ANALYZING TRADITIONAL BUILDINGS VIA EMPIRICALLY CALIBRATED BUILDING PERFORMANCE MODELS

Ardeshir Mahdavi[1], Kristina Orehounig[1], Nina Mikats[1],
Lyudmila Lambeva[1], and Alaa El-Habashi[2]

[1]Department of Building Physics and Building Ecology, Vienna University of Technology, Vienna, Austria
[2]Faculty of Architecture, University of Monofiya, Egypt

ABSTRACT

A systematic approach toward obtaining, analyzing, and simulation-based reproduction of performance data from traditional buildings is presented. This approach involves long-term data collection regarding local climate, indoor conditions in the selected building objects, construction methods, building materials, energy systems, ventilation regimes, and occupancy patterns. Subsequently, the collected data is analyzed and interpreted in view of the buildings' salient design features. Furthermore, a digital performance simulation model of the building is generated and calibrated based on collected indoor climate data. The approach is exemplified using the instance of a traditional hammam building located in Cairo, Egypt.

KEYWORDS

Traditional architecture, hammams, building diagnostics, performance simulation

INTRODUCTION

Traditional buildings often embody numerous intelligent design features that have emerged as the result of the process of adjustment to local climatic conditions and social functions (Bahadori 1979, Rezai-Hariri 1980, Mahdavi 2007, 1996, 1989). To tap into this potentially rich source of design knowledge, the typically available general qualitative descriptions of the respective design strategies are insufficient. Rather, detailed performance analyses are needed based on high-resolution empirical performance data. In this context, the present contribution describes a systematic approach toward obtaining, analyzing, and simulation-based reproduction of performance data from traditional buildings.

This approach is currently being applied within the framework of an EU-supported research project (Mahdavi 2007, Mahdavi and Lambeva 2006, Mahdavi et al. 2006, Hammam 2007). Thereby, amongst other activities, local climate and building performance data are being collected for a number of traditional hammam (bath) buildings in a number of North-African and Mediterranean countries (Grotzfeld H. 1970). The high-level objective of this interdisciplinary research effort is a comprehensive understanding of the technical and social aspects of hammams, including their current state, role, and functionality, as well as their future potential.

Our role, within the overall framework of this project, is to: *i)* Collect local climatic data as well as data pertaining to indoor conditions; *ii)* Collect data concerning the construction methods, building materials, and building systems; *iii)* Collect data regarding heating and ventilation regimes and occupancy patterns; *iv)* Analyze and interpret the collected data in view of the buildings' salient design features (location, massing, apertures, thermal mass, etc.); *v)* Create a digital performance simulation model of the building; *vi)* Calibrate the digital models using collected indoor climate data.

Using the example of a traditional hammam (located in Cairo, Egypt), we explore the process and the recent results of the data collection activity as well as the correspondence between the empirically collected data and the initial simulation results. A calibrated simulation model can be applied toward the assessment of the buildings' performance and prediction of the consequences of alternative options for its renovation, restoration, reuse, and adaptation.

APPROACH

Altogether, six hammams have been targeted for the project. These are located in Egypt, Turkey, Morocco, Syria, Algiers, and Palestine. So far we have visited five of these hammams and have equipped them with diagnostics equipment for long-term external and internal climate monitoring. This paper specifically addresses the selected hammam in Cairo, Egypt (Figure 1).

A weather station was installed in proximity of the hammam to monitor outdoor air temperature and relative humidity, global horizontal irradiance, and wind speed. Seven data loggers were installed in various rooms of the hammam (see Figure 1). These recorded continuously (every five minutes) indoor air temperature, relative humidity, and illuminance. The scheduled one-year environmental data collection in this hammam started in February 2006 and was completed in April 2007.

Obtaining construction information as well as data pertaining to occupancy and ventilation patterns in this hammam has been rather difficult. Initial simulation assumptions are based on the authors' observations. The corresponding data are, however, to be successively refined with the aid of local research partners.

