6th World Conference on Experimental Heat
Transfer, Fluid Mechanics, and Thermodynamics
April 17-21, 2005, Matsushima, Miyagi, Japan

THERMAL RESISTANCE OF MASONRY WALLS: IN SITU MEASUREMENTS

Cinzia Buratti*, Elisa Moretti*

* Department of Industrial Engineering, Perugia University, Via G. Duranti, 67 - 06125 Perugia, Italy.
E-mail : cburatti@unipg.it

ABSTRACT

In the present paper a new methodology for in situ measurement of the thermal resistance of masonry walls is proposed. Measurements on an external wall of the Acoustics Laboratory of the Department of Industrial Engineering, University of Perugia, were carried out, in compliance with prEN 12494. The heating and cooling cycles were natural, due to day and night alternation. A test period of 1500 hours was necessary, after a long period for the instrumentation calibration. In the data analysis the Progressive Average Methodology given in prEN 12494 was inadequate, so a new methodology of analysis was proposed; it gave good results, in agreement with data from Literature.

***Keywords**: thermal resistance, masonry walls, unsteady state measurements, thermal insulation of building elements*

1. INTRODUCTION

The 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 the thermal resistance is difficult for the following reasons: materials traditionally used in buildings are not homogeneous and not isotropy and their thermal conductivity values are not available; the thermal resistance values given in the Literature for different kinds of masonry walls are strongly related to the wall construction modalities and to the characteristics of the employed material. So, in order to employ the values obtained in laboratory tests in real situations, it would be necessary to carry out in situ measurements. In previous works [2, 3], a methodology for the laboratory measurements of thermal resistance of masonry walls in steady and unsteady state was proposed. In the present paper measurements in not controlled temperature conditions are carried out, simulating the real in situ conditions. So, an external wall of the Thermodynamics Laboratory of the University of Perugia was considered: measurements for a period of 1500 hours were carried out, in order to evaluate the thermal resistance of the wall. The Progressive Average Methodology [1] was inadequate for calculating the thermal resistance, so a new data analysis methodology was proposed.

2. REFERENCE NORM AND MEASUREMENT METHODOLOGY

The thermal resistance of masonry walls could be measured in situ in compliance with prEN 12494 *Building components and elements - In situ measurement of the surface to surface thermal resistance* [1]. The standard describes the measurement instrumentation, the installation and measurement procedure and the thermal resistance calculation method. The wall for the measurement of the thermal resistance is placed between an internal room and the external environment; their temperatures are not controlled. A heat flux meter is fixed on the hot side of the sample, in the center of a squared area (measurement section); nine thermo-resistances are applied over the same area, to measure the surface temperature. On the cold side of the wall, in specular position, nine thermo-resistances are placed. In order to evaluate the thermal flux parallel to the wall and to verify the surface temperature uniformity, a guard section around the measurement one is considered; the dimensions of the guard section as chosen as a function of the wall thickness[1]. On both the hot 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 very different, a significant heat flow parallel to the surface of the wall is generated: it must be less than 4% of the perpendicular one. The thermal resistance R_t is given by dividing the mean surface temperature difference (T_{si}-T_{se}) by the thermal flux (q) (Progressive Average Methodology) [1]:

$$R_t = \frac{\sum_{j=1}^{n}(T_{sij} - T_{sej})}{\sum_{j=1}^{n} q_j} \tag{1}$$

where the index j is related to each measurement.

3. SAMPLE DESCRIPTION AND EXPERIMENTAL FACILITY

An external wall of the Thermodynamics Laboratory of the Department of Industrial Engineering, University of Perugia, was used for the measurements (fig. 1). The masonry wall is composed by concrete blocks (dimensions: 195 mm x 195 mm x 500 mm) with a plasterboard of 15 mm thickness only in the interior side: the total thickness is 215 mm. The surface temperature on the both sides of the measurement and the guard sections of the wall was measured by 42 thermo-resistances, 21 placed in the hot side and 21 in the cold one (fig. 2). The thermo-resistances were connected to a DATALOGGER and a DELTA-LOGGER multichannels Delta-T Device. The air temperature was measured by four temperature probes BST101(LSI), two for the internal air and two for the external air. The thermal flux was measured by four thermal flux meters: three of them (HFP01 - Hukseflux, 80 mm diameter, connected to DATALOGGER) were placed on the hot side; one of them (BSR240 - LSI, connected to a BABUC/M acquisition system) was fixed on the cold side of the wall, in order to control the flux inversion. The thermal flux meters positions were chosen in order to consider the wall not uniformity, due to the connection joints between the blocks. All the data were registered in 30 minute intervals; a simplified scheme of the experimental facility is sketched in fig. 3.

