FAÇADE-INTEGRATED VENTILATION SYSTEMS IN NORDIC CLIMATE

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ABSTRACT

The work evaluates the applicability of façade-integrated ventilation systems in a Nordic climate. For this purpose the state of the art of façade-integrated ventilation (FIV) and demands for ventilation system in Norway and criteria for an comprehensive evaluation are identified. In this framework agreements between national requirements and system-specific performance are assessed. The evaluation investigates indoor environment and comfort with focus on aspects of indoor air quality. Energy efficiency and emission efficiency are evaluated by comparison with a centralised ventilation system.

The used tools in this work include “ESP-r”, “Simien” for dynamic simulation of building performance and energy performance

The results of the evaluation show that current systems do not comply with all requirements of the Norwegian building code and related regulations. Some aspects need adaptation to local requirements. However, good performance and many possibilities can be expected in other fields e.g. indoor environmental comfort and user satisfaction since advanced principles are exploited.

The technology has an enormous potential. It might be an alternative if there is demand for high expectations on indoor environment and conventional ventilation systems are not applicable.

The technological limits of façade-integrated ventilation are not reached yet. Possibilities of further development of the concept itself and related technologies are outlined in the work

KEYWORDS: FAÇADE, INTEGRATION, VENTILATION, SIMULATION

INTRODUCTION

As buildings become more and more thermally super-insulated and airtight, ventilation accounts for an increasing portion of heat loss and energy consumption. Strategies have been developed to decrease the energy demand connected with ventilation. In case of mechanical ventilation systems the focus lies on the optimisation of transported volume, treatment and distribution of air within the system. The discussion about minimised airflow rates and demand controlled operation is in the centre of attention [1].

Other concepts like hybrid ventilation integrate ´free´ natural ventilation to provide a robust and sustainable strategy. Aim is to benefit from the best of both, mechanical and natural ventilation. Highlighted is the positive response from users, the possibility of individual control and the transparency of the ventilation's response. Less dependency on mechanical systems and increased flexibility while reducing costs are strong motivations in this respect [2].

Primary goal of most of these concepts is to ensure a comfortable indoor environment with acceptable indoor air quality. Especially in non-domestic buildings high requirements on the indoor air quality meet a high energy demand [1].

Decentralised ventilation systems are proposed to be a state-of-the-art technology which has shown favourable performance in the field. Flexibility and individual control are combined with high energy efficiency and reduced need for space. In the last decade the technology has proven to be mature and successful in operation. This good performance was experienced so far only in the context of Central Europe. If it can be also an option in another climate like Norway will be investigated in this work.

METHODOLOGY

The building is a low-energy office building with ambitions for lowest possible energy demand. Oslo as standard reference location was selected as geographical position. For the “Simien” simulation could be drawn on the standard climate condition for Oslo/Blindern [9]. This climate data is not available for “ESP-r” where the climate file for Oslo/Fornebu is used which has been retrieved from the US DoE website. Here seasons and typical weeks have been determined in agreement with the procedure described in [3].

Ventilation

Centralised systems with demand-controlled ventilation suffer from constraints mainly related to the throttle valves in the ductwork which are necessary to control the air distribution. The dampers in ventilation systems can neither be completely opened nor closed. As a consequence the airflow rate through the damper is limited to a range of 30 to 80% of the maximum airflow rate. Furthermore, the control of dampers within the distribution network of a centralised DCV system is very complex as discussed in length by Grini and Wigenstad (2011) [4].

The common practice to deactivate the ventilation outside occupancy is not in compliance with TEK 10 § 13-3 [5]. A minimum airflow rate of 0.7 $m^3/(h\cdot m^2)$ is required to remove material and interior related emissions. Grini and Wigenstad (2011) argue that the background for this regulation is not clear. The airflow rates were not related to EN 15251 regarding the procedure described in Annex B.1.2 [6]. However, a requirement for an airflow rate of 0.1 to 0.2 $l/(s\cdot m^2)$ can be found in EN 13779 as secondary option to ventilation with two air volumes prior to the occupancy [7]. In the related standard NS 3031 this is taken into account as the operation time for ventilation starts 6:00 to supply fresh air two hours before working hours (Dokka, Berg and Lillelien, 2011) [8;9]. Additionally the minimum airflow rate outside occupancy is required which poses the question why both measures, morning boost and basic ventilation rate are used in NS 3031 [8].

