Retrofitting fossil-based heating systems with air to water heat pumps in multifamily houses

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Abstract

We have studied three pilot projects of replacing fossil-based heating systems by air to water heat pumps in multifamily housing in Geneva, Switzerland. The pilot projects are being realized by the local public utility Services Industriels de Genève (SIG), under its energy program portfolio *éco21*.

The project is implemented with an owner of 600 buildings in Geneva, who has a legal obligation to reduce energy consumption and/or increase the part of renewables in its building stock. Feasibility studies revealed the difficulties of the task: solar is not technically possible (due to complicated old roof, building being under historical heritage protection, no place available for water storage), geothermy, wood and biomass are not authorized by law (due to water and air protection regulations). Air to water heat pumps are therefore the only solution for integrating renewable energy supply into the buildings.

The challenge is important: buildings are old, there is few place and an old distribution system, investment costs are high, which requires energy consumption to be highly efficient. Due to the age of the buildings and the restrictions to insulate the buildings envelope, the distribution temperatures are not always compatible with the ones needed for the high efficiency of the air to water heat pumps. In two cases, the boilers were also replaced and the systems were made bivalent. The three pilot projects demonstrate technical and economic difficulties and solutions for integrating air to water heat pump solution in existing multifamily houses, which can be used for development of renewable heat program and energy contracting in Geneva and other locations.

Selection and/or peer-review under responsibility of the organizers of the 12th IEA Heat Pump Conference 2017.

Keywords: heat pumps, multifamily houses, energy contracting, retrofit

1. Introduction

Renewable energy development is one of the main energy policy priorities in Europe and other regions. In the past most of attention and financing efforts were put into renewable electricity. With the adoption of carbon emissions reduction targets, greater interest from policy-makers, energy sector and academia are put into renewable heat. However, the share of renewable heat supply in most countries is still minor.

In Switzerland the share of renewables in heat supply is about 16% (including 11% of wood-based systems, 5% of other renewables) [1, 2]. The majority of heat supply (75%) is coming from imported fossil fuels, including

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40% from heating oil, 33% from natural gas and 2% from coal [1, 2]. The Swiss federal policy targets include 20% decrease in overall carbon emissions and 40% decrease in buildings emissions in 2020 comparted to 1990 level [3-5]. In 2014 overall carbon emissions were reduced by 9% compared to 1990 level [2]. In buildings the emissions were respectively reduced by 30%, about 5.2 million tCO2-eq. are still to be saved by 2020 [2]. A variety of policy instruments has been put into place to achieve carbon emissions reduction and promote renewable heat solutions, including carbon tax and the federal subsidy program *Programme Bâtiment* [3, 4]. However, it was officially recognized that these solutions are not sufficient to achieve the desired level of carbon emissions.

In addition to the federal policy targets and instruments, some cantons undertake actions to promote renewable heat solutions within their geographic jurisdictions. In the canton of Geneva the local public utility *Services Industriels de Genève (SIG)* is mandated by the canton to provide support for renewable heat uptake by final consumers, including single family and multifamily housing sectors. This support is implemented via *SIG* energy efficiency program portfolio *éco21* [6-9]. In the case of single housing sector *éco21* offers subsidies that cover about 10% of initial investment costs (including equipment and installation services). This type of support is not suitable for multifamily houses due to the peculiarities of Swiss housing legislation. Contrary to the single housing sector, the majority of inhabitants of multifamily houses are tenants [10]. Tenants are responsible for payment of the energy bills, while it is the responsibility of the owners to invest in heating system. Investment costs cannot be transmitted to tenants via heating bills [11]. Currently for existing buildings the investment costs of the renewable heat systems such as heat pumps are from three to five times higher compared to the conventional solutions (fossil fuel-based). The owners therefore have no incentive to opt for renewables. A possibility to overcome this barrier is energy contracting, when an ESCO is investing in renewable heat system and is recovering its costs by selling energy service to the inhabitants of the building. However, this solution is not widely used due to a limited number of ESCOs in Swiss market and a lack of experience in renewable technologies implementation. This is particularly the case of heat pumps integration in the existing buildings, as this solution demands multiple professional services: energy concept development; noise, static and building physics assessment; planning and implementation of heating, electricity and sanitary works; administrative procedures. In order to develop energy contracting practice, case studies demonstrating technical-economic feasibility, as well as environmental assessment of the renewable heat projects are needed. In this view, it is the objective of our paper to evaluate “air to water heat pump energy contracting” solution developed by *éco21*, based on three pilot projects currently implemented. We provide description of the case study followed by methodology. We further present the results, including on solutions to overcome technical and economic barriers of the projects implementation, together with estimated environmental impacts. Finally, we discuss how these results could be used for development of renewable energy contracting solutions in Switzerland and other locations.

