Design and operation of ventilation in low energy residences – A survey on code requirements and building reality from six European countries and China

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ABSTRACT

One of the key objectives of the IEA Annex 68 research programme entitled "Indoor Air Quality Design and Control in Low Energy Residential Buildings" is to provide a generic guideline for the design and operation of ventilation in residential buildings. They need to have minimal energy consumption, and at the same time maintain a high level ofIndoor Air Quality (IAQ). The paper reports on preliminary results of an interview survey conducted among different stakeholders involved in design, installation and operation of residential ventilation in countries involved in the Annex. There were two main objectives, firstly to describe and analyse a transition between actual requirements (national building codes, standards) and current practice. For the second to investigate current barriers and challenges regarding installation of mechanical ventilation in residences. In total, 37 interviews from six European countries and China have been analysed, certainly not enough for a representative sample. However, the results provide a valuable snapshot of current practices and insights into potential barriers.Results show that mechanical ventilation with heat recovery is becoming the dominating ventilation system installed in new residences in Europe.However, there are countries, where, due to tradition, national legislation and/or cost reasons, other types of ventilation like mechanical exhaust or manual window ventilation are applied. Demand Controlled Ventilationis often allowed or even recommended in standards, but rarely implemented in practice,except for humidity controlledtrickle vents in France. The main barriers against mechanical ventilation with heat recovery seem to be high capital cost, space requirements and duct routing as well as problems resulting from poor construction, lack of commissioning and/or maintenance.

KEYWORDS

Indoor air quality, residential ventilation, mechanical ventilation with heat recovery, low-energy housing

1 INTRODUCTION

To reduce building energy consumption and carbon emissions, Building regulationsand standards require more insulated and airtight buildings, which may lead to a poor quality of indoor environment if the ventilation provision is not sufficient.For instance, IAQ problems were found in all three investigated low energy dwellings in England due to operation and maintenace issues ofthe Mechanical Ventilation Heat Recovery (MVHR) system (McGill, Qin, and Oyedele 2014). Conversely, new built houses with good IAQ may also be found,like the houses investigated by Langer et al. (2015), where the mechanical ventilation ensured high ventilation rates.

One of the key objectives of IEA Annex 68 research project entitled "Indoor Air Quality Design and Control in Low Energy Residential Buildings" is to provide generic guideline for the design and operation of ventilation in residential buildings. In order to provide this guideline, investigation of the current situation of ventilation systems, regarding requirements and practice, in countries involved in the project is necessary. This is crucial since without a strong alignment between the two, no progress towards high IAQ in residences can be achieved. First, a review of the ventilation and IAQ requirements in six countries in Europe and China was conducted. Subsequently, interviews with relevant expert groups in these countries were carried out. Findings from the interviews were used to map the transition between today's strict requirements (EU directives, national building codes, standards) on one side and the actual situation in practice, identifying key barriers, challenges and needs regarding design,commissioning, operation and maintenance of ventilation systems to ensurea healthy indoor environment in low energy domestic buildings.

2 METHODOLOGY

2.1 Literature review

A review of the national building regulations and standards in Austria, China, Denmark, Estonia, France, Norway and United Kingdom (UK) was conducted. This review focused on ventilation requirements highlighting key aspects such asrecommended ventilation systems,background ventilation rates, supply and extract airflows from habitable rooms, wet rooms and kitchen, state-of-the-art system typology, andrequirements for heat recovery.

2.2 Interviews

Gathering of the information about today's practice in design, operation and commissioning of residential ventilation systems was based on semi-structured interviews. Five different interview templates were prepared dependent on the target group of stakeholders to be interviewed:*A. Ventilation designers / Consultants, B. Facility management companies/ Building administration, C. Public authorities, D. Housing developers, E. Producers of ventilation systems*. Each survey template consisted of two parts. The first part was focused on stakeholders' opinion regarding state of the art for ventilation systems that are installed in modern dwellings. The second part focused on barriers and problems during design, commissioning, operation or maintenance as well as on key changes in legislation, technical measures, financial incentives, market requirements and outreach programmes that stakeholders believedwereneeded to provide high IAQin energy efficient homes.Each of the two parts included 3 to 4 main (open) questions as well as several, more precisselly defined sub-questions, which should help the interviewer to keep structure of the interview. A selection of the questions chosen for analysis in the present paper is shown in Table 1.

