AN INQUIRY INTO THE THERMAL, ACOUSTICAL, AND VISUAL ASPECTS OF INDOOR ENVIRONMENT IN TRADITIONAL HAMMĀMS

Ardeshir Mahdavi and Kristina Orehounig

Abstract

In the present paper, the authors focus on the indoor environmental performance of traditional Islamic hammām (bath) buildings. In the course of a long-term monitoring effort within the framework of an EU funded project (HAMMAM, 2008), data on indoor environmental (thermal) conditions and outdoor microclimatic conditions in the immediate vicinity of five traditional hammāms located in Egypt, Turkey, Morocco, Syria, and Algeria was collected. Moreover, short-term visual (lighting) and acoustical measurements were performed in a number of these buildings. The monitoring results provide the opportunity for an objective assessment of the actual performance of these buildings and evaluation of their strengths and weaknesses. In addition to evaluation and interpretation of indoor environmental conditions, the authors also used the monitored data to calibrate digital performance simulation models of the objects studied. These calibrated models of the hammāms can be applied to predict the consequences of alternative options for their renovation, restoration, reuse, and adaptation.

Keywords:
Traditional architecture; hammāms; indoor climate; diagnostics; simulation.

Introduction

The conceptual background of the research presented in this paper is based on the following three propositions:

i) Traditional buildings embody intelligent design features that have emerged through the long-term process of adjustment to local climatic conditions and social functions (Bahadori, 1979; Mahdavi, 1989, 1996, 2007).

ii) Investigation methods of modern building science (diagnostics, simulation) can be applied to tap into this encapsulated design knowledge of traditional architecture and provide a deeper understanding of the underlying strengths of environmentally adapted buildings, beyond typically available qualitative descriptions of the respective design strategies and features.

iii) Equipped with the knowledge of the original functions and workings of traditional buildings, modern methods, tools, and products of building science and technology can be effectively applied to support the processes of restoration and adaptation of such buildings.

The specific case in point is, in the present contribution, the traditional Islamic hammām (bath) building. Within the framework of an EU-supported research project (HAMMAM 2008), the authors collected data on indoor environmental (thermal) conditions and outdoor microclimatic conditions in the immediate vicinity of traditional hammams in Egypt, Turkey, Morocco, Syria, and Algeria over a period of one year.

Moreover, short-term acoustical and lighting measurements were performed in a number of spaces. The monitoring results allow for an objective assessment of the actual performance of these buildings and evaluation of their strengths and weaknesses. Using data visualization and performance analysis, it is possible to identify those design-relevant parameters (such as space layout and zonal sequence, thermal mass distribution, envelope and apertures, indoor surface properties, energy systems) that contribute to (and explain) such strengths and weaknesses in view of the related health and comfort implications.

In addition to the evaluation and interpretation of indoor environmental conditions, the monitored data were also used to calibrate digital performance simulation models of the buildings studied. These calibrated models of the hammāms were applied to predict the consequences of alternative options for their renovation, restoration, reuse, and adaptation. Thus performance implications of the utilization of modern technologies and products, in the culturally and historically sensitive context of traditional bath buildings, can be carefully scrutinized before such interventions are actually carried out.

Approach

Buildings

Table 1 provides an overview of the selected buildings. Thermal measurements were performed in the following buildings: Bab el Bahr (BAB), Sengül (SEN), Saffarin (SAF), and Souq El Ghezal (SEG). Acoustical measurements were performed in the spaces of SAF, SEG, Ammuna (AMH), Bougouffa (BOU), and Belebdjaoui (BEL). Visual (lighting) measurements were performed in buildings BAB, SEN, SAF, AMH, and SEG. While each of these hammams has a distinct architectural layout (varying number and sequence of rooms), a number of similar room functions can be found in most hammāms. However, space naming conventions are different in various countries and in the pertinent literature. In the present paper we specifically deal with four recurrent kinds of spaces, namely: changing room (CH), cold room (CR), warm room (WR), and hot room (HR).