2. Case study and methodology

Three different types of buildings were chosen for the pilot projects to represent the most common building types in Geneva built during the three main phases of the city development (Table 1). The first multifamily house (further referred as *Pilot 1*) was built in1990s during a construction boom as a pre-fabricated envelope building in an increased population density area, near the city centre. The second house (*Project 2* respectively) was built in 1970s during the baby-boomers period, when construction dynamics was fast, population density grew quickly, buildings were cheap but of poor quality. The third building (*Pilot 3* respectively) was built in the beginning of the 20th century, when Geneva grew quickly from a small town into a city. It was a time of the first “high” buildings (up to 6 floors) and densification of the downtown.

Table 1 Features of the three pilot projects

	Building age [year]	Heated surface [m2]	Previous heating	Heating consumption [kWh/m2]	Power [kW]	Heating consumption [kWh]
Pilot 1	1992	7'563	Gas	147	550	1'111'761
Pilot 2	1972	4'047	Oil fuel	144	280	582'768
Pilot 3	1911	1'902	Oil fuel	180	170	342'360

The chosen buildings do not have specific thermal insulation which is common in Geneva. It is not possible to implement ground source heat pump or wood and biomass boiler due to technical and legal constraints. Air to water heat pumps remains the only solutions for renewable supply. There is a number of technical and economic challenges that should be addressed.

One of the major technical challenges is related to unavailability of air to water heat pumps specially designed for multifamily housing. Most of the residential heat pumps have currently capacity of 3 – 30 kW and are suited for single-family houses. Most of the industrial heat pumps have currently capacity of 30 – 600 kW, but the noise level is high. In this context, the objective of the pilot projects is to find solution for upsizing traditional heat pumps designed for single family houses or adapting equipment from industrial application into a rooftop of multifamily houses. Among the other major technical challenges are achieving good efficiency with the outside air as a heat source, addressing noise and static requirements, integrating the heat pump in the existing distribution system in an efficient and reliable way. Among the technical aspects integrated in the feasibility studies are thermal engineering, rooftop static, soundproofing, vibration, electricity capacity and extra height construction limits. Addressing the above-mentioned aspects differs considerably for different types of buildings with respect to the age of construction.

Implementation of the pilot projects was decided to be in energy contracting format. The investor (*SIG*) payed the initial investment costs and recovered them through selling energy to inhabitants of the buildings (consumers). All the technical choices have been constrained by financial objective to keep the *annual heating costs* for consumers (or energy bills) equivalent to the previous fossil solution. It means optimizing the *initial investment costs* (i.e., equipment and installation services plus WACC[†]), *energy* (i.e., fossil fuels or electricity consumption) and *maintenance* costs. The addition of these three cost parts gives the *total cost* or *annual heating cost* if distributed over the lifetime of the project.

In the pilot projects *initial investments costs* of heat pump solution is three to five times higher compared to the costs of traditional fossil-based systems. As it has been mentioned above, according to the Swiss law the tenants pay the *energy* and *maintenance costs*, while the building owner pays the *initial investment costs* and have no right to pass them to the tenants via the energy bills [11]. There is a real need to rethink the repartition between the cost paid by the building owners and the tenants and no subsidy can cover this gap. The Swiss law provides exception for district heating systems: a possibility to affect all the three parts – *initial investment*, *energy* and *maintenance cost* – to the tenant [11]. The interpretation of the law tends to extend the exception from district heating to more heating solutions types in case when contracting is implemented and the *annual heating cost* increase does not overpass 10% limit. Still to keep the *annual heating cost* nearly constant for the tenant we have the opportunity to ask a contribution to the building owner investment which reduces the *initial investment*. The amount depends on the existing heating system state; if the existing system is old the building owner spends the equivalent amount of a new fossil equipment but if it is new the building owner do not contribute the *initial investment*.

