HUMIDITY SOURCES AND INFILTRATION EVALUATION IN SCHOOLS

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Abstract. *Measurements were performed in seven schools of A Coruña and Ferrol from February to June 2005. These cities are located by the Atlantic Sea and 60 Km away from each other. Four of these schools are located in Coruña and the other three in Ferrol. The oldest building was built in 1889 and the newest in 1999. We have selected a representative classroom in every school for our study. In the present paper results from the oldest and newest schools will be presented. They will be designated as "old" and "new". There were twenty six students in the classroom of the old school and twenty five in the new one. The outdoor annual average parameters during the last five years were: average temperature 13.5ºC; average maximum temperature 18.7ºC; average minimum temperature 8.7ºC; absolute maximum temperature 36ºC; absolute minimum temperature -3.5ºC; and relative humidity 87.9%. The most important indoor humidity sources in these buildings are due to people and infiltration. We have evaluated the following parameters in each classroom: outdoor and indoor temperatures, relative humidity and air infiltration. Since these buildings use naturally ventilated, their evaluation is "open to chance". We have observed that humidity emission from people is around 26.74 g/h in the old school and 20.83 g/h in the new one. The infiltration in the old school is around 33.24 m^3/h and 14.38 m^3/h in the new school.*

Keywords: *humidity sources, schools, infiltration.*

1. INTRODUCTION

Measurements have been performed in seven schools of A Coruña and Ferrol, from February to June of 2005. These cities are located by the Atlantic Sea, in Northwest cost of Spain and 60 Km away from each other. Four of these schools are located in Coruña and the other three in Ferrol. The oldest building was built in 1889 and the newest in 1999. We have selected a representative classroom in every school for our study. In the present paper we present the results from the oldest and newest schools. The parameters from other schools are between oldest and newest schools and they will be designated as "old" and "new". The most important indoor humidity sources in these old and new buildings are due to people and infiltration.

We have evaluated the following parameters in each classroom: outdoor and indoor temperatures, outdoor and indoor relative humidity and outdoor and indoor air infiltration. Since these buildings use naturally ventilated, their evaluation is "open to chance".

A Coruña and Ferrol have mild climate and heating is used to control the indoor temperature during the cold season. The heating is usually used from middle of November to middle of March. But the rest of year the indoor temperature fluctuates freely. As stated in a recent study Hens (2005), the value of indoor temperature depends on the instantaneous balance between heat gains and heat losses. Indoor relative humidity is not controlled at all. At any moment, the values noted are the result of the balance between humidity gains, humidity losses and moisture storage indoor materials surfaces.

Assuming perfect mixing of the classroom air, the moisture balance in every classroom can be written as:

$$x_e G_{a.e.i} + \sum_{j=1}^{n}\left(x_j G_{a.j.i}\right) - x_i\left(G_{a.i.e} + \sum_{j=1}^{n} G_{a.i.j}\right) + G_{v.P} + \sum_{m=1}^{P}\beta_m\left(\phi_{s.m} p_{sat.s.m} - p_i\right)A_m + \sum_{n=1}^{q}\beta_m\left(\phi_{s.m} p_{sat.s.m} - p_i\right)A_m = \rho_a V \frac{dx_i}{dt} \tag{1}$$

Terms $x_e G_{a.e.i} + \sum_{j=1}^{n}\left(x_j G_{a.j.i}\right) - x_i\left(G_{a.i.e} + \sum_{j=1}^{n} G_{a.i.j}\right)$ represents the vapour in and outflow as a consequence of the air exchanges between the classroom and its environment (outside and adjacent spaces such as the corridor), where G_a is the air flow (kg/s) and x is the water vapour ratio in the air (kg/kg); term $G_{v.P}$ stands for the vapour released in the classroom by the people;

terms $\sum_{m=1}^{P}\beta_m(\phi_{s.m}p_{sat.s.m}-p_i)A_m$ reflects sorption/desorption by all surfaces in the classroom; where β is the surface film coefficient for vapour transfer; ϕ_s the surface relative humidity, $p_{sat.s}$ is the water vapour saturation pressure at the surface and p_i is the vapour pressure in the classroom; $\sum_{n=1}^{q}\beta_m(\phi_{s.m}p_{sat.s.m}-p_i)A_m$ considers surface condensation and drying; and $\rho_a V\frac{dx_i}{dt}$ represents water vapour storage in the classroom air.