Table 1: Interview questions analysed in the present paper

State of the art	Barriers, problems and needs
a) What types of ventilation systems are installed in modern dwellings and what it the most prevailing system?	a) What are the main problems/barriers during the design process of a ventilation system?
b) Elaborate more on type, topology and setup of the system (centralised/decentralised, etc.).	b) What are the main problems during commissioning and operation (including maintenance)?

c) How integration of additional appliances that influence ventilation is handled (cooker hood, woodstove)?	c) What are the main needs to ensure high IAQ and high energy efficiency in residential buildings?
d) What type of a heat recovery system is typically installed?	d) To what extent is MVHR accepted in your country/region? Please give a grade from 1 to 10 (1 = Not accepted, 10 = Fully accepted).
e) How efficient is the system in delivering the outdoor air to each location in the room?/ How is the air distributed in dwellings?	e) How would you rank reasons why people do not use their mechanical ventilation system at homes?
f) What type of automatic control system to regulate the flow rate and flow balance is integrated with the ventilation system?	
g) What are requirements for minimum supply/exhaust airflows and IAQ in dwellings?	

The results presented in the paper are based on 37 interviews: Austria (6), China (1), Denmark (5), Estonia (4), France (5), Norway (7) and United Kingdom (7).

3 RESULTS AND DISCUSSION

3.1 Review of national requirements

Requirements to ventilation for residential buildings in the seven investigated countries are listed in Table 2. Mandatory mechanical ventilation has not been identified for any of the countries. For all cases, the recommendations prioritize neither mechanical ventilation (MV)nornatural ventilationincluding manual window ventilation (NV). All countries require minimum background ventilation rates (see Table 2), however, the requirements vary for the countries and are for some given as air change rate (ACH), while for other the airflows depend on the number of occupants, floor area, number of habitable rooms (i.e. living room, bedrooms, offices, etc.) or number of bedrooms only. The national building codes set also requirements to minimum exhaust rates from wet rooms in all investigated countries, e.g. in France the minimum extract rates depend on numbers of habitable rooms and in a 3-room dwelling there is required extraction of 45 m3/h for a kitchen and 30 m3/h for a bathroom and a toilet. According to the Danish building regulations, extraction of at least 20 l/s must be possible in a kitchen, and extraction of at least 15 l/s and 10 l/s in a bathroom and a toilet, respectively. For a comparison, the Chinese regulations state requirements in ACH, i.e. 3 h^{-1} for a kitchen and 5 h^{-1} for a bathroom/toilet. Dependent on the country either a kitchen hood integration in MV is required orit has to work as a separate system (exhaust outside or just recirculation). Requirements related to heat recovery in new mechanical systems, including minimum efficiency, apply only for some of the countries.

