IMPLEMENTATION OF VENTILATION IN EXISTING SCHOOLS – A DESIGN CRITERIA LIST TOWARDS PASSIVE SCHOOLS

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ABSTRACT

Present paper analyses the best-practice solutions for classrooms' ventilation that fit the objective of quick and inexpensive implementation. The paper decomposes the relations between ventilation and building into manageable elements and analyzes them. The analyses are performed qualitatively; they evaluate both scientific and practical implementation The analyses lead to a list of criteria associated with the implementation of ventilation in existing schools. Generic retrofitting scenarios which prioritize energy savings, indoor climate and building/facade integration are assembled and illustrated to target and offer design advice to the different stakeholders/focus groups: professionals and users.

1. INTRODUCTION

Public schools opting for renovation are often obliged to follow municipal or governmental guidelines for low energy consumption [1]. However, saving energy is growing increasingly difficult because demands on the quality of the indoor climate are rising backed by research linking air quality and thermal environment with the ability to learn [2]. Combined with the fact that many existing schools have very poor thermal indoor climate and air quality [3], ventilation in existing schools is no longer a technical and economic issue but also a major political issue.

2. METHODOLOGY

The appropriate ventilation solution for an existing school is primarily constrained by the existing conditions (service space, load-bearing elements, room height, location etc.) and secondary by trade-offs between initial costs, running costs, desired indoor climate quality, expected energy use and aesthetics, see Fig. 1. The task of determining a ventilation solution for classrooms is therefore a complex task where various interrelated performance variables need to come together as a whole.

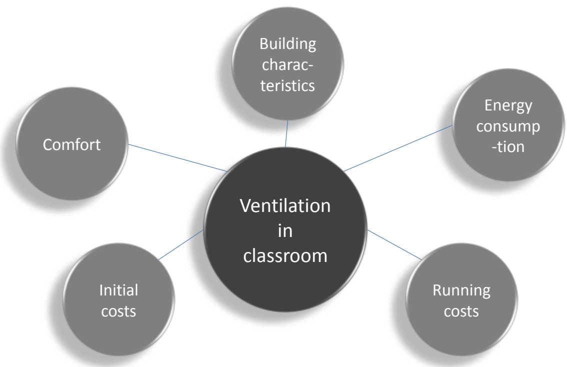


FIGURE 1: INFLUENTIAL ASPECTS OF 'VENTILATION IN CLASSROOMS'

In this study we seek to facilitate this complex task by decomposing the problem complex into manageable variables and assign best-practice values to them, hence a criteria list is generated. The parameters are put together again to form design charts for natural, mechanical and mixed solutions, respectively. The aim is to enable designers to determine the most appropriate type of ventilation for any existing school, which currently has no ventilation, in an easy and quick way.

3. COMFORT

Thermal comfort

The main objective in comfort ventilation design is to remove contaminants and thermal gain without causing risk of draught to the occupants in the comfort zone. Thermal comfort requirements in classrooms are on European level generally fixated in EN15251. However, studies show that the learning ability [2] deteriorates quickly in temperatures above 23°C and in air quality with more than 1000 ppm CO_2.

Ventilation

Table I shows the required ventilation flow rate in classrooms in different countries.

	Denmark Building Code [1]	**Austria EN13779 IDA3**	**Belgium EN13779 IDA3**	**England Bld. Bulletin 101 [4]**	**USA ASHRAE Standard 62.1-2001**
Min vent. flow rate in classrooms	5,7 l/s per person	5,5 l/s per person	6,1 l/s per person	3/5 l/s per person (nat./mech)	7 l/s per person
Noise, L_{Aeg}	35 dB(A)	-	-	35 dB(A)	-
Additional demands	Ctrls for 1000 ppm	Ctrls for 1000 ppm	-	Ctrls for 8 l/s per pers.	-

TABLE I: REQUIRED VENTILATION FLOW RATES IN CLASSROOMS IN DIFFERENT COUNTRIES

Room supply

Ventilation can be supplied in a number of ways in the classroom with more or less risk of draught to the occupants in the comfort zone. The different supply options are located:

- close to the comfort zone supplying air at low momentum (displacement ventilation).
- outside the comfort zone supplying air at high momentum (mixing ventilation). High momentum supply requires space for proper entrainment and jet dissipation
- A third option, low-momentum ceiling ventilation [5], supplies air from above the comfort zone and relies on convective heat sources for effective mixing

In a classroom the occupant density is high and therefore the internal heat gain is high. To remove the heat gain, the supply airflow rate has to be large and at a low temperature. Hence, to minimize the draught risk the air supply must preferably be located outside the comfort zone. This effectively excludes displacement ventilation because careful and expensive precautions must be taken and because it requires constant conditioning of the supply air.

