Evaluation of hybrid heating systems with a combination of fossil and renewable energy sources

Anatolijs Borodinecs¹, Raimonds Bogdanovics¹, Aleksejs Prozuments¹, Jelena Tihana¹, Baiba Gaujena²

¹ Institute of Heat, Gas and Water Technology, Riga Technical University
² Department of Building Production, Riga Technical University

Abstract. Natural gas heating systems are traditionally very popular in private sector in Latvia because of their numerous advantages, such as high efficiency, relatively low CO₂ emissions, automation possibilities and convenient fuel supply, as well as widely available natural gas distribution network. Household natural gas consumption has remained fairly stable over the last decade and accounted for 11.3% of total natural gas consumption in 2017, however, natural gas consumption may decline in the near future, because of installation of renewable energy powered systems which improve systems’ resilience and reduce expenses on heating and hot water preparation. Currently hybrid gas boilers in combination with solar thermal panels are promoted on the market as the most efficient and environmentally friendly solutions. The main aim of this study is to perform a detailed simulation on hybrid gas systems energy production in Latvian climate and to evaluate potential energy savings. The performed simulation results show that solar thermal panels do not actually reduce the consumption of natural gas in November, December and January, whereas in the summer months solar thermal panels almost entirely provide the needed energy to prepare hot water. Nevertheless, the annual savings for a single family house are minor and the payback time for the installation of hybrid gas/solar systems could exceed 20 years.

1. Introduction
Complying with the European Union goals of reducing greenhouse gas emissions by at least 20% compared to 1990, a 20% increase of energy production from renewable sources and a 20% improvement in energy efficiency by 2020 [1], a choice of suitable and modern heating system in private housing sector becomes very reasonable. According to Eurostat, household sector consumes approximately quarter of all energy used in Europe (EU-28) [2].

In Latvia natural gas boilers traditionally are very common in private housing sector due to a number of advantages, such as high efficiency, relatively low CO₂ emissions, automation possibilities and convenience of fuel supply, as well as widely available natural gas distribution network. Nevertheless, over the last decade the total natural gas consumption in Latvia has been falling steadily; according to the information available in Central Statistics Center’s database between the years of 2010 and 2017 natural gas consumption in Latvia has decreased by 33% [3] (Figure 1).
Household natural gas consumption has remained fairly stable over the last 10 years and in 2017 it constituted 11.3% of the total natural gas consumption. It is very likely that in the nearest future natural gas consumption may continue to decline, because of the following factors:

- the end users more often tend to choose modern technological solutions for heating systems;
- national and EU legislation requires construction of energy efficient buildings.

The bulk of natural gas consumption in households is attributed to meeting heating and hot water demands. The possibilities of gas boiler modernizations and a decrease in natural gas consumption, while the efficiency of the system is increased, are explored in the following sections.

Nowadays convection-type gas boilers are outdated and are barely used. The exhaust gas temperature in such boilers reaches 150-200 °C in order to prevent water condensation in the boiler and, thus, to avoid corrosion [13]. Thereby, huge amount of energy is lost through flue gas. Nowadays condensing – type boilers are used in newly constructed buildings. The dependence of gas boiler efficiency on air surge $\alpha$ and flue gas temperature is shown in Figure 2.

Based on [5] article, it can be concluded that condensing-type gas boilers consume less fuel and emit less CO2 into the atmosphere (16.8 g - 18.5 g CO2eq per 1 MJ of energy produced) under similar climatic conditions compared to the conventional gas boilers (19.8 g - 21.3 g CO2eq to 1 MJ).
2. Review of hybrid heating systems and their performance

2.1. Gas boiler and heat pump

In order to increase the efficiency of the building’s heating system and reduce the operating costs, it is possible to combine a natural gas boiler with a heat pump in a single hybrid system. With the help of sensors and automation, the hybrid system itself chooses the most efficient heating mode based on the operating conditions [8].

Air-to-water heat pumps are quite common in Latvian market, as they can be easily and quickly installed in almost any building type. These pumps also require minimal maintenance, do not create exhaust gases and therefore do not pollute the environment, and moreover, they are cheaper than ground heat pumps. The highest drawback and remaining concern of the air-water heat pumps is the efficiency drop, when the outdoor temperature decreases. [9]. According to the local standards the heating systems have to be designed for the coldest five-day average air temperature, at which the air-to-water heat pumps’ efficiency is relatively low. If a heating system consists of just an air-to-water heat pump, most part of the heating period the heat pump will operate in low capacity mode. [11] performed a study with TRNSYS software, where the effectivity of hybrid system (air heat pump and condensing gas boiler) was analyzed. It was shown in the study that the total efficiency of hybrid system reaches 125.2% which is more efficient in comparison to heat pump (96.6%), gas condensing boiler (104.1%) and microCHP system (119.8%).