Figure 1: External (a) and internal (b) side of the tested wall.

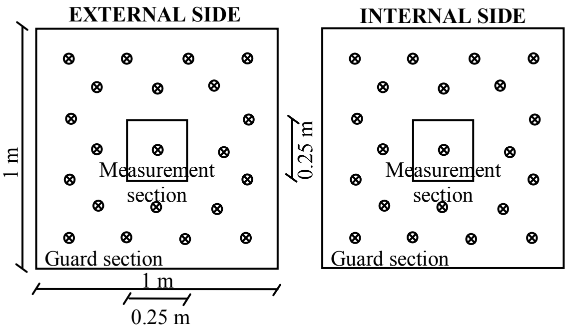

Figure 2: Disposition of the thermo-resistances in the hot and in the cold side of the wall

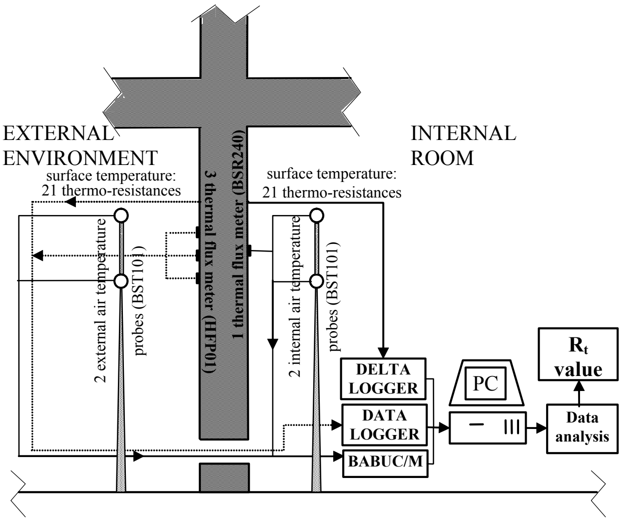

Figure 3: Experimental facility

4. MEASUREMENT PROCEDURE

At the beginning, a long period for the instrumentation calibration was necessary. Then, in order to evaluate in situ thermal performances of the wall, four measurements in different conditions were carried out, for a total period of about 1500 hours. Measurements in not controlled temperature conditions were carried out: the heating and cooling cycles were natural, due to day and night alternation; tests were carried out in the following conditions, in various combinations: the employment of an external fan, the installation of a polystyrene panel outdoor or indoor, the presence of two fan-coils in the internal room that were on or off (table 1).

The parameters measured by the sensors were elaborated: the mean value of the thermal flux, the external and internal air temperature, the surface temperatures vs. the time for all the tests were calculated.

A high value of the surface temperature difference between the hot and the cold side of the wall is necessary, in order to obtain a positive thermal flux; measurements were carried out in summer, so the hot side was the external side of the wall. However, in some cases, during the night, the external surface temperature was lower than the internal one, so a thermal flux inversion was registered; thus, in some tests, the fan-coils were on (tests 1, 2 and 4). In order to minimize the direct influence of the fan-coil on the temperature of the measurement and guard sections of the internal surface, a polystyrene panel was placed behind the fan coil, at a distance of 1,5 m (tests 2, 3 and 4); a polystyrene panel was placed also outdoor, in order to protect the external surface of the wall by the direct solar radiation (test 4). A forced convection heat transfer was established on the external surface, with 2 m/s air speed (test 2) given by a fan, in order to fix the convection conditions and to avoid the dependence by the wind speed. Table 1 shows the different conditions of the tests.