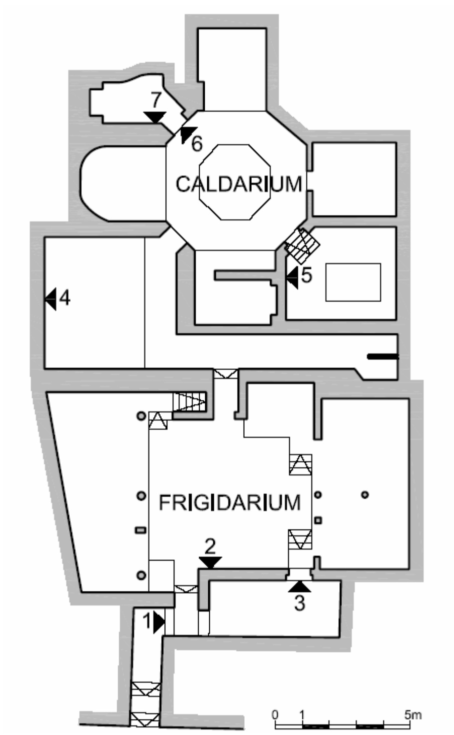

Figure 1 The schematic plan of the hammam in Cairo, Egypt with the location of indoor climate data loggers

The intended process for the generation and application of calibrated simulation models for the selected hammams is illustrated in Figure 2. An initial simulation model is to be generated based on collected geometry, construction, and operation data. To run the simulations, a weather file is generated based on data obtained from the locally installed weather station. The initial simulation results (e.g. indoor air temperature values) can then be compared to the measurements, leading to a calibrated version of the simulation model. Using such a calibrated model, alternative scenarios for the thermal improvement of the building can be assessed and evaluated.

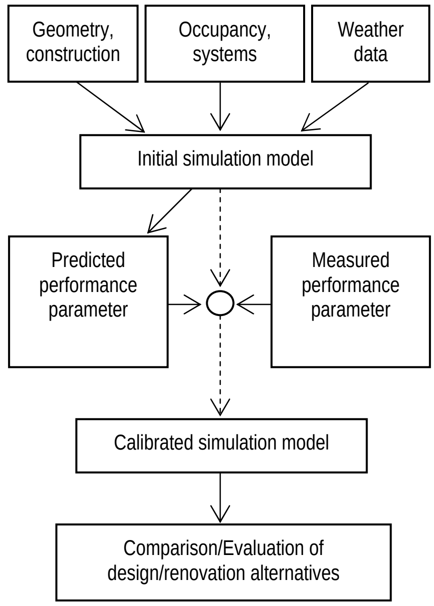

Figure 2 Illustrative depiction of the process of simulation model generation, calibration, and application

RESULTS

Weather information

Figures 3 and 4 provide examples of collected data on external weather conditions in the close proximity of the hammam. The comparison of this data with information available in "standard" weather files (Meteonorm 2004) reveal significant differences (see Figures 5 to 8). This strongly implies that both the interpretation of monitored data and the simulation-based regeneration of indoor climate data require a dedicated weather station close to the object of the study.

Indoor conditions

Examples of indoor measurement results are provided in Figures 9 to 14.

As Figures 11 to 14 clearly indicate, indoor conditions in the rooms of an operating hammam can vary considerably as a function of the time of the year. Thus, an overall evaluation of indoor conditions in such a building cannot be based on short-term spot measurements. Rather, substantiated judgments can be made only based on continuous monitoring of the indoor conditions over a longer period of time. To further exemplify the importance of such long-term monitoring for the evaluation of thermal comfort, Figures 15 and 16 illustrate the indoor climate conditions in the frigidarium and caldarium over the course of three reference days in the months of March, June, and October on a standard psychometric chart.

