REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Governance of the Energy Union and Climate Action, amending Directive 94/22/EC, Directive 98/70/EC, Directive 2009/31/EC, Regulation (EC) No 663/2009, Regulation (EC) No 715/2009, Directive 2009/73/EC, Council Directive 2009/119/EC, Directive 2010/31/EU, Directive 2012/27/EU, Directive 2013/30/EU and Council Directive (EU) 2015/652 and repealing Regulation (EU) No 525/2013. Brussels: European Union, 2018:PE-CONS 55/18.
[3] Council of the European Union. Council Conclusions on Energy Union management system. Brussels, 2015.
[4] Council of the European Union. Conclusions on Climate and Energy pact. Brussels: EUCO, 2014:169/14.
[5] Ministry of Economics. Latvijas nacionālais enerģētikas un klimata plāns 2021. – 2030. gadam. Riga: Ekonomikas Ministrija, 2018:19122018(2).
[6] Central Statistical Bureau of Latvia. [Online]. [Accessed 25.04.2019]. Available: https://www.csb.gov.lv/en/sakums
[7] Yoon T., Ma Y., Rhodes C. Individual Heating systems vs. District Heating systems: What will consumers pay for convenience ? *Energy Policy* 2015:86:73–81. doi:10.1016/j.enpol.2015.06.024
[8] Fraga C., Hollmuller P., Schneider S., Lachal B. Heat pump systems for multifamily buildings: Potential and constraints of several heat sources for diverse building demands. *Applied Energy* 2018:225:1033–1053. doi:10.1016/j.apenergy.2018.05.004
[9] Alam M., Zou P. X. W., Sanjayan J., Ramakrishnan S. Energy saving performance assessment and lessons learned from the operation of an active phase change materials system in a multi-storey building in Melbourne. *Applied Energy* 2019:238:1582–1595. doi:10.1016/j.apenergy.2019.01.116
[10] Agathokleous R., et al. Building façade integrated solar thermal collectors for air heating: experimentation, modelling and applications. *Applied Energy* 2019:239:658–679. doi:10.1016/j.apenergy.2019.01.020
[11] Wang G., Zhao Y., Quan Z., Tong J. Application of a multi-function solar-heat pump system in residential buildings. *Applied Thermal Engineering* 2018:130:922–937. doi:10.1016/j.applthermaleng.2017.10.046
[12] Albatayneh A., et al. The Significance of Building Design for the Climate. *Environmental and Climate Technologies* 2018:22(1):165–178. doi:10.2478/rtuect-2018-0011
[13] Ziemele J., et al. System dynamics model analysis of pathway to 4th generation district heating in Latvia. *Energy* 2016:110:85–94. doi:10.1016/j.energy.2015.11.073
[14] Soloha R., Pakere I., Blumberga D. Solar energy use in district heating systems. A case study in Latvia. *Energy* 2017:137:586–594. doi:10.1016/j.energy.2017.04.151
[15] Polikarpova I., Rosa M. Energy reduction potential of the district heating company introducing energy management systems. *Energy Procedia* 2017:128:66–71. doi:10.1016/j.egypro.2017.09.016
[16] Žandeckis A., et al. Solar and pellet combisystem for apartment buildings: Heat losses and efficiency improvements of the pellet boiler. *Applied Energy* 2013:101:244–252. doi:10.1016/j.apenergy.2012.03.049
[17] Kuznecova I., Gedrovics M., Kalnins S. N., Gusca J. Quantitative Analysis of Individual Heating Sector of Latvia. *Energy Procedia* 2017:113:494–500. doi:10.1016/j.egypro.2017.04.049