Volumetric and mass flows in the Swiss National Library, room 3UG

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Part I

Volumetric flows

Room 3UG is underground, and has therefore no windows. It has one door giving to a staircase which leads to a glass house connected to the main building with a double sliding door. The staircase connects the four underground depot room (at each floor one very large depot room). The glass house has on the ceiling openings which will be opened if the temperature of the glass value becomes higher than a certain value (which value?). The glass house has also a ventilation system which can cool the air in case the openings are not sufficient (in this case the openings are closed and the ventilation plus cooling works, all automatic). The staircase has no indipendent air conditioning but gets air from the depot rooms. The depot room are kept at an overpressure of 10 Pa (with respect to what?). The openings between the depot rooms and the staircase have thin plates (fins) and are approximately ?? large.

Despite it seems possible that the outside pressure (because of wind, different temperature and different humidity) becomes larger than the pressure outside, we still consider that infiltrations are negligible (check).

There is a main HVAC unit and a local HVAC unit for this room. Both units have chemical filters. The local HVAC can not umidify or dehumidify. During working hours fresh air is taken in and mixed with recirculated air. During non working hours the system works in 100% recirculation.

The following equation is for working hours.Despite the volume of air coming into the room comes from a single duct, it contains fresh and recirculated air and I write explicitely these two contributions. Both of them are constant in time.

$$\frac{dV_{in}}{dt} = \frac{dV_{in,rec}}{dt} + \frac{dV_{in,fresh}}{dt} \tag{1}$$

$$\frac{dV_{in,rec}}{dt} = A \tag{2}$$

$$\frac{dV_{in,fresh}}{dt} = B \tag{3}$$

Air is taken out of the room, a part of it goes in the recirculation system, a part goes out of the room (fortluft, check) and a part leaves the room in direction staircase through a specific opening provided with thin plates (fin) (this is done so that the staircase gets air conditioning). The pressure in the room is, acording to the engineers, higher than the pressure outside (check: than the pressure outside or than the pressure in the staircase?)

$$\frac{dV_{out}}{dt} = \frac{dV_{out,rec}}{dt} + \frac{dV_{out,exit}}{dt} + \frac{dV_{out,exf}}{dt} \tag{4}$$

$$\frac{dV_{out,rec}}{dt} = A \tag{5}$$

$$\frac{dV_{out,exit}}{dt} = C \tag{6}$$

$$\frac{dV_{out,exf}}{dt} = v_{ex} S_{ex} = D \tag{7}$$

where v_{ex} is the air speed in proximity of the fin, or according to the Hagen-Poiseuille equation:

$$\frac{dV_{out,exf}}{dt} = \frac{\pi r^4}{8 \mu L} \triangle P = D \tag{8}$$

As much air comes into the room as air leaves the room, therefore:

$$B = C + D \tag{9}$$

NB: plugging in typical values for r (=0.1m), L (=0.1 m) , $\mu = 18.27 \times 10^{-6} Pa$ s (air) and $\triangle P = 10Pa$ in 8 and calculating v_{ex} from 7we get a speed of air in proximity of the fin of 600 m/s which is way too big. Why? 1. equation 8 ignores the presence of the thin plates, 2. the resistance might be the whole staircase, 3. the difference of pressure is much lower than 10 Pa.

If the exfiltrations can be neglected we will get:

$$B = C \tag{10}$$

Part II

Mass flows

The mass flow entering the room is given by:

$$\frac{dM_{in}}{dt} = c_{in}\epsilon_1 \frac{dV_{in,rec}}{dt} + c_{out}\epsilon_2\epsilon_1 \frac{dV_{in,fresh}}{dt} = c_{in}\epsilon_1 A + c_{out}\epsilon_2\epsilon_1 B \tag{11}$$

where ϵ_1 is the reduction factor of the chemical filters present in the local HVAC and ϵ_2 is the reduction factor of the filters present in the main HVAC.

