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Air Infiltration and Ventilation Centre

Trends and drivers in the Finnish ventilation and AC market

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1 Introduction

Finland is the county with the highest penetration rate of mechanical supply and exhaust ventilation and air conditioning in the EU. Almost all new residential buildings are equipped with mechanical heat recovery ventilation. Air conditioning systems with mechanical supply and exhaust ventilation with chilled beams have been a standard solution in office and public buildings for the last ten years. Arguably Finland uses the highest indoor climate standard in the world with an outdoor air ventilation rate of 2 l/s per m^2 and air velocities below 0.2 m/s in office-type buildings.

There are several reasons for the high indoor climate standard in Finland:

- A cold climate has been an effective driver for the ventilation system development. Passive stack and mechanical exhaust ventilation (both widely used in older Finnish buildings) evidently cause draft and enormous energy use in a cold climate.
- Finland, like other Nordic countries, has a strong manufacturing industry for air handling units, ventilation components and room conditioning units, etc.
- Regulations stated as minimum requirements in the building code for ventilation have formed the standard for residential buildings, especially for apartment buildings. However, detached houses have already been above the minimum stabdard for the last 20 years by using a higher standard with heat recovery ventilation.
- Performance based ventilation regulations, with most requirements being for indoor climate and fewer requirements for system-specific issues, have offered a good background for innovative solutions.
- Finland has had successful and large-scale research programs in the area of indoor climate and ventilation technology during the last 20 years. Research conducted in close cooperation with the manufacturing and construction industries as well as with building owners and officials has led to widely-used voluntary guidelines and the labelling system that have drastically changed the market.
- The Finnish indoor climate classification is arguably the most advanced one in the developed world.

In this paper, important aspects and achievements in innovative ventilation/indoor climate technology will be identified and discussed. The developments during recent decades, as well as the latest changes, will be reported. For some aspects, such as the air tightness and energy performance of buildings, a lack of drivers can also be shown, as the development has been slower compared to other Nordic countries.

2 Indoor climate regulation

The Finnish building code, part D2 Indoor Climate and Ventilation [1] includes minimum requirements for adequate ventilation and IAQ and thermal comfort. For a long time, from 1966 to 2002, a minimum outdoor air flow rate of 4 l/s per person and 0.5 ach were requirements or guidelines (still interpreted as minimum requirements) stated in the building code and its predecessors. The regulation demanding the end result, i.e. being based on guideline values of airflow rates (not intake areas or other descriptive requirements) made possible the flexible development of ventilation systems. There have been no requirements referring to mechanical supply ventilation system or heat recovery since 2003. This regulation led to mechanical exhaust ventilation in apartment buildings for many decades.

In the 1980s air heating systems for houses were launched by Finnish manufacturers. Air heating was not successful because of the noise and dust circulation, but air handling units remained a standard ventilation solution from those times onwards. This started the common use of heat recovery ventilators in houses, Figure 1.

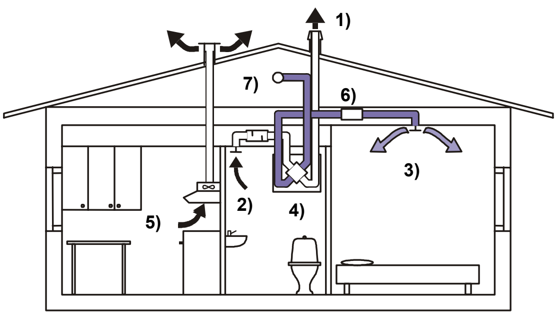

Figure 1: Typical mechanical supply and exhaust system in Finnish houses from the 1980

1) Exhaust air 2 Extract air 3) Supply air to the bed room 4) Heat recovery exchanger 5) Kitchen exhaust 6) Sound attenuator 7) Outdoor air intake for ventilation.

The building code has promoted the use of cooker hoods since 2003, as the guideline value for kitchen extract was 20 l/s with a hood and 50 l/s without hood (i.e. assuming 60% capture efficiency for the hood). Since 2003 this guideline has not existed any more, as all new kitchens have cooker hoods anyway.

