Appropriate Ventilation Solutions for the Iconographic Buildings from the Fifties – A Cross Disciplinary Investigation

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Abstract

In Denmark we currently have an increased focus on preserving the most valuable domestic building examples from the period 1945 - 60. New literature deals with these architectural heritage matters. The authors of this paper argue, that due to question of preservation the buildings physiology is not enrolled in the discussion, and argue that especially this issue can cause a huge damage on the aesthetics of the architectural expression, the facades and the use of the buildings in terms of comfort demands for people living here.

The starting point for the research is preservation, comfort and aesthetics. The primary topic of the survey is the building envelope as a transmitter of external climate to internal climate and vice versa. Three case studies and one reference building as principal renovations are used as information for new innovative and integrative solutions. Analyses and discussions will show a development to the introduction of mechanical ventilation in the building stock with a particular focus on decentralized ventilation systems. To evaluate the retrofitting initiatives a cross-disciplinary corporation between the professions of architecture and engineering are required: this integrated working methodology develops new renovation processes.

Based on both quantitative measurements and on qualitative judgements the cases are analysed comparatively. Parameters such as ventilation solutions in facades are discussed as architectural consequence and value. User interviews will also inform the evaluation. Cases are chosen from earlier research projects and brought into the analysis in order to either see a development or to see more clearly how integrated evaluations of the ventilation and the preserving strategies can lead to a better understanding of an optimized intervention. The paper concludes that interdisciplinary ways of working will improve both architecture and preservation and comfort, and that higher value hereby is created. Furthermore the new initiatives from the industry are shown, which indicates a movement towards innovation of decentralized ventilation solutions.

Keywords: cross-disciplinary cooperation, indoor climate, decentralized ventilation, energy renovation solutions

1. Introduction

The Modern Movement in the 1920s was a reaction to the former stylistic architecture and to the urgent need for low income housing: several architects took the initiatives towards the Modern Movement (CIAM 1933).The modern architectural ideas were among many other ideas defined according to new construction possibilities and industrialized methods: new forms and proportions, flat roofs and no decoration, new materials such as reinforced concrete and steel. New rational building methodology was the new mantra for the movement. The housing areas were laid out in open parks and designed with better flats, where the functionality was the basic fundament for space, distribution and orientation, sun, light and air for people from the working class.

Danish progressive architects were inspired by these ideas and they designed new ways of living at the outskirts of the cities. After WWII there was scarcity of materials, and the modern ideas were moderated to the actual possibilities of solving a huge demand for dwellings. This situation created the modest functionalistic architecture (Nygaard1984), where architectural ideas were designed and built by Danish local craftsmanship, constructions and materials. The result was a special local translation (Lund1993) of these modern thoughts into a large number of very fine suburban areas characterized by masonry and very fine architectural design.

This paper will focus on the functionalistic housing built in the period after WWII 1945 – 1960 (Vestergaard 2011), which represents a most valuable treasure in the diverse Danish urban fabric, especially regarding functionality and aesthetical qualities. The period is known for its embedded qualities both in respect to architecture, space and daylight, but also paying respect to traditional materials and modernistic form and detailing.

Figure 1: Typical housing block, entrance, balconies

The buildings are of different value, but a considerable majority belongs to the architectural heritage of the period (Bech-Danielsen 2015). The buildings are characterised by red or yellow masonry and of high aesthetic quality. The facades are aesthetically well designed and the geometry includes important functional detailing such as very efficient ways of dealing with materials and proportions, balconies and details see figure 1. Basically the architecturally expression of these treasures must be kept through the future retrofitting. The building law is reflected by the designs which address demands to staircases, balconies, indoor design/organisation and size, but also address demands to fresh air and ventilation.

The airflow through the dwellings reflects the building practice of the time and the Copenhagen Construction Law (Københavns byggelov 1939) and was originally operated by separate natural air channels related to the bath and kitchen, see figure 2.

