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MEASUREMENT OF THE THERMAL RESISTANCE OF MASONRY WALLS

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ABSTRACT

In the present paper, a methodology to measure the thermal resistance of walls and the results for three masonry walls are presented. Measurements were carried out by using two thermal chambers with different volumes, separated from the wall for which the thermal resistance was evaluated. A thermal gradient between the two chambers was determined, to attain heat transfer through the wall. The calculation of the thermal resistance was carried out by measuring the difference between the surface temperatures of the warm and the cold side of the wall and the thermal flux. The measurements were carried out in steady state, following the indications of EN 1934 [1], and in variable regimen, in compliance with prEN 12494 [2], so to compare the two methodologies. Results show that they give the same values of the thermal resistance, therefore the variable regimen methodology could be employed for *in situ* thermal resistance measurements.

1. INTRODUCTION

The correct design of an air conditioning system strongly depends on the calculation accuracy of the thermal loads; their values are related to building and materials characteristics, such as the thermal resistance of the walls. A theoretical evaluation of thermal resistance is difficult for the following reasons: materials traditionally used in buildings are not homogeneous and not isotropy; the thermal conductivity values are not available; the values of the thermal resistance available in Literature for various kinds of masonry walls are strongly related to the building modalities of the wall and to the characteristics of the specific material employed. So experimental determination of the thermal resistance is very important; it can be easily carried out through laboratory measurements in steady state, employing climatic chambers at different temperatures and separated by the wall for which thermal resistance is needed; the air temperature of the chambers can be closely adjusted and controlled. But in order to apply the values obtained in laboratory to real situations, it would be necessary to simulate the temperature conditions *in situ*; in fact the values of thermal resistance calculated in these two conditions could differ considerably. In the present paper, a measurement methodology for calculating the thermal resistance of walls between two chambers in steady and variable state was developed. In the first case, the temperature is constant in both chambers; in the second case, temperature variations are produced in one of the two chambers, in order to simulate the daily thermal excursions in outside air; in the other chamber, the temperature is maintained constant, in order to simulate the temperature in air conditioned rooms. The value of the thermal resistance was determined in compliance with prEN 12494 [2], which prescribes a valid methodology of calculation in variable regimen. The comparison between the values obtained in steady and variable state, employing also methodologies different from [2], concurs to establish if the methodology in variable state can be employed *in situ*.

2. REFERENCE NORM

The measurement of the thermal resistance of masonry walls in steady state is regulated by EN 1934 "Thermal performance of buildings - Determination of thermal resistance by hot box method using heat flow meter - masonry" [1], while in variable regimen it is regulated by the prEN 12494 "Building components and elements - In situ measurement of the surface to surface thermal resistance" [2]. Both establish the same criteria about the disposition and the employment of the measurement instrumentation, but differ in the calculation modalities of the thermal resistance. The sample for the measurement of the thermal resistance is placed between a warm and a cold chamber, in which the temperature conditions that allow heat transmission through the wall are produced. A heat flux meter is fixed on the warm side of the wall, in the center of a squared area (measurement section), to measure the thermal flux throughout the area; nine thermo-resistances are applied over the same area, to measure the surface temperature. On the cold side of the wall, in specular position, there is a second section of measurement with nine thermo-resistances. Measuring the mean difference of the surface temperatures of the two sections and the thermal flux, the thermal resistance R_t in steady state is given by [1]:

$$R_t = (T_{si} - T_{se})/\Phi \qquad (1)$$

In variable regimen, indicating with j the moment in which the surface temperatures and the thermal flux are measured, the value of the thermal resistance R_t is given by (Progressive Average Methodology) [2]:

$$R_t = \frac{\sum_j (T_{sij} - T_{sej})}{\sum_j \Phi_j} \qquad (2)$$

Norms prescribe that it is necessary to evaluate if there is an orthogonally thermal flux to the wall; so, in order to verify surface temperature uniformity, a guard section around the measurement section is considered; on both the warm and the cold side of the guard section at least 12 thermo-resistances must be placed, in order to measure the surface temperature. If the mean surface temperature of the measurement and guard sections are different, a heat flow parallel to the surface of the wall is generated: it must be less than 4% of the perpendicular one. The parallel heat flow is due to the perimeter of the measurement section, and diminishes as the surface of the guard section increases. Table 1 gives the dimensions of the guard section (measured from the edge of the measuring section) as a function of the wall thickness.

Table 1: Dimensions of the guard section of the samples as a function of wall thickness [1, 2].

Overall size (mm)	Metering section width (mm)	Guard width (mm)	Maximum specimen thickness (no edge insulation) (mm)
800	500	150	115
1000	500	250	175
1250	500	375	245
1500	500	500	315
2000	500	750	450