The building code does not promote the use of demand-controlled ventilation, as lower airflows cannot be taken into account in the reference building compensation method of the energy performance requirements. This may explain why generally available CO_2, RH and occupancy controls have not made a breakthrough in either residential or office ventilation.

Public and commercial buildings started to use mechanical supply and exhaust ventilation from as early as the 1960s. In school buildings, mechanical exhaust ventilation was used from the 1970s, but then also changed to supply and exhaust ventilation with heat recovery in the 1980s.

From 2003, the building code increased the airflow rate guideline value from 4 to 6 l/s per person and introduced a new requirement for heat recovery: 30% of the heat energy of exhaust air is to be recovered. This heat recovery requirement was launched to supplement the rather primitive energy performance regulation based only on U-value requirements. However, it did change ventilation systems in apartment buildings. Mechanical exhaust ventilation was no longer used and was completely replaced by mechanical supply and exhaust ventilation with heat recovery. Both central air handling units and small units in each apartment (similar to Figure 1.) are commonly used in these buildings. Another change was in air flow rates, as 12 l/s per bedroom was generally accepted as the design value. In reality, lower ventilation rates are often used as air handling units are operated at lower speeds [2].

It should be stressed that the building code has had little effect on AC/ventilation systems in commercial buildings. These have used a significantly higher standard compared to the minimum code requirements.

3 Indoor climate classification

The significance of indoor climate for health, comfort and productivity has been well recognised in Finland in recent decades. As a result of many extensive research projects on indoor climate and clean ventilation, the *Classification of Indoor Climate, Construction and Finishing Materials* was published in 1995 [3]. This classification changed the installation work at construction sites (clean ventilation) as well as the building material market (low-emission building material labeling) and has systematised designs.

During the first five years the Classification was taken into general use and it was received with satisfaction by construction clients and building owners, designers, and the manufacturers of building materials, as well as the contractors being pushed to accept the new measures needed. This was confirmed by the survey in 2003 discussed in chapter 3.1.

The classification was updated in 2001, *Classification of Indoor Climate 2000, Target Values, Design Guidance and Product Requirements* [4], and the next update is ongoing and should be completed during 2008.

The classification has three important parts aiming at a good indoor climate, marked with S, P and M in Figure 2.

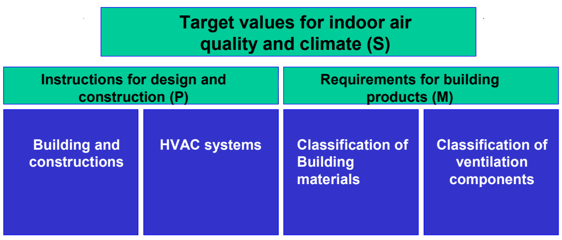

Figure 2: The structure of the Classification of Indoor Climate 2000

3.1 Indoor climate target and design values

The first part of the Classification deals with indoor climate target values. The Classification has three categories: S1, S2 and S3. Category S1 corresponds to the best quality, meaning higher satisfaction with the indoor climate and lower health risks. Category S3 is in line with the official quality set by building codes. Target values are not given separately for different building types, but this will possibly be implemented in the 2008 version. For this reason the Classification is most suitable for office and public buildings and less suitable for dwellings.

In addition to the target values, the Classification gives the most important design values for heating, ventilation and air-conditioning equipment and systems. Design values regarding thermal comfort are shown in Table 1. In a similar fashion, airflow rate, noise level, filter class and air-tightness values are given.

Table 1: Design values for heating and cooling system

Factor	Unit	S1	S2	S3
Room temperature, summer	°C	24	26	27
Room temperature, winter	°C	21	21	20
Individual control of temp, summer	°C	2	2	--
Individual control of tep, winter	°C	2	--	--
Air velocity, summer (24°)	m/s	<0,14	<0,17	<0,20
Air velocity winter (21°)	°m/s	<0,20	<0,25	<0,30
Relative humidity, winter	%	25	--	--

The use of the Classification in building design was studied in 2003 [5] mainly with questionnaires and interviews for construction clients' consultants and building owners. The survey shows that the Classification has been widely used for the determination of the indoor climate targets in office and public buildings. Construction clients' consultants reported in the survey that target and design values of classification are used in 50 to 90% of of office and public building construction projects. They also reported that the design and target values of the Classification have established a common design standard followed as a default one by HVAC-consultants. By means of follow-up studies it has also been shown that S1 targets have been met in some building projects, showing that these targets are realistic. In most cases S2 targets were followed. Thus, Category S2 has been well accepted as the default target level in office and public buildings. The most typical AC and ventilation system in office buildings providing these indoor climate targets is shown in Figure 3.

