BUILDING RETROFIT USING FAÇADE-INTEGRATED ENERGY SUPPLY SYSTEMS

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1 SUMMARY

A new approach of highly-efficient thermal refurbishments of multi-family buildings is presented that has a high potential to reduce costs and simplify the renovation processes significantly. This approach is based on prefabricated curtain wall elements that integrate components for the energy supply system such as heat pumps, PV panels and all the necessary pipework for supply and waste water lines. By using pre-fabricated curtain wall elements, scaffolding and the relocation of inhabitants can be avoided.
Three different system concepts have been evaluated and compared to a reference retrofit in terms of primary energy and life cycle costs. It has been shown that the new concepts can reduce the primary energy consumption significantly while reducing the costs over the lifetime of the system.
Finally, a functional mockup of such as pre-fabricated façade was constructed and successfully tested in the laboratory.

2 INTRODUCTION

There is a huge potential for highly efficient thermal refurbishments of multi-family buildings that would result in significant reductions of CO_2-emissions. However, the renovation rate for existing buildings has been declining for the past few years. In the case of comprehensive thermal renovations in Austria, it was only 0.6% from 2004 to 2014 which is significantly lower than the goals set in the Austrian climate protection report. The current technical renovation standard as well as the renovation process have repeatedly proven to be insufficient in terms of providing the appropriate incentives. This applies not only to structural but also to HVAC refurbishments.

A comprehensive paradigm change is necessary in order to increase the refurbishment rate. There is a need not only for financial incentive mechanisms but also for technical solutions and business models which allow for a simplification of the renovation process. This, in turn, will result in lower costs for the owner and the users as well as in an increased property value which will be reflected in monetary terms.

Façade elements with a high level of insulation are a very promising technology for large-scale buildings. They can be prefabricated to a high degree which allows for quick installation and excellent quality of implementation. One possibility for reducing costs substantially and simplifying the prevailing renovation processes is the integrating of more functionality into traditional curtain walls, e.g. using the surfaces as energy conversion areas or for energy storage, integrating small-scale heat pumps and ventilation elements into the prefabricated component as well as distribution lines for heat, water, air or disposal of waste water. The recently completed research project “HVACviaFACADE” examined exactly this approach.

3 POTENTIAL

In a first step, it was assessed which type of buildings from which period of construction offers the highest potential to introduce retrofitting with pre-fabricated curtain walls. Based on statistical data from Austria, multi-family buildings from the 1960s to 1970s were selected. The reason is that there is an especially large number of such buildings in Austria that have not yet been renovated. Typical floor plans of buildings from this period were used to define a reference building with 4 floor levels and 12 apartments (see Fig. 1). The total gross floor area is 687 m². This reference building was used to define a reference retrofit and a few renovation concepts with pre-fabricated curtain walls that include different functionalities of the heat supply system for the apartments. These concepts were compared with the reference retrofit from the point of view of primary energy consumption and life cycle costs.

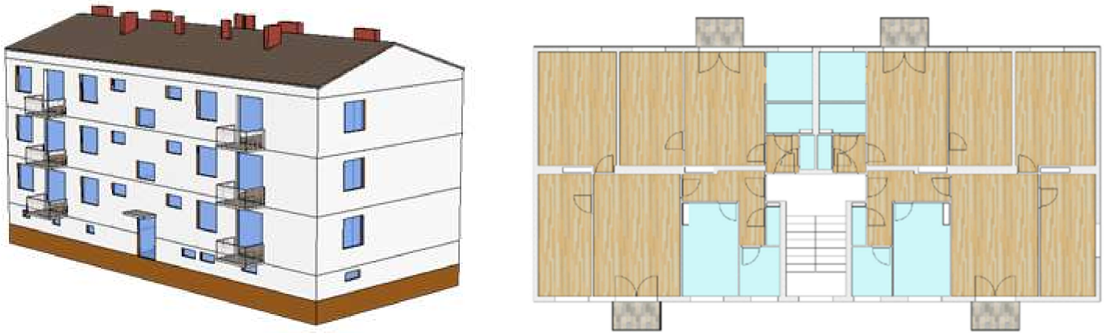

Fig. 1: Reference building

The reference retrofit consists of a thermal insulation composite system with supply and waste water lines all led inside the building. The energy supply system is a central gas boiler for space heating and electrical water heaters for domestic hot water in each apartment.