4. ENERGY

The energy characteristics of a ventilation system can be divided into electricity consumption and heating consumption. Heat recovery efficiency and average pressure drop indicates best performance in relation to the building structure.

Pressure drop
The fan power is linearly proportional with the pressure drop and the flow rate. The pressure drop stems from the available space for the ductwork. A typical frictional pressure drop of 1-2 Pa/m is desired in low-energy schools.

Heat recovery
Very high heat recovery efficiency in schools with low transmission losses is pointless as >85% efficiency generates supply temperatures that are too high for removal of the thermal load (>16°C at -18°C outside). Hence, heating coils and the associated pressure drop can be discarded and space-saving rotating exchangers can easily match the recovery requirements.

Cooling
Schools typically have no air-conditioning because of the installation and running costs. Also the extra energy consumption does not fit well with overall low-energy objective. Alternatively, free cooling by night ventilation potentially offers a significant reduction in the cooling load of the classroom. Table II shows the potential heat exchange of the internal constructions during a heat+cool cycle of 12+12 hours. Provided that 4K is the allowable temperature rise during a day, the expected cooling potential of a middle heavy construction is minimum 20 W/m2 during 6 hours of school (half of a 12 hours cycle).

Room characteristics	Description	Akkumul. W/m^2 K
Extra light	Light partitions, no heavy constructions	5-6
Middle light	Light concrete, negligible heavy constructions	7-9
Middle heavy	One heavy, dominating concrete constructions	10-12
Extra heavy	Multiple heavy constructions of concrete	13-15

TABLE II: GUIDANCE FOR HEAT ACCUMULATION OF INTERNAL CONSTRUCTIONS PROVIDED A MAXIMUM OF 12 HOURS OF HEAT LOAD PER DAY [6]

5. BUILDING TYPOLOGIES

In order to identify the appropriate ventilation type for a certain school building, we need to know the building characteristics. In a European perspective schools can be categorized as shown in Table III and IV.
The structure in some schools comprises load-bearing outer and inner walls while others are built from columns and beams with light façade elements and

partitions. Ventilation requires space and penetration of structural elements is, if possible, financially expensive. Consequently, building characteristics that restrain certain ventilation solutions are important to register. The tables list parameter values specifically influencing the final choice of ventilation solution.

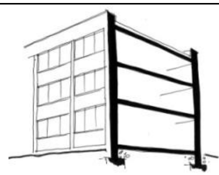
Façade structures	**Punctuated façade**	**Façade elements**
Façade type		
Characteristics	Massive structures perforated with windows	Skeleton structures with light facade elements
Structural elements	Monolithic load-bearing external walls	Load-bearing columns in façade or behind façade. Sometimes horizontal beam in façade restricts window size
Glazed façade	Low area	High area

TABLE III: STRUCTURAL ELEMENTS IN THE FAÇADES WHICH INFLUENCES ON THE VENTILATION SOLUTION. DRAWINGS COURTESY OF: SONJA GEIER, AEE INTEC

6. COSTS

Implementation of ventilation in existing schools entails changes to the constructions of the building. Changes that compromise structural stability, are, of course, financially expensive to implement. The installation cost different ventilation solutions in different building categories in different European countries is beyond the scope of this paper. However, we do assume a linear relation between structural building changes and installation costs in the design charts.

The running costs are, apart from energy costs, largely determined by the service costs. E.g. the cost and quantity of new filters, the lifespan of vital parts, time spent on replacements depending on serviceability and finally the salary level.

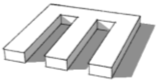
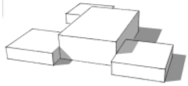
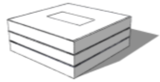
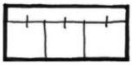
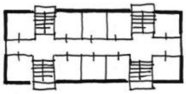
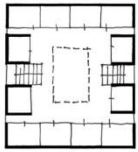
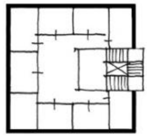
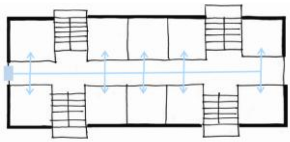
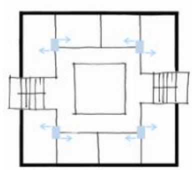
Internal structures	**Horizontal low**	**Horizontal high**	**Centered**	**Vertical**
Building shape				
Floor plans				
Structural elements	Internal load-bearing walls	Internal load-bearing walls	Columns and beams with light partitions, some stabilizing walls	Internal load-bearing walls
Main duct routing	 Horizontal supply duct		 Vertical supply ducts	
Room height	Determ. by slabs,low	Determined by slabs, high	Determined by slabs	Determ. by slabs, low
Corridor height	Same as room height	Same as room height	Determined by beams	Determined by beams

TABLE IV: DIFFERENT SCHOOL GEOMETRIES AND TYPICAL CONSTRUCTIONS. DRAWINGS COURTESY OF SONJA GEIER, AEE INTEC AND MICHELA PENTERICCI, DTU BYG

7. VENTILATION TYPES

Natural ventilation

Natural ventilation is characterized by fresh air supply directly from outside to the individual rooms in the building and thereby limited possibilities for heat recovery, air flow control and conditioning of inlet air. Fig. 2 illustrates the three main principles in natural ventilation: single-sided, cross and stack ventilation.

