Actual energy performance of student housing: case study, benchmarking and performance gap analysis

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Abstract

While recent studies have shown an important gap between design and real energy use of multifamily buildings, this study analyses the energy performance gap for student housing. A very high energy performance (VHEP) student residency was analysed in detail, followed by a comparison of energy and water consumption with student residencies and other dwellings in Geneva. The analysis shows that for this VHEP residency the limit values according to the actual thermal regulations and MINERGIE label are exceeded: actual heat demand is 98 MJ/m2.a for heating (without double-flow ventilation) and 116 MJ/m2.a for hot water while the MINERGIE-index is 137 MJ/m2 (38 kWh/m2.a). Nevertheless, its thermal energy consumption (IDC=224 MJ/m2.a) is similar to other VHEP buildings, and half of Geneva’s average values. The study points to factors which highly influence real performance of VHEP buildings and concludes that there is a huge optimisation potential during use phase of a building.

Reference


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Abstract

While recent studies have shown an important gap between design and real energy use of multifamily buildings, this study analyses the energy performance gap for student housing. A very high energy performance (VHEP) student residency was analysed in detail, followed by a comparison of energy and water consumption with student residencies and other dwellings in Geneva. The analysis shows that for this VHEP residency the limit values according to the actual thermal regulations and MINERGIE label are exceeded: actual heat demand is 98 MJ/m².a for heating (without double-flow ventilation) and 116 MJ/m².a for hot water while the MINERGIE-index is 137 MJ/m² (38 kWh/m².a). Nevertheless, its thermal energy consumption (IDC=224 MJ/m².a) is similar to other VHEP buildings, and half of Geneva’s average values. The study points to factors which highly influence real performance of VHEP buildings and concludes that there is a huge optimisation potential during use phase of a building.

Keywords: energy performance gap, student housing, heat demand, electricity consumption, water use, residential sector, actual performance

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1. Introduction

The stepwise tightening of building energy requirements and labelling is leading to the design of buildings with high energy performance. However, previous research has shown that the actual energy use of buildings exceeds in many cases the estimated value in the design phase (also known as energy performance gap [1]). While some recent studies have dealt with performance gap in retrofitted multi-family buildings, this study focuses on student housing. Despite the specific users and the different operating procedures, this subsector is not a separate category in SIA recommendations (SIA: Swiss society of engineers and architects). There is surprisingly little information available about the actual energy performance of such student residencies. Among the literature about this topic, studies about German student residencies by Engelmann [2] have shown that the thermal energy consumption of VHEP student residencies is about half of the average residencies. Planned space heating demand was exceeded by 30% to 145%, but there was also one example where the actual heat demand was 30% lower than expected. In this latter case, low heat demand was due to low ventilation rates, resulting in inferior air quality. In VHEP buildings, hot water contributes 50% to 60% of the thermal energy consumption. Engelmann and Voss [3,4] also showed that the per capita water consumption does not differ between student homes and the German average (122 l/cap.d). Due to high density, hot water energy consumption per surface was higher in student residencies than in multifamily buildings. They noted seasonal and daily variations (holidays and week-ends). While German studies found the lowest consumption in new homes with water saving appliances, Alborz & Berardi [5] showed for some LEED certified US residence halls that technology alone does not reduce consumption; despite water saving appliances, water consumption was not lower than in traditional residences, but 60% higher than planned. For electricity consumption, Engelmann found a lower per capita electricity consumption than the German average, and among residencies, a higher value in small apartments (studios) [3].

Against this background, the current study analyses actual performance of a very high energy performance (VHEP) student residency as well as energy and water consumption of a set of 35 residencies in Geneva.

This study aims to evaluate for the case of Geneva if student housing reaches its MINERGIE-P objectives (Swiss label for VHEP buildings) and corresponds to the SIA limits and standard values, and if not, which parameters explain the energy performance gap. Furthermore, this study analyses whether there is a difference in energy consumption between student residencies and Geneva’s multifamily buildings, in order to derive recommendations for the design, construction and use phase of student accommodation.

2. Methodology

First, we performed a detailed analysis of a very high energy performance student house. This case study is applied to a building called “Pavillons” owned by the Cigué (a self-managed housing cooperative for people in training). This building offers housing to 40 students who live in 8 apartments. “Pavillons” was built in 2009 in accordance with the MINERGIE-P-ECO standard. A wood-pellet furnace and a solar thermal installation provide heat for domestic hot water (DHW) and space heating (SH). A “double flow” ventilation system recovers heat from the extracted air in order to preheat fresh air before blowing it into the building.