3.2 State of the art for installed ventilation systems

Majority of the stakeholders provided information regarding multi-storey residential buildings (MFH), where the apartments range from 35 to 130 m^2. Regarding single family houses (SFH), the only provided information was from France with range 90 - 110 m^2. With respect to types of ventilation systems (questions a and b, see Table 1) interviews revealed that MVHR systems are dominant. However, there are variations in all countries. In Austria, natural ventilation as well as mechanical exhaust (MEV) systems are receiving comparable attention. For example, one HVAC planner in the province of Vorarlberg stated that they used to have a legal requirement to build all publicly built housing in Passive House (PH) standard, which required MVHR ventilation. After removing this requirement, implementation of MVHR dropped drastically and most new housing projects in that province installed a simple extract air system or solely rely on NV. That planner explained that “Non-public housing developers were put in a tight spot” having to argue why social housing had “higher standard” than their buildings. He added that the situation was distorted due to the housing subsidies received by the social housing developers and that consequently, the private constructors were able to promote their views, that ventilation is a) questionable and b) the capital and operation costs are too high. At the same time, the designer referred to an Austrian research project (Ploß 2016) which showed that 70% of the 55 most economic building design variants (based on Lifecycle costs) were with MVHR, the rest with MEV. Since the cost differences between these 55 variants were negligible, his opinion was that the solution with the higher comfort should be prioritized. Another designer stated that in the projects, which do not aim for any public subsidy, manual window ventilation or MEV systems are applied. In France single extract, humidity based Demand Control Ventilation (DCV) systems applied in combination with humidity-sensitive trickle ventilators seem to be the state of the art. The dominance of MVHR systems is obvious in Scandinavian countries and in the UK. What is commonly mentioned by stakeholders from these countries is the maintenance issue. Centralized air handling systems are often used in social apartments, because inhabitants are not interested in maintaining a decentralized system and it is more expensive to service several individual units. On the contrary, they design decentralized systems for privately owned dwellings where inhabitants are responsible for maintaining the unit placed in their apartment. Generally, the stakeholders more often mentioned centralised ventilation systems. Decentralised system was never stated alone as an only solution provided.

Other appliances that influence ventilation (question c) are mostly taken into account. Kitchen hoods were, as expected, mostly mentioned. In the interviews from Estonia, the separate exhaust system for a kitchen hood is mentioned. None of the Austrian stakeholders mentioned integrated solution for a kitchen hood, but referred to the use of recirculating range hoods. In contrast to that, the Norwegian stakeholders mentioned that it is common to connect the kitchen hood to the system and in the case that the separated fan is used; the pressure-sensor is applied to ensure balanced ventilation. Danish designers also mentioned integration of a kitchen hood and consequent boost of a supply fan to provide balance. Another argument for integration of a kitchen hood was optimal functioning of a heat recovery. One of the Danish designers had an opposite opinion; noting that system could be polluted with fat from cooking.

Counter-flow plate heat exchanger is mostly used as heat recovery (question d), followed by cross-flow heat exchanger. Rotary heat exchangers were mentioned only in connection to decentralized ventilation units – it is not very clear from the answers, but it can be assumed that stakeholders refer to decentral (flat-wise) solutions. Either one unit per apartment in apartment buildings or installation in single-family houses. Rotors can potentially transfer condensable odorous substances (e.g. from cooking), so in centralized systems of apartment buildings there would be the risk of smelling a neighbour's lunch. Within one dwelling, a small potential odour transmission (e.g into a bedroom) is not considered a problem.

Efficiency in delivering air into particular rooms (question e) has been addressed in different detail by different stakeholders. Some described quite precisely their strategy for air distribution; others did not seem very interested or concerned about this issue and just mentioned mixing ventilation. When designing/implementing balanced systems in Austria, the so-called cascade systems seem to be preferred. A designer stated that if possible (due to a floorplan disposition) an extended cascade ventilation principle (with no supply air terminal in the living room) would be used. Otherwise, a standard air distribution (supply in bedrooms and living room, extract in kitchen/bath/toilet) would be adopted. Norwegian and Danish designers stated that in their systems fresh air is supplied into bedrooms and living room while it is extracted from bathrooms, toilets and kitchens. This principle is actually required by Danish building regulation. French designer pointed out important aspects regarding both MEV and MVHR system. In the case of single exhaust, a tight building is necessary to keep air distribution as designed. In the case of balanced systems, tight ductwork is necessary.

