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Energy and Thermal Performance of Hammams

About this chapter

This contribution describes a recent research effort to collect and analyse data concerning traditional bath buildings (›hammams‹) in Egypt, Turkey, Morocco, Syria, and Algeria. Thereby, the energy performance of and the thermal comfort conditions in five hammams were studied. Moreover, empirically calibrated building performance simulation models were generated in order to predict the consequences of alternative thermal retrofit measures. The results provide the opportunity for an objective assessment of hammams' actual energy and indoor environmental performance.

Keywords: energy performance, thermal comfort, traditional bath buildings, calibrated building performance simulation models, retrofit measures

1. Introduction

1.1. Background

The early Islamic hammams consisted of a relatively large changing room and three successive bathing chambers, the latter two of which were heated. The designated room sequence was derived from the roman baths consisting of the apodyterium (changing room), the frigidarium (room with cold water pool), the tepidarium (room with warm water pool), the caldarium (room with hot water pool), and the sudatorium (sweating room) (Grotzfeld 1970). The main constructive components of hammam buildings are rather massive and are either made of stone (Limestone, Sandstone, or Rubble stone) or brick. Vaults and domes are usually built with brick. Frequently, lime was used for surface finish as well as for mortar in the constructions (Orehounig 2009). In some regions (e.g., Egypt, Algeria), wood is also applied in the construction of changing rooms (especially the roof structures). Floors are typically tiled by marble, stone or ceramic tiles and, in the changing rooms, sometimes additionally covered by carpets. Hammams generally use the same method to bring daylight into the heated spaces. Numerous round, octagonal or stellar shaped apertures are built into the dome overhead. Warm and hot rooms are usually heated by a hypocaust system, already used at roman times. Hypocausts are floor heating systems where the hot smoke from the furnace passes under the raised floor in hot and warm room before rising up through chimneys in the walls. Hot rooms are additionally tempered due to hot water usage.

1.2. Motivation

An increasing number of traditional bath buildings (›hammams‹) in the Mediterranean region (Dow 1996) either gradually dilapidate, or are preserved with altered functionality (e.g. museum, restaurant, performance space). It has been argued that these buildings should not only be preserved because of their historical value, but also should continue to play the role that they have traditionally played as a kind of health, ›wellness‹, and communication centre in the Islamic countries. A recent EU-supported research effort focused on the collection and analysis of data regarding hammams in Egypt, Turkey, Morocco, Syria, and Algeria (HAMMAM project 2008). Thereby, buildings' energy performance, thermal comfort conditions, and the dependency of indoor climate on outdoor environmental parameters were studied. Moreover, empirically calibrated building performance simulation models of a number of buildings were generated in order to predict the consequences of alternative thermal retrofit measures.

2. Approach

2.1. Overview

The present contribution reports on five hammams located in Egypt, Turkey, Morocco, Algeria, and Syria, for which data pertaining to energy use and thermal conditions were collected over a period of approximately one year. Moreover, building performance simulation models were generated based on collected information, and further used to test various thermal improvement options via parametric simulation runs.

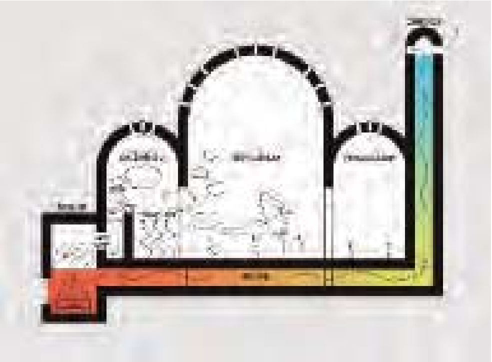

Field work

2.2. Selected buildings

The five selected buildings vary in terms of location and construction period ranging from 13th century in Syria up to 19th century in Egypt. Table 1 summarizes general information such as area of the spaces, mean outside and inside temperatures, as well as information regarding visitor numbers and water use. Note that particularly the latter two sets of data must be regarded only as order of magnitude information, given the uncertainty involved in their collection (specifically lack of consistent metering and logs). In this contribution, we use certain abbreviations to denote distinct spaces within a hammam, namely CH (changing room), CR (cold room), WR (warm room), and HR (hot room).

