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Hybrid ventilation in residential and office buildings

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Abstract. This project is focused on hybrid ventilation systems, a combination of natural and mechanical ventilation in residential and office buildings. Especially in dwellings hybrid ventilation systems are quite common. For instance, this can be the frequently occurring combination of exhaust fans in bathroom and toilet and / or a range hood in the kitchen with window ventilation in the other rooms. Currently, these systems are part of the planning reality, however, there are neither planning aids nor focused building standards available. A recently completed research project documents the state of the scientific knowledge, identifies most common planning challenges, and thus provides the basis for future planning aids for hybrid ventilation. This paper sets out to define the term "hybrid ventilation", presents the most common hybrid ventilation systems in Switzerland and gives planning guidelines for current components of hybrid ventilation systems.

1. Background

Hybrid ventilation systems are a combination of natural and mechanical ventilation. In today's existing buildings, hybrid ventilation systems are widely used. A hybrid system, for example, is the combination of exhaust fans in the wet rooms or the cooking zone and natural (window) ventilation in other rooms, regardless of how the replacement air is provided. Despite their widespread use particularly in dwellings no planning aids or focused building standards are available. A recently concluded project closes this gap by compiling the current state of knowledge in theory and practice, identifying most common planning challenges, and documenting open questions. This serves as a basis for the development of a new Swiss standard concerning natural and hybrid ventilation, “SIA 382/3: Natural and hybrid ventilation of buildings – basic principles and requirements” (in German), a work in progress since the beginning of 2023. While the project covers various aspects of hybrid ventilation systems [1] this paper has its focus on three practical aspects, namely: a) definition of the term “hybrid ventilation”, b) presentation of relevant hybrid ventilation systems for the Swiss building sector with their pros and cons and c) listing frequently used components of hybrid ventilation systems with planning guidelines.

2. Scientific Methodology

2.1. General approach

As a basis for the project, an extensive literature review is conducted. Around 150 references are considered and evaluated. These are relevant articles from building related and scientific journals, research reports, standards and product descriptions. The search is carried out systematically (e.g. by keyword) and by backwards reference searching (e.g. by reviewing the bibliography of central works). In terms of content, the search covers twelve national and seven international research projects, demonstration projects (nine residential buildings, twelve office buildings), 34 products and components, as well as 14 relevant building standards.

The screening criteria for inclusion are mainly the relevance to the topic of hybrid ventilation and, in the case of the demonstration projects, that measurements (1st priority) or user surveys or simulations (2nd priority) were carried out. From the literature reviewed, definitions for hybrid ventilation are collected and evaluated. Furthermore, as a key element of the project, significant planning topics for hybrid ventilation are extracted and commented. This includes the description of challenges, normative and technical methods of resolution and open questions. Workshops with experts from science and planning ensure practical relevance.

2.2. Assessment of hybrid ventilation systems

Two qualitative assessments are conducted: The first one on the topic of energy comprises heat recovery, waste heat recovery, electricity consumption (fans) and influence on heating and potential cooling energy demand.

The second, more comprehensive assessment, considers additional aspects such as thermal comfort, Indoor Air Quality (IAQ), acoustics, robustness (user behaviour), security (fire protection, burglary protection), material ecology and economy. Both assessments distinguish between "good", "neutral" and "unfavourable".

3. Findings

3.1. Definition of hybrid ventilation

A total of eight definitions of hybrid ventilation with varying scope are obtained from the literature. For the purpose of the project, none of the given definitions seems to be precise enough to cover and delimit the whole spectrum of hybrid ventilation in Switzerland. The resulting project-specific definition is as follows: Hybrid ventilation is ventilation for a given building zone or apartment, that relies on natural and fan-assisted supply and extraction of air and is operated depending on the given situation (with either natural or mechanical driving forces or a combination of these driving forces). The function of the system therefore requires devices to ensure natural ventilation (such as windows, externally mounted air transfer devices) as well as mechanical ventilation (air ducts, fans).

Based on prEN 15665:2022-09-30 [2] the type of combination can be differentiated as follows:

- Alternate natural/mechanical ventilation (defining criterion: sequence of time or room segment)
- Basic system natural ventilation with supportive mechanical ventilation (defining criterion ventilation stage / outdoor conditions)
- Basic system mechanical ventilation with supportive natural ventilation (defining criterion ventilation stage / outdoor conditions)

3.2. Concepts of hybrid ventilation

3.2.1. General aspects of energy use and sustainability

Compared to uncontrolled ventilation via tilted windows, the ventilation heat losses are up to 15 % lower in concepts with hybrid ventilation or simple ventilation systems with externally mounted air transfer devices (EMATs), assuming comparable indoor air quality (in the sense of a maximum CO_2 concentration) [3],[4]. In terms of embodied energy and greenhouse gas emissions, air ducts have a large share in the load caused by the ventilation system. With their minimisation, a reduction of about 20 – 40 % can be achieved for the building’s ventilation installation [5], [6].

