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Let There Be Light! Investigating Vernacular Daylighting in Moroccan Heritage Hammams for Rehabilitation, Benchmarking and Energy Saving

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Received: 11 August 2018; Accepted: 28 October 2018; Published: 31 October 2018

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Abstract: This paper provides the first study of vernacular daylighting provision in Moroccan heritage public bathhouses in order to rehabilitate it for experiential authenticity, energy saving and improved users' well-being. The analysis of a representative sample of 13 still working hammams reveals recurrent patterns of oculi numbers and configurations. These consist of one to three rows of eight circular roof openings (oculi) of 18 to 20 cm diameter, arranged along the roof vault of each bathing space. The ratio of total roof openings' area to internal floor area rarely exceeds 2%. Synchronised measurements of horizontal illuminance on the roof and inside the bathing spaces in a case study hammam were conducted in July and August 2016, after rehabilitating all roof oculi. Recorded levels indicated that maximum horizontal illuminance never exceeds 60 lx. The calculation and plotting of daylight factor based on real data reveal levels under 2% and a sudden decline in the hot room early afternoon due to steam accumulation. The paper provides the first benchmark of vernacular daylight rehabilitation in Moroccan heritage hammams and the illuminance it affords. It introduces an innovative combination of historical, architectural and building science methodologies that can be extended to other heritage building types.

Keywords: hammam; oculi; vernacular roof lighting; energy saving; well-being; daylighting rehabilitation; authenticity; horizontal illuminance

1. Introduction

The provision of daylight in heritage buildings is rarely considered adequate in terms of responding to contemporary standards issued by international institutions and which have been wrongly based on Daylight Factor (DF) or climate-based daylight modelling (CBDM) [1]. Therefore, daylighting levels afforded by the original daylighting strategy in heritage buildings are rarely maintained as an intrinsic heritage experiential value in the rehabilitation or re-use of these buildings. In the context of public bathhouses (hammams), daylight provision is frequently done from the roof space. A single oculus at the centre of a dome is a feature that is commonly found in the architecture of large Roman public bathhouses as illustrated in Pompeii's Roman baths [2].

The decline of the Roman and Byzantine public bath institution in the West was followed by the development and proliferation, during the early Islamic era, of small public baths, reminiscent of the Roman baths known as balnea. These baths feature three successive bathing rooms of increasing temperature, as well as the underfloor heating system known as hypocaust, both were maintained in the architecture of Islamic hammams. However, daylighting provision was replaced by a number of small oculi, pierced in the vaults and domes of the hammam roof, becoming a distinctive characteristic of hammam buildings. This architectural feature can be seen in two early Islamic baths: Hammam Qusayr Amra, an 8th Century structure [3] in the Jordanian desert (Figure 1) and in Hammam Aghmat, an 11th Century Almoravid structure [4] excavated in Aghmat, 30 kilometres South East of Marrakech in Morocco [4,5]. The Aghmat hammam [6] displays rows of circular openings or oculi in the three vaults covering the cold, warm and hot rooms (Figure 2). Such a configuration will continue unchanged in the architecture of Moroccan and Andalusian hammams for many centuries onwards [7–9]. The small circular piercings of 18 to 25 cm in diameter, located in the vaults and domes of the hammam roof are capped with blown glass bells. These allow shafts of daylight and sunlight to penetrate into the bathing spaces, cutting through the thick steam and creating different atmospheres at different times of the day. They constitute one of the unique and authentic experiential qualities of hammam buildings as illustrated in the case of one Mamluk and one Ottoman hammam (Figure 3a,b). Known in Arabic as little moons "Qamariyyat" or little suns "Shamsiyyat", they make a clear connection between the bather and the changing sunlight conditions of the sky. They also allow low levels of daylight into the steamy bathing spaces, hence maintaining some level of visual privacy, bearing in mind the strict religious codes governing nudity and gazing at another bathers' body. The act of washing one's body is indeed not a task that requires high levels of daylight, however, the manipulation of daylight in hammam spaces is believed to be highly linked to cultural and spiritual norms. It is argued in this paper that the vernacular daylighting system in hammams constitutes an intrinsic part of the heritage value and authenticity of this building type that needs to be fully understood in order to be properly rehabilitated in existing heritage structures and carefully reintroduced in the architecture of contemporary hammams in Morocco and beyond.

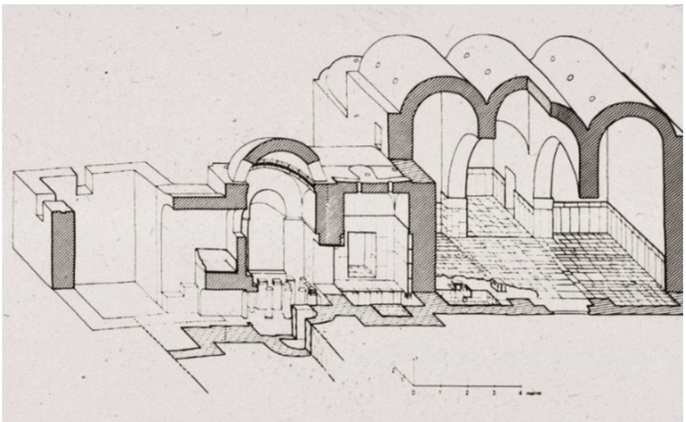


Figure 1. Qusayr Amra three vaulted bathing rooms with small oculi [2].

Figure 2. Hammam Ahgmat: 11th Century Almoravide era, Morocco [3].

(**a**) (**b**)

Figure 3. Hammam lightscape in the hot room of (**a**) Hammam al Hussayniya in Cairo (Mamluk era); (**b**) Hammam al Bacha in Acre (18th Century Ottoman era).

Existing studies on hammam daylighting systems are few and far apart. The most recent studies focus on Ottoman hammams that have lost their original function. This is the case of the study conducted by Al Maiyah et al. [10] which rightly argue the importance of understanding the daylighting system in vernacular buildings, as this is rarely considered as a key feature worth preserving as part of adaptive reuse strategies of heritage buildings. The study focuses on how to maintain the original daylighting conditions in the hot room of the Demirci hammam in Bursa, while allowing it to function as a museum or an art gallery; the hot room being the only surviving part of this Ottoman structure. The main concern is to establish how to reuse the existing vernacular daylighting system without exposing the exhibited artefacts to levels of light that are likely to be damaging. Measurements were made to validate a simulation modelling tool, Radiance, used with a digital model of the building produced using Integrated Environmental Solutions (IES) software. The aim was to develop an understanding of the behaviour of daylight in this Ottoman hammam hot room during a whole year and determine the most appropriate spaces for placing museum or art gallery exhibits. The study highlights that the average monthly illuminance level on the South wall of the hot room remains under 140 lx in the summer months in Bursa-Turkey (Latitude: 40°11′44″ N Longitude: 29°03′36″). Although this study rightly argues the need to avoid relying solely on lighting standards for the adaptive reuse of heritage buildings, and work with the existing lighting qualities of the spaces in a vernacular hammam, it does not provide an understanding of the nature of the hammam vernacular daylighting system in all the bathing spaces as it concentrates on analysing one main redundant space.

Another study focuses on investigating the vernacular daylight provision in seven still surviving Ottoman hammams in the city of Thessaloniki in Greece [11]. Measurements of daylight levels were, however, conducted in one case study building only, the Bey Hammam, a 15th Century twin structure used as a cultural centre was selected for recording daylight levels under different sky conditions in March 2008. The results of these measurements are presented graphically on the plan of the building with illumination levels plotted on a grey scale, ranging from 0 lx to 120 lx at a step of 10 lx [10]. Measurements were made using a lux meter at different points of the three bathing spaces and were carried out during a single day. This study indicates a clear correlation between the intensity of daylight, the type of activities carried out in the spaces and the level of visual privacy they require. The central spaces under the domes received the most light (due to the large number of oculi found in the domes of Ottoman hammams). This is the case of the central marble table in the hot room (the main shared space in Ottoman baths), whereas the peripheral spaces used for individual washing have much lower levels of daylight, indicating a clear correlation between the intensity of daylight and the level of privacy required by the bathers.

It is clear that the al Maiyah [10] and Tsikadoulaki et al. [11] studies focused on a single case study of Ottoman hammams that have lost their original function: One in Bursa, (Turkey) the other one in Thessaloniki (Greece). In both studies, daylight measurements, limited in time and space, were made in redundant structures without the steam conditions typical of a working hammam. Furthermore, all case study buildings where daylight levels were measured focus on a single bathing space, usually the hot room. However, it is clear from these studies that daylight levels in Ottoman hammam bathing spaces are relatively low and are in most cases below 140 lx as one moves away from the central domed part of the hot room.

This low level of daylighting in hammam bathing spaces is also confirmed by an earlier study carried out by Mahdawi and Orehounig [12,13] in the context of an EU-funded research project (HAMMAM 2008). Mahdawi and Orehounig collected data on indoor environmental (thermal) conditions and outdoor microclimatic conditions in the immediate vicinity of one traditional hammam in each of Egypt, Turkey, Morocco, Syria, and Algeria over a period of one year. Horizontal illuminance was measured (at one metre from the floor) at a single point in the centre of the different bathing spaces of the five case-study hammams of Cairo, Ankara, Fez, Damascus and Constantine. These measurements are of indicative character only and not reliable as they were carried out at different seasons in each of the five hammams and under different sky conditions in different geographies. Furthermore, measurements were made in conditions where the vernacular daylighting system was either in a poor state of repair or completely redundant and did not exclude the contribution of electric lighting at the time of the measurements. However, the results of horizontal illuminance measurements clearly indicate consistently low levels of lighting (mostly below 100 lx) in the five case study buildings of different historic eras and geographical locations. These measurements present however a number of limitations as they do not link to outdoor sky conditions at the time of the measurements and are not directly comparable. Furthermore, they fail to convey a clear understanding of the hammam daylighting levels afforded by the vernacular oculi system. Despite their limitations, it is clear from these previous studies that daylight levels in the bathing spaces of hammam case-studies located in different geographies (north and south of the Mediterranean) are generally low, varying between 50 and 150 lx.

This literature review has revealed that there have been no studies so far that attempt to develop an understanding of daylight levels in all the bathing spaces of heritage hammams under working steam conditions. Measurements of daylight levels in working heritage hammams where the vernacular daylighting system is still in operation, or has been fully restored, are completely non-existent. The lack of such studies makes it difficult to specify the vernacular hammam natural lighting for hammam rehabilitation purposes and for the design of new built structures that aim to create an authentic daylighting hammam experience. This is needed in all of the Maghreb countries of North Africa where the hammam tradition is still alive. Morocco is where the largest number of working heritage hammams are found and where housing planning regulations dictates the inclusion of a hammam facility in every new residential neighbourhood [14]. It is estimated by the Moroccan federation of hammam managers, that Morocco has more than 12,000 operating hammams, however, it is very likely that the number is much higher as there have never been a systematic national census for hammams. These operate day and night and tend to rely on electric lighting during daylight hours because of their redundant vernacular daylighting system or their poorly designed daylight provision. No studies have been carried out so far to develop an understanding of the hammam vernacular daylighting strategy and the unique spatial experiential qualities it provides. This paper provides a timely and much needed historical and architectural understanding of the hammam vernacular daylighting strategies that embed tacit cultural and social norms for visual privacy and spiritual connection to the sky. In order to do so, the following methodology was adopted.