Name	**Bab el Bahr**	**Şengül**	**Saffarin**	**Ammouneh**	**Suqal Ghazal**
Code	BAB	SEN	SAF	AMH	SAG
Location	Cairo Egypt	Ankara Turkey	Fez Morocco	Damascus Syria	Constantine Algeria
Century	19th	16th	14th	13th	18th
CH area [m²]	92.7	266	121	62	77.5
CR area [m²]	24.8	—	71.8	6.8	30.0
WR area [m²]	—	73.1	72.2	17.3	—
HR area [m²]	78.4	202.3	65.2	34.3	78.7
Total area [m²]	195.9	541.4	330.2	120.4	186.2
$\theta_{e,m}$ [°C]	22.2	11.3	17.7	17.4	15.7
$\theta_{i,m}$ [°C]	29.6	28.2	28.3	—	24.0
Visitors per day	80	84	120	27	21
Annual water use [m³]	4 400	21 700	12 300	3 100	900

Table 1. Overview of the selected objects (name, code, general information, floor areas of different rooms, average outdoor $\theta_{e,m}$ and indoor $\theta_{i,m}$ temperatures, visitors per day, and annual water consumption)



Scheme of a hypocaust

2.3. Indoor environmental data

Indoor climate parameters were measured in various rooms of the hammams over a period of one year. Each building was equipped with seven to twelve data loggers for regular measurements of air temperature, relative humidity, and illuminance. Additionally, we installed close to each hammam a weather station to collect detailed information regarding microclimatic conditions.

2.4. Energy use

Information regarding the current energy performance of the hammam buildings was collected by Nigel Mortimer and Garry Jenkins (HAMMAM project 2006a, 2006b, 2007a, 2007b, 2007c). It is based on on-site energy surveys, interviews with the staff, and readings from electricity and water meters. Regarding water and space heating system (boiler, storage tank and pipework for water heating, and hypocaust and chimneys for space heating) additional information regarding temperatures of the furnace walls, flue gas emerging from the hypocaust vents, and supply water was collected. Given the uncertainty associated with the short-term nature of such surveys as well as the limited reliability of metering information, the collected energy use data provides order of magnitude information rather than precise values.

2.5. Simulation study

Simulation calibration

The monitored indoor climate data was also used to calibrate digital performance simulation models of three buildings, namely BAB, SEN, and SAG. Initial simulation models were generated based on collected geometry and construction data. Assumptions were made based on in-situ observations and historical documents. Simulation assumptions regarding construction data are summarized in Table 2. Assumptions regarding opening and cleaning hours and detailed occupancy information were based on logs generated by the local partners in the aforementioned EU project. Additional collected information pertained to water use, energy use for lighting and heating, as well as water supply temperatures and floor surface temperatures. Heating load assumptions for the simulation models were estimated based on the aforementioned energy use data. To run the simulations, weather files were generated based on data obtained from the locally installed weather stations.

Building	**Component**	**Materials**	**U-value [$W.m^{-2}.K^{-1}$]**	**m [$kg.m^{-2}$]**
BAB	Roof HR	Brick, rubble stones with lime mortar	1.8	315
	Walls	Brick, rubble stones with lime mortar	1.1	750
	Floor	Marble and limestone slabs	1.6	317
	Glazing	—	5.8	—
SEN	Roof CH	Timber, roof tiles	0.6	128
	Roof HR	Reinforced concrete	1.8	1100
	Walls	Rubble stone	0.8	1620
	Floor CH	Marble on compressed earth	1.3	2370
	Floor HR	Marble on stone	0.8	3670
	Glazing	—	5.6	—
SAG	Roof CH	Limestone mortar, brick, wood, and tiles	0.4	582
	Roof HR	Limestone mortar, brick, cement mortar	2.2	409
	Walls CH	Limestone with mortar	1.0	1800
	Walls HR	Limestone with mortar	0.8	2400
	Floor CH	Tiles, limestone and soil	0.7	1560
	Floor HR	Marble, limestone and soil	0.7	2490
	Glazing	—	5.6	—