The aim of the detailed analysis is to assess its actual energy consumption, i.e. to check whether the VHEP-objective is reached and to identify the main causes behind the energy performance gap.

The analysis is based on meter readings over a two-year period (July 2010 to June 2012) and information derived from energy bills, as electricity consumption and pellet deliveries. In-situ measurements were made to complete data and identify causes of heat losses: thermal images, heat flow measurements, data collections concerning the electric power of appliances and the recordings of the solar control system.

Secondly, the obtained results were compared to a set of 35 student residencies located in the canton of Geneva (both new and existing buildings).

In terms of thermal consumption for space heating and hot water, a cantonal index (indice de dépense de chaleur, IDC) is available as open-source data. Electricity and water consumption, obtained through agreement of the different residencies, were aggregated to the building level and a three years mean was established.
This benchmarking analysis aims to better understand the specific characteristics of the student housing subsector and to compare energy consumption between VHEP and traditional student residencies and the multi-family residential sector.

3. Results

Actual energy performance of “Pavillons” is described in the following sections and compared to the average consumption of other student residencies, as well as mean values of Geneva’s multifamily buildings.

![Sankey diagram of the VHEP residency « Pavillons », average 2010-11/2011-12, unit MJ/m².an, correction HDD16/20.](image)

3.1. Design and actual heat energy performance

As illustrated by the Sankey diagram, actual heat demand of the VHEP student house is divided into two nearly equal portions: 46% for space heating and 54% for domestic hot water. The annual domestic hot water demand is 116 MJ/m².a. As the solar thermal installation produces 61 MJ/m².a of heat, it covers nearly 50% of the annual hot water demand. The remaining heat (65 MJ/m².a) is provided by pellet combustion.

In total, the wood-pellet furnace produces 191 MJ/m².a of heat. Our analysis shows that it delivers 98 MJ/m².a to space heating. The heat recovery ventilation system has an efficiency of 70%. It recovers during the heating period 57 MJ/m².a of heat from the extracted air and reduces space heating demand by about 40%.

Design and limit values for SH and DHW calculated in accordance with SIA standards are exceeded. This is also the case for the MINERGIE index (planned: 19 kWh/m².a, limit: 30 kWh/m².a, measured 38 kW h/m².a).

Nevertheless, the thermal energy consumption of the building is similar to two other VHEP residencies (mean IDC 232 MJ/m².a) as well as VHEP multifamily buildings in Geneva. The VHEP buildings’ thermal consumption amounts to approximately half of the average value of the 35 studied student residencies (502 MJ/m².a) and of multifamily buildings average (483 MJ/m².a [6]).

3.2. Explanation of the gap

To explain the gap between the SIA limit value for space heating (54 MJ/m².a) and the real consumption of the building “Pavillons”, on-site measurements were made.
Thermal images and heat flow measurements through building envelope by the aid of sensors (Hukseflux HFP01) showed that the energy performance of envelope is as good as expected, with an exception for the roof which has a larger \textit{U-value} than planned (measured 0.12 W/m$^2$K, planned 0.09 W/m$^2$K).

Overall electricity consumption of the building “Pavillons” is 71 MJ/m$^2$.a and hence lower than the SIA standard value (100 MJ/m$^2$.a). On the other hand, the number of inhabitants per unit of heated space exceeds the SIA standard value. Therefore internal electric heat gains are lower, but internal human heat gains are higher.

Temperature measurements in several rooms showed an average temperature of 21°C, which is 1 K higher than assumed in the SIA standard. As shown by [7–9], space heating demand of VHEP building rises by more than 11% with a temperature rise by 1 K.

To estimate heat losses by aeration, window openings were observed during several days in winter (72 observations). On average, 20% of the windows of kitchens and living rooms were open. Especially kitchen windows stayed in tilt position over several hours in winter. This could be due to inattention, no perception of responsibility, or lack of ventilation of the kitchen (no exhaust hoods).

We observed that on average 40% of the windows of bedrooms were obscured by closed shades, which restricts heat gains by sunlight.

Simulation of the heat demand helped to quantify the influence of the different parameters. For this purpose, the values of the identified parameters were adapted in several steps from the theoretical assumptions to the observed real-use of the building: Simulation was started using the planned value of 28 MJ/m$^2$.an, which includes heat recuperation by the double flow ventilation. Correction of internal heat gains, \textit{U}-value of the roof and use of new weather norm slightly influenced heat demand. Reduced solar heat gains by shading due to other buildings and closed shades increased the heat demand of “Pavillons” by about 6 MJ/m$^2$.a. Raised internal temperature (+ 1 K) added a supplementary 9 MJ/m$^2$.a. After these corrections, the gap still was 61 MJ/m$^2$.a. This amount can be related to ventilation losses and to non-identified factors. When applying a ventilation rate of 1 m$^3$/m$^2$.h instead of 0.3 m$^3$/m$^2$.h for double flow ventilation, the simulation results correspond to real heat demand. As shown on Fig. 2, simulation indicates that the largest part of heat demand gap of this building is due to air exchange losses, which includes ventilation and window openings.

