# 187: Assessment and evaluation of the thermal and acoustical conditions in traditional bath buildings

**Ardeshir Mahdavi, Kristina Orehounig, Belinda Kainrath**

*Department of Building Physics and Building Ecology, Vienna University of Technology, Vienna, Austria*
*amahdavi@tuwien.ac.at*

**Abstract**

This paper presents the results of a number of case studies concerning the thermal and acoustical behavior of traditional Islamic bath buildings (hammams). Within the framework of a long-term monitoring effort, we collected data on indoor environmental conditions and outdoor microclimatic conditions pertaining to hammams in Egypt, Turkey, Morocco, Syria, and Algeria. Moreover, short-term acoustical measurements were performed in a number of these objects. 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 in view of the related health and comfort implications.

Keywords: Traditional architecture, hammams, indoor climate, diagnostics, simulation

## 1. 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 [1, 2, 3].

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 institution of Islamic hammam (bath) buildings. Within the framework of an EU-supported research project [4], we collected data on indoor environmental (thermal) conditions in (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 measurements were performed in a number of objects. 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 evaluation and interpretation of indoor environmental conditions, the monitored data were also used to calibrate digital performance simulation models of the objects studied. These calibrated models of the hammams 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.

## 2. Approach

### 2.1 Objects

Table 1 provides an overview of the selected objects. The thermal study was conducted in objects BAB, SEN, SAF, and SEG. The acoustical study was performed in objects SAF, SEG, AMH, BOU, and BEL. While each hammam has a distinct architectural layout (varying number and sequence of rooms) certain room types can be found in most hammams. However, space naming conventions are different in various countries and in the pertinent literature. In the present paper we refer to these as changing room (CH), cold room (CR), warm room (WR), and hot room (HR).

### 2.2 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 hammams.

These recorded continuously (every five minutes) indoor air temperature, relative humidity, and illuminance. A weather station was installed in proximity of each hammam to monitor outdoor air temperature and relative humidity, global horizontal irradiance, and wind speed.

Collected data are being analyzed in view of the buildings' thermal performance, comfort conditions, transition between various spaces within the hammam 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 [5]. In the present paper, we consider a simulation model of the Cairo hammam 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.

Table 1: Overview of the selected objects (name, code, location, century of origin, total net floor area)

| **Hammam** | **Code** | **Location** | **Cent.** | **Floor area [m²]** |
|---|---|---|---|---|
| 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 |
| Ammouneh | AMH | Damascus, Syria | 13 | 95 |
| Bougouffa | BOU | Constantine, Algeria | 18 | 80 |
| Belebdjaoui | BEL | Constantine, Algeria | 18 | 130 |

### 2.3 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. 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.

Reverberation times were simulated for three buildings (SEG, BEL, BOU). Simulations were performed using a commercially available room acoustical simulation and auralization tool [6].

The 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 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 hammams. Given these considerations and upon consultation of pertinent literature (see, for example [7]), target values were assumed for the selected object as 1.1 seconds for SEG and 1.0 second for BEL and BOU. Measured reverberation times were also compared with simulation results to determine the extent of simulation errors.

## 3. Results

### 3.1 Thermal conditions

Table 2 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 2 suggests, indoor temperatures in hot room and warm room do not vary as much as those in changing room. Thus, Figures 1 to 4 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 [8].

To explore the thermal transition in the course of progression from one space of the hammam to another, Figures 5 to 8 show the mean monthly indoor temperatures (for four different months) in changing room, cold room and/or warm room, and hot room.

Table 2: Min, mean, and max measured average temperatures over observation period.

| | | θ [°C] | | | 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 |
| | **EX** | - | - | - | - | - | - |

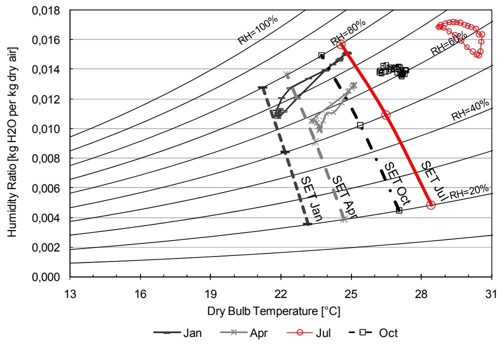


*Fig 1. Depiction of indoor climate conditions in the changing room in BAB for July and October 2006, January and April 2007, compared to Standardized Effective Temperature SET for each month*

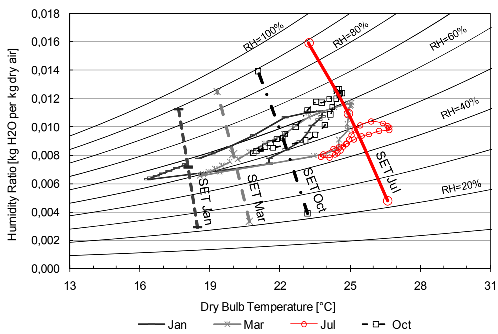


*Fig 2. Depiction of the indoor climate conditions in the changing room in SEN for July and October 2006, January and March 2007, compared to Standardized Effective Temperature SET for each month*