Figure 2: Natural ventilation distributed through facade related to kitchen and bath

Today's urgent demand for retrofitting is caused by the massive backlog in the housing sector, rising energy prices and fulfilling the European targets of CO2-reduction within 2020 and recently 2030 (EU 2010), which generates a growing demand for new renovation solutions for insulation and air-tightness of the existing climate screen.

By upgrading the climate screen and introducing balanced mechanical ventilation in a number of cases this paper will show, how the comfort in the dwellings is improved through the controlled indoor climate and how the air change has become a parameter to estimate indoor air quality. Balanced mechanical ventilation has been introduced to the existing brick buildings from the 1950s social housing, and development of innovative ventilation solutions have moved from centralized to more decentralize over the last decade (Klint 2009b).

This paper argues that there is a development in new ventilation solutions, towards more sensible solutions, while introducing the balanced mechanical ventilation to the buildings from before 1960. Considerations of where and how to place the ventilation unit will be carried out. Economical perspectives and development towards higher energy efficiency of units will be predicted. The challenge of securing a good indoor climate and a high user satisfaction will be argued. It is realized that very little Danish statistic references in terms of technical ventilation systems in existing multi-story housing, have been carried out. Whereas the statistical investigations have been done in Central Europe regarding office buildings (Mahler and Himmler 2008). However; it is here estimated, that mechanical extraction is the most commonly used ventilation system of today in the multi-story housing in Denmark.

When discussing renovation and architectural heritage, it is very important to establish a holistic understanding and framing. The aim of this paper is to review the complex problem in which the research focus is imbedded. To challenge the discussion it has been chosen to focus specifically on the climate screen as an instrument for better comfort in respect to light, sound, temperature, humidity, energy and air and not to forget preservation of the aesthetics of the architecture. In order to point out broader perspectives the complex challenge is done interdisciplinary.

The research question to explore: How to perform a cross-disciplinary cooperation in renovation of social housing to preserve the architectural expression and the facades and the use of the buildings in terms of indoor comfort?

2. Methodologies

The investigation is based on measurements and simulation from four cases, in which selected parameters within energy renovation has been documented, analyzed and evaluated through a triangular survey of quantity, quality and user experiences from questionnaires.

General and newly developed knowledge from the study of literature are brought into the discussion and compared to the case studies.

In order to open the research and discussion, we have used comparative analysis methodology. The reference and the three cases represents a development in Denmark from 1915 up to 1960, both as architectural and construction wise relatively broad change, but especially the demands to indoor climate and energy efficiency compared with the preservation question.

An integrated research process can be understood as a concept in which the determination and development of a product or a process integrates all relevant parameters, ranging from the aesthetical and the psychological aspects to the technical, the logistical and economical aspects. The authors of this paper have as a team developed the research as an integrated research process, which methodologically builds on tools such as ‘Clean Process’ (Blyt 2013).

Regarding the content of the research we have focused on architecture and engineering, on architectural heritage, on indoor comfort and on user demands: from this foundation the idea of the abstract has appeared. From the very beginning of this survey the broad discussion has played a driving role for defining the content, the analysis and the discussions of both the problem and the working methodology of the integrated research process.

In order to establish the current state of ventilation principles in existing multistory housing, the conditions are shown, see figure 3 for three different balanced mechanical ventilation approaches for renovated housing and for a reference case characterized by natural ventilation as a normal situation for housing built before 1939.

