A GLOBAL APPROACH TO EVALUATE IAQ AND THERMAL COMFORT IN A HEALTHY BUILDING PERSPECTIVE

F. Sicurella[1]; P. Colamesta[2];

1: Planair SA; fabio.sicurella@planair.ch

2: Planair SA; perla.colamesta@planair.ch

ABSTRACT

In recent years many progress have been made in the knowledge of Indoor Air Quality (IAQ), ventilation, and building-related health problems in schools, offices and other workplaces. Ensuring the IAQ inside these kinds of buildings is very important since people spend about 90% of their time indoors. Currently new buildings are the most affected by indoor pollutants (CO_2, VOC, formaldehyde etc.) since they are characterized by a very high air tightness that significantly reduces the inlet of fresh air through infiltrations. For this reason the ventilation (natural and mechanical) is becoming a very important topic for the health in new buildings. In this study the concentration of indoor pollutants was evaluated for different envelope air tightness and ventilation strategies. The simulations were run on EnergyPlus. The methodology proposed in the present paper includes a parametric multi-objective analysis that takes into account not only IAQ but also thermal comfort; this approach allows to propose optimised solutions during the concept and the design of new "healthy" buildings.

Keywords: IAQ and thermal comfort, healthy buildings, ventilation strategies

INTRODUCTION

Problems of IAQ are recognized as important risk factors for human's health worldwide. IAQ is also important because people spend a substantial proportion of their time in buildings. In residences, day-care centres, retirement homes and other special environments, indoor air pollution affects population groups that are particularly vulnerable owing to their health status or age. The World Health Organization (WHO) indicate a number of chemicals commonly present in indoor air that can cause momentary troubles [1]. In [2] it is suggested that when 20% of a single building's occupant suffers such troubles, the structure is suffering from sick building syndrome (SBS).

Guarantee the IAQ means also sparing the discomfort caused by these pollutants. In this paper, for brevity, only two pollutants were simulated to analyse IAQ and thermal comfort: Formaldehyde and CO_2; the first usually linked to furniture the latter to metabolic activity.

INDOOR POLLUTANTS IN BUILDINGS: FORMALDEYDE AND CARBON DIOXIDE

Indoor sources of formaldehyde may be combustion processes such as smoking, heating, cooking, candle or incense burning. However, major sources in non-smoking environments appear to be building materials and consumer products that emit formaldehyde [3]. Predominant signs of short-term exposure to formaldehyde in humans are irritation of the eyes, nose and throat; with higher concentration, lachrymation, sneezing, coughing, nausea, etc. (Figure 1, left). Symptoms are often more severe at the start of exposure than after minutes or hours, when they gradually diminish.

Concerning CO_2, the indoor primary source is human metabolism. An average person, in fact through the natural process of breathing, produces approximately 1 kg of carbon dioxide per day, even though it strongly depends on the person's activity level [4]. Many researches have shown that high CO_2 concentration are associated with perceptions of poor air quality and may increase prevalence of acute health symptoms (e.g., headache, mucosal irritation), slower work performance and absence. Even a moderately high indoor concentration of CO_2 can significantly impair people's decision-making performance [5] (Figure 1, right).

Concentration range or average (mg/m^3)	Time range or average	Health effects in general population
0.03	Repeated exposure	Odour detection threshold (10th percentile) [a]
0.18	Repeated exposure	Odour detection threshold (50th percentile) [a]
0.6	Repeated exposure	Odour detection threshold (90th percentile) [a]
0.1 – 3.1	Single and repeated exposure	Throat and nose irritation threshold
0.6–1.2	Single and repeated exposure	Eye irritation threshold
0.5 – 2	3–5 hours	Decreased nasal mucus flow rate
2.4	40 minutes on 2 successive days with 10 minutes of moderate exercise on second day	Post-exposure (up to 24 hours) headache
2.5 – 3.7	– [b]	Biting sensation in eyes and nose
3.7	Single and repeated exposure	Decreased pulmonary function only at heavy exercise
5 – 6.2	30 minutes	Tolerable for 30 minutes with lachrymation
12 – 25	– [b]	Strong lachrymation, lasting for 1 hour
37 – 60	– [b]	Pulmonary oedema, pneumonia, danger to life
60 – 125	– [b]	Death

[a] Frequency of effect in population.

[b] Time range or average unspecified.