We split the *total cost* into eight parameters affecting *initial investment*, *energy* cost or *maintenance* costs (Figure 1): a) total of initial investment cost, b) subsidy, c) WACC, d) initial investment paid by building owner (deducted from contracting offer), e) share of renewable energy in heat supply, f) electricity price, g) SCOP (i.e., seasonal performance coefficient), h) extra heating quality. The overall objective of the program administrator (*éco21*) in developing contracting offer is to upgrade significantly the environmental quality of the heating systems so the percentage of renewable energy is at least at 70% and the equipment chosen reaches an excellent SCOP.

[†] Weighted Average Cost of Capital

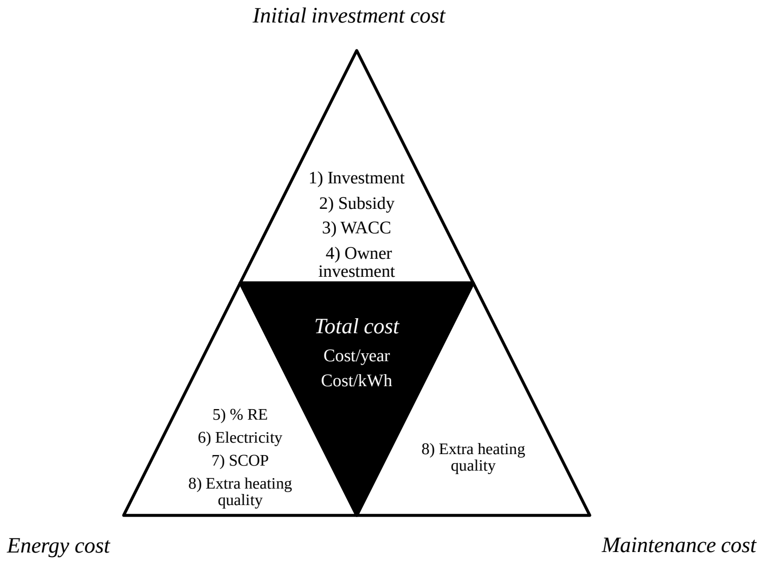

Fig. 1 Eight parameters in the tree main parts of the total cost

The analyse how to optimise each of the above-mentioned elements influence the *total cost*.

3. Results

The Pilot 1 do not present difficulties in the implementation except the fact that the total energy consumption is high. The effective needed heating power is not exactly known. So it was decided to replace the boiler with the heat pumps and to keep the second boiler for peak demand (power and temperature). The difficulty is that the boiler is not condensing and must be run at high temperature (at least 70/50 degrees C) and it is not modulating. So a specific hydraulic plan (Figure 2) has been engineered and validated by the heat pump manufacturer.
The 6 heat pumps are organized in two groups of 3 machines each, one of them working as master and the other 2 as slaves.

In the heating mode, all 6 machines works together in a cascade. They are driven by the outside temperature with and the temperature at the top (heat pump on) and bottom (heat pump off) of the first boiler (low left in figure 2). The water flows then to the next boiler (second from the low left in figure 2) and then to the distribution system (radiators with thermostatic valves). If the power of the heat pump does not cover the demand, the existing gas furnace comes on and makes a post-heating in this second boiler only. In order to avoid any problem with too high return temperatures, the heating curves of the heat pumps and the furnace are the same. So they work parallel all the time. The heat pumps are never turned off in an alternating mode because the lowest temperatures in this area are between -5°C and -10°C. The cantonal law requires a 100% covering of the heat demand by 5°C.

Domestic hot water in pre-heated by the three heat pumps in the lowest right boiler up to 45°C and then post-heated up to 70°C by the gas furnace. Fresh cold water is coming in from the lowest right in figure 2.

So the heating system can be run at temperatures to allow a good efficiency of the heat pump and facing peak demand of heating and domestic hot water.

