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Case study of a low-energy (Minergie®) multifamily complex in Switzerland. First appraisal after two years of exploitation

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ABSTRACT: A large multifamily complex of about 21'000 square meters (three buildings) was recently raised in the suburb of Geneva (Switzerland) and was certified Minergie®, a Swiss quality label. From the preliminary draft to the buildings construction, a close attention has been given to the energy concept by an interdisciplinary group made up of architects and engineers. This outstanding realization is actually under monitoring by the Energy centre of the University of Geneva (CUEPE) for a four years period. This paper presents some aspects of the project of realizing a large-scale Minergie building. Annual gas consumption per unit of gross heated floor was measured as 228 MJ/m2 for the first year, more than the predicted value of 92 MJ/m2, and will probably lower to 191 MJ/m2 for the second year. Although higher than the designed value, the performance of these buildings remains excellent compared to the usual measured values for recent buildings (350-400 MJ/m2), especially considering their large scale and residential nature. The design, realization and exploitation stages are currently under investigation in order to better understand the difference between designed and measured value.

Keywords: energy, large-scale residential buildings, Minergie, monitoring

1. INTRODUCTION

A large multifamily complex – three buildings of about 21'000 square meters of gross heated area – was recently constructed in the suburb of Geneva (Switzerland) with quite an innovative approach concerning the energy concept. As a matter of fact, under the impulse of the promoter, an interdisciplinary group made up of architects and engineers was in charge, from the preliminary draft to the final project, of finding the best balance between energy efficiency, architectural design, housing quality and financing. Special considerations were given to the quality of the envelope and the reduction of the thermal bridges. The energy centre of the University of Geneva (CUEPE) contributed to the project by carrying thermal simulations on some constructive elements and by performing an insolation assessment. The outcome of this teamwork is an outstanding realization that has been certified Minergie®, a private Swiss label given to very low energy buildings whose specifications will be expressed later on this paper [1].

So far, few realizations of that size have been given such close attention to the energy concept. However, significant differences may occur between designed and measured performances, especially for large-scale residential buildings [2,3,4]. Then, in order to learn as much as possible from this experience and to improve the applicability of best solutions to large-scale applications, the Geneva's office of energy and the contractor, the Provident fund of the state of Geneva (hereafter referred to as "CIA"), have commissioned the CUEPE for a detailed analysis of the thermal performance of the buildings and a technical and economical evaluation of the different subsystems.

One of the aim of this paper is to encourage well monitored, impartial and critical case-studies in order to highlight the strong features and weaknesses of innovative strategies used in low energy building and, when necessary, to propose improvements.

This paper will first describe the project of realizing a Minergie® multifamily building. Then, an architectural and technical description of the complex will be given. Finally, an energy balance of the first heating season will be presented as well as an estimation of the second one.

2. DESCRIPTION OF THE PROJECT

2.1 A new district

A district called "Le Pommier" is currently rising in the suburb of the canton of Geneva (Grand-Saconnex, Switzerland). Located on the north-west part of the city close to the international organizations zone, it will contribute significantly to the housing development project of the canton, providing it with 650 new apartments. This district will also include some commercial activities, a school, and a communal center. CIA is leading the whole project in partnership with the state of Geneva (DAEL) and the commune of Grand-Saconnex.

The studied multifamily complex is part of this district project and was constructed in 2004. From the beginning, CIA has given close attention to housing quality, public space organisation and was also favourable to renewable energies. From this point, the gap left to comply with the Minergie® label requirements was quite small and CIA decided to make it. They went even further and equipped all the apartments with the best available energy-efficient household appliances (A or B class).

2.2 Typology of the buildings

As buildings location was imposed by a quite restricting district development plan (PLQ), best advantage has been taken of the big building thickness fixed by this same PLQ at 15.3 meters (Fig. 1). This last value conditioned the internal housing repartition. A transversal typology was then adopted with a central hall that can be added to the kitchen and the living room thus offering either a subdivided or an open space on all the building depth (Fig. 4). Facades were provided with large bay windows and balconies were sat up on the street side (Fig. 2,3).