3.2.2. Comparison of typical hybrid ventilation systems

There are many system variants for hybrid ventilation. In Switzerland, seven common systems are identified for residential and office buildings (see Table 1). Not all these systems meet the requirements of the currently valid Swiss standards (e.g. if the replacement air for the exhaust air system is provided by undefined leakages in the building envelope).

A qualitative assessment focusing on energy aspects shows that system 2, 6 and 7 are rated "good" in three topics. A more comprehensive assessment leads to the following conclusions: In the residential sector, systems with mechanical ventilation and supplementary natural ventilation (# 2) or mechanical basic ventilation with free distribution (# 4) are favorable, as they can retain the advantages of mechanical ventilation and still bring about a certain reduction in material and space requirements if designed correctly. Systems with fan assisted exhaust air systems and window ventilation (# 1) or trickle vents (#5) are more demanding in planning because of possible limitations in comfort, robustness, and the greater dependency on local conditions (building/site topography and surroundings). In the area of service buildings, the use of natural ventilation for night ventilation (# 6) is judged positively compared to mechanical ventilation without a corresponding function (# 7). If a significant reduction in material and space requirements and costs is to be achieved in office buildings, hybrid ventilation systems with a free passage of air and with active air transfer devices between spaces are a possible solution. Special attention must be paid to possible restrictions due to fire protection and the influence of external conditions (robustness) (# 7).

Table 1. Typical hybrid ventilation systems. Note: for each system manifold variants are existing. Used abbreviations: G = general, E = Energy consumption, HR/WHR = heat recovery, waste heat recovery possible, QAE = qualitative energy assessment.

#	System	Remark
1	Dwelling: natural ventilation (airing) with demand-controlled fan assisted exhaust ventilation in bathroom/toilet	G: Most common in Switzerland
2	Dwelling: mechanical ventilation with supplementary natural ventilation used for airing or a (seasonal) alternation	G: Most common in Switzerland. Heat recovery, E: HR/WHR, QAE: rated "good" in three categories
3	Dwelling: Combined system with parallel use of mechanical and natural ventilation	E: HR/WHR
4	Dwelling: Mechanical basic ventilation with free air distribution.	E: HR/WHR
5	Dwelling: Natural ventilation with windows and trickle vents in combination with a fan assisted exhaust ventilation.	
6	Office building: mechanical ventilation with additional airing at night in summer.	E: HR/WHR, QAE: rated "good" in three categories
7	Office building: System with passive air distribution supported by active air transfer devices between spaces, natural ventilation of the freely ventilated space	E: HR/WHR, QAE: rated "good" in three categories
8	Dwelling and Office building: Extract air with natural shaft ventilation and assistance by fans (no stand-alone solution, but part of a ventilation concept)	E: HR/WHR

3.2.3. Challenges and limitations of hybrid ventilation systems

One of the most common causes of problems are differences in the strictness of requirements for natural and mechanical ventilation systems [1]. One example is thermal comfort in winter. Another source of problems is the exposure to outdoor conditions due to hybrid ventilation systems (air pollution, noise, heat), for instance caused by air inlets for natural ventilation. How to overcome such differences in requirements is a relevant open research question.

Due to the proportion of natural ventilation, guaranteed and constant requirements for air quality and thermal comfort cannot be met by a hybrid ventilation system. A user agreement is recommended for hybrid ventilation systems.

3.3. Resulting planning instructions for typical ventilation components

Especially in residential buildings, a number of typical components are often found in hybrid ventilation systems. For such components Table 2 summarizes some instructions derived from the project.

Table 2. Planning instructions for components of hybrid ventilation systems. Used abbreviations: M = Measurement, S/C = Simulation/Calculation, EW = Expert Workshops, T = Theory.