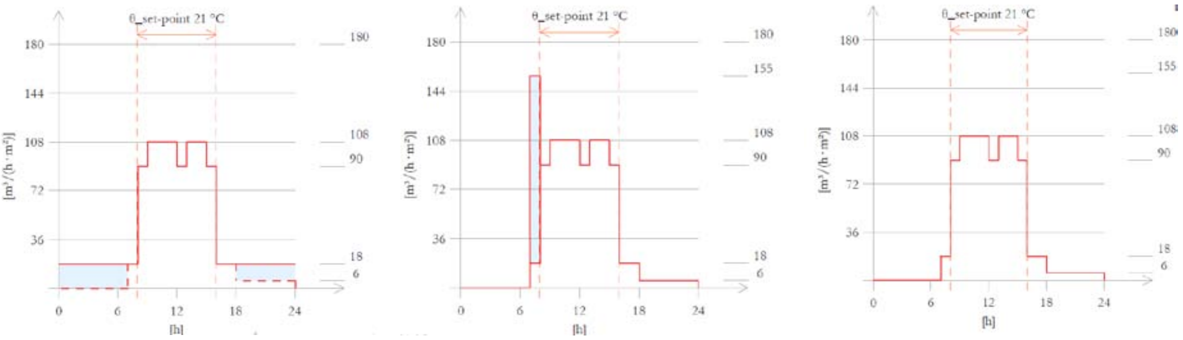

Figure 1. Illustration of different ventilation strategies.

Preventing growth of micro-organisms in the air handling unit is considered a reason for continuous operation. Reviewed research on the alternative operation strategies (continuous vs. night shut-off) shows no clear advantage for one strategy [4].

However, the necessity of regular cleaning and maintenance was highlighted in this context. These issues do not apply to FIV. Units can run for short periods only outside occupancy which is advised by EN 13779 as third alternative. Running one of the two units for 18 minutes an hour at an airflow rate of 60 m³/h can provide the required 0.7 m³/(h· m²) for the exemplar room, for instance. Furthermore, dampers and ductwork are not present and hence problems linked to them can be neglected.

The influence of the different strategies on the thermal comfort and energy performance was investigated. The continuous operation is represented in the base case of the “ESP-r” model and will be compared with the alternatives of a morning boost and total deactivation outside occupancy (figure 1).

Modelling and simulation

For whole year energy performance simulations the software “Simien” version 5.010 is used. “Simien” is based on the the method for dynamic simulation as described in NS 3031 and has been validated against EN 15625 [10].

The detailed simulation and parametric studies are performed with “ESP-r” utilising the airflow network model. “ESP-r” was developed at the Energy Systems Research Unit (ESRU) at the University of Strathclyde [11]. In this work the most recent distribution 11.11 for GNU Linux was used. Optical properties for the glazing and shading (“complex fenestration constructions”) are obtained from “GSLedit” using specifications for glazing and shading from “Pilkingtion” and “Warema” [12].

One single exemplar room is simulated instead of an entire building. This approach reduces complexity, improves quality control and allows flexibility for multi-criteria assessments [3]. (Hand, 2010). The exemplar room represents a generic office room for three persons with two FIV units in the uppermost floor of a fictitious office building in Norway. The generic room is not project specific allowing the simulation of conditions in new buildings as well as in energy-focussed refurbishment of existing buildings. The setting can be considered as worst-case scenario. The room is exposed to outdoor conditions both, on the façade and via the ceiling (roof) while having a high occupancy (8.64 m² per person).

Construction

Buildings elements facing outside are super-insulated. Walls and the roof feature U-values of 0.08 W/(m²K) and the U-value of the window glazing and framing is 0.8 W/(m²K). As typical in Norway, the wall construction is a light-weight timber construction with low heat storage capacity. The size of windows is guided by TEK 10 § 14-3 limiting the window area to 20 % of the usable area BRA [5]. The triple-pane glazing has a g-value of 0.45 and external shading with 80 mm Venetian blinds and automatic control triggered 200 W/m² insolation limits unwanted solar gains. The concrete slab at the ceiling is fully exposed. A raised floor with parquet flooring is assumed for the energy calculations and results in a light-weight floor construction (in the detailed simulation the floor is a separate zone). Internal walls are light-weight partitions with gypsum plasterboard finish. Thermal bridges are considered with 0.03 W/(m²K). All building materials are considered normal-emitting.

