Air to water heat pumps for heating system retrofit in urban areas: understanding the multi-faceted challenge

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Abstract. Air has an important role to play as a renewable resource to supply heat in urban areas. The implementation of heat pumps in multifamily buildings represents an important and underexploited development potential. Financial comparison of heating costs depending on building size and heat production technology shows how retrofit projects with air-to-water heat pumps compare to gas. Feedback from experience based on pilot projects presents the various challenges faced and proposes solutions.

Keywords: heat pumps, retrofit, multifamily buildings, energy contracting, air-to-water

1. Introduction
The energy transition to renewable resources is currently a priority in many countries. After focusing on producing green electricity, efforts now concentrate on supplying sustainable heat which plays a key role to achieve CO₂ emissions reduction targets.

Feasibility studies revealed the difficulties for owners to increase the share of renewables in an urban context: solar is not technically feasible (complicated old roof, building under historical heritage protection, no space available for water storage), geothermic, wood and biomass installations are not authorized by law due to water and air protection regulations. Air to water heat pumps (HP) are therefore often the only achievable solution to supply renewable energy to the buildings for heating purposes when district heating does not cover the area. The ambient air hence has an important role to play as a renewable resource for sustainable heat production in urban areas.

1.1. Current state in the canton of Geneva, Switzerland
The thermal energy produced for heating and domestic hot water production in Switzerland is responsible for about 30% of the country’s CO₂ emissions [1]. The built housing stock in the canton of Geneva accounts for about 44’000 residential buildings, 58% of which are single-family houses. However, the share of these villas reaches less than 30% of the installed power in the canton (2,24GW in total) [2] [3]. An important potential for improvement lies in retrofitting the heat production units of larger multifamily buildings (MFB) which add up to 1.58 GW. The total heating capacity of residential buildings amounts to about 64% of all constructions in Geneva. The energy resources used today across
the canton of Geneva for heating purpose in buildings are split up as follows: 51% gas, 32% heating oil, 12% district heating and 5% of others.

2. Financial comparison according to technology and building size

2.1. Methodology

In order to compare the heating costs of renovation projects, the two following axes are proposed in a recent thesis work [4]: how do air-to-water (A/W), water-to-water (W/W) and ground source (B/W) heat pumps compare to gas boilers and how does the building size impact the costs. Three categories were defined for the latter question: single-family, average-size multifamily and big multifamily houses. Hypothesis for each category are shown in Table 1 below. The scope of application of this study does not extend to newly built houses where the heat distribution temperature is lower and domestic hot water (DHW) to heating needs ratio much higher.

The heating costs computation takes into account the technology efficiency, initial investment (including annuity), maintenance, energy cost (without CO$_2$ tax) and CO$_2$ tax taken separately [4].

### Table 1: Hypothesis for financial computation as per building type. SRE: heated floor area, IDC: specific yearly energy demand [4]

| Building type | Heat + DHW [kWh/yr] | SRE [m2] | IDC [MJ/m2/yr] | Thermal power [kW] | Gas price [CHF/kWh] | Electricity price [CHF/kWh] | Interest rate [%] |
|---------------|----------------------|----------|----------------|-------------------|---------------------|---------------------------|-----------------|
| Single family | 26'400               | 198      | 480            | 23                | 0.090               | 0.212                     | 4.5             |
| Average MFB   | 225'000              | 1'700    | 476            | 113               | 0.080               | 0.205                     | 4.5             |
| Big MFB       | 500'000              | 3'750    | 480            | 250               | 0.075               | 0.160                     | 4.5             |

2.2. Heating costs comparison results

The computation results are shown in the graphical displays below. Their match with field return values is satisfactory [5]. Figure 1 gives insight on how air-to-water heat pump is indeed the most cost-effective solution in a single-family building renovation project by about 6.3% (0.16 CHF/kWh) as compared to a gas boiler (0.17 CHF/kWh) and a ground source heat pump (0.17 CHF/kWh). In relation to gas, the higher initial investment is compensated by lower maintenance and energy costs over the operating life.

![Figure 1](https://example.com/figure1.png)

**Figure 1:** Heating costs in a single-family building for gas boiler (left), air-to-water HP (middle) and ground source HP (right). The bar graph refers to the investments and the orange line to the heating costs in CHF/kWh [4]

The results for average and big multifamily buildings (both shown in Figure 2) follow comparable trends with similar heating costs despite the large difference between their investment amounts. Heat pump solutions are globally more expensive, in particular because there is currently no standardized solution proposed by suppliers for residential buildings. The similarity between middle-size and large
size houses results is explained by the same challenges and project complexity faced when upscaling heat pumps for larger multifamily buildings. These aspects are discussed in chapter 3. Figure 3 gives insight on how one technology performs in terms of costs depending on the building size. The left graph shows that medium-size buildings are the least favorable for air-to-water heat pump projects (0.17 CHF/kWh) with higher heating costs compared to smaller (0.16 CHF/kWh) or larger buildings (0.15CHF/kWh). As expected, gas boilers shown on the right keep getting cheaper as they grow in size.

