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Costs of ventilation systems for the retrofit of residential buildings

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Abstract

The cost of energy retrofit is the main barrier to an increase of the retrofit rate in Europe. Among the retrofit measures, ventilation is often neglected to allow a more significant part of the budget to façade insulation, window exchange or for the heating system. The importance of a good ventilation system in order to guarantee a correct indoor air quality as well as to avoid high heat losses has been underlined by a large number of scientific articles. Therefore, an analysis of the costs of different ventilation systems within the context of energy retrofit is necessary.

The total costs are divided in invest effort, maintenance and energy costs (heat demand due to the ventilation and electricity demand of the fans). Different case studies are analysed and, in order to increase the reliability of the comparison between different concepts, virtual costs are calculated for the retrofit of a unique building for all compared ventilation systems.

Keywords - Ventilation; Heat recovery; Costs; Building retrofit

1. Introduction

Ventilation represents a major challenge within the context of energy retrofit of residential buildings. The high investment cost of central heat recovery ventilation is the main barrier explaining why exhaust ventilation systems are almost always implemented in renovation projects. One aim of the research presented here is a comparison between the total costs of heat recovery ventilation and the total costs of simple exhaust ventilation. A second goal is to find out how the costs are usually split and which of them are susceptible to be reduced in a significant range. A first part evaluates the costs of retrofit examples basing the calculations on the VDI Guideline 2067 [1]. The annuity method implemented in this Guideline makes it possible to summarise investments and running costs during a specific observation period. The analysed examples comprise cases with and without heat recovery and enable a comparison between central and decentralised systems. A second part specifically evaluates the detailed investment costs of 3 projects. At last, a third part will compare the different ventilation systems on the basis of simulated costs.

2. Evaluation based on case studies

The first part of this cost analysis is based on an evaluation of ventilation concepts in 36 different retrofit projects. The data have been provided either directly by building owners, architects or engineers involved in the analysed projects or by reports documenting the retrofit work [2-11]. The buildings analysed here are situated in Germany (19 buildings), France (15 buildings) and Austria (2 buildings). According to the VDI guideline 2067 [1], the costs have been analysed with the annuity method and separated into 4 categories: capital related costs (investment costs based on a 25-year lifetime), maintenance, electricity and heat energy. These costs are related to the usable floor area. The results presented here have to be carefully analysed for the following reasons: only a small number of case studies could provide appropriate data and some costs are missing for many of these examples. Table 1 summarises the different types of ventilation systems analysed in this part and the quantity of available data for each of them. The number of case studies for which maintenance costs are available is especially low. Maintenance costs are not always outsourced. Some large building owners have internal services to perform part of the maintenance operations corresponding to internal costs that are probably not always considered in the case studies. For window ventilation, the airflows could not be measured but have been estimated by Kah [7] and Großklos [8] to determine the heat energy costs corresponding to this ventilation concept. Because of the large variety of sources, different methods to measure the heat demand due to ventilation have been implemented. For some examples, the investment costs were not detailed so that it is not clear if costs like the design of the ventilation system, plastering or painting are included or not.

Table 1 Quantity of available data for each type of system

	Window ventilation	Demand controlled exhaust ventilation	Central with heat recovery	Dwelling Central with heat recovery	Decentralized with heat recovery	Total
Total number of analysed systems	2	15	8	9	2	36
Total heat energy costs	2	2	5	7	1	17
Total electricity costs	2	2	7	6	2	19
Total Maintenance costs	2	2	4	1	2	11
Total Investment costs	2	14	7	7	2	32

The heat energy costs have been harmonised according to the heating degree days of the measurement period. The reference climate has been set in Frankfurt (3842 HDD). Since the retrofit projects have been executed between 2003 and 2014, the investment and maintenance costs have been adjusted to the reference year 2014 according to inflation rates. In Fig. 1, the costs of all case studies used here are detailed. The missing costs have been replaced by the average value of the corresponding ventilation concept (appearing in grey on the figure). The diversity of the existing building stock leads to an important spread in each category. For example, the investment costs (annuity capital related costs) for demand controlled exhaust ventilation are varying from 0.2 €/m².a to 2.7 €/m².a.