Table 2: Summary of requirements to residential ventilation; based on:OIB-Richtlinie 3 (2015), ÖNORM H 6038 (2014), GB/T 18883-2002 (2002), JGJ 134-2010 (2010), JGJ/T309-2013 (2013), BR15 (2017), Estonian legal acts 03.06.2015 nr 55 (2015), Estonian legal acts 05.06.2015 nr 58 (2015), Arreté 24.03.82 (1983), DTU 68.32 (2017), TEK 10 (2010), The Building Regulations. Approved Document Part F (2010), The Scottish Building Regulations 2015 (2015); Legend: RH-relative humidity, E&W-England&Wales, S-Scotland

Country	Austria	China	Denmark	Estonia	France	Norway	UK
Natural Ventilaiton (NV)	Allowed	Not addressed	Allowed (same requirements to background vent. and energy req.)	Opening of windows only to improve thermal comfort in summer	Allowed (same requirements to background vent.)	Allowed (same requirements to background vent. and energy req.)	E&W:Allowed(samereq. to background vent.) S: not suitable if airtightness< 5 m^3/hm^2(50 Pa)
Mechanical Ventilation (MV)	Required if NV cannot ensure healthy IAQ	No addressed	Always MVHR	MVHR	MEV MEHV	Not specified	MEV MVHR
Permission to switch off ventilation	Not addressed, min. ACH=0.15 required during non-occupancy	No addressed	Not allowed	Not addressed	Never	Not addressed, but min. 0.7 $m^3/h\ m^2$ during non-occupancy	Not addressed
Heat Recovery	None (local req.to receive subsidies)	Not addressed	decentralized ≥ 80% centralized ≥ 67%	N/A	Not addressed	≥70%	Not mandatory (recommended min. 66%)
Kitchen hood integration	Not integrated into MVHR	Not addressed The minimum exhaust ACH=3 h^{-1}	Not addressed; recirculation not allowed	Not addressed	Not integrated	N/A	Not addressed The minimum exhaust is 30 l/s
Background ventilation rate	Min. ACH=0.15 required during non-occupancy	30 m^3/h per person dwelling air; ACH=1h^{-1}	0.3 l/s m^2 heated floor area	SFH: 0.42 l/s m^2 MFH: 0.5 l/s m^2	Dependent on number of "main rooms" (3 rooms min. 75 m3/h)	1.2 $m^3/h\ m^2$ (0.7 $m^2/h\ m^2$ non-occupied space)	E&W: min. 0.3 l/s m^2net floor/n. of rooms (3 rooms - 76 m3/h)S:spec. by min. area of vent. opening
Controls	DCV recommended Min. 3 levels for fan speed required	Not addressed	DCV may be used; background vent. rate has to be ensured	DCV may be used (CO_2< 1000 ppm)	Not addressed	Not addressed	DCV/ manual;RH contr. rec. in wet rooms; Trickle ventilators control by occupants

Considering the prevailing type of control (question f), application of DCV seems to be rare. As adesigner from Austria noted, DCV for residential housing sector definitely does not prevail onthe market. The higher costs came into effect. He also mentioned technical problems with positioning of sensors. According to his opinion, the only reasonable approach is to place a sensor in each room. This however increases both cost and complexity of the system. A special situation could be noted in France, where humidity based control is being used in combination with MEV systems. A French producer nameddifferent types of systems and mentionedthat when balanced ventilation is used, airflows are fixed and occupants have possibility to boost akitchen hood. Typical control consists of user-operated switch that allows changing amount of supplied air in relation to user activity in a dwelling:"away", "normal occupation", "party", etc. Norwegian housing developer saidthat for decentralized systems occupants had possibility to adjust theairflow manually in three levels. Inthe case of centralized systems, occupants seldom can do any adjustments. Another Norwegian housing developer confirmedthe previous statement, but addedthat there can be an "indirect control" in abathroom, either a humidity-controlled valve or an on-off switch as well as in a kitchen there can be a switch on a kitchen hood. A centralized control was also mentioned by a producer from Estonia. Both developers and designers from the UK mentioned a manual (switch) or humidity based boost modes for bathroom and kitchen. They also mentioned that users can switch theirsystem off, but they are encouragedby developers and installers not to do so. This topic seems to be also important for Danish designers who pointed out that even if asystem has a simple "on/off" control, the off does not actually mean that there is no airflow through the system, because this is not allowed according to building code.