Hammām	Code	Location	Century	Floor Area
Bab el Bahr	BAB	Cairo, Egypt	19	190
Şengül	SEN	Ankara, Turkey	16	670
Saffarin	SAF	Fez, Morocco	14	380
Souq El Ghezal	SEG	Constantine, Algeria	18	200
Ammuna	AMH	Damascus, Syria	13	95
Bougouffa	BOU	Constantine, Algeria	18	80
Belebdjaoui	BEL	Constantine, Algeria	18	130

Table 1: Overview of the Selected Objects (name, code, location, century of origin, total net floor area). (Source: Authors).

Thermal Performance

We equipped the selected hammams with diagnostics equipment for long-term external and internal climate monitoring. Data loggers were installed in various rooms of the hammāms (see Figure 1). These recorded continuously (every five minutes) indoor air temperature, relative humidity, and illuminance. A weather station was installed in proximity of each hammām to monitor outdoor air temperature and relative humidity, global horizontal irradiance, and wind speed (Figure 2). Collected data was analyzed in view of the buildings' thermal performance, comfort

Figure 1: Installation of Internal Data Loggers in Hammāms of Cairo (left), Ankara (middle), and Fez (right). (Source: Authors).

Figure 2: Weather Stations for Hammāms in Cairo (left), Ankara (middle), and Fez (right). (Source: Authors).

conditions, transition between various spaces within the hammām, and the dependency of indoor climate on outdoor environmental parameters.

As mentioned earlier, simulation models of the selected objects have been generated that, upon calibration (based on measured data), allow for the examination of possible retrofit measures. Simulations are performed using a commercially available application (EDSL 2008). In the present paper, we consider a simulation model of the Cairo hammām that was generated using the building's geometry together with material assumptions based on authors' observations at the site. Model input assumptions regarding heating energy, internal gains (occupants, lighting, equipment), ventilation, and their respective schedules were based on a rough survey conducted by the local research partners and additional information collected during the site visit. 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. In the present paper we focused on three scenarios (see Table 2). The first scenario represents the existing conditions. The second scenario involves the improvement of the thermal insulation of the roof and parts of the external wall areas. Sceneario 3 involves, in addition, the use of double-glazing (instead of the existing single-glazing) for windows (changing room) and roof apertures (cold room, hot room). The U-values of the relevant building envelope components for the respective scenarios are summarized in Table 2.

	U-values assumptions (in W.m-2.K-1) for simulation scenarios		
	S1	S2	S3
Roof	1.76	0.2	0.2
Walls	1.13	0.22	0.22
Glazing	5.75	5.75	1.36

Table 2: U-value Assumptions of the Pertinent Building Components for Thermal Simulation Scenarios S1 to S3. (Source: Authors).

Room Acoustics

Frequency-dependent reverberation times were measured in the objects SEG, BEL, and BOU. Reverberation time measurements were conducted in empty (non-occupied) conditions. In addition, ambient sound levels were measured in AMH and SAF. During these measurements, the respective spaces were in use. It is important to note that the latter measurements were conducted on a short-term basis. Thus, they provide a snapshot of the prevailing ambient sound levels and are not representative in strict statistical terms.

Measured ambient sound levels and reverberation times were evaluated. Specifically, measured reverberation times were compared with pertinent target values. Toward this end, desirable ranges for the selected objects (space function, space size) were needed. This is, however, not trivial, as the use patterns of the spaces are, in this case, not clearly stated. On the one hand, speech intelligibility would be desirable, given the social (communication) function of such spaces. On the other hand, a certain impression of reverberant field in these spaces is naturally expected (given the volume and surface properties) and probably appreciated. Moreover, people sometimes sing in traditional hammāms. Given these considerations and upon consultation of pertinent literature (see, for example Fasold, 2003), target values were assumed for the selected object as 1.1 seconds for SEG and 1.0 second for BEL and BOU.

Simulation Condition	**Frequency [Hz]**					
	125	250	500	100	2000	4000
A1	0.03	0.03	0.03	0.04	0.05	0.05
A2	0.15	0.19	0.29	0.46	0.58	0.7
A3	0.64	0.87	0.84	0.62	0.47	0.5

Table 3: Absorption Coefficient Assumptions for the Acoustical Simulation Conditions A1 to A3. (Source: Authors).