3. EXPERIMENTAL FACILITY

The surface temperatures over the sides of the two walls were measured by 20 thermo-resistances, ten placed in the warm room and ten in the cold room. In both chambers five thermo-resistances have been placed over the measurement section and five over the guard section (fig.1). A preliminary test, with 12 thermoresistances in the guard section and 9 thermoresistances in the measurement section was carried out; a good uniformity of the temperature over the entire area of the measurement and guard sections was obtained, so only five thermoresistances for each section were used to simplify the acquisition system. The thermo-resistances were connected to a multichannel Delta-T Device DATALOGGER. The temperature in the cold room was controlled by an air conditioner mod. SAECO 110/E; the condenser was placed outside the room. The cold air flow did not hit the wall sample and the thermo-resistances directly, but the air was directed toward the wall opposite the sample. The temperature in the warm room was supplied by three electrical burners of 2 kW nominal power each; it was possible to choke the power distributed from each burner in 0,75 kW or 1,25 kW. The warm air flow didn't hit the sample wall and the thermo-resistances: a panel was put behind the sample wall, in order to direct the warm air movement from the bottom to the top, flowing in the inner-space; air movement was fun delivered. The thermal flux was measured by a thermal flux meter of 3 cm diameter, connected to a BABUC/M acquisition system. It was placed in the middle of the measurement section and its position was chosen in order to consider the wall lack of uniformity, due to the connection joints between the single elements (bricks, blocs, etc.); the values of the surface temperatures and of the thermal flux were registered in 10 minute intervals. The experimental facility is sketched in fig. 2.

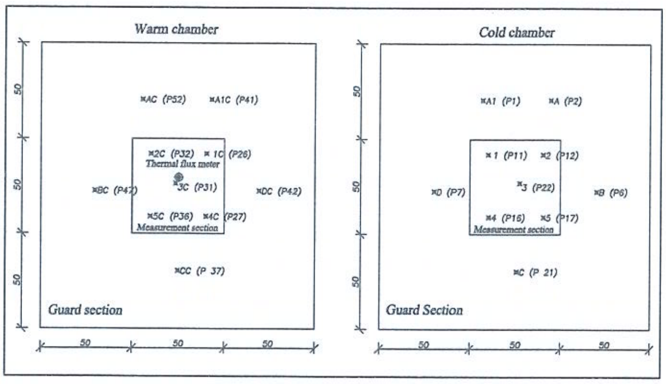

Figure 1: Disposition and acronym of the thermoresistances in the cold and in the warm room.

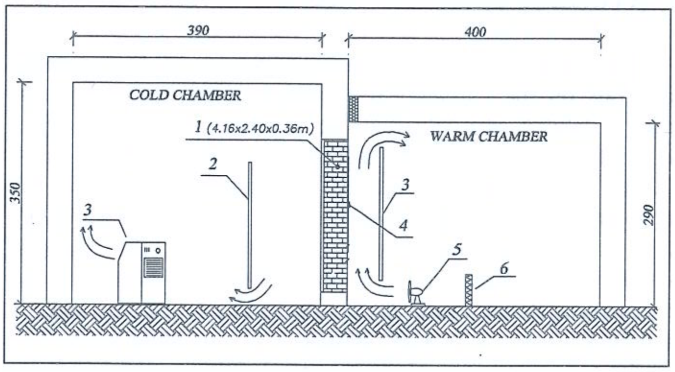

Figure 2: Experimental facility (1 – sample; 2 – panel; 3 – air conditioner; 4 – thermal flux meter; 5 – fan; 6 – electrical burner).

4. WALL SAMPLE DESCRIPTION

Wall n. 1 was composed by thermal blocks, of high thermal resistance, dimensions 15 cm x 60 cm and thickness 25 cm (density 550 kg/m^3). The surface area of the wall was 10 m^2 (4,16 m x 2,4 m) and 25 cm thick.

Wall n. 2 was composed by full bricks; they were of 12 cm x 25 cm x 5 cm dimensions. The bricks were placed in order to form a 38 cm thick-wall. The wall was plastered (plaster thickness: approximately 3 milimeter) only on the face in the warm chamber, while the cold side showed the bricks. The surface area of the wall was 10 m^2 (4.16 x 2.4 m).

Wall n. 3 was composed by two sheets in air-bricks of 25 cm x 25 cm dimensions and 8 cm thickness. The inner space was 5 cm thick and it was filled 3 cm with rock wool and 2 cm with air. The surface was 10 m^2. The wall was plastered and painted on both sides; the total thickness of plaster and paint was approximately 3 cm.

5. MEASUREMENT PROCEDURE

5.1 Steady state measurements

In the steady state measurements, the air temperature difference between the two chambers was about 20 °C (EN 1934). The thermal flux and the surface temperatures must be constant; the variations were within the limits prescribed by EN 1934: temperature fluctuations of the air must be within ± 2% of the air-to-air temperautre difference, so the induced fluctuactions of the heat flow are less than 2% of its steady state value; the maximum long-term drifts shall not exceed 1% of the difference through the specimen. So, in the cold chamber, the air conditioner was set to the minimum temperature, approximately 18 °C. In the warm chamber, two burners were on; the total power was 3,25 kW. The third burner was employed for fine regulation and was switched on by a temperature regulator, CAL 3200: a thermocouple gave the signal to adjust the thermal power between 0 and 2 kW. The temperature limit was set to 40 °C and the thermocouple was placed between the fan and the burner. Once the Normative prescriptions are verified, the thermal resistance of the wall is given by relation (1).

5.2 Variable regimen measurements

The measurements in variable regimen were carried out at a constant temperature in the cold room and with temperature oscillations in the warm room. In the cold room, the air conditioner was set to the minimum temperature of approximately 18 °C; in the warm room heating and cooling cycles of 12 hours each were scheduled. Measurements began with a heating cycle set up by means of three burners (total power 5,25 kW). After 12 hours, two of the three burners were switched off (total power 2 kW). In variable regimen, the surface-to-surface thermal resistance is obtained by equation (2); estimating this equation after each measurement, a convergence to an asymptotic value is observed. This asymptotic value is close to the real value if the following conditions are met:

- the internal energy of the element and moisture distribution is the same at the end and at the beginning of the measurement;
- the surface-to-surface thermal resistance is constant during the test.

