VENTILATION AND COOLING

18^{TH} ANNUAL AIVC CONFERENCE
ATHENS, GREECE, 23, 26 SEPTEMBER, 1997

INDOOR AIR QUALITY AND NATURAL CONTROLLED VENTILATION - EXIGENCE, PERFORMANCE AND STANDARD ASPECTS

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Synopsis

As everybody knows, today the air quality of an indoor environment may have several effects on our health; the beginning of serious breathing pathologies and of some forms of cancer, are with no doubt due to the presence of polluting and extremely noxious agents in the places we most frequently use.

That's the reason why it is very important that indoor rooms are correctly aired also in our homes where, due to several incidental factors, the healthiness of the environment is still guaranteed by the mere and discretionary operation of users of opening the windows.

In considering the growing attention drawn to these problems and in agreement with the provisions of the 3rd essential requirement laid down in Common Directive 89/106, 'Hygiene, Health and the Environment', ICITE has undertaken to develop a research and experimentation study aimed at establishing a device for the controlled natural ventilation of residential environments.

The main objectives have focused on the technical and performance-oriented characteristics of the devices that are already available on the Community markets and on the regulative aspects for what concerns air healthiness in domestic environments, while the final phase of the work, still in progress, will give new developping guidelines, both in regulative and productive terms.

1. Historical outline

The indoor ventilation problem is not related to modern history, but it concerns the human civilization from its origin. Cooling needs or simply smells removing, have been solved in different way over the centuries, according to the technological evolution and climatic conditions.

In any case, natural ventilation is based on the difference between indoor and outdoor pressure: when the indoor temperature exceeds the outdoor one, a continous air cycle is created throught the wall openings.

Early solutions were based on this very simple approach such as, for instance, wind towers, studied and realized during the Pre-Christian era from the Middle-East. These towers maintained their technical validity for many years.

The Roman age also considered ventilation as an health important factor. In fact they studied wind direction in order to improve building orientation. With regard to the Mitilene inhabitants, Vitruvio wrote: "When the Auster wind blows Mitilene's inhabitants fall ill, when the Mistral wind blows they have a cough, when the North wind blows they became healthy again".

The typical Roman house solved ventilation needs by creating open spaces inside: all rooms faced the impluvium and perystilium.

During the Middle Age new techniques were developed, based on the double air flow (drawing and ejection), and other passive techniques were developed to ventilate houses and castles. The ecclesiastical construction continued to apply Roman principles.

During the Renaissance the techniques based on wind studies were improved by introducing mechanical systems to stimulate air, and passive ventilation was left in part.

Also in Italy, mechanical ventilation was adopted, improving the performaces of early ventilators and using valves that, controlled by wires, sent air into those rooms only used from time to time.

Occasionally, wind towers were again adopted, which in Italy where known as "ventiere".
In the eighteenth century and during the Industrial Revolution, scientific progress led to the first forms of calculus for determining the unitary air flow to guarantee hygiene and health indoors.
England produced the most important resultus of this study at that time, where prisons were provided with heating and ventilation systems. The employment of prisoners to set their own ventilators was unique. Elsewhere, heating systems were steam-driven.
The systems set up at Westminster in London, in the first half of the nintheenth, re-adopted the concept of the wind towers (Victoria and Clock towers), by conducting air to the cellars, from where it reached the rooms and was then conveyed through the combustion systems which exploited the induction effect. Other examples of the survival of the wind towers were in Great Britain and America. Nevertheless the principle of ventilation linked to conditioning systems was maintained for a long time.
This principle is valid and operative even today, but the indoor ventilation problem for building without conditioning systems is still open.

2. Indoor air quality

The Common Directive on building products 89/106, relative to the proximaty of legislative, regulatory and administrative provisions of the Member States, adopted in Italy on 21 april 1993, with D.P.R. n. 246, specifies, among other things, the following essential requirements, to which every structure has to answer:
- Health, safety and environment

In order to satisfy this requirement, each structure has to be conceived and built so that it does not constitute a threat fto the health and safety of the occupants or neighbours. This threat is caused in particular by noxious gas, particles or dangerous gas present in the air, dangerous radiation emission, polluted or contaminated water or soil, evacuation defects of water, smoke and solid or liquid residuals and formation of humidity in some parts or within the interior surface of the structure.

