Performance gap analysis of a new Minergie A/P district

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Abstract. The eco-district “Les Vergers”, located in Meyrin (Geneva, Switzerland), hosts around 1,350 dwellings and some activities. It is heated by a 5 MW<sub>th</sub> geothermal centralized heat pump. This study proposes a detailed analysis of the thermal demand of 23 selected buildings in this district as a representative panel of buildings meeting high Swiss energy performance standards (Minergie A/P) and equipped with different heat recovery systems. Although the buildings have better thermal performance than the average buildings of Geneva, most show an important performance gap between the actual space heating demand and the design values. A strong correlation between performance gap and cut-off temperature of the heating system suggests that the regulation of the heat distribution system plays a determinant role in the overall performance. Regarding the domestic hot water preparation, the buildings of this district present an average demand 23% lower than the standard value and 31% lower than a benchmark.

1. Introduction

During the year 2019, more than 90% of the domestic heat production for Geneva’s housing stock (Switzerland) relied on fossil fuel agents [1]. The cantonal energy master plan released in December 2020 [2] has the ambitious target to reduce, by 2030, the CO<sub>2</sub> emissions by 60% compared to their 1990 level. To reach this goal, the main pillars of the strategy consist in retrofitting existing buildings, reinforcing minimal efficiency requirements of new buildings and increasing the share of renewable energy through the expansion of existing district heating (DH) networks. Currently, approximately 10% (545 GWh/year) of the total heating demand is covered by DH networks [2]. The 2030 target set by the cantonal energy master plan is to reach 1,150 GWh/year, 80% of which from renewable sources or waste heat, thereby representing 20% of the current heating demand of the canton.

The eco-district “Les Vergers” is an exemplary project in line with this strategy. It is a new district hosting around 1,350 dwellings and various activities, heated by a 5 MW<sub>th</sub> geothermal centralized heat pump. A low temperature district heating (LTDH) network distributes heat to the 33 connected buildings, which meet high Swiss energy performance standards (Minergie A or P [3]). They are equipped with different types of heat recovery systems on exhaust air (see below).

This study proposes a detailed analysis of the thermal demand of 23 buildings (i.e. those in operation during the first two years of monitoring of the LTDH network). The actual demand for space heating (SH) is compared with the theoretical demand calculated for the building permit. Comparing these values allows to quantify the performance gap of Minergie certified buildings. In addition, the heating demand for domestic hot water (DHW) preparation is compared to standard values, as well as to an existing benchmark consisting of 61 DH substations located in Geneva (Switzerland), totaling close to a million m<sup>2</sup> of conditioned floor area [4].
2. Methodology
Each building is connected to the district heating network by its own heating substation (SST). Each SST is composed of two heat exchangers, one for space heating distribution and one for DHW preparation, as well as two regulation valves (Figure 1). The SST provides heat for SH and DHW alternatively. At fixed time, twice a day, the temperature of the district heating network is raised from 50°C to 65°C and the DHW buffers are heated up over a 90-minute period.

For the sake of this study, buildings are grouped into three categories, depending on the type of heat recovery on exhaust air: (i) ERV: energy recovery ventilation; (ii) HP DHW+SH: exhaust air heat pump for preheating of domestic hot water and space heating; (iii) HP DHW: exhaust air heat pump for preheating of domestic hot water.

![Hydraulic diagram of a typical substation equipped with heat recovery by an exhaust air heat pump for DHW preparation (heat recovery type “HP DHW”).](image)

Figure 1. Hydraulic diagram of a typical substation equipped with heat recovery by an exhaust air heat pump for DHW preparation (heat recovery type “HP DHW”).

2.1. Energy balance
Two years of 10-minute time resolution data is collected for the primary side of the substations connecting the 23 selected buildings to the district heating network. It includes temperatures, regulation valves status, primary flow rate and total energy delivered (“DH” on Figure 1).

In addition, various energy meters are read monthly to complete and to check the validity of the automatically retrieved data. For instance, some buildings are equipped with an energy meter measuring the heat produced by the exhaust air heat pump (e.g. “HP for DHW” on Figure 1).