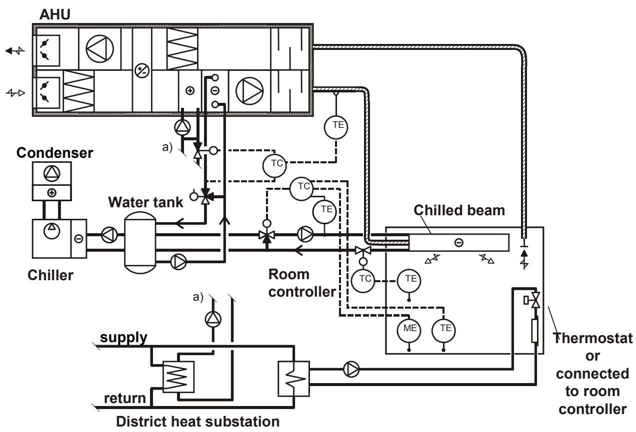

Figure 3: Standard solution for the last 10 years in Finnish office and public buildings

The AC system shown in Figure 3 is a constant-pressure and mainly CAV system with active chilled beams, which provide quiet and draft-free air distribution. Rooms are heated with hot-water radiators using district heat. The air flow is constant in normal office rooms, but is CO_2 and temperature-controlled in meeting rooms. Room conditioning is performed with chilled beams installed in the ceiling and controlled by room temperature sensors. A chilled water system serves both the air handling unit and chilled beams. Free cooling can be provided with circulation through a condenser when the outdoor temperature is below 10 °C. In several areas district cooling is available for chilled water production. The supply air flow is selected on the basis of ventilation requirements but is heated or cooled, depending on the requirements of the room. The major part of the cooling and heating is supplied by the water systems (beams and radiators respectively).

The widespread use of the Classification with commonly accepted S2 targets demonstrates a remarkable improvement in indoor climate and ventilation and air conditioning systems, as these targets are very strict compared to the minimum level corresponding to the building code. It can be concluded that the specification of targets in three categories, together with the successful launching of the Classification, has significantly improved Finnish buildings, as no more buildings that are just in line with the official minimum S3 quality level have been constructed. This illustrates very well the twofold situation in the Finnish construction market, where office and public buildings follow a high standard of the Classification, while residential buildings mainly attain only the minimum level specified in the building code.

3.2 Construction and ventilation system cleanliness

The second part of the Classification, Guidance for design and construction, deals with construction and ventilation system cleanliness issues and moisture control issues. It introduces a P1 class for ventilation system cleanliness and another P1 class for construction work cleanliness. To achieve P1, possible measures are:

- cleanliness of construction work (site planning, storage, schedules etc.)
- protection of building materials and HVAC components
- protection of open duct ends on the construction site and during transportation
- AH units are not used before the P1 construction cleanliness stage

The ventilation system P1 is verified by a visual inspection method for ducts and air handling units. Inspected components are compared to a visual scale: an example is shown in Figure 4.

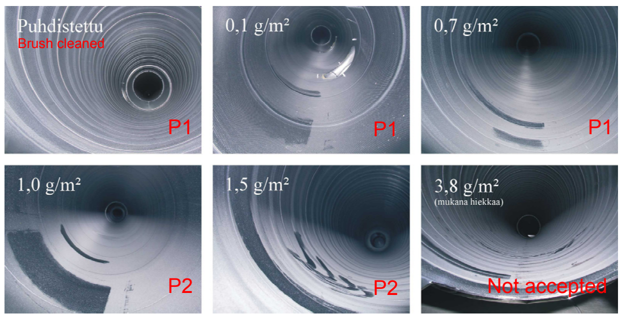

Figure 4: Visual inspection scale for ventilation components [6]

P1 caused a highly visible change at construction sites. Since P1 was specified, it was a contractor's duty to deliver ventilation ductwork/air handling units meeting the specification. The measures listed above were generally implemented. Building sites with non-protected ducts have no longer been the case since the P1 specification. The system is also a win-win system for the client and contractor, as a clean ventilation system delivered does not need brush cleaning. If the P1 criterion is not met, then it is a contractor's duty to clean the systems so that it will meet the criteria.