4 EVALUATION OF CONCEPTS

At the start of the project, 24 energy supply concepts were defined that allow for the integration of HVAC into pre-fabricated curtain walls. Their suitability as well as implementation was evaluated in a quantitative as well as qualitative way. The technologies evaluated are based on the five main technology groups: solar thermal, photovoltaics, heat pumps, ventilation technology as well as water heaters and heat transmission system. Most concepts consisted of a combination of technologies or of hybrid systems.

Three system concepts were selected based on this evaluation of concepts. They were simulated in detail for the reference multi-family building with 12 apartments and for 2 different thermal insulation standards (heating demand 30 and 15 (kWh/m²a)) implementing wood curtain walls. For this analysis, the dynamic simulation environment TRNSYS was used. Two system concepts use outdoor air heat pump solutions in combination with façade-integrated photovoltaic systems. One model has a central heat pump and the other one uses decentralized small-scale heat pumps which are integrated into the façade. The third concept is an electric heating system using infrared heating elements in combination with photovoltaics. All system concepts were simulated with different PV surface areas and rely on the same ventilation technologies depending only on the thermal insulation standard. For space heating demand 30 it is a controlled ventilation system with a central exhaust fan and air intake via an opening in the window structure. For space heating demand 15 it is a controlled ventilation system with heat recovery.

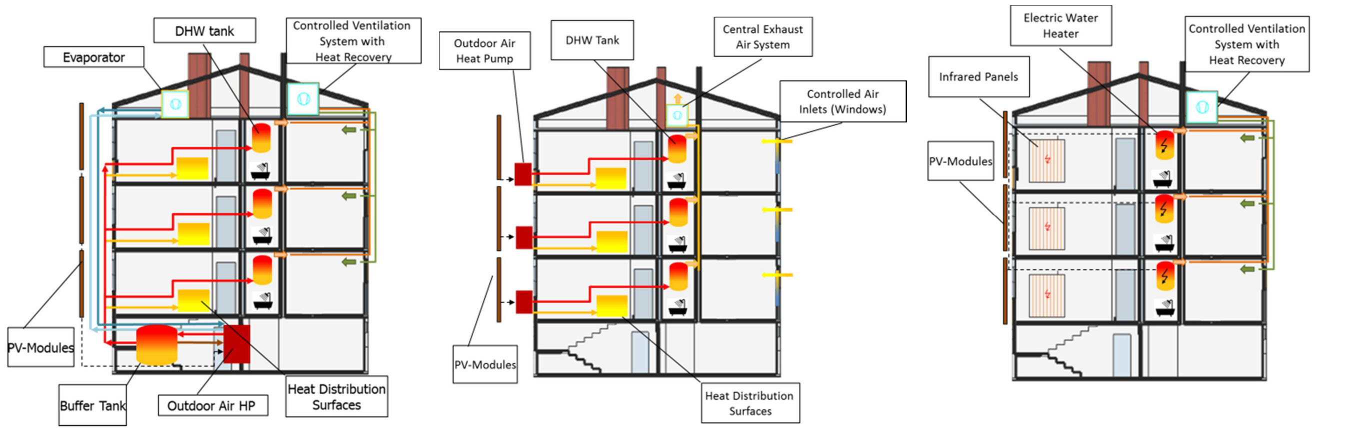

Fig. 2: Schematic representation of chosen system concepts (left: central heat pump, middle: decentralized small-scale heat pumps, right: electric heating system)

5 ADVANCEMENTS OF THE PRE-FABRICATED CURTAIN WALL SYSTEM

Based on the experiences from previous projects, the wood curtain wall system was further developed. The goal was to reduce the costs by minimizing the number of layers and by transferring simpler construction steps from pre-fabrication to the construction site. One main step was that the equalizing layer that is necessary to align the curtain wall with the existing wall was considered as a constructive element. The necessary insulation layer is used to equalize the existing wall (see Fig. 3). On the construction site, battens are mounted on the existing wall to equalize it. Then the pre-fabricated façade is mounted and insulation material is blown into the gap between the existing wall and the façade element. In addition, active as well as passive HVAC elements such as ascending pipes, descending waste water pipes, ventilation pipes etc. are integrated into the façade.