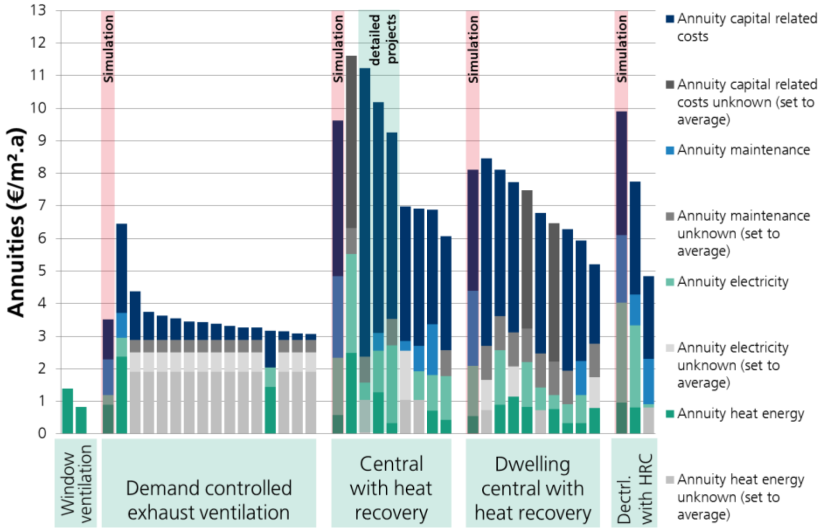

Fig. 1 Detail of the total costs for all case studies

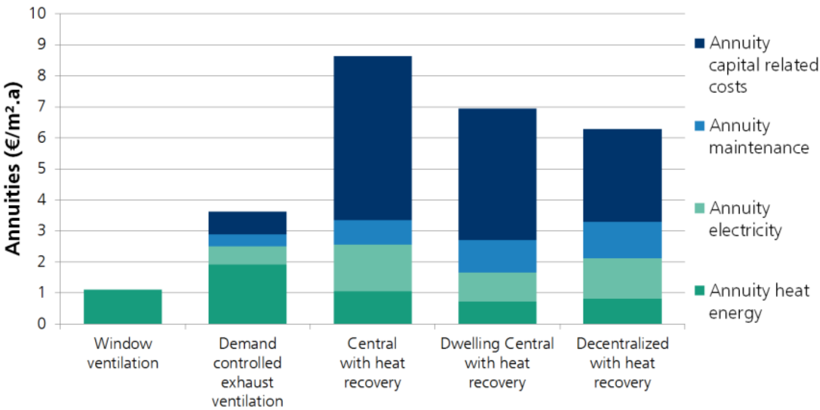

Fig. 2 Average total costs for the different systems implemented in the available examples

Fig. 2 shows the average costs grouped per ventilation concept. Since no electricity, no maintenance and no investment are necessary for window ventilation, the costs are only due to heat energy and represent the cheapest solution. Even the heat energy cost of this solution is much lower as for demand controlled exhaust ventilation. This means that the average airflow is lower and that the ventilation effectiveness does not reach the necessary level to ensure a good indoor air quality [12] so that it is difficult to compare the corresponding costs to the other systems. Demand controlled exhaust ventilation reaches the highest heat energy costs, but also the lowest investment, maintenance and electricity costs among all mechanical ventilation systems. Globally, this ventilation concept is around twice less expensive as heat recovery ventilation. For heat recovery ventilation, whatever the centralisation level is, the most important cost is the investment cost. Electricity and heat energy costs are similar for all three heat recovery systems. This is also true for maintenance costs, but the low number of case studies for which these costs are available reduces the reliability of this analysis. Globally, the more centralised the systems are, the higher the investment costs and therefore the total costs are.

3. Investment costs of central heat recovery ventilation systems

Table 1. Description of the 3 case studies

	Buggingerstraße 50 Freiburg Germany	Heinrich Lübke Siedlung Frankfurt Germany	Rue Vendôme Lyon France	Single family house Selm Germany
Year of retrofit	2010	2011	2009	2013
Number of dwellings	before retrofit: 90 after retrofit: 144	69	8	1
Net heated floor area	before retrofit: 7200 m² after retrofit: 8582 m²	6832 m²	367 m²	111 m²
Type of ventilation system	Central ventilation with heat recovery 2 devices placed in non-heated attic	Central ventilation with heat recovery - 2 devices placed on the roof	Central ventilation with heat recovery 1 device placed in non-heated attic	Central ventilation with heat recovery 1 device placed in non-heated attic
Picture after retrofit				

In order to understand why the investment costs of central ventilation systems with heat recovery are so high, three case studies (presented in Table 1) have been detailed and compared to a single family house. The investment costs (Fig. 3) have been separated into following categories: planning and design, installation work, construction work, plastering and paintings, core holes, material for distribution networks, silencers, air duct insulation and fire protection and ventilation device.