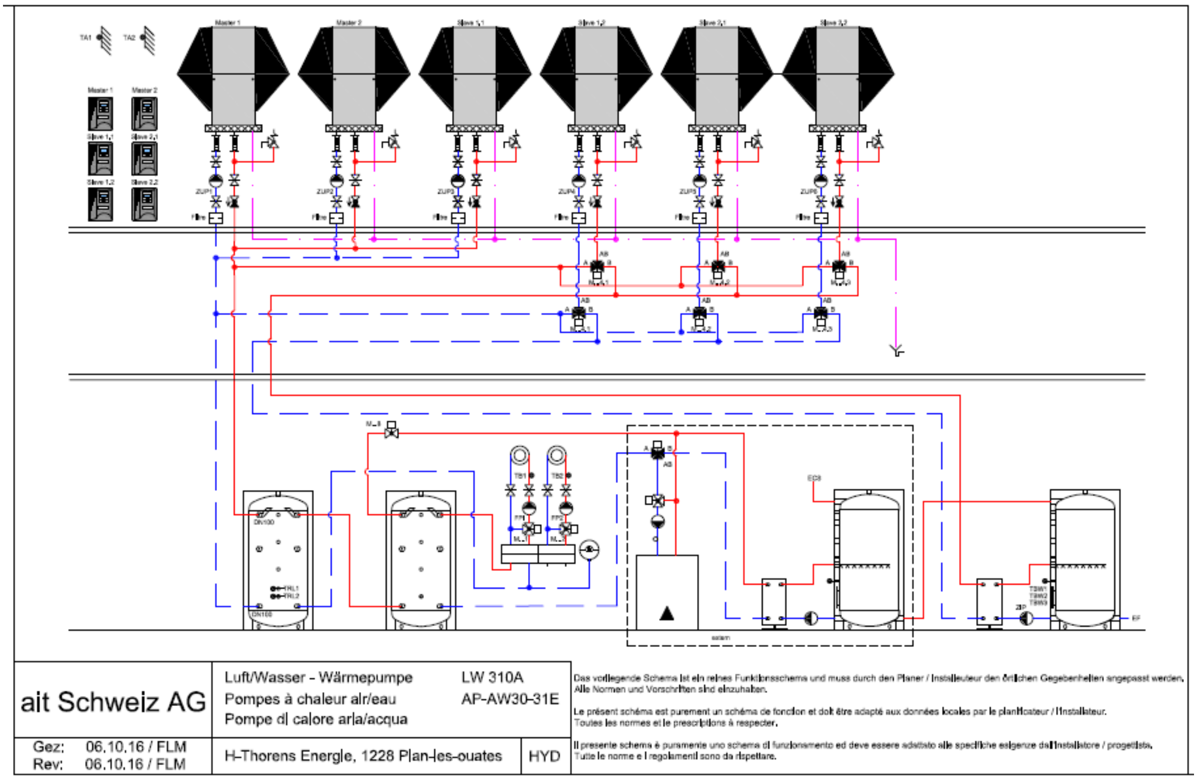

Fig.2 Hydraulic plan for Pilot 1

This hydraulic plan allows an upgrading utilisation of small individual heat pumps installed in a coherent group. Instead of producing 30 kW the group of 6 heat pumps produces 180 kW for the heating and hot water heating needs. There is no need of investing for a specific soundproofing structure because these heat pumps are already optimised from an acoustic point of view.

The Pilot 2 has a lower energy consumption and the rooftop surface is big enough to install the total power of 270 kW. The needs of temperature are high in the coldest days. The choice of industrial heat pumps units is done in order to provide all the needs. A specific, expensive and heavy structure has to be installed for the soundproofing. Static calculations have been done to check the solidity of the roof which is just good enough to carry the whole installation (Figure 3). The main issue is NOT the resistance of the structure but its deformation. The relatively thin roof construction (17 cm) is likely to be deformed by the weight of the heat pumps. This result in following critical problems:

- Solid vibration of the roof with an woofer-effect so that the solid vibrations are projected as noise in the upper rooms,
- Blocking of doors which cannot be moved any more unless they are shortened according to the deformation of the frames…

The other challenge is to satisfy the whole demand with heat pump only. This was decided because the boiler must be replaced and the customer wanted to get completely rid of fossil energy. The challenge is to reach efficiency and cover the demand with reliability.