Thanks to all these measures, it was possible to optimize the current construction technique for wood curtain walls so that the costs could be reduced by 30%.

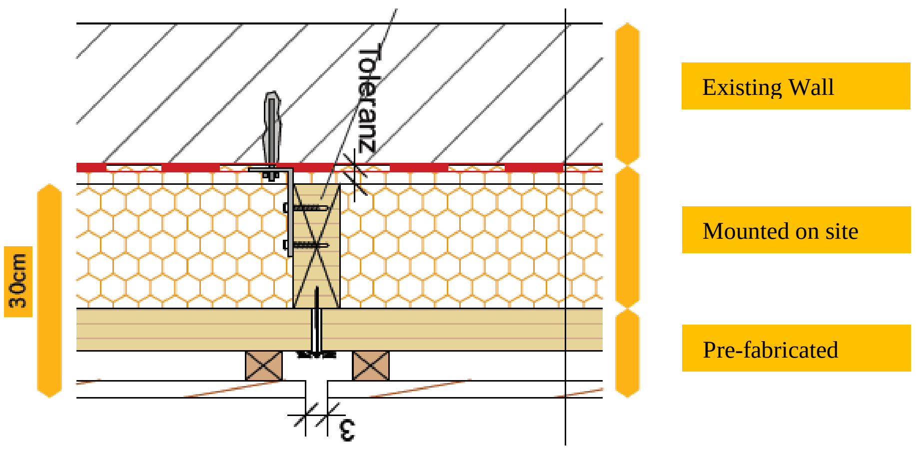

Fig. 3: Schematic representation of the newly developed concept for pre-fabricated wood curtain walls

6 SIMULATION RESULTS

The simulation results were analyzed based on the primary energy consumption of each innovative system concept compared to the reference retrofit. The primary energy factors 1.17 for gas and 1.91 for electricity (annual mean value) were used. For PV electricity no storage was assumed. That means the electricity that could be used directly by the system, was determined and deducted from the final energy consumption of the system. Excess PV electricity was assumed to be fed into the grid but not taken into account for the energetic or cost analysis.

The simulations showed that for the low energy building (30kWh/(m² a) space heating demand) implementing heat pumps already reduces the primary energy demand by 40-50% compared to a reference scenario and a PV system increases this reduction to 65-70% (see Fig. 4). Electric heating via infrared elements without photovoltaics does not lead to any advantages in terms of primary energy demand, compared to the reference renovation. In order to keep up with the primary energy demand of the heat pump systems, it requires huge PV areas which cannot fit onto the building anymore. The electrical heating system without photovoltaics consumes slightly more primary energy than the reference system due to the heat losses in the reference system.

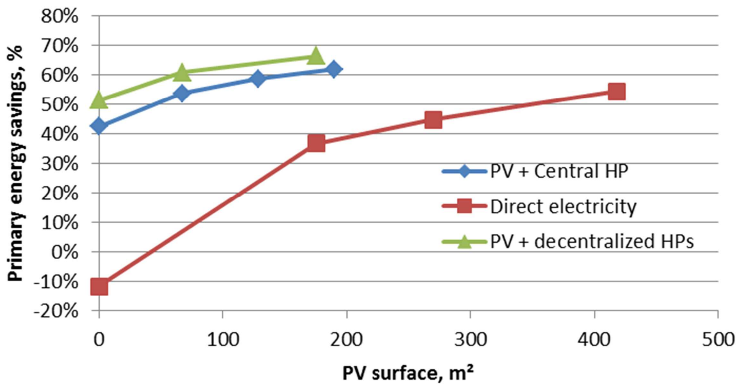

Fig. 4: Primary energy savings for the three system concepts compared to the reference retrofit (30 kWh/(m² a) space heating demand)

For the passive house retrofit (space heating demand 15), the primary energy savings are somewhat larger and the direct electricity system can reach the same primary energy savings of 70% with a PV surface of roughly 420 m² which would mean that the entire east, west and south facades as well as the roof (except for the windows) would have to coverered with PV panels (see Fig. 5).

