HEATING SYSTEM EVALUATION OF AN ANCIENT TURKISH BATH; THE BATH OF SULEYMANIYE HOSPITAL

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ABSTRACT

This research aims at evaluating the original heating system of the 16th century historic bath (hamam) section of Suleymaniye Hospital (Darüşşifa), a part of Süleymaniye Mosque Complex in Istanbul, in terms of its original heating system elements, their locations inside the building, suitability, and approximate dimensions and materials.Two types of heating system have been assessed within the context of the study. First, hypocaust underfloor heating provided by means of the circulation of hot smoke produced by the combustion of solid-fuel at the furnace of the bath and circulated under the floors of heated rooms of it has been evaluated. Second, wall heating provided by means of the circulation of this hot smoke inside the vertical chimneys called as *tüteklik* located inside the walls of the bath has been assessed. The research included the reconstitution of original heating system elements such as detection of original and possible locations of brick foots and smoke canals in hypocaust section, of vertical *tüteklik* chimneys inside the walls and their roof extensions, of furnace inside the building and included the distribution of heating system elements at the caldarium, *halvet* and tepidarium sections of the bath. Heated volumes of these spaces (V-m^3), number of vertical *tüteklik* pipes (Tp-n) and ventilation holes (Vh-n) inside the walls of the rooms, thickness of the walls (Tw -m), volume of hot smoke circulated in hypocaust section (Vs –m^3), and effective heated floor surface (A_f-m^2) were the main parameters of heating system elements determined in those spaces. Also, possible thermal performance analysis methods heating system elements of the bath of Suleymaniye Hospital have been investigated. The research developed in this study were considered useful for the evaluation heating system for the similar historical baths.

INTRODUCTION

Research on heating systems of historic buildings is rather limited. Among them, Tsakirgis [1] and Sparkers [2] studied heating and cooking practices in Ancient Greek houses and kitchens, and Wilkinson [3] analysed historic furnace, chimney, and brazier details in Nisapur. Zhuang et. al. [4] studied Kang heating system and its thermal performance mostly used in Chinese houses and Bong and Jeong [5] examined *ondol/gudul* heating in Korean buildings similar to Roman underfloor hypocaust system. Studies of Leonard [6] on ancient braziers and of Fournet and Redon [7] on heating systems of Ancient Greek baths are also among the important research in ancient heating practices. Hypocaust system used extensively in Roman period houses and baths and inspired the contemporary underfloor heating systems [8] has been studied in detail by Yegul [9], Bansal [10] and Turkovic et. al. [11]. Gulsen [12] and Kocyigit [13], on the other hand, examined wall-heating details, and Basaran studied thermal analysis in Roman baths [8, 14-16]. As for the heating system in historic Turkish baths, Onge [17], Aru [18], Akcay [19] and Ulgen [20] made important contributions on Anatolian historic baths. Kırmızıdag-Cicek [21] studied thermal performance of an Ottoman period bath, Disli [22] and Tukel-Yavuz [23-24] examined the heating practices in historic hospitals and caravanserais. In hypocaust underfloor heating system, the floor of the caldarium and tepidarium sections of the baths is raised off the ground, with brick, stone, or wooden footings underneath; this is called the hypocaust section. The occupied spaces above were heated with the hot air produced by means of the circulation of smoke and vapour produced by wood, charcoal, or coal burned in a furnace of the boiler room, which was generally attached to the hot-water storage room of the bath. The excess smoke and vapour that accumulated in the hypocaust section were transmitted through a vertical terracotta pipe called a "*tüteklik*" leading up to the roof [9, 25-26] (Figure 1a). In addition to hypocaust heating, in Roman baths there were also wall heating solutions used to complement the under floor heating system, such as tubuli (box flue tiles), tegulae mammatae (lugged tiles), terracotta spacer pins and spacer tubes of Roman baths. In Roman baths, cavities were created with one of the methods listed above within the main body walls and wall-covering units for the provision of hot air circulation and ventilation, thus for the effective heating of the walls (9, 12-13, 26) (Figure 1b, Figure 1c, Figure 1d, Figure 1e).