3.3 Product labelling

Finland has taken a significant step towards healthier indoor climate by creating emission tests for building materials and launching the labeling system operated by the Finnish Building Information Foundation RTS (www.rts.fi). This has led to remarkable reductions in material emissions and may also have significant consequences for airflow rates and ventilation design, not yet a fully implemented in practice, but addressed in the Classification 2008 and discussed later in this Chapter.

After the launch of the Classification in 1995 it took some years before the large-scale labeling of building materials started. By December 2000 the Finnish Building Information Foundation RTS had granted an M1 label in accordance with the Classification criteria for over 400 building materials.

The requirements for the M1 emission class are following:

- TVOC < 0.2 mg/m^{2}h (70 % of VOCs have to be identified)
- Formaldehyde < 0.05 mg/m^{2}h
- Ammonium < 0.03 mg/m^{2}h
- Carcinogenic compounds < 0.005 mg/m^{2}h
- Dissatisfaction with odour < 15 % (0.1 ≤ acceptability vote)
- Plasters and tiling products, levelling agents, putty, mastics, fillers, screeds and renders shall not contain casein.

In the 2008 revision these requirements will be slightly updated for the harmonisation of test methods with latest CEN/ISO standards. The revision will include renewed criteria for VOCs and new product groups such as furniture, cleaning and treatment products.

The Classification 2000 launched a new product labelling system for clean ventilation products. This includes requirements for components odour (substituted by cleanliness criteria for oil and dust for ducts) and requirements for cleanability and other hygienic requirements.

The cleanliness criteria for ventilation components are the following:

- Oil concentration g/m^2 of
  - ducts <0.05
  - terminal units and dampers <0.05
  - pressed components <0.3
- Mineral fibres (MMVF), f/cm^3 <0.01
- Dust concentration, g/m^2 <0.5
- Odour
  - acceptability of air quality passing through the components >0.05

In 2007, more than 1100 building material products from over 115 producers and more than 100 clean ventilation products from 8 producers passed the Classification criteria and were granted the M1 label. The largest product groups are plaster, rendering, putties, fillers, flooring, paints and varnishes, building boards and mineral wool. See ref. [7] for a complete listing and [8] for testing protocol. These figures simply mean that great majority of building materials on the Finnish market are M1 labelled today.

It is shown that product labelling has led to drastic reductions in material emissions. Emissions have generally dropped down from a level of 0.5-1 mg/m^{2}h to below 0.1 mg/m^{2}h, Figure 5.

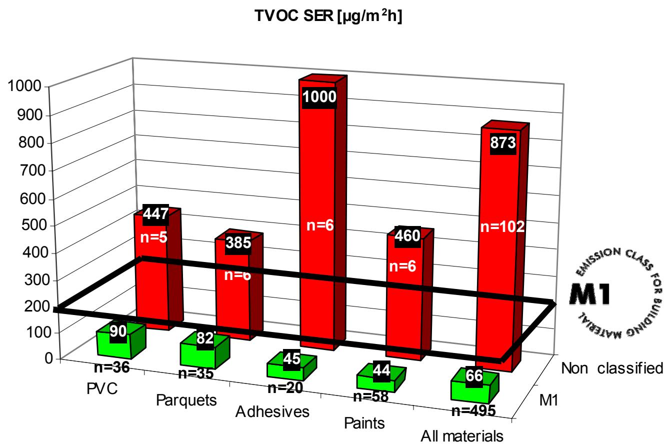

Figure 5: VOC emissions from M1-classified and non-classified products [9]

It should be noted that the material emissions of finishing materials depend on the moisture content of the material underneath the finishing material (i.e. concrete or brick etc.). This issue is addressed in the Classification through strict requirements for moisture control plans and measures at building sites, which are carefully followed in practice, also because of the risk of microbial growth in wet materials or surfaces.