The same analysis was also carried out including household electricity consumption. Of course some of the excess PV electricity can then be used to cover the consumption of the household appliances. However, the primary energy savings go down by about 10 percentage points for the same PV areas.

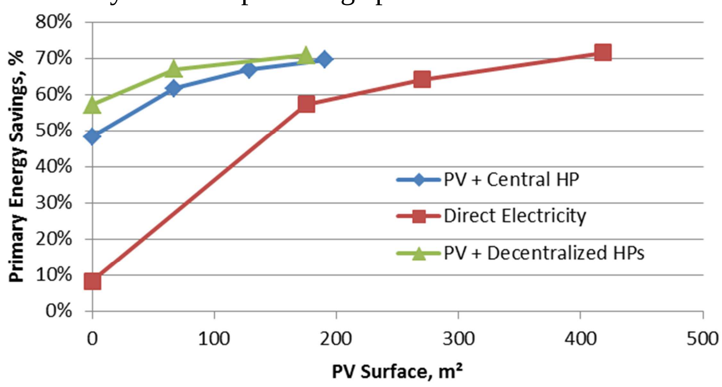

Fig. 5: Primary energy savings for the three system concepts compared to the reference retrofit (15 kWh/(m² a) space heating demand)

7 LIFE CYCLE ANALYSIS

Another important aspect of the project was the dynamic cost calculation of the entire renovation concepts and processes over the whole life cycle, from the construction to the demolition and removal of the building. The analysis was carried out using the present worth method that assesses all occurring costs during the lifetime of a building relating the costs that occur in the future to their present worth. For that purpose interest and inflation rates were defined (see Tab. 1). The investment costs are lowest for the reference retrofit: The direct electricity concept shows the lowest investment costs of the new concepts followed be the central heat pump system and the decentralized heat pump system. Important factors are the cost of the necessary PV system and the operating costs.

Tab. 1: Parameters for present worth method

Economic Factors	
Period under consideration [a]	**40**
Interest rate on capital [%/a]	**4.0**
General inflation rate [%/a]	**2.0**
Inflation rate on natural gas [%/a]	**4.1**
Inflation rate on electricity [%/a]	**4.0**

When combining energy-related as well as economic aspects and calculating the heat generation costs over the whole life cycle, it becomes clear that the heat pump systems not only achieve lower primary energy demand but also lead to lower life cycle costs than the reference renovation (using conventional thermal insulation systems and gas boilers). In Fig. 6, this is shown for the heat demand 15 building. The reduction of life cycle costs depends on the size of PV area included in the system. Highest life cycle cost savings can be achieved with no PV area, but primary energy savings are highest with roughly 180 m² of PV i.e. it's a trade-off between life-cycle costs and primary energy savings. Life cycle cost savings are somewhat smaller or for some cases negative for the decentralized heat pump system. The reasons here are quite high investment costs for the small-scale heat pumps which may be reduced once they are mass-produced.

The cost reduction potential of the electric heating system via infrared heating depends heavily on the thermal insulation level. Heat demand 15 allows for cost advantages over the reference scenario while heat demand 30 does not (compare Fig.6 and Fig. 7).

