Thermal Analysis of an historical bath (hammam) by quantitative IR thermography

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Abstract

The study is focused on the use quantitative IR thermography (QIRT) for the examination of the hidden structure of a historical bath (hammam) using indirectly its thermal performance. The building is analyzed in terms of the thermal insulation characteristics. The differential IR images were produced from the IR sequences by taking temperature differences as a function of time. This allowed to locate thermal failures, such as heat loss, thermal bridges and air leakages, on building envelope. The study was supported by microclimatic monitoring of indoor and outdoor conditions.

A simple heat transfer model is applied to achieve reference temperature during the IRT surveys. The heat loss calculations are considered locally, trying to better understand the historical structure in a non destructive way. Another issue is the failures evaluation in relation to the recent restoring interventions.

The thermo-physical properties of the historic materials are estimated with laboratory analysis. The drawing of the building and geometric measurements are coupled with a photographic scanning to estimate the heat transfer.

1. Introduction

A comprehensive study is needed in order to discover the materials and construction technologies contributing to the thermal performance of historical baths, "*hammams*" and to keep their proper functioning for such a long period of time. In this regard, it is essential to investigate the microclimatic indoor characteristics particular for an hammam structure and thermal insulation characteristics of its components. This investigation would be, without doubt, highly desirable if done by non-destructive methods, such as by IR Thermography (IRT), which is a very practical, fast and accurate non-destructive method, commonly used qualitatively for the detection of thermal failures in the building envelope, such as heat loss, thermal bridges and air leakages.

Such a non-destructive study was conducted on a 15th century Ottoman bath, the Sengul Hammam, located in the province of Ankara, Turkey. Its thermal performance was examined in terms of its features, thermal properties of its historic masonry and failures happened in time in relation to the recent repairs. For these purposes, the quantitative IR thermography (QIRT) was used in the study together with the microclimatic monitoring, laboratory analyses on thermo-physical properties of the historic materials and heat transfer calculations.

2. Materials and Methods

The Sengul Hammam is a typical Ottoman double bath consisting of two separate parts for men and women. It still represents the continuous experience of hammam culture in Anatolia by keeping its original architecture and building technologies. It was constructed with stone masonry walls with brick transitions and brick upper structure. The bath was composed of basically seven sections: undressing room, tepidarium, caldarium, cold water storage room, hot water storage room, firewood storage room and furnace. The tepidarium and caldarium sections are used for bathing purposes. The body is gradually adapted to heat in tepidarium section before entering the hottest section, the caldarium.

A decrease in interior ambient temperature with an average value of 2°C was observed between the seasons of summer and winter, signaling the presence of heat loss problems which may be due to air leakages and/or insufficient thermal resistance of the building components.

The whole structure has been examined to discover such failures and large variation in thermal properties of the materials in relation to the indoor and outdoor air temperature conditions. Furthermore, thermal signatures of the building envelope have been examined to find out recent incompatible repairs.

The study was performed in three steps: 1) microclimatic monitoring, 2) thermographic survey and 3) heat transfer calculations.

The temperature and RH data for the indoor and outdoor of the structure were continuously-monitored along for a year by means of data loggers, "*HOBOware Pro*".

In-situ IRT studies were done by single IR imaging and sequential IR imaging. The exterior wall and roof surfaces, as well as the interior floor surfaces were scanned in segments by taking single IR infrared images together with their visible-light photographs, as shown in Figures1-3. At some regions, the IR images were taken in sequences at 5-10 seconds intervals for a period of 5-10 minutes. The differential IR images were produced by taking the temperature differences as a function of time. The surface temperature varying was evaluated during the cooling period of exterior surfaces at night, while interior surfaces were exposed to a very hot and wet air. The IRT survey of Sengul Hammam was done by using the "*AGEMA ThermaCAM 550*" and *"FLIR ThermaCAM E65"* thermographic equipments. The images were then analysed by using the softwares of *"ThermaCAM Reporter* 2000" and "ThermaCAM Researcher Professional".

Some thermo-physical properties of the materials forming the masonry structure, such as density, porosity, specific heat and thermal conductivity, will be determined by laboratory analyses. By using these data, the heat flux transmitted by conduction through the wall and dome sections will be calculated for the periods of winter and summer by using the thermal resistance of each layer and the boundary air layers, as in the Eq.1 given below [1].

$$U = \frac{1}{R_{si} + R_{so} + R_1 + .. + R_n + R_a} \qquad (1)$$

where, U is the thermal transmittance *(W/m²K)*, R_{si} is the inside surface adductive resistance *(m²K/W)*, R_{so} is the outside surface adductive resistance *(m²K/W)*, R_n is the overall thermal resistance of the materials forming the wall/dome section *(m²K/W)*, R_a is the resistance of air space *(m²K/W)*.