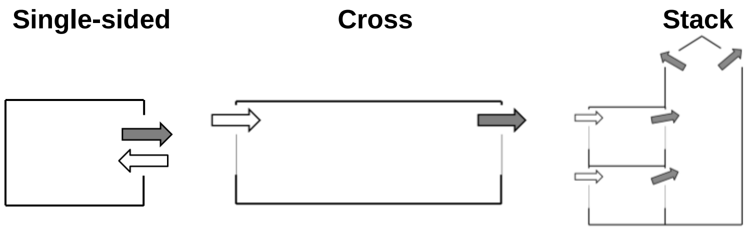


FIGURE 2: The three main principles of natural ventilation. Other variants of especially stack ventilation are possible.

Mechanical ventilation

Mechanical ventilation characterized by fan transported inlet and/or outlet air through duct systems where heat recovery, air flow control and conditioning of inlet air are possible. A mechanical ventilation system is either characterized as a *central system* or as a *decentralised system* as illustrated in Fig. 3a-c.

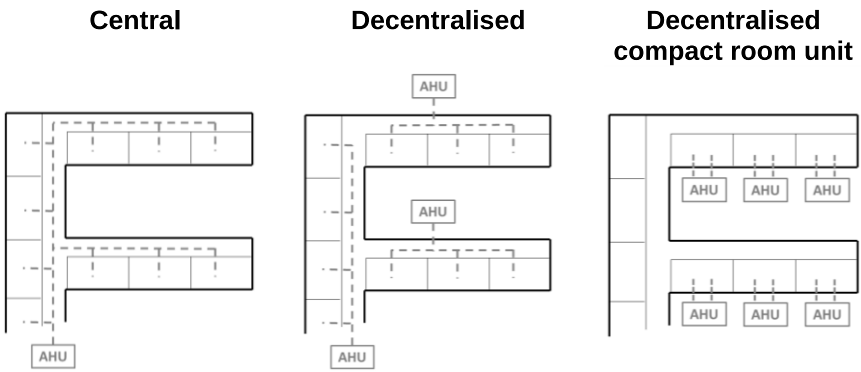


FIGURE 3a: ONE AIR HANDLING UNIT AND LARGE DUCTS VENTILATE LARGE AREAS

FIGURE 3b: MULTIPLE AIR HANDLING UNITS AND SMALLER DUCTS FOR SMALLER AREAS

FIGURE 3c: COMPACT AIR HANDLING UNIT IN EACH ROOM ELIMINATES DUCTS

Hybrid systems

Hybrid systems are combinations of the above, e.g. natural ventilation through façade openings in summer and mechanical ventilation with heat recovery in winter or fan-assisted natural ventilation (mechanical exhaust).

8. DESIGN CHARTS

Any ventilation type could in principle be chosen for a specific building case. However, a potential restricting factor on the performance of a ventilation type, and thereby on the choice of ventilation type, is the specific building characteristics. The design charts in Fig. 4 and Fig. 5 illustrates prioritized and best-practice ventilation solutions in terms of comfort, energy, building implementation and running costs. Table V shows the general design assumptions. The charts do not consider the use of floor space for vertical routing. Typically storage rooms, cleaning rooms, parts of classrooms or hallways, the basement and the roof must be employed. The charts are generated with the following solution priority based on qualitatively weighing of the afore-mentioned performance parameters:

1. Central or decentral balanced mechanical
2. Decentral compact units
3. Mechanical exhaust
4. Stack ventilation
5. Cross ventilation
6. Single-side ventilation

Assumptions	Values
Facade length x room width	8 x 6 m
Minimum room height	2.5 m
Occupancy	24 persons
Occupant heat load	80 W/person
Occupant density	2 m^2/person
Solar load, approx.	10 W/m^2, 30% glazed facade, ext. shd.
Lighting load	0 W/m^2 (off when sun is shining)
Night cooling, approx.	-20 W/m^2 (see Table II)
Transmission loss, approx.	0 W/m^2 (very low in passive schools)
Total heat load	40+10-20 = 30 W/m2
Design rate for duct sizing	Table I: 5.7 l/s per pers. (20.5 m^3/h)
Design rate for room supply	CO_2: 7.5 l/s per pers. (27 m^3/h)
Variable-air-vol. controls	Redirects flow and shuts down unused rooms
Natural ventilation	Bottom-hung windows located below ceiling
Mech. ceiling supply	4 Lindab LCA circular diffusers Ø160, noise <20 dB(A)
Mech. side-wall supply	2 Lindab PR1 grilles 500x300 mm placed symmetrically, noise ~27 dB(A)