Material emissions have dropped roughly by 10 times and the general availability and use of M1-labelled materials makes it possible to use reduced airflow rates in buildings. This will lead to significant savings in equipment costs, as well as energy savings. The reduction of air flow rates is addressed in the new indoor climate standard EN 15251:2007 [10] and will be addressed in a similar fashion in the Classification 2008. In EN 15251:2007 ventilation rates are based on the pollution load from occupants and materials:

$$q_{tot} = n \cdot q_p + A \cdot q_B$$

Where:
q_{tot}= total ventilation rate of the room, l/s
n = design value for the number of persons in the room,-
q_p = ventilation rate for occupancy per person, l/s, pers
A= room floor area, m^2
q_B = ventilation rate for emissions from building, l/s,m^2

This leads to an airflow reduction by a factor of 2 in normal office rooms, as shown in Table 2, if M1 materials are used.

4 Energy performance

4.1 Lack of drivers in energy performance regulation

While indoor climate, comfort and productivity issues are very well addressed in the Finnish ventilation and AC market, some lack of drivers in energy performance issues can be seen. Energy costs which are among the lowest in the EU, together with the primitive energy performance regulation, which since 2003 has been based on U-value requirements only, have led to rather poor energy performance, especially in the cost-sensitive residential building market.

In office and public buildings, the use of efficient AC systems with supply and exhaust ventilation with heat recovery and good thermal insulation has led to adequate energy performance. However, energy performance is still seldom optimised, while cooling loads are carefully simulated for almost all buildings. Demand-controlled ventilation is not commonly used, with the exception of meeting and conference rooms which have strong load variations. On the positive side, demand-controlled displacement ventilation is commonly used in high rooms such as auditoriums, concert halls etc.

As discussed in chapter. 2, the heat recovery requirement of 2003 changed ventilation in apartment buildings, as the penetration of mechanical supply and exhaust ventilation changed from less than 10% to 100%.

The lack of energy performance regulation in terms of specific annual energy use (kWh/m^2 type requirements), as well as primary energy requirements (energy carrier factors) factors has led to the following drawbacks:

- About 60% of the Finnish detached and row house stock uses electrical heating.
- Finland “missed” a general use of heat pumps as well as the related manufacturing potential of ground heat pumps; this market has become active only very slowly compared to Sweden.
- In apartment buildings, electrical floor heating in wet rooms is used as a standard solution, with a combination of water radiators and district heating in other rooms.
- Small air handling units use less efficient heat recovery (typically 50-60% temperature ratio) and a higher specific fan power (typically SFP=2.5 because of AC fans and non-optimised pressure drops) than in some other leading markets. These two factors can also be seen as a lower level of energy performance which is not in line with the good thermal insulation of building envelopes.

Table 2: EN 15251 ventilation rates for non-residential buildings with default occupant density for three indoor climate categories

Type of building or space	Category	Floor area (m²/pers)	q p	q B	q tot	q s	q tot
			l/s, m² for occupancy	l/s, m² for very low polluted building		l/s, m² for non low polluted building	
Single office	1	10	1,0	0,5	1,5	2,0	3,0
Landscaped office	I	10	0,7	0,3	1,0	1,4	2,1
	III	10	0,4	0,2	1,0	0,8	1,2
	I	15	0,7	0,5	0,6	2,0	2,7
	II	15	0,5	0,3	1,2	1,4	1,9
	III	15	0,3	0,2	0,8	0,8	1,1
Conference room	I	2	5,0	0,5	5,5	2,0	7,0
	Ii	2	3,5	0,3	3,8	1,4	4,9
	III	2	2,0	0,2	2,2	0,8	2,8

4.2 Air tightness

As there has hitherto been no requirement for the air-tightness of buildings in the building code, Finnish houses are relatively leaky as regards the cold climate. The average building leakage value n_{50} for newly-built wooden-frame houses (the most typical construction type in Finland) was 3.9 ach at 50 Pa in 2005 [11], and 1.1 for apartment buildings in 2007, Figures 6 and 7.