Table 2. Simulation assumptions regarding construction data (materials, thermal transmittance and surface density of building components)

Retrofit options

The calibrated simulation models were used to assess the thermal improvement possibilities of three hammams (BAB, SEN, and SAG). Toward this end, a set of five simple scenarios were established for a parametric study (see Table 3). The first scenario (S1) represents the existing conditions. As the air change rates in this case appear to be insufficient (as corroborated by spot measurements of CO_2 concentration levels), a second scenario (S2) was defined involving an increased air change level of 0.5 h^{-1}, which – given the occupancy density and room volumes – would provide for the hygienically necessary ventilation rate. The remaining scenarios (S3 to S5) take this higher ventilation rate into account. The third scenario (S3) involves the improvement of the thermal insulation of the roof construction. Scenario 4 (S4) involves the improvement of the thermal insulation of external walls. The fifth scenario (S5) involves the use of double-glazing (instead of the existing single-glazing) for the buildings' windows (CH) and roof apertures (CR, WR, and HR). The respective U-value and g-value assumptions (for roof, walls and glazing) in these scenarios are summarized in Table 3.

		Roof	**Wall**	**Glazing**	
Building	**Scenario**	**U [$W.m^{-2}.K^{-1}$]**	**U [$W.m^{-2}.K^{-1}$]**	**U [$W.m^{-2}.K^{-1}$]**	**g**
BAB	S1	1.80	1.1	5.80	0.54
	S2	1.80	1.1	5.80	0.54
	S3	0.28	1.1	5.80	0.54
	S4	1.80	0.6	5.80	0.54
	S5	1.80	1.1	1.36	0.41
SEN	S1	1.21	0.8	5.60	0.69
	S2	1.21	0.8	5.60	0.69
	S3	0.19	0.8	5.60	0.69
	S4	1.21	0.4	5.60	0.69
	S5	1.21	0.8	1.36	0.40
SAG	S1	1.39	1.4	5.60	0.40
	S2	1.39	1.4	5.60	0.40
	S3	0.20	1.4	5.60	0.40
	S4	1.39	1.2	5.60	0.40
	S5	1.39	1.4	1.36	0.41

Table 3. Description of the simulation scenarios (S1 to S5) with associated U-value and g-value assumptions regarding the pertinent building components

Simulation-based inquiry into massive versus lighter construction types

Plans for new bath buildings deviate – mostly due to cost and space saving considerations – from the highly massive construction styles of traditional hammams. It was thus of interest to consider the implications of a rather low-mass construction style for the thermal performance. Note that in the absence of compensatory insulation, such low-mass construction results also in a higher U-value. To explore this difference, we used simulation to compare the performance of the existing buildings with virtual counterparts that would resemble them in all aspects other than the high thermal mass and the thermal conductivity value. Thereby simulation runs were performed to obtain annual heating loads for all spaces. The respective sets for the simulation assumptions regarding air change rates, internal gains, and heating set points are summarized in Table 4.

	Opening hours			Closing hours		
	CH	**CR/WR**	**HR**	**CH**	**CR/WR**	**HR**
AHC	0.5	0.5	0.5	0.3	0.3	0.3
Internal gains	10	10	10	0	0	0
Heating setpoint	25	30	35	15	20	25

Table 4. Assumptions pertaining to air change rates (ACH in h^{-1}), internal gains ($W.m^{-2}$), and heating set point (°C) for the study of thermal mass impact on the hammams' heating loads

3. Results

3.1. Indoor environment

Figures 1 to 5 provide an overview of the thermal conditions in the selected objects based on a monitoring period of approximately one year. It shows the cumulative temperatures during opening hours for objects BAB, SEN, SAF, AMH, and SAG. Indoor air temperatures are given for changing room (CH), cold room (CR), warm room (WR), and hot room (HR). To further explore the thermal comfort conditions in the changing rooms, psychometric charts (Figures 6 to 9) were generated with temperature and relative humidity information for four months (January, March or April, July, and October). These charts also include SET lines (Standardized Effective Temperature), which denote, according to the adaptive thermal comfort theory (Szokolay 2004), desirable indoor conditions for the corresponding time of the year and applicable activity and clothing assumptions.