The value for airtightness n50-value is 0.4 h-1 which is considered easily achievable with proper quality of the construction. For “ESP-r” the n50-value must be converted to infiltration in normal pressure conditions. Therefore 0.4 h-1 is multiplied with the screening factor e = 0.07 in agreement with NS 3031. The resulting value for n4 is approximately 0.03 h-1 and applied to the zone of the raised floor only.

Model

The façade of room is 4.80 m wide representing four common Norwegian façade raster of 1.20 m [13]. To investigate different usage scenarios the exemplar room spans over two single office room modules with 2.40 m width. The partition walls and the connecting central wall depend on the usage. The height of the room is 3.00 m.

The determination of the room depth and the eventual total space volume is a result of considerations related to the FIV system to find an optimum starting point for a parametric study. The room could be designed according to heating, cooling or ventilation capacity of the FIV units. However, heating and cooling are not crucial parameters because firstly, the units are powerful enough to cover the loads and secondly, compensation with auxiliary systems is possible. In contrast, designing a system according to indoor air quality dictates high benchmarks when using TEK 10 and EN 15251.

Most commercial systems have three-stage pre-sets. Common settings are 60, 90, 120 m³/h outdoor air supply. A first literature review in DeAL (2008) shows that airflow rates higher than 90 m³/h may cause acoustic issues [14]. Therefore this value is considered as design airflow rate during occupancy. Up to 120 m³/h airflow rate may be used outside operation hours e.g. for night cooling or higher occupancies.

The dimensioning airflow rates follow TEK 10 § 13-3 – during occupancy 26 m³/h per person and 3.6 m³/h per square meter floor area for materials and outside occupancy 0.7 m³/h per square meter floor area. The size of the room was chosen to find reasonable matches between the required airflow rates and the air volumes of the FIV units. In the base case which will be used in the energy calculations two units with each 90 m³/h and a total of 180 m³/h supply air to an office with an occupancy of three persons representing a demanding setting with 8.64 m²/person.

In summary, the dimensions of the exemplar room are 4.80 x 5.40 x 3.00 metres, the floor area is 25.92 m², and the heated air volume 77.76 m³. Windows are treated differently in “Simien” and “ESP-r”. In “Simien” each window measures 2.20 x 1.20 m. In “ESP-r” a window measures 2.40 x 1.20 m whereof 10 cm frame all around result in a glazing area of 2.20 x 1.00 m. The exterior surface/volume ratio A/V equals 0.52 m-1, which makes the room an ambitious environment for studies.

Schedules and internal loads

Various schedules and loads are used for different simulations due to their significant impact on the performance. Initial input values for the energy performance simulations with “Simien” have been reviewed since the test room does not include secondary spaces like corridors, storage, etc. [15].

“ESP-r” allows very dynamic schedules and loads. This will be taken into account for the detailed simulation focussing on transient conditions. Design values for human loads and equipment from EN 13779 will be used. The possibility to express the delay between presence and actuation (See also further discussion of the time delay TD-OFF in Halvarsson, 2012 was discarded to reduce the complexity but also because instant response from FIV system can be expected [16].

Schedules

The occupied period in NS 3031 is scheduled as 12 hours a day five days a week in 52 weeks per year. Default settings in “Simien” are set from 6:00 until 18:00 and are used for the simulations there. Since normal working hours are from 8:00 until 16:00 this results in two hours overhang before and after the working hours. It is assumed that the ventilation system starts two hours before the occupancy begins at 8:00 and remains active one hour after the occupancy has ended at 17:00 [9]. For an advanced representation of DCV a scenario was developed with an occupied period from 8:00 until 17:00. This schedule is assigned to the

case studies with index “b”. ´Unforeseen´ occupancy is assigned then in the hour between 16:00 and 17:00. This is in good agreement with with measured data for operation hours in offices by Halvarsson (2012) [16].
The presence during the occupied period is estimated in NS 3031 by reducing the standard values by 20 %. PR 42 assumes 60 % actual presence to establish input values for lighting loads and ventilation rates. The results of Halvarsson (2011) reinforce this assumption. Based on his profile for high occupancy on page 164 a slightly modified and simplified occupancy pattern was developed for the “ESP-r” simulations. The assumption of variable occupancy equivalent to 2 minutes per hour in the evening was kept.