2. Materials and Methods

A representative sample of heritage hammams from different historical periods was selected in the old city of Marrakech. A total of 13 still functioning heritage hammams out of a total of fifteen were surveyed and recorded for the first time by the author, allowing the production of their plans, sections and elevations, as well as their roof plans and a photographic record of their various spaces (see Table 1 and Figures 4–6). More recently built hammams were deliberately excluded as the focus of this study is on the original vernacular daylighting system in heritage structures. The examined sample of hammams represents 90% of the total number of heritage hammams, located in every residential neighbourhood, within the proximity of small or large mosques inside the UNESCO world heritage intra-muros urban fabric of the city of Marrakech.

Table 1. List of the surveyed hammams in the world heritage medina of Marrakech.

Map Reference	Hammam Name	Dynasty When Originally Built	Dynasty When Rebuilt
1	Bab Ailan	Merinid	Saadi-Alaouite
2	Dhahab	Saadi (16th Century)	Alaouite
3	Bab Doukala	Saadi (16th Century)	NA
4	Darb Arjaan	Saadi (16th Century)	Alaouite
5	Laksour	Saadi (16th Century)	Alaouite
6	Qannaria	Saadi (16th Century)	Alaouite
7	Al Souq	Saadi (16th Century)	Alaouite
8	Mouassine	Saadi (16th Century)	Alaouite
9	Al Ziani (Sensla)	Saadi (16th Century)	Alaouite
10	Azbezt	Almohade	Saadi/Alaouite
11	Sidi AbdelAziz	Saadi	Alaouite
12	Sidi Ayyoub	Saadi	Alaouite
13	**Ben Cherga**	**Saadi**	**Alaouite**
14	**Dabbachi**	**Alaouite**	**NA**
15	El Bacha	1930s	NA

Hammams 13 and 14, bolded in Table 1, have not been surveyed as they were transformed into spas.

In order to establish a clear understanding of the hammam vernacular daylighting system, the following methodological steps have been followed:

Step 1: Architectural analyses of heritage hammam roof plans with their oculi number, location and configuration

The plans and roof openings of the 13 hammams, documented during field work in Marrakech, are systematically analysed to establish whether there are recurrent patterns in the number, location and configuration of roof openings (oculi). The aim of such analyses is to identify any tacit rules that are applied for the configuration of the Moroccan hammam vernacular daylighting strategy.

Step 2: Analyses of ratios of total roof openings area over internal floor area in each the three bathing spaces of the 13 surveyed hammams

The calculation of the percentage of the total area of roof openings for each bathing space in relation to its internal floor area will reveal whether there are any recurrent ratios and whether there any variations between the cold, warm and hot rooms. This is achieved through the comparison of these ratios in the 13 investigated historic structures. This analysis also allows for the extraction of any underlying tacit rules that can inform both the rehabilitation of existing heritage structures and the design of future new hammams.

Step 3: Measurement of horizontal illuminance afforded by the vernacular daylighting system after its rehabilitation in a working heritage hammam

A working heritage hammam, presenting a vernacular lighting configuration of roof oculi over its bathing spaces, has been selected in order to restore the blown glass caps that originally covered the roof openings and carry out measurements of daylight levels afforded by the system in each of the three bathing spaces under working conditions. Water resistant HOBO pendant data loggers for temperature (range of −20 °C to 70 °C) and light (range of 0 to 320,000 lx) were chosen due to their discreet small size and their ease of installation in working hammam spaces with high levels of humidity [15].

They were installed at similar and comparable locations in each of the three retrofitted bathing spaces (of similar size, colour and texture and hence similar reflectance) and on the roofs to record outdoor horizontal illuminance under open sky conditions. The data loggers were placed on the south facing parallel walls of each of the three bathing spaces and at a height of two metres from the floor (away from the bathers), allowing for comparable points of measurements. All data loggers were synchronised to measure horizontal illuminance continuously every 20 min in July, August and September of 2016. This allowed for three measurements per hour for three months which is sufficient to establish the levels of horizontal illuminance falling at similar points in each of the three similar hammam bathing spaces during the summer season of 2016.

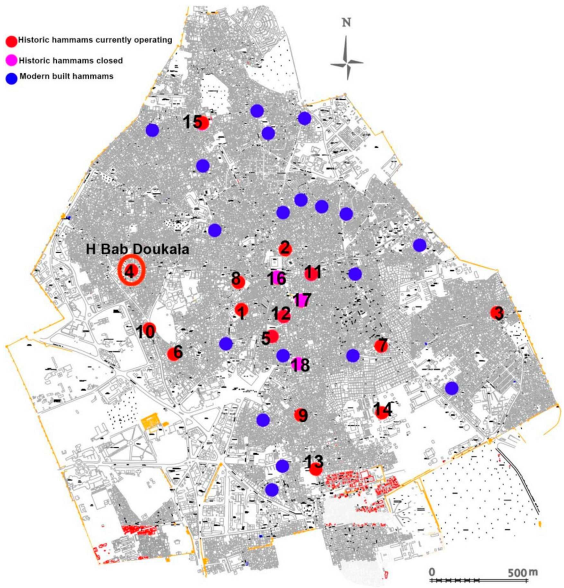


Figure 4. Location of the surveyed heritage hammams of Marrakech with numbers corresponding to the names of the hammams in Table 1.

3. Results

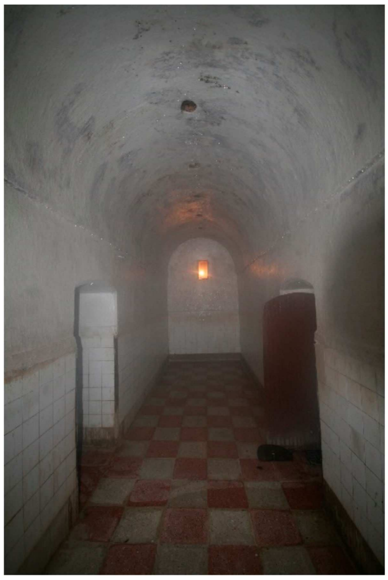
3.1. Analyses of Roof Oculi Configuration in the Representative Sample of 13 Heritage Hammams

During the field work survey, it became clear that all the visited hammams had their roof oculi poorly repaired or completely blocked and none of the original blown glass caps covering the oculi had survived in any of the hammams. Furthermore, the identification from the roof spaces of the original oculi, their number and position was not always possible. This was due to inadequate roof maintenance practices consisting of different layers of cement applied to the roof surfaces. This not only reduced the roof openings' diameter (and the light penetrating to bathing spaces) but completely covered some of the original openings (Figure 5) leading to the use of poor indoor electric lighting during daytime hours. The examination of the hammam ceiling from the inside of the bathing spaces was therefore necessary (although not always easy) to locate and count the blocked oculi.

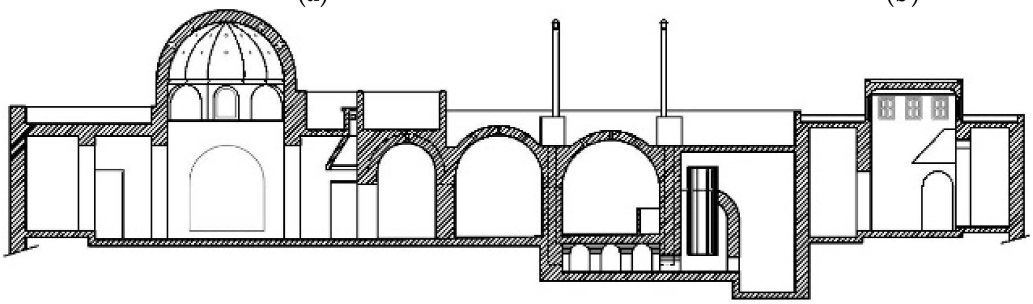
The examination of the architecture of the 13 documented hammams reveals a consistent linear organisation of three successive rectangular parallel bathing spaces of increasing temperature and steam and are as follows:

- The cold room, called "al-Barrani" (The Roman Frigidarium)
- The warm room, called "al-Wasti" (The Roman Tepidarium)
- The hot room, called "al-Dakhli" (The Roman Calidarium)

(**a**)

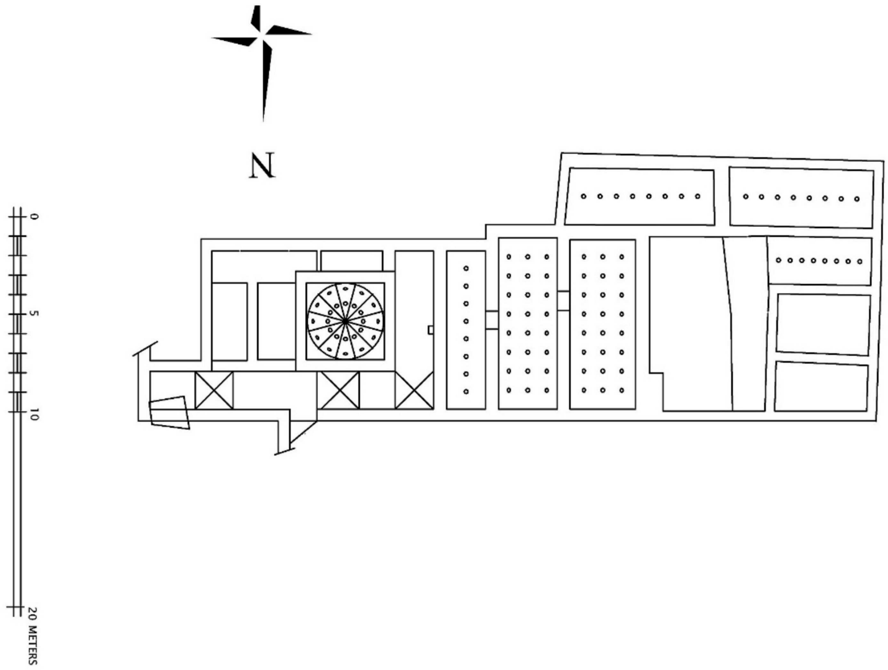


(**b**)



(**c**)

Figure 5. *Cont.*

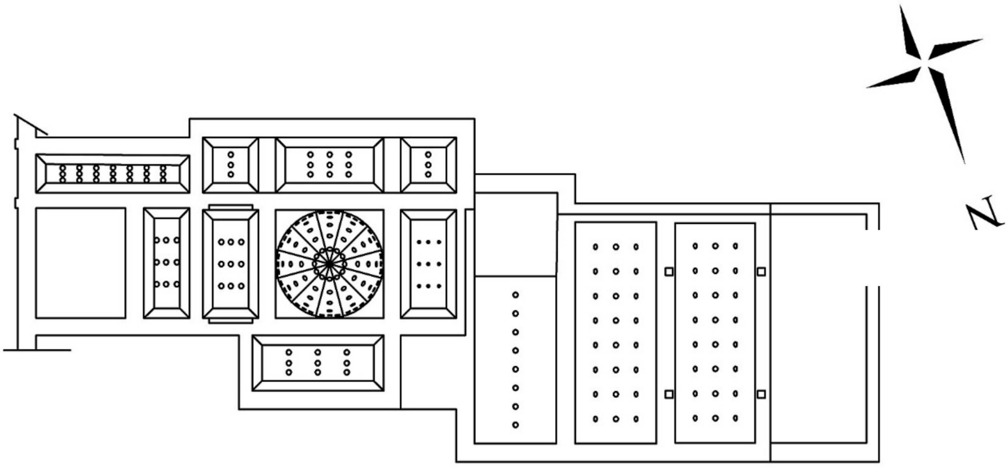


(d)