To explore the thermal transition in the course of progression from one space of the hammam to another, Figures 10 to 13 show the mean monthly indoor temperatures (for four different months) in changing room, cold room and/or warm room, and hot room.

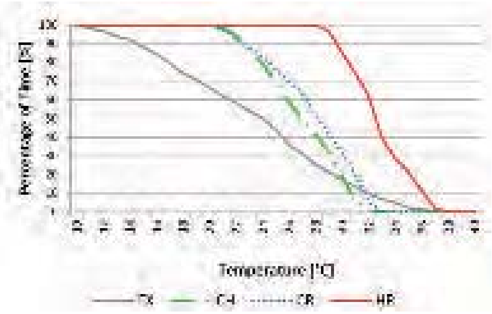


Figure 1. Cumulative Indoor Temperatures in CH, CR, and HR (BAB, April 2006 to March 2007)

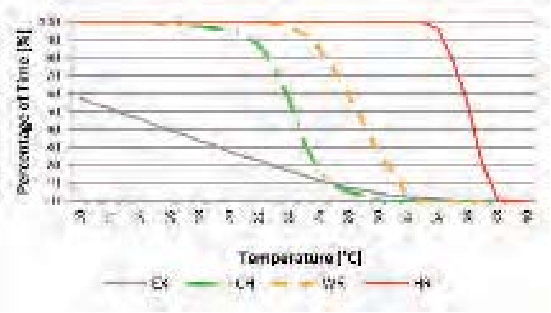


Figure 2. Cumulative Indoor Temperatures in CH, WR, and HR (SEN women section, July 2006 to June 2007)

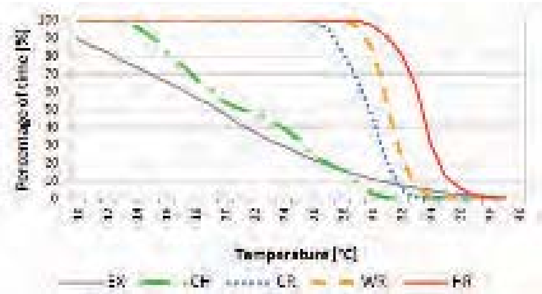


Figure 3. Cumulative Indoor Temperatures in CH, CR, WR, and HR (SAF women section, October 2006 to September 2007)

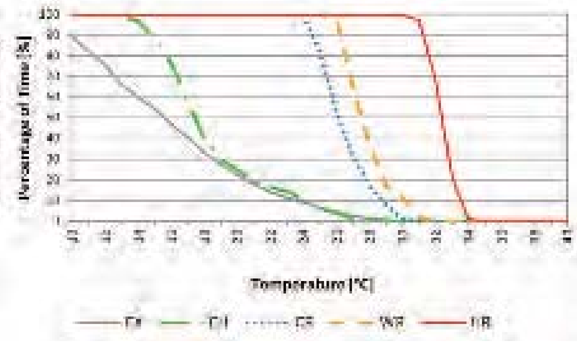


Figure 4. Cumulative Indoor Temperatures in CH, CR, WR, and HR (AMH, February 2007 to May 2007)

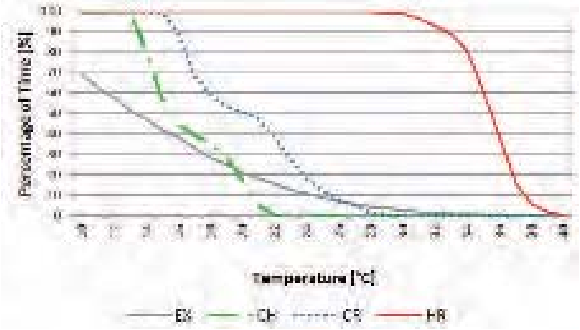


Figure 5. Cumulative Indoor Temperatures in CH, CR, and HR (SAG, July 2007 to June 2008)

