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The way from gas boilers to heat pumps

De la boilere pe gaz la pompe de căldură

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ABSTRACT. *The paper presents challenges to be considered by engineers and by owners, managers and occupants in the perspective of the global warming, requiring measures for replacing the fossil fuel sources with renewable ones, as used by HVAC equipment. Air Source Heat Pumps, ASHP and Ground Source Heat Pumps GSHP are issues considered for the transition to "A Clean Planet for All" as a decarbonization path of the building sector. Retrofitting the envelope and using heat pumps is aimed for a greenhouse gas GHG mitigation in order to limit the climate change. Reaching a net reduction in CO_2 emission involve a series of stages- envelope insulation, replacing the boiler with a heat pump, new, oversized heat emitters (and pipes), adapted circulation pumps, predictive control systems, and possible new network concepts.*

Key words: *heat pumps, greenhouse*

1. Introduction

The recent REHVA-issued "Report on the Shift Away from Natural Gas in Buildings" presents some innovative solutions concerning some supply possibilities for space heating and for the domestic heat water, DHW in terms of greenhouse gases, GHG mitigation. The Sustainable Development Goals established by the United Nations for 2050 and having the European Commission as a stakeholder with its strategic long-term vision for "A Clean Planet for All" aims at the decarbonization of the building sector in order to achieve the climate neutrality.

In Romania approx. 53% of residential buildings are built before 1970 and more than 90% before 1989 (in terms of m^2), having an energy performance level between 150-400kWh/m^2. Heating energy represents around 55% of the overall energy use in apartments and up to 80% in individual houses. The buildings built before 1990 have poor energy performance at around 180-400kWh/m^2/yr. [2]

Central heating systems used in the existing block of flats have been designed for higher temperatures, i.e., 90/70°C, or 80/60°C. The supply water temperature designed for later buildings was then decreased from 90°C to 70°C, with a return temperature of 55°C as the building envelope became better insulated. This trend is about to continue and supply temperature of 50°C with a return one of 40°C exist in case of condensing gas-boilers installed in better insulated buildings.

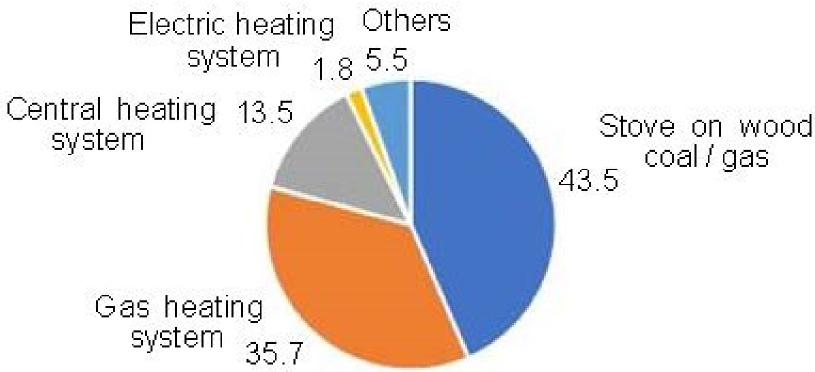


Figure 1. Home heating sources used during the cold season in Romania 2019 [7].

Optimizing the operation of heating installations with condensing boilers and heat pumps. In many cases, with existing heating systems, which have been dimensioned for high temperatures supply (90/70°C ... 80/60°C), after the rehabilitation of the building envelope, we will need lower temperatures supply. These temperatures are usually higher than those required for optimal operation for condensing boilers.