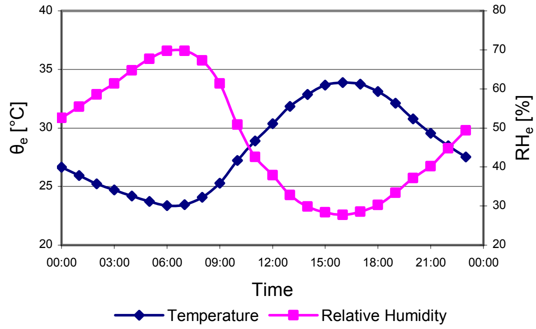

Figure 3 Measured outdoor air temperature and relative humidity (mean hourly values, June 2006, Cairo, Egypt)

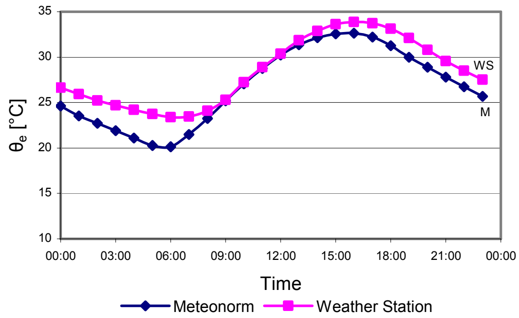

Figure 6 Outdoor air temperature in Cairo, Egypt in July. WS: Local measurement in June 2006; M: data from Cairo weather file (Meteonorm 2004)

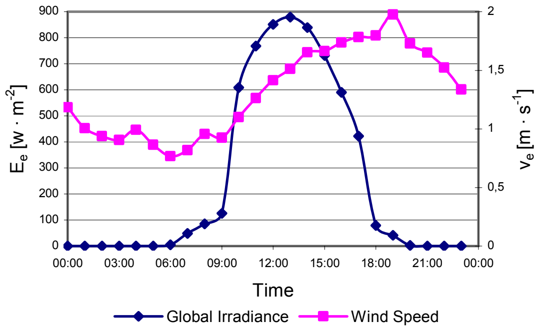

Figure 4 Measured mean daily global irradiance and wind speed (mean hourly values, June 2006, Cairo, Egypt)

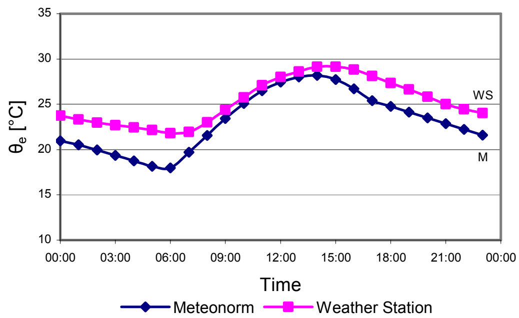

Figure 7 Outdoor air temperature in Cairo, Egypt in July. WS: Local measurement in October 2006; M: data from Cairo weather file (Meteonorm 2004)

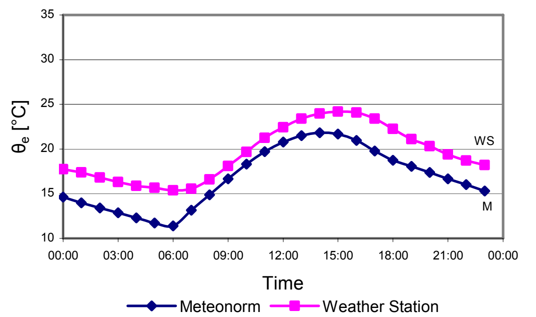

Figure 5 Outdoor air temperature in Cairo, Egypt in July. WS: Local measurement in March 2006; M: data from Cairo weather file (Meteonorm 2004)

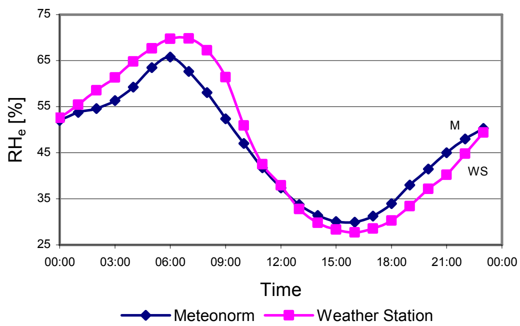

Figure 8 Outdoor air relative humidity in Cairo, Egypt in July. WS: Local measurement in June 2006; M: data from Cairo weather file (Meteonorm 2004)