Table 1 Tests conditions

Test number	Test start	Test end	Fan-coil 1	Fan-coil 2	External panel	Internal panel	External fan
1	16/06/03 17:00	30/06/03 16:30	ON	ON	absent	absent	OFF
2	01/07/03 10.30	07/07/03 11:30	OFF	OFF	absent	present	ON
3	14/07/03 12:30	18/07/03 16:00	ON	OFF	absent	present	OFF
4	18/07/03 16:30	28/08/03 12:00	ON	ON	present	present	OFF

Fan coil 1: fan coil at 8 m from the wall

Fan coil 2: fan coil at 2 m from the wall

5. RESULTS

Results showed that only the test n. 4 was reliable for the calculation of the R_t value: the other tests were employed in order to determinate the optimal measurement conditions. However, for the sake of completeness, data related to tests n. 1, 2 and 3 are also reported. The mean external surface temperature, the mean air temperature and the mean thermal flux vs. the time, during the test n. 1 are reported in fig. 4. For all the tests, the measured values were periodic and during the night, when the outdoor air temperature was higher than the external surface temperature, the thermal flux values were negative, so the thermal resistance could not be calculated, in compliance with prEN 12494.

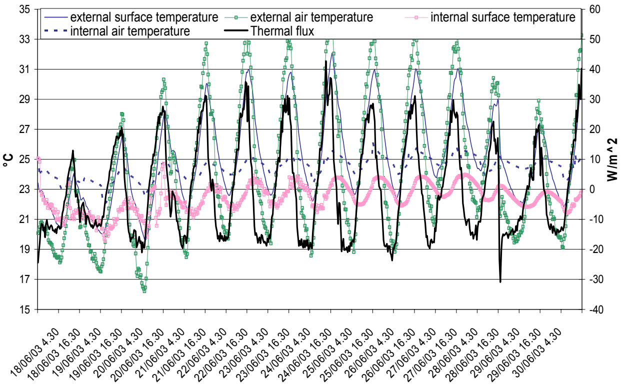

Figure 4: Mean surface temperatures, air temperatures and thermal flux vs. the time, during test n. 1

The same data related to test n. 2 are reported in fig. 5: the external air temperature was similar to the external side one, due to the forced convection by the external fan. Moreover, for the tests n. 2 and 3, the internal surface temperature and the internal air temperature were very similar, because the fan coil near to the wall was off (fig. 5 and 6). Instead, for tests n. 1 and 4 (fig. 4 and 7) the internal surface temperature is about 2°C lower than the internal air temperature, due to the fan-coil near to the masonry wall that was on; moreover, the temperature of the external side of the wall was greater almost always than the internal surface temperature.

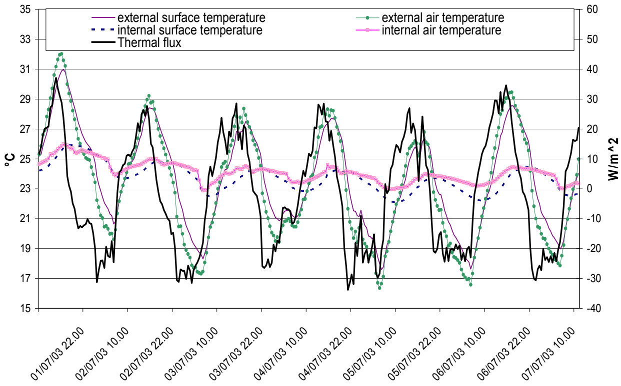

Figure 5: Mean surface temperatures, air temperatures and thermal flux vs. the time, during test n. 2

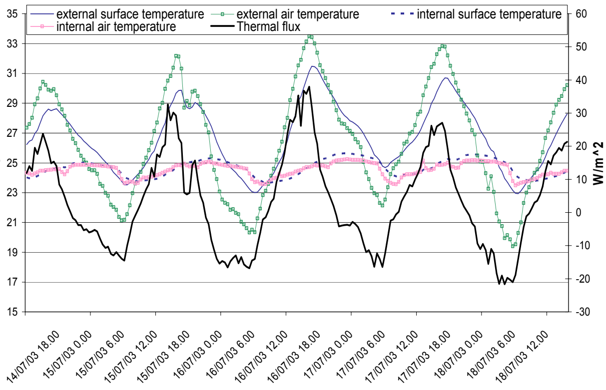

Figure 6: Mean surface temperatures, air temperatures and thermal flux vs. the time, during test n. 3

