Real time thermal analysis of an exterior wall solution used as envelope for an energy efficient building

I. Boros, K. Schmiedt, C. Tanasa, T. Nagy-Gyorgy, D. Dan and V. Stoian

***Abstract*—**Energy efficiency of buildings is a topic of wide interest nowadays. Current local legislation and research is still underdeveloped and needs improvement. This paper contributes in reducing the gap between theory and practice, by gathering real time data through a complex monitoring system. To determine the theoretical data, the ANTHERM software was used, and then compared to the values obtained from practice. Numerous sensors were introduced in various locations along the envelope to present the realistic temperature distribution through detail stratifications. Results show that there are certain differences between calculated and measured data and in order to obtain the best insulation solutions, a detailed dynamic approach is needed. Resource efficiency and higher interior comfort can be achieved by buildings designed according to methodology adapted to real-time data measurements.

***Keywords*—**Energy efficiency, monitoring, thermal transfer, envelope, school.

I. Introduction

BUILDING industry is one of the major consumers of energy, also greenhouse gas emitters. A solution for this environmental issue is the energy efficient buildings, which reduces the energy use to a minimum and the demand is covered by renewable energy.

The current methodology [1] presents numerous deficient calculations, out-of-date parameters and technologies, resulting in a gap between theory and practice. Using new materials and constructive solutions force the designer to make assumptions, altering even more the final values. The data gathered from the monitoring system can update the norms, which reveal more substantial and practical information.

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II. Case Study – Energy Efficient School Building

The four storey building with a total area of 4000 m^2 is located in Salonta [2]. The building functions include: kitchen with a 500 meals / day capacity, dining hall for 200 students, storage rooms, library, classrooms, laboratories, administration offices, housing to 60 students, recreation hall, room for the medical staff. The school has a capacity of 450 students, 65 teachers and auxiliary staff.

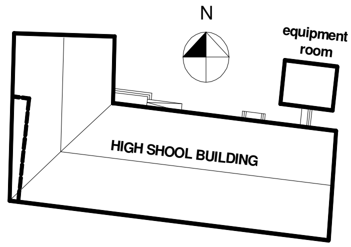

Fig. 1 Site plan

The building has a reinforced concrete frame structural system, with reinforced concrete slabs, continuous foundations and a wooden frame roof system. The exterior walls [3] are composed of 15 cm mineral wool and 25 cm CCA masonry (Fig. 4). This constructive detail is used on all four storeys, on every orientation and various functions to study the difference between orientation heat gains, difference between functions.

Fig. 2 Facade

III. MONITORING SYSTEM

A complex monitoring system [4] was implemented to demonstrate the utility of the used constructive details, and to gather information about the parameters that define the efficiency of the thermal envelope: interior and exterior temperatures, solar radiation intensity, hot water use, electricity and gas use.

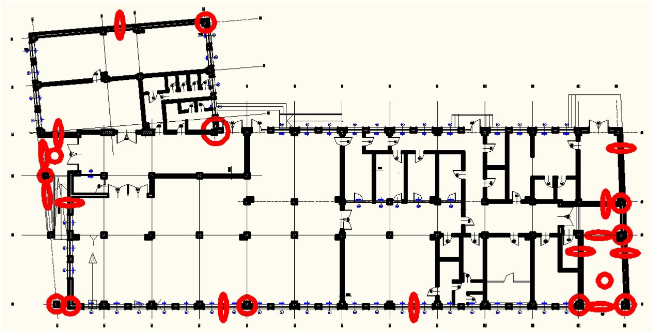

Fig. 3 Sensors distribution floor plan

Over 660 sensors compose the monitoring system. The readings are recorded in several “data logger” devices, in which sensors are connected. A sensor is an assembly of reading device, data transmission cable and shrinking tube protection. To avoid damage, the sensors embedded in concrete must be additionally protected, by inserting them in polyethylene tubes. To observe different behaviour of the same detail, sensors were places in various location (Fig. 3): soil, reinforced concrete continuous foundations, socket beams, slab stratifications, reinforced concrete beams and pillars, wall stratifications, etc.

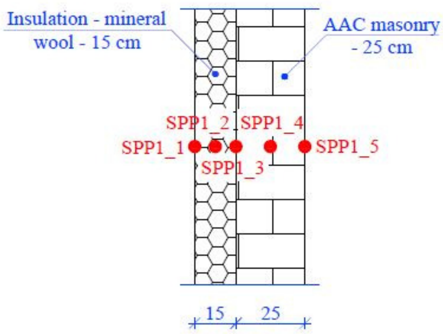

Fig. 4 Detail for exterior wall

IV. REAL TIME DATA

The result data charts gather data from a specific period, 5 – 20 May, even though the measurements extend for over a month. When the values where saved, the building was still under construction and without a heat source, presenting lower indoor temperature.