These conditions are fulfilled, for heavier elements, when the tests comply with the following requirements:

- the duration of the test exceeds 72 hours;
- the R_t value obtained at the end of the test does not deviate by more than ± 2% from the value obtained 24 hours before;
- the heat flux meter is not exposed to solar radiation and to rain penetration;
- the change of internal energy in the element estimated is less than 2% of the heat passing through the element over the test period;
- if DT is the duration of the test in days and INT the integer part of DT, the R_T value obtained by analysing the data from the first time period of INT (2 X DT/3) days does not deviate by more than ± 2% from the value obtained from the data of the last time period of the same duration.

6. RESULTS

For each wall, results in steady state and in variable regimen are reported. For each situation two figures are shown: surface mean temperatures (measurement section) in the warm and in the cold room vs. time and thermal flux vs. time. The air temperature in the warm and cold room have the same trend of the respective surface temperature so, for the sake of brevity, they are not reported. For the variable regimen tests, a figure showing the Progressive Average Methodology in the thermal resistance is reported too.

6.1 Wall n. 1

Steady state. The mean surface temperatures as a function of time in the warm and in the cold chamber are sketched in fig. 3; the maximum difference between the values measured by the different thermo-resistances in the measurement section is about 0,2 °C; the maximum difference between the surface temperatures of the measurement and guard sections is about 0,05 °C, so the parallel flow rate is negligible (<4% of the ortogonally flow rate, such as in EN 1934).
The thermal flux as a function of the time is sketched in fig. 4; it is about 6 W/m^2, with ±3 W/m^2 standard deviation.
The calculation of the thermal resistance R_t of the wall was carried out by means of relation (1); the R_t value obtained for wall n.1 is 2,46 m^2 K/W.

Variable state. Figure 5 shows the mean surface temperature trend in the measurement section in the warm and cold chambers. In the cold chamber, the surface temperature is constant and is about 21 °C. In the warm chamber, the maximum and minimum temperature of each cycle increases during the test, from a minimum of 32 °C up to a maximum of 36°C. The thermal excursion established is about 2 - 4 °C. In fig. 6 the thermal flux during the test is shown. During the cooling cycle the thermal flux is about 6 - 7 W/m^2, in the heating cycle it is about 11 W/m^2. Thermal resistance R_t has been calculated employing relation (2) (fig. 7). The curve at the end of the test converges to the same R_t value of the steady state test, equal to 2,46 m^2 K/W.

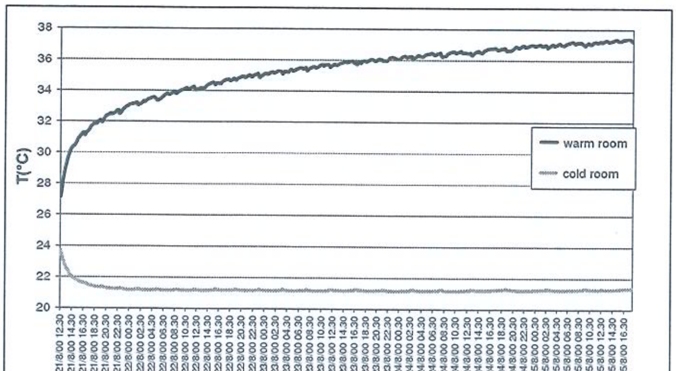

Figure 3: Measurement section surface mean temperature in the warm and in the cold room (steady state, wall n.1).

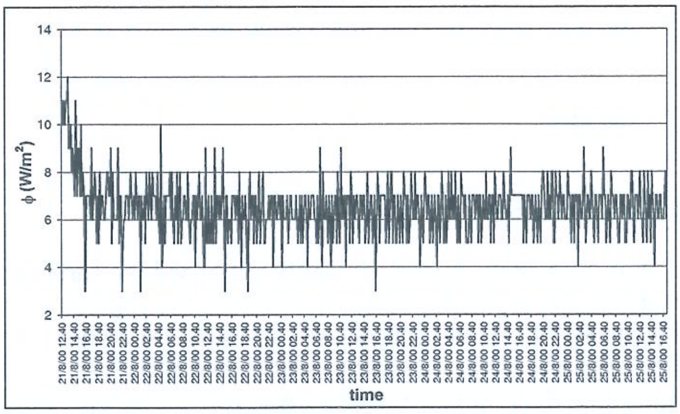

Figure 4: Steady state thermal flux (wall n.1)

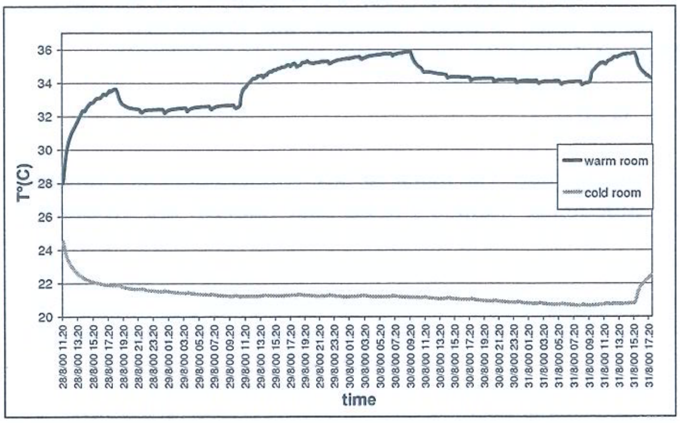

Figure 5: Measurement section surface mean temperature in the warm and in the cold room (variable regimen, wall n.1).