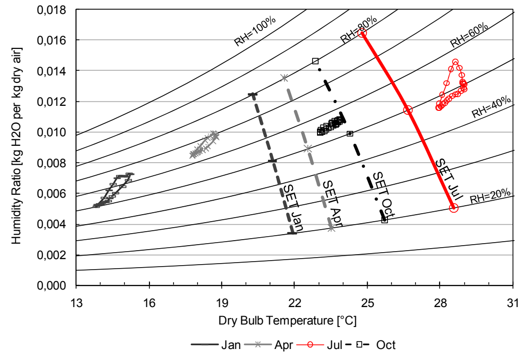


*Fig 3. Depiction of the indoor climate conditions in the changing room in SAF for October 2006, January, April and July 2007, compared to Standardized Effective Temperature SET for each month*

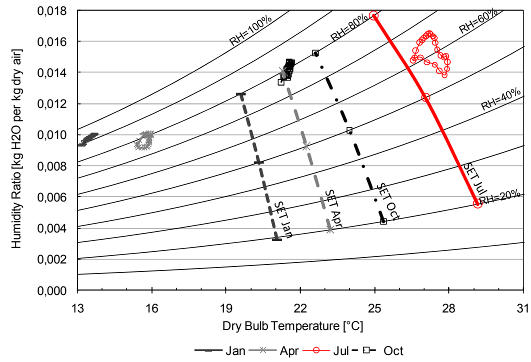


*Fig 4. Depiction of the indoor climate conditions in the changing room in SEG for July and October 2007, January and April 2008, compared to Standardized Effective Temperature SET for each month*

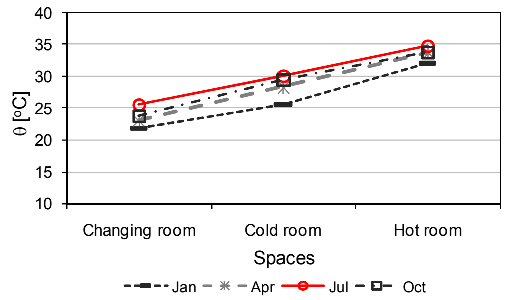


*Fig 5. Temperature transition between spaces in BAB (mean monthly values during opening hours)*

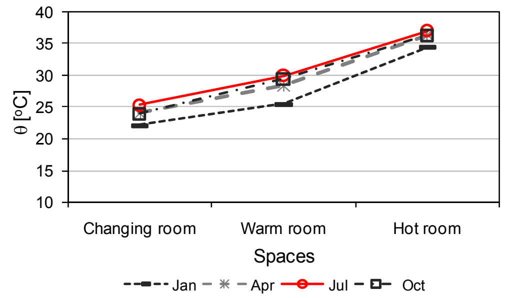


*Fig 6. Temperature transition between spaces in SEN (mean monthly values during opening hours)*

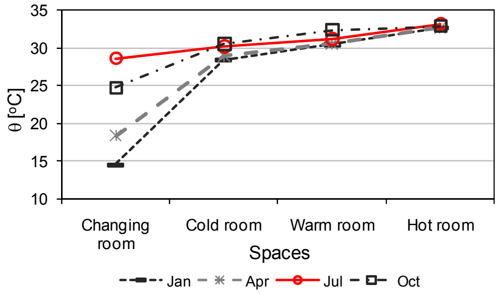


*Fig 7. Temperature transition between spaces in SAF (mean monthly values during opening hours)*

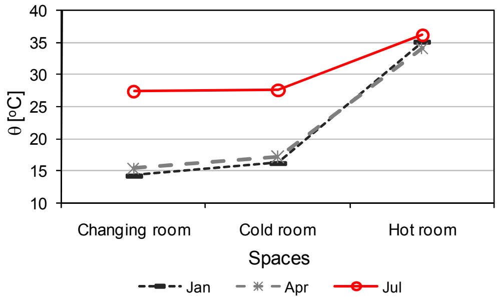


*Fig 8. Temperature transition between spaces in SEG (mean monthly values during opening hours)*

To compare the predictions of the calibrated simulation model with the measured values, Figure 9 depicts simulated and measured indoor air temperatures in two spaces in Hammam 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 10 shows a comparison of simulated space heating demand of Hammam BAB for three different scenarios (see Table 3). 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).