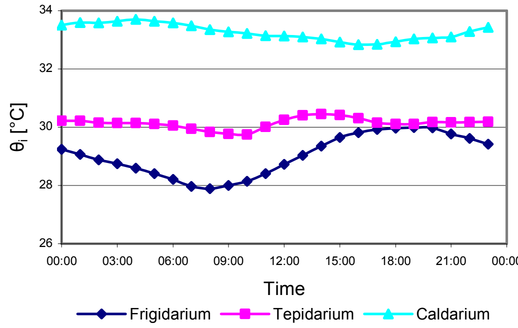

Figure 9 Measured indoor air temperatures in 3 locations in Cairo hammam (mean hourly values, June 2006)

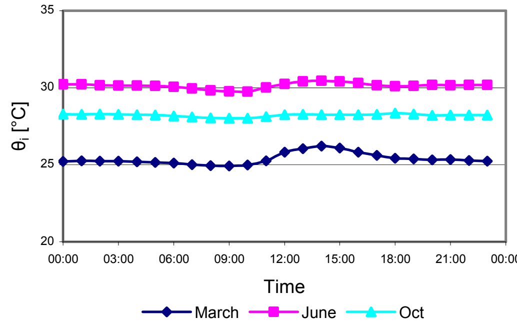

Figure 12 Measured indoor air temperature in tepidarium, Cairo hammam (mean hourly values, March, June, and October 2006)

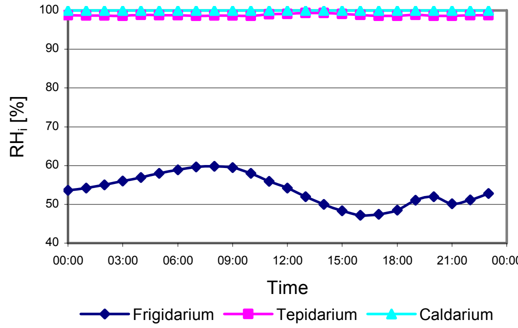

Figure 10 Measured indoor air relative humidity in 3 locations in Cairo hammam (mean hourly values, June 2006)

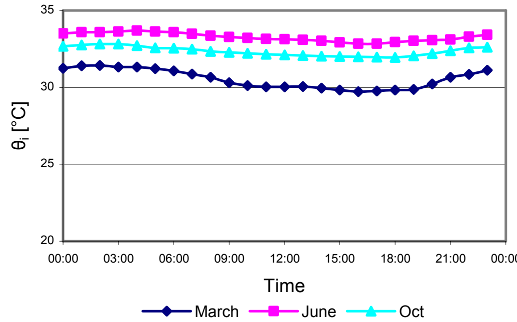

Figure 13 Measured indoor air temperature in caldarium, Cairo hammam (mean hourly values, March, June, October 2006)

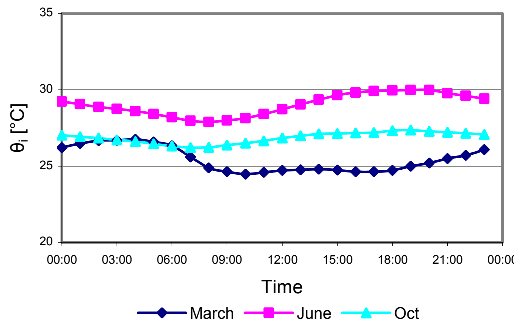

Figure 11 Measured indoor air temperature in frigidarium, Cairo hammam (mean hourly values, March, June, and October 2006)

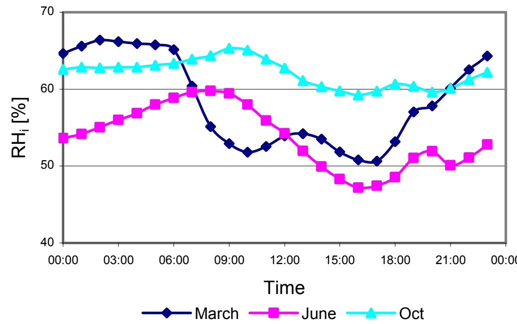

Figure 14 Measured indoor air relative humidity levels in frigidarium, Cairo hammam (mean hourly values, March, June, October 2006)