Calibrated simulation models were also generated in the acoustical domain. Toward this end, reverberation times were simulated for three buildings (SEG, BEL, BOU). Simulations were performed using a commercially available room acoustical simulation and auralization tool (Christensen, 2005). The simulation input data assumptions concerning the absorption coefficient data for surface finishes were based on various sources of information available (architectural documentation, plan documentation, literature, simulation tool's database). Measured reverberation times were also compared with simulation results to determine the extent of simulation errors. To further investigate acoustical improvement possibilities (mainly the reduction of the reverberation times) using the calibrated simulation models, two different acoustical absorption measures were considered. Thereby the surface finish of a 20 m2 wall segment of the hot room (HR) in hammām BOU was modified in the simulation model. Table 3 shows the assumed absorption coefficients of this wall segment for the status quo (A1) and the two simulated modifications, involving a moisture-resistant acoustic plaster (A2) and a broad-band acoustical absorber system (A3).

Visual Aspects

During the site visits, spot measurements of horizontal illuminance levels and daylight factors in a number of rooms of some of the selected hammāms were performed. Horizontal illuminance was measured at a height of about 1 meter above the floor level.

Results

Thermal Conditions

Table 4 provides an overview of the hygro-thermal conditions in the selected objects based on monitoring period of approximately one year. It shows minimum, mean, and maximum monthly indoor and outdoor temperatures for objects BAB, SEN, SAF, and SEG, as well as indoor relative humidity values. Indoor parameters are given for changing room (CH), cold room (CR), warm room (WR), and hot room (HR).

As Table 4 suggests, indoor temperatures in hot room and warm room do not vary as much as those in changing room. Thus, Figures 3 to 6 focus on the thermal comfort conditions in the latter space. Thereby, hourly temperatures for four different months (January, March or April, July, and October) in changing rooms are plotted in psychometric charts. Note that these graphs also show the ranges of desired indoor temperatures in the respective months as implied by the adaptive thermal comfort theory (Szokolay, 2004).

To explore the thermal transition in the course of progression from one space of the hammām to another, Figures 7 to 10 show the mean monthly indoor temperatures (for four different months) in changing room, cold room and/or warm room, and hot room.

		[oC]	RH [%]				
		min	mean	max	min	mean	max
BAB	CH	20.9	26.5	31.2	47	61	76
	CR	20.8	27.3	32.2	94	99	100
	HR	28.6	32.1	36.9	100	100	100
	EX	12.9	24.4	34.8	24	49	75
SEN	CH	16.3	24.2	29.5	38	52	66
	WR	23.9	28.6	32.0	98	100	100
	HR	34.2	36.0	37.6	87	95	98
	EX	-1.2	14.6	33.8	16	49	88
SAF	CH	13.8	21.7	29.4	47	59	76
	CR	27.0	29.7	32.2	97	100	100
	WR	29.1	31.1	33.1	73	96	100
	HR	30.6	33.3	36.5	93	99	100
	EX	6.4	21.3	36.4	19	52	89
SEG	CH	13.5	19.2	28.0	53	76	94
	CR	15.9	20.3	28.0	93	97	100
	HR	32.9	35.4	38.3	95	99	100

Table 4: Minimum, Mean, and Maximum Measured Average Temperatures during Observation Period. (Source: Authors).

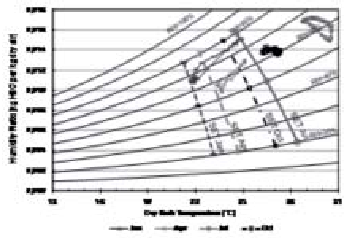


Figure 3: Depiction of indoor climate conditions in the changing room in BAB for July and October 2006, January and April 2007, compared to Standardized Effective Temperature SET for each month. (Source: Authors).

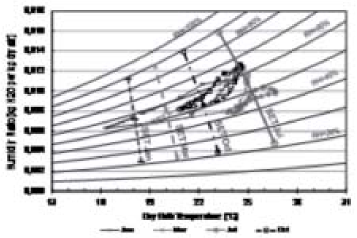


Figure 4: Depiction of the indoor climate conditions in the changing room in SEN for July and October 2006, January and March 2007, compared to Standardized Effective Temperature SET for each month (Source: Authors).

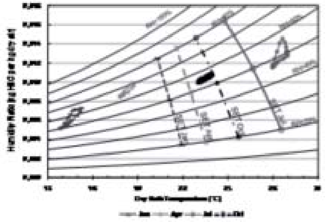


Figure 5: Depiction of the indoor climate conditions in the changing room in SAF for October 2006, January, April and July 2007, compared to Standardized Effective Temperature SET for each month. (Source: Authors).

