Energy-economical analysis of building heating with heat pumps

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Abstract: In the actual economic and energy juncture, the reduction of thermal energy consumption in buildings became a major, necessary and opportune problem, general significance. The heat pumps are alternative heating systems more energy efficiency and less pollutant in comparison with classic plants (liquid or gas fuel thermal boiler). This paper presents the energy and economical efficiency criteria which show the opportunity to implement a heat pump in a heating/cooling system. It is developed a computational model of annual energy consumption for an air-to-water heat pump based on the bin method implemented in a computer program. Also, from a case study is performed a comparative economical analysis of heating solutions for a building and are presented the energy and economic advantages of building heating solution with a water-to-water heat pump. Heating installations with heat pumps produces minimum energy consumption in operation and are certainly a solution for energy optimization of buildings.

Key-Words: Building heating/cooling, Heat pump performances, Economic indicators, Energy indicators, Annual energy consumption

1 Introduction
Buildings are an important part of European culture and heritage, and they play an important role in the energy policy of Europe. Studies have shown that saving energy is the most cost effective method to reduce green house gas emissions (GHG). It has also pointed out that buildings represent the biggest and most cost effective potential for energy savings. The reduction of 26% energy use is set as a goal for buildings by the year 2020 which corresponds to 11% of the reduction of total energy use in European Union (EU) countries.

The buildings sector is the largest user of energy and CO₂ emitter in the EU, and is responsible for more than 40% of the EU’s total final energy use and CO₂ emissions. At present heat use is responsible for almost 80% of the energy demand in houses and utility buildings for space heating and hot water generation, whereas the energy demand for cooling is growing year after year. There are more than 150 millions dwellings in Europe. Around 30% are built before 1940, around 45% between 1950 and 1980 and only 25% after 1980. Retrofitting is a means of rectifying existing building deficiencies by improving the standard and the thermal insulation of buildings and/or the replacement of old space conditioning systems by energy-efficient and environmentally sound heating and cooling systems.

In order to realize the ambitious goals for the reduction of fossil primary energy consumption and the related CO₂ emissions to reach the targets of the Kyoto-protocol besides improved energy efficiency the use of renewable energy in the existing building stock have to be addressed in the near future.

On 17 December 2008, the European Parliament adopted the Renewable Energy Directive. For the first time, this Directive recognizes aero-thermal, geothermal and hydrothermal energy as renewable energy source. This directive opens up a major opportunity for further use of heat pumps for heating and cooling of new and existing buildings.

Heat pumps enabling the use of ambient heat at a useful temperature level need electricity or other auxiliary energy to function. Therefore, the energy used to drive heat pumps should be deducted from the total usable heat. Aero-thermal, geothermal and hydrothermal heat energy captured by heat pumps shall be taken into account for the purposes provided that the final energy output significantly exceeds the primary energy input.

The amount of ambient energy captured by heat pumps to be considered renewable energy $E_{res}$, shall be calculated in accordance with the following formula [12]:

$$E_{res} = Q_u \left( 1 - \frac{1}{SPF} \right)$$  \hspace{1cm} (1)

where: $Q_u$ is the estimated total usable heat delivered by heat pumps; SPF – the estimated average seasonal performance factor for these heat pumps.
Only heat pumps for which SPF>1.15/η shall be taken into account, where η is the ratio between total gross production of electricity and the primary energy consumption for electricity production. For EU-countries Average η=0.4. Meaning that minimum value of seasonal coefficient of performance should be SPF=COP_{seasonal}>2.875.

This paper presents the energy and economical efficiency criteria which show the opportunity to implement a heat pump in a heating/cooling system. It is developed a computational model of annual energy consumption for an air-to-water heat pump based on the bin method and it is performed a comparative economical analysis of different heating solutions for a building.

2 Energy-economical computation elements

The performances of heat pump and building – heating/cooling installation system is determined based on economical and energy indicators of these systems.

- **Economical indicators.** Usually the heat pump (HP) realizes a fuel economy ΔC (operating costs) comparatively of the classical system with thermal station (TS), which is dependent on the type of heat pump. On the other hand, heat pumps involve an additional investment I_{HP} from the classical system I_{TS}, which produces the same amount of heat.