For 15 buildings, this also includes secondary energy meters allowing to split the total heat supplied by the DH network between energy used for DHW and energy for SH (“DH for DHW” and “DH for SH” on Figure 1). For the remaining 8 buildings, for which this information is not available, the fraction of each energy use is estimated based on the opening percentage of hydraulic regulation valves of the substation (“SH valve” and “DHW valve” on Figure 1). When detailed data are occasionally missing, this operation is not possible and the corresponding energy is thus affected to the space heating.

Finally, the total heating demand of each building is split into: (i) heat delivered by the DH for DHW, (ii) heat delivered by the DH for space heating; (iii) heat produced by the exhaust air heat pump for DHW and, in some cases, for SH (does not apply to the heat recovery type ERV).

2.2. Performance gap in space heating
For a subset of 15 of the 23 buildings, we were able to access the theoretical demand calculated for the building permit or the swiss Minergie certification. The theoretical demand is compared with the total space heating demand, defined as the sum of the energy supplied by the DH for SH and ¼ of the heat...
produced by the exhaust air HP (for heat recovery type HP DHW+SH). To estimate the share of the heat pump production assigned to space heating, it is assumed that during half of the year, half of the heat is used for space heating. Finally, this allows to evaluate the performance gap as the ratio of the measured demand to the theoretical demand. Note that the total space heating demand is normalized to the heating degree days (HDD) of swiss SIA 2028 standard, in base 18/12 [5].

In order to identify possible reasons for the performance gap, the energy signature is generated for each building, based on daily averages of heat delivered by the DH as a function of the outside air temperature. It provides an estimate of the heating cut-off temperature set by each regulation system.

2.3. Heating demand for domestic hot water preparation

In such energy efficient buildings, the DHW consumption can represent up to half the total heat demand. Due to the high temperature levels required compared to the space heating, it becomes a consumption worthwhile to monitor as well, especially when the heat generator is a heat pump.

The total DHW demand of the buildings is the sum of: (i) the heat delivered by the DH for DHW; (ii) when applicable, all the heat produced by the exhaust air heat pump (for heat recovery type HP DHW) or ¼ of it (for heat recovery type HP DHW+SH), i.e. the remaining heat production not assigned to space heating.

It is first compared to the standard value of 32 kWh/m².year, which corresponds to the swiss SIA 380/1 [6] standard value of 20.8 kWh/m² (useful energy) with 35% storage and distribution losses, as suggested by [7]. In addition, the DHW demand is also compared to a benchmark of 61 SST providing heat to multi-dwelling buildings in Geneva [4], totaling close to a million m² of conditioned floor area. The buildings of this benchmark were mainly built between 1946 and 1980, which represented almost half of Geneva’s multi-family dwellings area in 2010 [8]. Even though the buildings of “Les Vergers” district are more recent (built after 2013), this benchmark serves as a representative sample of Geneva’s multi-family building stock, assuming the age of the buildings has a limited impact on the DHW demand.

Because the DHW usage depends not only on the size of the building but also on the number of inhabitants, the results are calculated in kWh/m².year and kWh/person.year.

For this analysis, only buildings for which the total DHW demand is known are considered, i.e. the DHW production from the DH and from the exhaust air heat pump.

3. Results and discussion

3.1. Overall performance

Following the methodology described above, a complete energy balance of each building was performed over two consecutive years: (i) year 1: 1 October 2018 to 31 September 2019; (ii) year 2: 1 October 2019 to 31 September 2020. Figure 2 shows the total heating demand of each building during year 1, broken down per usage and heat source. The buildings are grouped according to their heat recovery system.

The results show a significant discrepancy in consumption among the studied buildings. In fact, the total annual heat consumption for SH and DHW ranges from 32 to 110 kWh/m² within the district, with an average of 61 kWh/m². The latter is significantly below the average heating demand of Geneva’s multi-family dwellings, equal to 132 kWh/m² per year [9]. It is even lower than the average of buildings constructed after 2010 (75 kWh/m²).

While buildings with heat recovery type ERV and HP DHW+SH show in general a better overall performance, several of them benefit from closer monitoring of the energy demand. This concerns also building X27, which presents the best performance for heat recovery type HP DHW. Classifying the performance of the three heat recovery systems can hence not be done on the basis of this sole figure, and would require further investigation. Also, the relevance of combining decentralized heat pumps with a DH network already supplied by a heat pump could be discussed. It would however need more in-depth analysis taking into account the energy, comfort, economic and legal constraints.
Figure 2. Total heating demand of the buildings per usage (SH and/or DHW) and source (DH or exhaust air HP) for year 1. "*" = buildings for which the separation of the heat supplied by the DH network per usage (SH/DHW) was estimated.

