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Correlation Between Carbon Dioxide Concentration and Condensation in Homes.

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CORRELATION BETWEEN CO_2 CONCENTRATION AND CONDENSATION IN HOMES

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1. INTRODUCTION

Ventilation systems in dwellings should not only maintain the quality of the air, in other words limit pollutant concentration whatever the origin, but protect the structure, that is, limit condensation and the storage of excessive humidity in existing materials.
Domestic ventilation represents a significant element of energy loss. It is a function that should be provided at minimum cost in terms of energy and therefore be directly dependent on fresh air requirements. Hence the introduction on the market of so-called hygro-adjustable ventilation systems. However, these systems do not necessarily meet air quality requirements and, at present, on the French market, there is no existing model of a ventilation system adapted to the residential sector and controlled by gaseous pollution content.
To be able to offer dual heating/ventilation systems which meet air quality requirements, while remaining low on energy costs, the ADEME, GDF, EDF, FNB and CEBTP have combined their skills and capabilities in a research programme involving, first a national survey followed by in-situ measurements and, second, the development of a hygrothermal and ventilation code incorporating pollutant transfers i.e: the BILGA programme (FNB/CEBTP).
One application of the programme was to find out whether there was a correlation between carbon dioxide concentration (present in most pollutive productions) and condensation hazards in dwellings, making it possible to control ventilation on the basis of a single criterion and then examine various ventilation strategies.
This study is currently in progress.

2. THE BILGA PROGRAMME

Developed in 1980 by the CEBTP and the FNB, BILGA is a hygrothermal and multi-zone ventilation simulation tool based on a detailed description of the building shell, the ventilation system, occupancy and environment.

In order to best define indoor atmospheres, the basic version was completed by two modules which allowed for humidity exchanges with the furniture and the walls, as also the transfer of gaseous pollutants, the aim being to determine an overall air quality index for a given dwelling.

2.1 Humidity Exchanges

The general equation of the mass balance of steam in a room may be written as follows:

$$\dot{m}_w = \dot{m}_e - \dot{m}_s + \dot{m}_o + \dot{m}_a - \dot{m}_m - \dot{m}_p \qquad [kg/s]$$

where:

$\dot{m}_e$, $\dot{m}_s$ are the mass flowrates of steam entering and leaving the room by convection process,

$\dot{m}_o$, $\dot{m}_p$ the internal production due to the metabolism and activities of the occupants,

$\dot{m}_m$, $\dot{m}_p$ the flowrates of steam absorbed/desorbed by the furniture and walls.

2.2 Gaseous Pollutant Transfers

The model currently takes into account the evolution of ten gaseous polluants (CO_2, CO, NO_2, HCHO, O_3, ...).

The overall equation of the mass balance of a pollutant in a given room can be written:

$$V.dC/(Ef.dt) = Fp \qquad [g/s]$$

V being the volume of the zone, C the pollutant concentration, Ef the ventilation system efficiency (as a function of the air renewal rates, the location of the ventilation openings and the source of pollution). Fp being the pollutant flux corresponding to:

- internal productions due to occupancy and appliances,
- productions/absorptions due to materials and chemical reactions,
- pollutant fluxes exchanged with the exterior and with other rooms, by convection, diffusion and gravity.

2.3 Air Quality Index

An air quality index defined by the "Fédération Nationale du Bâtiment" (National Building Federation), postulates occupant exposure to a pollutant and two limit concentration values:

$$AQI\ (p,ts) = \frac{E(p,ts) - LRV(p,ts)}{SRV(p,ts) - LRV(p,ts)}$$

E(p,ts) [exposure] is the maximum mean concentration level during the life ts of the pollutant p in the room,
LRV the Limited Risk Value,
SRV the Significant Risk Value, as defined by the pollutant.

If AQI $\leq$ 0, the pollutant is without effect on the occupants,
if AQI $\geq$ 1, the risk due to pollution is deemed "unacceptable".

The air quality index of the least favourable room in a dwelling was assumed to be the overall air quality index for that dwelling.
For this study, the overall air quality index for a dwelling was determined on the basis of carbon dioxide concentrations, considered to be the polluant the most representative of domestic activity (occupancy, smoking, cooking appliances, the exterior).

Confronted with the diversity of the limit values proposed for carbon dioxide, we have assumed the WHO values (1982):

LRV CO_2 = 4500 mg/m^3 (2300 ppm)
SRV CO_2 = 12000 mg/m^3 (6100 ppm).