Figure 2: Heating costs for average multifamily (left) and big multifamily buildings (right) according to technology: gas boiler, air-to-water HP, water-to-water HP and ground source HP. The bar graph refers to the investments and the orange line to the heating costs in CHF/kWh [4]

Figure 3: Heating costs for air-to-water heat pumps (left) and gas (right) for single family, average multifamily and big multifamily house. The bar graph refers to the investments and the orange line to the heating costs in CHF/kWh [4]

One can hence draw recommendations as to what technical solution would be cheaper depending on the type of building. As for villas, standardized A/W heat pump solutions available on the market are now competitive compared to gas. For average and big multifamily buildings, W/W and B/W heat pumps are still much more expensive than gas installations. Air-to-water heat pump projects in larger buildings (Figure 3, left) imply tailor made solutions including aspects like acoustic, static, electrical connection, hydraulic schemes that cause extra costs. These complications raise the cost of the initial investment in addition of the heat pump itself which is about three times more expensive than the gas boiler. Initial investments for an A/W heat pump installation are 3 to 6 times higher in MFB compared to a gas heating system: electrical reinforcement can raise the total cost of 30%, acoustic insulation can raise the total cost of 20% and static and hydraulic schemes can raise the total cost of an additional 20%. In the case of big multi-family buildings however the cheaper electricity market price compensates for these aspects showing heating costs (0.15CHF/kWh) even cheaper than for single-family houses despite the larger investment. This is not true for medium size residential buildings which make up a significant part of the built housing stock where heating systems will have to be replaced. This category could be targeted for subsidies in order to help more renewable projects to emerge in urban areas.
3. Feedback and dissemination

3.1. Feedback from experience on multifamily houses projects

A heat pump retrofit in the context of a large residential building consists of a multi-faceted project. The following sub-chapters highlight some of the aspects faced, suggest solutions and present current pilot projects taking place in Geneva.

3.1.1. Technical and economic challenges. These barriers concern medium to large size multifamily buildings in which heat pumps are intended for a retrofit as standardized solutions are already available for single-family houses (products, standard hydraulic schemes). There is currently a lack of silent (< 60dB (A) acoustic power) and large heat pumps (50-100kW/module) on the market [6]. The engineer is hence faced with two choices in order to provide a large heating capacity with available heat pumps: either scaling-up small installations and cascading several HP modules or turning to larger industrial products which aren’t designed for residential use (noise, vibrations). Hydraulic schemes have to be specifically developed with the manufacturer as to reliably integrate the heat pumps with the constraint of existing heat and DHW distribution systems. For rooftop implementation or small existing technical rooms, the dimensions and weight of large machines are also critical. Static, acoustic and vibratory aspects must be addressed. The complexity of such projects imply a good management of ancillary works that are not to be underestimated. This also reflects in the initial investments which are about 3 to 6 times higher than this of fossil-based heating systems. The high distribution temperature in existing buildings can be supplied by heat pumps, although impacting the efficiency of the machine just like the local climate does. A production complement with gas (keeping an existing installation for example) can be a pragmatic solution to guarantee that all heating needs are satisfied during the year without oversizing, although large monovalent heat pump installations are being realized today [5]. Besides, the building’s electrical connection could have to be reinforced due to HPs massive absorbed power.

3.1.2. Swiss tenancy law. Unlike the single housing sector, large buildings are mainly inhabited by tenants [1]. The latter pay their energy bills but no investment towards a renewable heating system such as a heat pump can be transmitted to them. Tenants would on the other hand benefit from cheaper energy charges resulting from such a replacement. Owner therefore have no incentive to opt for renewables. An energy contracting system (ESCO) has been implemented in Geneva by the local public utility Services Industriels de Genève (SIG), under its energy program portfolio éco21 to help carry out such projects [7]. This solution is aimed at air-to-water heat pumps in particular for they represent the most suitable solution in urban area.