Thus, it can be determined the recovery time TR, in years, to increase investment, ΔI=I_{HP}-I_{TS}, taking into account the operation economy realized through low fuel consumption ΔC=C_{TS}-C_{HP}:

\[ TR = \frac{\Delta I}{\Delta C} \leq TR_{n} \]  

where TR_{n} is normal recovery time.

It is estimated that for TR_{n} a number 8...10 years is acceptable, but this limit varies depending on the country’s energy policy and environmental requirements.

- **Energy indicators.** The operation of a heat pump is characterized by the coefficient of performance COP or thermal efficiency ε_{PC}:

\[ COP = \varepsilon_{PC} = \frac{Q_{PC}}{P_{A}} \]  

in which: Q_{PC} is the thermal power of heat pump, in W; P_{A} – the drive power of heat pump, in W.

If the heat pump operate in cooling regime is defined energy efficiency ratio EER, in Btu/(h·W) by equation:

\[ EER = \frac{Q_{0}}{P_{A}} \]  

in which: Q_{0} is the cooling thermal power, in Btu/h; P_{A} – the drive power of heat pump, in W.

To determine the real efficiency of the heat pump with electro-compressor can be used the relation bellow [8]:

\[ \varepsilon_{PC} = \frac{T + \Delta t}{T + \Delta t - (T_{o} - \Delta t_{o})} \eta_{r} \eta_{m} \eta_{em} + \eta_{r} \eta_{m} (1 - \eta_{i}) \]  

where:

\[ \eta_{r} = 1.666 - 0.004(T_{o} - \Delta t_{o}) - 0.00625(T + \Delta t) \]  

\[ \eta_{i} = 0.425 + \frac{0.493Q_{PC}}{1.16Q_{PC} + 0.06} 3.23 - 1.835 \frac{T + \Delta t}{T_{o} - \Delta t_{o}} \]  

\[ \eta_{em} = 0.85 + \frac{0.158Q_{PC}}{1.16Q_{PC} + 0.1513} \frac{T + \Delta t}{(T + \Delta t) - (T_{o} - \Delta t_{o})} \]  

\[ \eta_{em} = 0.85 + \frac{0.139Q_{PC}}{1.335Q_{PC} + 0.0904} \frac{T + \Delta t}{(T + \Delta t) - (T_{o} - \Delta t_{o})} \]

in which: T, T_{o} are the hot and cold source absolute temperatures, Δt, Δt_{o} – temperature differences between condensation temperature and hot source temperature, respectively, between cold source temperature and vaporization temperature; η_{r} – efficiency of the real cycle toward a reference Carnot cycle; η_{i}, η_{m} – internal and mechanical efficiency of the compressor; η_{em} – electromotor efficiency; Q_{PC} – heat pump thermal power

In Figure 1 is represented the real efficiency variation of heat pumps according to the source temperature T_{o} and temperature t at the consumer.

Another energetic indicator for heat pumps is the specific consumption of electricity w_{PC}, in kW/GJ:

\[ w_{PC} = \frac{10^{3}}{3.6\varepsilon_{PC}} \]  

In Figure 2 is illustrated the electricity consumption for heat pumps depending on the heat source temperature T_{o} and the consumer temperature t.

The sizing factor (SF = α_{PC} = Q_{PC}/Q_{max}) of the heat pump is defined as ratio of the heat pump capacity Q_{PC} to the maximum heating demand Q_{max} and can be optimized in terms of energy and economic, depending on the source temperature and the used adjustment schedule.
The energetically indicators of heat pumps are determined as average values, taking into account the annual heat consumption variation.

In order to properly compare the performances of various heat pumps types, have to uniform the action energy. In this sense, is reported the useful heat delivered annually $Q_{u,\text{year}}$ at annual equivalent fuel consumption $B_{fe,\text{year}}$, necessary for driving power production, achieving the degree of fuel use $\phi_{\text{year}}$, in kW/kg:

$$\phi_{\text{year}} = \frac{Q_{u,\text{year}}}{B_{fe,\text{year}}} \quad (10)$$

The fuel economy depends by heat pump type, according to Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Plant type</th>
<th>Degree of fuel use $\phi_{\text{year}}$ [kW/kg]</th>
<th>Primary energy $E_p$ [%]</th>
<th>Fuel economy $\Delta C$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>Gas boiler</td>
<td>0.800</td>
<td>125.00</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Heat pump with electro-compressor</td>
<td>1.083</td>
<td>92.34</td>
<td>−32.66</td>
</tr>
<tr>
<td>3</td>
<td>Heat pump with electro-compressor and thermal boiler</td>
<td>0.969</td>
<td>103.20</td>
<td>−21.80</td>
</tr>
<tr>
<td>4</td>
<td>Heat pump with thermal motor compressor</td>
<td>1.416</td>
<td>70.62</td>
<td>−54.38</td>
</tr>
<tr>
<td>5</td>
<td>Absorption heat pump</td>
<td>1.219</td>
<td>82.03</td>
<td>−42.97</td>
</tr>
<tr>
<td>6</td>
<td>Ejection heat pump</td>
<td>0.970</td>
<td>103.09</td>
<td>−21.91</td>
</tr>
</tbody>
</table>

### 3 Energy consumption computation of an air-to-water heat pump

Annual energy consumption of heating/cooling system for a building contributes to minimizing the life cost of the building. This consumption is obtained by time integration of instantaneous consumption during the cold season, warm season respectively. Instantaneous consumption depends on the efficiency of the HVAC system.

For computation of the annual energy consumption of a heating/cooling system can be used the degree-day method or bin method.

For many applications, the degree-day method should not be used, even with the variable-base method, because the heat loss coefficient, the efficiency of the HVAC system, or the balance point temperature many not be sufficiently constant. Heat pump efficiency, for example, varies strongly with outdoor temperature $t_e$; efficiency of HVAC equipment may be affected indirectly by $t_e$ when efficiency varies with load (common for boilers and chillers). Furthermore, in most commercial buildings, occupancy has a pronounced pattern, which affects heat gain, indoor temperature, and ventilation rate.

In such cases, steady-state calculation can yield good results for annual energy consumption if different temperature intervals and time periods are evaluated separately. This approach is known as the bin method because consumption is calculated for several values of the outdoor temperature $t_e$ and multiplied by the number of hours $N_{bin}$ in the temperature interval (bin) centered around that temperature:

$$Q_{bin} = N_{bin} \frac{U}{1000\eta}(t_{ech} - t_e) \quad (11)$$

in which: $Q_{bin}$ is the energy consumption, in kW, for each temperature interval; $N_{bin}$ – number of yearly hours in the temperature interval (bin) centered around outdoor temperature; $U$ – heat transfer coefficient of building, in W/K; $t_{ech}$ – balance point temperature, in °C; $t_e$ – outdoor temperature, in °C; $\eta$ – efficiency of the HVAC system.

The superscript plus sign indicates that only positive values are counted; no heating is needed when $t_e$ is above $t_{ech}$ ($t_e > t_{ech}$). Equation (11) is evaluated for each bin, and the total energy requirement $E_{bin}$, in kWh, is the sum of the $Q_{bin}$ over all bins.

This method is defined in European Standard EN 15316-4.2 [15].
Knowing the thermal power $Q_{PC}$ and power drive $P_A$ of the heat pump for each bin temperature interval, can determine the following:

- Heat loss (heat demand) of the building $Q_{nec}$, in kW:
  \[ Q_{nec} = \frac{U}{1000} (t_{ech} - t) \]  
  \( (12) \)

- Heat pump efficiency, $\varepsilon_{PC}$:
  \[ \varepsilon_{PC} = \frac{Q_{PC}}{P_A} \]  
  \( (13) \)

- Heat pump operation coefficient, $f$:
  \[ f = \min \left( \frac{Q_{nec}}{Q_{PC}} \right) \]  
  \( (14) \)

- Thermal energy provided by heat pump $E_{PC}$, in kWh:
  \[ E_{PC} = f Q_{PC} N_{bin} \]  
  \( (15) \)

- Electric energy to drive heat pump $E_A$, in kWh:
  \[ E_A = f P_A N_{bin} \]  
  \( (16) \)

- Energy requirement $E_{bin}$, in kWh, is obtained by summing the values $Q_{bin}$ given by (11).

- Energy delivered by auxiliary source $E_{aux}$, in kWh:
  \[ E_{aux} = E_{bin} - E_{PC} \]  
  \( (17) \)

- Total energy consumed by the heat pump and auxiliary source $E_t$, in kWh:
  \[ E_t = E_A + E_{aux} \]  
  \( (18) \)

The computer program METBIN has been elaborated based on this computational model, in EXCEL for PC compatible microsystems.