Connexions established by this design between the streets and the courtyard through the stairwells – considered as well as passageways – and common spaces available all around the square strengthen the urban and collective character of this unit. Each entrance is located at a particular height in order to allow the adequacy between the natural slope of the preserved public space and the level of the stairwells. From a space point of view, this constraint actually gives the building bases an appreciable diversity.

2.3 Integrating the energy concept

Building «Minergie®» at this scale requires a highly motivated team in order to carry out the project in total agreement with the planned energy concept. Thus, a very close attention and a great precision have been needed in the execution stage of the complex. As a matter of fact, structure, spaces organisation, transparency, style or outdoor spaces must be treated with great care during all stages in order to stick with the energy concept requirements and within the allocated cost ranges. This «mastery of works» is very important since it will influence future building maintenance and inhabitant comfort.

2.4 Choices of materials

Structure is in reinforced concrete with a punctual system of supports, starting from the ground floor. To a great extend the concrete elements are prefabricated. The envelope, based on the principle of ventilated "façade", is composed of wooden and fibrocement elements, of windows in wood and metal and a green roof insulate with foam glass.

Apartments are cross ventilated and organized in relation to the structure. Partitions are formed with plaster panels. Covers are made out of materials such as: plaster, cement screed, oak wood, vitrified clay, paint, wallpaper, etc.

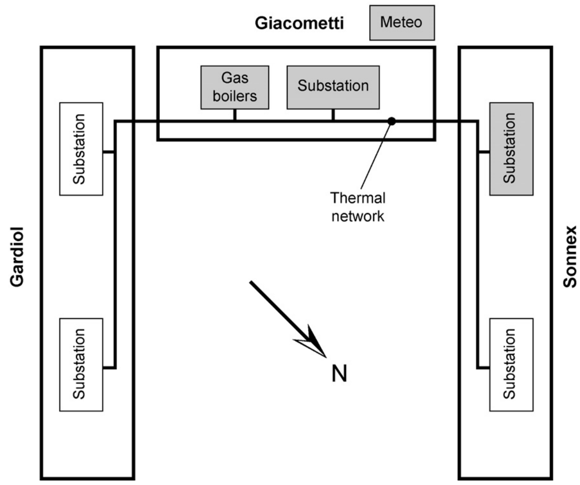

Figure 1: Buildings location, orientation and technical concept of the energy distribution. Grey parts are systems under monitoring.

Figure 2: Street side of the Giacometti building (SW).

Figure 3: Solar collectors and accessible roof on Gardiol building (NW).