3.1.3. Legal procedures. There is no administrative procedure to replace an existing system (oil or gas) with a similar system, this is quite straightforward. The retrofit with any kind of heat pump implies to go through an application process with an official request. This demand circulates in all concerned offices of the administration: energy, environment, security and safety of the population, protection of monuments and historical sites… Every office gives an advice. If one of them decides negatively, the demand is rejected. In Geneva city, there are 14 different forms to be filled up. The administrative procedures needed for heat pump retrofits are hence unsuitable in relation to the will to turn to sustainable heat production. Blocking of projects led by undertaking owners is detrimental to a much needed broader development in this direction.

3.1.4. Performance gap with heat pump supplier data. The question arises as to what extent the given performance value (COP) provided by a heat pump supplier is truly representative of the machine behaviour that can later be measured during operation. A recent master thesis based on the in situ analysis of 12 villas in Geneva [8] assessed this performance gap. Heat pumps installed in three non-renovated nor isolated single-family houses were monitored during several months in order to collect efficiency data over a range of outdoor temperatures representative of what can be faced anytime over
the year. The values were further projected over a typical heating year profile based on the measured efficiencies. The plotted results in Figure 4 show a satisfactory match with the COP announced by the supplier (red line). Blue dots show hourly measured values whereas black circles correspond to daily values. Measured COPA were found to be between 2.9 and 3.1 which is slightly lower than the announced supplier values. The performance gaps in annual efficiencies (COPA) for the three sites are of -6.7% (for 44'900kWh), -4% (for 37'200kWh) and -14% (for 27'100kWh). What appears from experience is that larger discrepancies with expected performance are more likely to originate from the realisation phase which needs to be carefully followed-up. Difficulties can appear through monitoring and a running-in period of several months should be allowed to fix and optimize the installation until results can be considered as final.

![Figure 4: Heat pump measured performance (scatterplot of points: hourly values in blue dots, daily values in black circles) compared to announced COP from supplier (red line) [8]](image)

3.2. Case studies currently under analysis

Three pilot projects aimed at replacing fossil-based heating systems by air to water heat pumps in multifamily buildings in Geneva are realized by SIG under its energy program portfolio éco21 [5]. The projects are implemented with an owner of 600 buildings in Geneva, who has a legal obligation to reduce energy consumption and/or increase the share of renewables in its building stock. Feasibility studies revealed that air to water heat pumps is the only solution to supply renewable energy to the buildings. Three different types of multifamily buildings were chosen for the pilot projects which represent the most common construction types in Geneva (without specific thermal insulation). The challenge is significant: buildings and their distribution systems are old, there is little space available and investment costs are high which requires a highly efficient energy production.

Two of the projects (53 and 68 apartment buildings) have been completed and are currently under monitoring hence showing that this type of renewable solution is technically and economically feasible with high quality engineering, cost optimisation efforts and energy contracting which helped to lift the legal and financial barriers.

The main technical challenges are the rooftop integration of the installations (difficult access, static calculations for deformation, transmission of solid vibrations, adjustment of rooftop infrastructure to withstand compression forces, fire related legal compliance); supplying the entire heat demand (heat pumps only or bivalent system); development of specific hydraulic schemes (reliable and efficient
systems, optimisation of existing gas boiler switching point); available machines (cascading standard heat pumps, soundproofing industrial installations). It is interesting to note that an “optimization” made by an installer in one case led to poorer performances. The reason for it being that he looked for reliability but not efficiency. Both of these aspects should of course be taken into account together.

Monitoring results for these sites aren’t available yet. The buildings are currently in a running-in phase where adjustments still need to be made to reach the expected performances.

3.3. Dissemination
Retrofitting heat production systems with heat pumps in large buildings are necessarily cross-disciplinary projects. Feedback from experience has been gathered in a practical guide aimed at disseminating good practice and supporting future projects. The document called “Vademecum for roofed air-to-water heat pumps” was conceived and written together by SIG and CSD Engineers SA following the two pilot projects carried out together and was supported by the Swiss confederation [9].

4. Discussion and recommendations
There is a large and underexploited potential for air-to-water heat pumps in urban areas. Such projects can efficiently help meet environmental targets by reducing CO₂ emissions from fossil-based boilers. Study results show that heating costs for single-family houses are more attractive today for air-to-water heat pumps despite higher initial investments than for gas boilers. Average-size multifamily buildings financially represent the most unfavorable case for the integration of heat pumps. Energy contracting has proven to be an efficient tool to enable the realization of projects in multifamily buildings.

Retrofitting larger buildings with heat pumps are complex projects requiring experts in the fields of heating engineering, electricity, acoustics and statics. The lack of adapted products on the market is one of the main challenges faced. The legal framework regarding heat pumps involves authorizations and additional procedures as well as satisfying a number of norms (unlike retrofitting a boiler by the same type of boiler) which further increases the costs and does not support a broader development of such innovative projects.

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