Answers to question regarding minimum required ventilation rates and IAQ in dwellings (question g in Table 1) indicated that stakeholders were mostly aware of the lower limits for ventilation flows imposed by particular building codes. The Austrian building code (OIB 3) has general statements on required ventilation for rooms where people reside and for sanitary rooms. No explicit values regarding air exchange rate, supply or exhaust airflows are given in the building code, but there is a reference to standard dealing in detail with ventilation plants (ÖNORM 2014). Several stakeholders from Austria mentioned a building certification program launched by the Austrian ministry ("klimaaktiv") which includes measures to improve IAQ (system efficiency, filters, etc.). Extra points are given within the subsidy application if this "klimaaktiv" certification is done.In the case of Denmark, stakeholders mentioned that there is not a clear standard about indoor air requirements and that the documents available are old. This is rather interesting result, because IAQ is specifically mentioned both in the Danish building code (BR15 2015) as well as in related standards. Building regulation deals with general requirements for IAQ and in addition mentions specific pollution sources such as formaldehyde. In Estonia, stakeholders expressed clearly that supply and exhaust airflows need to follow Estonian requirements to the minimum airflows: 1 l/s m^2 supply in living room and bedrooms, 10 l/s exhaust from toilets, 15 l/s from bathrooms and kitchen 20 l/s. There is no regulation concerning air humidity. Recirculation is not allowed according to Estonian requirements.Ventilation designers in France mentioned that no IAQ classification schemes, guidelines or standards are applied, only exhaust airflow requirements and rules for air inlet sizing according to DTU 68.3 (2017). Minimum extract airflows are given for each type of a humid room depending on the total number of normal rooms. In Norway, the stakeholders reported that national standard (TEK 2010) determine minimum airflows regarding materials and number of persons. For non-occupied spaces, only minimal ventilation rate is required. In addition, a technical guideline developed by Norwegian Building Research Institute (Building series 2017), was used as well to show examples of ventilation requirements defined in TEK (2010). Approved Document Part F of the Building Regulations (HM Government 2010) and the Domestic Technical Handbook of the Scottish Building Regulations(The Scottish Government 2015), are the IAQ standards used for ventilation in England and Wales, and Scotland, respectively. One of respondents mentioned that IAQ is not a design priority outside major cities i.e. they only provide a basic and cost-effective design to comply with the regulations. While more attention is payed to the other aspects of the design that are more pertinent in the given context.

3.3 Barriers, problems and needs

Table 3 lists the barriers and problems identified in this survey. The number of times each item was raised in the interviews carried out in each country is provided in Table 3as frequency of occurrence and the identified problems are listed in descending order of frequency.

The investment required to provide whole-house mechanical ventilation along with spatial and maintenance requirements of these systems are among key concerns during decision making and design phase. Several stakeholders pointed out that the capital cost required for MVHR systems is notably higher than conventional ventilation systems such as intermittent humidity-controlled extract ventilation (MEV). However, there is often no life-cycle consideration of operational savings achieved and the health benefits of better indoor air quality. Furthermore, these systems require more space and duct routing can be challenging. Maintenance is also a key consideration especially in decentralised installations in apartment blocks where the MVHR system is installed inside an apartment and access to the unit for regular maintenance might be difficult.

Most respondents also reported a dis-jointed approach to design, installation and commissioning of MVHR systems whereby designers are often not involved in system commissioning. This can lead to discrepancies between actual operation and design intent. Another issue that can exacerbate this problem is shortcomings in the skillset of installers who are often not up to date regarding the latest ventilation and energy efficiency requirements. Non-compliance with regulatory requirements due to poor system installation and lack of commissioning was raised as a common concern. Lack of clear instructions about system operation and maintenance requirements in user manuals and during building handover was another major issue.