3. CONDENSATION AND AIR QUALITY INDEX

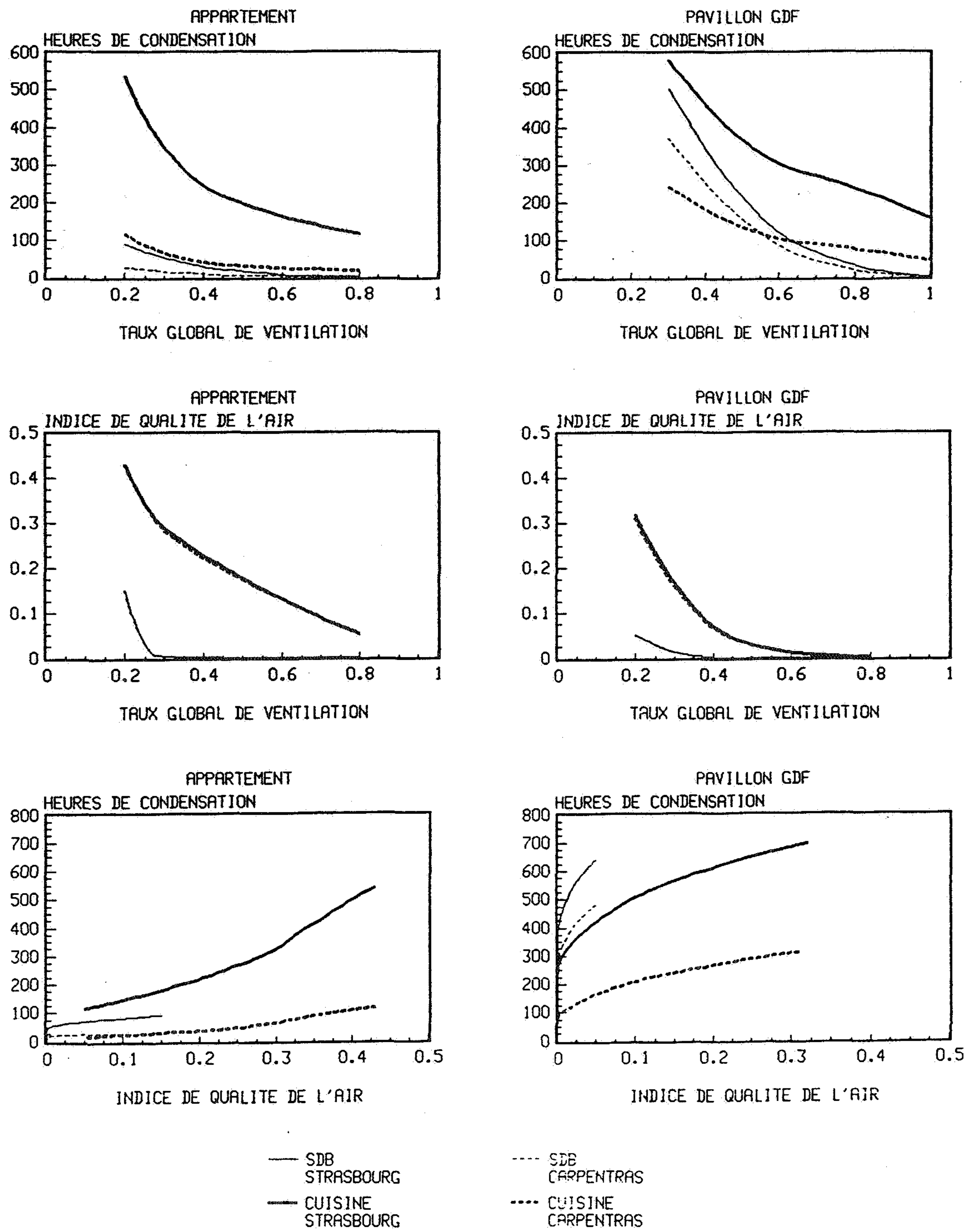
3.1 Hypotheses

This study covered an eight-month period and involved two types of dwellings (an individual house and an appartment in a multi-family appartment block) in a temperate climate (STRASBOURG and CARPENTRAS).
The global ventilation rate (single status) varied from 0.2 to 0.8 volume/hour. The internal masses were not taken into account. Daily steam production in the kitchen was 3.2 kg.
The kitchen was fitted with a 2.3 kW oven (CO_2 emission: 98 mg/s) and with a 3 kW cooker (CO_2 emission: 150 mg/s) operating according to 9 min. sequences.

3.2 Results

The graphs hereinafter show the relations obtained between ventilation rates, condensation hazards and the air quality index in the different situations analysed.

Condensation times and air quality index
as a function of the ventilation rate



Whatever the climate and type of housing, the highest condensation hazards are to be found in the kitchen (production of 3.2 kg/24 h).