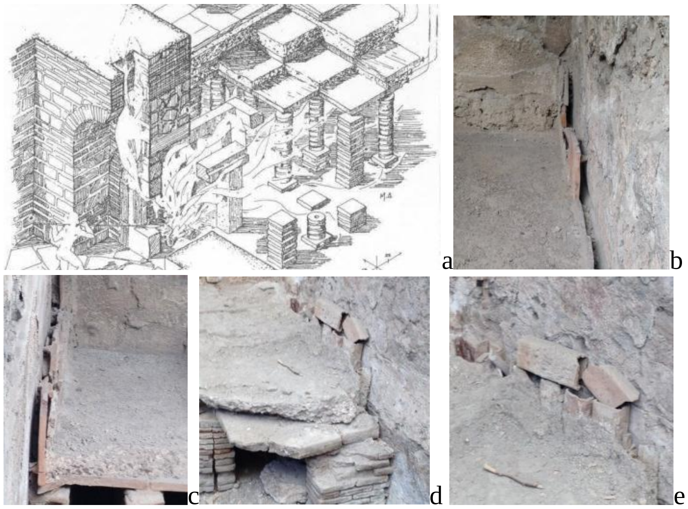
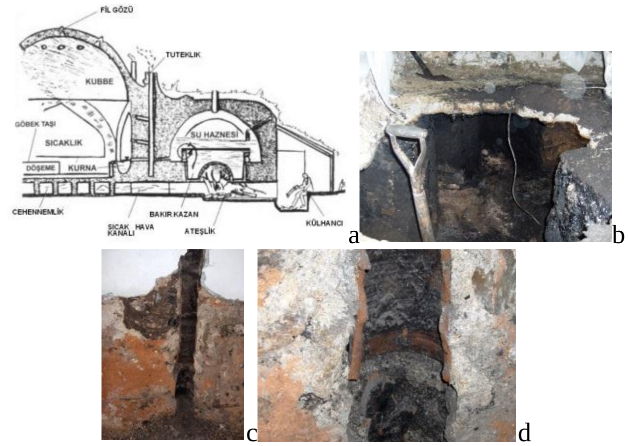

a b c d e

Figure 1 a-Hypocaust Section of Roman Bath in Ankara, Turkey [26] and b, c, d, e- tegulae mammatae and tubuli wall heating details in Pompei, Stabian Bath [27]

HEATING SYSTEM IN HISTORIC TURKISH BATHS

Heating technology of Turkish baths is attributable to Roman baths. In Turkish baths, hypocaust channels, boiler's room and furnace section are the primary underfloor heating elements. In hypocaust section, raised with stone, brick or wooden foots approximately 1.00 m beneath the ground floor surface, hot smoke is circulated through the foots and heats the floor above (Figure 2a, Figure 2b). Water in hot water storage room is also heated by means of the combustion of solid fuel at the furnace located just beneath the hot water storage room. Whereas, wall heating details of Roman baths such as tubuli and tagulaee mammatae are not observable in historic Turkish baths. Instead, those details were replaced with *tüteklik*/vertical pipes located inside the walls with certain rare intervals. *Tüteklik* pipes are made of terracotta and generally circular in section intertwined at the upper and lower parts and raise from hypocaust section up to the roof level. Hot smoke also circulates inside these vertical pipes and excess of the smoke is emitted from the chimneys at the roof. Thus, the bath is heated partially from the walls by means of *tüteklik* pipes (Figure 2c, Figure 2d). In historic Turkish baths, different temperatures and relative humidity values are observable in different sections of the bath. As an instance, in Ankara, Sengül Hamam, a 15th century Ottoman period bath, during site studies in October, 2006, temperature and relative humidity values were found to be 28 C^{o} and %30 in boilers room, 28.1 C^{o} and %92 in tepidarium section of the women's part, 35.1 C^{o} and %100 in central part of the caldarium section, and 32.8 C^{o} and %100 in one of the halvets of the caldarium.[1] Similarly, Aru (1941: 37-40) defines the temperature values 30-40 C^{o} for the caldarium and 20-30 C^{o} for the tepidarium of a typical Turkish bath.

[1] Field observation notes of the authors belonging to Şengül Hamam, 6 October, 2006. *Halvet* is a closed bathing room, generally opening to caldarium section of the bath.



a b c d

Figure 2 a-Heating system detail from a typical Turkish bath [18], b-hypocaust section in Bolu, Mudurnu, Yıldırım Bayezid Bath in Turkey with c-d-*tüteklik* pipe detail [27]

THE BATH OF SULEYMANIYE HOSPITAL

Suleymaniye Hospital was built in 1556 on the northwest side of the Suleymaniye Mosque Complex. The hospital has a double madrasa plan type with two courtyards surrounded by porticos. According to the original waqf deed of the hospital and secondary sources, the bath of the hospital might have been built together with the hospital building for the patients [28].[2] It is a single bath used separately by female and male patients at different days and hours. The bath has three parts; frigidarium, tepidarium and caldarium. Frigidarium is a rectangular space with the dimensions of 2,34 x 5,46 m covered with a vault (Figure 4a). Tepidarium is located on the northwest side of frigidarium, and has a square floor plan with the dimensions of 2,34 x 2,26 m covered with a dome (Figure 4b). Caldarium section is on the southwest side of frigidairum and again with a square plan (2,18 x 2,50 m) and covered with a dome (Figure 4c). *Halvet* with a square floor plan (2,18 x 2,30 m) is opened to caldarium on the southeast side and a toilet is located on the northwest side of the caldarium. Hot water storage room is adjacent to the caldarium and an observation window[3] is opened to the *Halvet* on the northwest wall. Boiler's room is adjacent to the hot water storage room on the north wall and its floor level is ≈0,72 m below the floor level of other sections.[4] Brick is densely used material in the building; walls, vault, domes, chimney of the furnace, hypocaust foots and channels are the main building construction elements with brick. Because bath buildings necessitate privacy during cleaning, oculi illumination openings are used on the domes and vaults instead of window openings on the walls [17], and the same is valid for the case study bath.[5] Wall thicknesses of the bath vary between ≈0,50-1,10 m and total surface area of the bath including the exterior walls is 90 m^2 (Table 1). Volumes, floor,

[2] Suleymaniye (Kanuni) Waqf Deed, M. 1557, Directorate General of Foundations, Archives of Department of Culture and Registration, Ankara, Turkey, 1390/ 135.
[3] It is used to control the level of water in hot water storage room and generally opened to one of the walls of caldarium.
[4] Boiler's room ground floor level is same as the hypocaust floor level.
[5] During its restoration in 2011, 21 oculi illumination glass covers were located on the dome of caldarium section, 18 on the halvet dome, 17 on the dome cover of tepidarium section and 22 on the frigidarium vault cover.

wall, and dome surface areas of each space inside the bath are given in Table 2. Restoration of the bath together with the hospital is substantially completed in 2011, but they are not used in their original function.

Table 1 Data on the interior and exterior wall thicknesses and materials in case study bath building

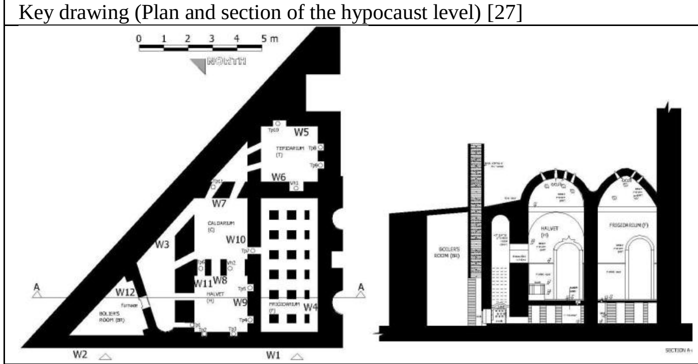
# Wall	Thickness of the wall (Tw) (m)	Wall material
W1	0,65	Brick
W2	0,50	Brick
W3	1,10	Brick +rubble stone
W4	1,06	Brick +rubble stone
W5	0,61	Brick
W6	0,66	Brick
W7	0,66	Brick
W8	0,66	Brick
W9	0,54	Brick
W10	0,54	Brick
W11	0,78	Brick
W12	0,61	Brick +rubble stone
Key drawing (Plan and section of the hypocaust level) [27]		
		