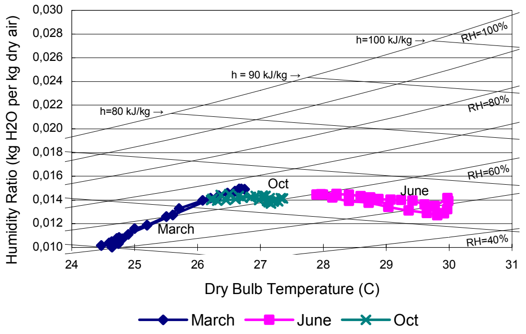

Figure 15 Depiction of the indoor climate conditions in frigidarium for March, June, and October 2006

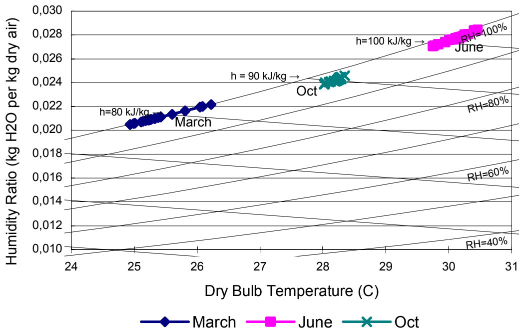

Figure 16 Depiction of the indoor climate conditions in tepidarium for March, June, and October 2006

Initial simulation studies

The onsite data monitoring has recently been completed. Thus, we have already started conducting exploratory simulations. These initial simulations are performed using a commercially available application (TAS 2006). A simulation model of the Cairo hammam was generated using the building's geometry together with material assumptions (see Table 1) based on authors' observations at the site.

Thermally, the hammam was modeled in terms of ten distinct zones. In the present paper, we focus on three thermal zones, namely one zone in caldarium (pool) along with tepidarium and frigidarium. Model input assumptions regarding heating energy, internal gains (occupants, lighting, equipment), ventilation, and their respective schedules (see Table 2) were based on a rough survey conducted by the local research partners and additional information collected during the site visit.

There exists no dedicated space heating system in the Cairo's hammam. Rather, the space is heated because a pool in caldarium is regularly filled with hot water. We thus had to estimate the effective heating energy released in the space based on pool volume and water supply temperature (as obtained via a spot measurement in the course of the site visit).

To exemplify the possibilities of model calibration, the assumptions pertaining to heating power is a good case in point. The information provided to the research team at the site suggested that the pool water was changed twice a day. However, our long-term indoor temperature measurements in caldarium in general and in the pool area in particular imply that the pool water is actually changed only once every day, namely late afternoon (see, as an indicative sign, the indoor temperature measurements shown in Figures 9 and 13). This information, together with the measured indoor air temperatures provided the basis for the calculation of heat transfer rate from the pool water to room air. Associated heating power assumptions are provided in Table 2, rows 3 to 6.

Figures 17 to 28 depict simulated and measured indoor air temperatures in three spaces in Cairo hammam, namely frigidarium (measured via sensor 2, Figure 1), tepidarium (sensor 4), caldarium/pool (sensor 5), for reference days in four different months (January, April, July, and October). Note that these Figures include also the respective measured outdoor temperature values.

Table 1 Simulation assumption regarding construction data

		R_t $[m^2 \cdot K \cdot W^{-1}]$	m $[kg \cdot m^{-2}]$	g-Value [-]
1	Roof	0.429	315	-
2	Walls	0.714	750	-
3	Floor	0.417	317	-
4	Glazing	0.004	10	0.4

Table 2 Simulation assumption regarding internal gains (people, lights, equipment), air change rate, and heating power for January, April, July, and October

	ZONE	FRIG.	TEPID.	CALD.
1	Air Change $[h^{-1}]$	0.6 - 1	0.3 - 0.5	0.1
2	Internal gain $[W \cdot m^{-2}]$	8.4	9.4	10.3
3	Heating (Jan.) $[W \cdot m^{-2}]$	10 - 50	5 - 20	85
4	Heating (Apr.) $[W \cdot m^{-2}]$	-	-	40
5	Heating (Jul.) $[W \cdot m^{-2}]$	-	-	37
6	Heating (Oct.) $[W \cdot m^{-2}]$	-	-	55