By comparison with the individual house, for a same given climate and same global ventilation rate (0.3 vol/h), the appartment exhibited less significant condensation hazards in the kitchen (lower occupancy rate) and in the bathroom (no wall in contact with the exterior).

Although the influence of climate was significant on condensation hazards, it was negligable on the air quality index.

The global air quality index is that of the kitchen (related to the use of cooking appliances).

By comparison with the individual house, for a same given total ventilation rate, the total air quality index was higher in the appartment (the kitchen air renewal rate was lower), but remained acceptable for a low total ventilation rate (0.2 vol/h).

In spite of the existence of Controlled Mechanical Ventilation, steam and carbon dioxide migrations from the kitchen to the main rooms were observed.

Such transfers are the consequence of extensive ventilation recycling caused by a temperature rise in the kitchen when cooking appliances are put to use.

Condensation can occur on windows while the quality of the indoor air is satisfactory and, conversely, in the presence of smokers and with an extremely reduced ventilation rate, an unacceptable pollution level is observed without any concomitant condensation.

There is a predominant occurrence of condensation in bathrooms.

The mildness of the climate increases the degree of independence of condensation hazards in relation to the air quality index.

The correlation between condensation hazards and the overall air quality index being globally slight, the results of the study show that the dependence of domestic ventilation on a single criterion (condensation or pollution), cannot constitute a universal solution for maintaining satisfactory indoor atmospheres.

However, as will be seen later, the situation should be examined differently for each type of room, and allowance made for the type of heating and domestic equipment.

4. STUDY OF DIFFERENT VENTILATION CASES

4.1 Objective

A proposal for a ventilation system can be based on a forecast estimation of efficiency in respect of the three criteria i.e: air quality, hygrometry limitation and energy saving.

By virtue of their different functions, the situations in the rooms of a dwelling show extreme differences:

Kitchen : significant emissions, short and generally correlated of CO_2 and steam.
Bathroom : significant short steam emission, CO_2 emission limited to a single person.
Bedrooms : slight correlated emissions of CO_2 and steam.
Living-room: slight steam emission related to occupancy, occasional emission of pollutants (smokers).

A very slight ventilation rate is required in the absence of any occupancy.
The ventilation system should therefore provide a response adapted to each situation.

The following study proposes an example of a comparison between certain ventilation strategies in order to single out certain trends.

4.2 Study hypotheses

The study was carried out on a standard, multi-family, four-roomed dwelling (210 m^3), based on realistic occupancy hypotheses (assumed in order to assess the hygro-adjustable systems), over the course of two five-day periods, typical of winter in the Paris area, one being moderately cold (-5, +1 °C, 70-95 % HR) and the other mild and damp (+5, +10 °C, 75-95 % HR).
The CO_2 emission from appliances was the same as above.
Humidity exchanges with the furniture and walls were taken into account.
Three types of ventilation were considered:

- conventional CMV system : (Type 3)
  45 m^3/h in kitchens, 60 m^3/h in sanitary units.
- hygro-adjustable ventilation: (Type 2)
  kitchen : 10 to 45 m^3/h for 35 to 65% RH
  bath-room : 5 to 45 m^3/h for 35 to 65% RH
  W-C : 30 m^3/h permanent basis.
- reduced ventilation : (Type 1)
  10 m^3/h in kitchens, 35 m^3/h in sanitary units.

With or without, in each case, the utilization of a high flow-rate in kitchens (120 m^3/h) for 2 hours a day, when cooking appliances were in use.

4.3 Results

The graphs hereinafter show the different types of results for both periods:

- In-flow, heating consumption on fresh air intake,

- Condensation times (kitchen and bath-rooms),

- Maximum CO_2 concentrations (averaged over an hour).

The **minimum ventilation** option results in unacceptable condensation times and air quality.

In rooms located on facades that are oriented "under the wind", the effect of the prevailing wind impedes the effect of ventilation, and moreover, the air quality deteriorates in such rooms (not shown).

Hygro-adustable ventilation is more efficient when climatic conditions are cold and dry. In periods of mild damp weather, efficiency and utilization costs are comparable to those of the conventional CMV.

In all cases, the use of **accelerated ventilation flow** in the kitchen considerably reduces the risk of condensation and maximum CO_2 concentration for only a minor extra cost in terms of energy.