- **Numerical application.** For a building heated by a heat pump are known: heat transfer coefficient $U = 850$ W/K and balance temperature $t_{ech} = 17.8$ °C, and is determined energy consumption during heating period using METBIN program. The results are summarized in Table 2. In Figure 3 is shown the variation of heat loss and thermal power of the heat pump depending on the outdoor temperature.

![Fig. 3 Variation of heat requirement and HP thermal power with outdoor temperature](image)

**Table 2. Results provided of computer program METBIN**

<table>
<thead>
<tr>
<th>Temp (bin)</th>
<th>$t_{ech}$-t $[\degree C]$</th>
<th>Hours $N_{bin}$ [h]</th>
<th>$Q_{nec}$ [kW]</th>
<th>$Q_{PC}$ [kW]</th>
<th>$P_A$ [kW]</th>
<th>$\varepsilon_{PC}$</th>
<th>Coef. $f$</th>
<th>$E_{PC}$ [kWh]</th>
<th>$E_A$ [kWh]</th>
<th>$E_{bin}$ [kWh]</th>
<th>$E_{aux}$ [kWh]</th>
<th>$E_t$ [kWh]</th>
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<td>0</td>
<td>1.8</td>
<td>904</td>
<td>1.53</td>
<td>28.9</td>
<td>7.11</td>
<td>4.06</td>
<td>0.05</td>
<td>1383.12</td>
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<td>340.3</td>
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<td>766</td>
<td>4.08</td>
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<td>3.90</td>
<td>0.15</td>
<td>3125.28</td>
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<td>2</td>
<td>7.8</td>
<td>647</td>
<td>6.65</td>
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<td>6.58</td>
<td>3.66</td>
<td>0.28</td>
<td>4289.61</td>
<td>1171.2</td>
<td>4289.6</td>
<td>0</td>
<td>1171.2</td>
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<tr>
<td>3</td>
<td>10.8</td>
<td>601</td>
<td>9.18</td>
<td>21.6</td>
<td>6.31</td>
<td>3.42</td>
<td>0.43</td>
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<td>4</td>
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<td>3.14</td>
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<td>5</td>
<td>16.8</td>
<td>691</td>
<td>14.28</td>
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<td>5.47</td>
<td>2.95</td>
<td>0.89</td>
<td>9867.48</td>
<td>3349.4</td>
<td>9867.5</td>
<td>0</td>
<td>3349.4</td>
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<td>-2</td>
<td>19.8</td>
<td>644</td>
<td>16.83</td>
<td>14.6</td>
<td>5.23</td>
<td>2.79</td>
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<td>9402.45</td>
<td>3368.1</td>
<td>10838.5</td>
<td>1430.1</td>
<td>4804.2</td>
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<td>11.6</td>
<td>4.66</td>
<td>2.49</td>
<td>1.00</td>
<td>1879.25</td>
<td>754.6</td>
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<td>2086.6</td>
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<tr>
<td>-14</td>
<td>31.8</td>
<td>77</td>
<td>27.03</td>
<td>10.2</td>
<td>4.37</td>
<td>2.33</td>
<td>1.00</td>
<td>785.45</td>
<td>336.5</td>
<td>2081.3</td>
<td>1295.9</td>
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<td>-17</td>
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<td>29.58</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>1005.7</td>
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<tr>
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<td>32.13</td>
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<td>0</td>
<td>482.0</td>
<td>482.0</td>
<td>482.0</td>
<td>0</td>
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<td>-23</td>
<td>40.8</td>
<td>5</td>
<td>34.68</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>173.4</td>
<td>173.4</td>
<td>173.4</td>
<td>0</td>
<td>173.4</td>
</tr>
</tbody>
</table>

**TOTAL** |                            |                    | $54259.47$       | $12568.4$     | $30706.0$     |

### 4 Comparative economic analysis of heating solutions for a building

- **Assumptions for calculation.** A study is performed for the heating of a living building in rural areas with a water-water heat pump, using as heat source the underground water comparative to other sources of primary energy.