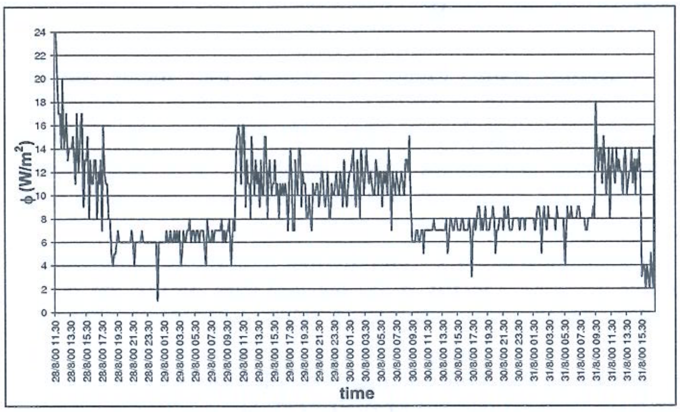

Figure 6: Variable regimen thermal flux (wall n.1)

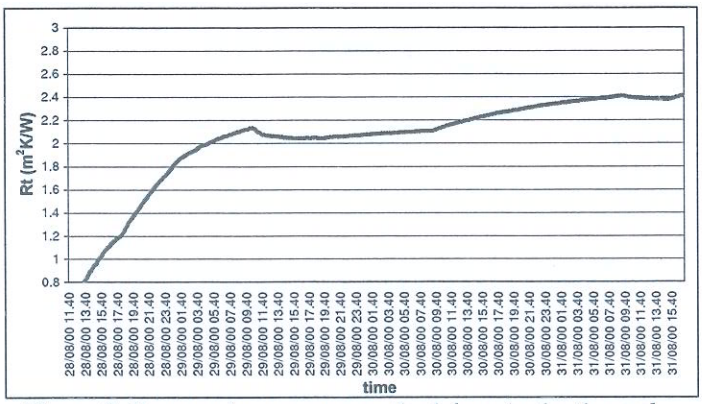

Figure 7: Progressive average methodology in the thermal resistance calculation (wall n. 1).

6.2 Wall n. 2

Steady state. Fig. 8 shows the mean surface temperature of the measurement section in the warm and cold side of the wall. The maximum difference between the values measured by the different thermo-resistances is of 0,2 °C, while in the guard section it is of 0,9 °C for both sides. The stationary conditions are reached after 5 days, when the temperature stabilizes on values of about 35 °C in the warm room and 23°C in the cold room. The thermal flux trend is shown in fig. 9: the mean value is 29,5 W/m^2; the standard deviation is 1,2 W/m^2. The wall parallel heat flow is less than 4% of the one transmitted orthogonally. The R_t thermal resistance was calculated with the same modalities described for wall n. 1; its value is 0,41 m^2 K/W.

Variable state. Figure 10 shows the mean surface temperature in warm and cold chambers during 5 cycles of measurement in variable regimen (5 days). In the warm chamber the air temperature varies between a minimum of approximately 30 °C and a maximum of approximately 42 °C; the corresponding surface temperatures vary between 33 and 39°C. The air temperature in the cold chamber was kept constant and equal to 18,5 °C, with oscillations below 0,5 °C. The surface temperatures have a regular periodic trend, with a minimum at about 16 and a maximum at about 4 o'clock and a mean temperature oscillation of about 0.4 °C. The temperature cycles in the warm chamber affect the surface temperature in the cold chamber too, because of the slow thermal inertia of wall n. 2.
The thermal flux trend is shown in fig. 11; it is about 50 W/m^2 in chamber and about 15÷20 W/m^2 in the periods of minimum temperature. The R_t of wall 2 in variable regimen, calculated with the same procedure as the wall n.1, didn't give a convergent value; so it was calculated with a new methodology proposed in the present paper and described in paragraph 7.

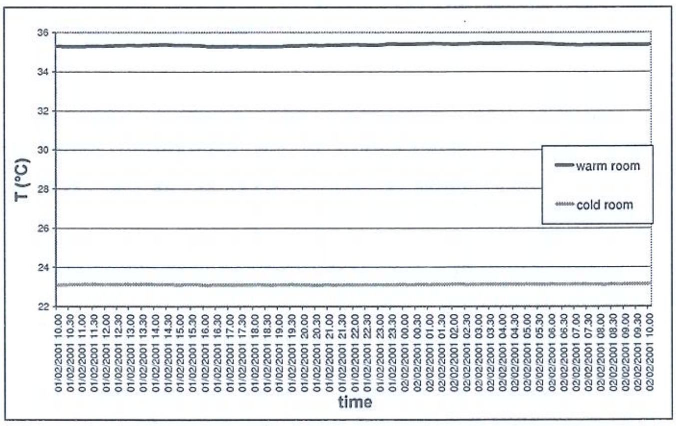

Figure 8: Measurement section surface mean temperature in the warm and in the cold room (steady state, wall n. 2).