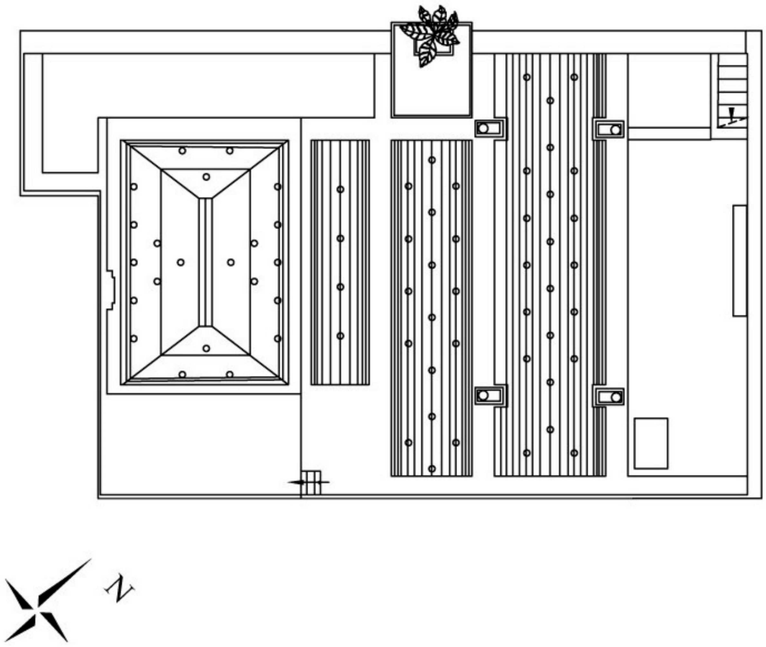
(e)

Figure 5. Hammam Sidi Ayyub (16thC) from left to right (**a**) view of the roof; (**b**) internal view of the blocked oculi in the cold room; (**c**) building section illustrating the proportions of the three bathing spaces; (**d**) roof plan with oculi location; (**e**) internal view of the blocked oculi in the warm room.

This organisation is found in the vast majority of the hammams (11 out of 13) as illustrated in the case of hammam Sidi Ayyub (Figure 5) and is reminiscent of the early Moroccan Islamic hammams excavated near the Roman settlement of Volubilis and the Alomravid settlement of Aghmat. In addition to the bathing spaces, all hammams comprise a changing room with an intermediate space with toilets connecting the changing room to the cold room. The configuration of three successive vaulted rectangular bathing rooms is reflected in the roof architecture of 11 out of the 13 heritage hammams surveyed as illustrated in Figure 6. The architecture of the cold and hot rooms, consisting of long rectangular rooms of varying dimensions, remains constant in all the surveyed hammams. The three rooms are covered by barrel and/or crossed vaults pierced by a number of roof openings.

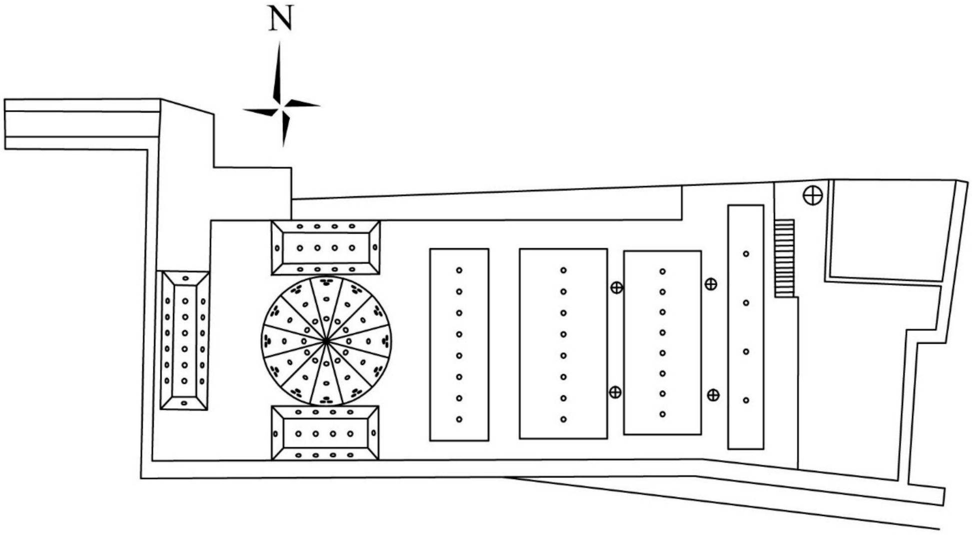


(**a**) Hammam al suq

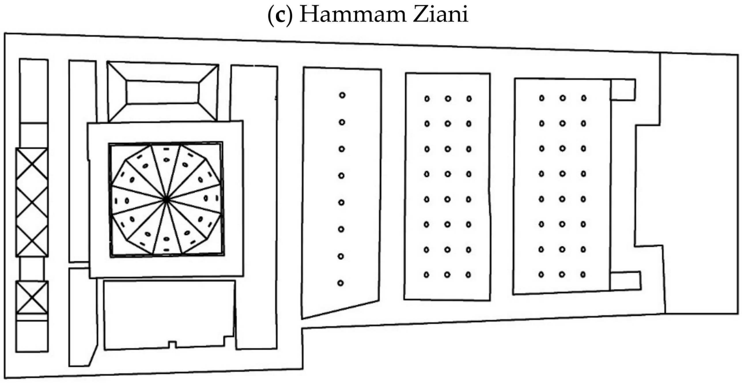


(**b**) Hammam Bab Ailene

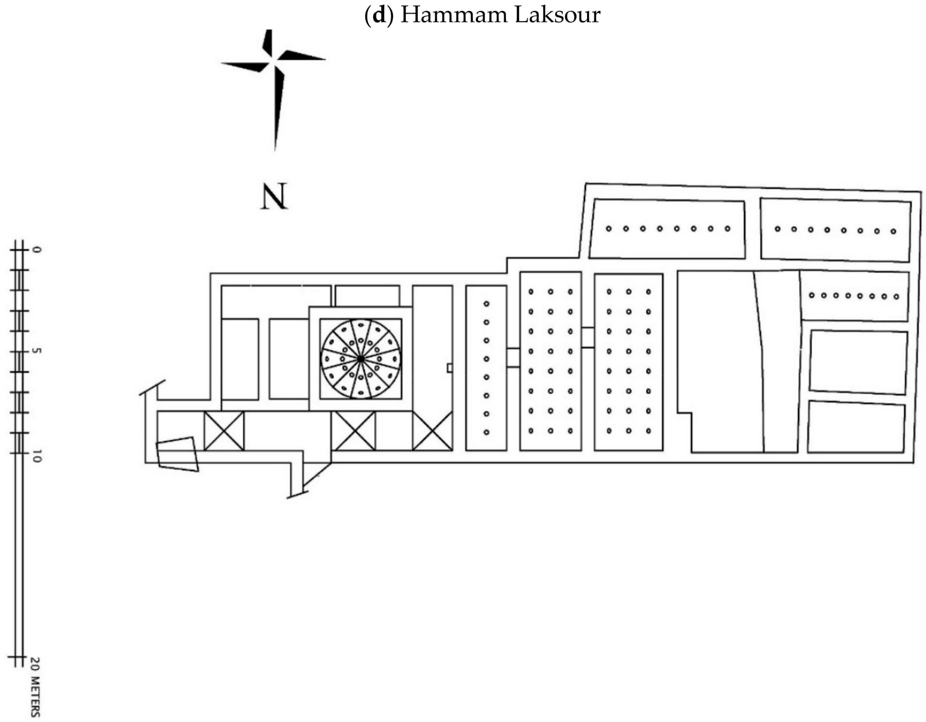
Figure 6. *Cont*.



(**c**) Hammam Ziani

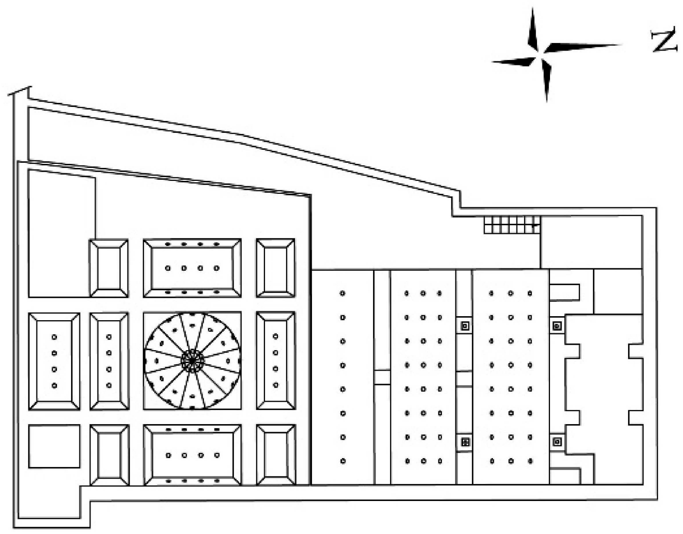


(**d**) Hammam Laksour

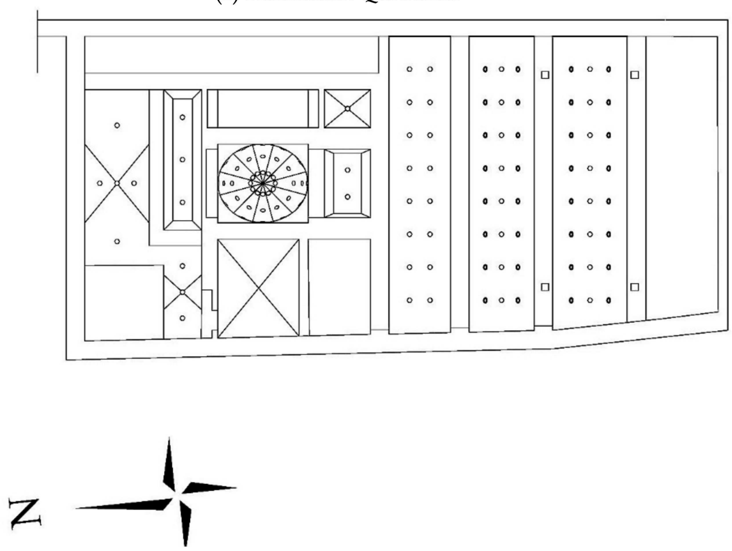


(**e**) Hammam Sidi Ayub

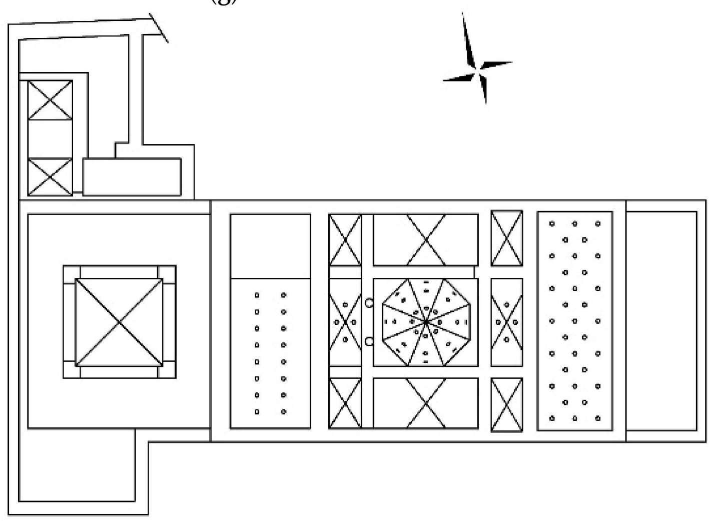
Figure 6. *Cont*.