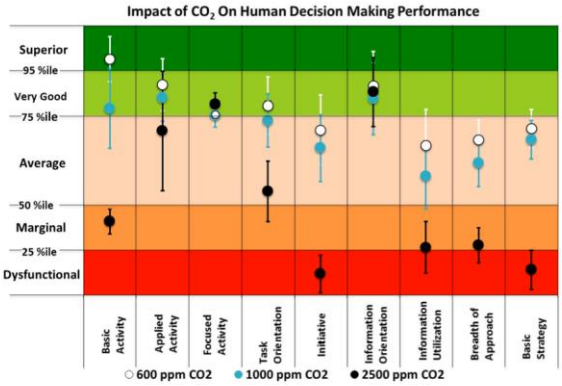

Figure 1(left): Effects of formaldehyde in human after short-term exposure. Source: [1]

Figure 1(right): Impact of CO_2 on Human Decision-Making Performance. Source: [5]

FORMALDEHYDE AND CARBON DIOXIDE GENERATION RATE AND LIMITS

In the present study formaldehyde class E1 (release equal to 3.5 $mg \cdot m^{-2}h^{-1}$, [6]) was considered for indoor furniture.

In technical standards and literature it is possible to find different values of suitable formaldehyde concentration inside a building. The authors have analysed the limits imposed by the WHO, the OFSB (Office fédéral de la santé publique en Suisse), the Leed and Minergie-ECO standards and have chosen the more restrictive, the Leed limit, equal to 27ppb.

The contaminant generation rate in an office building is equivalent to the combination of the constant coefficient model defined in the sources and sinks element types of CONTAM 3.0. The basic equation used to calculate formaldehyde source and sink for the constant model is given below:

$$S_f(t) = G_f(t) - R_f(t)C_f(t)10^{-6} \tag{1}$$

where:

S_f : Formaldehyde source strength [m^3s^{-1}]

G_f : Formaldehyde generation rate [m^3s^{-1}]

R_f : Formaldehyde effective removal rate [m^3s^{-1}]

C_f : Formaldehyde concentration value at a given previous time step [ppm]

In urban environments, outdoor formaldehyde concentrations is considered as 20 $\mu g \cdot m^{-3}$[1, 7]. Concerning Carbone dioxide, only CO_2 emitted by people was considered in this study.

In literature and technical standards it is possible to find different values of suitable CO_2 concentration inside a building. Following the ASHRAE Standard 62 [8], this limit can be set at 1000 ppm even though the standard revision [9], suggests as upper limit 700 ppm above the outdoor concentration. According to [10] the outdoor CO_2 concentration is 400 ppm. As a consequence the authors decided to choose the more restrictive of these rate values for CO_2 concentration, which in this case study was set at 1000 ppm.

The basic equation used to calculate carbon dioxide source and sink for model is given below:

$$Sc(t) = N_p\, S_p(t) A_p(t)\, G_c(t) \tag{2}$$

where:

Sc : carbon dioxide source strength [m^3s^{-1}]

N_p : Number of People [dimensionless]

S_p : People Schedule [dimensionless]

A_p : People Activity [$Wperson^{-1}$]

G_c : Carbon Dioxide Generation Rate [$m^3s^{-1}W^{-1}$]; (equal to $3.82\cdot10^8 m^3s^{-1}W^{-1}$, following [11]).

EVALUATION OF VENTILATION AIR FLOW RATE AND THERMAL COMFORT

The calculation model used for simulating the ventilation air flow rate is a function of wind speed and thermal stack affect, combined with the infiltration effect.

The equation used to calculate the ventilation rate driven by wind is:

$$Q_w = C_w A_o F_s V \tag{3}$$

where:

Q_w : Volumetric air flow rate driven by wind [m^3s^{-1}]

C_w : Opening effectiveness [dimensionless]

A_o : Opening area [m^2]

F_s : Open are fraction [dimensionless]

V : Local wind speed [ms^{-1}]

The equation used to calculate the ventilation rate due to stack effect is:

$$Qs = C_d A_o F \sqrt{(2g\Delta H_{NPL}\, (|T_{zone} - T_{odb}| / T_{zone})} \tag{4}$$

where:

Q_s : Volumetric air flow rate driven by wind [m^3s^{-1}]

C_d : Discharge coefficient for opening [dimensionless]

A_o : Opening area [m^2]

Fs : Open are fraction [dimensionless]