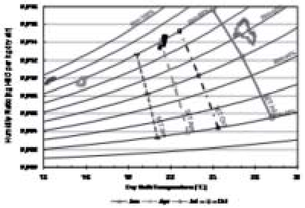


Figure 6: Depiction of the indoor climate conditions in the changing room in SEG for July and October 2007, January and April 2008, compared to Standardized Effective Temperature SET for each month. (Source: Authors).

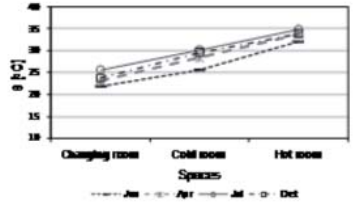


Figure 7: Temperature Transition between Spaces in BAB (mean monthly values during opening hours). (Source: Authors).

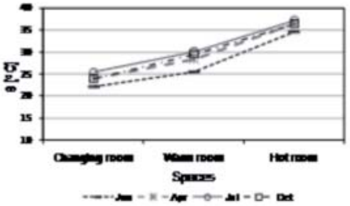


Figure 8: Temperature Transition between Spaces in SEN (mean monthly values during opening hours). (Source: Authors).

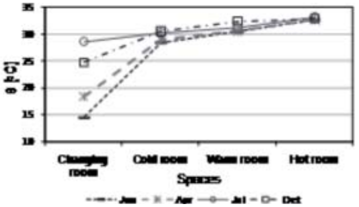


Figure 9: Temperature Transition between Spaces in SAF (mean monthly values during opening hours). (Source: Authors).

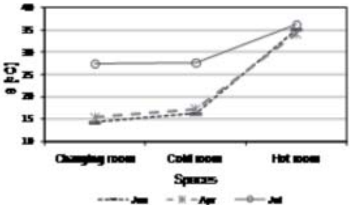


Figure 10: Temperature Transition between Spaces in SEG (mean monthly values during opening hours). (Source: Authors).

To compare the predictions of the calibrated simulation model with the measured values, Figure 11 depicts simulated and measured indoor air temperatures in two spaces in hammām BAB, namely changing room and hot room for a reference day in July. Note that this figure includes also the respective measured outdoor temperature values. Figure 12 shows a comparison of simulated space heating demand of hammām BAB for three different scenarios (see Table 2). The first scenario represents the existing conditions. The second scenario involves the improvement of the thermal insulation of the roof and parts of the external wall areas. Scenario 3 involves, in addition, the use of double-glazing (instead of the existing single-glazing) for windows (changing room) and roof apertures (cold room, hot room).

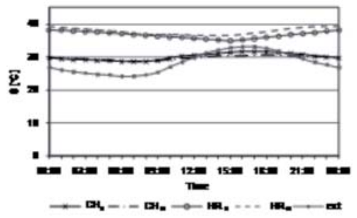


Figure 11: Simulated versus measured indoor air temperature in changing room and hot room of BAB for a reference day (mean hourly values, July 2006). (Source: Authors).

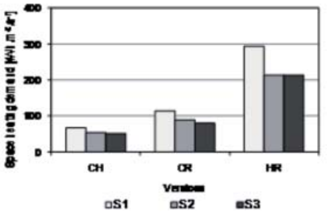


Figure 12: Simulated space heating demand (kWh.m-2.a-1) of BAB for scenarios S1 to S3. (Source: Authors).

Acoustical Conditions

Table 5 summarizes spot measurement results of the A-weighted overall ambient sound levels in the spaces changing room, warm room, and hot room in two hammāms.

	Ambient SOund Level (dB)		
	CH	W4	HR
SAF	64	74	82
AMH	61	57	52

Table 5: A-Weighted Ambient Sound Pressure Level in SAF and AMH. (Source: Authors).

Figure 13 illustrates the measured reverberation times in three objects (SEG, BEL, BOU). Figure 14 shows the comparison of simulated reverberation times in hot room of object BOU for three different conditions (see Table 3). The first condition represents the status quo. The second condition involves the treatment of parts of the wall surface with a humidity-resistant acoustic plaster. The third condition involves the treatment of the same wall surface area with an alternative (broad-band) acoustical absorber. The respective absorption coefficient values are shown in Table 3.