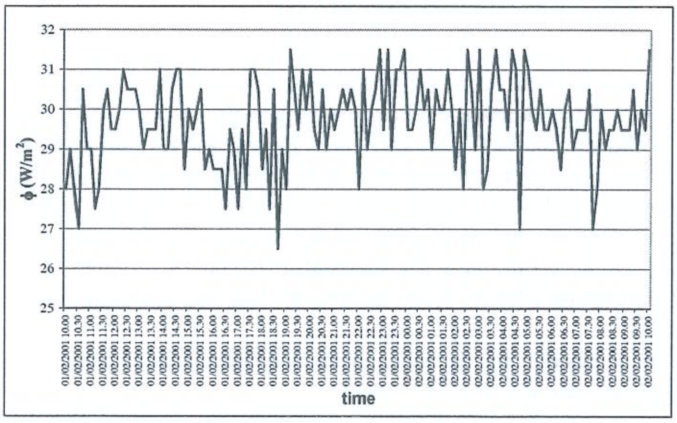

Figure 9: Steady state thermal flux (wall n. 2)

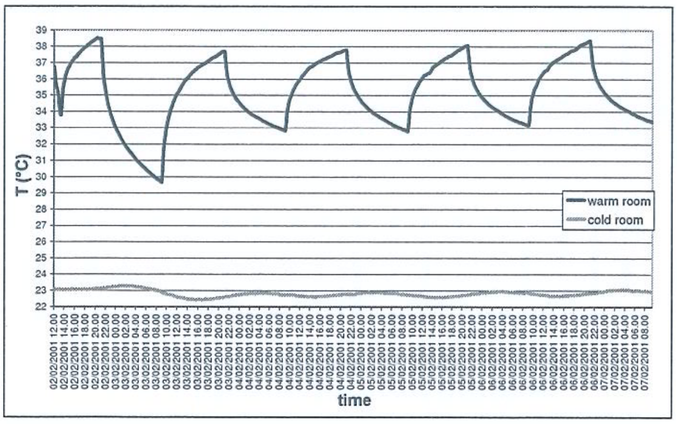

Figure 10: Measurement section surface mean temperature in the warm and in the cold room (variable regimen, wall n. 2).

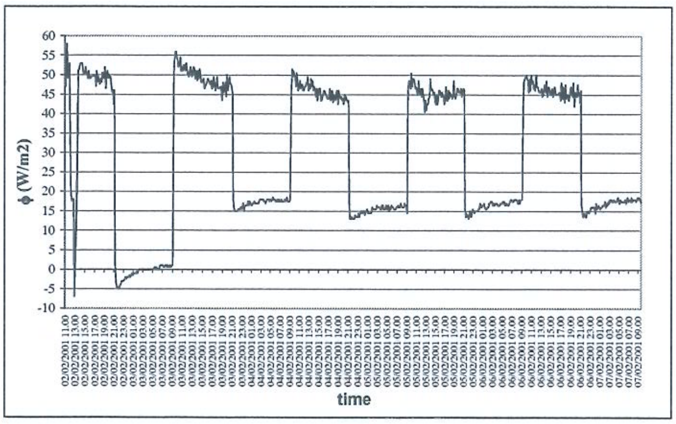

Figure 11: Variable regimen thermal flux (wall n. 2)

6.3 Wall n.3

Steady state. Fig. 12 shows the mean surface temperature in the measurement sections of warm and cold chambers; the differences between the values verify the condition on the parallel thermal flux (< 4% of the orthogonally one); the thermal flux (fig. 13) has a mean value of 11 W/m^2, with a standard deviation of about 1 W/m^2. The thermal resistance was calculated employing relation (1); a R_t value of 1,84 m^2 K/W was obtained.

Variable state. Figure 14 shows the mean surface temperature in the measurement sections of the warm and cold chambers. In the warm chamber the temperature has minimum excursions of 5 °C and maximum excursions of 9 °C; in the cold chamber the excursions are about 0,6 ÷ 1 °C. The thermal flux (fig. 15) has wide oscillations, because of the quick variation in air temperatures. The methodology employed for wall n. 1 also in this case seemed to be not convergent, even if the thermal resistance value around the steady state was obtained. So a different methodology, described in paragraph 7, was introduced.

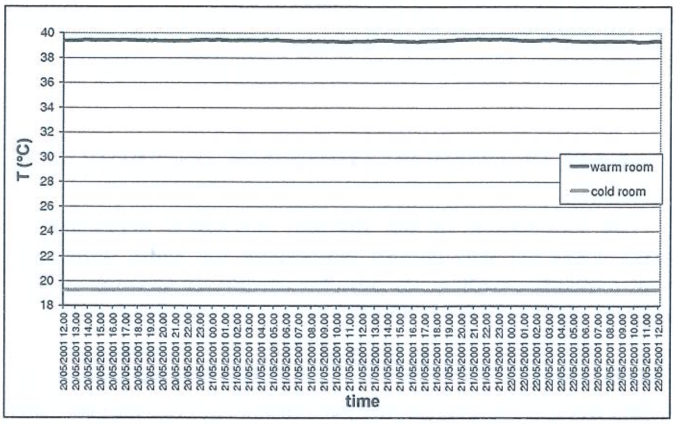

Figure 12: Measurement section surface mean temperature in the warm and in the cold room (steady state, wall n. 3)

