All-in-one high-performing system for ZEB houses



MARIA FERRARA
Grant researcher
TEBE Research Group
Energy Department
Politecnico di Torino at Turin, Italy
maria.ferrara@polito.it

FREDERIC KUZNIK
Full professor
CETHIL, UMR 5008,
INSA of Lyon, at Villeurbanne,
France
frederic.kuznik@insa-lyon.fr

JOSEPH VIRGONE
Full professor
CETHIL, UMR 5008
INSA-Lyon, Université Claude-Bernard
Lyon 1 at Villeurbanne, France
joseph.virgone@insa-lyon.fr

The construction of nearly Zero Energy Buildings implies not only a good envelope design, but also the use of highly efficient systems for heating, cooling and mechanical ventilation. This paper describes a good practice example where the high performance of the all-in one HVAC system was studied through dynamic simulation and resulted in a cost-effective high performance.

Keywords: nZEB, dynamic simulation, monitoring, reversible heat pump, mechanical ventilation, canadian well, France.

The Corbioli House is a single-family house situated in Ambérieu-en-Bugey, in the French region of Rhône-Alpes. It was built in 2011 by the construction company "Maison and Résidence Corbioli". This area is classified by the French thermal regulation RT2012 [1] as a H1c zone, where the C_{max} for residential buildings is equal to 60 kWh_{ep}/year [2]. Because of its bioclimatic design and its innovative and efficient HVAC system, the house represents a good practice for high-performing single-family houses in that region, which is a low altitude area with temperate climate.

A bioclimatic design

The Corbioli House is a two-floors residential building of which the total gross floor area is equal to 155 m².

Figure 1. Picture of the Corbioli House, south front (left) and north front (right).

Coherently with principles of passive houses, in order to reduce heat loss due to windows and benefit of solar gains, the maximum of large openings are south-oriented (49% of total glass surface on the south external wall, 19% on the south roof slope) while the percentage of openings in east and west orientation is less relevant (respectively 10% and 15%) and there are only very small north oriented openings (7%). Window area is approximately 1/5 of the floor area: the minimum imposed by the national regulation, which is equal to 1/6 of the floor area, is largely exceeded. A roof overhang protects south-oriented windows. The heated volume (**Figure 2**) has a compact shape that minimizes the exchange surface between the outside and inside (Surface/Volume ratio is equal to 0.68 m^{-1}).

The envelope is well insulated (**Figure 3**): the external walls are composed by 20 cm of concrete blocks (thermal resistance R = 1 m^2K/W) and 20 cm of internal insulation (R = 6.3 m^2K/W), the wooden roof includes 40 cm of insulation (R = 12.5 m^2K/W) and the floating slab incorporates 30 cm of insulation material (R = 9.3 m^2K/W). The use of thermal bridge breakers limits the thermal bridge at the intermediate floor. All windows have triple glazing for a thickness of 44 mm (4/16/4/16/4), the solar factor is equal to 0.5 and the thermal transmittance U_w of the entire opening (glasses and frame) is equal to 0.7 W/m^2K. A blower door test attested the air tightness of the house equal to 0.6 $m^3/(h\ m^2)$.

A compact HVAC system

The house is equipped with the Tzen-3000 system, provided by Aldes [4], (**Figure 4**), which is composed of a mechanical dual flow ventilation system combined to a cross flow heat exchanger and an air-air reversible heat pump that are included in the thermodynamic central C3000 (**Figure 5**). Before joining the distribution ducts, after the heat pump, the fresh air passes

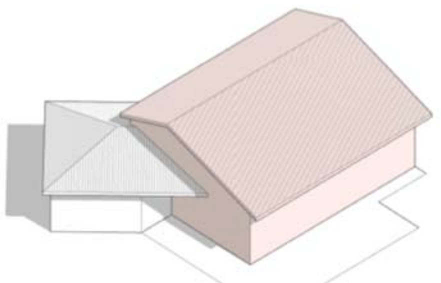

Figure 2. Volumetric representation of the Corbioli House. The heated volume is coloured in orange.

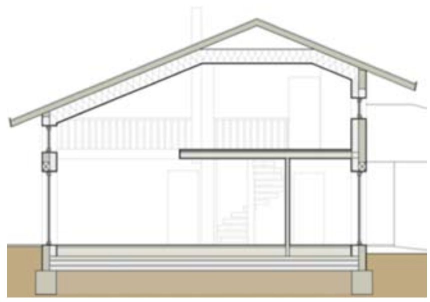

Figure 3. Corbioli House, transversal section.

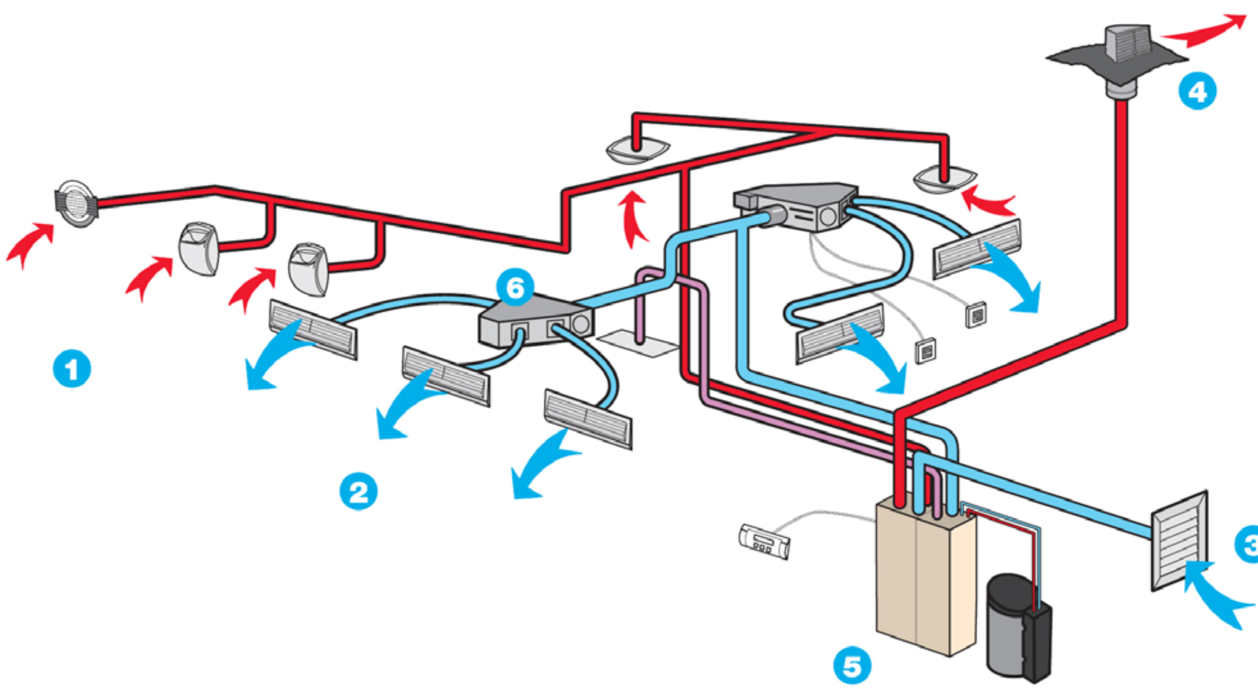

Figure 4. T-zen. (1) Extraction, (2) Blowing, (3) External air, (4) Exaust air, (5) Central, (6) Heating module. (Aldes)

through the auxiliary modules (one module per floor) that allow the temperature regulation room by room, while providing additional heating sometimes required in winter. Each duct of the heating module is indeed equipped with an electric battery that is controlled by a thermostat disposed in the room to which the same duct is connected. The entire system can be controlled using a keyboard located in the kitchen, and thermostats in other rooms. Once the set point temperature is given, the system automatically manages the comfort through the perfect control of flows induced by ventilation while providing air to guarantee internal comfort regardless of the season. The technical documentation specifies that for a 5-room house with two bathrooms, a shower room and a separate WC the standard airflow rate is equal to 150 m³/h, reaching 240 m³/h in peak flow and dynamically varying according to the operation mode.

The all system in the Corbioli House is controlled according to the following conditions:

- The winter set point temperature is fixed to 19°C in all conditioned zones;
- The difference between the ambient temperature and the inlet air temperature is controlled adjusting the recycling rate in order to not exceed 20°C;
- In order to avoid the frequent switch between different operation modes, the limit to differentiate the warm period and the cold period is set to 22°C for indoor temperature with a 3°C dead band hysteresis cycle;
- The heat exchanger is by-passed in the cold period and in hot period when the outdoor temperature exceeds the indoor temperature;
- The building is subjected to hyperventilation in hot period when the outside temperature is below 24°C and the inner one is higher 24°C.

Given this regulation scheme, a calibrated model of the whole building was built in order to simulate and study the HVAC system behaviour in the three different operation modes.

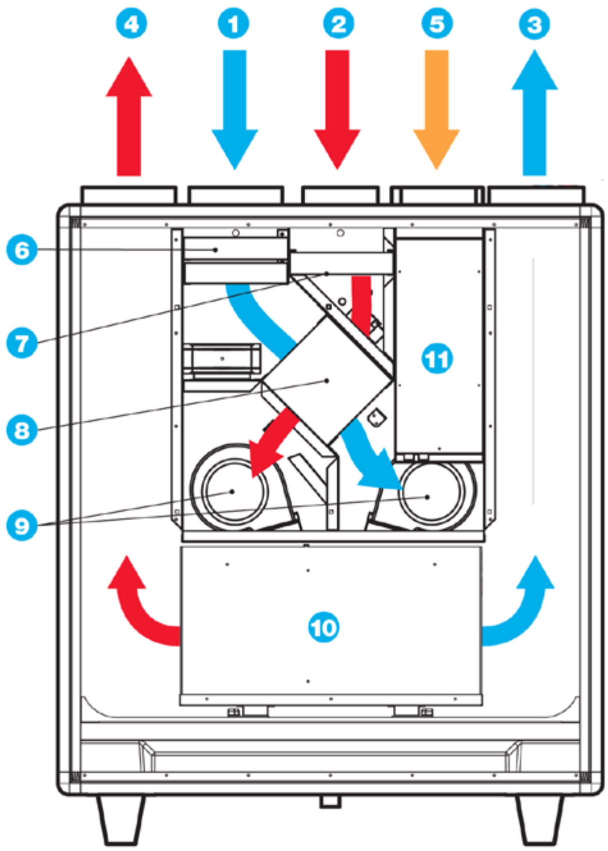

Figure 5. C3000. (1) External air, (2) Extract air, (3) Fresh air, (4) Exaust air, (5) Additional extract air, (6) Fresh air filtration, (7) Extract air filtration, (8) Heat exchanger, (9) Fans, (10) Heat pump, (11) Electronic card. (Aldes)

Heating mode

In winter, the temperature control system is generally set to the heating mode, and the heat pump is on. The cross flow heat exchanger included in the thermodynamic central is able to recover 60% of heat from the extracted air. The heat pump heating power varies depending on the outdoor temperature, the desired indoor temperature and the flow rate. The coefficient of performance (**Table 1**) also varies in relation to the combination of all these parameters, going up to 8 in particular conditions.

Table 1. Heat pump COP in function of indoor and outdoor temperatures, air flow rate and compressor speed.

Outdoor temperature	Indoor temperature	Flow rate m³/h	Compressor speed	Recyclage	Heating power	Global COP
-7°C	20°C	160	20 Hz	No	1663 W	7,6
			60 Hz	Yes	2861 W	4,2
			80 Hz	Yes	3220 W	3,4
7°C	20°C	160	20 Hz	No	1130 W	5,1
			60 Hz	Yes	2881 W	3,4
			80 Hz	Yes	3468 W	2,8

In a typical French winter period, the outside temperature may reach –10°C. The higher the heating need, the higher the heat pump compressor speed is and the higher the outlet air temperature is requested. In order to maintain the indoor temperature equal to 19°C, the outlet air temperature can go up to 70°C. However, for comfort reasons, the difference between the outlet air temperature and the air temperature of the room cannot exceed 20°C. That is why a recycling system for indoor air is set up to maintain the temperature difference to 20°C maximum. The recycled air, mixed to the fresh air leaving the heat pump, lowers the outlet air temperatures while increasing the air flow, as shown in **Figure 6**. Moreover, as already mentioned, the T-Zen system is able to adjust outlet temperatures in each room. If in some rooms the air temperature is lower than the set-point, the auxiliary heating modules start working in order to adjust the temperature to the set-point value. Heating modules should start only when the heat pump is not enough to maintain the required temperature. The **Figure** 7 reports the global operation of T-zen in January: thanks to the perfect balance of the volume and the temperature of the blowing air flow, the indoor temperature is maintained to 19°C and the blowing air temperature never exceed 38°C, while the heat pump power varies depending on outdoor temperature.

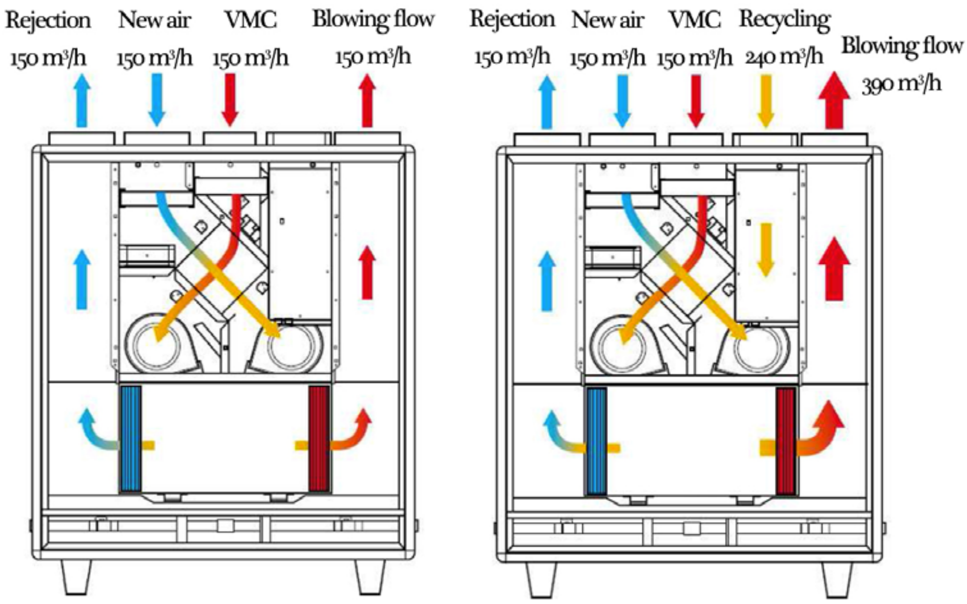

Figure 6. C3000. (Left) Heating mode without recycling, (Right) Heating mode with recycling.

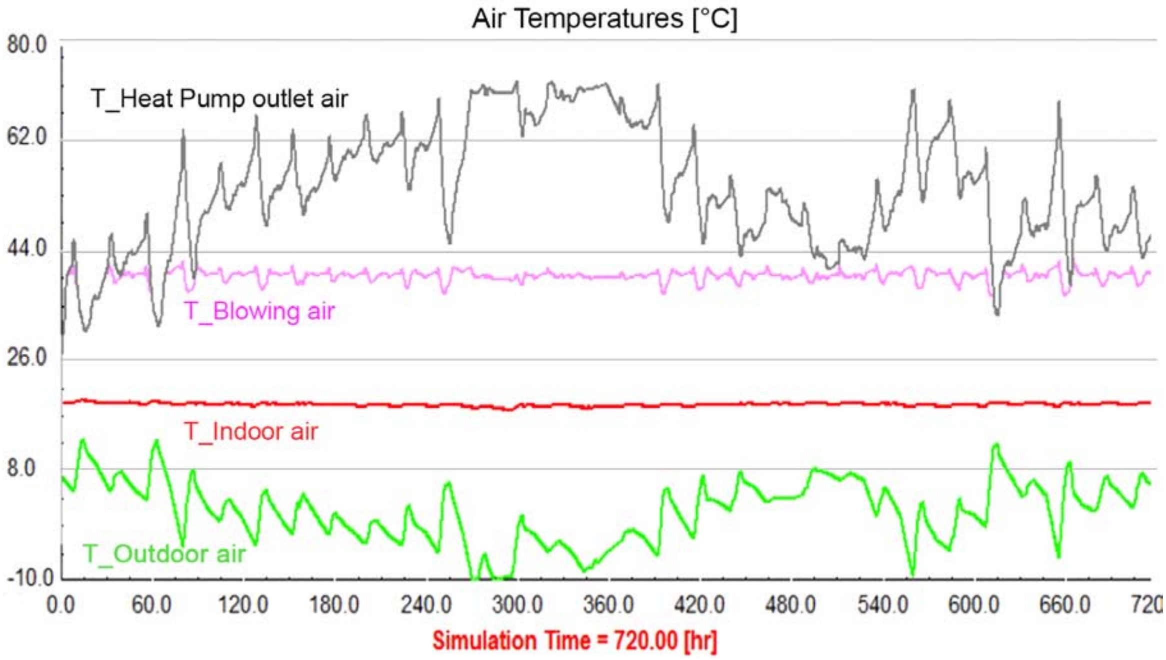

Figure 7. T-zen in January. Outdoor temperature (green), Indoor temperature (red), blowing air temperature in the living room (pink), heat pump power (black).

Cooling mode

In summer period, the T-zen works in cooling mode and the heat pump reverses its cycle and cools the air entering the house. Its cooling power and COP also varies depending on the outdoor and indoor temperature, the flow rate and the compressor speed. In addition, a system of over-ventilation is implemented when the outside air is cooler than the indoor air (particularly at night). Finally, the heat exchanger can also be switched on if the internal temperature is colder than the outside temperature; in such a way it helps cooling the fresh air. The over-ventilation rate corresponds to the maximum speed defined above, 240 m³/h, and the bypass of the heat exchanger is switched on when the over-ventilation starts. This is controlled with a hysteresis effect, which prevents the over-ventilation system from switching on/off too frequently. The T-zen operation in a typical summer month (from 8/6 to 7/7 of year 2013) is shown in **Figure 8**, where the over-ventilation starts working at the early night and stops later, in order to reduce the phenomenon of overheating during the day while avoiding a too low temperature in the night. Moreover, when the indoor air is cooler than the outside air the exchanger cools the inlet fresh air with the inside outlet air. In **Figure 9**, the evolution of the outdoor temperature, the indoor temperature, and the fresh air temperature at the outlet of the heat exchanger in the same period are shown. The heat exchanger is able to cool the fresh air when the outside temperature is too high, with peaks of 3°C of temperature decrease.

Ventilation only mode

The ventilation only mode allows mediating between the heating mode and the cooling mode, when heating or cooling requirements are very low, typically in spring and autumn. In this case, the heat pump never turns on and the air can only pass through the heat exchanger. When the house requires a small supply of heating energy, the heat exchanger turns on and allows heat recovery from exhaust air. However, when the temperature of the house is too high, the heat exchanger is bypassed and the temperature of the blowing air is therefore the same temperature of the outside air. As usual, the control system allows a hysteresis effect, which prevents the exchanger from switching on and off too frequently.

The Canadian well

The presented T-zen system is coupled to an underground heat exchanger. It consists in pre-treating the external fresh air through pipes buried in the ground, before it enters the HVAC system: the principle is to make passive use of geothermal energy (**Figure 10**). In winter, the deep soil is warmer than the outside temperature, and therefore the cold air is preheated as it passes through the pipes. In summer, the soil is colder than the outside temperature and is able to warm the temperature of the air input, sometimes allowing cutting down the air conditioning. The more the pipes are deep and long, the more efficient is the system. In the case of Corbioli house, the diameter of pipes is 200 mm and the length is 30 m. It is placed in the garden soil at a depth between 1.5 m e 2.6 m: the 2% slope is necessary for the condensation water drainage.

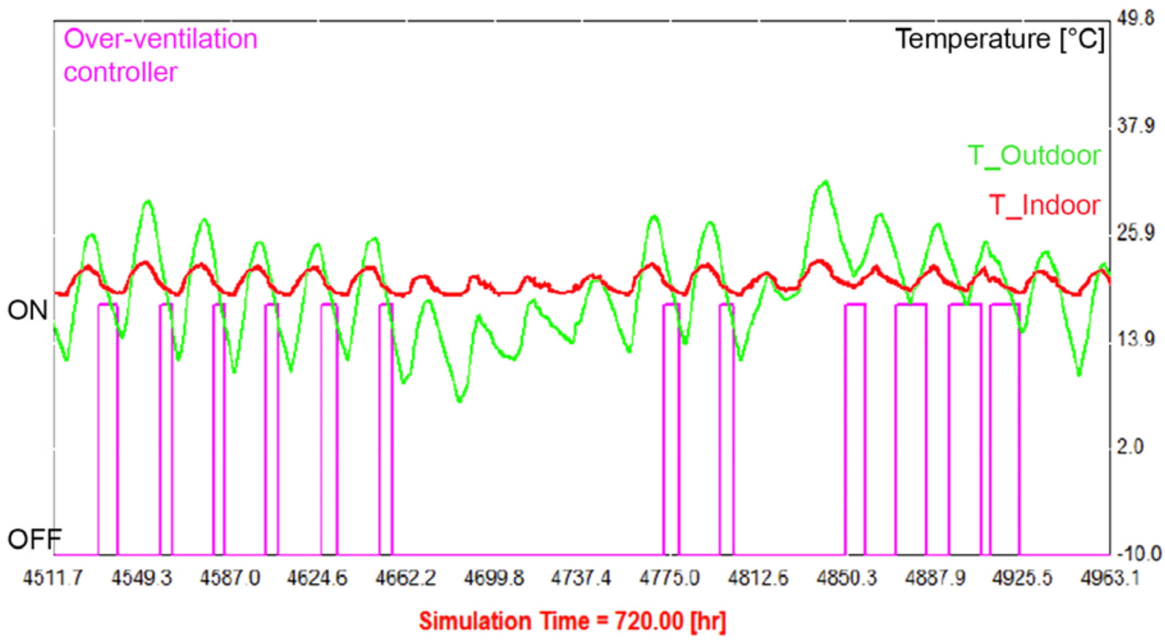

Figure 8. T-zen cooling mode (2013, 8/6-7/7). Outdoor temperature (green), Indoor temperature (red), Over-ventilation on/off (pink).

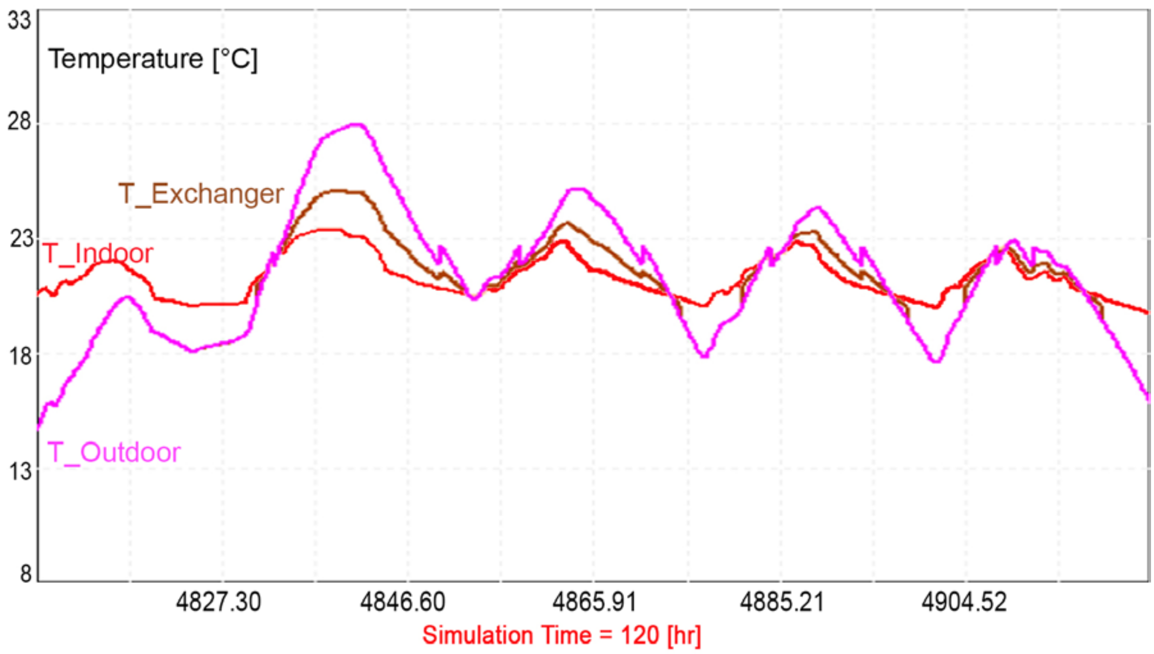

Figure 9. Heat exchanger benefits in cooling mode. Outdoor temperature (pink), Indoor temperature (red), heat exchanger output temperature (brown).

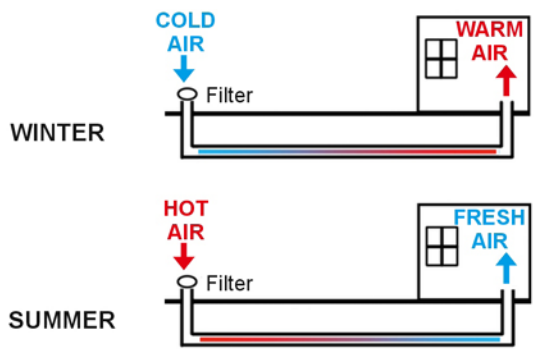

Figure 10. Canadian well operation in different seasons.

The total building energy performance

As mentioned, the study of the Corbioli House was studied through building model and dynamic simulation has been used to evaluate the energy performance of the Corbioli house. As the house is currently unoccupied, the internal loads related to lighting and appliance (8 W/m^2 in main rooms) and occupancy (100 W/person) were modelled using schedules for a standard 5 people family working life, considering weekends. The sum of infiltration and ventilation rate is fixed equal to 0.7 ach in all building. Given these conditions, without considering the HVAC system, the sensible heating demand of the Corbioli House is equal to 48 kWh/m^2/year, while the cooling demand was estimated to be 12 kWh/m^2/year. If a traditional French all-electrical system (radiators for heating, fans for cooling and no mechanical ventilation) would be installed in the house, the total annual primary energy consumption would be equal to 134 kWh$_{ep}$/m^2/year, considering the French primary energy conversion factor of 2.58 and the efficiency of the cooling system equal to 3. However the T-zen HVAC system allows the estimated annual energy consumption for heating, cooling and ventilation to be equal to 12.59 W/m^2/year, leading to a total primary energy consumption of 32.5 kWh$_{ep}$/m^2/year, fully meeting the current regulatory requirements [1]. This low energy demand can be covered by an on-site renewable energy production plant (PV and solar), leading the Corbioli House to be close to the target Zero Energy.

The financial performance

Several studies have been performed concerning the financial optimization of the Corbioli House, comparing many combination of design options related to the envelope and the HVAC system [5-7]. The analysis have been carried out following the cost optimal methodology, introduced in [8] and defined in [9]. When compared with other systems, if combined with the opportune envelope design, the installation of the T-zen system resulted a cost-effective energy efficiency measure leading to the lowest global cost (including investment, replacement maintenance and operation energy cost) over a building lifecycle period of 30 years.■

References

Please see the complete list of references of the article in the html-version at **www.rehva.eu**
-> REHVA Journal