(**f**) Hammam Qannaria

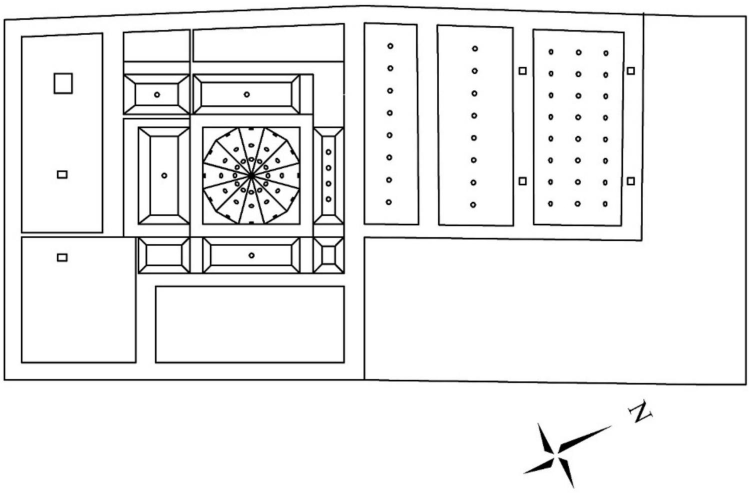


(**g**) Hammam Sidi Abdelaziz

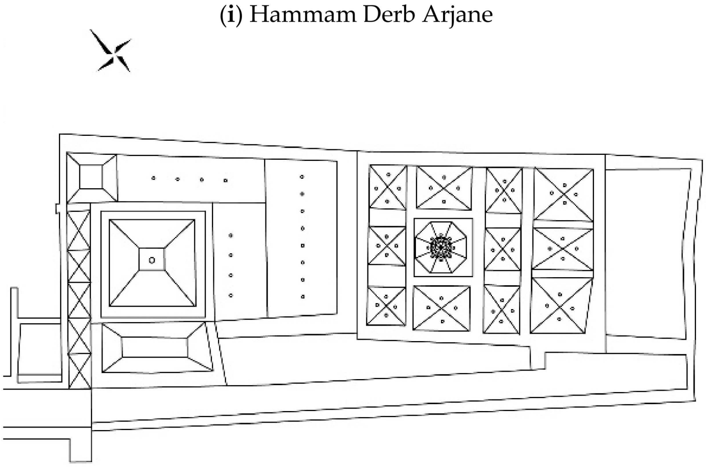


(**h**) Hammam Bab Doukala

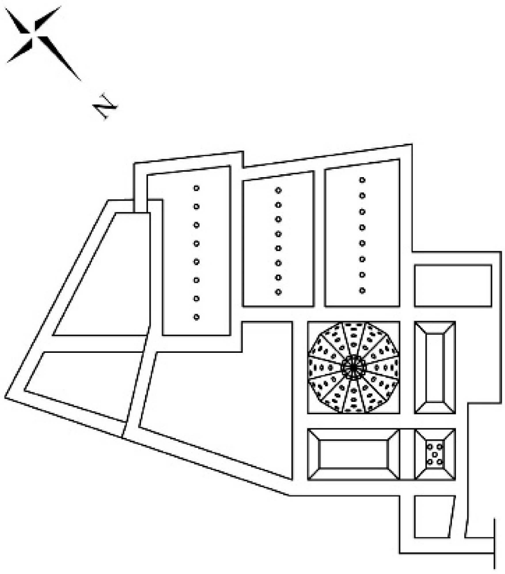
Figure 6. *Cont*.



(**i**) Hammam Derb Arjane

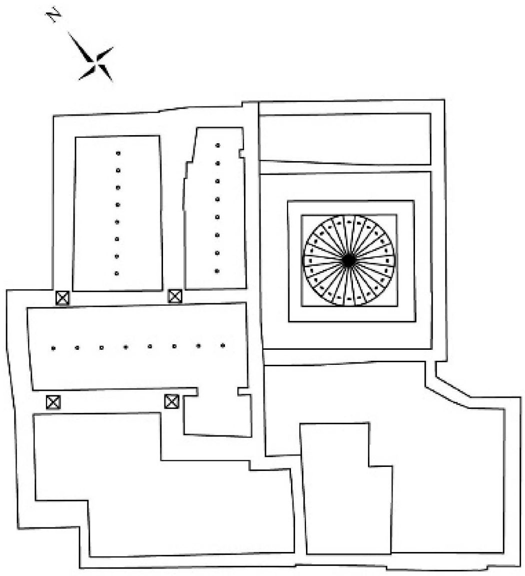


(**j**) Hammam Mouassine

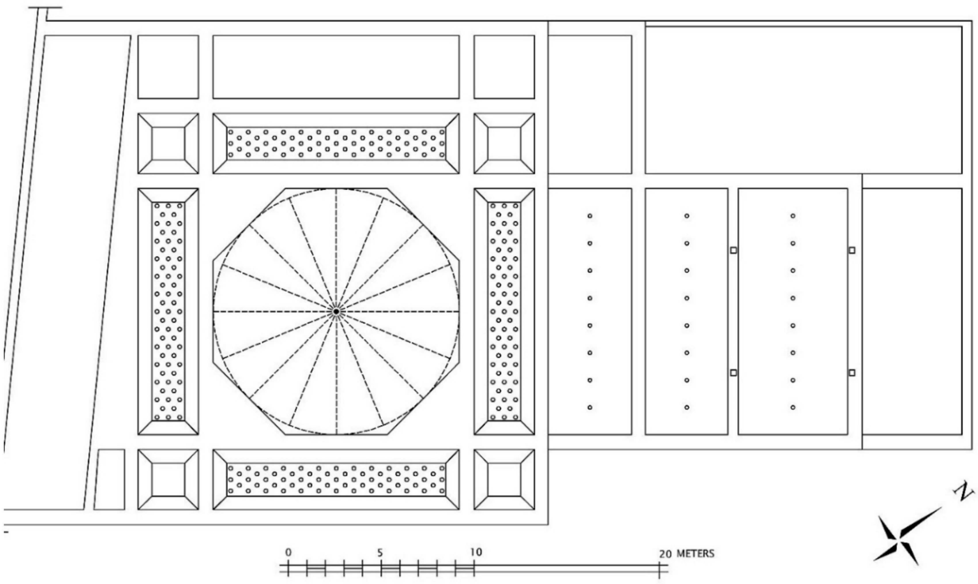


(**k**) Hammam Dahab

Figure 6. *Cont*.



(**l**) Hammam Azbezt



(**m**) Hammam al Bacha

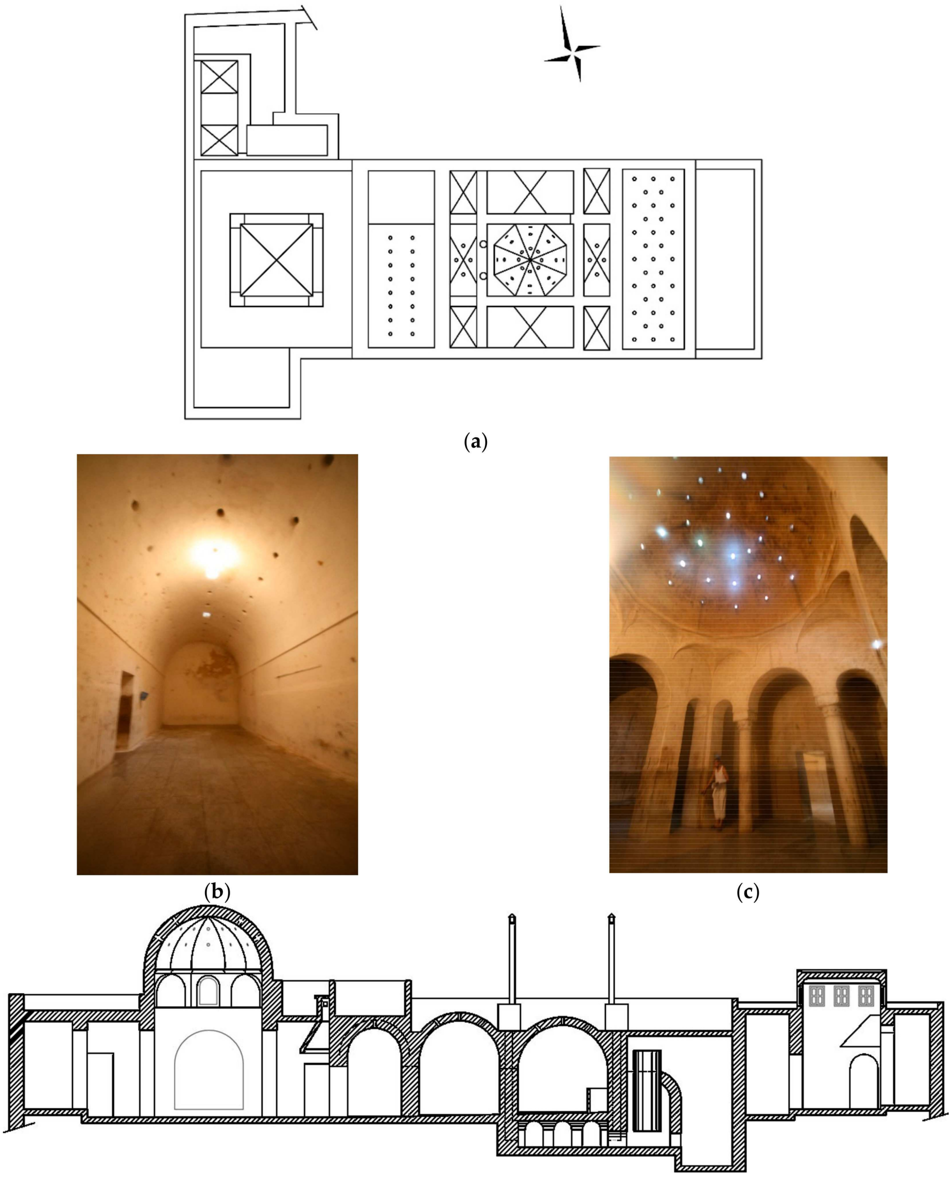
Figure 6. Roof plans of the 13 surveyed hammams. (**a**) Hammam al suq (**b**) Hammam Bab Ailene (**c**) Hammam Ziani (**d**) Hammam Laksour (**e**) Hammam Sidi Ayub (**f**) Hammam Qannaria (**g**) Hammam Sidi Abdelaziz (**h**) Hammam Bab Doukala (**i**) Hammam Derb Arjane (**j**) Hammam Mouassine (**k**) Hammam Dahab (**l**) Hammam Azbezt (**m**) Hammam al Bacha.