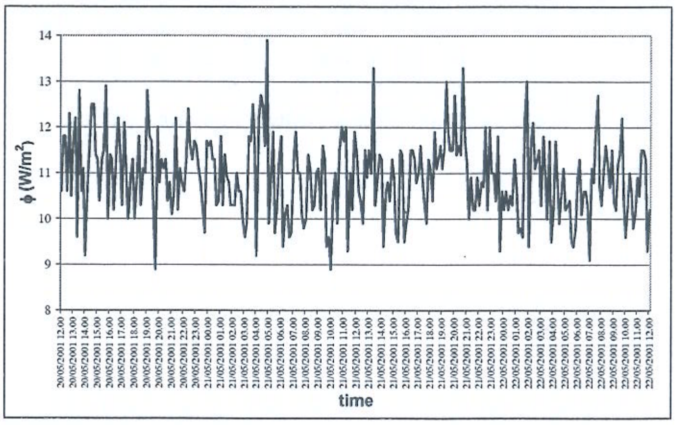

Figure 13: Steady state thermal flux (wall n. 3)

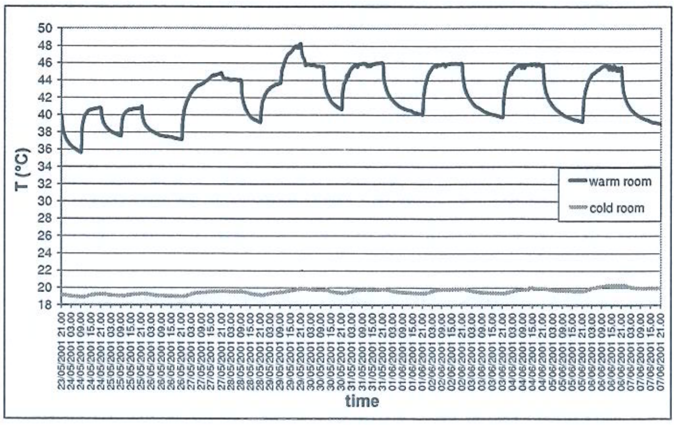

Figure 14: Measurement section surface mean temperature in the warm and in the cold room (variable regimen, wall n. 3).

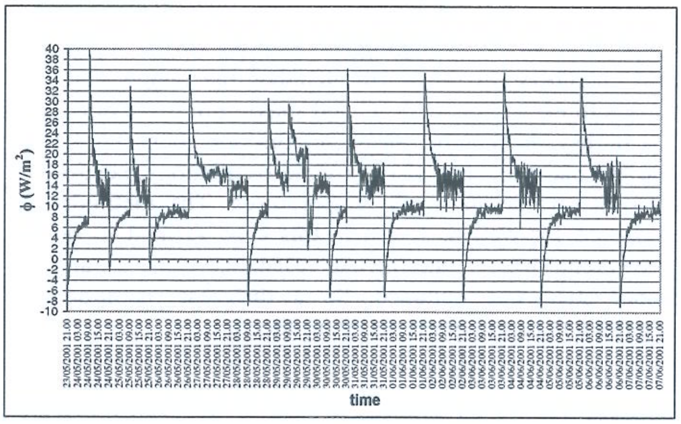

Figure 15: Variable regimen thermal flux (wall n. 3).

7. CALCULATION METHODOLOGIES PROPOSED

The calculation of the thermal resistance proposed by prEN 1934 [2] was proven inadequate for walls with high heat capacity (wall n. 2) and for strong excursions of the thermal flux (wall n. 3). During experimentation on wall n. 2 it was observed that in each cooling and heating cycle, a stabilized periodic regimen is estabilished and the sum of the differences of the surface temperatures (T_{si} - T_{se}) and the sum of the thermal flow Φ_i are constant. So an extension of the test was carried out by inserting in relation (2) sums of (T_{si} - T_{se}) and Φ_i related to simulated thermal excursions, for a fixed number of cycles (see fig. 16). Simulating the test for a period of time multiple of the cooling and heating cycles, after some days the temperature and thermal flux trend becomes periodic; the subtotals in relation (2) relate to an entire cycle are constant, after an initial transitory period:

$$\sum_{24hours} \Delta T = \sum_{j=1}^{\bar{n}} (T_{sij} - T_{sej}) \qquad (3)$$

$$\sum_{24hours} \Phi = \sum_{j=1}^{\bar{n}} \Phi_j \qquad (4)$$

So, simulating an extension of the test for a period of time multiple of 24 h, the thermal resistance is calculated by:

$$R_t = \frac{\sum_{j=1}^{n} (T_{sij} - T_{sej}) + N \sum_{24horus} \Delta T}{\sum_{j=1}^{n} \Phi_j + N \sum_{24hours} \Phi} \qquad (5)$$

For wall n. 2, introducing a 5 days simulation, the thermal resistance shows oscillations that diminish in amplitude and converges to the value measured in steady state (Fig. 16), equal to 0,41 m^2 K/W.

The method of calculation based on the simulated extension of the test was applied also to wall n. 3; in this case the convergent value is obtained after about 2 months of simulation, but the value converges to 1,9 m^{2}K/W (v. fig. 17), different from the value in steady state (1.84 m^2 K/W). Another method of calculation was finally proposed, although still employing relation (2), but temperature and thermal flux data are filtered to speed up the convergence to the asyntotic value in the test period. During the variable state test, after the inversion of the temperature trend in the warm chamber, a negative thermal flux could be observed, due to local thermal exchange phenomena between wall and air. So the thermal resistance was calculated excluding from relation (2) some thermal flux data external to an appropriate range including the mean value. Considering a suitable range including not less than 80% of the measured data, results in fig. 18 were obtained: the thermal resistance R_t converges to the value of 1,86 m^2 K/W, next to the one measured in steady state.