The air exchanges are quantified using the air balance technique, while the surface temperature and related water vapour saturation pressures are found solving the thermal balances in the classroom. When looking to long term averages, the terms $\sum_{m=1}^{P}\beta_m(\phi_{s.m}p_{sat.s.m}-p_i)A_m$ and $\rho_a V\frac{dx_i}{dt}$ are supposed not to intervene; and simplifying the balance to:

$$x_e G_{a.e.i}+\sum_{j=1}^{n}\left(x_j G_{a.j.i}\right)-x_i\left(G_{a.i.e}+\sum_{j=1}^{n}G_{a.i.j}\right)+G_{v.P}+\sum_{n=1}^{q}\beta_m(\phi_{s.m}p_{sat.s.m}-p_i)A_m=0 \qquad (2)$$

In a naturally ventilated classroom, air exchanges with the outdoor environment are only possible via the windows and via the door to the corridor.

2. SCHOOLS

2.1. Old school

This school has two areas, Fig. 1. The older area of this school was built in 1890 and other area was built in 1960.

The floors of the classrooms have pine wood. All classrooms are adventitiously ventilated by operable windows and random leaks.

We select a classroom located on the second floor of the old area, which it is in the north part of the school. The walls are 0.90 m thick without insulation.

The classroom has a volume of 210 m^3 and the area is 42 m^2. This classroom has 3 windows pine wood with single glazed. The schedule occupation is 26 students and 1 teacher between 08:30 and 14:10 h, and 20 students and 1 teacher between 16:30 and 19:30 h, from Monday to Friday

The building has a central heating system that operates from 08:00 to 10:30 h and 16:30 to 18:30 h, during the period from November 17 to March 18.

Fig. 1. The old school (Eusebio da Guarda).

Fig.2. The new school (Paseo as Pontes).

2.2. New School

This school was built in 1999, Fig. 2. The floors of the classrooms have terrazzo. All classrooms are adventitiously ventilated by operable windows and with random leaks.

We select a classroom located on the first floor, which it is north-east part of the school. The walls are 0.23 m thick thermal insulation by compound glass fibre.

The volume of the classroom is 150 m^3 and the area is 50 m^2. Every classroom has 3 aluminium windows with double glazing.

The scheduled occupation is 25 students and 1 teacher between 08:30 to 14:10 h, from Monday to Friday, and between 16:00 to 19:00 h on Tuesdays.

The building has a central heating system that operates from 08:00 to 10:30 h, during the period from November 17 to March 18.

3. METHODS

To measure the indoor temperature and relative humidity, Tiny Tags data logging were hung in the middle of each classroom at a height from the floor of 4 m in the old school and 2.70 m in new school.

The indoor measurements of temperature and relative humidity have been start on February 19 and ending on June 4, 2005 in every classroom of each school. Bough temperature and humidity data readings were every 10 minutes in all schools. For these evaluations and comparative purposes of indoor and outdoor conditions, we obtained the outdoor temperature and humidity dates from a local meteorological station.

Indoor and outdoor air infiltration was measured by tracer gas method. The tracer gas was sulphur fluoride (SF_6). The measurements of indoor and outdoor air infiltration conditions were by the multigas monitor 1312 and software 7620 from INNOVA AirTech Instruments. We used decay gas traces concentration model and concentration is across-the-board decrease, according to:

$$N = \frac{\ln C(0) - \ln C(\tau_1)}{\tau_1} \tag{3}$$

Where N are air renovations per hour; $C(0)$ is concentration in time = 0, in m^3/m^3; $C(\tau_1)$ is concentration in time τ_1, in m^3/m^3; and τ_1 is total time, in h.

Weigh up humidity decay by nights and weekends, to evaluate emission from people we used the same model, according to Eq. (3).

Because opening windows was without control, we gathered measurements up with different outdoor weather conditions and we present average values.

4. RESULTS

Table 1 represents the outdoor and indoor dry bulb temperature statistics. Table 2 has the outdoor and indoor relative humidity (%) statistics. Table 3 has the outdoor and indoor partial vapour pressure statistics.

The outdoor annual average parameters during the last 4 years were temperature 13.5 ºC and relative humidity 87.9 %; the maximum average temperature was 18.7 ºC; the minimum average temperature 8.7 ºC; the absolute maximum temperature 36 ºC; and the absolute maximum temperature -3.5 ºC.

4.1. Humidity sources

Humidity sources are the people inside the classroom, infiltrations in-out classroom from outside through windows and infiltrations in-out classroom from the corridor through the door.