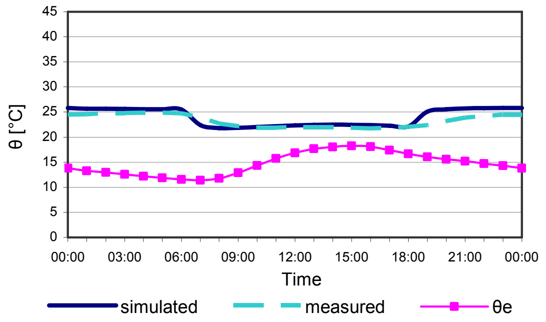

Figure 17 Simulated versus measured indoor air temperature in frigidarium for a reference day (mean hourly values, January 2007)

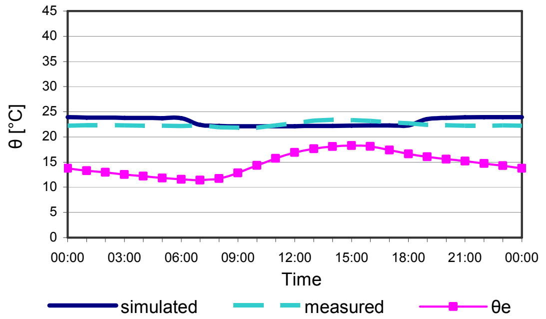

Figure 18 Simulated versus measured indoor air temperature in tepidarium for a reference day (mean hourly values, January 2007)

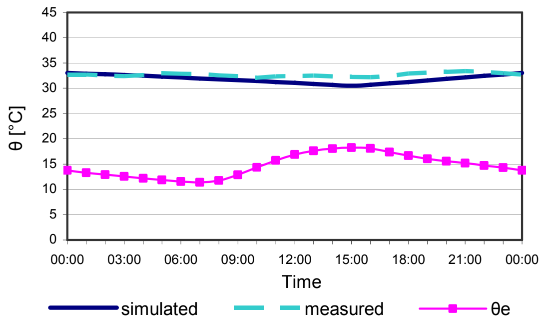

Figure 19 Simulated versus measured indoor air temperature in caldarium/pool for a reference day (mean hourly values, January 2007)

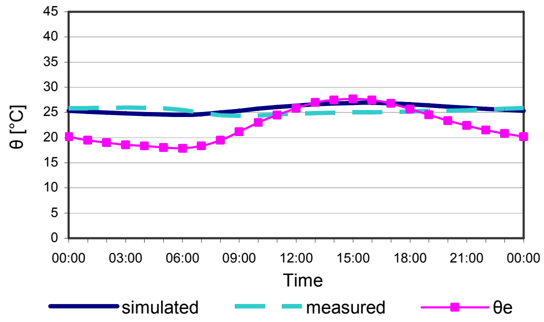

Figure 20 Simulated versus measured indoor air temperature in frigidarium for a reference day (mean hourly values, April 2006)

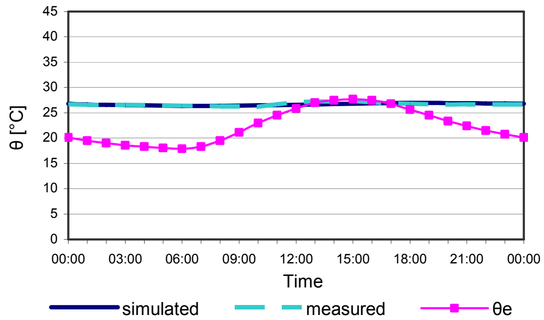

Figure 21 Simulated versus measured indoor air temperature in tepidarium for a reference day (mean hourly values, April 2006)