Visual Conditions

The results of horizontal illuminance measurements (in lx) in objects BAB, SEN, SAF, AMH, and SEG are shown in figures 15 to 18 and 20. Note that these results are of indicative character as they reflect the combined effect of daylight (at the time of the measurements) and electrical lighting (default operation mode). The results of daylight factor measurements (in %) in objects SEN and SEG are shown in Figures 16 and 19. Daylight factor denotes the measured ratio of indoor to outdoor horizontal illuminance in percentage.

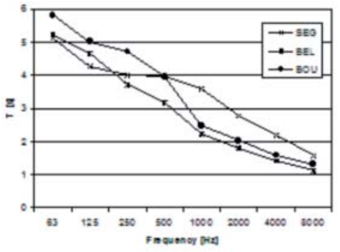


Figure 13: Measured Reverberation Times in SEG, BEL, BOU. (Source: Authors).

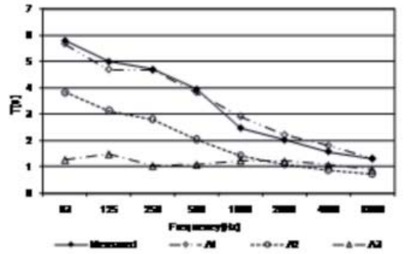


Figure 14: Simulated Reverberation Times in BOU with Improvements of Surfaces. (Source: Authors).

Figure 15: Measured Horizontal Illuminance Levels (expressed in lx) in Various Spaces of a Hammam in Cairo March 2006 11:50. (Source: Authors).

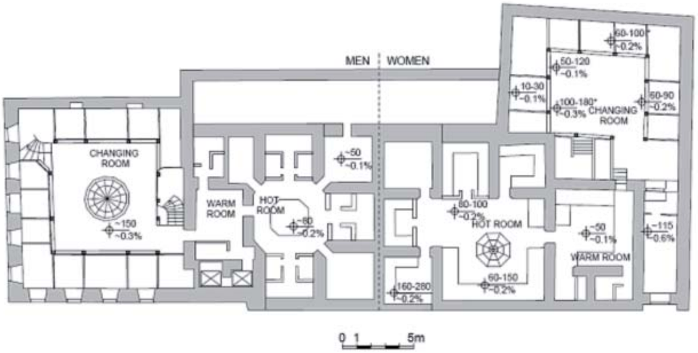
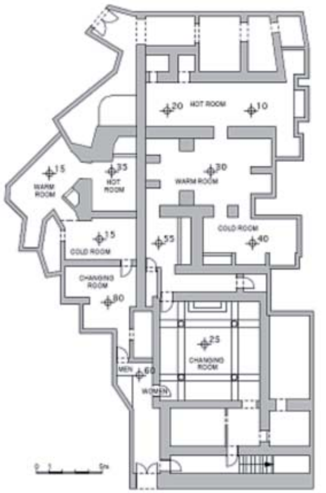
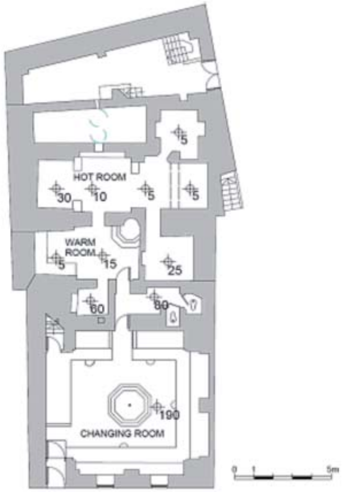


Figure. 16: Results of Horizontal Illuminance Measurements (lx) and Daylight Factors (%) in Hammām Sengül July 2006. (Source: Authors).



17.



18.

Figure. 17: Results of Horizontal Illuminance Measurements in Hammām Saffarin November 2006 9:00 (in lx). (Source: Authors).

Figure 18: Results of Horizontal Illuminance Measurements in Hammām Ammuna February 2007 10:30 (in lx). (Source: Authors).

19.

20.

Figure 19: Results of Daylight Factor Measurements in Hammām Suq El-Ghezal May 2007 7:30 (in %). (Source: Authors).