The humidity emission from one person was estimated around 26.74 g/h in the old school and around 20.83 g/h in the new school.

But these values could be influenced by infiltrations through windows and door. By night and weekends, there isn't indoor humidity emissions from people.

On Fig. 3 about weekly instantaneous temperature and partial vapour pressure we weigh up close partial vapour pressure near linear decrease every night, and especially in weekends.

But without dependence from outside partial vapour pressure in that period of time. So inside instantaneous partial vapour pressure decrease less than outside, there are influence of higher indoor temperature and moisture buffer capacity of indoor materials surfaces.

We have observed that humidity emission from people is around 26.74 g/h in the old school and 20.83 g/h in the new one.

Because the water emission from floor mopping in this classroom was estimated about 0.420 kg/day in the old school and 0.500 kg/day in the new school, this effect could be contempt.

4.2. Infiltrations

The possibilities of air renovation from the outside throw uncontrolled open windows is open to chance.

The values of renovations (infiltration) in the classroom of the new school is: N = 0.0959 renov/h and 14.38 m^3/h

The values of renovations (infiltration) in the classroom of the new school is Old (42 m^2): N = 0.1583 renov/h = 33.24 m^3/h

Table 1 Outdoor and indoor dry bulb temperature (ºC) statistics

	Outdoor	Indoor Old School	Indoor New School
Average	11.5	19.2	20.1
RMS deviation	5.5	2.5	2.1
Maximum	26.46	26.9	26.9
Minimum	-4.15	13.7	14.0

Table 2 Outdoor and indoor relative humidity (%) statistics

	Outdoor	Indoor Old School	Indoor New School
Average	85.85	59.1	53.2
RMS deviation	15.13	7.5	6.2
Maximum	100.0	78.9	73.8
Minimum	28.9	33.9	29.7

Table 3 Outdoor and indoor partial vapor pressure (Pa) statistics

	Outdoor	Indoor Old School	Indoor New School
Average	1186.40	1327.9	1266.8
RMS deviation	332,8	225.9	243.3
Maximum	2191.6	2086.9	2158.3
Minimum	432.22	752.9	590,3

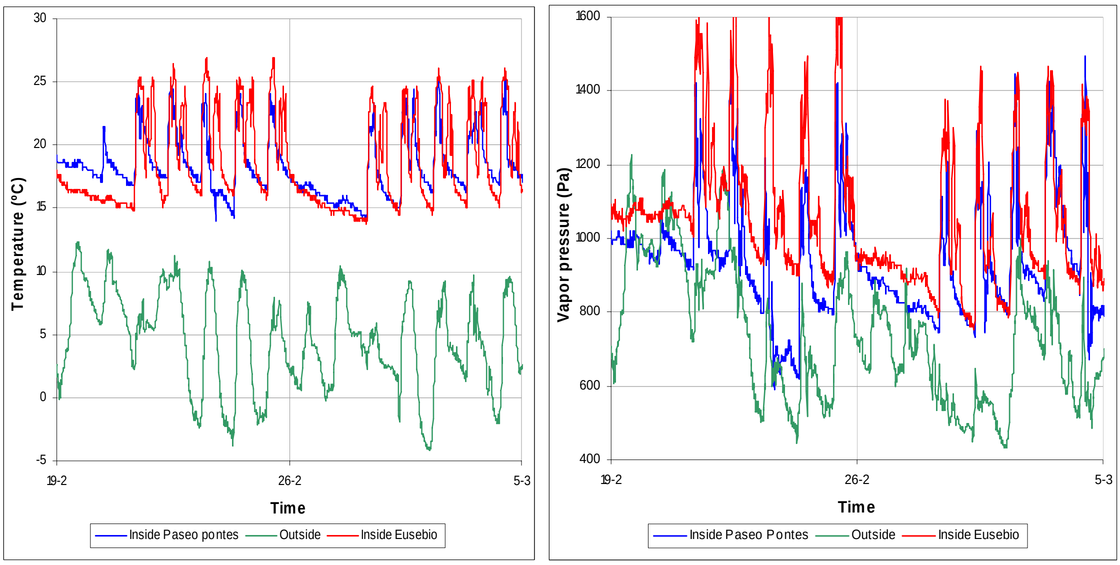

Fig. 3. Weekly instantaneous temperature and partial vapour pressure in the Old and New schools.