The first group of five sensors is placed on the exterior wall stratification (Fig. 4). The sensor located on the external side (SPP1_1 - Fig. 6) shows the direct and intense influence of the exterior temperature, which is also presented in the weather forecast for May (Fig. 11). Comparing measured and weather forecast data, concludes in little differences between the minimum read temperatures (5.88ºC on the 17th, 8.80ºC on the 9th) and exterior temperatures (4ºC, respectively 7ºC). Regarding maximum values, the sensor read greater temperatures than the effective exterior temperature: 22ºC on the 17th, 41ºC on the 9th, compared to 15ºC and 21ºC. This difference can be explained by long period sun exposure.

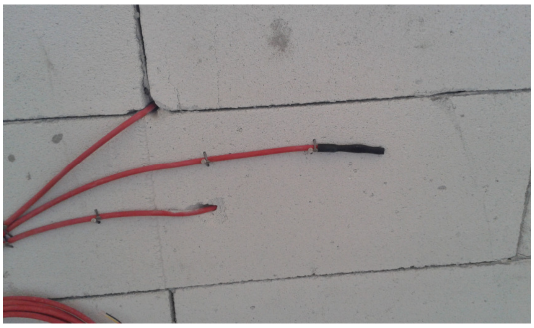

Fig. 5a View of sensors installation

Fig. 5b View of sensors installation

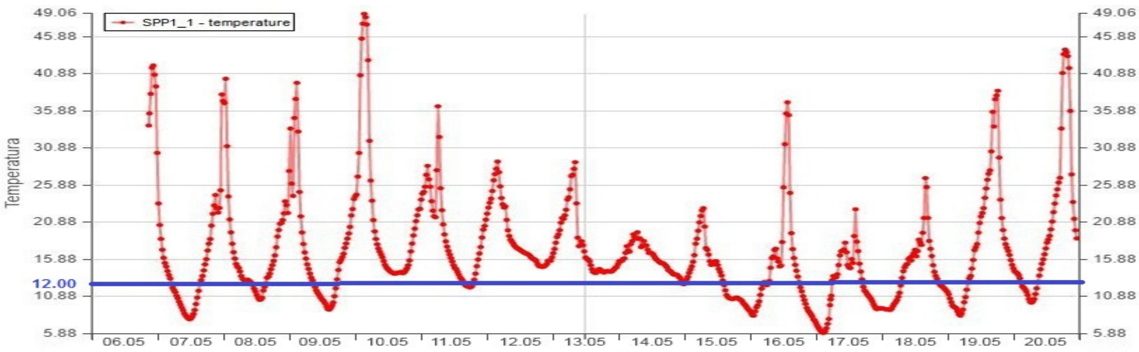

Fig. 6 SPP1_1

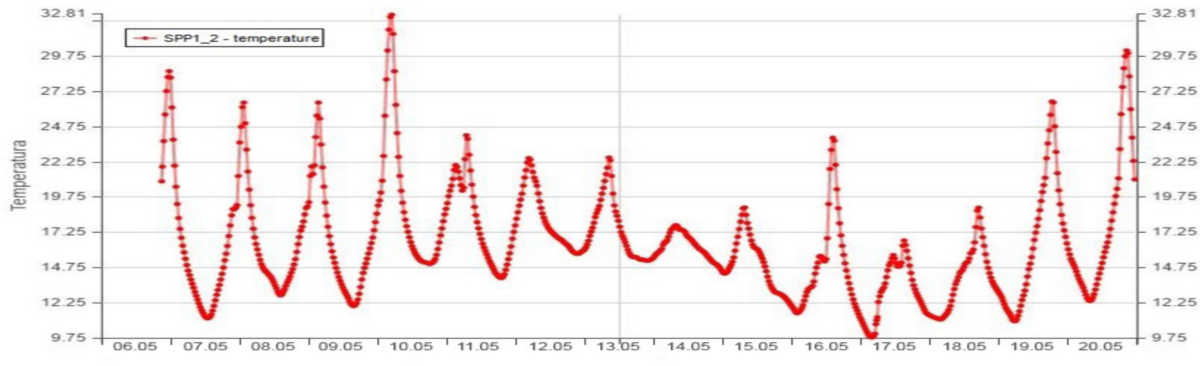

Fig. 7 SPP1_2

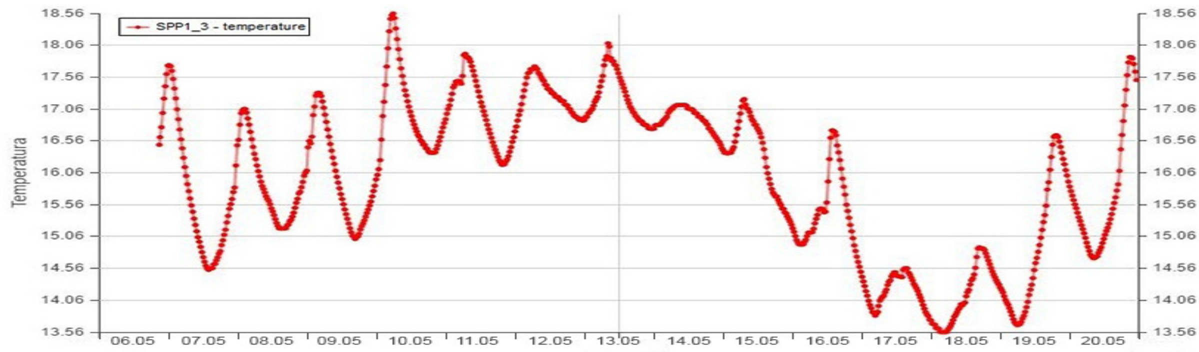

Fig. 8 SPP1_3

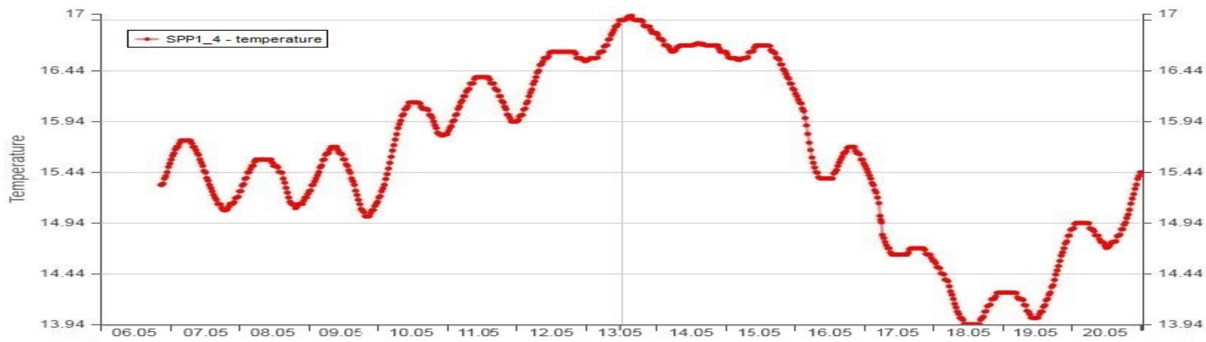

Fig. 9 SPP1_4

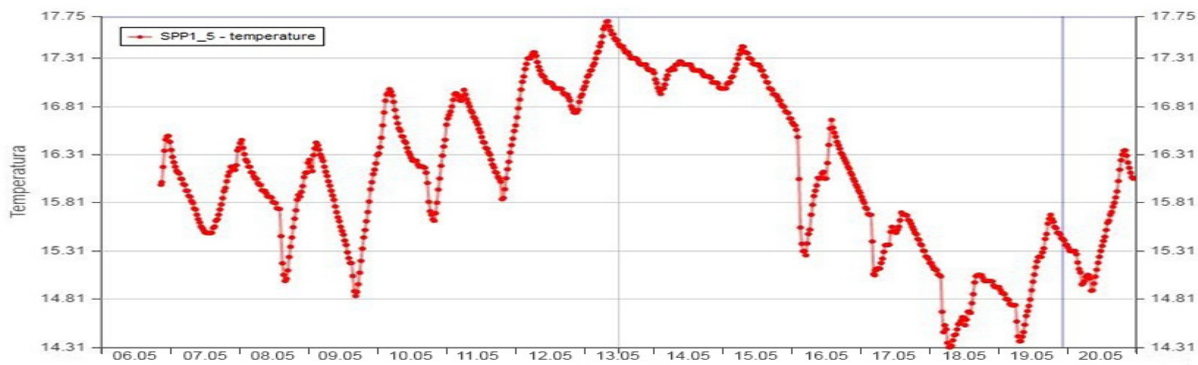

Fig. 10 SPP1_5