Between the three analysed projects, the main differences are concerning the costs of the ventilation device and the planning costs. The other costs are similar from one project to another. The price per square meter of the ventilation device itself is the highest for the building having the lowest heated floor area and represents in average 12 % of the total costs due to the ventilation system. The part of the costs corresponding to the planning and design of the ventilation system is similar for two projects but is much more important for the Heinrich-Lübke-Siedlung. As the system was not more complex, no reason could apparently explain this difference. This important spread shows that the implementation of ventilation systems in the context of building retrofit is not mature yet and still requires more experience to harmonise practises. An interesting point is the fact that the average costs of construction, plastering, paintings and core holes represent 32 % of the global costs against 6 % for the single family house. Therefore, it represents an important potential for cost reduction.

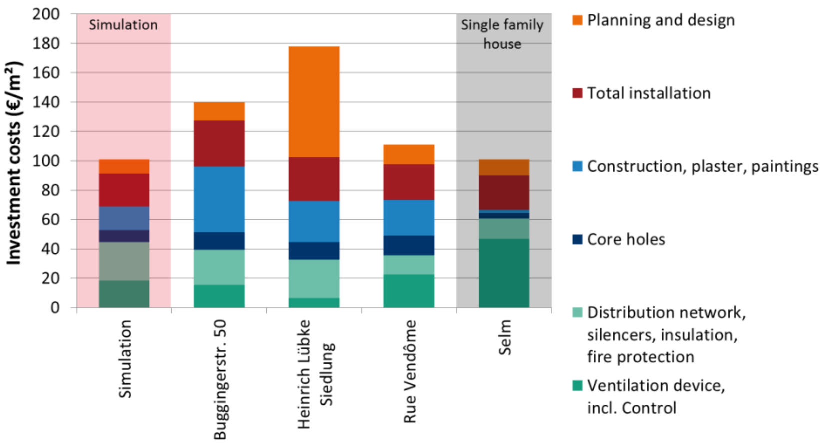

Fig. 3 Detailed investment costs of three case studies sorted in descending order of net heated floor area (central ventilation systems with heat recovery)

1. Simulated costs

The building used for the simulations is an existing building situated in Frankfurt, composed of 8 dwellings for a total gross floor area of 576 m²

(Fig. 4). For all ventilation configurations, the maximal airflow was set to the nominal airflow requested by the DIN 1946-6 [13]. The list of ventilation systems having been simulated is provided in Table 2 and includes different airflow controls for each system since the airflow control is playing a key role regarding energy costs.

Table 2 List of the simulated ventilation systems

System denomination	Centralisation level	Heat recovery	Airflow control
1 - C-EXH-C	Central	Exhaust ventilation without HRC	Constant
2 - C-EXH-RH			Relative humidity
3 - C-EXH-CO_2			CO_2
4 - C-HRC-C		η = 0.7	Constant
5 - C-HRC-RH			Relative humidity
6 - C-HRC-CO_2			CO_2
7 - DC-EXH-C	Dwelling central	Exhaust ventilation without HRC	Constant
8 - DC-EXH-RH			Relative humidity
9 - DC-EXH-RH_{fsv}			Relative humidity of exhaust air Fan speed variation
10 - DC-EXH-CO_2			CO2
11 - DC-HRC-C		η = 0.7	Constant
12 - DC-HRC-RH			Relative humidity
13 - DC-EXH-RH_{fsv}			Relative humidity of exhaust air Fan speed variation
14 - DC-HRC-CO_2			CO2
15 - D-EXH-RH_{fsv}	Decentralised	Exhaust ventilation without HRC	Relative humidity Fan speed variation
16 - D-HRC-C		η = 0.75	Constant
17 - D-HRC-RH_{fsv}			Relative humidity Fa n speed variation
18 - D-HRC-$CO_{2\text{-}fsv}$			CO2 Fan speed variation
19 - D-HRC-CO_2+RH_{fsv}			Relative humidity in Kitchen and bathroom CO2 in living room and bedrooms Fan speed variation

The simulated costs are including:

- the investment costs, based on the detailed component costs suggested by the French website "Batichiffrage" [14] (reference tool, widely used by the French professionals of the building sector) and completed by individual costs extracted from the detailed analysis and from 2 French installation companies,

- the maintenance costs, based on individual intervention costs provided by a French building management company and by a German housing company,
- the energy costs based on simulations performed with WUFI+ [15].