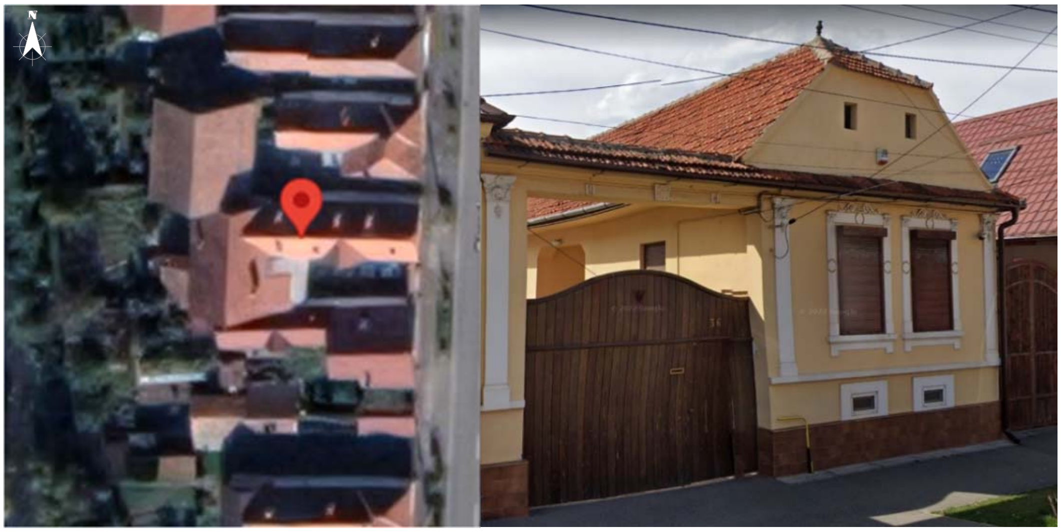
The heating installations are dimensioned for unfavorable winter situations, a period of time that is relatively short, on the order of days, maybe weeks. In order to optimize the existing heating installations, with a view to the optimal operation of the condensing boilers and heat pumps, it is necessary to provide external temperature sensors and regulate the supply temperature of the heating agent, according to a pre-imposed operating curve.

Hydraulic aspects. In the case of condensing boilers, there are no negative influences on the hydraulic regime of the existing heating installations, as they operate at the same temperature difference. With heat pumps, they can be disturbed in operation, because of some lower temperature difference, i.e., 8 ... 10°C. It can cause an increase in heat flow rate, and in circulation speed with higher hydraulic losses. Because of this, it is necessary to check by calculation the existing heating installations and adapt them to the new requirements.

2. The building envelope insulation and the supply temperature reducing

The heating demand of an existing building is reduced after the renovation of the envelope and as a result the supply temperature of the water entering the radiator can be decreased.

Figure 2. The investigated house.



Considering the case of a building (117 sqm) located in Rasnov, near Brașov (climate zone IV), see figure 2 and having a *design* heat consumption of 33141 kWh/year, that is *reduced* to 9688 kWh/year as a result of the renovation. The corresponding heat loads are $\phi_d = 4681$ W and $\phi_{d,r} = 1740$ W respectively.

These values lead to a reduced dimensionless heat load [8]

$$\Upsilon_{d,r} = \frac{\phi_{d,r}}{\phi_d} = \frac{1740}{4681} = 0,37$$

The designed heat load ϕ_d will be covered by a radiator having the same heating capacity depending on the radiator constant, K_m determined by test and published by the manufacturer, and on the radiator design excess temperature, $\Delta\theta_{ar} = \frac{\theta_{\sup;d} + \theta_{ret;d}}{2} - \theta_{i;d}$, where $\theta_{\sup}$ is the design radiator supply temperature, and $\theta_{ret;d}$ is the design radiator return temperature, and $\theta_{i;d}$ represents the design indoor temperature; the exponent *n* depending on the radiator type (cast-iron, baseboard radiation, convectors, ceiling, or floor heating/cooling [5]. The recommended value for cast-iron radiators [1] is *n*=1.3.