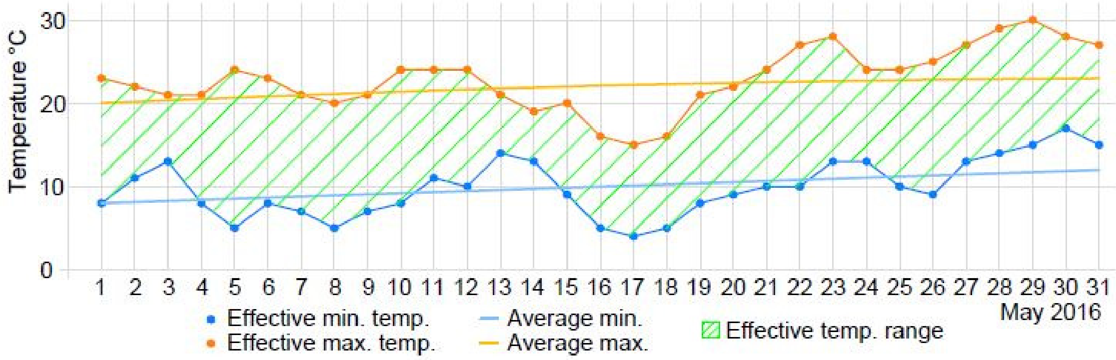

Fig. 11 Weather forecast for Salonta

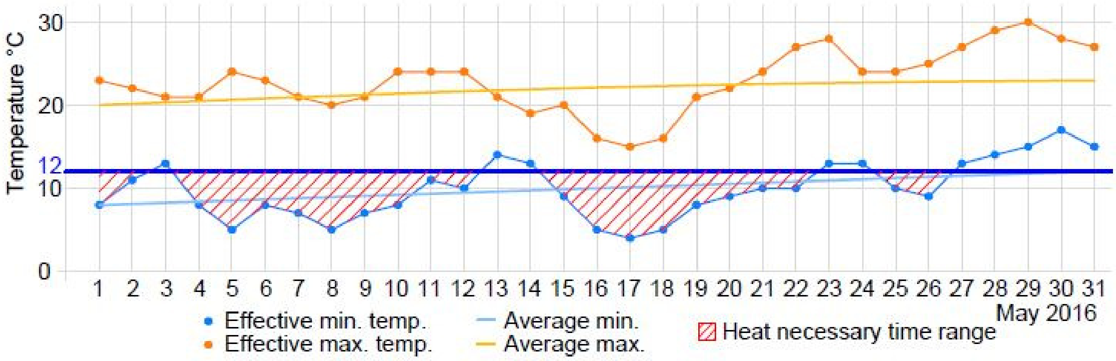

Fig. 12 Required heating demand

The day / night variation of the measured data is similar to the exterior environment. It is easy to notice how the temperature is increasing from morning to midday and decreasing through the night.

The sensor placed in the middle of insulation (SPP1_2 - Fig. 7) presents a reduced day/night variation and a 4ºC temperature difference to the exterior, resulting a quantified influence of the insulation, even on half of its thickness.

The next group of sensors that are located on the contact surface between insulation and masonry respectively in the middle of the masonry (SPP1_3, SPP1_4 – Fig. 8, Fig. 9) present an even reduced day / night variation and an increase in temperature with another 4ºC, proving the influence of the insulation on heat loss.

In case of the sensor placed on the interior side of the wall (SPP1_5 – Fig. 10) the variation between day and night is even more reduced, offering a more controlled indoor environment. The temperature difference between the exterior and interior is high as 8ºC.

The methodology presents the temperature which indicates requirement for heating, lower than 12ºC. The charts show that for a few number of days, a short period of time at night, heating is necessary (red hatch, Fig. 12). In case of cooling, there are only 2 days, for a few hours, when the temperature greater than 30ºC, which is covered by the overheating frequency, less than 0.1% (Fig. 12).

V. THEORETICAL DATA

The theoretical temperature distribution in the exterior wall was determined through a numerical simulation using ANTHERM [5], a software specialized in heat flow calculation in building construction elements. The theoretical temperature distribution graphs are compared with the graphs of measured temperature. The analyzed data is from a period when the building was not heated nor inhabited. The numerical simulations were performed using measured exterior temperature and corresponding interior air temperature as boundary conditions. The evaluation is made for two situations: minimum and maximum exterior temperature registered in the same day.