Equipment
Dokka et al. (2009) assumes the use of equipment (a total of 100 W / person, same as used in EN 13779 for design load) for 80 % of the occupied period in the primary area while in the secondary area the load is assumed as 2 W/m² during the occupancy. Therefore the gains in the scenarios PR42 and FIV of the energy simulations are also decreased to 80 W per person. In the detailed simulations the loads follow the percentages of the schedule assuming 100 W/person as 100%.

Lighting
Dokka et al (2004) refers to “Lyskultur” and uses 6.4 W/m² as initial value for the primary area without control and 100 % occupancy. In the case study PR42_0 this values is used adjusted for 60 % presence. For case studies with higher precision (PR42_a, PR42_b, FIV_a, FIV_b) loads for the single months are respecified using an “Ecotect”/”Radiance” daylight simulation of the test room in combination with EN 15193. In a second step the values have been altered depending on presence (60 %). The last column is the reference value from PR 42 with static values for each month. (Table 1)
For “ESP-r” 6 W/m² are assumed in case of 100 % presence throughout the year. The hourly values depend on the dynamic schedule.

month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**mean**	**default**
based on 100% presence	6.1	5.6	5.0	4.5	4.5	4.5	4.5	4.5	5.0	5.5	6.0	6.2	5.2	6.4
Adjusted for 60% presence	3.7	3.4	3.0	2.8	2.7	2.7	2.7	2.7	3.0	3.3	3.6	3.7	3.1	3.8

Table 1. Monthly internal gains from lighting according to EN15193.

RESULTS

Energy consumption

A FIV system with two different schedules (FIV_a and FIV_b) based on detailed design input parameters is compared with an ideal TEK 10 compliant centralised system. Two reference settings are based on standard values in the corresponding sources NS 3031 and PR 42 (TEK10_DCV, PR42_0). They are adjusted for DCV and primary area. Others reference cases (PR 42_a and PR 42_b) use design values equivalent to the FIV case study for a direct comparison of performance. Cases FIV_a and PR 42_a will be in the main focus as both allow a direct comparison.

Heat loss
Figure 2 shows the heat loss budgets for the case studies FIV_a and PR 42_a.

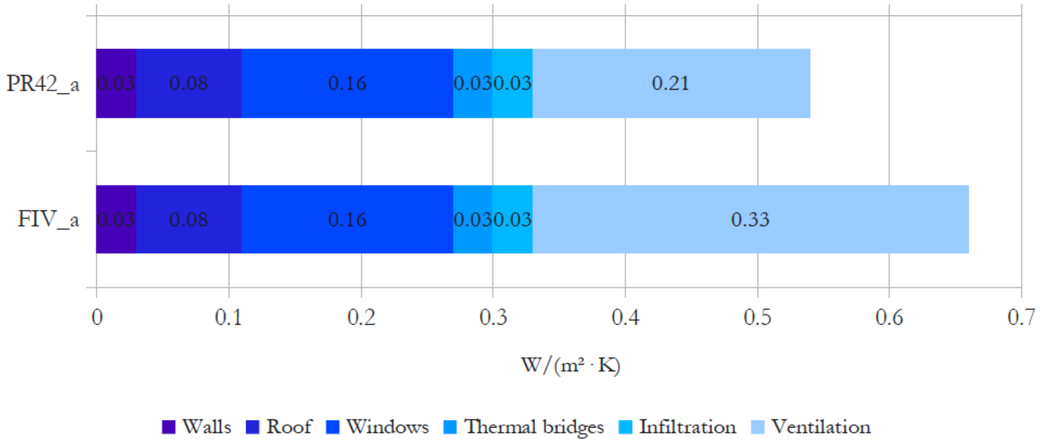

Figure 2. Heat loss of the two cases (PR42_a and FIV-a).