In particular, the interpretative documents of the Product Directive, in underlining the principles to verify the respect of essential requirements, (re- point above-mentioned) indicate ventilation (natural or artificial) as one of the most important aspects in order to pursue healthy and safe environment in buildings.
In this way, the technical specifications require that the presence of polluting agents are brought back to safety levels, applying evalutation criteria of air quality, calculus methods to forecast the renovl rate, starting from climatic conditions and ventilation systems. Further measures referred to the calculus rate of the ventilation in building, determining its effectiveness, indentifying the kind of pollution and its concentration indoors.
In general, the complete characteristics of ventilation systems have to be verified in terms of their speed and air flow and differences of pressure.
The Directive 89/106 also highlights, through its *nouvelle approche* to building products, that past cares about indoor aeration have continued to increase during last few years and the absence of ventilation has been shown as a great threat to human health.
On the basis of a statistics study, carried out in the United States on a sample of 350 buildings, demonstrated that the effects due to the absence of ventilation (50%), the wrong air distribution, inadequate conditions of temperature and humidity, on top of tobacco smoke and endogenous pollution, are responsible for bodily discomfort known as 'sick building syndrome'. This syndrome causes various symptoms, such as headaches, fatigue, nose and throat irritation, etc.

The incidence of endogenous pollution is responsible for a smaller part of this temporary bodily discomfort, but they have a biggest responsibility to long term, in supporting great pathologies, not always curable with the up-to-date medicine. This is the case, for instance, of some adhesives and sealants delivering carcinogent and toxic substances, such as formaldhehyde, radon, etc., in the environment.
The absence of ventilation also allows the increase of relative humidity, which causes condensing phenomena and, as a consequence, mould formation accountable of respiratory pathologies.

3. The research proposal

These further elements of knowledge, point out very clearly that the termal and hygrometric performances of a building and its components, have to satisfy environmental safety and healty needs, with optimum energetic consumptions.
In fact, after superseding the economic restrictive worries, which imposed "hermetic sealing", the attention is today turned on indoor microclimate as an essential factor for the comfort of the occupants.
In this way, the frequence of air changes, especially in winter, is the crucial point of the problem, in considering that the energetic consumption has to be compared with air safety.
External windows have always met the primary need of air change allowing, with easy operations, the opening of one or more of its components, but living to frequency and the amount of air to be recycled to the discretionality of the occupants.
The increased attention drawn the objectives of safety and healthiness of domestic rooms has to be beyond the occupants' discretion, imposing on to external window additional performances able to guarantee permanent safety conditions.
The window, also known as 'the intelligence of walls', is still able to fulfil new expectations, as simply as in the past, but it needs receive new inputs in the technical and standard fields.
The modern construction sector in Italy, having to face several problems, doesn't seem to relying a satisfactory way on ventilation, and also the route of natural ventilation systems seems,to have still a long way to go.
In such a situation, indoor natural ventilation is affected by multidisciplinary factors, having to interact with technical, normative, sanitary and economic variables.
So, in order to give some acceptable answers to the up-to-date needs and to give useful orientation to the industry of the sector, and on the occasion of a specific demand coming from production world, the Systems and Components Department of Icite deemed it necessary to undertake a research study on the subject of natural controlled ventilation.
The work programme has prelimanarily, outlined the necessity to follow two directions:

- laboratory characterization and performance evaluation of a window filled with a ventilation unit;
- analysis and evaluation of national lows and standards, with reference to indoor ventilation criteria;
- analysis and evaluation of the effectiveness of operational instruments currently adopted.

In this field, the analytical phase of the study under way, aims at defining a reference frameworkin order to investigate and outline the existing gaps, concerning both need and performance aspects and legislative and normative aspects, all contributing to make a correct evaluation.

3.1 Laboratory characterization of the ventilation system and preparation of test methodology

The investigated ventilation system is of the self-adjusting type, it is conceived to be fitted in the upper part of the window, breadthwise, between the transom and the glazing unit, reducing this way the glazed surface.

Inside the system works a ventilation grid that with faint or no wind, allows for a satisfactory level of natural ventilation of the indoor environment, while it automatically stops working due to the action of the external pressure as soon as the atmospheric conditions change. The system is conceived in a way that it allows to keep acceptable conditions of indoor ventilation even when there is a strong wind outside.