System maintenance after building handover was a key problem raised in most countries. In addition to problems around access, respondents reported that unless there is a follow-up service contract in place, which is mostly applicable to apartment blocks with centralised systems, key maintenance requirements may not be met in practice as occupants are not well briefed about these requirements and the consequences of poor maintenance. Noise and the perceived cost of operation, which in extreme cases had led to occupants turning their systems off, were among other problems identified in the survey.

There was a stark contrast between feedback received from respondents in European countries and the feedback received from China. The 'blank-house' method used to procure most dwellings in China means designers and developers have very limited control on the indoor environment as air quality, to a large extent, is determined by the materials occupants use to decorate their homes. It should be noted that the feedback received from China in this survey is based on only one interview and therefore cannot be generalised. However, supportive evidence from the literature point to the significance of indoor sources of pollutions in new dwellings in China. Investigations carried out in China show rapid increase in pollutants emitted by indoor sources in new buildings and refurbishments(Du et al. 2014; Liu, Liu, and Zhang 2013; Zhang, Mo, and Weschler 2013).

3.3.1 Potential measures to improve IAQ in energy efficient homes

Legislative requirements: The key legislative requirements and improvement opportunities identified by the respondents can be summarized as follows: a) Calls for more flexibility in legislation, codes and building standards including a more holistic approach that allows for trade-offs; b) The necessity of a coordinated approach to energy efficiency and indoor air quality; c) Control mechanisms required to ensure good implementation and operation.

As for post-handover phase, a respondent in France drew an analogy between the mandatory requirements for maintenance of heating systems in France and most European countries, where building owners are legally responsible for annual service and maintenance of these systems, and maintenance of MVHR systems. Currently, the responsibility for maintenance of mechanical ventilation systems in dwellings is not well-defined (e.g. MVHR filter replacement).**Technical measures:** in addition to legislative requirements, respondents suggested that training and accreditation of installers of ventilation systems would be necessary to improve the quality of installations and avoid problems such as excessive air leakage, unbalanced systems, draughts, noise and poor specific fan powers. Furthermore, it was stated that it is important to keep the design as simple as possible, and at the same time flexible for user control. A respondent in Denmark, however, pointed out that better IAQ performance in some circumstances may be achieved by refined zonal control and increasing the number of sensors. This shows that finding the right balancebetween system complexity and IAQ performance objectives seems challenging and may be very much country and even project dependent. It is also important to identify the risk factors and failure modes of a design strategy and specify appropriate mitigation measures throughout the building procurement process.**Financial incentives:** financial incentives in form of government subsidy or grants for specific systems or insurance incentives for system maintenance can be very effective. One respondent from Austria estimated that around 50% of the multi-family housing projects in Tirol, western Austria, utilise balanced ventilation system with heat recovery thanks to additional housing subsidies available for these systems. **Market requirements:** calls for quality labels for ventilation system, more building products with low emissions, and potential market interventions to balance energy effectiveness and cost of installation were among the key market requirements identified in the survey. A producer of ventilation systems in Estonia also suggested that there must be a level playing field in the market. This producer provides additional measures for heat recovery and frost protection in cold climate whereas their competitors do not necessarily consider these problems and the potential consequences. Stricter regulatory requirements may lead to improvements in system performance and fairer market competition. **Outreach programmes:** Clearer guidance on air quality from the governments, feedback to designers about the actual performance of systems, enhanced industrial training for various practitioners involved in construction supply chains, and outreach campaigns to improve the understanding of building administrators and occupants about the benefits of mechanical ventilation especially in the context of low-energy buildings were identified as key outreach measures required to facilitate the use of these systems.

3.3.2 Acceptability of MVHR strategy

The acceptability of MVHR in all countries represented in the survey, but Denmark, can be divided in three categories: low – medium (France, China and UK), medium – high (Austria and Estonia) and high (Norway). It is notable that countries with strong financial incentives for MVHR (Austria) or where it is almost mandatory to install MVHR due to strict energy use requirements (Norway and Estonia) show the highest acceptance level.