$\Delta HNPL$: Height from midpoint of lower opening to the neutral pressure level [m]

T_{zone} : Zone air dry-bulb temperature [K]

T_{odb} :Local outdoor air dry-bulb temperature [K]

The total ventilation rate is given by:

$$\text{Ventilation}_{\text{Wind and Stack}} = \sqrt{Q_w^{\ 2} + Q_s^{\ 2}} \tag{5}$$

The equation used to calculate infiltration in the effective leakage area is based on LBNL model [7,12] where:

$$Infiltration = \frac{A_L T}{1000}\sqrt{C_S \Delta T + C_w U^2} \tag{6}$$

where:

A_L : Effective Air Leakage Area at 4 Pa [cm^2]

C_S : Stack Coefficient [$(Ls^{-1})^2(cm^4K)^{-1}$]

ΔT : average difference between zone air temperature and the outdoor air

C_W : wind coefficient [$(Ls^{-1})^2(cm^4(ms^{-1})^{-2})$]

U : average wind speed [ms^{-1}]

The Effective Air Leakage Area is function of the n_{50} that is a variable parameter in this study.

Concerning thermal comfort, it was evaluated following the SIA 180:2014 [13]. The approach used to evaluate IAQ and thermal comfort simultaneously is presented in [14, 15].

THE CASE STUDY

The results presented in this work refer to a south-oriented meeting room of a new office building in Courtelary (Switzerland) (Figure 2). It is 3.65 m large, 6.80 m length and 2.8 m high, and it is occupied by six people (following [16]) from 9 am to 12 am et from 2 pm to 5 pm. The floor and all furnishing are considered made by formaldehyde class E1 (74 m^2). The glazing area is 8.8m^2, only 2.2 m^2 is an openable area in bottom hung mode. The simulations were presented in a typical day (21.09).

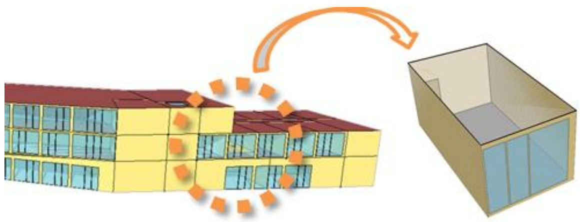

Figure 2: Southern view of the building with in evidence the analysed office

AIR TIGHTNESS AND VENTILATION STRATEGIES

In order to understand the impact of the envelope air tightness and the ventilation strategies on IAQ and thermal comfort, the following simulations were run (Table 1):
Case 1: standard air tightness, without ventilation; ***Case 2***: high air tightness (Standard Minergie), without ventilation; ***Case 3***: very high air tightness (Standard Minergie-P), without ventilation, ***Case 4, 5, 6***: Standard Minergie-P with different mechanical ventilation rates (activated only during occupation); ***Case 7***: Standard Minergie-P with natural ventilation.

	n_{50} [h^{-1}]	Natural ventilation	Mechanical ventilation
Case 1	2	/	/
Case 2	1	/	/
Case 3	0.6	/	/
Case 4	0.6	/	36 $m^3(h\cdot person)^{-1}$ [23]
Case 5	0.6	/	12 $m^3(m^2h)^{-1}$ [23]
Case 6	0.6	/	0.5 h^{-1}
Case 7	0.6	Bottom hung mode	/

Table 1: Simulations.

THE RESULTS

On the basis of the results shown in Figures 2, 3 and 4 one can observe that:

- a high envelope air-tightness without adequate ventilation entails relevant IAQ problems. Figures 2 and 3 show that, without ventilation, formaldehyde and CO_2 concentration exceed standard limits. The ventilation becomes necessary for high performance buildings. For buildings with higher infiltration rate (case 1) these concentrations are significantly lower and could be enough for formaldehyde dilution but not for CO_2;
- for new high performance buildings (e.g. Minergie, Minergie-P) an intense mechanical or natural ventilation rate is usually enough for IAQ purposes; nevertheless, for this case study, the rate of 0.5ACH (case 6) revealed to be insufficient for IAQ during occupation;
- a natural ventilation strategy (case 7) implies from one hand a higher reduction of pollutant concentration, but from another hand a higher fluctuation in terms of indoor temperature than a mechanical ventilation strategy (Figure 4 left); as a consequence a higher thermal discomfort for cold can occur (Figure 4 right) as well as local discomfort (drafts).