The mass flow leaving the room is given by:

$$\frac{dM_{out}}{dt} = c_{in}A + c_{in}C + c_{in}D \tag{12}$$

In the steady state the mass entering the room is equal to the mass leaving the room plus the mass abosrbed by the surfaces:

$$\frac{dM_{in}}{dt} = \frac{dM_{out}}{dt} + \frac{dM_{abs}}{dt} \tag{13}$$

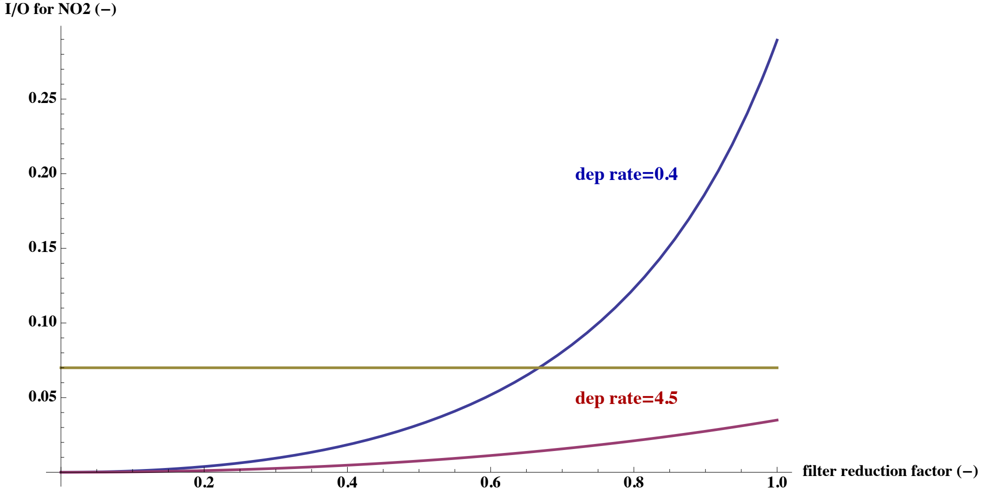
Inserting 11 and 12 and using the (?Weshler) expression for the mass absorbed we get

$$c_{in}\epsilon_1 A + c_{out}\epsilon_2\epsilon_1 B = c_{in}A + c_{in}C + c_{in}D + c_{in}v_{dep}S_{dep} \tag{14}$$

which can be rewritten as

$$\frac{c_{in}}{c_{out}} = \frac{\epsilon_2\epsilon_1 B}{A(1-\epsilon_1) + C + D + v_{dep}S_{dep}} \tag{15}$$

The following graph shows the I/O ratio as a function of the efficiency of the filter (assumption ϵ_1=ϵ_2) and with B=800 m3/hr, A=7000 m3/hr, D=0 and C=800 m3/hr. For the deposition rate ($v_{dep}\frac{S_{dep}}{V}$) I have taken two values for NO2 reported by [2](taken from [1]): 0.4/hr for a large and open gallery and 4.5/hr for a storage room:



The green line represent the lower I/O limit which can be measured and it is calculated from the average outside NO2 concentration in the vicinity of the HVAC inlets (14 ppb measured in 2008) and from the lower detection limit of passive samplers: 1 ppb. As we see any filter with reduction factor lower than 0.65 should result in not detecatble inside NO2 concentration, even for low occupied rooms. For a storage room the reduction factor of the filter plays no role. Even in the case of no filter (reduction factor equal to 1) and almost empty room, the NO2 level inside is 30% of the average outside level, which means about 4.2 ppb. This is due to the low fresh air intake (800 m3/hr) in comparison with the volume of the room (4900 m3).

In the next weeks we will measure cin and cout. After we will be able to assess: the deposition rate on the collection and therefore the total amount of NO2 absorbed per kg of paper in this room.

References

[1] N. Blades, May Cassar, Tadj Oreszczyn, and Ben Croxford. Preventive conservation strategie for sustainable urban pollution control in museums. In A. Roy Smith and P., editors, *Tradition and Innovation, advances in conservation, contribution to the IIC Melbourne Congress, 10-14 Octber 2000*, pages 24–28. London, 2000.

[2] Morten Ryhl-Svendsen. Indoor air pollution in museums: prediction models and control strategies. *Reviews in conservation*, (7):27–41, 2006.