In order to validate the results, the detailed investment costs of the central system with heat recovery and constant air flow have been compared to the projects presented in Fig. 3. The simulated investment costs are lower as for these 3 projects but this can be explained by the fact that all 3 detailed projects have higher investment costs as the average for this type of ventilation system as shown in Fig. 1. The simulated planning and design cost (9.6 €/m²) is rather low in comparison with the Bugginger Straße 50 (12.1 €/m²) and with the Rue Vendôme (13.6 €/m²) and much lower as the corresponding cost for the Heinrich-Lübke-Siedlung (75.7 €/m²) which seems to be largely overestimated. Apart from this cost, the most diverging cost is the cost for construction, plaster and paintings since it reaches 15.9 €/m² for the simulation against 32.4 €/m² for the average of the detailed projects. This is due to the high value reached by the Bugginger Straße 50 for which an additional storey had to be built on the attic to place both ventilation devices.

All detailed simulated investment costs are presented in Fig. 40. The most striking observation is that heat recovery plays the main role regarding investment costs. All systems with heat recovery reach investment costs above 70 €/m² and all systems without heat recovery remain under 50 €/m².

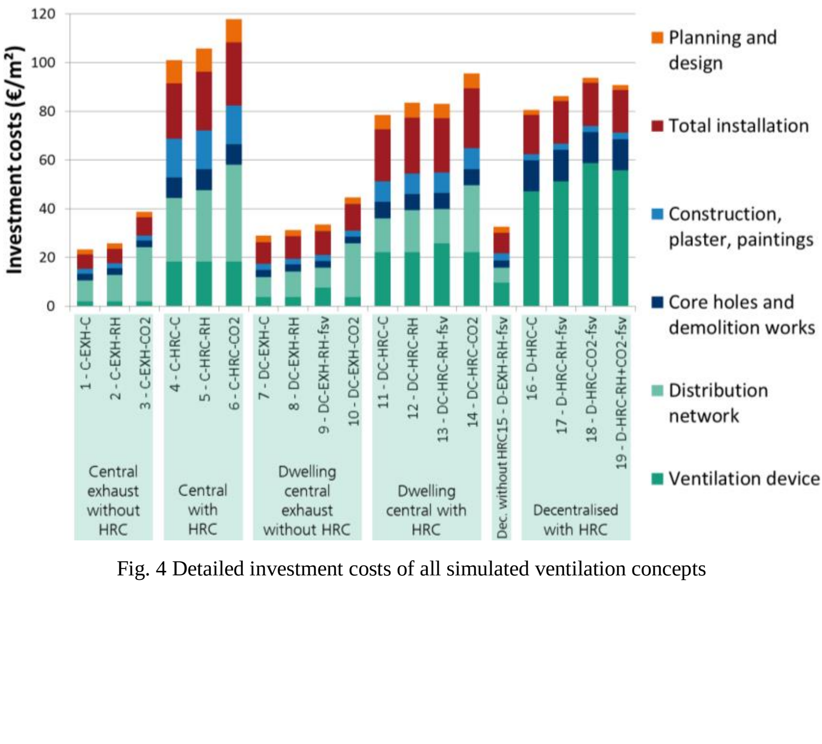

Fig. 4 Detailed investment costs of all simulated ventilation concepts

Control systems (moisture or CO_2 sensors, air dampers or rotation speed variators) also play a significant role but they are representing an additional cost of around 3 €/m² for moisture controlled systems and 18 €/m² for CO_2 controlled systems. For decentralised systems, the absence of costs related to distribution networks is balanced by the high number of ventilation devices. The centralisation level does not considerably modify the investment costs for systems without heat recovery. However, for systems with heat recovery, central systems reach the highest investment costs (above 100 €/m²). Dwelling central systems and decentralised systems are all situated between 80 €/m² and 100 €/m².