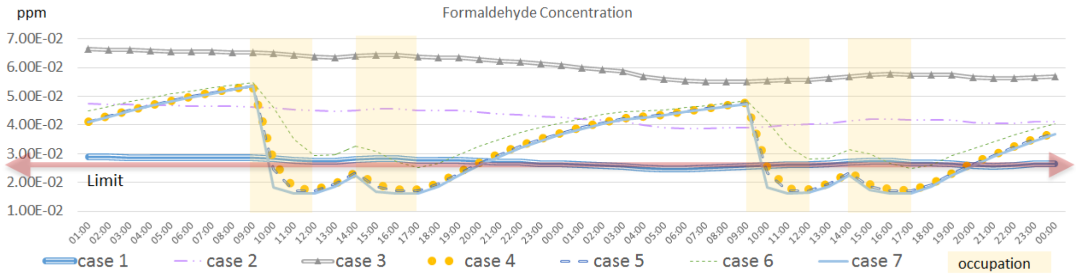

Figure 2: Simulation results: Formaldehyde concentration

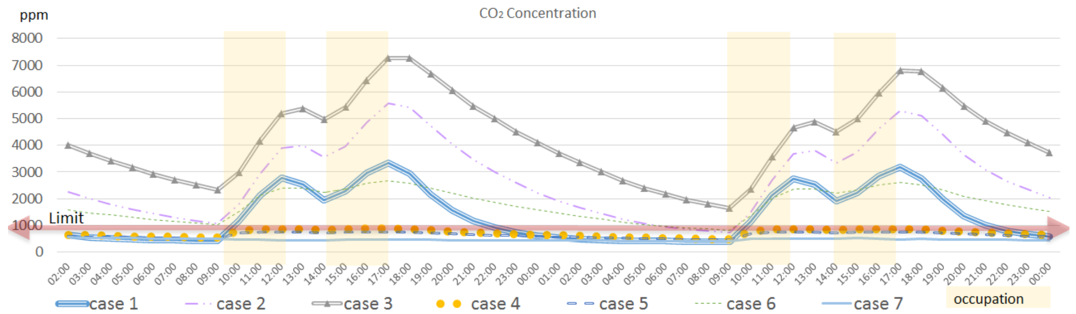

Figure 3: Simulation results: Carbon dioxide concentration

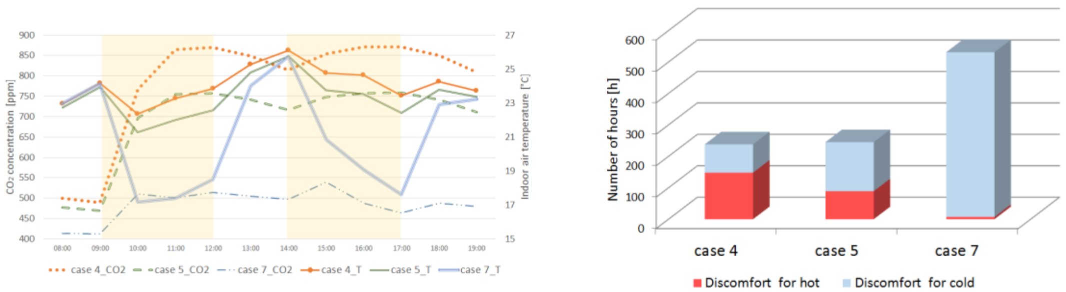

Figure 4 (left): Comparison between ventilation strategies for IAQ and thermal comfort
Figure 4 (right): Comparison between ventilation strategies for thermal discomfort (case 4 and 5 analysed with SIA 180 model for conditioned room, case 7 with SIA 180 model for non-conditioned room; analysed period: 15.05-15.10 [13])

CONCLUSIONS

Achieving IAQ and thermal comfort for new high performance buildings characterised by a very high air-tightness is a real challenge. For these buildings, dynamic simulations show an actual risk in terms of concentration of indoor pollutants that only an adequate ventilation (natural or mechanical) can overcome. Both (natural and mechanical ventilation) are very effective to dilute pollutants. Natural ventilation can be even more effective than mechanical ventilation but strongly depends on the occupant's behaviour and can easily entail thermal discomfort and drafts. In any case for new high performance buildings a ventilation strategy becomes primordial and should be defined during the preliminary phases of the building design.

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