As the heat load is reduced after the building envelope renovation, $\theta_{d;r}$ a similar expression can be written for the radiator supplied with a lower water temperature $\theta_{\sup;r}$ $(\Delta\theta_{ar,r} = \theta_{\sup;r} - \frac{\Delta\theta_r}{2} - \theta_{i;d})$, $\phi_{d,r} = K_m \cdot \Delta\theta_{ar,r}^n$

$$\Upsilon_{d,r} = \frac{\phi_{d,r}}{\phi_d} = \frac{\Delta\theta_{ar;r}}{\Delta\theta_{ar}^n}$$

$$\theta_{\sup;r} = \theta_{i;d} + \frac{\Delta\theta_r}{2} + \Upsilon_{d,r}^{1/n} \cdot \Delta\theta_{ar}$$

For the discussed case ($\theta_{\sup;d} = 90^{o}C$; $\theta_{ret;d} = 90 - 20 = 70^{o}C$ and $\theta_{i;d} = 20^{o}C$, $n = 1.3$)

$$\Upsilon_{d,r} = \frac{\phi_{d,r}}{\phi_d} = \frac{\left(\frac{\theta_{\sup;r} + \theta_{ret;r}}{2} - \theta_{i;d}\right)^n}{\left(\frac{\theta_{\sup;d} + \theta_{ret;d}}{2} - \theta_{i;d}\right)^n}$$

$$0.37 = \frac{\left(\frac{\theta_{\sup;r} + \theta_{\sup;r} - \Delta\theta_r}{2} - 20\right)^{1.3}}{\left(\frac{90 + 90 - 20}{2} - 20\right)^{1.3}}$$

For $\Delta\theta_r = 10^{o}C$, $\theta_{\sup;r} = 60 \cdot (0.37)^{1/1.3} + 25 = 52.96^{o}C$ $\theta_{ret;r} = 52.93 + 10 = 42.96^{o}C$

and for $\Delta\theta_r = 15^{o}C$, $\theta_{\sup;r} = 60 \cdot (0.37)^{1/1.3} + 27.5 = 55.43^{o}C$, $\theta_{ret;r} = 55.43 - 15 = 40.43^{o}C$

Such low-values for the reduced supply temperature $\theta_{\sup,r}$ are specific for condensing boilers.

The supply temperature reducing depends on the extent of the renovation: if in the presented example the building was initially in a poor state of insulation, a substantial improvement after the renovation resulted in a diminution of heat losses, so that the reduced dimensionless heat load $\gamma_{d,r}$ has a low value, i.e., 0.37. But in other cases, as that of an apartment in a block of flats, the reduced dimensionless heat load usually is in the range of 0.8…0.6 and that will lead to a reduced supply temperature of only $\theta_{\sup,r} = 70...80^{o}C$ as can be seen in figure 3.

3. Condensing boilers-a step to the heat pump technology

As the dew point is around 55ºC in case of the natural gas boilers, the temperature of the water in the return pipe (exiting from the radiator) needs to be 55ºC or lower for an efficient operation of the condensing boiler. But even if the condensing onset will start at 54ºC it must be specified that the best boiler efficiency occurs for a much lower temperature of the entering water. i.e., less than 27ºC.

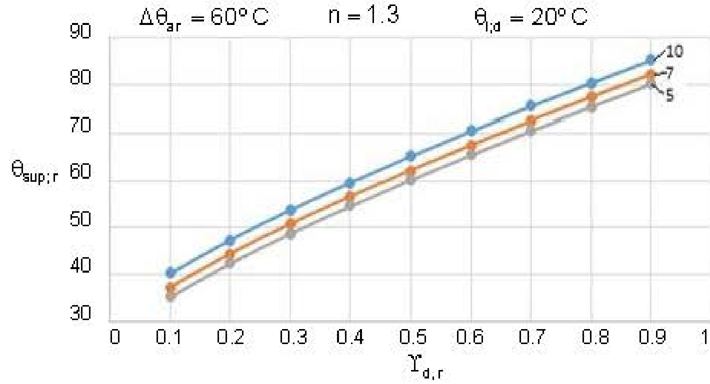


Figure 3. The reduced supply temperature vs. the reduced dimensionless heat load.