Table 3: U-value assumptions of the pertinent building components for thermal simulation scenearios S1 to S3

| | U-values assumptions (in $W.m^{-2}.K^{-1}$) for simulation scenarios (see Figure 10) | | |
|---|---|---|---|
| | **S1** | **S2** | **S3** |
| **Roof** | 1.76 | 0.2 | 0.2 |
| **Walls** | 1.13 | 0.22 | 0.22 |
| **Glazing** | 5.75 | 5.75 | 1.36 |

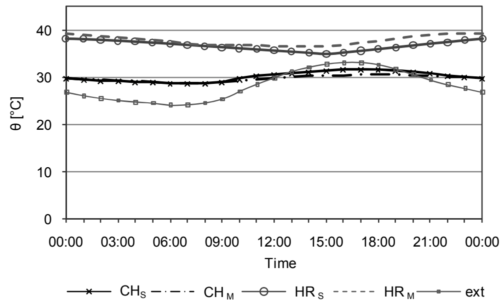


*Fig 9. Simulated versus measured indoor air temperature in changing room and hot room of BAB for a reference day (mean hourly values, July 2006 )*

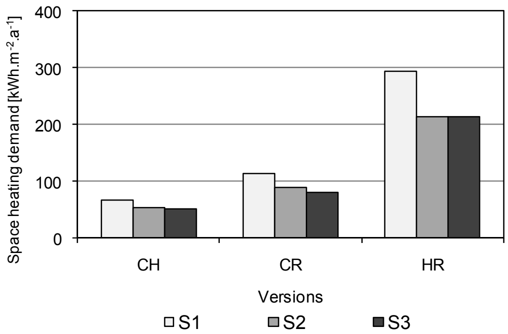


*Fig 10. Simulated space heating demand ($kWh \cdot m^{-2} \cdot a^{-1}$) of BAB for scenarios S1 to S3*

### 3.2 Acoustical Observations

Table 4 summarizes spot measurement results of the A-weighted overall ambient sound levels in the spaces changing room, warm room, and hot room in two hammams.

Table 4: A-weighted ambient sound pressure level in SAF and AMH

| | Ambient sound level [dB] | | |
|---|---|---|---|
| | **CH** | **WR** | **HR** |
| **SAF** | 64 | 74 | 82 |
| **AMH** | 61 | 57 | 59 |

Figure 11 illustrates the measured reverberation times in three objects (SEG, BEL, BOU).

Figure 12 shows the comparison of simulated reverberation times in hot room of object BOU for three different conditions (see Table 5). 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 5.

Table 5: Absorption coefficient assumptions for the acoustical simulation conditions C1 to C3

| Simulation condition | Frequency [Hz] | | | | | |
|---|---|---|---|---|---|---|
| | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| **C1** | 0.03 | 0.03 | 0.03 | 0.04 | 0.05 | 0.05 |
| **C2** | 0.15 | 0.19 | 0.29 | 0.46 | 0.58 | 0.7 |
| **C3** | 0.64 | 0.87 | 0.84 | 0.62 | 0.47 | 0.5 |

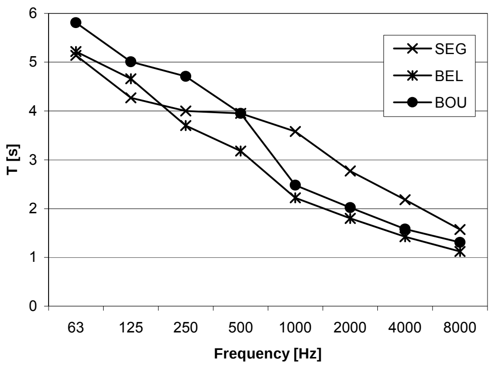


*Fig 11. Measured reverberation times in SEG, BEL, BOU*

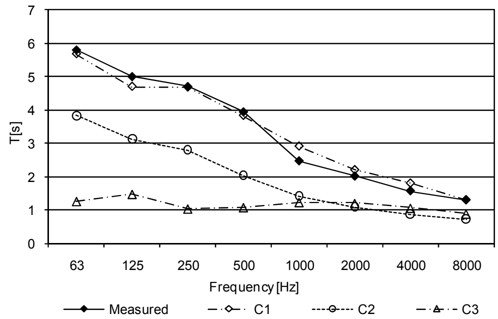


*Fig 12. Simulated reverberation times in BOU with improvements of surfaces*

## 4. Discussion

### 4.1 Thermal issues

Our results display a wide range of hygro-thermal conditions in hammam 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 hammams provide a fairly stable and appropriate temperature range throughout the year (see Table 2). 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 1 to 4 were generated to further explore the widely fluctuating temperature ranges (and the thermal comfort ramifications) in the changing rooms of the hammams. 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 hammams 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 Hammams BAB and SEN (see Figures 5 and 6). In SAF (see Figure 7), 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 8), 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 3. 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.

### 4.2 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). 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 4).

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 C2 in Table 5 and Figure 12), 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 5, case C3) has a better potential to provide acoustically preferable conditions (see Figure 12).

## 5. Conclusion

There is a concern that traditional hammam 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 and acoustical conditions in traditional hammams in Cairo (Egypt), Ankara (Turkey), Fez (Morocco), and Constantine (Algeria).

Hygro-thermal conditions in hammams vary considerably over time and space, implying the importance of long-term measurements. We established that hot rooms in all observed hammams 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 hammams.

From the acoustical point of view, a certain level of reverberation is both appropriate and expected from traditional hammams, providing them with a characteristic perceptual "feeling" of the spaces. However, the hammam 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.

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 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 hammam to evaluate the energy implications of thermally improving the building's envelope. Likewise, we used a calibrated acoustical model of Bougouffa hammam 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 hammam buildings.

## 6. Acknowledgements

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