The examination of the number and location of roof oculi eveals some recurrent patterns as follows:

- There is a recurrence in the number of eight oculi or multiples of eight, ranging from 8 to 24 oculi (of 18 cm diameter) in the roof vaults covering the bathing spaces (see Table 2).
- The configuration of oculi on the roofs of the cold, warm and hot bathing spaces tends to be in rows of eight along the length of the vaults. The number of rows can vary from one to a maximum of three rows, depending on the width of the bathing space. A single row seems to be a constant feature of the cold room and is not dependent on its floor area (Figure 6).
- Pierced masonry domes tend to be found in the majority of changing rooms' roofs as illustrated in 10 out of the 13 surveyed hammams (Figure 6). They are also found in the warm room of a few

larger hammams, as illustrated in the roof plans of hammams Mouassine and Doukala (Figures 7 and 8). The dome openings are based on the octagonal formation of the dome resulting from a 45-degree rotation of one square plan over another. This explains the number of dome openings as multiples of four.

- The number of oculi on a dome is generally much larger than that of a vault and can exceed 60 oculi.
- The warm room is the only bathing space where a central dome with a large number of oculi is sometimes found and is surrounded by cross vaulted spaces (Figures 7b and 8d).
- Three of the 13 surveyed hammams have a tiled roof wooden structure covering the central area of their changing room as illustrated in the case of hammams Doukala and Mouassine (Figures 7 and 8).

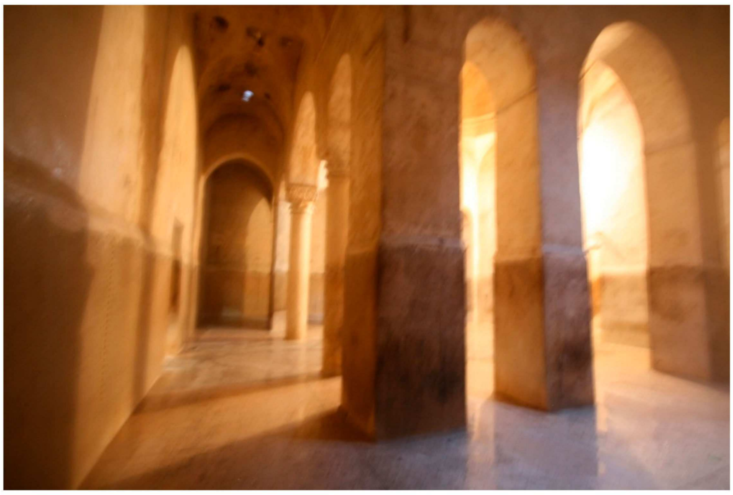


(a)

(b) (c)

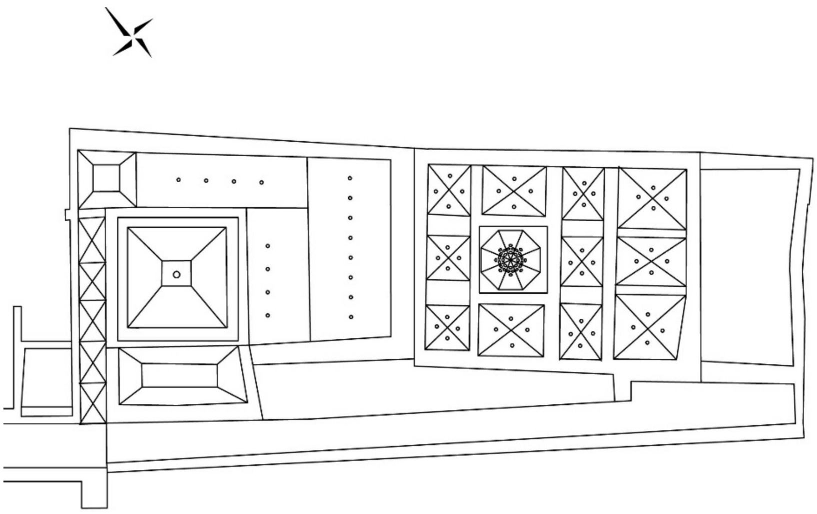
(d)

Figure 7. *Cont.*

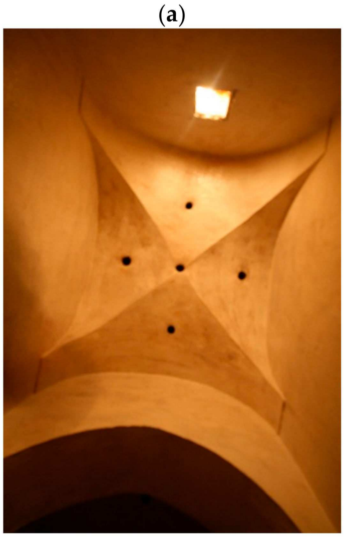


(**e**)

Figure 7. Hammam Bab Doukala from top left clockwise: (**a**) Roof plan; (**b**) interior view of hot room pierced vault; (**c**) warm room central pierced dome; (**d**) building section; (**e**) warm room pierced cross vault.

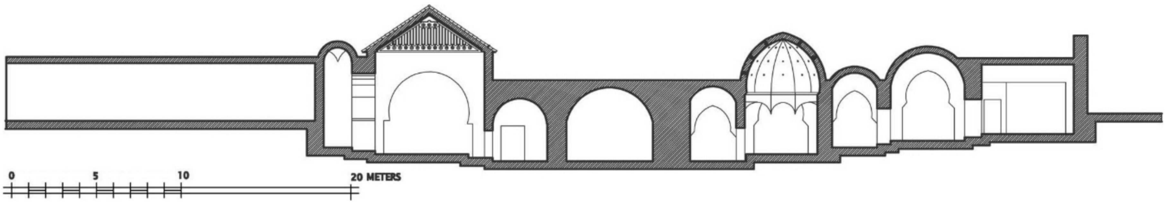


(**a**)



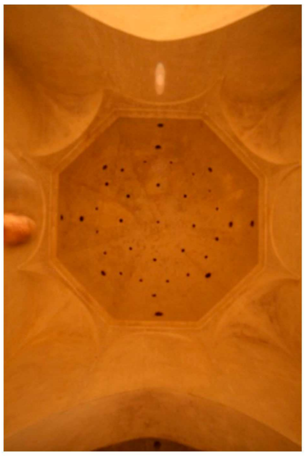
(**b**)

Figure 8. *Cont.*



(**c**)

(**d**)



(**e**)

Figure 8. Hammam Mouassine: From top left clockwise: (**a**) Roof plan; (**b**) warm room cross vault; (**c**) section across all the hammam spaces; (**d**) external view of warm room's dome; (**e**) internal view of the warm room's dome.

The comparative analysis of the plans of the 13 hammams reveals that the warm room and the changing area are the main spaces where more architectural variations and elaborate oculi configurations are to be found. This is clearly illustrated in the hammams of Bab Doukala (Figure 7) and Mouassine (Figure 8). Both hammams display the same principle of space and roof configuration in their warm room where the space is based on a central square configuration with a central pierced dome and a series of pierced cross vaults surrounding the central domed square. More elaborate architecture in their changing room is also found as illustrated in Figures 7 and 8. A systematic examination of the location of these two hammams in their wider urban context reveals their proximity to a large complex of a Friday mosque, madrassa and public fountain. Being part of a cluster of important public facilities at the wider urban scale, these two hammams enjoy a larger catchment area of bathers. Since the changing room and the warm room are the spaces where bathers spend most of their time, this explains their larger scale and more elaborate architecture. Furthermore, the changing room acts as a hub for bathers' relaxation and social interaction and as a venue for pre-wedding hammam celebrations for future grooms and brides. The majority of the hammams are, however, smaller structures with modest size and architecture and are located in the proximity of small residential neighbourhood mosques. The roof configuration as well as the number and location of oculi is therefore dependent on the size of the hammam, which depends on its location in the city within the medieval urban fabric's hierarchical system of clusters of facilities. Hammam al Bacha, a very large hammam built in the 1950s, is an exception due to its relatively recent construction.

Table 2. Floor area, number of roof openings and ratios of total roof opening area in the three bathing spaces of the 13 surveyed hammams.

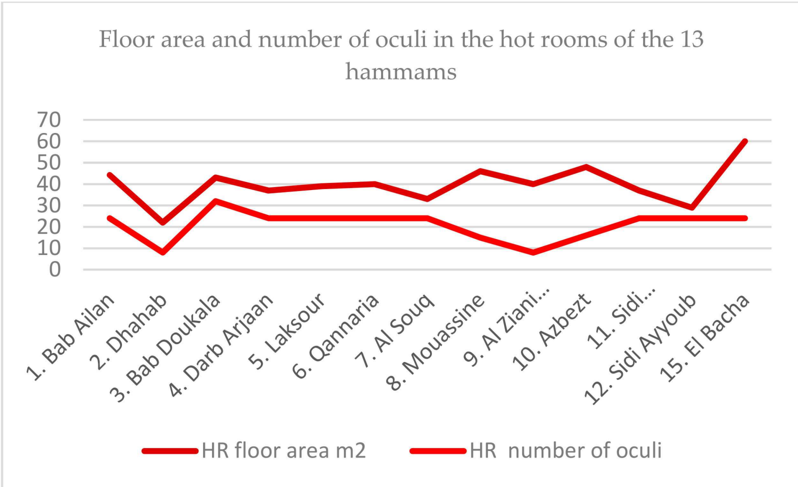
Hammam Name	HR Floor Area (m^2)	HR Oculi	HR Total Oculi Area/Floor Area (%)	WR Floor Area (m^2)	WR Oculi	WR Total Oculi Area/Floor Area (%)	CR Floor Area (m^2)	CR Oculi	CR Total Oculi Area/Floor Area (%)
Bab Ailan	44.24	24	1.38	26	16	1.57	13.68	8	1.49
Dhahab	22	8	0.92	17	8	1.20	20	8	1.02
Bab Doukala	43	32	1.89	69	34	1.25	32	16	1.27
Darb Arjaan	37	24	1.65	32	8	0.64	23	8	0.68
Laksour	39	24	1.57	34	24	1.80	30	8	0.68
Qannaria	40	24	1.53	32	24	1.91	29.5	8	0.69
Al Souq	33	24	1.85	30	12	1.02	30	8	0.68
Mouassine	46	15	0.83	103	62	1.53	48	8	0.42
Al Ziani (Sensla)	40	8	0.51	29.50	8	0.69	24	8	0.85
Azbezt	48	16	0.85	45	8	0.45	34	8	0.60
Sidi AbdelAziz	37	24	1.65	34	24	1.80	32.5	8	0.63
Sidi Ayyoub	29	24	2.10	26	24	2.35	16.2	8	1.26
El Bacha	60	24	1.02	40	24	1.53	40	3	1.49
Averages	39.86	20.84	1.37	39.80	21.23	1.36	28.68	8.23	0.90

3.2. Analyses of Total Area of Roof Openings Expressed as a Percentage of the Internal Floor Areas of Each of the Three Bathing Spaces in the 13 Surveyed Hammams

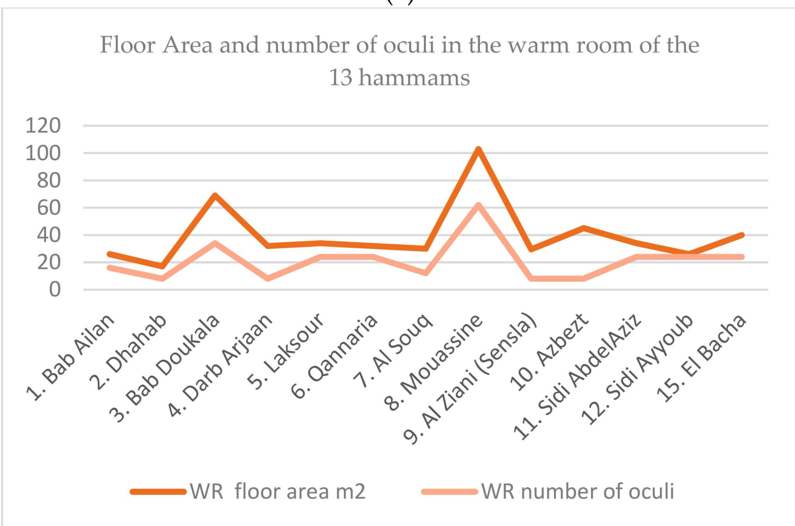
The internal floor area, the number of roof oculi, and the ratio (in percentage) of total area of roof openings in relation to internal space floor area have been calculated in each of the three bathing spaces of the 13 hammams as presented in Table 2.