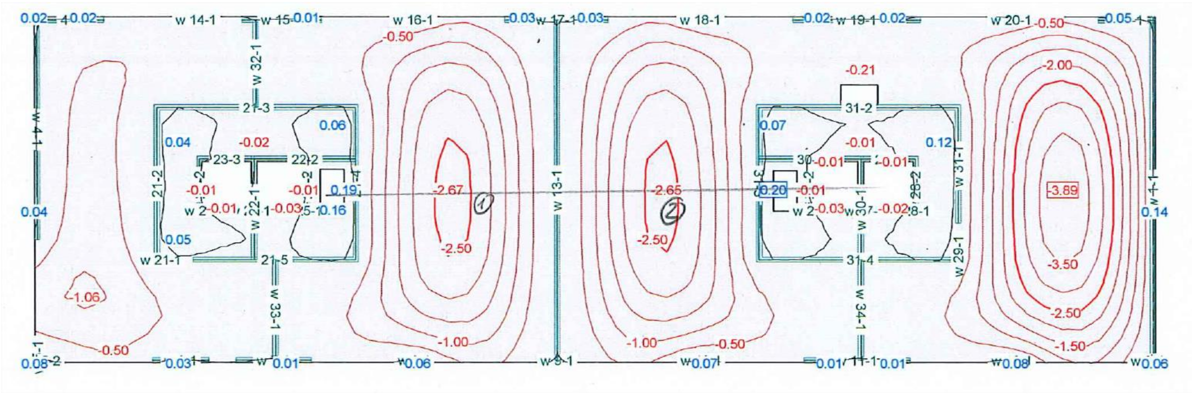

Fig.3 Static calculations for Pilot 2. The numbers are lines of equal deformation in cm.

The Pilot 3 is the most difficult because it is an old building with multiple constraints: low heat power (which makes fossil solution very cheap), low electricity power available on site, a difficult access to the roof. Further, the intervention to adapt the rooftop for air circulation for the heat pump required the authorization of several administrations. Among them, the fire police which rated the building as not compliant with the legal obligations. Constructive adaptations must be made to bring the building in an acceptable level of fire-prevention and protection. The subsidy has been upgraded and the extra heating system stays with oil fuel. These chosen parameters keep the increase of the total cost under 10% in comparison with the previous 100% fossil heating production.
Figure 4 shows the estimation of the impact of each parameters on the *annual heating cost* for Pilot 3. The impact of the parameters is similar in the case of Pilots 1 and 2. Variation of the parameters with high values (i.e., investment, subsidy, WACC, % renewable and extra heating) allows to achieve economic feasibility of the Pilot projects. SCOP, owner investment and electricity price have less impact on the result.

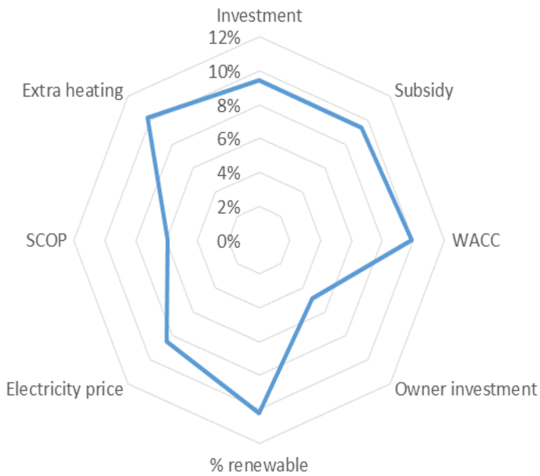

Fig. 4 Impacts of the parameters on the total heating cost per year

The WACC chosen is equivalent to the district heating WACC used by *SIG*.‡ The electricity price in the case of Pilot 1 and 2 is 0.16 CHF/kWh. This is a relatively low value achieved due to high electricity consumption needs of the buildings: more than 100’000 kWh/year. In the case of Pilot 3 the electricity price is 0.21 CHF/kWh due to lower electricity consumption. We do not apply any discount rate for electricity price according to the current *SIG* practice.
All the main parameters are synthesised in the Table 2.