Regarding the reasons for not using the MVHR in residences, stakeholders mentioned noise as a main reason, followed by running costs, awareness and operation difficulties. In addition, second order problems include draughts, prejudice, complexity and pathogens fear. These issues have not been identified as important as the first set of problems, but point to subtle socio-technical issues that must be considered to overcome the barriers against using mechanical ventilation strategy in low-energy dwellings.

Table 3. Barriers against and problems associated with whole-house mechanical ventilation of low-energy dwellings identified in the survey

Country (interviews)	**Design** (decision making, concept design & detail design)	**Construction** (installation & commissioning)	**Post-handover** (operation & maintenance)
Austria (6)	High capital cost of MVHR systems (4) Spatial requirements & duct routing (3) Implementation in refurbishments particularly challenging (2) Lack of flexibility for flow rates to account for real occupancy (1) Prejudice against MV systems (1)	Lack of up to date training and skills among system installers (1)	Noise especially in decentralised systems (4) System maintenance & access (2) Re-programming the systems (1) No proper support for tenants (1)
China (1)	Lack of control over internal sources of pollution (1)	'Blank housing' procurement method (1)	The original ventilation strategy can be compromised when occupants decorate their homes (1)
Denmark (5)	Spatial requirements & duct routing (4) High capital cost of MVHR systems (2) Fire safety requirements for centralized vent. in apartments (1) Stringent energy efficiency requirements (1) Working with architect's design (2)	Designers are often not involved in commissioning (1) Big centralised systems become too complicated (1)	Maintenance issues (3) Occupants block the inlets distorting the air balance (1) Poor support & aftercare for users (1) No proper support for tenants (1)
Estonia (4)	Spatial requirements & duct routing (1) Challenging frost protection (1) Cost & technical complexity especially in renovating old buildings (1)		Noise (2) Operational failures (2) Cold draughts (1) Smells/odour (1) No proper support for tenants (1)
France (5)	High capital cost of MVHR (2) Maintenance requirements of MVHR (1) Complexity of MVHR compared to humidity-control extract (1) Spatial requirements for MVHR (1) Design acceptability (1) Lack of project-specific design/planning (1)	Poor quality in system installation & commissioning (2) Non-compliance with technical requirements (2)	Lack of maintenance (1)
Norway (7)	Spatial requirements & duct routing (6) Difficult to position the units to minimise noise (1) Difficult to find an appropriate location for air intake (1)	Designers are often not involved in commissioning (1) Systems not balanced (1)	Maintenance issues (3) No follow-up service arrangement (1) Noise (1)
UK (7)	Difficult to position the units to minimise noise (1) Spatial requirements & duct routing (1) Coordination within all design stakeholders (1) No minimum requirements for pollutants in the regulations (1) Costs (1) No control over emission sources introduced by occupants (1)	Installation and commissioning not in accordance with design intent (3) Insufficient skills of installers (1) Balancing the flow rates only, with less attention to pressure drop (1)	Maintenance issues (3) Noise and perceived energy cost (tenants switch the unit off) (2)

CONCLUSIONS

MVHR systems are dominant even though natural ventilation is allowed by most building codes (if the minimum ventilation rates required are achieved). There is not a minimum efficiency requirement for heat recovery except for Denmark and Norway, and in practice, counter-flow plate heat exchanger is mostly used, followed by cross-flow heat exchanger. Application of DCV is not required by standards and it seems to be rare in practice due to higher costs and complexity. All countries provide a definition of minimum ventilation rate and stakeholders seem to be aware of them. Several stakeholders pointed out that the capital cost required for MVHR systems is notably higher than conventional ventilation systems, which is a barrier for wider implementation. Furthermore, these systems require more space and duct routing can be challenging. Maintenance is also a key consideration and non-compliance with regulatory requirements was raised as a common concern. Finally, noise and the perceived cost of operation, were among other problems identified in the survey.To overcome the previous issues, the main needs identified in the survey were: more flexibility in legislation, codes and building standards, a coordinated approach to energy efficiency and IAQ and control mechanisms to ensure good implementation and operation.

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