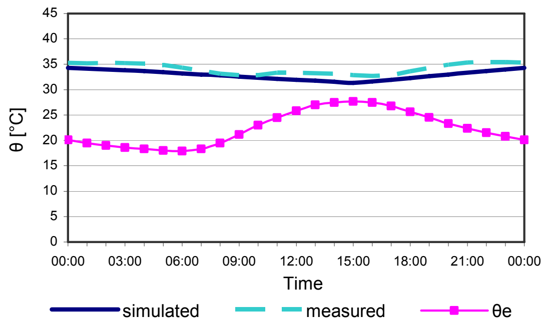

Figure 22 Simulated versus measured indoor air temperature in caldarium/pool for a reference day (mean hourly values, April 2006)

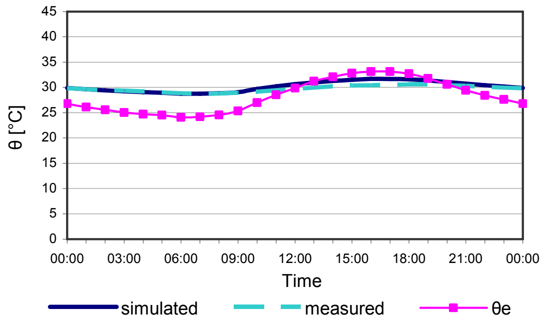

Figure 23 Simulated versus measured indoor air temperature in frigidarium for a reference day (mean hourly values, July 2006)

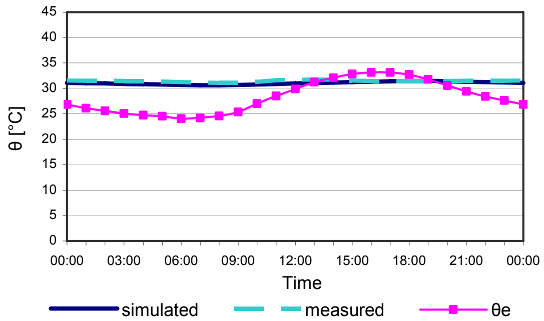

Figure 24 Simulated versus measured indoor air temperature in tepidarium for a reference day (mean hourly values, July 2006)

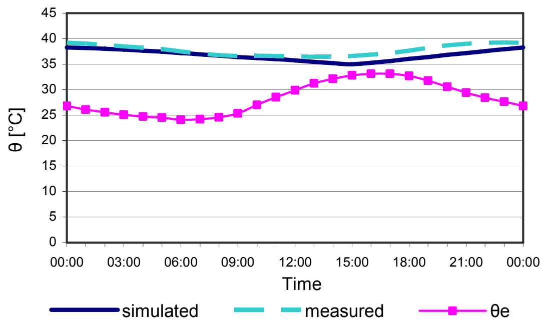

Figure 25 Simulated versus measured indoor air temperature in caldarium/pool for a reference day (mean hourly values, July 2006)

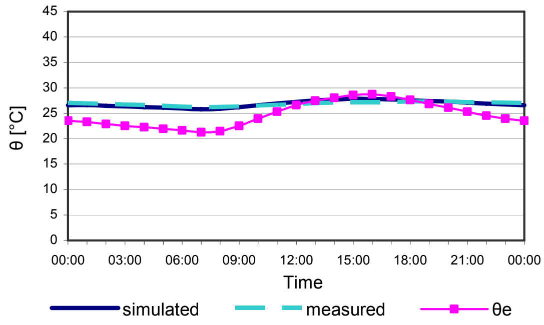

Figure 26 Simulated versus measured indoor air temperature in frigidarium for a reference day (mean hourly values, October 2006)

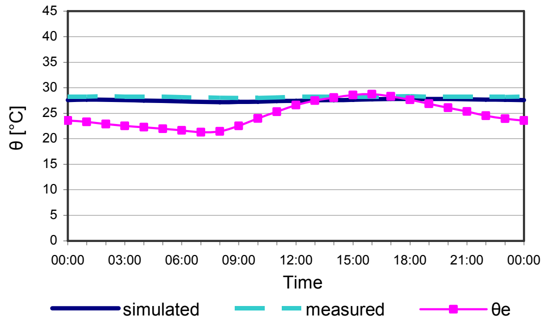

Figure 27 Simulated versus measured indoor air temperature in tepidarium for a reference day (mean hourly values, October 2006)