2.2. Gas boiler and solar thermal collectors

The main downside of a single solar thermal collector system is the unpredictability of the produced thermal energy as well as an insufficient amount of energy production in winter time.

Combining the use of solar energy with gas boilers in a hybrid system can simultaneously provide stability of energy supply, significantly reduce the consumption of natural gas and minimize negative environmental impact. When the amount of incident solar energy is sufficient, i.e., in the summer or spring, the system can operate solely on the solar energy, while in the cold season the gas boiler serves as a heat source. Natural gas savings were examined in [12] study, in which the comparison of a hybrid system and a gas convection boiler under similar climatic conditions was described. The results of the study can be seen in Figure 3. The total annual gas consumption in a hybrid system was only half the gas consumption compared with the system employing a convection-type gas boiler.

![Figure 3](image-url)

**Figure 3** Natural gas consumption in hybrid (solar / gas) and convection-type gas boiler heating systems [12]

It should be noted, that the above-mentioned study focuses on the application of hybrid systems in commercial buildings. Such buildings have a profoundly different energy usage profile. Thus, the results from that study cannot be effectively applied to family houses.
3. Evaluation of gas/solar system energy efficiency for a single family house in Latvian climate conditions

In order to analyze the consumption of natural gas in households, a dynamic simulation model with the use of the TRNSYS program was developed.

A 2-floor single family house with geometric parameters of 10x10x6 m was selected as the most viable customer type model for future mass installation. Heat transfer coefficients of the external building elements (walls, floors, ceilings, windows and thermal bridges) were defined according to LBN 002-15 [14] “Thermal performance of building envelope”. Some additional input parameters for the simulation model are shown in Table 1.

| Parameter                                      | Value  |
|------------------------------------------------|--------|
| Average heat transfer coefficient, W/(m²·K)   | 0.25   |
| Indoor air temperature, °C                     | +21    |
| Total enclosure area, m²                       | 460    |
| Total building volume, m³                      | 550    |

Ventilation system losses were assumed to be compensated by heat gains. Meteorological data (except for the outside temperature) was derived from TRNSYS library collections. The hourly outdoor temperature was calculated as the average specific hourly temperature for the 5 years period (2013-2017) based on meteo.lv available data [15]. Heating would be switched on during the heating season, which lasts for 207 days [16]. It is assumed that the building is occupied by 4 people and that one person per day consumes 36 liters of hot water (according to Table A.1 of Annex A, table LVS 15316-3-1). According to the recommendations of solar collector manufacturers, 4 flat type solar collectors with a total surface area of 10 m² were added to the model. To use solar energy for both heating and hot water, a storage tank with a capacity of 750 liters was added. The efficiency of the condensing boiler (calculated from the highest calorific value) was defined as 90%.

City of Riga was selected as the location of the analyzed building, the most populated and growing area in Latvia. Also, the City of Riga as well as its suburban areas have a wide network of natural gas pipelines. It should be mentioned that the number of sunny days doesn’t vary extensively across the country of Latvia due to its relatively small area and geographical location.

4 Results

The performed simulation has shown that solar collectors do not reduce natural gas consumption in November, December and January, while in the summer months they almost entirely provide all the energy needed for hot water preparation. Consequently, the installation of solar collectors in private homes increases the imbalance of gas consumption during the year.

![Consumption of natural gas in a hybrid system](image-url)
According to the simulation results, just with condensing boiler heating and hot water needs 15143.6 kWh of energy per year, or 1437.7 m³ of natural gas (medium highest calorific value of natural gas during the year was 10,589 kWh/m³, [17]). The installation of solar thermal collectors reduces the energy which need to be supplied from gas boiler, to 12889.1 kWh, or 1,225.3 m³ of natural gas. The annual calculated saving is 2254.5 kWh or 212.4 m³ of natural gas. If it is assumed that the natural gas tariff is EUR 0.04524 / kWh (effective from 1 July 2018) [18], the approximate annual saving is € 102.

Considering the design, construction and operating costs, the payback period may exceed 20 years and therefore the matter of economic profitability and overall reasonability of implementing such system becomes uncertain.

5 Conclusions
Installing solar collectors in a conventional private house in Riga as an additional source of energy for a condensing gas boiler for hot water preparation and heating systems allows to reduce natural gas consumption by up to 15% per year.

According to the scientific articles reviewed, a similar economy (5-20%) can be provided by increasing the efficiency of the system by cooling the flue gases with an integrated absorption-type heat pumps or by recirculation-condensation water recirculation-heat loss recovery condensing boiler, or installing hybrid heating systems with air-to-water heat pump.

A the current cost level the hybrid gas/solar system allows to save 102 euros per year, which, given the high initial cost of system modernization, does not provide a clear basis for the economic justification for such modernization. Therefore, there is no reason to expect a rapid increase in popularity of alternative energy sources in the Latvian market because they are not able to compete with natural gas at current prices. This, in turn, shows that the consumption of natural gas in households will not continue to decrease further in the near future.