The main factors behind the SH demand gap appear to be the high ventilation losses through mechanical ventilation and additional window openings, the increased internal temperature, and the obstruction of solar gains.

![Fig. 2. Planned heat demand, simulation (addition of parameters in several steps), and actual value](image-url)
3.3. Electricity consumption

Several of the studied student residencies are organised as shared apartments. For these, there are separate electricity meters, which allow to study household electricity consumption. The average household electricity use per capita for the building “Pavillons” is close to the sample average of 580 kWh/cap.a. This is half of Geneva’s multifamily buildings (1081 kWh/cap.a [10]), but similar to some cooperative’s buildings [11,12]. Only few student residencies have a per capita household electricity consumption at the level of average multifamily buildings. Apartment sharing seems beneficial for low electricity consumption, as common spaces and appliances are shared between more people, and big appliances are often shared between several apartments. Furthermore, in some cases electricity is billed separately from the room rents, resulting in higher awareness.

3.4. Water consumption and solar production

Heat demand for hot water of Pavillons (116 MJ/m².a) exceeds SIA standard value (75 MJ/m².a). This cannot be explained by the user group. Occupancy rate is slightly higher in student residencies than in multifamily buildings. Density is not the reason for the DHW demand gap, but it shows the importance of considering the type of use of the building, the number of users and hot water use per capita rather than a standard value by heated surface.

Total water consumption (hot and cold water) in “Pavillons” is 123 l/cap.d, which is slightly lower than in other residencies (mean value 138 l/cap.d) and in line with the national average (142 l/cap.d [13]). Comparison between different residencies showed that water saving devices in new and renovated buildings seem to help reducing water consumption, while especially older buildings and such containing activities such as restaurants have high water consumption.

Analysis of the water consumption of “Pavillons” showed that it is about 30% lower during July - August and December. This decrease can be explained by a lower occupancy rate due to university holidays. About half of the water (63 l/cap.d) is used as hot water. It is approximately 60% higher in winter than in summer. Therefore, daily heat demand for DHW varies between 360 MJ/d in summer and 580 MJ/d in winter.

DHW is preheated by the solar thermal installation representing an area of approximately 1 m²/cap. Its conversion yield is 45% and its annual productivity is 680 kWh/m².a, which are good values. Analysis of the annual curve of heat production and DHW consumption shows that the heat surplus produced by the solar panels is only small. DHW is entirely covered by the solar installation for two months per year, while in winter the wood-pellet furnace produces most of the heat, with only 15% to 25% of DHW being heated by the sun. Annual solar energy coverage of DHW supply is nearby 50%.

Using the data stored in the solar control system, long-term failures of the solar installation occurring during several years could be diagnosed. Even though the solar thermal installation was out of order for more than one year, neither the higher pellet consumption and annual IDC index nor the visits by the heating contractor revealed the problem until it was identified by this study. Failure of the solar installation shows the importance of regular and rigorous control.
It is essential that managers and enterprises are interested in building’s performance and that they follow consumption and check settings to optimise energy demand by adjustments of the system. Mandatory and more detailed performance checks could contribute to significant energy savings.

4. Conclusion

Results are generally in line with German student housing studies. For the case of Geneva, thermal energy and water consumption of the subsector is similar to the residential sector as a whole, but some differences concerning student housing could be noted. The co-usage of space and appliances can help to reduce the overall environmental impacts, as brought to light by notably smaller household electricity use per capita in the subsector. It is important to consider specific characteristics of student residencies as high density, varying occupation (due to university holidays) and high turnover is high.

The VHEP residencies were found to consume less than other residencies, but planned and limit values are exceeded, as in many cases of multifamily buildings. As real use does not correspond to standard conditions, it would be useful to calculate attainable targets and then compare real consumption to latter. Analysis shows that the most important factors are related to operation and use of the building. Technical solutions and accurate regulation of the installations can help to decrease energy consumption.

Monitoring plays an essential role for actual energy performance: failures can only be detected if the installations are checked regularly. Key indicators can help diagnose the energy consumption and production and help to optimise it. In order to get obtain results the technical solutions should be explained to the users. Information to managers and users of the building allows them to better use and control the building, while feedback to the planners and constructors helps to learn from the experience made.

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