In order to validate the total cost determined by simulation, a comparison with the case studies is shown on Fig. 1. The simulated energy cost is rather low for the central system without heat recovery in comparison with the corresponding case studies. This can be due to the low number of corresponding case studies and to the fact that the simulated control strategy has been idealised. Fig. 5 shows the total costs for all simulated cases.

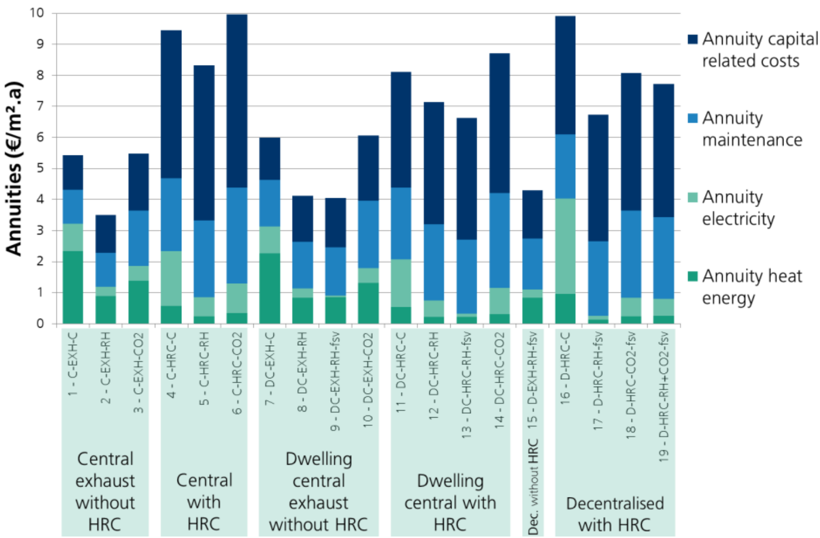

Fig. 5 Total costs of all simulated ventilation concepts

The simulated cost of the decentralised system with heat recovery is higher as both available case studies. This is partly due to the high simulated electricity cost corresponding to constant airflows. No precision could be provided regarding the airflow control for these case studies but the corresponding costs let suppose that an airflow control has been implemented in the second case study.

All simulated maintenance costs are much higher as the costs appearing in the case studies. This is due to the following reasons: the costs provided by the different partners are mostly only including the preventive maintenance and exclude sometimes internal costs and part of the maintenance operations are either assumed by the tenants (filter exchange, when the filters are in the dwellings or cleaning of air inlets and outlets) or not performed at all.

The reduction of the heat demand due to heat recovery does not balance the high corresponding investment costs. All exhaust ventilation systems without heat recovery have total annuities between 3 €/m².a and 6 €/m².a whereas the total annuities of all systems with heat recovery are in a range between 6 €/m².a and 10 €/m².a. CO_2 control is much more expensive as relative humidity control because of the high price of the CO_2 sensors. The highest energy costs (heat plus electricity) are reached by the decentralised system with heat recovery and constant airflow and the lowest energy costs by the moisture controlled decentralised system with heat recovery. Central systems with heat recovery reach the highest global costs because of their investment costs but also because of the maintenance costs. These high maintenance costs are explained by the necessity to clean the ductwork every five years. The costs differences between dwelling central and decentralised systems are not significant.

2. Conclusion

The diversity of buildings to be renovated makes it difficult to have a global evaluation of ventilation costs within retrofitting projects. Not only the buildings but also the way of working can be very different from one installation company to another. This diversity leads to a high spread between case studies. A second reason for this high spread is that the implementation of ventilation systems within the context of building retrofit is not mature yet and still requires more experience to harmonise practises.

It is confirmed that heat recovery ventilation is globally more expensive than exhaust ventilation with average annuities of around 8.3 €/m².a against 4.9 €/m².a. Other criteria like environmental impact, hygrothermal comfort or indoor air quality are necessary to justify these extra costs. An additional conclusion is that among the heat recovery systems, central systems are the most expensive ones with average annuities of around 9.2 €/m².a against 8.1 €/m².a for decentralised systems. At last, it is shown that demand controlled ventilation with moisture control leads to a significant cost reduction of exhaust ventilation systems (-34 % in comparison with constant airflows) as well as of heat recovery systems (-21 % in comparison with constant airflows).

Acknowledgements

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