3.2. Space heating demand

The total demand for space heating of two consecutive years is presented in Figure 3. The horizontal line (available for 15 buildings out of 23) corresponds to the theoretical demand of building permit, as calculated in normalized conditions of use (namely indoor temperature of 20°C, closed windows, etc.).

Figure 3. Theoretical and measured space heating demand (normalized) for two consecutive years.

Despite this excellent overall efficiency compared to the Geneva’s multi-family building stock, there is a performance gap between predicted and actual SH consumption for most buildings. Some buildings, such as X6, use up to three times the predicted energy for SH.

Most buildings have a stable demand over the two years, although there is a significant decrease for 3 of them (X28, X17, X21) and an important increase for 5 of them (X11, X10, X14, X23, X7).

Some evidence suggests that the performance gap is related to the regulation of the heat distribution system [10]. In particular, Figure 4 reveals a strong correlation with the cut-off temperature: the higher the temperature, the higher the performance gap. The cut-off temperature ranges from approximately 12°C to 19°C. Since all buildings meet the same energy standard and have similar thermal envelope quality, there is no obvious reason to such variations. This means that some buildings, such as X6, are
over-heated. Thus, a non-optimal regulation of the heating system could explain a significant part of the performance gap. A more detailed analysis is needed to confirm this hypothesis.

![Figure 4. Performance gap of each building as a function of the heating cut-off temperature.](image)

3.3. Domestic hot water demand

The DHW demand analysis (Figure 5) reveals that the average demand of the district (24.6 kWh/m².year) is 23% lower than the Swiss standard value of 32 kWh/m².year. It is also significantly lower than the benchmark average, both in terms of kWh/m².year and kWh/person.year, resulting in a reduction of 31% and 19%, respectively. The results are very similar for the first year of this study.

As with the total heating demand, the DHW demand of the district shows a great discrepancy. It ranges from values twice lower than the standard (16 kWh/m².year), up to 53% higher (49 kWh/m².year). However, only 2 buildings out of the 14 selected buildings exceed the standard value of 32 kWh/m².year, whereas almost two thirds of the substations of the existing benchmark do.

![Figure 5. DHW demand comparison between standard value [6][7], benchmark [4] and 14 buildings of the eco-district “Les Vergers” for the second year of this study.](image)

There are several possible explanations to this low energy consumption for DHW preparation. First, these buildings are recent high efficiency buildings. Thus, their heat distribution system is likely to be more efficient than those of the existing benchmark, with an increased insulation of storage tank and supply pipes. Further analysis performed on two buildings of the district revealed storage and distribution losses close to 25% of the total DHW demand, which is lower than usually observed (30-35%). Second, as all buildings meet high energy performance standards, the apartments may be
equipped with low-flow fixtures, thereby reducing the DHW consumption compared to older buildings. Finally, awareness-raising campaigns have been carried out in some buildings, a measure that can also have a positive impact on the DHW consumption.

4. Conclusions
This paper presents an analysis of the thermal demand of 23 Minergie A/P certified buildings (swiss high energy performance standard) located in an eco-district in the canton of Geneva, Switzerland. The consolidation between gathered and calculated energy meter data shows: (i) a high discrepancy in energy consumption between the buildings; (ii) most buildings have a significant performance gap for space heating; (iii) nevertheless the overall performance is good compared to the average of Geneva’s multi-family building stock. The performance gap is strongly related to the cut-off temperature of the heating system, suggesting that it could be reduced by optimizing the heat distribution system.

The heat demand for domestic hot water preparation is lower than normative values and benchmark values. This may be the result of high efficiency storage and distribution systems (losses of about 25%), low flow fixtures and occupants awareness.

Three of the few buildings with the smallest heating demand and performance gap correspond to those with close energy consumption monitoring and high occupants’ awareness. This demonstrates once again the importance of close monitoring and awareness campaigns. Further analysis will consist in a detailed study of two buildings with the same owner and heating system configuration, but very different energy demand. This will include a survey of the inhabitants regarding thermal comfort.

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