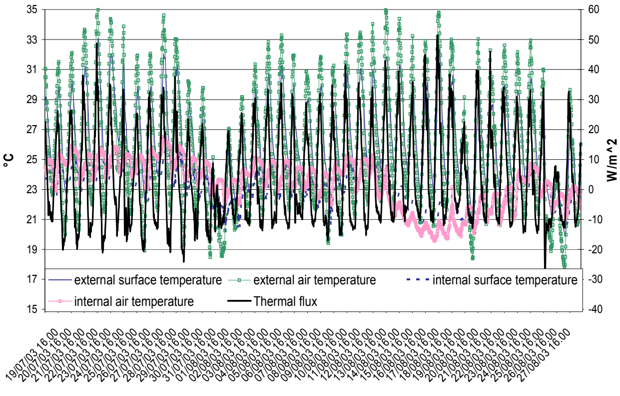

Figure 7: Mean surface temperatures, air temperatures and thermal flux vs. the time, during test n. 4

Finally, the detailed temperature results of the 42 thermo-resistances show that the polystyrene panel don't affect the uniformity of the surface temperature (test n. 2, 3, 4).

6. DATA ANALYSIS AND PROPOSED METHODOLOGY

Results were employed to calculate the thermal resistance value following the Progressive Average Method, in compliance with prEN 12494, but it didn't give a convergent value, due to the wide oscillation of the thermal flux (as an example, in figure 8 the result for the test n. 1 is reported). So, new methodologies were proposed, by processing the measured data before the calculation.

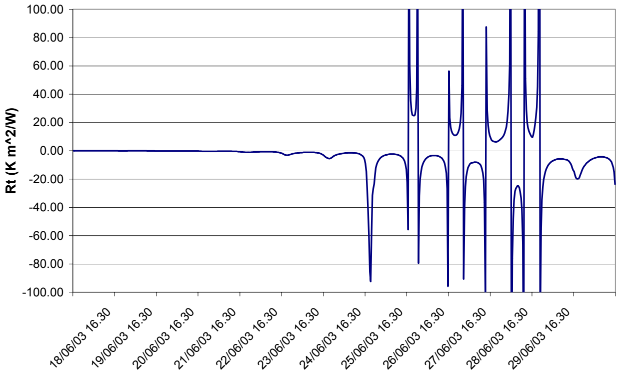

Figure 8: Progressive Average Method in the thermal resistance calculation, without data processing, for the test n.1.

6.1 Depuration of the thermal flux

The measured thermal flux could be calculated as follows:

$$q_j = q_{j1} + q_{j2} \tag{2}$$

where:

- q_{j1} is the thermal flux across the wall due to the temperature difference between the two sides;
- q_{j2} is the convective heat transfer between the external surface of the wall and the outdoor air.

The external surface temperature was always higher than the internal one, so qj1 was always directed inside. During the night the external air temperature was often lower than the external mean surface temperature, so qj2, in these situations, was directed outside; otherwise, when the absolute value of qj2 was higher than the qj1 one, an inversion of the thermal flux was observed. The thermal resistance of the wall could be calculated employing the following relation, considering only qj1:

$$R_t = \frac{\sum_{j=1}^{n} \left(T_{sij} - T_{sej}\right)}{\sum_{j=1}^{n} q_{j1}} \tag{3}$$

q_{j2} could be calculated as a function of time by:

$$q_{j2} = K_a \cdot \left(T_1 - T_2\right) \tag{4}$$

where T_1 is the mean external surface temperature of the wall, T_2 the outdoor air temperature and K_a a heat transfer coefficient (convection plus radiation) given by:

$$K_a = 5.62 + 3.9 \cdot u \tag{5}$$

u is the wind speed and it was equal to zero for test n. 1, n. 3 and n. 4 (the masonry wall was not exposed to the wind), 2 m/s (wind speed value due to the fan) for test n. 2. Figures 9, 10, 11, 12 show the thermal flux q_{ji} calculated without the contribution of the convection heat transfer and the temperatures vs. the time in the different tests.

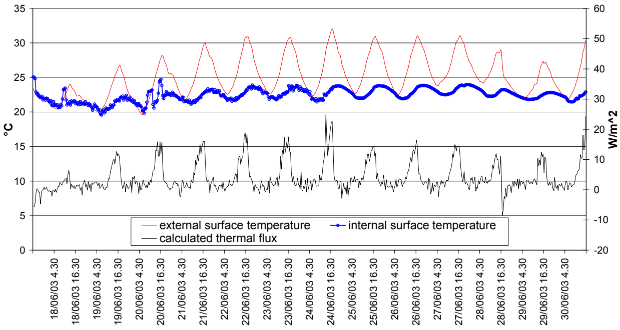

Figure 9: Test n. 1: thermal flux q_{1j} (without external convection in the periods when $T_{si} < T_{se}$), external and internal surface temperature.