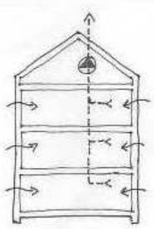
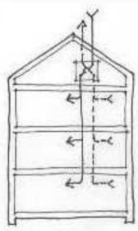
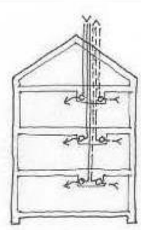
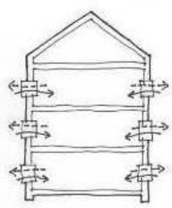
	Reference	Case 1	Case 2	Case 3
Location:	Horsens	Copenhagen	Copenhagen	Copenhagen
Built/optimized:	1945/-	1927/2000	1950/2001	1915/2015
Ventilation system:				
Extraction	X			
Centralized		X		
Decentralized, ceiling			X	
Decentralized, facade				X
Graphical illustration of ventilation solution				

Figure 3: Overview reference case and case 1, 2 and 3

3. Criteria and Findings

The defined parameters for the survey are listed below. Data and sources are quantified and qualified, and user satisfaction is brought into the evaluation. Through the survey the value based importance of the parameters are found.

3.1 Architecture and preservation

It is evident that many of the housing schemes from the 50s are facing modernization, but coordinated knowledge is lacking of how to bring the buildings into the future without compromising the principal preservation values (Dansk Bygningsarv 2015). This brings the headline ´architecture and preservation´ as a highly rated parameter into this paper´s evaluation of both aesthetic and historic values.
The buildings from the period are obviously challenged as both materials, details, cold bridges, joints and the overall aesthetics and a huge amount of buildings must be kept untouched besides from the installations. At the recently published Danish literature of the period the ventilation question is hardly mentioned, but from several case studies from the 50s it is obvious that the question of air exchange can bring these building´s indoor and outdoor expression in danger if not taking properly consideration to the huge damage centralized systems can force. That is basically why we in this paper have focused only on ventilation renewal. Under these circumstances the ventilation devices must be implemented and expressed through a very gentle design. If talking about the façade, the existing façade construction is born with functional perforations such as fresh air canals and filtered masonry to the food store/room. These can be brought in activity in the renovation design.
Through studying this parameter several innovative products have appeared, such as the ventilation window and the integrated parapet solution from Ecovent, see figure 4. Also some products like ventilation windows are very promising constructions for solving the design of the façade (Klint 2009b).

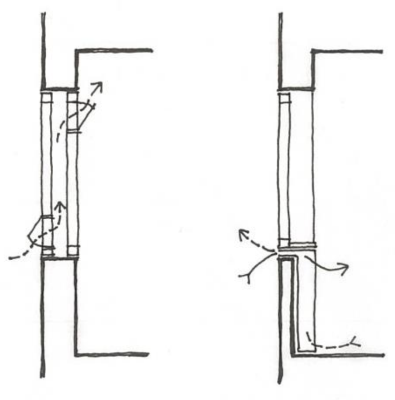


Figure 4: Innovation: Ventilation window and facade solution from Ecovent. To reduce the necessary space required for facade integrated solutions the companies continuingly works with new decentral solutions.

3.2 Space and daylight

Common value based set of norms are existing amongst professional architects regarding a successful experience of architecture: the space should be well defined and proportioned, space should be well lit and the choice of materials should be in harmony and allow the tenants to influence the space with their own selection of arrangement. In addition to this the space should also be designed as extremely functional with good possibilities for furnishing and easy to clean. This means that every disturbing visual installation should be avoided. Both the building regulation in the 50s and a good design ability of the architect shaped the daylight quality. For the future it is important to pay attention to efficient space and to respect the daylight distribution.

The design of the ventilation points in many aspects to the façade ventilation solution. The decentral solution distributing canals to all rooms in the flat, hidden above a hanging ceiling; occupy space primarily in the corridors. Also canals in the rooms can occur. The decentral solutions concentrated under the window inside the heating niche looks very discrete and can be developed to a high aesthetic standard. The decentral solution, described as devices hanging on the wall perpendicular to the façade, will disturb the room feeling. But if integrated under the roof above the window, there will be more discrete possibilities for an acceptable solution. Example of innovation: Change of filters is a huge issue for organizations maintaining the buildings, because this has to be done inside the flat. Also related to this issue it is observed that new innovative filter components are developed. A better insulation value of the window, either 3 layer energy glass or similar will reduce the amount of incoming daylight.