All the results, for the three walls in steady state and variable regimen, are reported in Tab. 2.

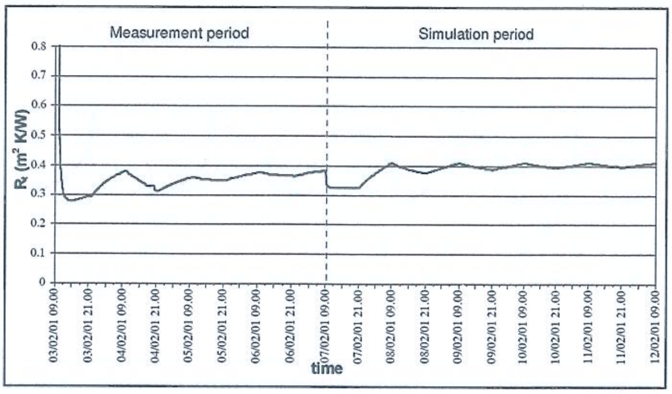

Figure 16: Progressive Average Methodology with simulation period of 5 days (wall n. 2)

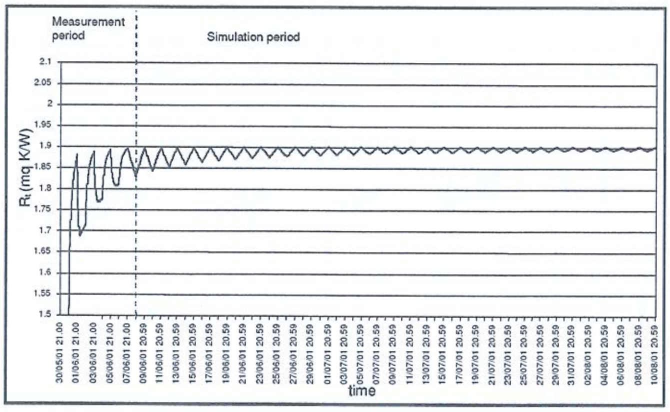

Figure 17: Progressive Average Methodology with simulation period of 60 days (wall n. 3)

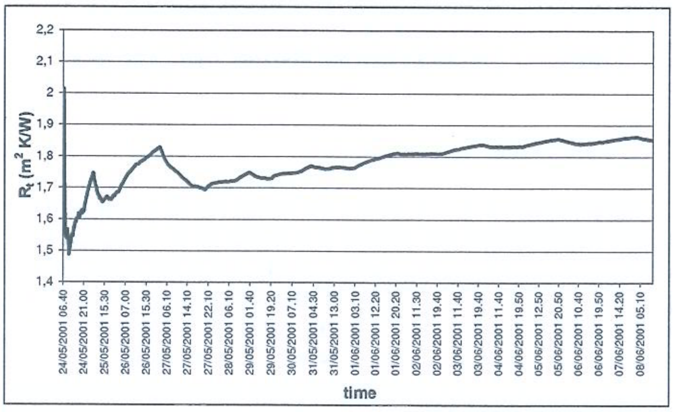

Figure 18: Progressive Average Methodology with filtered data (8<Φ<18 W/m^2, wall n. 3)

Table 2: Thermal resistance values of the three walls in steady state and variable regimen.

Thermal resistance ($m^2 K/W$)	Wall 1	Wall 2	Wall 3
Steady state	2.46	0.41	1.84
Variable regimen	2.46	0.41	1.86

8. MEASUREMENT UNCERTAINTY

The measurement uncertainty was evaluated in compliance with UNI CEI ENV 13005 [3]; it is possible to evaluate both type A and B uncertainties.

Type A Uncertainty. The thermal resistance measurement uncertainty depends on the uncertainties on the difference of surface temperature and on the thermal flux.

The uncertainty in the temperature measurement is due to:

a) thermoresistances precision u(TP4), equal to a = ± 0.2°C (DIN-IEC 751): considering a symmetrical and rectangular probability distribution in the precision range, u(TP4) is given by:

$$u(TP4) = \frac{a}{\sqrt{3}} = \frac{0.20}{\sqrt{3}} = 0.11547°C \quad (6)$$

b) resolution of the acquisition system u(AS), equal to a = ± 0.01°C: with the same assumptions as in a), u(AS) = 0.00288 °C is obtained.

So the uncertainty $u(T_s)$ on the temperature measurement is given by:

$$u(T_s) = u(TP4) + u(AS) = 0.11835°C \quad (7)$$

In the thermal resistance calculation, a temperature difference is employed; so the composed uncertainty of the function $\Delta T = T_{si} - T_{se}$ is given by:

$$u_c^2(\Delta T) = \left(\frac{\partial \Delta T}{\partial T_{si}}\right)^2 \cdot u^2(T_{si}) + \left(\frac{\partial \Delta T}{\partial T_{se}}\right)^2 \cdot u^2(T_{se}) = 0.16737\ °C \quad (8)$$

The uncertainty in the thermal flux measurement is due to:

a) thermal flux meter precision u(F), equal to a = ± 1 W/m^2: considering a symmetrical and rectangular probability distribution in the precision range and employing relation (6), u(F) is equal to 0.57735 W/m^2.

b) resolution of the acquisition system u(Ac), equal to a = ± 0.1 W/m^2: with the same assumptions as in a), u(Ac) = 0.02887 W/m^2 is obtained.