From the point of view of a condensing boiler, temperatures for the water supplying radiators in the range of 53 to 54°C are feasible with no impact on thermal comfort when considering a building with an improved envelope insulation and draft proofed. Very well insulated buildings-walls, floor and loft too, with triple glazing- will be comfortable even in a cold day when the condensing boiler is set to 50 … 45°C.

If in the case of a condensing boiler the return temperature is important for an efficient operation of the system, then when replacing it with a heat pump, the supply temperature is becoming crucial: temperatures of around 40 to 45°C are the operational ones. Some specificities exist when considering boilers, condensing or traditional ones, and heat pumps, i.e., the temperature differential and the flow rate. If boilers usually operate with 20 to 15°C temperature differential between supply and return, in case of heat pumps it reaches only 8 to 10°C (some heat pumps have an even lower Δt=5°C) see figure 4.

As a result, a higher flow rate is characteristic for heat pumps in contrast with boilers: when shifting away from boilers to heat pumps larger circulation pumps to move the fluid will be required.

Considering the transition of the supply temperature from higher values to the lower ones when improving the envelope insulation, followed by the replacement of the traditional boiler with the condensing one, and then with the heat pump it can be noticed the optimization trend in exergy efficiency of the energetic system. [3]. A similar trend exists for the temperature differential.

By the lowering of the supply temperature, the capacity of the heat emitters will be altered. Figure 5 shows the effect of the design excess temperature, $\Delta\theta_{ar}$ as a mean water to air temperature difference, on the radiator capacity, [5].