Figure 20: Results of Horizontal illuminance Measurements (daylight and electrical light) in Hammām Suq El-Ghezal May 2007 7:30 (in lx). (Source: Authors).


21.


22.

Figure 21: Deterioration of Daylight and Fresh Air Supply to the Interior Spaces of a Hammām in Fez (Morocco) due to the blockage of roof apertures. (Source: Authors).

Figure 22: Electrical Lighting in the Changing Room in Hammām in Cairo (Egypt). (Source: Authors).

Discussion

Thermal Issues

Our results display a wide range of hygro-thermal conditions in hammām spaces over the course of the observation period. They clearly demonstrate, thus, that a reliable evaluation of indoor conditions in such buildings 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.

Hot rooms in all observed hammāms provide a fairly stable and appropriate temperature range throughout the year (see Table 4). Changing rooms and – to a lesser degree – cold rooms, however, display at times temperature ranges that would not be thermally appropriate for lightly clothed users. Specifically, cold rooms of the objects BAB and SEG are not heated. Likewise, the changing room is heated only in SEN and – minimally – in BAB. Figures 3 to 6 were generated to further explore the widely fluctuating temperature ranges (and the thermal comfort ramifications) in the changing rooms of the hammāms. These figures imply a relative good match between existing and desirable indoor conditions in BAB and SEN. Thermal conditions in changing room SAF and SEG are, however, problematic, especially during the winter period, when they remain unheated.

Gradual temperature progression (i.e., increasing ambient temperature as one moves from changing room to hot room) in spaces of hammām has been regarded as an important feature of the thermal environment in these buildings. Consequentially, we examined our monitored data to see if, and to which extent, such transition is evident. We found clear evidence for such transition in the hammāms BAB and SEN (see Figures 7 and 8). In SAF (see Figure 9), a gradual transition can be observed only within a rather narrow thermal range: the major temperature gradient exists between the changing room and the heated spaces. A real transitional pattern is de facto absent in SEG (see Figure 10), as no noteworthy difference in temperature between the changing room and the cold room can be observed.

Illustrative instances of thermal performance improvement possibilities are shown in Table 2. According to simulation results, better insulated roof and walls lead to a lower space heating demand (particularly in hot rooms). Improvement of glazing does not influence the energy demand of hot room and leads only to minute demand reduction in cold room and changing room.

Acoustical Issues

The spaces studied make a predominantly reverberant and – when occupied – loud impression. The measured reverberation times are drastically longer than assumed target values (particularly in the lower frequency range), as mentioned in section 2.3. Note that this conclusion is valid despite the fact that the reverberation time measurements were conducted in empty conditions: the sound absorption effect of unclothed occupants is rather small. The perception of loudness is corroborated by the snapshot measurements of ambient sound levels (see Table 5).

Acoustically hard room enclosure surfaces and relatively large (sparsely furnished) volumes represent the main reasons for these conditions. Smooth and hard surfaces have been naturally applied in highly humid spaces as they can withstand water and moisture impact and are relatively easy to cleanse. However, they typically possess low absorption coefficients and are thus highly reflective acoustically. Even though special types of acoustically more effective plasters can increase the absorption (see, for example, case A2 in Table 3 and Figure 14), the overall result may still not be satisfactory, if the absorption effectiveness is not broadband and occurs only selectively for certain – in this case higher – frequencies. The application of a broad-band absorber system (see Table 3, case A3) has a better potential to provide acoustically preferable conditions (see Figure 14).

Visual Issues

Our illuminance and daylight factor measurement results imply rather low light levels in the selected objects (see Figures 15 to 20). It has been argued, that mild and dampened light levels are an intrinsic feature of indoor spaces in hammāms and are to provide a welcome contrast to the typically harsch outdoor lighting circumstances in many countries were hammāms were constructed. However, some of the currently prevailing low daylight levels do not seem to be the result of original design intentions. In fact, our observations revealed that in some hammāms the original roof apertures (openings) for daylight were occasionally blocked ex post facto. This means that in some hammāms the originally planned daylight penetration (and in certain cases the ventilation possibility) were compromised later on (see, for example, Figure 21, for a view of the HR of a hammām in Fez (Morocco) with almost entirely blocked daylight apertures). The addition of the "modern" electrical lighting components – necessary for the night operation of the hammām – are in all objects we studied neither sensitive architecturally, nor appropripate from the illuminating engineering point of view (see, as an example, Figure 22 with the view of CH in hammām BAB).