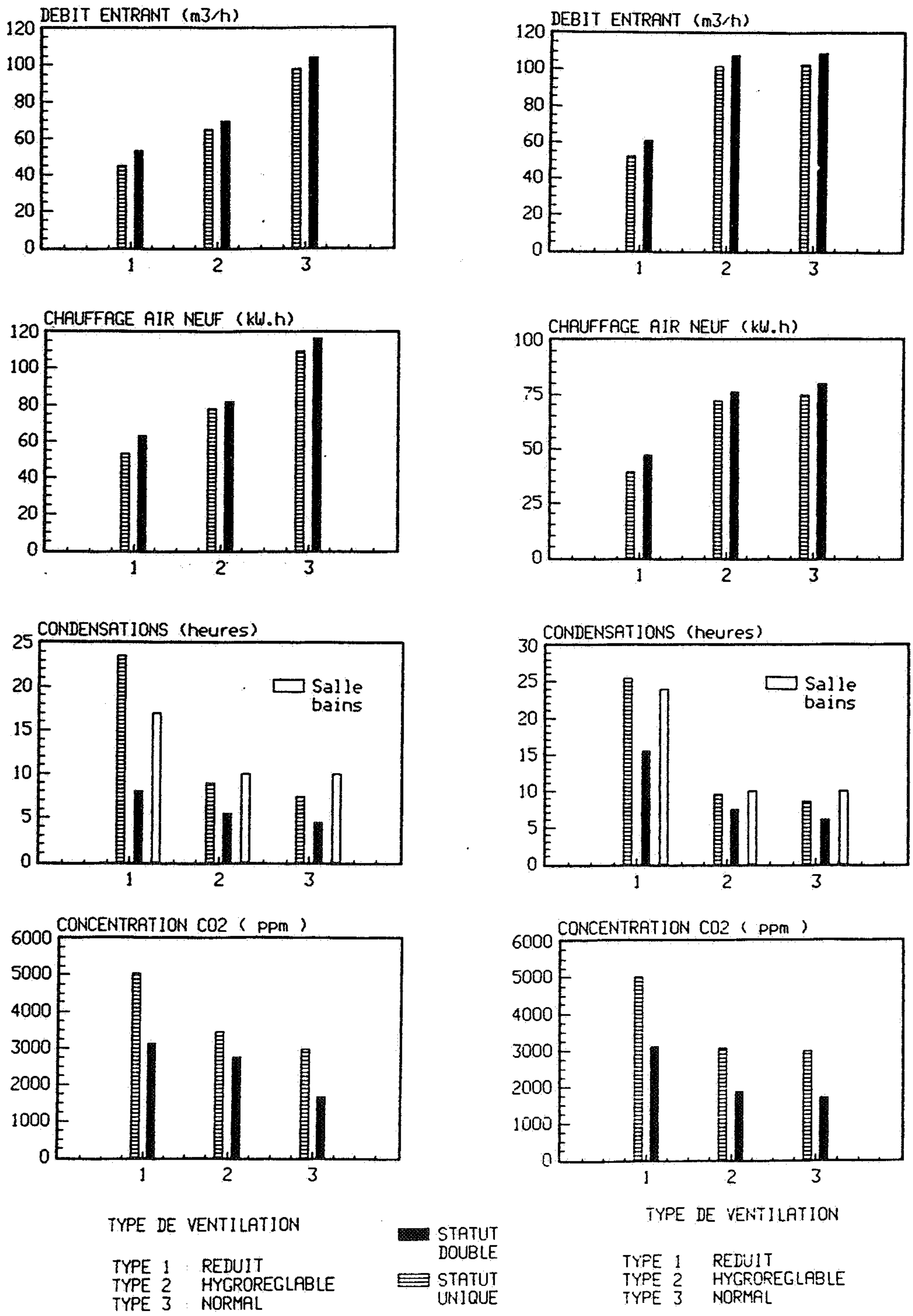
Absence of condensation in the bath-room, when in use, can only be achieved under accelarated operating conditions.

These observations suggest, that for systems of ventilation by extraction, provision should be made for 3 levels of activity:

- reduced operating conditions for periods of non occupation (governed, for instance by CO_2 concentration used as a monitor),

- low occupancy operating conditions, which complement the above,

- forced operating state, governed by the presence of humidity or CO_2 according to the intended purpose of the room in service and the manner in which it is fitted out.


DEBIT ENTRANT (m3/h)
CHAUFFAGE AIR NEUF (kW.h)
CONDENSATIONS (heures)
Salle bains
CONCENTRATION CO2 (ppm)
DEBIT ENTRANT (m3/h)
CHAUFFAGE AIR NEUF (kW.h)
CONDENSATIONS (heures)
Salle bains
CONCENTRATION CO2 (ppm)
TYPE DE VENTILATION
TYPE 1 REDUIT
TYPE 2 HYGROREGLABLE
TYPE 3 NORMAL
STATUT DOUBLE
STATUT UNIQUE
TYPE DE VENTILATION
TYPE 1 REDUIT
TYPE 2 HYGROREGLABLE
TYPE 3 NORMAL