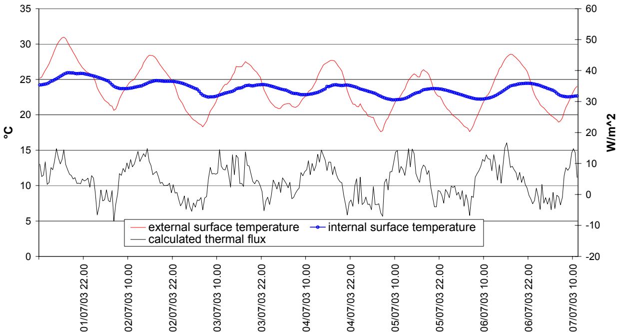

Figure 10: Test n. 2: thermal flux q_{1j} (without external convection in the periods when $T_{si} < T_{se}$), external and internal surface temperature.

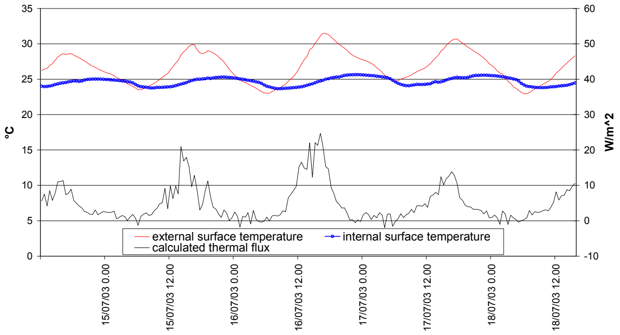

Figure 11: Test n. 3: thermal flux q $_{1j}$ (without external convection in the periods when $T_{si} < T_{se}$), external and internal surface temperature.

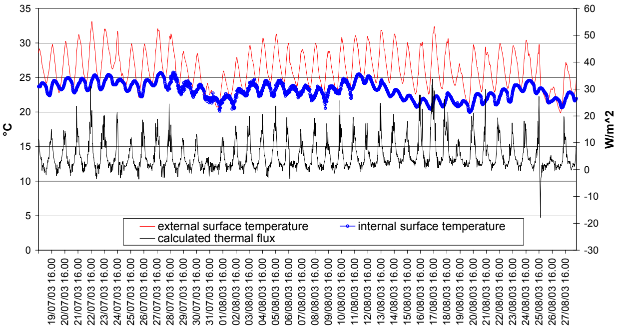

Figure 12: Test n. 4: thermal flux q $_{1j}$ (without external convection in the periods when $T_{si} < T_{se}$), external and internal surface temperature.

The thermal resistance was calculated employing eq. (3) (fig. 13, 14, 15 and 16); only the R_t values of the tests n. 1 and 4 were reliable: for the test n. 1 the value was 0.6565 K m^2/W, for the test n. 4 it was 0.5952 K m^2/W. The value obtained for the test n. 4 is very similar to the Literature value of 0.56 K m^2/W, referred to a similar wall without the 150 mm thickness plasterboard in the internal surface.

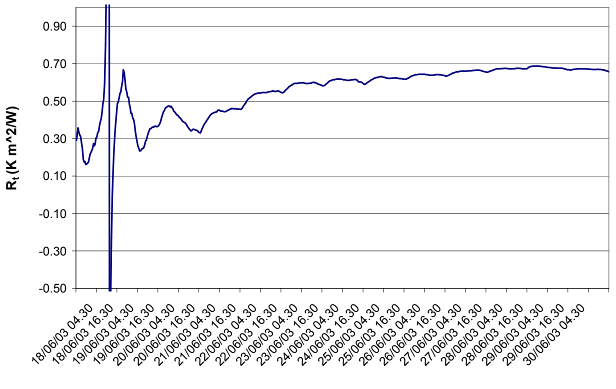

Figure 13: Thermal resistance calculated with the depuration thermal flux method, test n. 1