Fig. 13.a), 13.b) shows the calculated and measured temperature distribution in the wall for the minimum exterior temperature of 13.88°C and corresponding interior temperature of 15.90°C for the considered day (10 May 2016). Fig. 14.a), 14.b) shows the calculated and measured temperature distribution in the wall for the maximum exterior temperature of 24°C and corresponding interior temperature of 17.5°C for the considered day (8 May 2016). As expected, we can observe that the temperature variation from interior to exterior is the highest in the thermal insulation layer due to its higher thermal transfer resistance. There is a slight difference between the calculated and measured temperature distribution in the wall that might be caused by differences between the theoretical values of thermal conductivity of materials used in the simulation and the real properties of the used materials.

The nonlinear variation of the temperature distribution measured by the monitoring system is a result of the sensors

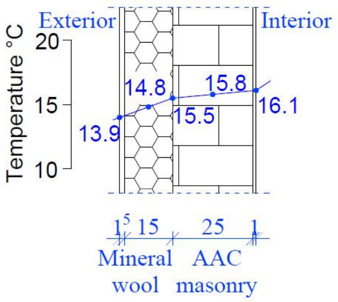

Fig. 13a Temperature distribution in the exterior wall – for the minimum exterior temperature in May 2016
Calculated using numerical simulation software ANTHERM

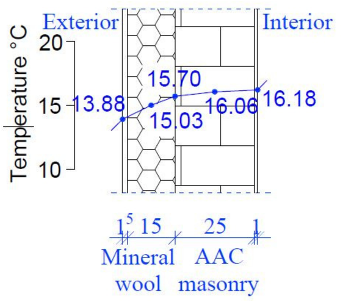

Fig. 13b Temperature distribution in the exterior wall – for the minimum exterior temperature in May 2016
Measured with the monitoring system

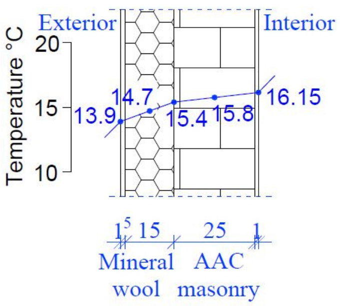

Fig. 13c Temperature distribution in the exterior wall – for the minimum exterior temperature in May 2016
Calculated with the simplified method

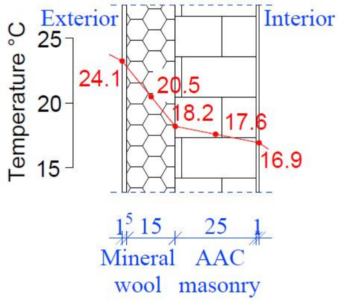

Fig. 14a Temperature distribution in the exterior wall – for the maximum exterior temperature in May 2016
Calculated using numerical simulation software ANTHERM

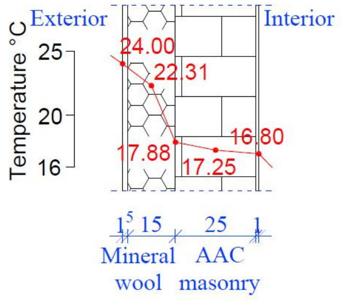

Fig. 14b Temperature distribution in the exterior wall – for the maximum exterior temperature in May 2016
Measured with the monitoring system

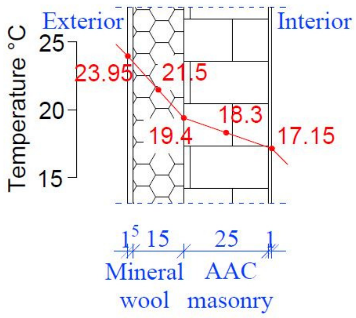

Fig. 14c Temperature distribution in the exterior wall – for the maximum exterior temperature in May 2016
Calculated with the simplified method

tolerance of ±0.5ºC, and the fact that the sensor cannot be placed in an exact position, in the middle of the insulation or masonry.

VI. Conclusion

The thick layer of insulation on the exterior side of the wall, shows a great influence on the energy use. The implemented monitoring system provides important information which completes the methodology. There are many gaps between theory and practice that can be reduced using real time data.

Precise model calibration in regard to temperature distribution is possible, because of the sensor local measurements, which can read information in a specific time.

Energy efficient buildings represent a solution that meets performance criteria assigned by the European Commission, and also increasing indoor comfort. Research in the energy efficiency field is essential for building evolution regarding energy use and it can highlight issues to raise environmental awareness on a more extended level.

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