An example of the geometric description of the building envelope part is given in Figure 4 for a dome, in order to compute the overall thermal resistance of the building layers. Basically, two cases of the wall and dome sections, the *AS-IS case* of Sengul Hammam including the recent incompatible repairs, and the *ORIGINAL case* representing its original wall/dome will be examined by means of heat transfer calculations.

Fig. 1. *The IR image taken from the Sengul Hamam's roof at night in summer at the boundary conditions of 26°C and 30% RH, showing the significant heat loss at the lower parts of the chimney and circular dome-lights.*

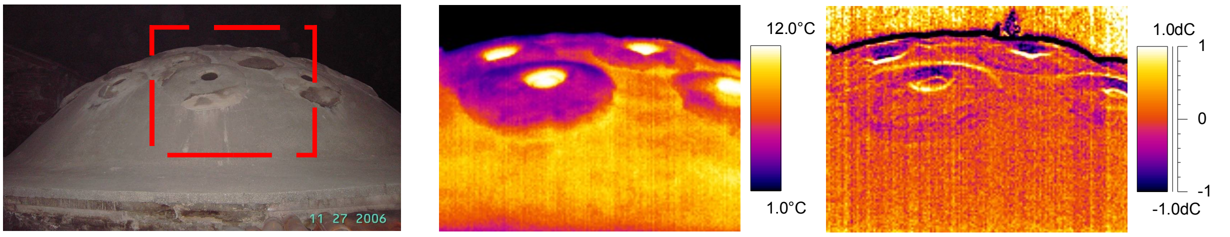


Fig. 2. *The IR image taken from the north side (*
conditions of 10.7°C and 40%RH; and its differential IR image (the temperature difference between the last and first IR images); showing the heat loss from the concrete-clad dome surfaces with ΔT=+0.2°C during the cooling period of night for 322s.

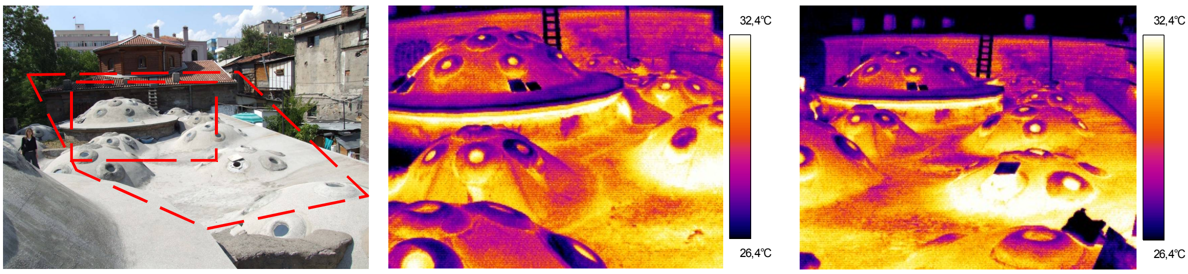
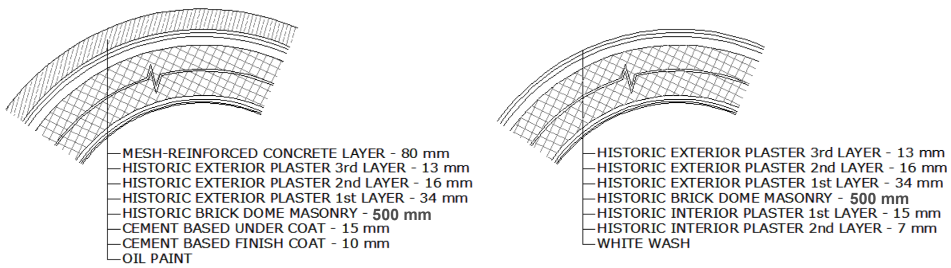


Fig. 3. *IR images of the selected regions taken at night in summer outdoor air temperature: 26°C and 30% RH, while the interiors' conditions being around 38°C and 95%RH. The concrete-clad roof surfaces were warmer than the ambient temperature; the circular dome lights seemed to be the hottest areas indicating the heat loss/air leakage from these regions while cement mortar peripheries encircling them being colder surfaces.*

Fig. 4. *The section drawings showing the order and thickness of the components forming the dome structure for the "AS-IS case" of Sengul Hammam (at the left) including the recent incompatible repairs, and for the "ORIGINAL case" representing its original dome structure (at the right).*



3. Conclusion

It is essential to control the microclimatic features particular to an historic hammam, such as hot and wet air, both for the comfort of the users and for its economically and properly functioning. The use of quantitative IRT together with the microclimatic investigations and heat transfer calculations provided a good combination for the assessment of the thermal performance for an historic hammam in terms of thermal insulation characteristics and thermal failures. This approach is very useful to evaluate the repair intervention effectiveness.

REFERENCES

[1] [F. Hall. Heat Losses, In: Building Services and Equipment, v.1, 3rd edition. Longman Group UK Limited (1994).