TABLE V: DESIGN CHART ASSUMPTIONS

Vertical space estimates of horizontal ducts	Central balanced	Central balanced	Decentral Balanced	Exhaust
Serviced classrooms	8	8	4	4
Supply ducts per room	1	2	2	1
Main duct Ø	400 mm	400 mm	315 mm	315 mm
Cross. distrib. Ø	200 mm	160 mm	160 mm	-
Suspended ceiling	50 mm	50 mm	50 mm	50 mm
Installation space	70 mm	70 mm	70 mm	50 mm
Sum	720 mm	680 mm	600 mm	420 mm
Rectangular duct space savings	-200 mm	-150 mm	-150 mm	-150 mm

TABLE VI: VERTICAL SPACE REQUIREMENTS FOR DUCTS IN DIFFERENT CONFIGURATIONS. DUCT SIZING PERFORMED FROM DESIRED AVERAGE FRICTION LOSS OF1.5 PA/M

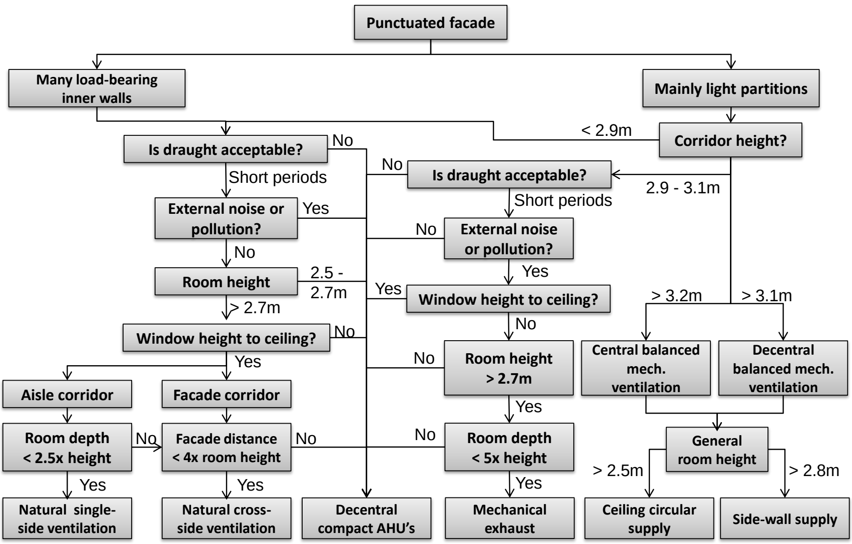


FIGURE 4: DESIGN CHART FOR BEST-PRACTICE SOLUTIONS IN MASSIVE BUILDING WITH PUNCTUATED FACADE

9. CONCLUSION

The paper presents a criteria list for implementation of ventilation in schools in need of radical renovation. The paper focuses especially on the relation between internal building structure and façade and ventilation options. It includes illustrations of the criteria in the form a design charts where information is condensed for the benefit of professionals and users.

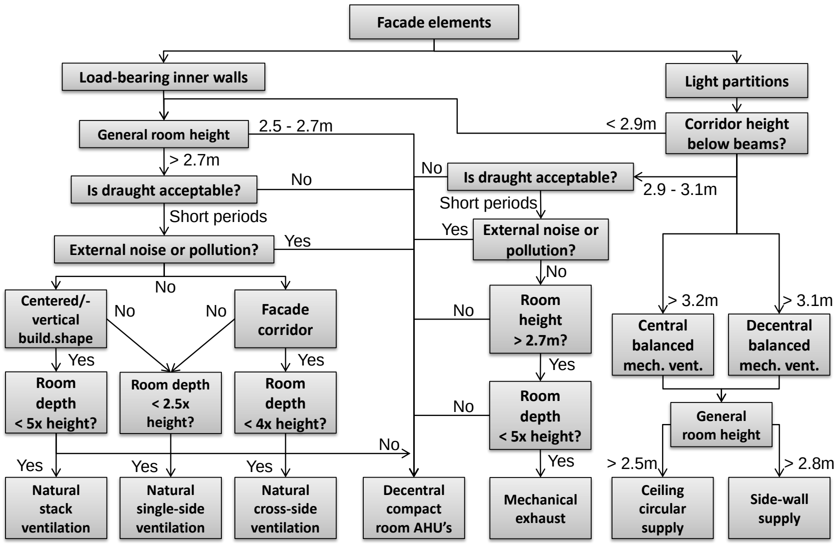


FIGURE 5: DESIGN CHART FOR BEST-PRACTICE SOLUTIONS IN SKELETON BUILDING WITH FACADE ELEMENTS

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