A heat loss factor of 0.5 W/(m²·K) as specified by PR 42 for office buildings cannot be achieved with either system due to the location of the exemplar room and the resulting heat loss to the roof. Case study FIV_a reaches a heat loss factor of 0.65 W/(m²· K) while the reference scenario PR42_a reaches 0.53 W/(m²· K). The ventilation heat loss of the FIV system accounts for half of all losses.

Heating and cooling

An overview of the simulation results is given in Table 2.

	Specific energy demand			**Specific installed capacity**		
	Space heating [kWh/(m2a)]	**Ventilation heating [kWh/(m2a)]**	**Ventilation cooling [kWh/(m2a)]**	**Frost protection [W/m2]**	**Ventilation heating [W/m2]**	**Ventilation cooling [W/(m2]**
TEK10_DCV	7.8	11.4	3.8	-	19.5	23.0
PR42_0	9.1	9.1	4.0	-	21.8	24.2
PR42_a	6.2	10.5	3.4	-	17.5	19.5
PR42_b0	9.4	11.7	3.1	-	17.0	19.5
FIV_a	5.3	24.3	2.4	12.6	36.2	18.7
FIV_b	9.4	20.3	2.7	9.8	36.2	18.7

Table 2. Specific energy demand and required heating/cooling capacities.

The space heating demand is approximately equal for both systems. However, the heating demand of FIV units is significantly higher than centralised systems. The ventilation heating demand is up to 2.5 times higher due the low efficiency of the heat recovery. This also affects the power requirements. The FIV case studies require 46 to 49 W/m² installed ventilation heating capacity where 36 W/m² account for the heat exchanger compared to the less than 18 W/m² of the comparable centralised system. However, even assumed 50 W/m² installed heating capacity result in approximately 650 W per unit which does not affect the applicability of FIV as the nominal heating capacities for FIV units begin at ca. 800 W (Appendix B). Furthermore, it has to be considered that these values do not include frost protection.

In general, the cooling demand is very low compared to the heating demand due to the night cooling strategy. The necessary capacities for corresponding centralised and decentralised systems are close to 20 W/m². The dependency of the cooling demand on the transported air volume is apparent comparing the results for FIV_a and FIV_b. If the schedules are optimised to the occupancy as in FIV_b then both, the energy demand for cooling and the installed power of centralised systems is lower than for the comparable case studies PR42_a and PR42_b.

Electricity demand for fans
The difference of the specific fan power between centralised and decentralised ventilation system is evident in the results for the electricity consumption of the fans (figure 3).

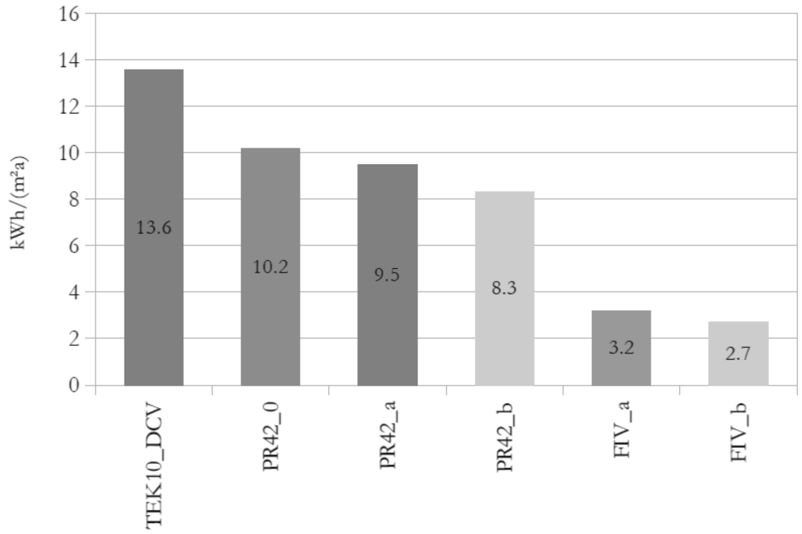

Figure 3. Specific energy demand for fans.