5. DISCUSSION AND CONCLUSIONS

According to Table 1, the indoor average dry bulb temperature in the Old School is one degree centigrade higher than in the New School and seven degrees higher than the outdoor temperature. At the same time, in Fig. 3 we can see that in Old School, the maximum temperature achieved during occupation is higher. And the minimum temperature is lower during unoccupied periods. This effect can clearly be observed en Fig. 4 during weekends.

The instantaneous weekly variation of the temperature in Fig. 3 clearly shows that the daily maximum can reach values as high as 26°C. The maximum is followed by a swift temperature reduction and reach a minimum of 16°C and 14°C during weekends.

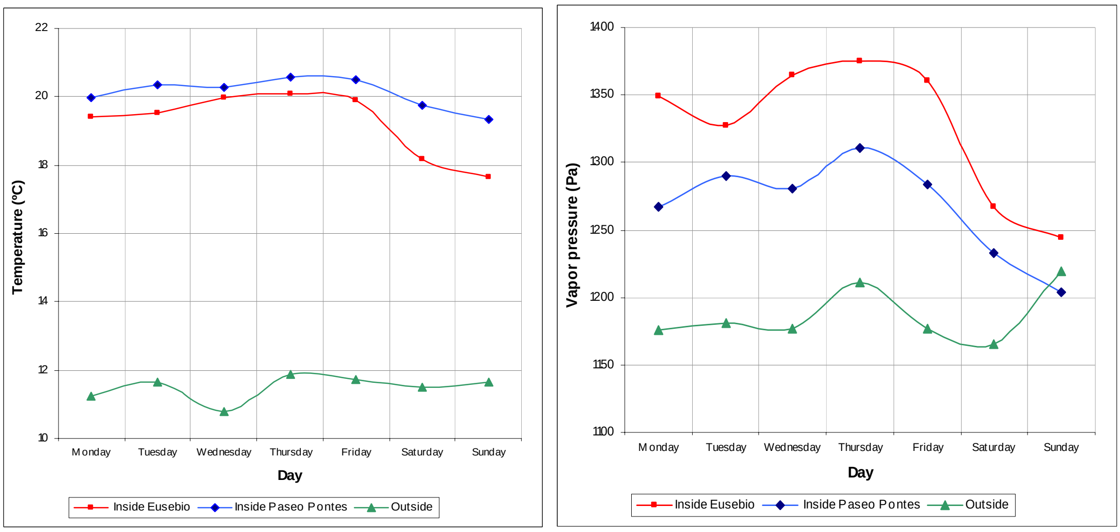

Fig. 4. Weekly average temperature and partial vapour pressure in the Old and New schools.

According to Table 2, the relative humidity is 6% higher in the Old School than in the New School for a standard deviation of the same order of magnitude. This result is consistent with the higher partial vapor pressure noted in the Old School with respect to the New School in Table 3.

Indoor conditions in School 1 are closer to the outdoor ones probably due to the higher uncontrolled air infiltration through cracks in windows.

Plots of the weekly average temperature on Fig. 4 clearly indicate that the temperature in the New School is generally higher than in the Old School probably due both to the thermal insulation of the walls and to lower rate of infiltration. This trend it is clearly observed during weekends and the minimum is being attained on Sundays.

The partial vapor pressure in the Old School is higher than in the New School. We can observe that vapor pressure tends to attain values closer to those of the outdoor air during weekends. And the vapor partial pressure tends to diminish with the temperature, according to Figs. 3 and 4

In Fig. 4, we can see that partial vapor pressure of the indoor air in the New School is closer to that of the outdoor air than in Old School. This trend might be related to a higher sorption/desorption by all surfaces in the classroom of the Old School than in the New School.

The humidity emission from people is around 26.74 g/h in the Old school and 20.83 g/h in the New one.

The values of renovations (infiltration) in the classrooms (Old School 33.24 m^3/h and New School 14.38 m^3/h) are very poor. Because the standart the value are 30 m^3/h.person, the needs would be 810 m^3/h in the Old School and 780 m^3/h and usually in winter conditions the ventilation is very poor in both schools (Hansen and Hanssen 2000).

6. REFERENCES

Hens, H. 2005. “Indoor climate in student rooms: measured values”. IEA-EXCO Energy Conservation in Buildings and Community Systems. Annex 41, “Moist-Eng” Glasgow Meeting, Scotland, pp. 1-12.

Hansen, H. L. and. Hanssen, S. O. 2000. “School environment and its contribution to children`s life quality and learning ability”. Proceedings of Healthy Buildings 2000. Vol 4, Helsinky, Finland, pp. 297-300.

5. RESPONSIBILITY NOTICE

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