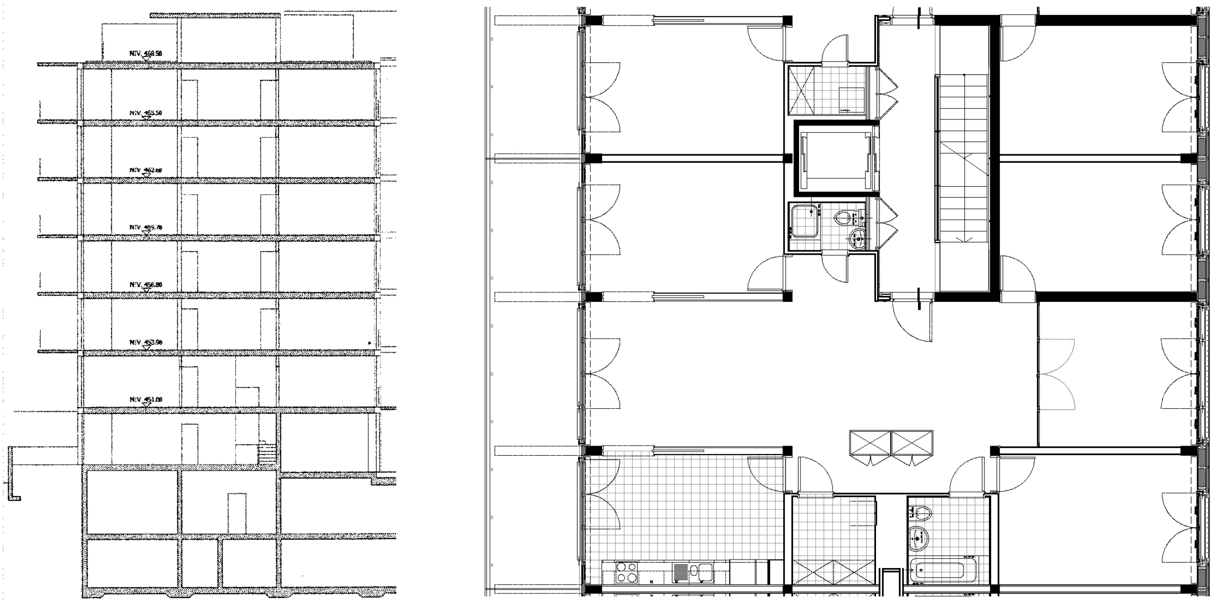

Figure 4 : Longitudinal view and typical floor plan (Giacometti).

2.5 Minergie® label requirements

Minergie® is a private quality label for new and refurbished buildings which have a lot of successes. This trade name is mutually supported by the Swiss Confederation, the Swiss Cantons along with Trade and Industry.

Comfort of the building users and low energy consumption are the main goals of this label. Plenty of room is left to architects and engineers in the design stage as long as the project complies with the label requirements. For instance, in order to get the label, new residential buildings (cat. I) must comply with the following requirements:

- Good thermal insulation and air tightness of the building's envelope.
- Mechanical renewal of indoor air.
- Weighted energy index must not exceed 42 kWh/m2.
- Added compliance costs from standard realization must not exceed 10%.

The weighted index is based on the standard building's regulation SIA 380/1, targeting 80% of the maximum heating demand value. It takes into account the energy for space heating, domestic hot water and electricity used for heat pumps and mechanical ventilation. Weighting factors are set to account for gross energy consumption (electricity has been arbitrarily weighted with a factor of 2) and for promoting the use of renewable energies. Thus, one has to be careful when comparing this weighted index with usual gross energy indexes used in buildings. For further information, please refer to [1].

3. DESCRIPTION OF THE BUILDINGS

3.1 General features of the buildings

The complex is composed of three buildings disposed around a central square (Fig. 1). It houses 117 apartments and 1660 m2 of commercial and administrative area. The square, open to the north-east, is shared by another set of three buildings located at the opposite. More details are given in the Table 1, typical designed U-values of some envelope components are given in Table 2 and typical floor plan is given on Figure 4.

Table 1: Description of the complex

Total gross heated floor area	20'915	m2
- Giacometti building	4605	m2
- Sonnex building	8107	m2
- Gardiol building	8203	m2
Net heated volume	48'678	m3
Net commercial area	1660	m2
Number of apartments	117	-

Table 2: Typical designed U-values

Windows (double glazing)	1.0	W/m2.K
Window frames	1.7	W/m2.K
Façade walls	0.2-0.3	W/m2.K
Roof	0.2	W/m2.K
Floor	0.3-0.4	W/m2.K