3.3 Energy Efficiency

Energy efficiency in buildings can initiate a mayor renovation, because of the potential annual savings in energy from optimization of the constructions and installations. More than 40% of all surveyed multi-storey housings in Denmark from before 1960 has an energy label D, which is comparable to a maximum annual heat consumption of 150 kWh/m^2/year (Kragh 2015). The heat consumption based on the ventilation of multi-storey housings in the period from 1931 to 1950 is estimated to approx. 25% of the total heat consumption (Wittchen 2004). By using new high efficient counter flow heat exchangers with an efficiency of 80 – 90% such as in the decentralized ventilation systems in case 2 and 3, energy savings as high as 30 - 40 kWh/m^2 per year of the annual heat consumption can be reduced in multi-storey housings from before 1960 (Tommerup 2004).

3.3.1 Energy consumption - Heat

The case studies and the reference building investigated are supplied with district heating. Figure 5 shows the annual heat consumption related to the net floor area for the 3 cases before and after installing the balanced mechanical ventilation system, and for the reference building the consumption before the proposed energy renovation.

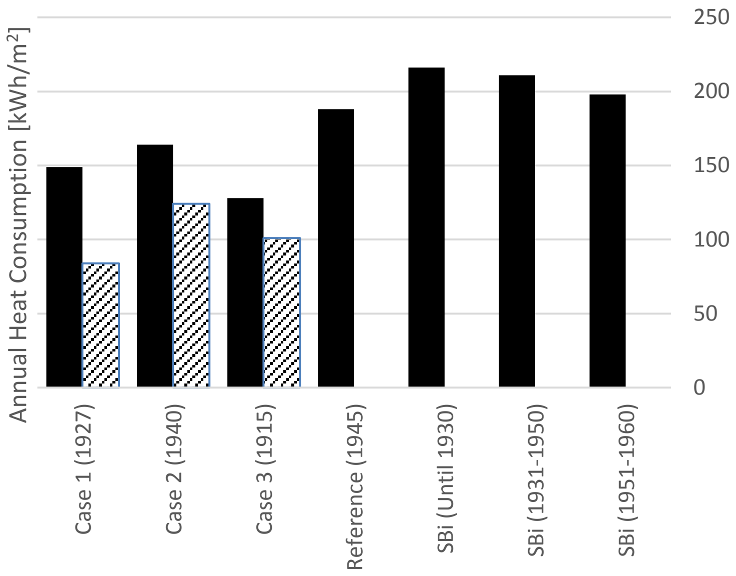


Figure 5: Annual heat consumption before and after renovation

Case 1: This energy renovation is based on balanced mechanical ventilation used with joint intake and exhaust, however there were both central and decentral heat recovery units for the winter combined with natural ventilation in the summer. The energy savings are obtained by preheating the ventilation air in solar low energy ventilation tower to hide ventilation ducts and produce solar energy at the same time.
Case 2: In this case the energy renovation was based on decentralized balanced mechanical ventilation with heat recovery in each dwelling and joint extraction ventilator in the roof space. Solar cells were used to match the electrical consumption of the ventilation units.
Case 3: The energy savings in this case are based on high efficient and low consuming decentralized balanced mechanical ventilation solution in the facade, replacement of the old windows with new triple layer energy glass and re-insulation of the cavity in the external wall and the story partition.
The average annual heat consumption for multi-story housings in Denmark is based on the SBi-report (Wittchen 2009) on the basis of registration made by the authorized energy labelling consultants in the period from 2005 and 2008. The annual heat consumption in the reference building is based on the registrations from 2013 to 2014 and corrected by the Danish Design Reference Year 2010.

3.3.2 Energy consumption - Electricity

Measurements of the electricity consumption shows that the energy consumption from a decentralized balanced mechanical ventilation unit type V300 from the company Ecovent, which generates a ventilation flow of 45 m^3/h, uses less than 8 Wh electricity comparable with 0,2 EUR per day and an annual electricity consumption of 70 kWh. With an electricity cost of 0,2 EUR per kWh (incl. vat) in Denmark the annual cost for a dwelling with two units is approx. 30 EUR (Klint 2009b).