The number of oculi in the roof of each of the bathing spaces is dependent on its floor area as illustrated in Figure 9a,b, where the graphs show (as expected) a clear correlation between the floor area of the space and the percentage of roof openings' total area in both the hot and warm rooms as illustrated in Figure 9a,b. The largest number of oculi is found in the warm room, when this has a central dome as is the case of hammam Mousassine (Table 2). However, the key finding here is that the cold room's total area of roof openings, consisting on one row of eight oculi, is not related in any way to its internal space floor area (Figure 9c).

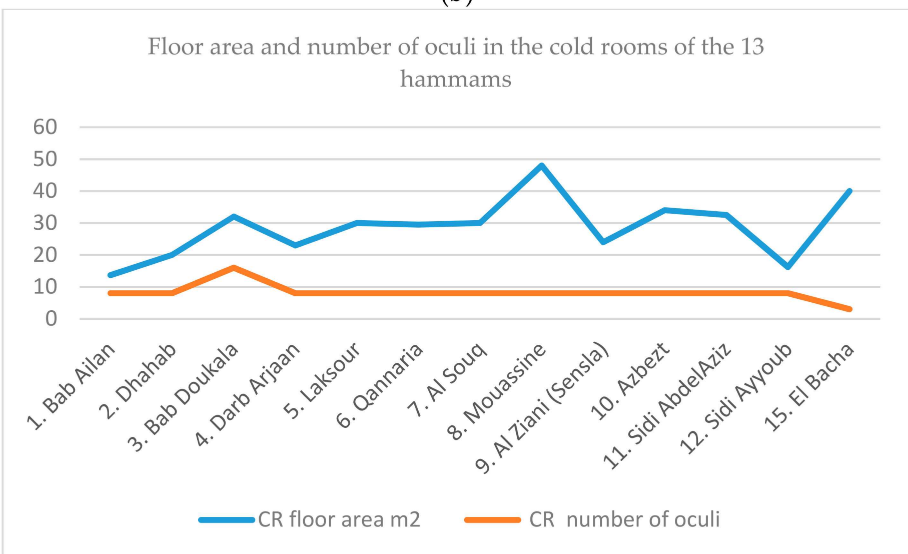
As the cold room is the first space bathers cross on their way to the warm and hot rooms (where most of the bathing takes place), its low levels of daylight help bathers' sight to adjust to the low light levels in the steamy bathing spaces of the warm and hot rooms. This indicates an underlying principle of allowing bathers' sight to adjust to the lowest level of light in the cold room so that they get accustomed to the slightly higher light levels in the warm and hot rooms, where most of the bathing activities take place. The bathers' journey through different spaces of increasing or decreasing temperature and steam is matched with an increasing or decreasing amount of daylight. The darkest room is the cold room where the number of oculi is not dependent on its internal floor area. There seems to be some symmetry in the transitions between extremes conditions of hot and lighter, cold and darker. The warm room presenting conditions of transitions between the two extremes of cold and hot room.



(**a**)



(**b**)



(**c**)

Figure 9. Relationship between floor area and number of roof oculi per type of bathing space: (**a**) The hot room; (**b**) the warm room; (**c**) the cold room. The horizontal axis is the hammam as they appear in Table 1.

It is clear from Table 2 and Figure 10 that the cold room has the smallest proportions of roof openings as compared to the hot and warm rooms in the vast majority of the surveyed hammams. It is also interesting to note that the maximum total area of oculi roof openings does not exceed 2% of the internal floor area of the bathing space above which they are located as illustrated in 12 of the 13 surveyed hammams (Figure 10).

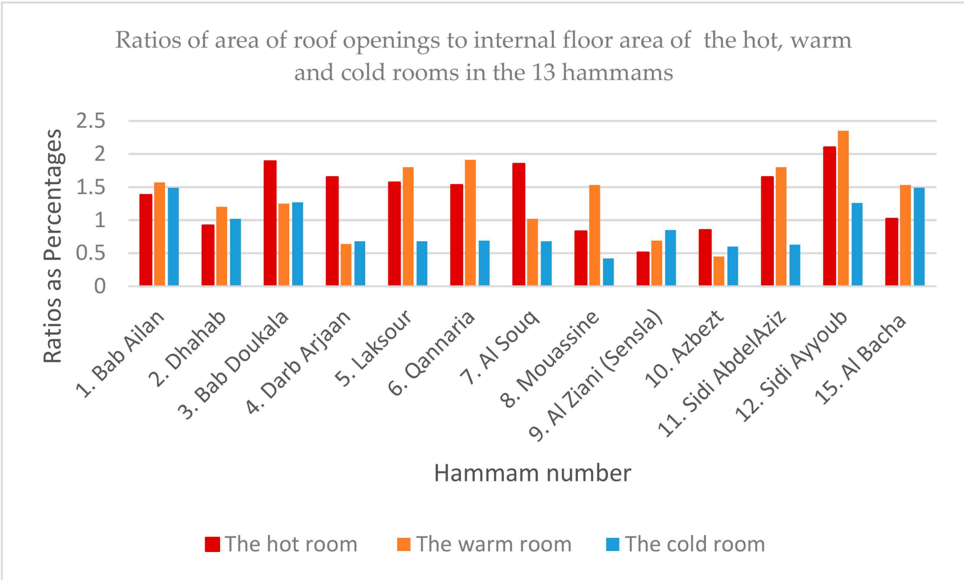


Figure 10. Comparison of ratios of roof opening total area in relation to floor area in the three bathing spaces of the 13 surveyed hammams.

3.3. Restoring the Vernacular Daylighting System and Quantifying Horizontal Illuminance Afforded by It in the Three Bathing Spaces of a Working Hammam

All surveyed heritage hammams have completely lost the original daylight qualities in their bathing spaces, as the vernacular blown glass caps (Figure 11) have all been replaced by poor alternatives, such as glass bricks or flat sheets of reinforced glass (Figure 12a), or have been completely blocked by layers of cement. Poor incandescent or fluorescent electric lighting that is neither appropriate nor safe for the steam conditions of these spaces was found to be used all day long in the surveyed hammams, increasing consumption of electricity. Furthermore, face-to-face interviews conducted with three female hammam workers in Marrakech indicated the occurrence of headaches and fatigue which they attributed to the lack of daylight and natural ventilation in the bathing spaces. A follow-on discussion with the head of the hammam managers association in Marrakech revealed that there was a lack of knowledge of the original blown glass caps which used to cover the roof oculi amongst most hammam managers. This situation is further exacerbated by the loss of glass blowing workshops in Moroccan cities, with the exception of the one and only glass blowing workshop opened by a French entrepreneur in Marrakech and employing the last two glass blowers in Morocco. Based on the form of vernacular glass bells, the transparent blown glass bells of 18 cm in diameter was used by the author as a prototype to produce locally 48 glass bells, using recycled glass (Figures 11 and 12).

Figure 11. Samples of blown glass bells produced in Syria in 2007 based on vernacular prototypes examined to restore hammam daylighting. The blue version is an openable oculus glass cap for natural ventilation.

Figure 12. The roof of Hammam Rjafalla: (**a**) Removing poor alternatives of oculi covers; (**b**) re-opening the oculi and placing the blown recycled glass caps; (**c**) solar panels over the warm room affecting indoor daylight measurements; (**d**) blocked oculi in the hot room; (**e**) vernacular daylight restored; (**f**) oculi natural light effect.

Access to a working heritage hammam in Marrakech to restore the blown glass caps over the oculi system was impossible. However, the opportunity to restore the vernacular daylighting system in a working heritage hammam presented itself in Rabat (the administrative capital of Morocco) in July 2016. Built in the 1950s, during the French protectorate, the Hammam Rjafalla is located in an informal, low-income housing neighbourhood, known as Hay Rjafalla, in the area of Yacoub al Mansour. The building presents a typical Moroccan vernacular hammam architecture, consisting of three successive rectangular parallel rooms with two rows of eight oculi in each of the three north/south facing vaulted roofs (Figure 12c).

The rehabilitation of the vernacular daylighting system took place in July 2016, under the initiative and supervision of the author, at a time when the hammam was temporarily closed for its annual maintenance work. The hammam manager has been in charge of the building for the last 36 years and is the only active female member of the National Federation of Moroccan hammam managers. She is also one of the key participants to the sustainable hammam initiative in Morocco which was presented at the COP22 in Marrakech in November 2016 [16]. The re-opening of the closed oculi and the installation of the blown glass bells was carefully conducted in order to avoid damaging the pottery tubes located in the masonry of the vaults and which form the base for the glass cap (Figure 12c). Once the vernacular daylighting system was restored, HOBO data loggers were installed in the same position within each of the three parallel bathing rooms at a height of two metres from the floor and at the base of the vault. This allowed for the recording of horizontal illuminance at a similar point on the internal south facing wall under the steam conditions of a working hammam and without interfering with bathers' activities (Figure 13).

Figure 13. Installation of HOBO data loggers for measuring temperature and light: Temperature range: −20 °C to 70 °C, light measurement range: 0 to 320,000 lx (0 to 30,000 lumens/ft^2).

The data loggers were set to record light levels simultaneously in the three bathing spaces, under the working hammam heat and steam conditions and with the oculi openings being the only source of daylight. A fourth HOBO data logger was placed on the hammam roof (on top of the warm room) to measure the horizontal illuminance on the roof, simultaneously with the data loggers installed inside the building. Measurements were taken from 19 July to 30 September 2016 at 20 min intervals.

The plotting of weekly averages of horizontal illuminance (recorded every 20 min between 11:00 a.m. and 17:00 p.m.) over a period of almost two months and a half, clearly indicates that the averages of daylight levels do not exceed 25 lx and that the cold room tends to have slightly higher averages than the hot room despite their same configuration and orientation (Figure 14). However, when examining daily plotting of recorded illuminance in the three spaces, the results show that horizontal illuminance (lx) recorded in the hot and cold rooms varies between 10 and 60 lx with the hot room recoding slightly higher levels than the cold room (Figure 15 and Table 3).

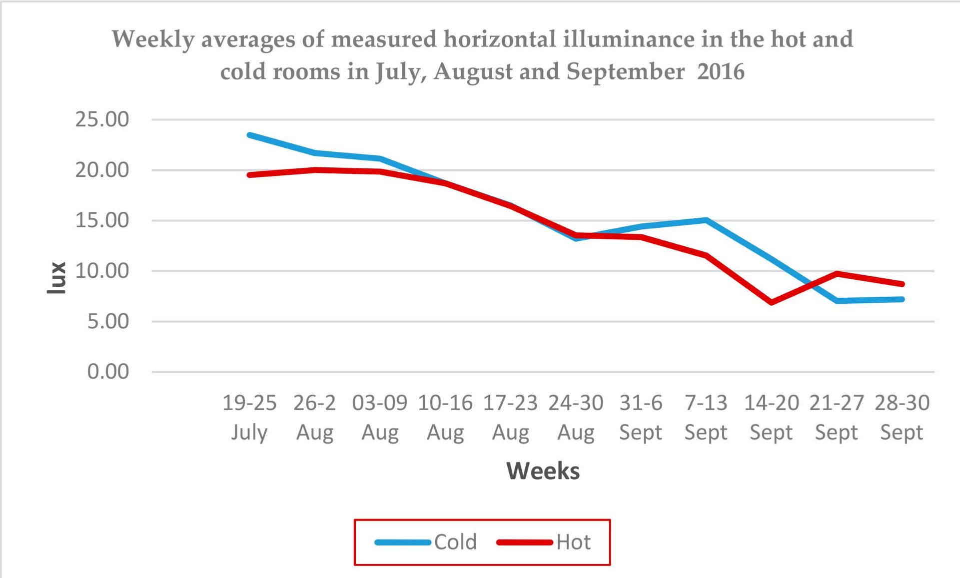


Figure 14. Weekly averages of horizontal illuminance (lx) recorded in the hot and cold rooms (19 July to 30 September 2016).

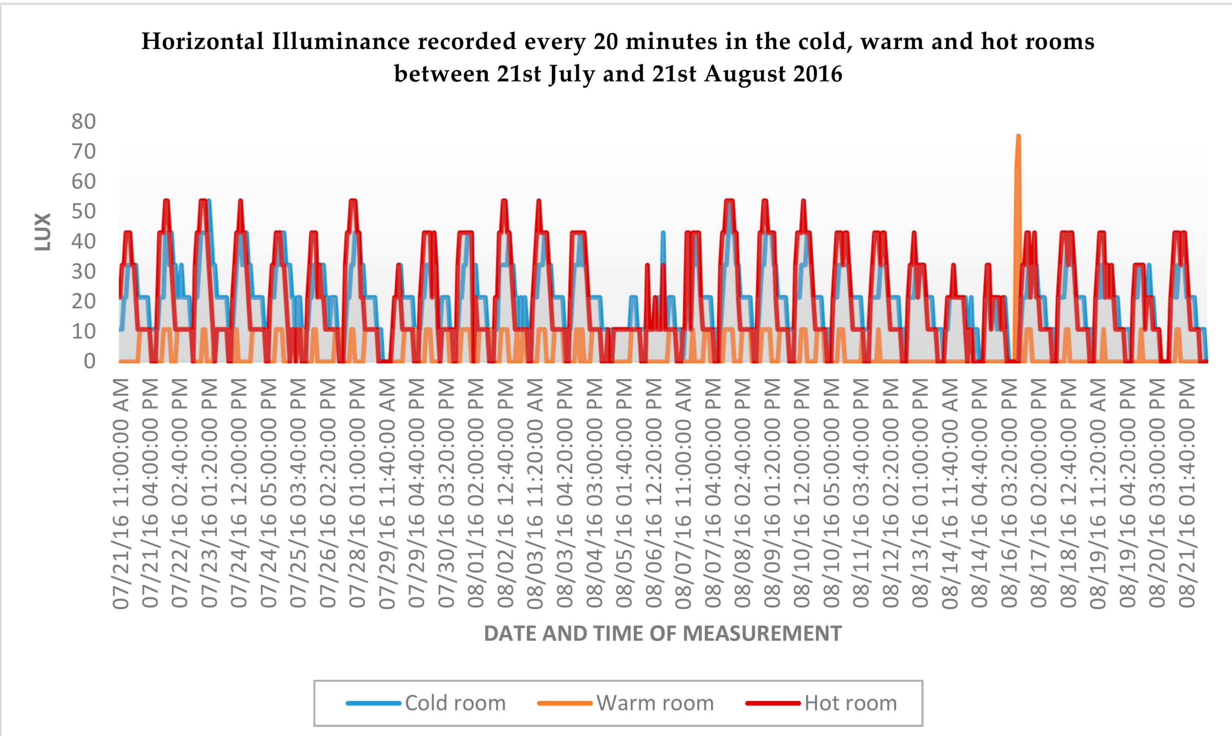


Figure 15. Horizontal illuminance values recorded in the three bathing spaces during the summer of 2016 on a daily basis between 11:00 a.m. and 05:00 p.m.

Table 3. Weekly averages of horizontal illuminance recorded in the cold room, the hot room and the room.

		Weekly Averages			Weekly Maximum			Weekly Minimum		
Wk	**Days**	**Roof**	**Cold Room**	**Hot Room**	**Roof**	**Cold Room**	**Hot Room**	**Roof**	**Cold Room**	**Hot Room**
0	19–25 July	159.3	23.48	19.52	204.49	29.46	23.82	128.35	12.48	13.60
1	26 July–2 August	177.9	21.69	20.01	190.56	25.50	25.51	170.84	14.73	9.07
2	3–9 August	173.8	21.13	19.85	194.34	26.63	27.21	132.26	11.92	8.53
3	10–16 August	136.0	18.69	18.69	177.51	22.66	24.38	32.03	11.33	11.90
4	17–23 August	128.0	16.51	16.44	148.80	22.10	22.11	66.86	3.98	1.14
5	24–30 August	118.3	13.20	13.54	146.91	16.99	18.26	76.875	9.64	8.51
6	31 August–6 September	125.5	14.41	13.36	148.36	19.26	19.28	86.583	6.82	5.10
7	7–13 September	130.3	15.04	11.52	138.50	15.85	13.03	113.70	12.46	10.77
8	14–20 September	112.1	11.18	6.87	144.59	15.86	10.34	21.355	3.96	0.00
9	21–27 September	103.4	7.05	9.73	131.68	10.77	19.27	50.035	0.57	5.67
10	28–30 September	112.6	7.20	8.70	112.97	7.39	13.04	111.23	6.82	3.98

The plotting of horizontal illuminance levels over a period of two months and a half clearly indicate that it is in the hot room where the highest levels of horizontal illuminance were recorded (Figure 15). However, these levels remain well below 100 lx and do not exceed 60 lx (Figure 14). The levels recorded for the warm room remain the lowest as they have been jeopardised by the installation of two large solar panels, casting shadows over the oculi (Figure 12c) and resulting in levels being at 10 lx or below despite the sunny and clear sky conditions during the summer months. However, this indicates that the vernacular daylighting provision works best in conditions where the roof vaults have a good sky exposure and are not shaded by roof installations or adjacent buildings.

There is a rapid decline in weekly illuminance averages in September leading to much lower levels inside the bathing spaces (Figure 14).

The plotting of the 21 July 2016 measurements in the cold, warm and hot room, as well as on the roof, reveals a more detailed pattern of illuminance variation in the three bathing spaces and the roof sky conditions (Figure 16). These plots, together with Table 3, illustrate a clear correlation between the sky conditions and the daylight levels afforded by the vernacular system.

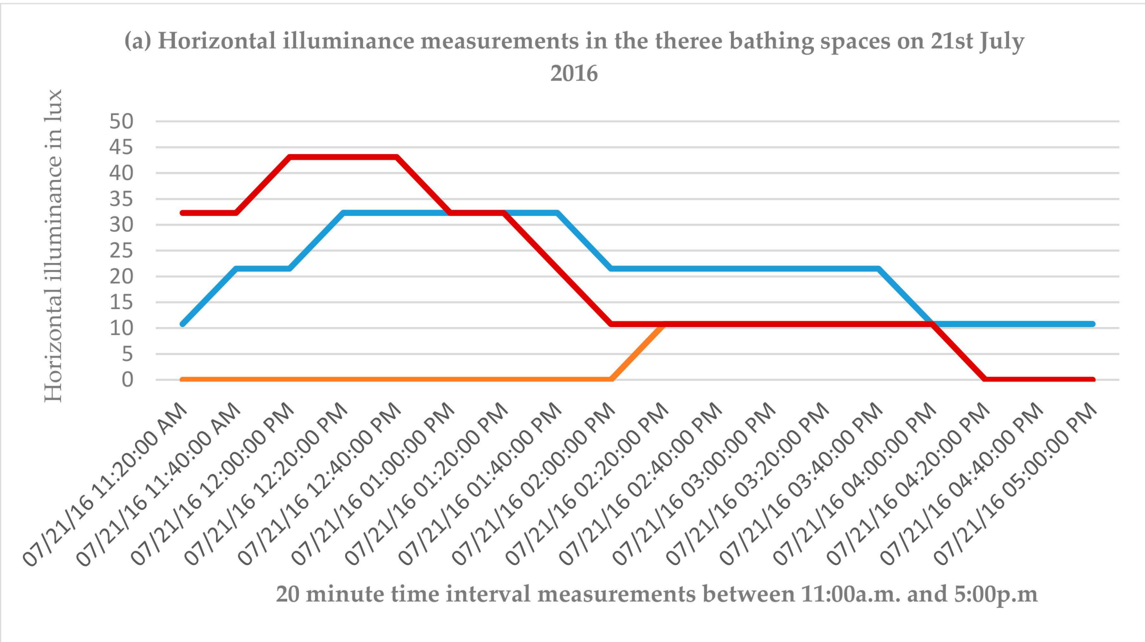
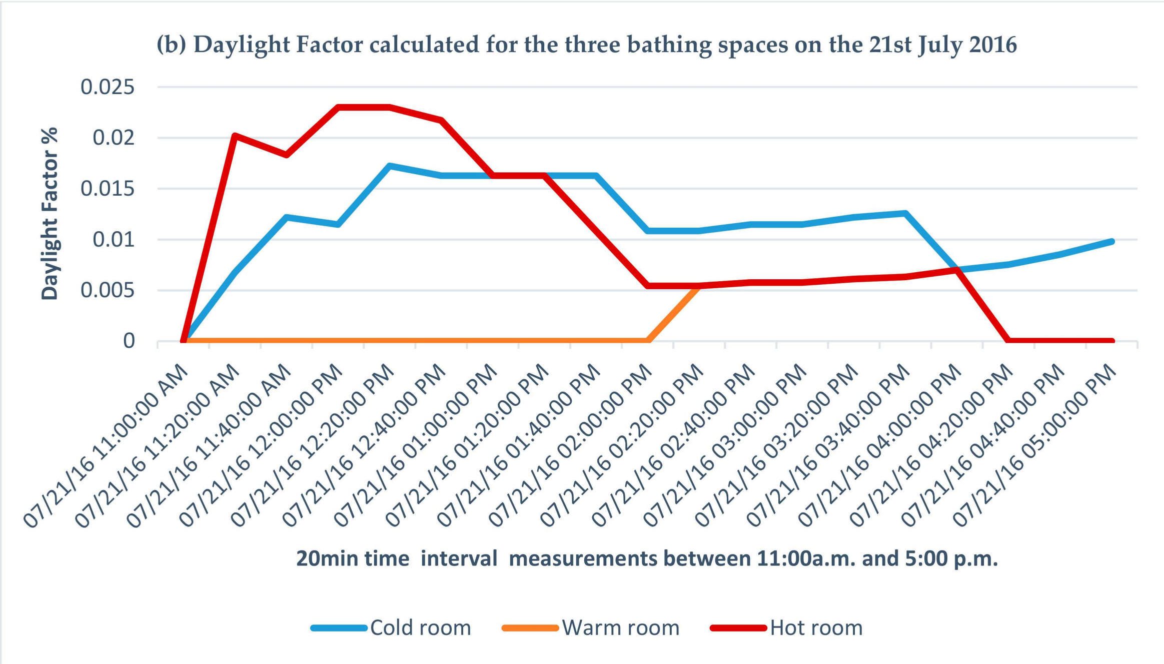


Figure 16. *Cont.*



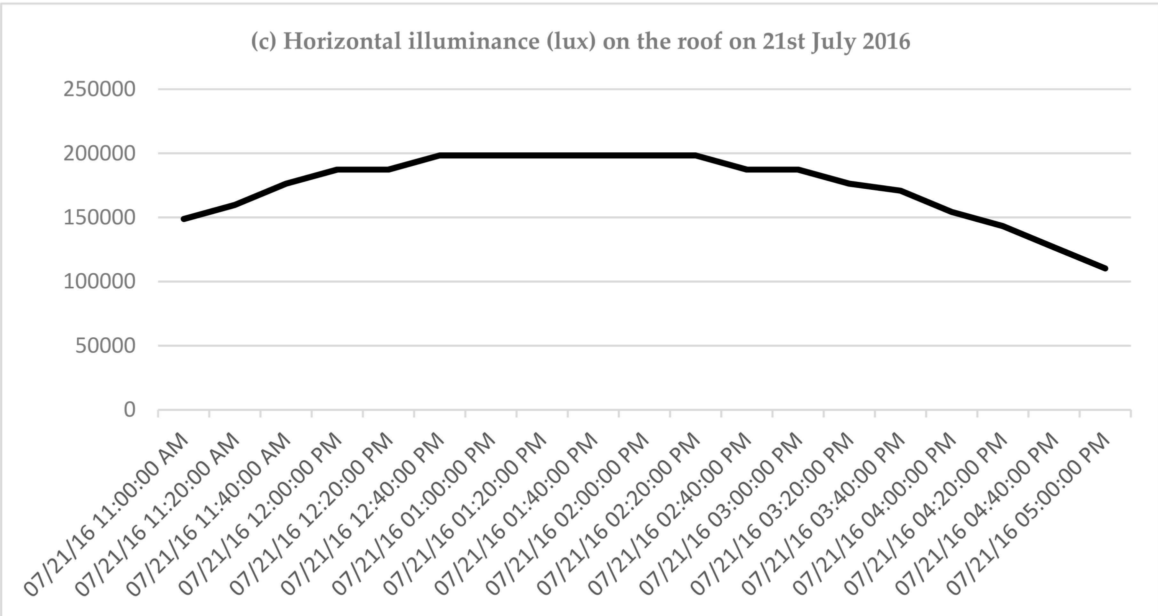


Figure 16. Horizontal illuminance in the three bathing rooms and on the roof and the calculated daylight factor on the 21 July 2016 between 11:00 and 17:00.

The drop in light levels is much more sudden in the hot room than in the cold room and this could be explained by the high level of steam (98% humidity) reached in the space by early afternoon, when the use of the hot room by bathers is at its highest. The daylight factor calculation for the same day, based on real data, reveals that there is a sudden reduction in the DF in the hot room early afternoon (Figure 16b) below that of the cold room as the humidity and steam in the hot room reach saturation levels.

The comparison of recorded illuminance on the roof and the three bathing spaces on the 21 July 2016 (between 11:00 and 17:00) clearly illustrates that the sky conditions are directly reflected into indoor daylight levels in the hammam bathing spaces (Figure 16). This indicates that the vernacular daylighting system in hammam buildings allows for users' strong connection to outdoor sky conditions and to the movement of the sun in the sky which is known to be important for users' well-being.

4. Discussion

Heritage public bathhouses (hammams) of North African Maghreb cities continue to provide an affordable hygiene and well-being facility for their residents. This is particularly the case in Morocco which has the largest number of heritage hammams. It is estimated that there are at least 12,000 hammams operating in Morocco. However, this number is likely to be much higher as new hammams are being built in every single new residential neighbourhood and no recent statistics are available to date. As hammams operate day and night, their electricity bill for lighting the building constitutes 25% of their energy consumption, the remaining 75% are for water and building heating [17]. The reintroduction of daylight into the bathing spaces is therefore estimated to reduce energy consumption by at least 12.5% (half the time is at night) and create healthier environments for both bathers and hammam workers.

The repair of the vernacular lighting system in heritage hammams of all historic urban centres in Morocco and in other North African cities can have a cumulative effect on reducing CO_2 emissions and increase users' well-being as well as revive the glass blowing crafts using recycled glass for the production of oculi glass caps. Furthermore, its adoption and adaptation to contemporary hammam projects can achieve higher levels of horizontal illuminance by increasing the number of roof oculi in the design of new structures in order to meet contemporary expectations of visual comfort from the users while maintaining architectural and cultural authenticity. Bathers, however, lack experience of the original luminous environment and their expectation of higher levels of illuminance has been reported through discussions with the manager of hammam Rjafalla. Although, bathers and staff were happy to see more daylight in the bathing spaces after the rehabilitation of the vernacular system, and commented positively about it, they still expected additional electric lighting to be used, particularly at the end of the summer months. The cultural and religious norms relating to nudity and visual privacy still apply to some extent in the use of the bathing spaces, although they are not always adhered to.

Despite the limitations of previous studies on hammam daylighting in other geographies, it is clear from the results of this study that the horizontal levels recorded in the present case study fall far below those measured in Ottoman hammams where the number of oculi in the roof is much higher than those found in Moroccan hammams.

Moroccan hammams fall under the umbrella of the Ministry of Habous and Religious Affairs (who own the majority of the heritage structures) and the Ministry of Culture and Traditional Crafts. Serious attempts have been made to reduce wood consumption in hammam furnaces to reduce CO_2 emissions, particularly after the COP 22 event held in Marrakech in 2016. However, the reduction of electricity consumption through the reintroduction of daylighting has not been considered. It has also been omitted by a study conducted by the Ministry of Culture and Moroccan Crafts aimed at establishing benchmarks of what constitutes an authentic Moroccan hammam [18]. Furthermore, the integration of bespoke off-grid LED solar powered lighting within the vernacular daylighting system for night illumination, as developed by the author in 2015, can lead to a highly sustainable hybrid innovative solution [17].

5. Conclusions

This paper has provided the first systematic study of the vernacular daylighting provision in Moroccan heritage public bathhouses (hammams). It combines historical and architectural analyses of a representative sample of 13 working heritage structures to reveal tacit rules underlying the number, location and configuration of roof oculi. These are then restored in a working hammam to establish the first benchmark for levels of horizontal illuminance afforded by the vernacular system in the bathing spaces under real working conditions. The results reveal a recurrent pattern of oculi number and configuration consisting of one to three rows of eight circular openings (of 18 to 20 cm in diameter) arranged along the roof vaults covering the bathing spaces.

The total area of roof openings for each bathing space was found to rarely exceed two percent of its internal floor area. Measurements of horizontal illuminance on the roof of sky conditions, as well as that of inside the bathing spaces, were carried out continuously and simultaneously in July, August and September of 2016 at 20 min intervals and at comparable locations. This has resulted in real time values, allowing for the calculation of daylight factor under real changing sky conditions. The results of horizontal illuminance measurements indicate that maximum levels are reached between 12:00 and 14:00 when the sun is high in the sky, but never exceeded 60 lx. The impact of the saturated air humidity on the daylight factor is evident in the hot room where the highest levels of DF are registered but suddenly decrease below that of the cold room as the air humidity levels reach almost 100%. Levels of horizontal illuminance are generally much lower than those recorded in previous studies in Ottoman baths and remain well below 60 lx as compared to 100 or 150 lx recorded in Ottoman hammams. Low levels of daylight are therefore a genuine experiential quality of Moroccan hammams afforded by small oculi in the vaults and domes of the bathing spaces.

This paper has provided a new understanding of the experienced luminous environment afforded by the vernacular daylighting system in Moroccan hammams and established the first benchmark for its rehabilitation in heritage structures and its future integration in new Moroccan hammams. Further studies are needed to investigate bather's sensorial experiences of heritage hammams daylighting ambiences to understand elements of comfort that are outside the norms of numerical quantification of light. As argued by Tregenza and Marjaldevic [19] in their review of half a century of research on daylighting, there are still important questions which fifty years of study have not fully answered: What are the criteria of good daylighting? What should be the central aim of the designer? What regulations or standards are required? "Describing lighting only in terms of illuminance is equivalent to describing music in terms of sound pressure level" [20]. As Bille and Sørensen [20] argue, light works as a significant constituent of experience. In their introduction to *an anthropology of luminosity*, they coin the term *lightscape* and highlight that "*by introducing an anthropology of luminosity; an examination of how light is used socially to illuminate places, people and things, and hence affect the experiences and materiality of these, in culturally specific ways.*" From a phenomenological point of view, Merleau-Ponty [21] argues that "*we do not so much see light as we see in it*."

Further research is needed to carry out wider measurements of illuminance as experienced and perceived by building users, combining real time measurements with recordings of users' space use and reactions during a whole bathing session in a working rehabilitated heritage hammam.

This paper opens up new avenues for further research based on the innovative combination of historical, architectural, building science research and environmental psychology methodologies to reveal tacit rules underlying the luminous environment of heritage buildings, as well as their perceived experimental qualities, in order to provide benchmarks for the rehabilitation of original luminous environment and their reinterpretation in contemporary designs.

Funding: The architectural survey part of the research on the public baths in Marrakech was funded by the Arts and Humanities Research Council (AHRC) as part of the UK grant number [AH/D503019/1].

Acknowledgments: The author would like to thank Khadija Kadiri, the manager of Hammam Rjafalla, for providing me with the opportunity to retrofit the vernacular daylighting system in her hammam, install data loggers and carry out measurements and interviews during the summer months of 2016. Sincere thanks to Mr Hadj Youssef, president of the hammam managers association of Marrakech and to all the hammam managers of Marrakech for allowing me to complete the roof surveys.

Conflicts of Interest: The author declare no conflicts of interest.

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