The building with useful surface of 240 m$^2$ (basement-floor, ground-floor, floor, and bridge) is heated from 1993 with radiators from thermal station with gas-oil. Indoor air temperatures were considered in accordance with the wishes of the client:
+20 °C for the stairway and annex spaces; +22 °C for day rooms and bedrooms; 24 °C for baths. Construction materials which distinguish heated spaces are: 50 cm brick for exterior walls, concrete 10 cm and 15 cm layer of expanded polystyrene insulation for the bridging, double glazing in oak. Exterior walls will be isolated from the outside with expanded polystyrene (10 cm).

Calculation of heat demand \( Q_{\text{loss}} \) was performed for the existing building envelope (exterior walls without insulation) and after thermal rehabilitation of it (exterior walls insulated with 10 cm expanded polystyrene), for more outdoor air temperatures (Table 3) in order to choose efficient heat source.

For the preparation of domestic hot water is necessary to consider a heat \( Q_{\text{dhw}} \) = 3 kW (3 persons, 3 bathrooms and a kitchen).

### Table 3. Heat demand for heating

<table>
<thead>
<tr>
<th>( t_o [\degree C] )</th>
<th>( Q_{\text{loss}} [\text{kW}] )</th>
<th>Existent envelope</th>
<th>Rehabilitated envelope</th>
</tr>
</thead>
<tbody>
<tr>
<td>+5</td>
<td>18.9</td>
<td>13.6</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>20.2</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td>−5</td>
<td>21.6</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>−10</td>
<td>23.0</td>
<td>18.3</td>
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<td>−15</td>
<td>24.3</td>
<td>19.1</td>
<td></td>
</tr>
<tr>
<td>−20</td>
<td>25.6</td>
<td>21.1</td>
<td></td>
</tr>
</tbody>
</table>

- **Proposed solution.** Building heating is realized as follows:
  - heating of living spaces (living rooms, bedrooms, stairway) with the floor convector-radiator;
  - bathroom heating with radiators (towel–port);
  - hot water temperature to radiators and convector–radiator: 50/40 °C;
  - for supply of radiators and convector–radiator are used distributor/collector systems;
  - distribution network for radiators and convector–radiator, pexal made, is placed at ceiling, basement-floor, ground-floor and floor.

The heat demand of building will be provided by a heat pump type Thermia Eko 180 and a boiler with the capacity of 300 liters. Mechanical compression heat pump (scroll compressor) operates with ecological refrigerant R404A. The heat source is the groundwater aquifers with minimum temperature of 10°C.

In the operating conditions with \( t_o = 8 \degree C \) and \( t_e = 50\degree C \) the thermal power of heat pump is \( Q_{\text{PC}} = 21 \text{kW} \).

It finds that this thermal power assure part of the building heat demand, only for outdoor temperatures higher than −5 °C, in the actual situation, and almost entirely (even for the outdoor temperature of −20 °C), in conditions of thermal rehabilitated envelope (exterior walls isolated additional). To assure the rest of heat demand (heating and preparation of domestic hot water) heat pump is equipped with 3 electrical resistances by 3 kW, which operate automatically, depending on the set indoor temperature.

- **Economic analysis.** Comparing the solution described for building heating with other possible variants of primary energy sources (LPG, gas-oil and natural gas) results a superior investment for heat pump, but also an economy in operating costs, which enable the recovery of additional investment.

In Tables 4 and 5 are presented the necessary investments and operating costs over a period of 10 years for the considered variants.

### Table 4. Investment costs I, in €, for heat pump (HP) and different thermal boilers

<table>
<thead>
<tr>
<th>Solution components</th>
<th>HP</th>
<th>Thermal boiler with fuel:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LPG</td>
</tr>
<tr>
<td>Heat pump/Boiler</td>
<td>7700</td>
<td>3000</td>
</tr>
<tr>
<td>Underground water capture</td>
<td>4900</td>
<td>–</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>1300</td>
<td>–</td>
</tr>
<tr>
<td>Circulation pumps</td>
<td>1200</td>
<td>–</td>
</tr>
<tr>
<td>Fuel tank</td>
<td>–</td>
<td>3500</td>
</tr>
<tr>
<td>Total</td>
<td>15100</td>
<td>6500</td>
</tr>
</tbody>
</table>