3.4 Comfort measurements

Measurement of the comfort in existing buildings with newly installed balanced mechanical ventilation shows that the indoor climate generally is improved. However, the comfort parameter of draft caused by leakiness in the climate screen or directly from the ventilation system (both the central and decentralized ventilation solutions) haven't been investigated thoroughly in any of the cases even if the user surveys reveals problems within this area.

Some results show an improvement of the draft problems after re-insulation or replacement of the climate screen; however the draft caused by the ventilation system itself hasn't been covered sufficiently. A research paper aiming at investigating air renewal effectiveness of decentralized ventilation devices with heat recovery (Coydon and Pfafferott 2014) concludes, that even if the ventilation system removes pollutions like CO^2 from the room, the distribution of air and the experience of the air supply is depending on the temperature, speed and direction of the airflow.

3.5 Ventilation rate (carbon dioxid measuring)

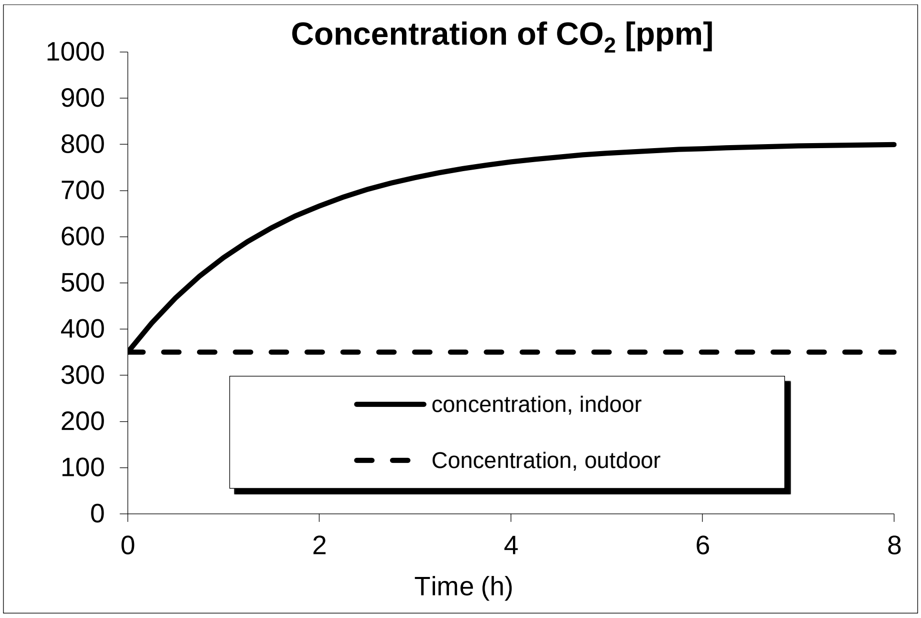


Figure 6: CO_2 concentration progress in case 3.

Figure 6 shows a calculation of the CO2 concentration in case 3 after the dilution principle with an air change of 0,6 h^{-1} corresponding to the measured ventilation amount in the dwelling from the decentralized units. The ventilation efficiency of the decentralized units shows very promising results to comply with the demands, which applies for new buildings in Denmark. However; this has to be documented in a larger scale to have been significance.

3.6 Noise emission from ventilation system

There are no qualified measurements of the noise from the decentralized ventilation solutions, however the units are undergoing a progressive development to reduce the risk of noise, such as optimizing and moving the fans to the primary side of the heat exchanger. The user survey showed no discomfort caused by noise, however a German study in 10 office buildings with decentral ventilation solutions the measured sound emissions in some buildings were above the limits of workspace environments (Mahler and Himmler 2008).

3.7 Users´ survey

In this investigation a user survey was carried out in the reference building with the purpose of comparing a building with mechanical extraction and high potential to saving energy by installing balanced mechanical ventilation with heat recovery.