Decentralised systems consume on average only one third of the respective centralised system. Advantageous for the FIV systems are the low SFP of 0.6 kW·s/m³ due to the use of energy-saving EC fan motors.
Also noticeable are the quite different results for the case studies of the centralised ventilation system depending on the used input parameters. Using design values shows in general lower demands than the default values. Separate calculations for clearly defined primary and secondary areas instead of assumptions for the whole building (60 % primary area in Dokka et al. 2009 or 65% in Dokka, et al. 2011) might show more refined results.

Net energy demand
Figure 4 shows the total energy budgets for the investigated case studies.

Within the framework of this study the examined FIV case studies show higher net-energy demands than the centralised ventilation systems. The energy demand of FIV_a is 8% higher than the equivalent case study PR42_a. However, considering the quick response which is typical for FIV the comparison between PR42_a and FIV_b is possibly more realistic. The reduced occupancy from 12 to 9 hours leads to reductions of 11 to 13% energy demand. The detailed energy budgets for PR42_a and FIV_a are presented in figure 5.

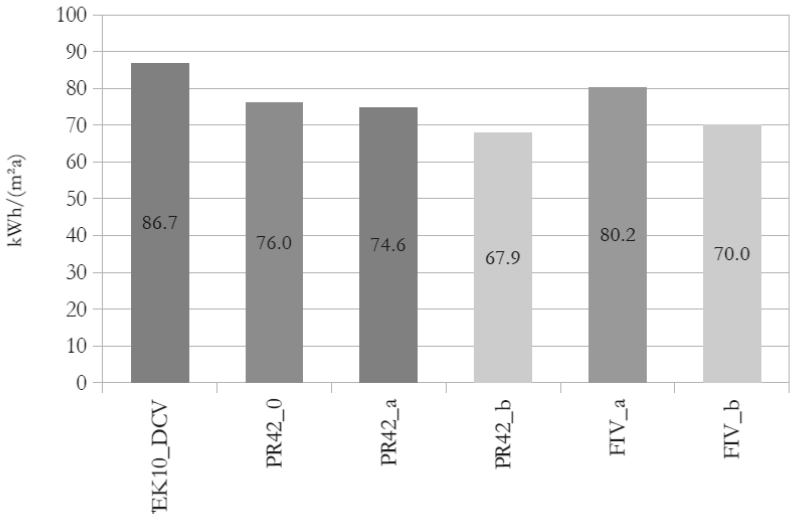

Figure 4. Specific net energy demand.

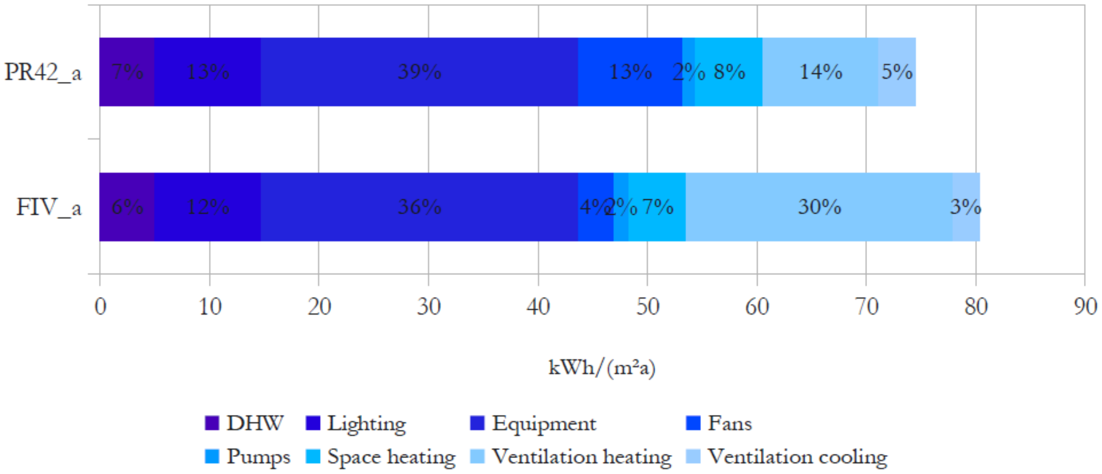

Figure 5. Specific net energy demand.