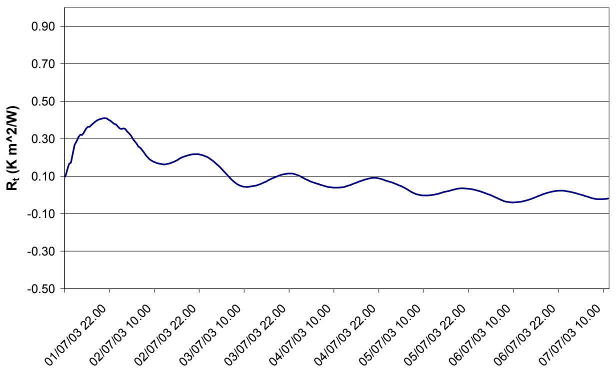

Figure 14: Thermal resistance calculated with the depuration thermal flux method, test n. 2

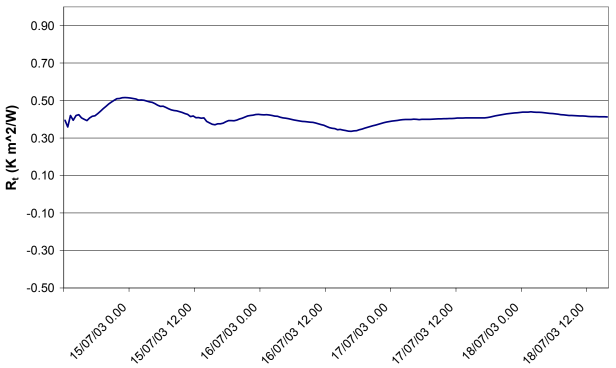

Figure 15: Thermal resistance calculated with the depuration thermal flux method, test n. 3

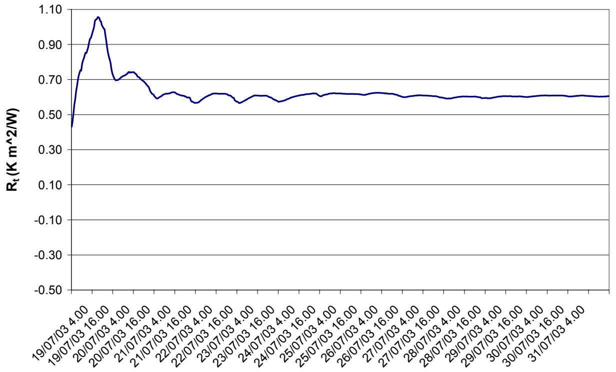

Figure 16: Thermal resistance calculated with the depuration thermal flux method, test n. 4

6.2 Simulated extension of the test

The method of the simulated extension of the test was developed in a previous work [2] for the variable regimen measurements in Laboratory tests. So, an extension of the test for a period of time multiple of 24 hours was simulated for the test n. 4 only, in order to compare the simulated data with the effective extension of the test: data considered for the 24 hours were obtained calculating the mean of the values registered from 16:00 18/07/2003 to 16:00 25/07/2003. The thermal resistance converges to the value of 0.6150 K m^2/W, next to the one obtained previously; however this method is useful only when the temperature and thermal flux becomes periodic, like variable regimen measurements carried out in Laboratory [3].

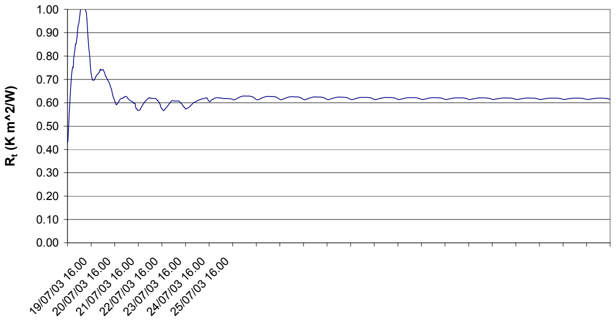

Figure 13: Thermal resistance calculated with the simulated extension of the test n. 4.

6.3 Filtered data Method (Kalman Filter)

A third method of calculation was finally proposed, although still employing eq. (1), but temperature and thermal flux data were filtered to speed up the convergence to the asymptotic value in the test period. So the thermal resistance was calculated, excluding from eq. (1) some thermal flux data external to an appropriate range, including the mean value [2, 3]. This method was applied to the test n. 4 only: considering a suitable range including values comprised between 2.30 W/m^2 K and 8.30 W/m^2 K (mean value of the thermal flux: 5.40 W/m^2 K), the thermal resistance Rt converges to the value of 0.7831 m^2 K/W, that differ from the value obtained without filter the data because the thermal flux trend is not symmetric respect to the mean value calculated: so, this method is not applicable in these conditions.