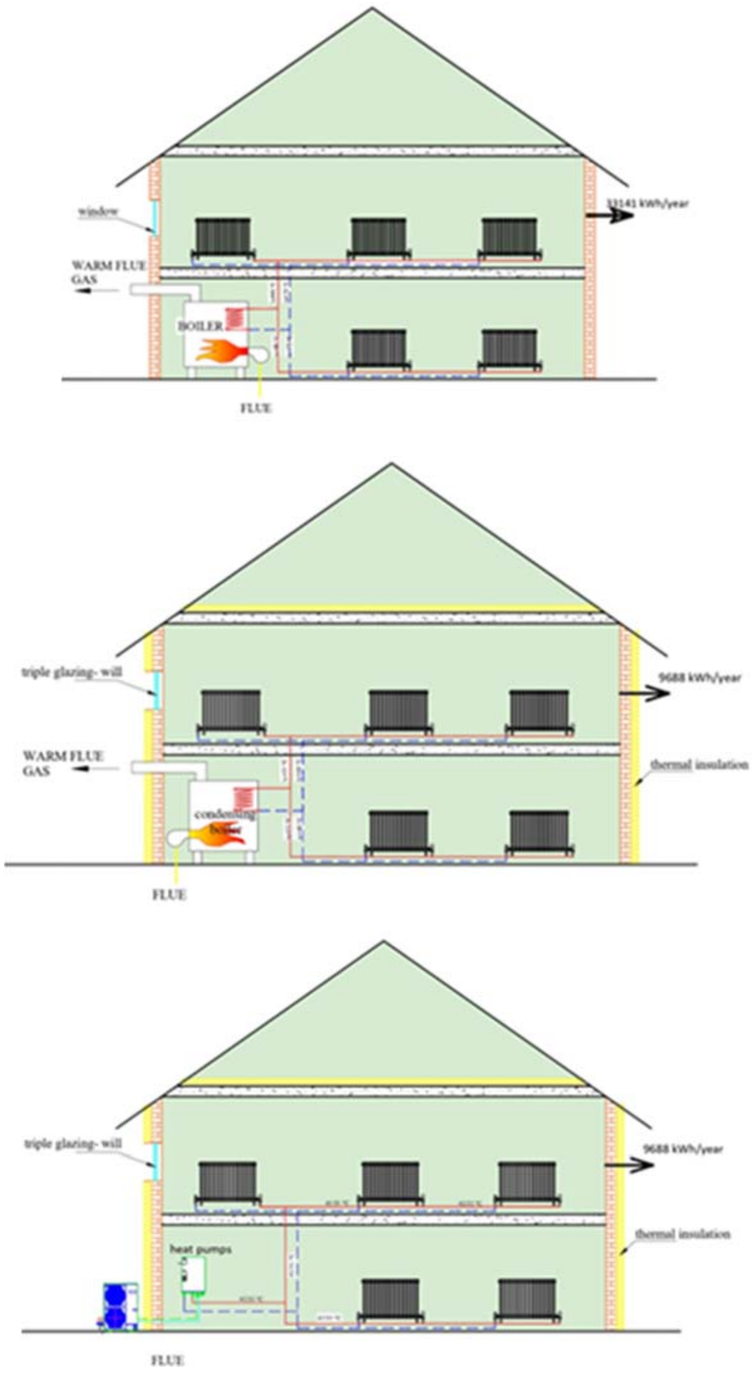


Figure 4. The transition from boiler to heat pump technology after an improvement of the building envelope insulation.

The correction coefficient c_t takes into account changes in the design excess temperature, $\Delta\theta_{ar}$ related to the standard one $\Delta\theta_{ar,n}$ and having as an effect the altering of the heating system capacity

$$c_t = \left(\frac{\Delta\theta_{ar}}{\Delta\theta_{ar,\,n}}\right)^n$$

where, the exponent n=1.3 is for standard and skirting radiators, 1.1 - for fan coils units, and 1.0 - for fan convectors.

It can be seen that a reduced design excess temperature, $\Delta\theta_{ar} = \frac{(80+60)}{2} - 20 = 50^{\circ}C$ will result in a diminished capacity of 80% (c_t=0.8) compared to that traditional, i.e., $\Delta\theta_{ar} = \frac{(90+70)}{2} - 20 = 60^{\circ}C$

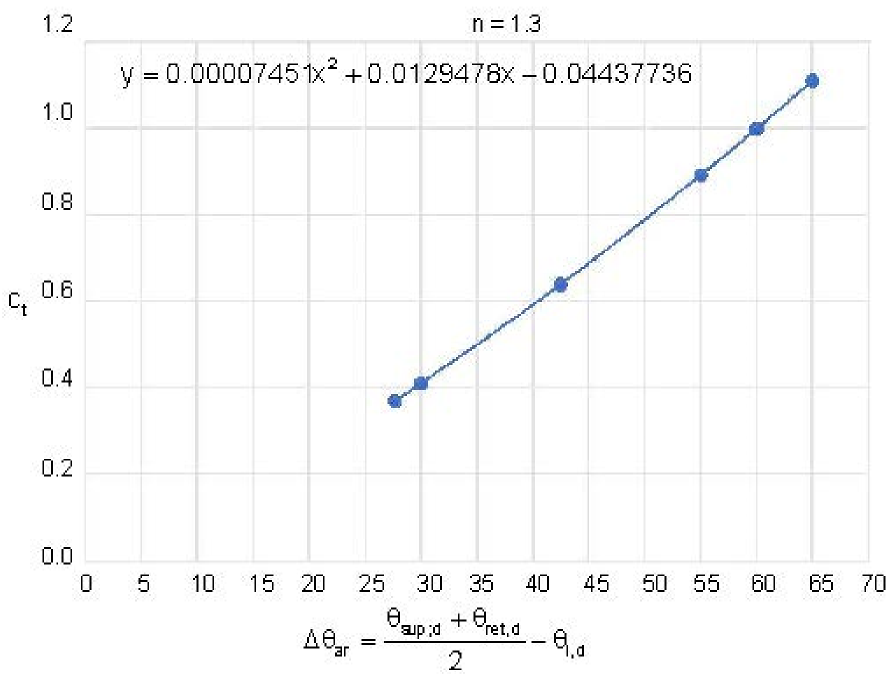


Figure 5. The correction factor as a function of the design excess temperature.