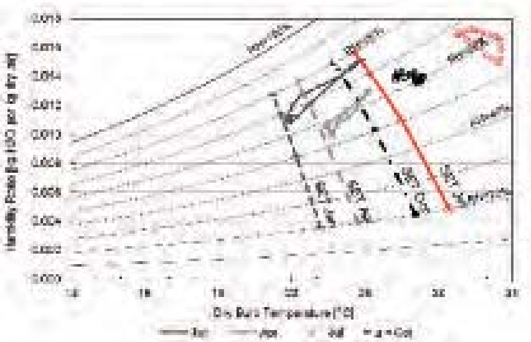


Figure 6. Indoor climate conditions in CH in BAB for July and October 2006, January and April 2007.

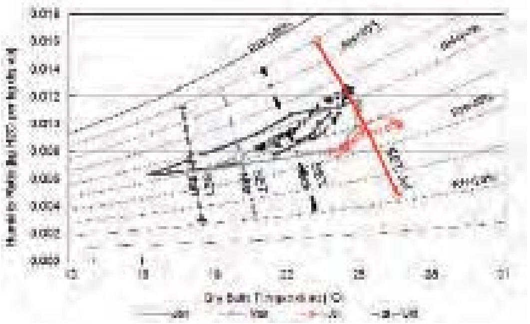


Figure 7. Indoor climate conditions in CH in SEN for July and October 2006, January and March 2007.

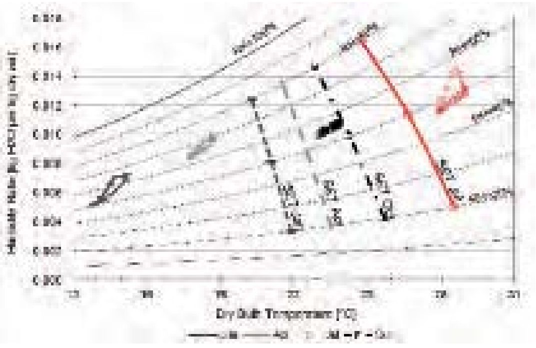


Figure 8. Indoor climate conditions in CH in SAF for October 2006, January, April and July 2007.

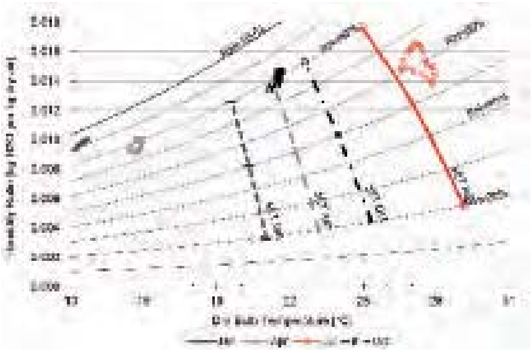


Figure 9. Indoor climate conditions in CH in SAG for July and October 2007, January and April 2008.

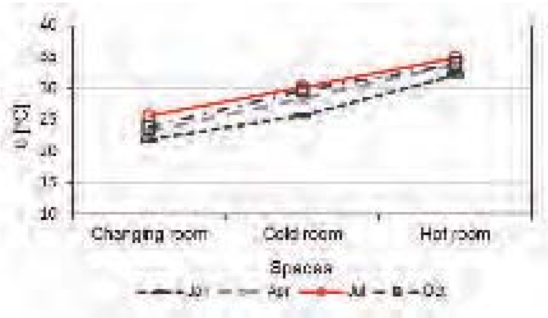


Figure 10. Temperature transition between spaces in BAB (mean monthly values during opening hours).