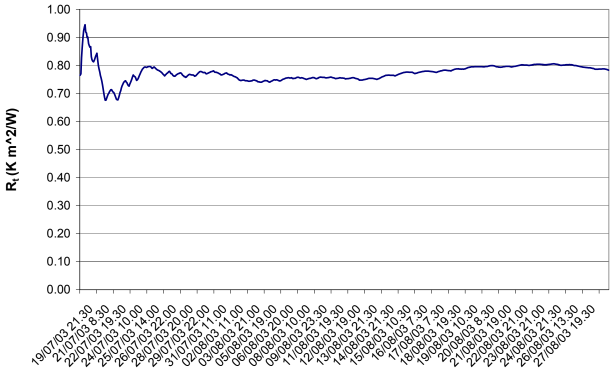

Figure 14: Thermal resistance calculated with the filtered data method

7. CONCLUSIONS

The aim of the present paper is the measurement of the thermal resistance of masonry walls, employing a methodology for in situ tests. So, measurements on an external wall of the Thermodynamics Laboratory of the University of Perugia were carried out, in compliance with prEN 12494; four tests in different conditions were carried out, for a total period of about 1500 hours. For all the tests, during the night, an inversion of the thermal flux was registered, so the thermal resistance could not be calculated without processing the measured data. Thus, three data analysis methodologies were proposed. In the first case, in the data analysis the thermal flux was calculated without the contribution of the external convection heat transfer. In the second 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. Finally, it was proposed to filter the set of data of the measured thermal flux, in order to eliminate the values farther from the measured medium thermal flux. In the first one, only the tests n. 1 and n. 4 verify the requirements of the prEN 12494: for the test n. 4, a R$_t$ value of 0.5952 K m^2/W was obtained, in agreement with data from Literature. Instead, the second and the third methodologies were not useful for this application. Finally, in order to verify the proposed methodology, in situ measurement should be carried out for different masonry walls.

REFERENCES

1. prEN 12494, Building components and elements – In situ measurement of the surface to surface thermal resistance, 1996.
2. F. Asdrubali, C.Buratti, A. De Lieto Vollaro, G. Galli, S. Ortica, S. Grignaffini: Misure di resistenza termica di pareti in muratura in regime stazionario e variabile, *56° Congresso ATI*, Napoli, September 2001, vol. 1,pp. 13-24.
3. C. Buratti, S. Grignaffini, Measurement of the thermal resistance of masonry walls, International Journal of Heat & Technology, Vol. 21, n. 2, December 2003.
4. Aureli C., Grignaffini S., Determinazione della resistenza termica di componenti edilizi in opera: misure sperimentali e metodi numerici*, 54° Congresso Nazionale ATI*, vol. 2, pp 1211-1221, L'Aquila, 1999.
5. Warren M. Rohsenow, James P. Hartnett, Young I. Cho, *Handbook of Heat Transfer*, Third Edition, Mc Graw Hill, 1998.
6. J.P. Holman, *Heat transfer*, SI metric edition, Mc Graw Hill, 1989.
7. Kosny J., Kossecka E., Multi-dimensional heat transfer through complex building envelope assemblies in hourly energy simulation programs, *Energy and Buildings*, vol. 34, June 2002, pp. 445-454.
8. Kossecka E., Kos'ny J., Equivalent wall as a dynamic model of complex thermal structure, *Journal of Thermal Insulation and Building Envelopes*, 1997.
9. Kossecka E., Heat transfer through building wall elements of complex structure*, Archives of Civil Engineering*, 1992, pp. 117-126.
10. Tsilingiris P.T., On the transient thermal behaviour of

structural walls – the combined effect of time varying solar radiation and ambient temperature, *Renewable Energy*, vol. 27, October, 2002, pp. 319-336.

11. Christian J.E., Kos'ny J., Thermal performaces and wall ratings, *ASHRAE Journal*, 1996.
12. M. Necati Özisik, Heat Transfer, Mc Graw Hill, 1985.
13. Antonopoulos K.A., On the non-periodic unsteady heat transfer through walls, *Int J Energy Research*, 1993, pp. 401-412.