One can notice that the modest 3.9 ach n_{50} average value for houses is very similar to the value for Swedish houses from the 1970s [12].

From January 2008, air-tightness was addressed in the building code for the first time. There are still no requirements for air-tightness as such, but for the energy performance calculation, a base value of 4 ach is given, which can be used as a default in all cases. When measured, or for new buildings assured with the relevant quality system (in the building permit phase), the measured or declared value can be used in the calculation. The same applies for the energy certificate calculation. This clause instantly led to interest on the part of the construction industry to build houses with a better building leakage value than 4 ach. For this purpose, a new voluntary quality assurance method has just been developed, making it possible to declare an assured value for the building leakage rate when applying for a building permit. This method is being prepared for publication now and is intended to be used mainly in the construction of pre-fabricated detached and row houses. Despite being in process, this issue is a good example of a regulatory measure initiating an improvement in building quality based completely on free market competition.

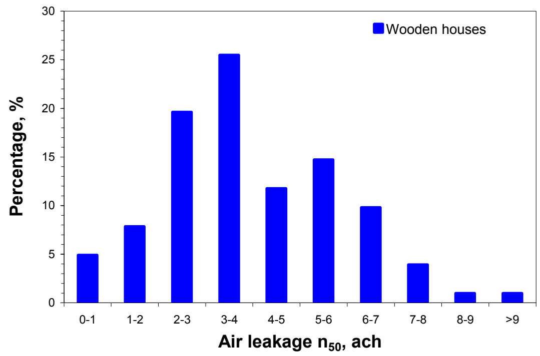

Figure 6: Distribution of air leakage n_{50} values in 102 newly-built houses [11]

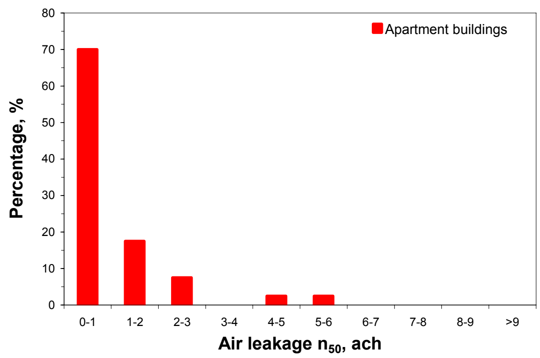

Figure 7: Distribution of air leakage n_{50} values in 40 newly-built apartments [13]

5 Conclusions

Performance based indoor climate and ventilation regulation, mainly has been based on the requirements for the end result with fewer requirements for the system description, supported by a voluntary advanced indoor climate classification and labelling system, have arguably led to the best indoor climate standard in the world in both residential and commercial buildings. In this respect, the Finnish story is ultimately a success story with the following milestones:

- The general use of mechanical supply and exhaust ventilation in offices since the 1960s and mechanical exhaust ventilation in dwellings since the 1970s has been a starting-point for developments in ventilation and AC systems
- Mechanical supply and exhaust heat recovery ventilation in houses in the 1980s (no regulatory background but stemming from an industry initiative, as discussed before)
- First version of voluntary indoor climate classification, including material labelling system, in 1995, which introduced three indoor climate categories and stopped the construction of office and public buildings according to the lowest category corresponding to code requirements, i.e. leading to a much better indoor climate standard compared to the minimum requirements
- 400 M1-labelled materials in 2000 and 1200 in 2007 demonstrate the common use of very-low-polluting materials
- Heat recovery requirement in 2003 “changed over” to mechanical supply and exhaust heat recovery ventilation in all new apartment buildings

On the energy performance side, the primitive regulation based only on the requirements of U-values has caused some drawbacks especially in low-rise houses:

- General restrictions on advanced system development aiming at low primary energy use and low CO_2 emissions
- About 60% of the Finnish detached and row house stock uses electrical heating
- Finland has had a late start in the use of heat pumps
- Peculiar electrical floor heating in bathrooms of apartment buildings using district heating with water radiators

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.