Conclusion

There is a concern that traditional hammām buildings in the Islamic countries are in decline. To explore the possibilities for sensible conservation of these buildings and their continued use in terms of their original functionality requires careful study of the status quo and analysis of appropriate preservation and renovation measures.

In this context, the present contribution provided a summary of monitoring results pertaining to the thermal, acoustical, and visual conditions in a number of traditional hammams.

Hygro-thermal conditions in hammāms vary considerably over time and space, implying the importance of long-term measurements. We established that hot rooms in all observed hammāms provide fairly stable and appropriate thermal conditions, where as changing rooms and cold or warm rooms could be at times (particularly in the winter period) thermally uncomfortable. An evidence for the existence of a kind of thermal progression (sequence) could be found in most – but not all hammāms.

From the acoustical point of view, a certain level of reverberation is both appropriate and expected from traditional hammāms, providing them with a characteristic perceptual “feeling” of the spaces. However, the hammām spaces we studied may be said to offer too much of a good thing in this regard: They make a predominantly reverberant and, in part, overly loud impression due to the abundance of hard room enclosure surfaces and the rather sparse furnishing. Such conditions are the result of construction requirements in highly humid spaces. Building elements must withstand water and moisture impact and should be relatively easy to cleanse.

Visual conditions in some hammāms we studied are sub-par, both due to ungainly interventions in the workings of the original daylight apertures and due to deficient “modern” electrical lighting devices.

In addition to analyzing the measurements, we also explored the potential of the application of digital performance simulation models toward the evaluation of possible thermal and acoustical retrofit measures. We demonstrated that the measured data could be used to calibrate such digital simulation models in order to increase the reliability of their predictions. Specifically, we illustrated the application of a calibrated simulation model of the Cairo hammām (BAB) to evaluate the energy implications of thermally improving the building’s envelope. Likewise, we used a calibrated acoustical model of Bougouffa hammām (BOU) to simulate the effect of acoustically more effective plasters on the reverberation times. Future efforts will involve a consistent use of such calibrated simulation models toward the comparative evaluation and optimization of proposals for the improvement and renovation of traditional hammām buildings.

Acknowledgements

This research is supported, in part, by a European Union grant; project: “Hammām, 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.. pp. 195 – 225.

Christensen C. L. 2005. ODEON Room Acoustics Program. Version 8.0. User manual. Industrial, Auditorium and Combined Editions.

EDSL (2008). A-TAS Version 8.5. Environmental Design Solutions Limited. www.edsl.net.

Fasold W. and Veres E. 2003. Schallschutz und Raumakustik in der Praxis. HUSS-MEDIEN GmbH Berlin, Verlag Bauwesen, Berlin Germany.

HAMMAM 2008. http://www.hammams.org.

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

Szokolay S.V. (2004). Introduction to Architectural Science the basis of sustainable design. Architectural Press. Oxford, United Kingdom.

Ardeshir Mahdavi

Professor Dr. A. Mahdavi is the director of the Department of Building Physics and Building Ecology at the Vienna University of Technology in Austria. His research activities cover a wide spectrum of work in building science, including building physics, computational building performance simulation, building automation, building ecology, human ecology, and sustainable architectural design. Professor Mahdavi has acted as the PI of a large number of national and international scientific research projects. He is a frequent keynote speaker at international scientific conferences and has authored over 400 publications in scientific conference proceedings and journals. In the years 2006 and 2007, Professor Mahdavi has been consecutively awarded the “Austrian Building Award” in the research projects category.

Kristina Orehounig

Kristina Orehounig is University Assistant at the Department of Building Physics and Building Ecology at the Vienna University of Technology in Austria and holds a Master degree in Architecture. Currently she is writing on her Ph.D. thesis concerning scientific analysis and evaluation of the traditional (environmentally adapted) Architecture. In the year 2007 Ms Orehounig received the Archdiploma Award for her Master thesis regarding cooling methods in office buildings. Ms Orehounig has also received “Austrian Building Award 2006” in the diploma thesis category. Her research interests include building physics, computational building performance simulation, and passive architecture.