So the uncertainty $u(\Phi)$ on the thermal flux measurement is given by:

$$u(\Phi) = u(F) + u(Ac) = 0.60622 W/m^2 \quad (9)$$

The mean value of the thermal flux is given by:

$$\Phi_m = \frac{1}{n}\sum_{j=1}^{n} \Phi_j \quad (10)$$

so the uncertainty $u_c(\Phi_m)$ is:

$$u_c^2(\Phi_m) = \sum_{j=1}^{n}\left(\frac{\partial f}{\partial \Phi_j}\right)^2 \cdot u^2(\Phi_j) = \frac{1}{n} \cdot u^2(\Phi_j) \quad (11)$$

where n is the number of allowable data.

The uncertainty $u(R_{t,j})$ of the thermal resistance measured at the instant j is:

$$u_c^2(R_{t,j}) = \left(\frac{1}{\Phi_m}\right)^2 \cdot u_c^2(\Delta T) + \left(-\frac{\Delta T}{\Phi_m^2}\right)^2 \cdot u_c^2(\Phi_m) \quad (12)$$

The evaluation of the thermal resistance is given by:

$$R_t = \frac{\sum_{J=1}^{n} R_{t,j}}{n} \quad (13)$$

so, applying the low of propagation of uncertainty, eq. (14) is obtained:

$$u_c(R_t) = \frac{1}{n} \cdot \sqrt{\sum_{j=1}^{n} u_c^2(R_{t,j})} \quad (14)$$

The values of the uncertainties calculated in the measured conditions with equations (12) and (14) are reported in table 3; the term $u_c(R_t)_{12}$ is related to a measurement period of 12 hours.

Type B Uncertainty. A numerous sample of data is available from the measurements, so a statistical analysis could be performed. In the measurement range it is possible to consider *n* time intervals of measurement; for each interval, a mean value and a standard deviation value for thermal flux, temperature difference and thermal resistance were obtained. Then weight could be associated to the different time intervals: it is as high as low is the standard deviation. The thermal resistance of the entire measurement period is evaluated as weighted mean value of the different intervals.

$$R_t = \frac{\sum_{k=1}^{n-30} R_{t,k} \cdot p_{R,k}}{\sum_{k=1}^{n-30} p_{R,k}} \quad (18)$$

Applying the law of propagation of uncertainty, the uncertainty on the thermal resistance is obtained:

$$u_c(R_t) = \frac{1}{\sum_{k=1}^{n-30} p_{R,k}} \cdot \sqrt{\sum_{k=1}^{n-30} (p_{R,k})^2 \cdot (\sigma_{R,k})^2} \quad (19)$$

Equations (18) and (19) were employed to calculate the data in Table 3; the comparison with Type A Uncertainty shows a good agreement.

9. CONCLUSIONS

The evaluation of the thermal resistance of masonry walls is very important in buildings thermal loads calculations and in designing the air conditioning systems. Data obtained in laboratory measurements are different from the ones obtained in situ; in the first case, the air temperature conditions in warm and cold chambers can be closely controlled, in the second case, they vary according to climatic conditions. A measurement methodology of the thermal resistance was developed; it can be extended to the situations in situ too. So the thermal resistance of three different masonry walls was measured in laboratory in steady and variable state, in compliance with EN 1934 and prEN 12494. The walls were built between two chambers at different temperatures; in steady state a constant temperature difference was maintained, in variable regimen the temperature in the warm chamber varied periodically while the temperature in the cold chamber was constant. The measurement of the thermal resistance in the two situations yields approximately the same values: so the real conditions could be simulated in laboratory and, with the same methodology, the thermal resistance could directly be measured in situ. The method is applicable neither in the case of walls of great mass for surface unit, having high heat capacity, nor in the cases with high fluctuations of the thermal flux. So two methodologies were proposed as a variation of the one proposed by prEN 12494 for the variable regimen. In the first case, a simulated extension of the period of test with periodic cycles of temperature was made, until the convergence of the thermal resistance to a fixed value, calculated using the Method of the Progressive Average, such as in prEN 12494. In the second case, it was proposed to filter the set of data of the measured thermal flux, to eliminate the values farther from the measured medium thermal flux. Both methodologies gave thermal resistance values approximately equal to those obtained in steady state; so they can be employed to determine the thermal resistance *in situ*.

Table 3: Measurement Type A and Type B uncertainties [3]

Wall	Type A Uncertainty (m^2 K/W)				Type B Uncertainty (m^2 K/W)	
	R_t	$u_c(R_{t,j})$	$u_c(R_t)_{12}$	$u_c(R_t)$	R_t	$u_c(R_t)$
1	2.516	0.2297	0.0271	0.0260	2.514	0.0602
2	0.4131	0.0101	0.0012	0.0008	0.412	0.0014
3	1.8559	0.1011	0.0119	0.0060	1.854	0.0088

10. LIST OF SYMBOLS

n = number of data [-];
N = number of cycles [-];
$P_{e,k}$ = weight of R_t in the k time interval [-];
R_t = thermal resistance [m^2 K / W];
T_{se} = surface temperature in the cold chamber [°C];
T_{si} = surface temperature in the warm chamber [°C];
u = uncertainty;
u_c = composed uncertainty;
σ = standard deviation;
Φ = thermal flux [W/m^2].

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