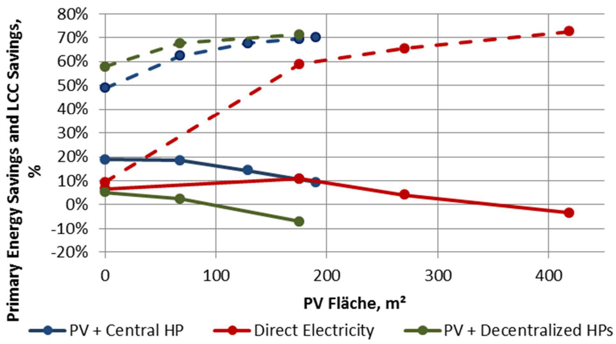

Fig. 6: Primary energy savings and savings in life cycle costs for the three system concepts compared to the reference retrofit (15 kWh/(m² a) space heating demand)

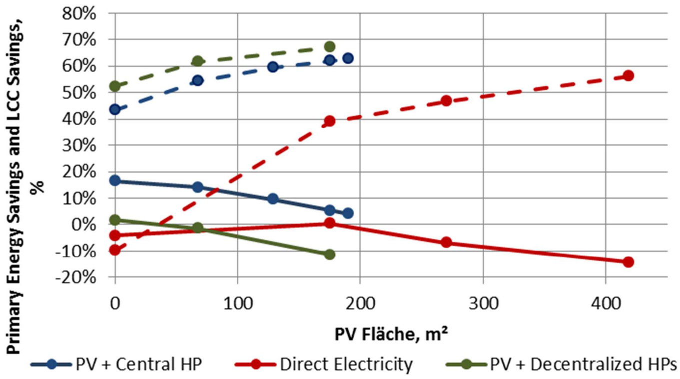

Fig. 7: Primary energy savings and savings in life cycle costs for the three system concepts compared to the reference retrofit (30 kWh/(m² a) space heating demand)

8 DEVELOPMENT AND CONSTRUCTION OF FAÇADE ELEMENTS WITH INTEGRATED TECHNICAL COMPONENTS

Due to the good performance of the heat pump systems, the concept using decentralized heat pumps for each apartment unit was selected for implementation into a curtain wall module as well as an 11 m² test element. A functional mockup of such a façade was constructed that combines several technical elements (see Fig. 8): A window element, normal façade elements as well as a duct element that includes a small-scale heat pump and the necessary pipework as well as a PV element.

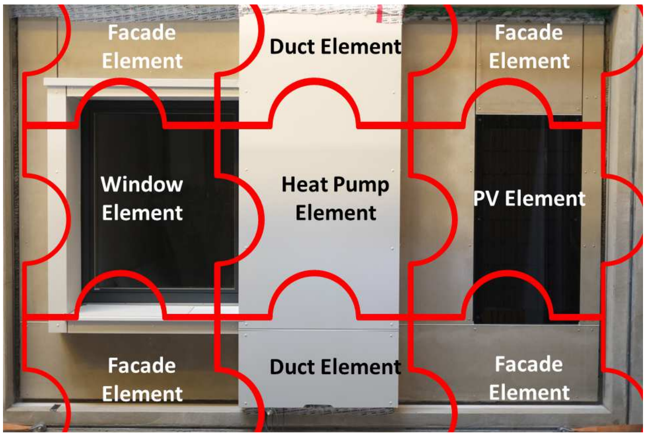

Fig. 8: Schematic representation of a curtain wall façade element built up from separate elements

The complete integration of the small-scale heat pump into the curtain wall proved to be very challenging. The heat pump concept had to be revised entirely so that the volume of the equipment could be reduced to only 60 liters, i.e. its size is comparable to a desktop PC while still producing up to 3 kW of heat. At the same time an intelligent solution for maintenance and repair work was developed by implementing a rolling system that allows for easy access to the heat pump when opening the windows. The heat pump is integrated into an HVAC duct together with all the other supply lines. This allows for easy prefabrication (can be done by HVAC contractors). For the integration of the photovoltaic system into the façade a mounting system was defined that follows the same sealing and mounting principles as the conventional mounting system for façade panels. This allows for aesthetic, simple and cost-effective integration of the PV system into the façade.