It can be concluded that the modernization plan of the existing heating system with natural gas as a heating source has to take into account the price of the new equipment and the relatively long payback period, as only optimal combination of the initial price and the running costs may ultimately lead to the competitiveness of the particular solution.

However, under fluctuating natural gas prices the long-term efficiency of hybrid natural gas/solar thermal collectors should be evaluated in a more detailed manner. It should be noted that Latvian energy sector depends on natural gas imports quite aggressively. It means that the hybrid natural gas systems shall be promoted by government and local incentives in order to minimize Latvian dependency on imported fuels. This also allows for minimal systems’ operation in the event of full shut down of gas supply, thus ensuring some degree of resilience of the energy system.

Aknowledgements
This study was supported by European Regional Development Fund project Nr.1.1.1.1/16/A/048 “Nearly zero energy solutions for unclassified buildings”.

Reference
[1] European Commission. 2020 climate & energy package [online]. [viewed 15.09.2018]. Available from: https://ec.europa.eu/clima/policies/strategies/2020_en
[2] Eurostat. Final energy consumption by sector [online]. [viewed 15.09.2018]. Available from: http://ec.europa.eu/eurostat/web/products-datasets/-/tsdpc320
[3] Central Statistical Bureau database. ENG020. Energybalab, TJ, thausn .toe (NACE 2. red.) in Latvian.
[4] M.C. Barma, R. Saidur, S.M.A. Rahman, A. Allouhi, B.A. Akash, Sadiq M. Sait: A review on boilers energy use, energy savings, and emissions reductions. Renewable and Sustainable Energy Reviews. 79, pp. 970-983 (2017).
[5] Vignali, G.: Environmental assessment of domestic boilers: A comparison of condensing and traditional technology using life cycle assessment methodology. Journal of Cleaner Production. 142, pp. 2493-2508 (2017).
[6] Zhu, K., Xia, J., Xie, X., Jiang Y.: Total heat recovery of gas boiler by absorption heat pump and direct-contact heat exchanger. Applied Thermal Engineering. 71, pp. 213-218 (2014).
[7] Lee, C.-E., Yu, B., Lee, S.: An analysis of the thermodynamic efficiency for exhaust gas recirculation-condensed water recirculation-waste heat recovery condensing boilers (EGR-CWR-WHR CB). Energy. 86, pp. 267-275 (2015).
[8] Rethink the future of heating Daikin Altherma Hybrid heat pump. 4 p.
[9] Asaee, S., Ugursal, V., Beausoleil-Morrison, I.: Techno-economic feasibility evaluation of air to water heat pump retrofit in the Canadian housing stock Applied Thermal Engineering. 111, pp. 936-949 (2017).
[10] Klein, K., Huchtemann, K., Müller, D.: Numerical study on hybrid heat pump systems in existing buildings. Energy and Buildings. 69, pp. 193-201 (2014).
[11] Di Perna, C., Magri, G., Giuliani, G., Serenelli, G.: Experimental assessment and dynamic analysis of a hybrid generator composed of an air source heat pump coupled with a condensing gas boiler in a residential building. Applied Thermal Engineering. 76, pp. 86-97 (2015).
[12] Sun, H.Q., Xu, Z.Y., Wang, H.B., Wang, R.Z.: A solar/gas fired absorption system for cooling and heating in a commercial building. Energy Procedia. 70, pp. 518-528 (2015).
[13] Qu, M., Abdelaziz, O., Yin, H.: New configurations of a heat recovery absorption heat pump integrated with a natural gas boiler for boiler efficiency improvement. Energy Conversion and Management. 87, pp. 175-184 (2014).
[14] Latvian Buildings Code LBN 002-15 "Thermal performance of building envelope"
[15] Latvian Environment, Geology and Meteorology Centre climatic data: https://www.meteo.lv/meteorologija-datu-pieejamiba/?&nid=462
[16] Data on length of heating season in Riga (in Latvian): http://www.rs.lv/lv/aktualitates/noslegusies-apkures-sezona
[17] Data on natural gas properties in Latvia (in Latvian). Pieejams: https://mans.gaso.lv/Caloricity.aspx
[18] Natural gas price calculator: https://lg.lv/majai/tarifi-un-kalkulators
[19] Shipkovs, P., Kashkarova, G., Lebedeva, K., Shipkovs, J. Perspectives for solar thermal energy in the baltic states. In D. Goswami (Ed.), Proceedings of the Solar World Congress 2005: Bringing Water to the World, Including Proceedings of 34th ASES Annual Conference and Proceedings of 30th National Passive Solar Conference 2. 2, pp. 1378-1383. Orlando: Curran Associates, Inc (2005).