In case of heat pumps, running most efficiently and providing water having a supply temperature of 45 … 40 ºC, a larger heat emitter is to be selected in order to assure the necessary output. When sizing a standard radiator supplied by a heat pump, the heat load calculated in advance (W) must be multiplied by an ‘oversize factor’ [6] that depends on the design excess temperature resulted from figure 6.

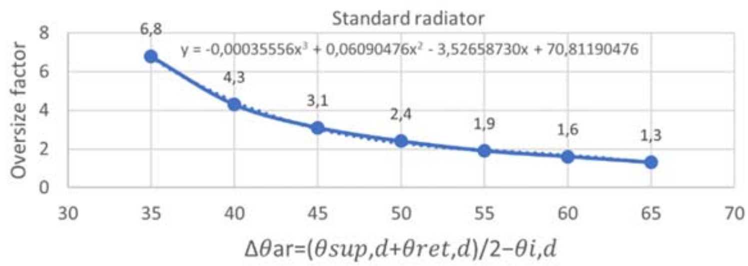


Figure 6. The oversize factor for a standard radiator as a function of the design excess temperature.

Then a suitable radiator having at least that output will be selected from a list of products. Attention must be paid if the output tables are rated on a 60°C or on a 50°C design excess temperature base.

When the wall surface is limited then some other devices are useful: fan assisted radiators, or fan coil units. These ones can provide higher outputs for a reduced volume. Figure 7 shows the corresponding oversize factors for different heat emitters. The underfloor heating offers the advantage of a larger surface but it is convenient especially in case of new constructed buildings.

The underfloor heating is characterized by the lowest possible temperature able to perform the necessary heating output. This system is able to avoid the air stratification, reducing de energy costs especially in high-ceilings buildings. Floor construction and floor covering must be treated with care so that the temperature on its surface should not exceed 28°C and the thermal resistance to be kept under 0.15 m^2K/W. The usual pipe spacing is 100 … 300 mm for underfloor screed, closer for carpet-covering and more distant for tile or wood covering.

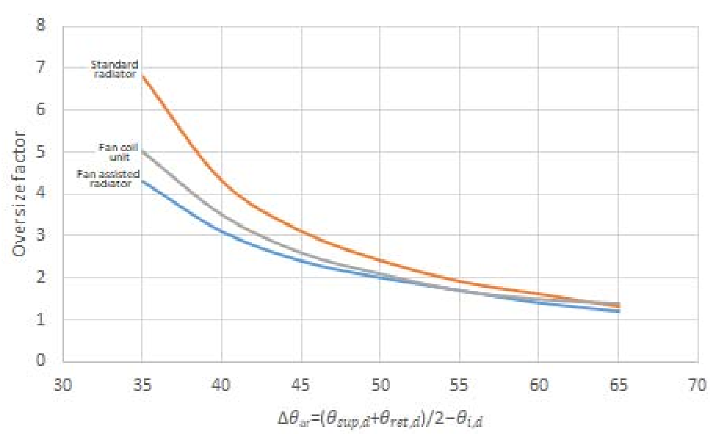


Figure 7. The oversize factor for a *standard radiator*, a *fan coil unit*, and for *fan assisted radiator* as a function of the design excess temperature.

4. Heat pump specific conditions

Delivering the adequate heat is possible if the flow rate of water leaving the heat pump to the emitters is in a correct range, not too little, but not excessive. For the existing installations being in the process of replacing the fossil fuel boiler with a heat pump it is essential to consider the fact that a reduced temperature differential -1/2 to 1/4 from that used in case of combustion boilers, will lead to a proportionately increasing in mass flow and in fluid velocity. As a result, load losses and pressure drops are affected, requiring a resizing of the pipes and of the circulation pump with higher cost for the electricity consumption. As a general rule, pipes having a bore diameter over 10 mm are suited, with velocities under 1m/s so that pressure drops not to exceed 300 Pa/m [4].

When selecting a heat pump for a specific application it must correspond to the heat load and to the comfort temperature, i.e., the evaluated Seasonal Performance Factor must comply with the oversize factor, as shown in figure 8.