Component	**Planning instruction**	**Reference / Method**
Externally mounted air transfer devices (EMATs), trickle vents	Draughts are a common problem in connection with trickle vents or EMATs. Certain measures (placement, opening cross-section, flow limiter) can reduce these. However, it is not advisable to use the devices in high-rise buildings and at noisy locations. In many cases, observed airflow rates are lower than expected. This is true even for ventilation systems operated in combination with fan assisted exhaust. Every occupied room (apart from zones for the air passage) must have at least one EMAT or one trickle vent. To reach a hygienic air exchange, two EMATs of typical design are often required per room.	[7] S, [8] M, [9] M, [10] M, [11] M, [1] EW
Windows	Exclusively manual window ventilation for bedrooms is unsuitable, because with natural ventilation CO_2 concentrations can only be kept below maximum threshold if a window remains tilted. This may result in high heat losses. Without prior evaluation, the resulting air flow rates through window ventilation often do not meet primary ventilation requirements, such as for IAQ. This is due to insufficient prevailing pressure differences, as well as awnings, curtains, closed sun blinds, etc., that may also impede the air exchange.	[11] M, [3] S/C
Internally mounted active/passive air transfer device	Initially, a distinction must be made as to whether the air exchange into the rooms takes place via an active or passive air transfer device. With passive air transfer devices such as grilles and gaps under the door leaf, the air exchange is induced solely by natural driving forces. This does not work, especially with closed room doors. Air transfer devices (ATDs) must be suitably dimensioned (problem: sufficiently free cross-section, disturbing incidence of light, sound insulation). Frequent design errors are insufficient cross-sections of ATDs between supply and exhaust air zones. Especially with bathroom doors, the higher requirements are often not met. The lack of ATDs may severely jeopardize the function of ventilation measures. In practice (EW) very good experiences have been made with free passage of air and with active air transfer devices between spaces in flats.	[10] M, [3] M, [12] M, [13] T, [14] T, [1] EW
Filters in EMATs and trickle vents	The use of filters in EMATs and trickle vents is advisable. If filters are used, however, mechanical support is always necessary, as the pressure drop of filters in EMATs is too high for purely natural ventilation.	[8] M, [15] M, [16] M
Control strategies	In concepts with automatic ventilation openings, the interface between the various trades involved (architecture, façade, electrics, measuring and control technology and HVAC) is critical for the function of the control system. For example, the interface and dependency between sun blinds and ventilation functions must be clearly defined in the control concept.	[17] T, [18] T, [19] M,
Range hood	When using range hoods, it must be ensured that no high negative pressures and, therefore, undesirable flows occur via hygienically sensitive paths, such as installation shafts. However, this is also the case (to a lesser extent) for mechanical exhaust air systems. In the case of exhaust hoods, the supply of exhaust air must be guaranteed. If this is not defined, a considerable negative pressure (up to 120 Pa) can occur and / or air can flow in from undefined sources and via undefined/undesirable pathways.	[20] M, [10] M, [21] M

3.4. Outlook and Discussion

Hybrid ventilation systems have an energy saving potential in two areas: Firstly, compared to uncontrolled ventilation via tilted windows, ventilation heat losses can be reduced. Secondly, compared to mechanical ventilation, it is possible to significantly reduce the amount of air ducts and thus embodied energy and greenhouse gas emissions of the ventilation system.

Section 3.2 shows that hybrid ventilation systems can be used for specific ventilation tasks in residential and office buildings. However, hybrid ventilation can only be used if no continuous, guaranteed indoor air quality standard is required, as might be the case in buildings for vulnerable persons, for example. Due to the proportion of natural ventilation, the users are more exposed to outdoor conditions than in buildings with a supply and exhaust air system. To avoid resulting shortcomings, e.g. in thermal or acoustic comfort, and to enable a correct design, careful planning and execution is required. In the case of hybrid ventilation, the mechanical part is well covered by existing standards, but the natural ventilation part is not. Therefore, it is advisable to specify certain items in a user agreement (the use of the rooms, user interventions, requirements for comfort and more). The interaction of natural and mechanical ventilation requires integrated planning across all trades. Hybrid ventilation systems can range from simple to highly complex, which is also reflected in the respective sophistication of the control. Especially for complex building controls - not only for ventilation – monitoring the building and actively optimizing operations/control is called for.

The explanations show that hybrid ventilation systems meet the desire for economical use of technology. Ideally, with good planning involving several trades in a multidisciplinary approach, the advantages of mechanical ventilation (e.g., constant indoor air quality, guaranteed moisture protection ventilation, heat recovery) can be combined with those of natural ventilation (e.g., user influence, night ventilation, reduced technical effort). But guaranteed and constant requirements for air quality and thermal comfort cannot be met by the proportion of natural ventilation. However, this is also not the case with pure window ventilation.

Co-author contribution’s statement

C Hoffmann: Conceptualization, Methodology, Investigation, Project administration, Writing - Original Draft
C Hauri: Conceptualization, Investigation, Writing - Review & Editing
A Primas: Conceptualization, Methodology, Investigation, Writing - Review & Editing
V Dorer: Conceptualization, Methodology, Investigation, Writing - Review & Editing
H Huber: Conceptualization, Methodology

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