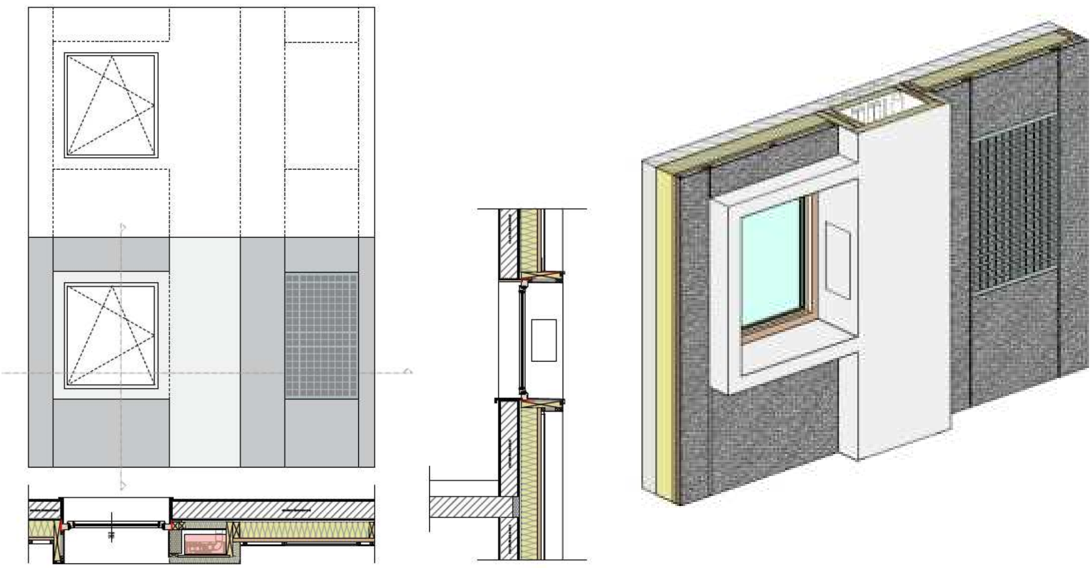

Fig. 9: Functional mockup – left: design drawing of the façade model with integrated small-scale heat pump in the duct element (in the horizontal plan the heat pump is shown in pink), right: design study of the façade model (picture source: Nussmüller Architekten ZT GmbH)

9 LABORATORY TESTS OF FUNCTIONAL MODEL

A number of laboratory test were carried out on the functional model to analyze the airtightness, the acoustic insulation and the sound intensity during operation of the heat pump. Also, a driving rain test was conducted.

Fig. 10: Setup for the driving rain test (picture source: TU Graz)

During the driving rain test according to EN 12154 and EN 12155, a small water intake was detected at a pressure difference of 300 Pa. After additional water proofing of the affected area, the test could be continued up to 600 Pa without problems. That means that the façade setup is well suited for the use as rain-proof barrier of a building.

An aspect that will need further attention during the continued development of the construction is the sound conduction from the heat pump in operation to other parts of the façade. In the tests, some vibration of the window element could be detected that need to be ruled out by constructive measures.

Overall, the metrological analysis of the functional model consistently showed positive results.

10 ACKNOWLEDGEMENTS

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11 CONCLUSIONS

There is a huge energy savings potential in the thermal retrofitting of multi-family buildings. However, the current retrofitting process is not suitable in order to reach the set climate goals in Austria and Europe. An entire paradigm change is necessary that includes new technical solutions, business models, incentive mechanisms, simplification of the retrofitting process as well as cost reduction.

The project presented in this paper suggests a technical solution that allows cost reduction and simplification of the retrofitting process by means of pre-fabricated highly insulated curtain walls that include functional elements such as heat pumps, PV panels and all necessary pipework. Thereby, retrofitting costs can be reduced by avoiding scaffolding and relocation of the inhabitants during retrofitting.

Three new system concepts were analyzed in detail by means of detailed system simulations and life cycle analysis. The results show large savings in primary energy consumptions as well as a reduction of life cycle costs.

Finally, a functional mockup of a façade element including PV and a small-scale heat pump was constructed. Laboratory tests of the façade show positive results that should lead to further development of the concept and first demonstration systems in the near future.

More details on the project HVACviaFacade can be found in [Fink et al., 2017]

12 REFERENCES

Fink et al. (2017): Final Project Report: Vorgefertigte Fassadenelemente mit maximal integrierten HVAC-Komponenten und –Systemen zur Bestandssanierung (in German), Austrian Klima- und Energiefond, Project number: 843945