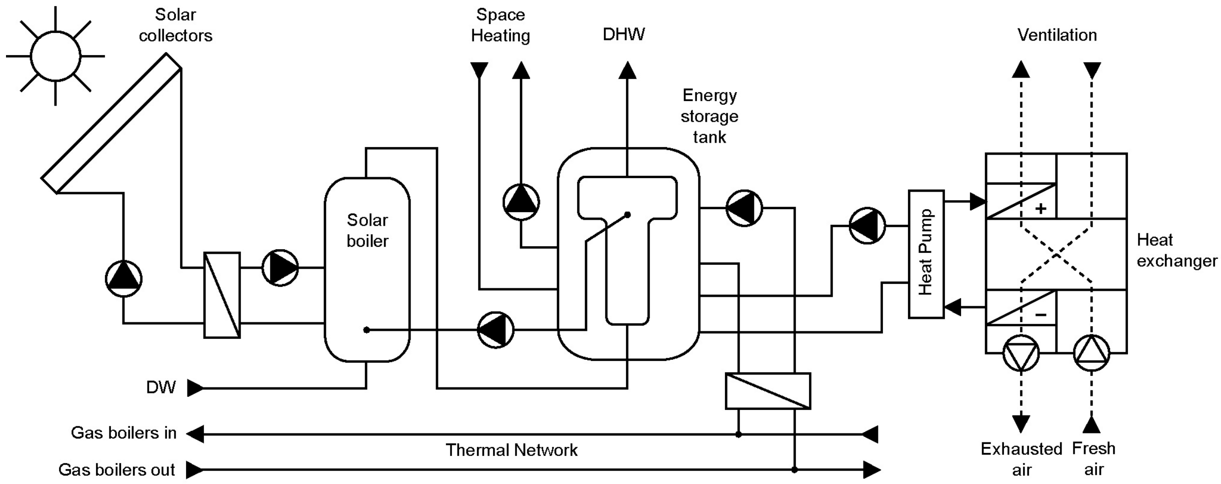

Figure 5: Schematic diagram of a substation.

The three buildings (Giacometti, Sonnex and Gardiol) present the same characteristics. Technical facilities, parking and storerooms are located in the basement. Ground floor is devoted to commercial activities as well as a part of the first floor of the Sonnex building. Floors one to six (and seven to the Gardiol building) are occupied by apartments. All of them are transversal. Last floors shelter duplex flats, giving an access to the roof and its greensward (Fig.3).

3.2 Technical system

The technical system concept, providing space heating, domestic hot water (DHW) and ventilation, was designed with the target of minimising gas consumption. It was done by integrating solar energy and maximum heat recovery. The whole system is composed of five substations connected through a small thermal network to two gas boilers (Fig. 1). The substations are designed to be self-contained during off heating season. In normal working conditions, the gas boilers and the thermal network are thus shut off during this period. Each substation is composed of an energy storage tank, a thermal solar system and a ventilation unit (Fig. 5). Here are some details about the system components:

- The two condensing gas boilers of 250 kW are connected in parallel to the thermal network. The output power is adjustable thus allowing a thermal production between 25 kW and 500 kW.

- The solar collectors are oriented south-west or south-east and located on the building roofs. Total installed area is 194 m2 which gives approximately 0.5 m2 per user. A solar boiler is used for DHW pre-heating.

- The ventilation unit (double flux) includes a heat exchanger and a heat pump. The heat pump is located on the exhausted air path just after the exchanger. Its priority task is to provide post-heating of the fresh air supplied. When not needed, in summer for instance, the heat pump provides heat to the DHW.

- The energy storage tank comes with a DHW boiler inside. The tank receives heat from the thermal network (gas boilers) and the heat pump (ventilation). It then supplies heat to convectors for space heating and to DHW. A connexion between the DHW boiler and the solar boiler allows a transfer from the second to the first one in the case the solar boiler is fully charged and there is still a potential for solar production.

An example of a substation's technical specifications is given on Table 3.

Heating pipes and ventilation ducts are integrated into technical girdles or in the concrete floor. Convectors in the apartments and common parts are all equipped with thermostatic valves. Stale air is sucked up from sanitary facilities and kitchens and then expelled into the parking area after being cooled down through the heat exchanger and filtered.

Table 3: Technical specifications of Giacometti's substation.

Solar panel area	44	m2
Solar boiler capacity	2000	l
Solar heat exchanger power	33	kW
Energy storage tank capacity	3600	l
- Inside DHW boiler capacity	1500	l
Thermal network heat exch. power	120	kW
Ventilation unit nominal air flow rate	6100	m3/h
- Heat pump max power	40	kW

4. ENERGY ANALYSIS

4.1 Monitoring

In order to perform a detailed thermal performance analysis of the buildings, a precise monitoring system has been set up. Due to the identical structure of the buildings and their substations, we decided to focus on the Giacometti building which also shelters the gas boilers (Fig. 1). A second substation in the Sonnex building is also monitored as well as meteorological data. All the apartments of Giacometti building were occupied by fall 2004. Giacometti's solar installation and DHW have been monitored since July 2004 and the building is fully equipped since January 2005 except the ventilation unit. This last one has been monitored since December 2005. Sonnex's substation is fully recorded since February 2006. Measurement period will last until 2008.

The 60 sensors used (thermocouples, flowmeters, solarmeters and hygrometer) were fully calibrated by the Cuepe. A precision datalogger was programmed to gather instantaneous sensor signals every 10 seconds and simultaneously calculate energies of liquid flows. Mean or cumulative values are stored at 5 minutes intervals. Regarding the ventilation units, a second datalogger specifically designed for the model used (Menerga) has been placed in the Giacometti's unit and can also collect data from the Sonnex's unit, thanks to the bus liaison connecting all of them. Every minute, 30 analogue and digital data are recorded.

In addition to this continuous monitoring, some spot measures were also performed such as the heat transfer coefficient of some envelope elements.

4.2 Energy balance 2004/05

Here we present the results for Giacometti building during the first heating season from July 2004 to June 2005. Predicted and measured values are given in Table 4 and monthly values for total heat demand are showed in Figure 6. Please note that, at this point of the study, neither the heat provided through the ventilation system by the heat pump nor the devices electricity consumptions are taken into account. The value showed for the heat pump is only the heat provided to the energy storage tank.

Annual gas consumption per unit of gross heated floor was 228 MJ/m2, which is two and a half times more than the predicted value of 92 MJ/m2. This difference is mainly due to a higher than expected space heating demand and the malfunction of the heat pump.

Although the reasons for this higher space heating demand can not be fully explained at this point of the study, we can however make the following assumptions. Firstly, the humidity contained inside the structure of a new building is gradually evaporated during the first years of exploitation. This drying process involves a certain amount of heat consumption. Secondly, predicted consumptions are based on an indoor temperature of 20°C. But the temperature of the air extracted from the apartments show higher value of indoor temperature between 21°C and 22°C. A sensitivity analysis performed on this highly insulated building shows a variation of about 13% of space heating requirement per degree of indoor temperature. In this case, it means an increase between 7 and 14 MJ/m2 per year. Thirdly, it is worth to mention that the relative complexity of the technical installations requires also some adjustments to be fully optimised. Some adjustments were carried out during summer 2005. Determinant factors such as air flow rate and heat recovery efficiency have not yet been fully investigated at this time. As for the heat pump, a communication problem between the ventilation unit regulation device and the general regulation system was at the origin of the malfunction. The problem was fixed by summer 2005, as can be seen on Figure 6, but this incident highlights the difficulties encountered by engineers to make different trademark subsystems work together.

Solar installation worked flawlessly and produced about 2500 MJ per square meter of installed solar panel per year, covering more than 30% of DHW preparation.

Despite a quite low distribution temperature set around 46°C for DHW, observed annual consumption was lower than expected with 70 instead of 87 MJ/m2.

Table 4: Predicted and measured energy consumptions of Giacometti building. Pred : predicted values, 04/05 : measured values from July 2004 to June 2005, (05/06) : measured values from July 2005 to March 2006 then estimated values from April to June. Heat provided through the ventilation system by the heat pump is not taken into account.

MJ/m2.year	Pred.	04/05	(05/06)
Space heating	53	158	(132)
DHW	87	70	(73)
Total demand	140	228	(205)
Solar production	25	24	(25)
Heat pump	35	2	(12)
Thermal net. (gas)	80	206	(172)
Total production	140	232	(209)
Gas (HHV)	92	228	(191)

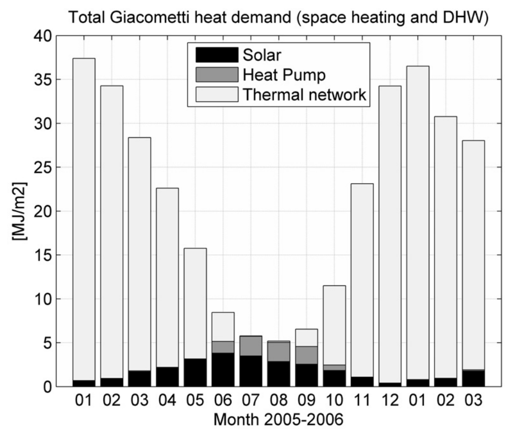

Figure 6: Monthly values of Giacometti building total heat demand (space heating and DHW) with solar, heat pump and thermal network (gas) contributions. Heat provided through the ventilation system by the heat pump is not taken into account.

4.3 Energy balance 2005/06

Second heating season is still running at the moment of writing this paper. However, the three missing months, from April to June 2006, can be estimated using past years measurements and heating signature. Estimated values are given in Table 4.

Past year DHW consumption and solar production are assumed to be constant and used to complete the missing months. Space heating demand can be foreseen using the heating signature, the plot of space heating power versus outdoor temperature. Figure 7 shows values for the past and present heating seasons.

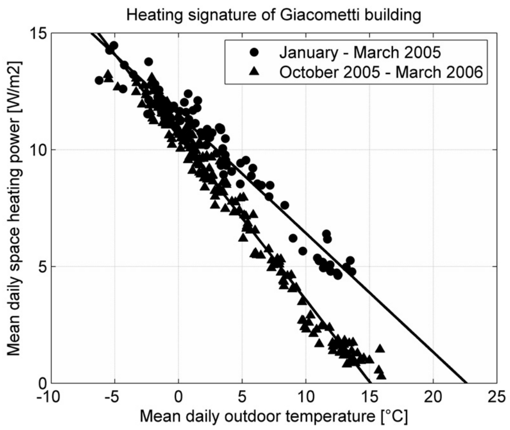

Figure 7: Heating signature of Giacometti building during the first (circle, 2004/05) and the second (triangle, 2005/06) heating season.

A net improvement in the building behaviour can be observed. Although there has been an increase in the sensitivity of the building to the outside temperature (from -0.5 to -0.7 W/m2.K), the decrease of the non-heating temperature from 23°C to 15°C leads to a lower annual space heating demand. Using this heating signature, local degree-days and an indoor temperature of 22°C we can estimate the space heating demand from April to June to be around 14 MJ/m2. In addition to the already consumed heat of 118 MJ/m2, the estimate for the annual space heating consumption is about 132 MJ/m2. Heat pump has produced close to 8 MJ/m2 from June 2005 to March 2006. Using characteristics of past year production, we can roughly estimate the expected production of the three coming months to be of 4 MJ/m2, thus giving an annual contribution of approximately 12 MJ/m2. Taking into account the same amount of annual losses (4 MJ/m2), the estimated annual gas consumption per unit of gross heated floor is about 191 MJ/m2. Although it still represents twice the predicted value, a net improvement of 16% can be observed. We think it is mainly due to the drying process of the building and to the optimisations carried out on the technical system and its regulation.

5. AIR QUALITY ANALYSIS

An assessment of indoor air quality was performed by the service of air quality control of the state of Geneva (STIPI) [5]. Two apartments were punctually monitored between October 2004 and May 2005 on the Gardiol building, before and after the inhabitants' arrival. Analysis showed that initial values in empty flats of volatile organic compounds (VOCs) and formaldehyde were very low. Those values rose up with the inhabitants' furniture and activities but still remained at a level qualified as good. This experience demonstrates the importance of the choice of the constructive materials on the indoor air quality. Delocalizing pollution production source is also a way to reach the goals. For instance, the glazing of the wooden floors, a very pollutant tasks usually carried out on site, was made in the production factory before the floors were brought inside the buildings to be laid down.

6. CONCLUSIONS

Although the first two years of exploitation show an energy index two times higher than the expected value, this realization is still very performing (191 MJ/m2 per year) compared to the usual consumption of regional new buildings (350-400 MJ/m2 per year).

The interdisciplinary approach of the energy concept from the beginning of the project, coupled with the close attention given to the execution stage seems to be an effective way to lower the energy consumption of large-scale residential buildings. Although some works are yet to be done to fully understand the differences between predicted and measured performances, we strongly encourage this kind of approach for future realizations.

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