The system works thanks to the internal grid with self-adjusting air intake consisting of punched thin plates oscillating perpendicularly to the ventilator and of two baffles, the former being placed on the outside for the natural collection of air, the latter inside, turned upwards, to convey the air flow indoors avoiding air draughts and rain water seepage.

According to the characteristics declared and checked in the laboratory, it is envisaged that with external air pressures greater that 20 Pa, the internal thin plates, by automatically placing themselves against the internal face of the system, manage to prevent a certain amount of air from seeping inside, by limiting the flow just to the air passing through the holes of the thin plates and throught the little gaps between them.

With pressures less than 20 Pa, the system must ensure a constant air flow lying between 15 m^3/h and 30 m^3/h, according to the size of the system.

In order to characterize the system, an "ad hoc" test chamber for the measurement of low pressures was used; the chamber was built according to the provisions contained in the Belgian standard NBN D 50-001.

The $3m^3$ test chamber was built with bolted and silicone-bonded sandwich panels and provided with vertical walls allowing to apply (see fig...) a constant air pressure in the inside.

The opposite closing walls were prepared to contain the test device and the air intake, with negative pressure, generated by a fan. A pressure gauge was used to measure the pressure difference between the test chamber and the laboratory, while inside the duct placed between the fan and the chamber, the air flow rate was measured by means of a Pitot tube. The device was installed with the internal face turned towards the laboratory and the external one towards the test chamber, in order to simulate, inside the chamber, the actual external atmospheric conditions.

3.2 Laboratory characterization of the window frame fitted with the ventilation system

The performance evaluation of the window system was carried out by means of official testing equipment for windows and structural glazings belonging to the "Components" service laboratory of ICITE, and thanks to the experience made over many years of activity in the field of compulsory and voluntary certification. In this connection, it must be remembered that ICITE is an active member of UEAtc and EOTA, the European organizations in charge of the harmonization of standards for granting technical agréments.

The whole system, consisting of an aluminium window frame with a horizontal bascule opening and provided with a ventilation system, was then fitted into the test wall and tested according to the methodologies envisaged by standards UNI EN 42-77.

Air permeability was measured by constantly increasing pressure at 50 Pa steps, from 50 to 500 Pa. The test was at first executed by sealing the system in order to assess the extent of the losses caused by the window frame, then, after removing the seal, the total losses were

recorded; the difference between the two values provided the amount of air passing through the system. Permeability values (table....) resulted to be quite high, thus contradicting the limits suggested by the official standards.
The watertightness test was not judged to be meaningful since it is not possible to make a comparison with the criteria suggested by the standards establishing that the nozzles used to spray water on the sample are to be fixed few centimeters below the upper transom of the window frame in the same place of the test set-up in which the ventilation system is to be installed.

The wind resistance tests previously carried out on the window frame not including the ventilation system, allowed to assign the highest resistance class. The same window frame, including the system and submitted again to the previous test, did not resist the 1800 Pa pressure due to the disjuntion of the lateral glazing beads.

4. National legislations and standards and assessment of the effectiveness of currently used working instruments

4.1 Indoor ventilation

The present national legislative situation on the subject of ventilation refers to Law No. 10 of 1991 "Standards for the accomplishment of the national energy Programme concerning the rational use of energy, energy saving and development of renewable energy sources" which somehow introduces the problem regarding the change of indoor air.
This law is very important since it goes beyond the restrictions imposed by Law 373/76, issued following the serious energy crisis which took place during the 70's, and it introduces important innovations about how to plan and realize living comfort and hygiene; moreover, it is structured on three levels of enforcement and this shows that the CPD has been satisfactorily adopted.
While the first level of the legislative apparatus provides the general directives, the intermediate level, consisting of the compulsory D.P.R. (Decree of the President of the Republic) No. 412, precisely defines and reaffirms the basic role of thermal insulation in view of energy saving and environmental welfare, delegating the application procedures to the technical standards drawn up by UNI.