Table 2 Chosen parameter values for the three pilot projects

‡ We cannot disclose value for confidentiality constraints reasons.

	Investment [CHF]	Subsidy [CHF/CO2]	WACC	Client investment [CHF]	Energy % by HP*	Electricity [CHF/kWh]	SCOP	Extra heating
Pilot 1	480'000	25	DH equivalent*	= 1/2 gas investment	75%	0.16	3.0	gas
Pilot 2	520'000	25	DH equivalent*	= gas investment	100%	0.16	2.8	none
Pilot 3	260'000	40	DH equivalent*	= gas investment	75%	0.21	3.0	fuel oil

*District Heating equivalent ; not explicit made due to confidentiality restriction *HP: Heat Pump

In terms of total cost the goal was to maintain current costs paid by tenants. A tolerance of 10% is permitted and it has been respected. For the Pilot 3 the decision taken of keeping the oil fuel as extra heating and the increase of the subsidy permitted to decrease the difference of about 20%. These adjustments made the project possible.

Table 3 Total costs of fossil vs. heat pump system

	Annual heating of fossil solution [CHF/year]	Annual heating of heat pump solution [CHF/year]	Cost difference [%]
Pilot 1	111'000	119'000	7%
Pilot 2	80'000	85'000	6%
Pilot 3	32'000	35'000	9%

In terms of environmental impacts, the difference is high due to large contribution of renewable air and to the certified electricity used with an environmental impact of 14.4 $gCO_2/kWh_{electricity}$ [12]. Table 4 shows the difference of environmental impact in terms of CO_2 between the previous fossil solution and the new heat pump solution.[§]

Table 4 Environmental impact in terms of equivalent CO2

	Fossil solution [tCO2 eq/an]	Heat pump solution* [tCO2 eq/an]	Difference [%]
Pilot 1	287	76	-74%
Pilot 2	184	3	-98%
Pilot 3	108	28	-74%

*Mix certified electricity: 14.4 [gCO2 eq/kWh] given by Ecoinvent

The difference is still high with the traditional Swiss electricity mix of 141 $g/CO_2/kWh_{electricity}$ instead of the value of 14.4 $g/CO_2/kWh_{electricity}$ with a difference of respectively 61% instead of 74% for the Pilot 1 or 84% instead of 98% for the Pilot 2.

[§] The calculation is based on IPCC 2013 GWP 100a in gCO_2 eq/kWh values, respectively 258 gCO2/kWh for gas and 315 gCO2/kWh for oil fuel.

Figure 5 shows this significant environmental impact obtained with a slight increase of the total heating cost.

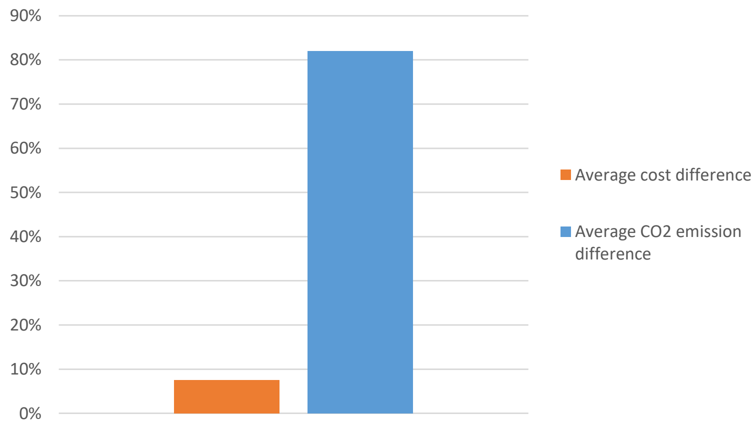

Fig. 5 Average cost difference vs average CO2 emission difference

4. Discussion and outlook

The results of the study confirm the existence of technical and economic barriers for air to water heat pump solution in existing multifamily houses (sections 1-2) and demonstrate that these barriers can be overpassed (section 3).