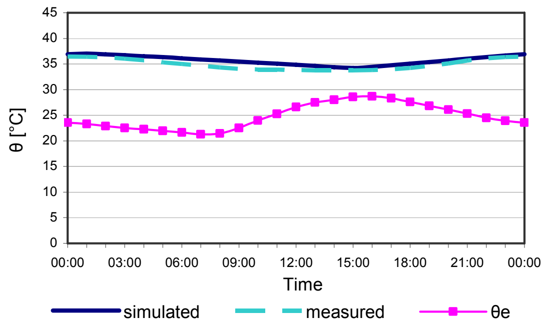

Figure 28 Simulated versus measured indoor air temperature in caldarium/pool for a reference day (mean hourly values, October 2006)

These results indicate a promisingly good match between the results of the numeric simulation and the measurements. We expect to achieve an even higher congruity level once more precise information regarding construction methods and materials as well as use patterns and operational regimes (including air exchange rates) will become available. Subsequently, we intend to apply such calibrated models toward comparative assessment of suggested alternatives for the remediation and renovation work in such traditional buildings.

CONCLUSION

We illustrated a systematic approach toward obtaining, analyzing, and simulation-based reproduction of performance data from a traditional bath building in Cairo, Egypt. We demonstrated how a digital performance simulation model of the building is generated and calibrated based on a documentation of the building (geometry, construction, systems, operation) and monitored outdoor and indoor environmental data. Similar simulation models are to be generated for a number of other hammams in North-African and Mediterranean countries. The models will be applied to compare and evaluate renovation and improvement options (regarding building envelope and associated components, energy systems) in view of building integrity and energy performance.

ACKNOWLEDGMENT

The research regarding hammam buildings presented in this paper is supported, in part, by a European Union grant; project: "Hammam, Aspects and Multidisciplinary Methods of Analysis for the Mediterranean Region", FP6-2003-INCO-MPC-2, contract no: 517704. Scientific coordinator: OIKODROM, Vienna, Austria.

REFERENCES

Bahadori MN. 1979. Natural cooling in hot arid regions. From "Solar Energy Applications in Buildings" (Edited by A. A. M. Sayigh). Academic Press, Inc. ISBN 0-12-620860-3. pp. 195 – 225.

Grotzfeld H. 1970. Das Bad im arabisch-islamischen Mittelalter. Otto Harrassowitz Verlag. Wiesbaden, Germany.

Hammam 2007. http://www.hammams.org.

Mahdavi A. 2007. Learning from traditional architecture through building diagnostics and performance modeling (Keynote). Proceedings of the 12th Symposium for Building Physics. Dresden, Germany. Vol. 1. ISBN 978-3-86005-564-9. pp. 11 – 22.

Mahdavi A. 1996. A Human Ecological View of "Traditional" Architecture. Human Ecology Review (HER). Autumn 1996. Volume 3, Number 1. pp. 108 - 114.

Mahdavi A. 1989. Traditionelle Bauweisen in wissenschaftlicher Sicht. Bauforum, 132. pp. 34 - 40.

Mahdavi A and Lambeva L. 2006. Calibrating building simulation models based on indoor and outdoor environmental monitoring. Proceedings (Tagungsband) of BauSIM 2006 (German speaking chapter of the International Building Performance Simulation Association), Munich, Germany. ISBN-10: 3-00-019823-7. pp. 132 – 134.

Mahdavi A, Lambeva L, Shehayeb DK, and El-Habashi A. 2006. A systematic approach to scientific study of traditional architecture. Proceedings of PLEA 2006 (23rd International Conference on Passive and Low Energy Architecture. Geneva, Switzerland, 6-8 September 2006). Vol 1. ISBN 2-940156-30-1. pp. 125 – 130.

Meteonorm 2004. Global meteorological database for applied climatology (Version 5.1.). URL: www.meteotest.ch.

Rezai-Hariri M. 1980. "Was du ererbt von deinen Vätern hast; Altpersische Bautradition als Muster einer energiebewußten Architektur". E'80 energie, 3/80. pp. 15 – 22.

TAS 2006. TAS Building simulation software (Version 9.0.8). URL: www.edsl.net.