In particular, D.P.R. No. 412 of 26 August 1993 "Regulations containing standards for the planning, installation, operation and maintenance of thermal plants of buildings in order to restrict energy consumption, in accordance with article 4, sub-section 4, of Law 10/'91 and following amendments" defines, among other things, the climatic areas, subdivides the buildings according to their intended use and provides the specifications of the plants. As regards dwelling buildings and buildings with similar intended uses, the D.P.R. assumes a room temperature, during the winter working period of the air-conditioning unit and a maximum value determined on the basis of the arithmetical mean of air temperatures of all the individual premises of the buildings, defined and measured according to the specifications contained in the technical standard UNI 5364.
Article 8 of the Decree also indicates the daily mean over 24 hours of the minimum number of air volumes that can be recycled in one hour, fixing it conventionally to 0,5 for dwelling buildings, if no controlled mechanical air changes are envisaged.

The whole regulative course outlines the calculation of energy requirements for an indoor environment as a physical magnitude depending on several interacting factors. In this sense, the ventilation requirement should act to correct and integrate the building's performances, to intermediate between the inside and the outside but , as specified by UNI 5364, it also depends on the intended use of the considered room, on its type, extent, orientation, on the resistance of frames, etc.
Nevertheless, as far as ventilation is concerned, the conventional value fixed by D.P.R. No. 412, is still 0,5 m^3/h.
What's more, in some cases, regional regulations provide for minimum ventilation limits; that's the case of Lombardia where the hygiene regulation in force establishes that for private premises the external filtered air change should not be less than $20m^3/h$ per person.
Uncertainties and misunderstandings could arise from such a complex situation; hence the need of having a national law taking charge of providing all necessary references, also related to the progress of other countries in this field.

For what concerns the dimensioning of ventilation grids, on the national level there are specific standards establishing the air flow rate values for ventilation according to the specific living premises. It's the case of the Belgian standard and of the Dutch standard:

NBN D 50-001

Destination des locaux	Débit (m^3/h)		
	Min.	Nominal	Max
Local de sejour	75		150
Chambre à coucher Chambre hobby ou étude	25		36 / personne
Cuisine Salle de bains Buanderie, local de sèchage et espaces analogues	50	surface (m^2) x 3,6	75
Couloirs, escaliers, hall de jour et de nuit et espaces de passages analogues	-	surface (m^2) x 3,6	-
Cuisines avec un passage ouvert vers d'auters espaces ou locaux	75		-
WC	-	25	-
Cage d'escalier	1/2 x volume par heure	-	-

NEN 1087

Destination des locaux	Débit nominal (dm^2/s)
Local de sejour	1 par m^2 min 21
Cuisine Salle de bains Buanderie Local de sèchage Espaces analogues	21 14 14 14 7
Cuisines avec un passage ouvert vers d'auters espaces ou locaux	1 par m^2 min 21
Chambre à coucher Chambre hobby ou étude	1 par m^2 min 7
Combles	1 par m^2 min 7
Garage	3 par m^2
Local poubelles > $3m^2$	100
Ascenseur	1 par personne
Cage d'escalier	1 x volume par heure

4.2 Standards for windows

The standards sphere specifically related to windows and to the relationship existing between windows and the different natural ventilation systems, deserve a thorough investigation.
The national standard UNI 7979 establishes the criteria for classifying windows according to their performances related to air permeability, watertightness and wind resistance, tested in testing laboratories according to the methods specified by the relevant European normative provisions, that have been adopted in Italy as UNI EN 42, UNI EN 86 and UNI EN 77.

Air permeability can be defined as the air amount, expressed in m^3/h, managing to pass through the close window system, due to the pressure difference between the external and the internal surfaces. The value measured in the laboratory, by submitting the window to an air mass under static pressure, is the indication used to assign one of the three classes of performance. The results of this test refer to the ratio between the square metres of opening surface ($m^3/h.m^2$) and the linear metres of the opening joint ($m^3/h.m$). Class A3 represents the most favourable case and therefore indicates that only a very small amount of air manages to seep through the joints.
Such an appraisal can not obviously be extended to a window including the natural ventilation unit which, beside the assessment referring to the unit itself, is an integral part of a system with which it interacts, deserving this way a global appraisal.
A great care should also be taken over the tests for the classification of wind resistance as far as this system is concerned. Such a test is used to assess the ability of the window to withstand a certain wind pressure which should engender neither functional degradations of the window frame nor failures of the mechanical parts representing a possible danger for the users. Some experiments executed at ICITE's laboratories on bottom hinged windows with the ventilation unit inserted breadthwise in their top part, produced resistance values much below the minimum class provided for by the standard. This shows a weakening of the whole system that therefore needs the application of additional safety measures in case of wind.