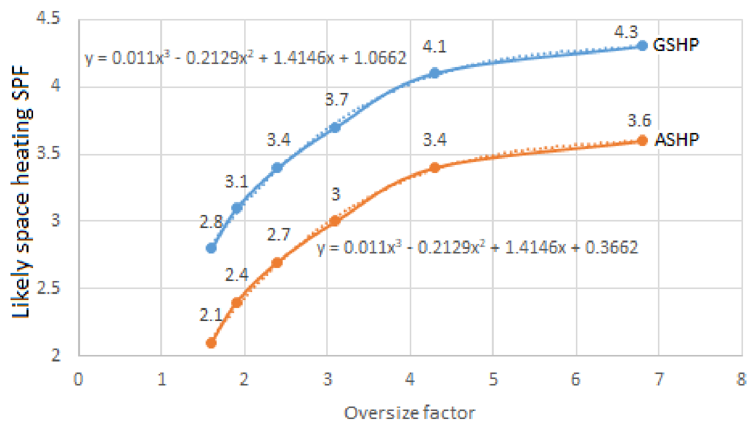


Figure 8. The required SPF corelated with the oversize factor.

As the outside-air temperature increases heat losses of the building decrease and a lower load result. A load correction correlated with the ambient air is necessary to have an improved efficiency of the system, meaning that the flow temperature will be reduced proportional with that of the ambient air.

Radiators react in a linear manner to flow temperature reduction but fan convectors and underfloor heating require a specific compensation curve for the inverter controlling the speed of the compressor.

During such milder condition, the output of the heat pump could be less than the inverter is able to control, and an *on and off* operation will result. Usually, less than six cycles per minute -*on and off*- is accepted in order to avoid a reduced system efficiency and a poor comfort control, not to mention the excessive wear on the components.

Inverter controlled ASHP require a minimum content of water, as shown in figure 9. This is necessary to avoid an excessive compressor cycling resulting in case of low loads, specific for higher outdoor temperature.

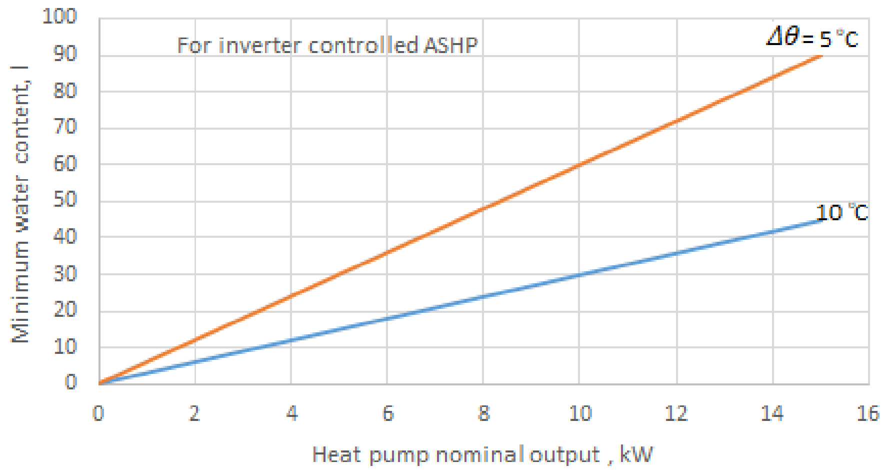


Figure 9. The minimum water volume required in case of inverter controlled ASHP corelated with the nominal output of the heat pump, for a number of 6 cycles per minute (*on and off*).

5. Conclusions

The decarbonizing of the building stock by shifting away from natural gas boilers to heat pumps as a renewable energy user, is considered a robust step. If in the case of new designed and constructed buildings the process can be considered as a feasible one, the big majority of the existing buildings, with its residential component, seems to be a major challenge. Replacing the boiler with a heat pump will be followed by a complex of actions involving radiators, pipes, control systems and having in the backstage the knowledge of specialists and owners, managers and occupants must be open to change.

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