User experienced dissatisfaction in %	Very often	Often	sometimes	Seldom	Not at all	No opinion
Room temperature	3	14	41	27	12	3
Vertical temperature	13	26	22	27	12	
Draft by the window	13	19	20	32	16	
Draft generally	8	23	17	25	27	
Air quality, smell	7	25	35	19	14	
Air quality, fresh air	1	4	21	31	43	
Air quality, generally	4	39	43	6	1	7
Sound level from int.	12	40	21	13	4	10
Sound level from ext.	3	30	25	23	5	14
Daylight	3	6	17	43	28	3

Figure 7: User survey in reference building

A similar user survey was conducted in a building after the installation of balanced mechanical ventilation with a decentralized solution integrated over the ceiling in the dwelling (Klint 2009b) see figure 7. In the reference building the tenants were generally satisfied with the indoor climate such as the room temperature, draft and daylight quality. However; they experience dissatisfaction concerning the air quality in general and specific when it comes to unwanted smell and noise from the external environment such as neighboring dwellings.

In the survey conducted in the multi-story housing with newly installed balanced mechanical ventilation the tenants generally experienced an improvement with the indoor climate; especially feeling of draft has decreased after the renovation.

In the decentralized ventilation solution integrated in the facade the tenant experienced a much higher comfort concerning the mix of fresh air and had no discomfort with draft, such as before the renovation.

4. Discussion

A movement in the innovation and development of ventilation systems for renovation of multi-storey housing towards more decentralized solutions such as integrated in the facade has been investigated. The parameters from the findings have been discussed in the triangular study and listed according to the starting point of this paper: aesthetic and preservation as well as indoor comfort forms the two paths of our investigation.

4.1 Aesthetic and preservation

- Ventilation doesn't necessary spoil the facade. Possibilities to reuse the existing perforations of the masonry must be taken into account when optimizing the solution. Innovative measures such as the facade integrated ventilation unit under the window (figure 4) can as an example provide acceptable solutions.
- Users must be involved in the renovation to get a higher acceptance of the installations.
- Decentralized ventilation solutions absorb less space for pathways inside the dwelling, which is an advantage to the users.
- When changing the existing windows to triple layer glass the daylight factor most likely will be reduced, however improvement of indoor comfort generally can compensate for this.
- Potential for saving heat, in this case approx. 25 % can accelerate the renovation rate.
- There is a potential for saving electricity compared to central solutions, which can be compensated for with a limited number of solar cells on the roof.

5.2 Indoor comfort

- The indoor climate generally improves with introduction of balanced mechanical ventilation; however, absence of draft must be identified and solved first.
- Possibility to reach a ventilation rate as for new buildings.
- Noise from the devices must be kept under the requirements.
- Users want individual control of the ventilation, which can be made by decentralized solutions.
- Noise from local noise sources, such as traffic, train etc. can be reduced through insulation of the climate screen.

5. Conclusions and perspectives

In the conclusion of the parameter study and the discussions the authors have identified three essential statements:

1. New interdisciplinary working methodologies will improve both quality, quantity and users satisfaction, and the new results will create value.

2. It is obvious that the movement towards development of decentral ventilation stimulates the industry to develop new and innovative products.

3. From the studies a high level of innovative initiatives has been identified, which indicates a movement towards development of more decentralized ventilation solutions in the introduction of balanced mechanical ventilation in the multi-storey housing in Denmark.

Perspectives

- New facade solutions must be developed in a gentle design to solve the perforation of the façade for decentralized ventilation solutions such as new window designs.
- Incoming daylight should not be compromised when changing the façade
- Draft caused by leakiness in the climate screen or directly from the ventilation system should be investigated more thoroughly with focus on temperature, velocity, turbulence and direction of the airflow.
- The ventilation efficiency of the decentralized units should be documented in a larger scale.
- Measurements of the noise from the decentralized ventilation solutions should be carried out.

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