### Table 5. Operating costs for heat pump (HP) and different thermal boilers

<table>
<thead>
<tr>
<th>Solution characteristics</th>
<th>HP</th>
<th>Thermal boiler with fuel:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LPG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Thermal power, [kW]</td>
<td>21+9</td>
<td>24</td>
</tr>
<tr>
<td>Fuel calorific power, [kW/l]</td>
<td>–</td>
<td>6.30</td>
</tr>
<tr>
<td>TS Efficiency / HP-COP</td>
<td>2.33</td>
<td>0.90</td>
</tr>
<tr>
<td>Hour consumption [fuel, [l/h]] / electric energy, [kW])</td>
<td>9.00</td>
<td>4.23</td>
</tr>
<tr>
<td>Annual operating, [h/year]</td>
<td>1870①</td>
<td>1700</td>
</tr>
<tr>
<td>Fuel price, [€/l] / Electricity price, [€/kWh]</td>
<td>0.087</td>
<td>0.500</td>
</tr>
<tr>
<td>Annual consumption, [l/an; kWh/an]</td>
<td>16830</td>
<td>7191</td>
</tr>
<tr>
<td>Annual energy cost, [€/an]</td>
<td>1464</td>
<td>3595.5</td>
</tr>
<tr>
<td>Estimated energy price increase in 10 years</td>
<td>1.30</td>
<td>1.40</td>
</tr>
<tr>
<td>Operating expenses (10 years), [€]</td>
<td>1903.2</td>
<td>5033.7</td>
</tr>
</tbody>
</table>

① Annual operation of electrical resistances is considered 10% of the normal operation period, so at the 1700 hours/year is adding 170 hours/year.

Results the recovery time of additional investment for heat pump, compared with thermal boilers:
Recent Advances in Environmental Science

References:

It is noted that compared to any of the heating solutions to boilers, heating with water-water heat pump has a recovery period of investment $TR$ smaller than normal recovery period $TR_n$, of 8 ... 10 years.

5 Conclusions
Correct adaptation of the heat source and the heating system for operating regime of heat pumps, leads to safe and economic operation of the heating system using heat pumps.

Heat pump provides the necessary technical conditions for efficient use of solar heat for heating and production of domestic hot water. Heating installations with heat pumps produces minimum energy consumption in operation and are certainly a solution for energy optimization of buildings.

The main barrier for the use of heat pumps for retrofitting is the high distribution temperature of conventional heating systems in existing residential buildings with design temperatures up to 70–90 °C which is too high for the present heat pump generation with maximum, economically acceptable heat distribution temperature of around 55 °C. Besides the application of existing heat pumps in already improved standard buildings with reduced heat demand, the development and market introduction of new high temperature heat pumps is a mayor task for the replacement of conventional heating systems with heat pumps in existing buildings.

$TR = \frac{T_{HP} - T_{TS,LP}}{C_{TS,LP} - C_{HP}} = \frac{15100 - 6500}{5033.7 - 1903.2} = 2.74$ years

$TR = \frac{T_{HP} - T_{TS, gas-oil}}{C_{TS, gas-oil} - C_{HP}} = \frac{15100 - 6500}{6468.7 - 1903.2} = 1.88$ years

$TR = \frac{T_{HP} - T_{TS, natural gas}}{C_{TS, natural gas} - C_{HP}} = \frac{15100 - 7000}{2897.0 - 1903.2} = 8.15$ years

$TR = \frac{T_{HP} - T_{TS, LPG}}{C_{TS, LPG} - C_{HP}} = \frac{15100 - 6500}{5033.7 - 1903.2} = 2.74$ years

$toward$ $boiler$ $to$ $LPG$: $TR = \frac{T_{HP} - T_{TS, LPG}}{C_{TS, LPG} - C_{HP}} = \frac{15100 - 6500}{5033.7 - 1903.2} = 2.74$ years

$toward$ $gas-oil$ $boiler$: $TR = \frac{T_{HP} - T_{TS, gas-oil}}{C_{TS, gas-oil} - C_{HP}} = \frac{15100 - 6500}{6468.7 - 1903.2} = 1.88$ years

$toward$ $natural$ $gas$ $boiler$: $TR = \frac{T_{HP} - T_{TS, natural gas}}{C_{TS, natural gas} - C_{HP}} = \frac{15100 - 7000}{2897.0 - 1903.2} = 8.15$ years

It is noted that compared to any of the heating solutions to boilers, heating with water-water heat pump has a recovery period of investment $TR$ smaller than normal recovery period $TR_n$, of 8 ... 10 years.

References: