Rapid Retrofit Solutions
Integrating HVAC into Prefabricated EWIS Systems

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Abstract
Within the context of energy renovation of buildings cost reduction is a key requirement to increase the retrofit rate as part of a long term strategy for reduction of CO2 emissions. A new concept consists in the prefabrication of façade components with integration of both, external wall insulation system (EWIS) and heating, ventilation and air conditioning components (HVAC). The semi-prefabrication, consisting in prefabricating only the most sensible parts of the façade, has the advantage of being more flexible and could allow a real reduction of the renovation costs, maintaining a high quality standard.
The integration of the ventilation system avoids problems like humidity condensation in renovated buildings with high level of air tightness. The life cycle cost of the ventilation device depends strongly on the centralization level of the device (one per building, per dwelling or per room). The actual market shows that the decentralized devices are very promising on this point of view.
The renovation of an office building belonging to the Fraunhofer ISE permitted to test an innovating concept of semi-prefabrication of the façade components, integrating a central balanced ventilation system. This concept simplifies the installation work, particularly for the treatment of the technical details which are concentrated around the windows. The thermal bridges are reduced and the installation of the air inlets and outlets is very easy thanks to their integration in the window frame. The heat losses of the integrated channels in the façade are the weak point of the system and modifications to this concept could be developed in order to improve its performances.

Keywords – Building, renovation, prefabrication, integration, ventilation

1. Introduction

In order to reach the goals for the reduction of CO_2 emissions set by the European Union, an effort is necessary especially in the sector of existing residential buildings. The rate of energy retrofit has to be multiplied by 2 or 3 and the quality of these renovations must allow reaching the same performances as the new buildings standards.

The principal curb of the retrofitting process are the costs which are often high because of the multiplicity of the tasks to be realized. Walls, roof and floor must be insulated, windows and heating device must be replaced and a ventilation system must be installed. The dwellings are mostly unfit for habitation during a few weeks, a few months or sometimes for the whole duration of the retrofit. This point is also blocking a lot of retrofitting measures.

An analysis of the dwelling ventilation shows that the percentage of the German housing stock having a ventilation device is extremely low. In a common study, the Institut Wohnen und Umwelt (IWU) and the Bremer Energie Institut (BEI) [1] bring out that only 1,5% of the habitations are equipped with a mechanical ventilation device and only 50% of these devices include a balanced ventilation system with heat recovery. The building modernization cannot consist in a simple replacement of the old device, as new components are larger and therefore use mostly an inopportune volume in the habitable space. As a consequence, a usual practice consists in focusing only on one part of the retrofitting measures. At last, the costs are considerably growing when for example only the insulation of the façade is implemented in combination with the replacement of all windows. The air tightness of the building envelope reaches a very high level and, as no ventilation device is installed, the damages due to humidity are quickly appearing. A second retrofitting work must be planned in order to install an adequate ventilation system.

In some European countries, the installation of ventilation is mandatory, e.g. the German DIN norm 1946-6 [2] imposes since 2009 to install a ventilation system, independent of the user and providing at least a protection against problems due to humidity. The retrofitting measures of a residential building must include this system as soon as a third of the windows are replaced. These points are justifying the conception of façade components integrating the window frame as well as the ventilation system.

As shown in recent projects [3-6], the process consisting in the prefabrication of façade elements and the integration of technical installations is very promising. On the one hand, it often allows letting the occupants staying in the building during the renovation work, on the other hand, the duration of the work is reduced. The industrialization of the process leads to a high quality level of technical details and particularly of the treatment of the thermal bridges between wall and window frame.

The expansion of this process could considerably reduce the retrofitting costs and raise the level of energy performances high above the actual standards. In this paper, three main aspects are discussed: comparison between prefabrication and semi-prefabrication of façade elements, appropriateness of different ventilation systems and integration of these systems in the prefabricated components. The last part illustrates an example of semi-prefabrication retrofitting.

2. Prefabrication vs. Semi-prefabrication

Prefabrication of façade elements for building energy renovation was already tested within the context of three projects: ECBCS Annex 50 [3], supported by the International Energy Agency, TES Energyfacade [4] and EnOB – Forschung für optimiertes bauen [5]. The elements tested were large scale panels, mostly using timber based frames. Integration of HVAC was tested as well as the use of vacuum insulation panels. Demonstrators showed that energy performances can reach a very good level (heat energy demand of less than 25 kWh/m^{-2}). The renovation costs were higher as the price of conventional solutions. The deciding point will be the cost reduction through further development and large-scale production.

The project « AERTOs Prefabricated multifunctional façade systems for building integration » [6] threw the advantages of semi-prefabrication into relief. Prefabricated façade elements integrate technical installations such as the ventilation system and are small scale panels which are not covering the whole façade. These elements include systematically the window frames in order to improve the quality of this place where many technical difficulties can be easily solved by prefabrication. The remaining part of the façade is treated on a traditional way. The time benefit of prefabrication and semi-prefabrication is illustrated by figure 1.

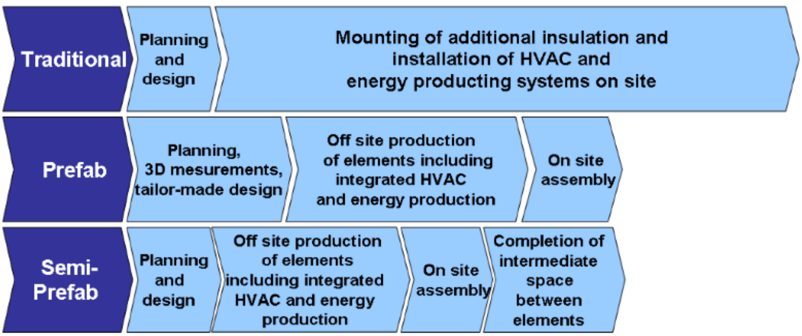


Fig. 1 Comparison between traditional process, prefabrication and semi-prefabrication [6]

The main advantages of semi-prefabrication compared to prefabrication of the whole façade components are summarized in table 1. The last advantage presented in this table is the most important for the costs of the retrofitting process. Industrialization and reduction of the costs through mass production can only occur if the façade elements can be used for a great number of buildings with no need of long and expensive design phases.

	Prefabrication	Semi-prefabrication
Logistics	Difficulties to bring large elements to the construction site	Transport of small elements is easier
Manipulation	Use of scaffolds not always possible	Small elements easy to manipulate through scaffolds
Solidity	Frame, mostly timber based, necessary to provide rigidity to the panels	Rigidity of the insulation material often high enough to insure the solidity of the panels
Fixation on the façade	Fixation tracks or brackets necessary to support heavy weight of large elements	Small elements easier to fix to the façade
Connections between panels	High precision level required to avoid gaps between elements	Precise link between each element easy to obtain
Repetition of the process	Each panel must be designed to be used on one particular façade of one building.	A same sort of panel can be used on many different buildings

Table 1. Advantages of semi-prefabrication

3. Integration of the ventilation system

The ventilation system can be in many ways integrated in prefabricated façade elements. The first parameter of choice is the centralization level of the device. This centralization level can be distinguished in four categories: one central system for the whole building, one central system in each floor, each apartment or one system per room. In a first step, the costs of different options will be analyzed and in a second step an energy analysis of the different possibilities will be carried out.

3.1 Ventilation solution in retrofit concepts

The first important parameter in this study is the cost of the entire life cycle of the system. The cost can be divided into 3 main categories: investment (conception and dimensioning, device, mounting), operation (energy and maintenance), end of life (dismantling and recycling of the materials). Five options are compared:

- Option 1 (figure 2): central balanced ventilation with heat recovery and integration of the air channels in the façade.

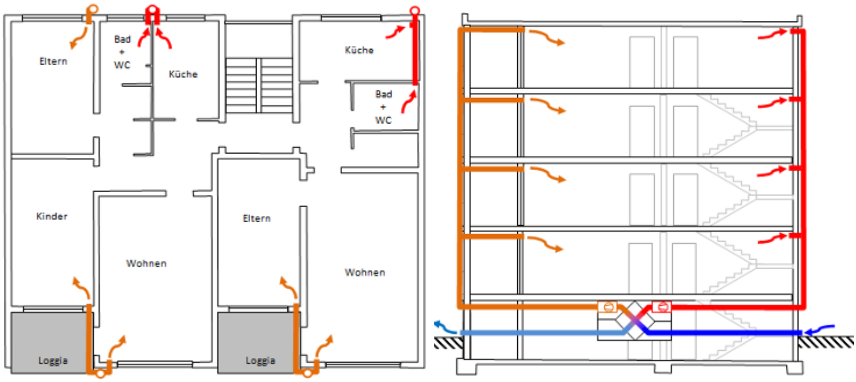


Fig. 2 : Central balanced ventilation – integration of the air channels in the façade

- Option 2 (figure 3): central exhaust ventilation with heat recovery through a heat pump and integration of the air channels in the façade.

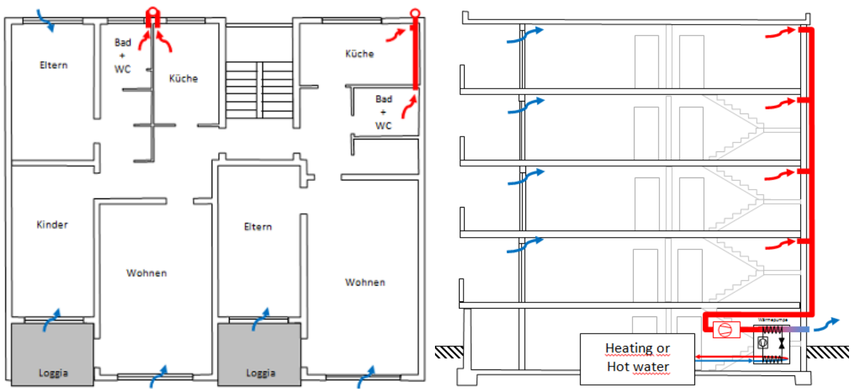


Fig. 3 : Exhaust ventilation – integration of the exhaust channels in the façade

- Option 3 (figure 4): central balanced ventilation in each dwelling with heat recovery and integration of air channels and ventilation device in the façade.

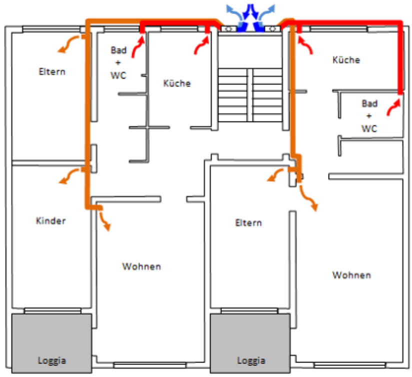


Fig. 4 : central balanced ventilation in each dwelling – integration in the façade

- Option 4 (figure 5): decentralized balanced ventilation with heat recovery, integration of the whole system in the window frame (for example Premivent developed by Profine and Zehnder).

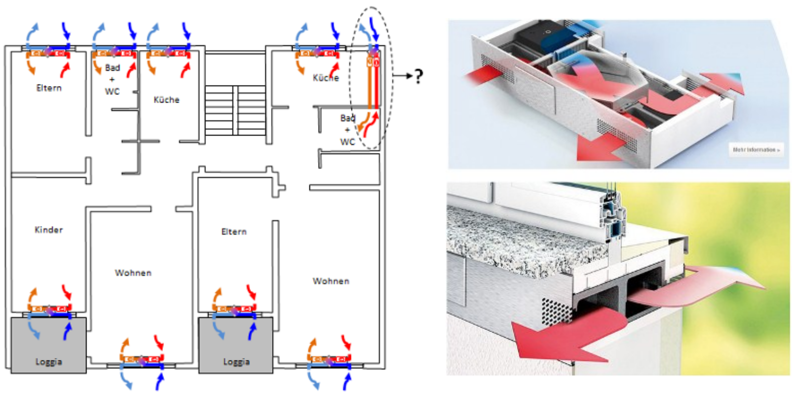


Fig. 5 : decentralized balanced ventilation, integration in window frame (Premivent)

For this option, a solution must still be found for the rooms without contact to an external wall.

- Option 5 (figure 6): decentralized balanced ventilation with regenerative heat recovery, (for example Lunos e²) combined to an exhaust system for the humid rooms (kitchen and toilet).

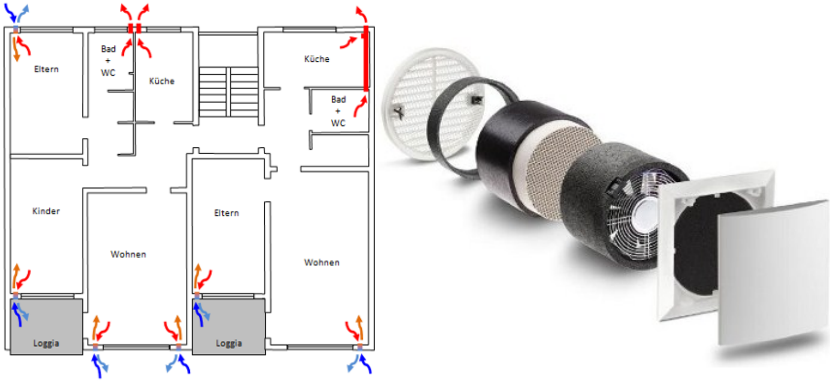


Fig. 6 : Decentralized balanced ventilation – regenerative system (Lunos e²)

The costs corresponding to each of these options are very different depending on the building and still have to be more precisely investigated. They will be presented in this study on a very simplified way using points and with a range of 3 points for each parameter (Table 2). The value of 1 is the optimum.

Options		1: Central balanced ventilation channels integrated in the façade	2: Central exhaust ventilation channels integrated in the façade	3: Central ventilation in each dwelling integration in the façade	4: Decentralized balanced ventilation integration in window frame	5: Decentralized balanced ventilation regenerative system
Costs	Conception	3	3	2	1	1
	Device	2	1	3	2	2
	Mounting	3	3	2	1	1
	Total Investment	8	8	7	4	4
	Energy	2	3	1	2	2
	Maintenance	1	1	2	3	3
	Total Operation	3	4	3	5	4
	Total End of life	3	3	3	2	1
	Total	14	14	13	11	9

Table 2. Costs of façade integrated ventilation systems

The energy consumption of the option 4 is superior to the consumption of the option 3 because the air is extracted and supplied in each room, so that the total air flow has to be doubled. This energy consumption stays moderately low because this system allows an independent control of the air flow in each room. On the same way, the energy consumption of the option 5 is superior to the consumption of the option 3. Even if the total air flow is inferior to the air flow of the option 4, the operating way imposes one control for two devices and cannot be very precise. Moreover the imbalance induced by the additional exhaust system in the humid rooms between exhaust air flow and supply air flow leads to a reduction of the heat recovery rate.

The decentralized options still show a very good economic potential. The main weak point appearing in this table is the maintenance which imposes to enter each apartment and is often unacceptable for housing companies. The possibility of doing this maintenance on the external face of the façade has to be investigated.

3.2 Energy performance

To determine the energy performances of each system, a study was carried out and compares the three first options on a multi-family building to a reference option [7]. This reference is a classical balanced ventilation system including heat recovery with air channels inside the building. The precise energy performances of the options 4 and 5 are still to be investigated. The simulation results show the end and the primary energy demand and the share of the electricity consumption of the fans and the heat energy compensating the losses of the ventilation. These results are illustrated on figure 7.

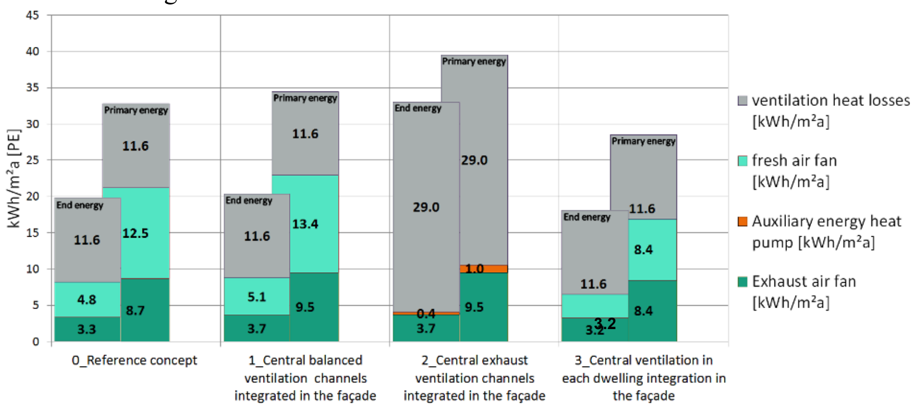


Fig. 7 End and Primary energy needs in relation with ventilation – comparison of four options. The used primary energy conversion factors are 2.6 for electricity and 1 for heat.

The electricity consumption of the fans is different in each option because of the pressure losses. The heat exchanger represents only 10 percent of the total pressure losses so that the important parameters are the length and the complexity of the air channels. The saving for the exhaust ventilation is due to the absence of supply air channels but it is compensated by the high demand of heat energy. The channels have to cover a longer distance when they are integrated in the façade and a shorter distance for the decentralized option. The simulations were realized considering that the fans are permanently running at their nominal air flow with an efficiency of 0,7. The control of this air flow can be realized for devices supplying several apartments, but the reduction of the air flow is produced by additional head losses at the inlets or outlets. This sort of control induces a reduction of the heat losses but not of the electricity consumption of the fans. For a decentralized device, the control is often realized by a reduction of the fan rotation speed. As the theoretical necessary power of the fan is proportional to the cube of its rotation speed, a reduction of this speed leads to important energy savings. In that case, both electricity consumption of the fan and heat losses are reduced. The difference between these two sorts of control still has to be investigated.