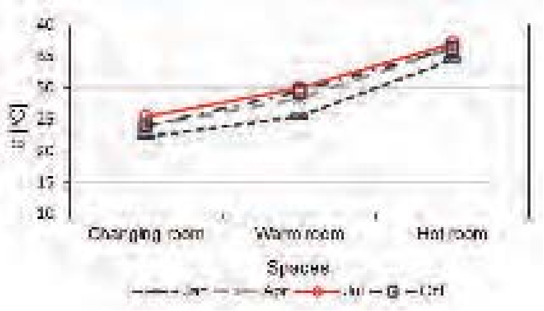


Figure 11. Temperature transition between spaces in SEN (mean monthly values during opening hours).

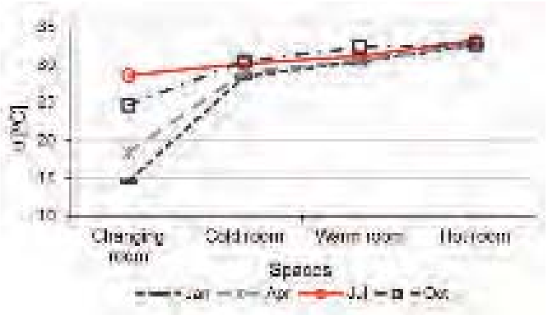


Figure 12. Temperature transition between spaces in SAF (mean monthly values during opening hours).

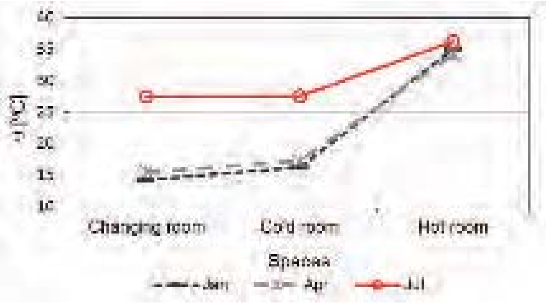


Figure 13. Temperature transition between spaces in SAG (mean monthly values during opening hours).

3.2. Energy use

Table 5 summarizes information regarding hammams' annual energy use for water and space heating as well as electricity.

Annual energy use for	Unit	BAB	SEN	SAF	AMH	SAG
hot water	**kWh.a^{-1}**	540 900	625 000	986 000	259 000	41 800
	kWh.m^{-2}.a^{-1}	2 760	1 150	2 990	2 150	220
space heating	**kWh.a^{-1}**	33 700	383 200	134 500	111 400	132 200
	kWh.m^{-2}.a^{-1}	170	710	410	930	710
space heating & hot water	**kWh.a^{-1}**	574 600	1 008 200	1 120 500	370 400	174 000
	kWh.m^{-2}.a^{-1}	2 930	1 860	3 400	3 080	930
electricity	**kWh.a^{-1}**	4 530	22 300	5 220	13 160	1 100
	kWh.m^{-2}.a^{-1}	23	41	16	109	6

Table 5. Overview of estimated annual energy use (total and per net floor area) in the five hammams

3.3. Simulation study

Table 6 and Figure 14 summarize simulated space heating demand for the simulation scenarios summarized in Table 3. Figure 15 shows the simulated annual heating loads of the hammam spaces for both light and massive construction styles.

Building	**Scenario**	**Space heating demand [kWh.m^{-2}.a^{-1}]**			
		CH	**CR/WR**	**HR**	**Total**
BAB	**S1**	65	112	292	164
	S2	53	112	338	177
	S3	47	97	314	162
	S4	49	99	291	155
	S5	52	108	337	176
SEN	**S1**	237	491	640	395
	S2	228	520	679	406
	S3	208	340	455	302
	S4	190	480	641	367
	S5	217	518	673	397
SAG	**S1**	45	299	338	167
	S2	47	299	363	176
	S3	43	259	189	114
	S4	35	292	352	165
	S5	46	294	356	172

Table 6. Simulated space heating demand (kWh.m^{-2}.a^{-1}) for BAB, SEN, and SAG (scenarios S1 to S5 as per Table 3)