5. International methodologies for the calculation of ventilation requirements in the indoor environment

The main objective of ventilation is to ensure the necessary air quality in an indoor environment. On the basis of this fundamental assumption, the first factor to be known is the air volume to be recycled, according to the pollution rate.
Polluting agents adding to endogenous noxious substances depend on how many people are in the room and on the type of activity that is carried out in it. In this connection, there are no official reference standards defining in full detail the overall pollution and relevant admitted levels, being the nature of the problem made more complex by the poor knowledge about the exact number of agents contained in the air and about the ensuing effects and the actions that can be synergically derived from them. The knowledge so far acquired is collected in the OSHA (Occupational Health and Safety Administration) Recommendations (see table...).
The presence of carbon dioxide, released by man in variable amounts, according to the activity he carries out in the indoor environment and to his metabolism, is a good indicator of air quality. ASHRAE standard 62-1989 "Ventilation for Acceptable Indoor Air Quality" assumes that the ventilation demand is acceptable whenever the concentration of carbon dioxide is not greater than 1000 ppm, as specified by the OSHA recommendations.
The revision of ASHRAE standard 62-89, which besides has not yet been adopted, has kept the assessment criterion based on the concentration of carbon dioxide; however, it has specified that the criterion is not based on sanitary principles but that it is just a parameter for the control of human smells, since it is mainly based on the individual input represented by crowding.
The American revised draft standard confirms the two previous methodological approaches; the compulsory approach and the performance-oriented approach, the former being used to calculate the minimum external air flow rate as the addition of two terms proportional to the index of indoor crowding and to the indoor area respectively, proposing proportional values that in the former case are of 3L/s per person and, in the latter case, are of $0{,}35 L/sm^2$.

The performance-oriented method needs a basic knowledge, namely:
- the nature of pollutants present indoors;
- the possible production of pollutants over a specific period of time;
- the admitted concentration in terms of health and comfort.

For the time being, it is extremely difficult to adopt this method since not all of the countless calculation inputs are known.

Another method used to dimension indoor ventilation was elaborated during the 80's in Northern Europe by a team of experts led by Prof. Fanger.

The theory in question was criticized by many but appears in the IAQ chapter of CEN/TC pre-standard 156 "Ventilation for Buildings: design criteria for the indoor environment" and suggests to dimension the air change requirements on the basis of the air quality that can be sensed by man himself. To this end, two units of measurement have been introduced: the *olf* after the Latin word"olfactus", that senses the polluting molecules dispersed in the air through the olfactory sensorial activity, taking place at the end of the nasal cavity; the *decipol,* after the Latin word "pollutio", turns the actions that irritate to a lesser or greater extent the mucous membranes of the upper tract of the respiratory system and of the eye, into different levels of pollution present in the area. In other words, decipol represents the air quality that can be sensed as a result of the interaction between pollutants and ventilation. This means that with a polluting source of one olf, detected in an indoor environment in which 10 l/s clean air are let in, the qualitative value expressed in decipols will amount to one and will prove that air and pollution have perfectly blended.

The equations proposed by Fanger are based on sensorial evaluations and, even if many people consider them rather superficial, still represent an effective and easy assessment instrument.

6. Future developments

The situation so far described clearly shows that future developments will mainly follow two ways: the technical/performance-oriented way and the legislative way.

The proposition of optimum ventilation values for indoor environments to be included in the Italian legislative and normative body becomes more and more meaningful also with reference to the present stage of the study which is trying to define, through a number of corrective actions to be applied to the studied prototype, performance-oriented criteria to be effectively applied to any atmospheric situation. To sum up, instead of completely closing the window when atmospheric conditions are bad, the application of a highly sensible mechanical regulator will ensure an air flow as an inverse funtion of the external pressure. Present difficulties concern the possibility of managing the air flow with pressures greater than 50 Pa, although even the most advanced standards ruling this subject do not envisage such a possibility.

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