4. Prototype study: Office Building – Fraunhofer ISE

A semi-prefabricated façade prototype was designed in partnership with the companies Zehnder and Beck&Heun and tested in 2011 within the retrofitting of an office building belonging to the Fraunhofer ISE. Prefabricated panels cover the façade of 8 offices and are preformed in order to easily integrate the channels of a central balanced ventilation system corresponding to option 1 (figure 8).

Fig. 8 Insulating panels, window frame, integration of ventilation channels and air outlet

They are combined to prefabricated window frames composed of insulation material and allowing a very precise link between frame and wall as well as between frame and window. Air inlets and air outlets are integrated in these frames and the rest of the façade is insulated on a traditional way. The air channels are connected to the central ventilation device which is mounted in a container above the entrance of the building.

Measurments are running in the whole system in order to determine its energy performances. The first results of this study caracterised the heat losses along the air channels in the façade. The evolution of inside temperature, ouside temperature and outlet temperature of the longest channel of the exhaust system is illustrated on figure 8.

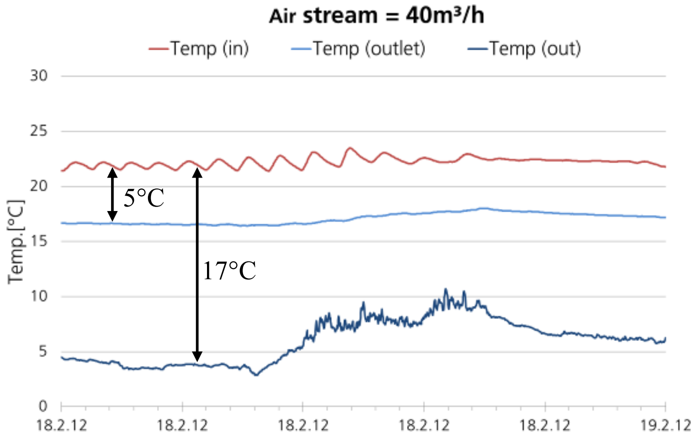
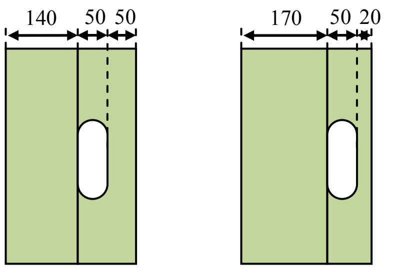


Fig. 8 Temperatures – exhaust air channel

In this exhaust channel, an air temperature decrease of 5 °C is observed for a temperature difference of 17 °C between inside and outside. This diminution shows that the heat losses in the channel are significant and reduce the potential of heat recovery. One solution could be a modification of the position of the channel into the insulation layer. This possibility is limited by risk of rupture of the panel during its handling (see figure 9).



Current position (mm) Modified position (mm)

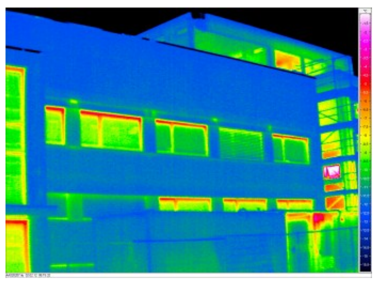


Fig. 9 Left: Modification of the channel position in the insulation layer / Right: Infrared picture of the retrofitted building

An infrared picture shows that no significant thermal bridges are to be noted. Another essential point to be investigated is the run of the installation work and the acceptance of the system by the different workers. On the one hand, the mounting of the channels was finished in only one day. The concerned workers have estimated that they would have needed four days for the same installation if the channels were installed inside the building. On the other hand, the workers responsible for the insulation had to come two times instead of one time for a traditional process. The two major objectives of this process have been achieved: improvement of the technical details, particularly around the window frames and simplification of the global mounting. The global energy evaluation of the system is still to be realized and will be based on the temperatures measured during winter 2012/2013.

5. Conclusion and Outlook

The different studies and demonstrators carried out at Fraunhofer ISE considering the prefabrication and semi-prefabrication concepts show that this process is a good option in order to reduce the costs of building retrofit. The integration of HVAC in prefabricated façade elements is an opportunity to stimulate the growth in the building retrofit rate. Some modifications and optimization of the presented systems, and the integration of other technical systems (heating pipes, hot and cold water pipes and wastewater) are the next steps.

6. Acknowledgements

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