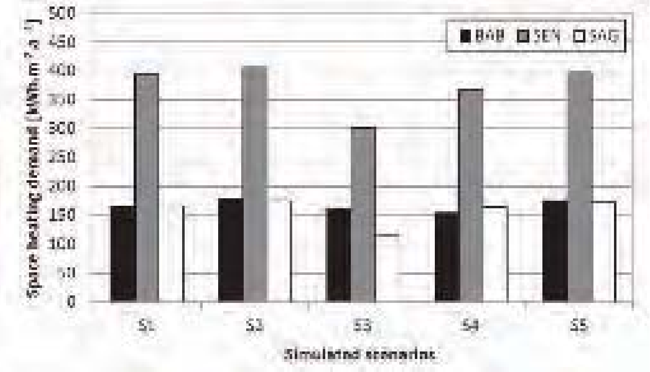


Figure 14. Calculated space heating demand [kWh.m^{-2}.a^{-1}] in BAB, SEN, and SAG for simulation scenarios S1 to S5 (see Table 3).

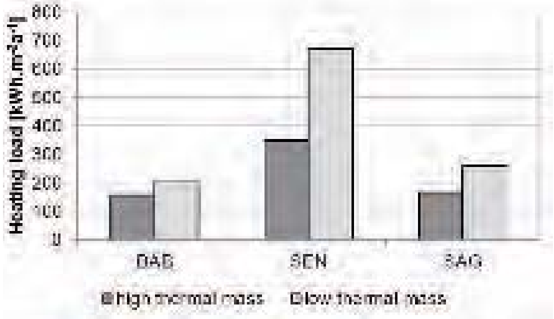


Figure 15. Simulated heating loads (in kWh.m^{-2}.a^{-1}) for historical (high thermal mass) and alternative (low thermal mass) hammam constructions

4. Discussion

4.1. Indoor environment

In hammams, indoor temperatures in the hot room and the warm room do not vary as much as those in the changing room (see Figures 1 to 5). Hot rooms in all observed hammams provide a fairly stable and appropriate temperature range throughout the year (50% of the time between 33 °C and 40 °C). 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 in BAB, AMH and SAG are not heated. Moreover, changing rooms are heated only in SEN and – minimally – in BAB.

Psychometric charts (Figures 6 to 9) imply a relatively good match between existing and desirable indoor conditions in BAB and SEN. Thermal conditions in changing room SAF and SAG 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, monitored data have been examined to see if, and to which extent, such transition is evident. Clear evidence for such transition could be found in the hammams BAB and SEN (see Figures 10 and 11). In SAF (see Figure 12), 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 SAG (see Figure 13), as no noteworthy difference in temperature between the changing room and the cold room can be observed (Mahdavi and Orehounig 2009).

4.2. Energy use

Estimated total energy use for water and space heating of the 5 hammams varies from about 170000 to 1120000 kWh.a^{-1}. Even after taking the respective net floor areas of these buildings into account, the total thermal energy use still shows a wide range from approximately 900 to 3400 kWh.m^{-2}.a^{-1}. This variance can be explained in part by the differences in the external climate, maintained indoor conditions, and use intensity. Taking the small sample of five hammams and removing the extreme values, average energy use estimates for water heating, space heating, and electrical equipment in hammams can be derived as shown in Table 7.

Energy use for	**[kWh.m^{-2}.a^{-1}]**
Water heating	2 000
Space heating	600
Water & space heating	2 600
Electrical equipment	30

Table 7. Average energy use [kWh.m-2.a-1] for water and space heating and electrical equipment in hammams.

These values are very high. Partial explanations pertain to extensive (hot) water usage, partly inefficient hot water heating systems, and the high indoor temperatures (particularly in the hot rooms). The estimated mean water usage (per visitor) in hammams amounts to 250 liters. This results, given the large number of visitors (approximately 65 visitors per day per hammam), in a considerable rate of water usage and the correspondingly large energy use for water heating. Given the rather moderate outdoor climatic conditions, the space heating demand appears to be extremely high. This may be attributed, in part, to the functionally necessary rather high maintained indoor temperatures of approximately 27°C (averaged over all hammam spaces). While both water and space heating demand estimates point to unsustainably large values, the water heating usage clearly represents the more dominant contributor to a hammams energy requirement. Our data suggests that the water heating constitutes approximately three quarter of a hammam's total thermal energy use. Reduction of water usage and the respective energy conservation potential should be thus the primary target of thermal retrofit measures.