The first major concern common in all three pilot projects was how to address inertia in choice of heating system type in case of renovation. In nowadays common practice the decision making chain is short: the building owner ask directly heating installer, who in return proposes to replace the existing fossil fuel boiler by the same type of equipment. When there is a change of heating system type, it is mostly from heating oil to natural gas boiler. We propose to add an engineering phase in this decision-making chain in order to propose for building owners renewable heating alternatives and energy contracting scheme. We first thought that the main issue was related to heating supply planning, but quickly noticed that other expert assessments are needed, including in the fields of electricity, acoustics and statics. Therefore, the proposed engineering phase requires participation of multiple specialists. In return, such an approach allows to develop technically and economically viable solutions for air to water heat pumps in the existing multifamily houses.

The second concern is technology choice and installation issues. Currently there are only few efficient and silent heat pumps available on the market, with a capacity over 30kW. Based on the data on the pilot projects, a number of recommendations can be given with regard to the choice and installation of the heat pump on the roofs of multifamily houses. A noise insulation layer should be put under the heat pump to absorb all kind of vibrations, Noise level should be under 55dB, which can be achieved by constructing noise insulation structures. Standard hydronic schemes, validated by equipment producers, should be used. In case of upscaling system capacity to multiple heat pumps, higher efficiency could be achieved when only some of the heat pumps are used for domestic hot water production.

The last concern is related to cost optimisation for developing competitive contracting offer. Keeping the annual energy costs of air to water heat pump solution at competitive level compared to fossil fuel-based solutions is in an important challenge. Apart from the cost optimisation described in section 3, we target to maintain the engineering costs at a low level on the long run, by developing standardised evaluation procedure based on experience obtained with the pilot projects and during the first stages of contracting offer implementation. Another possible solution could be to negotiate price discount with equipment producers, in case of significant number of projects being realized.

Retrofitting a boiler by the same type of boiler does not require any authorisation or additional procedures. In contrast, authorisation from cantonal energy and building authorities is mandatory when replacing fossil fuel-based system by an air to water heat pump. A number of norms should be satisfied, including with regard to noise level, electrical and fire security. Satisfying these norms often demands significant investment and therefore, increases the costs of renewable heat project. In this view, the current legislation creates more barriers for implementing renewable heat solutions in existing multifamily houses than gives support (for example, federal subsidies). The legal framework is not previewed to give more incentives in the future. Therefore, development of energy contracting by ESCOs and the energy programs such as éco21 can be seen as the major potential instrument for renewable heat promotion in existing multifamily houses building stock.

5. Conclusion

In this study we have analysed three pilot projects of air to water heat pump integration into existing multifamily houses in Geneva, Switzerland. According to our results, this type of renewable solution is technically and economically feasible in the case of energy contracting, although it demands high quality engineering expertise and cost optimisation efforts.

Our study represents a contribution to the current body of knowledge as this type of renewable energy contracting is not widely practiced and few information is available in order to support its development. We provide description of technical aspects to account for, including energy concept development; noise, static and building physics assessment; planning and implementation of heating, electricity and sanitary works; and administrative procedures. We give a step by step schema of project development for engineers. In addition, we demonstrate innovative technical solution of upscaling heat pumps capacity to meet multifamily housing heat demand needs. The three pilot projects are implemented in different building types with regard to the period of construction. The total costs of the projects increase for older buildings, as heat pumps integration demands additional works to modernise the buildings according to the current norms (e.g., fire security). In this view, initial investment costs of heat pumps solutions in existing multifamily houses is from three to five times higher compared to fossil fuel-based solutions. For comparison, in the case of existing single-family houses this cost difference is in the order of two times. Despite of significantly higher initial investment costs of renewable solutions, annual energy costs for consumers in the case of contracting are at competitive level: less than 10% difference with fossil fuel-based solutions. This is achieved through cost optimisation, accounting for different parameters of initial investment, energy and maintenance costs. In this view, air to water heat pump contracting can be seen as a viable solution to achieve significant reduction of CO2 emissions in existing multifamily houses.

It should be taken into account the pilot projects are at the beginning stage of implementation, and the results of the study are therefore based on estimated values. Real measurements of heat pump performance, as well as more precise cost data will be available in the upcoming years. This would allow to adjust the financing model and launch a real contracting offer. The results of this study, even being partially theoretical for now, can be used by other ESCOS and energy program administrators to develop renewable heat contracting for existing multifamily houses in different locations.

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