In both cases almost 60% of the energy budget is related to domestic hot water, lighting, and equipment where lighting is already adjusted to every single month. In case of the FIV scenario the positive impact of the little energy demand vanishes considering the high demand for heating which accounts for 37% of the total energy budget. In contrast, the centralised system has both, a low energy demand for fans and heating due to demand controlled ventilation. Apparent is the little demand for cooling. Reasons may be found in the impact of adjusted input parameters for schedules and internal loads due to demand control.

Heat recovery

Key issue to an improved energy performance of FIV systems is heat recovery. Most FIV units have heat recovery with low efficiencies due to the use of plate heat exchanger. Higher efficiencies have not been requested in previous applications. If a rotary heat recovery would be used then efficiencies can be further increased and frost protection is not required. The integration of rotary heat recovery in FIV is technologically possible as one system uses already rotary heat recovery with up to 62 % efficiency in a 160 mm thin FIV unit (LTG FVM, 2009).

This has been investigated further with case study FIV_a using PR42_a as reference. Figure 6 shows the net-energy demand for FIV_a equipped with either plate heat exchangers or rotary heat recovery with various heat recovery efficiencies. The maximum limit of the plate heat exchanger is assumed as 70 % efficiency.

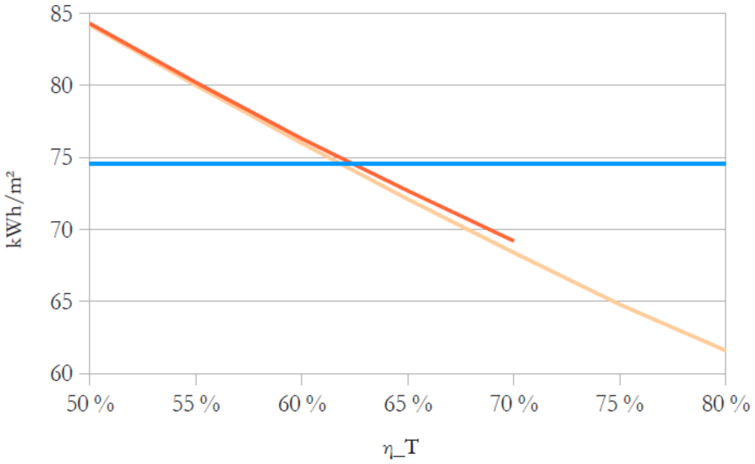

Figure 6. Specific net energy demand.

If the heat recovery of the FIV case study would reach an efficiency of approximately 62% then the net-energy demand equals the reference case with 80% efficiency. A rotary heat recovery unit with 70% efficiency results in an annual energy demand of 92% of the corresponding centralised system. With the same efficiency heat recovery as the reference the net-energy demand of a FIV system would be only 83% of the reference.

CONCLUSION

Aim of the work was to evaluate the applicability of façade-integrated ventilation in a Norwegian context. It can be seen that currently the reviewed FIV systems designed for Central European conditions do not comply with all requirements of the Norwegian building code.

Adaptations to Nordic conditions are necessary leading to custom-made systems which are possible if a demand arises. For some aspects a good performance can be expected also in Norway while other topics require upgrades.

Energy efficiency with respect to the net-energy demand is critical in Nordic conditions. Competitiveness with centralised systems cannot be achieved in this respect at the moment. If also the energy supply and related emission factors are considered then both systems can reach similar performances.

High indoor comfort and indoor air quality can be expected as state-of-the-art concepts and mature high-performance components are utilised. Acoustic and humidity conditions are critical where the first may be solved by proper planning. The possibilities of individual control and usability will results in high user satisfaction. On the other hand, cost and maintenance can be an issue especially in Norwegian conditions. If must be decided in the individual case if feasibility is given when the expenditures are traded off against user satisfaction.

However, the concept of façade-integrated ventilation has an enormous potential as the technology has not reached its limits yet. More research and development regarding design of components and operational strategies of the technology is necessary. Also the potentials of application have to be explored further. FIV can be a competitive alternative when conventional systems fail or are not applicable, in retrofitting for example.

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