4.3. Simulation study

As mentioned before, we used the calibrated simulation models of three hammams to estimate the potential of thermal improvement measures for space heating demand reduction. Table 6 and Figure 14 summarize simulated space heating demand for the improvement scenarios summarized in Table 3. They suggest that the provision of required ventilation rates (S2) would actually increase the space heating loads, albeit slightly. Improvement of the thermal insulation of the roof construction (S3) was – as expected – more effective in the colder climates of SEN and SAG (approximately 27% and 31% load reduction respectively as compared to S2, versus 9% for BAB). Thermal improvement of the wall elements (S4) does provide a modest level of load reduction. However, it must be noted that such improvements are in many instances rather unrealistic: in historically protected buildings such as SEN, the installation of external insulation is not possible. Moreover, many hammams are located in dense urban settings with partially shared external walls with adjacent buildings.

The improvement of the thermal properties of the glazing (S5) did not further reduce the heating loads in a noteworthy manner. This is mainly due to the rather low percentage of glazing in the overall building envelope area (Orehounig and Mahdavi 2010, 2011).

Overall, the simulation studies suggest that the improvement of the thermal insulation of the hammams' roofs could result in a heating demand reduction of approximately 20%. Assuming a proportional reduction in space heating energy use, this would save approximately 120 $kWh.m^{-2}.a^{-1}$ in energy use for space heating in hammams. If, on the other hand, the hammams' water usage would be reduced in the order of 50%, the resulting water heating energy use saving would amount to approximately 1000 $kWh.m^{-2}.a^{-1}$.

Regarding the comparison of light weight versus massive constructions, the simulation results confirm the starting point assumption. Traditional hammams with their considerable thermal mass and higher thermal resistance of their thick walls appear to have a lower heating load as compared to configurationally comparable buildings with light-weight constructions.

5. Recommendations

The present contribution provided a summary of monitoring results, energy use data, and the use of simulation models pertaining to the thermal performance of five traditional hammams.

Hygro-thermal conditions in hammams vary considerably over time and space. We established that hot rooms in all observed hammams provide fairly stable and appropriate thermal conditions, whereas changing rooms and cold 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.

1. Collected data regarding energy use suggests that the water heating constitutes approximately three quarters of a hammam's total thermal energy use. Reduction of water usage, together with more efficient water heating systems should be thus the primary target of thermal retrofit measures, given the considerable energy saving potential involved.

2. Parametric simulation studies suggest that the space heating demand of hammams could also be reduced via addition of thermal insulation. Better insulated roof constructions, for instance, could reduce space heating demand in the order of 20%.

3. The potential of renewable (primarily solar) energy to cover – at least partially – the hammams' energy demands must be further explored in the future. Despite challenges associated with the urban context and complex (roof) geometries of most hammams, the potential contribution of renewable energy is considerable, specifically given the relative abundance of solar radiation in the Mediterranean countries.

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6. Acknowledgement

The research presented in this contribution was supported, in part, by a European Union grant; project: HAMMAM, Aspects and Multidisciplinary Methods of Analysis for the Mediterranean Region, European Commission's 6th Framework Program Specific Targeted Research Projects FP6-2003-INCO-MPC-2 Contract No.: 517704. Scientific coordinator of the project was OIKODROM (director: Heidi Dumreicher), Vienna, Austria. The authors acknowledge the support of the research participants and local project partners toward the collection of information. These include Josef Lechleitner, Nina Mikats, Alaa al Habashi, Dina Shehayeb, Alp Güney, Kamal Raftani, Abdeslam Taleb, Samira Debache, Sarab Atassi, and Tarek Bouznada. The authors specially acknowledge the leading role of Nigel Mortimer and Garry Jenkins toward the collection and interpretation of energy use data for the hammams.