W1[29]	W2[29]	W3[29]
		
W4[29]	W5[29]	W6[29]
		
W7 [27]	W8[29]	W9 [27]
		
W10 [27]	W11 [27]	W12[29]
		

Table 2 Data on the areas and volumes of the bath sections

		Frigidarium (F)	Tepidarium (T)	Caldarium (C)	Halvet (H)	Boilers Room (BR)	Water storage room WSR
Floor surface area (A_f) (m^2)		12,78	5,29	5,46	5,00	4,36	4,48
Wall surface area (Aw) (m^2)	South east	6,74	6,80	6,22	7,98	9,51	3,37
	South west	18,22	8,27	9,15	7,64	9,41	8,67
	North east	19,98	8,27	7,39	8,42	12,33	13,82
	North west	8,56	8,56	6,22	6,22	-	9,48
Surface area of dome/vault/ roof (A_R) (m^2)		26,06	8,31	7,46	7,46	4,36	5,50
≈Interior Volume(V) (m^3)		66,57	24,07	23,30	21,14	15,35	16,40
≈Volume of hypocaust section(Vs) (m^3)		10,61	4,39	3,93	3,60	-	3,23
≈Height of hypocaust section (h) (m)		0,83	0,83	0,72	0,72	-	0,72

Figure 4 Interior views from the vault cover of frigidarium section (a) domes of tepidarium (b) and caldarium (c) [27] and exterior view from the domes and the vault (d) [29]

HYPOCAUST UNDERFLOOR HEATING SYSTEM IN THE BATH OF SULEYMANIYE HOSPITAL

Similar to typical Turkish baths, in the bath of Suleymaniye Hospital, also, hypocaust underfloor heating is observable in frigidarium, tepidarium, and caldarium sections (Figure 5a, Figure 5b, Figure 5c). Because the stone floor covers were not existent and removed during the past interventions, hypocaust sections in those spaces were clearly determined. Thickness of the stone floor could only be detected on the caldarium and frigidarium spaces. Caldarium, *Halvet*, tepidarium, frigidarium, and hot water storage room are the primary heated spaces in the bath. Among them, in typical Turkish baths, frigidarium space is not generally heated by means of hypocaust section; instead, a wall fireplace is used for the thermal comfort of the users. Yet, in the case study bath, the frigidarium section has an ≈0,08 m thick stone floor cover raised with in total eighteen brick foots, ≈0,83 m high, located at the hypocaust section (Figure 5b). In this space, brick foots are bond with ≈0,045 x 0,28 x 0,28 m bricklayers with ≈4-5 cm thick mortar in between. There are no brick foots in caldarium, halvet and tepidarium; instead, in those parts hot smoke produced by the combustion of solid fuel in furnace section is circulated underneath the stone floor covers and through the hypocaust channels opened on the walls extending up to the furnace (Figure 5a, Figure 5c). In caldarium section thickness of original stone floor cover is 0,19 m, and height of the hypocaust section is ≈0,72 m. In these spaces, also hypocaust channels are built with brick material and located as straight or with an angle providing an easy access for the circulation of hot smoke (Figure 5a).

Figure 5 Hypocaust section of caldarium (a) and frigidarium (b) spaces oat the bath of Suleymaniye Hospital [27] and furnace (c) of the boiler's room [29]

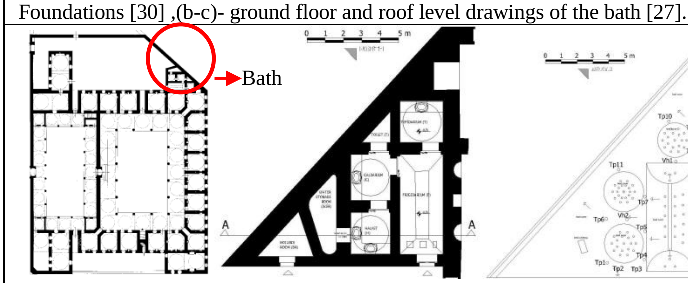
WALL HEATING SYSTEM WITH *TÜTEKLIK* PIPES IN THE BATH OF SULEYMANIYE HOSPITAL

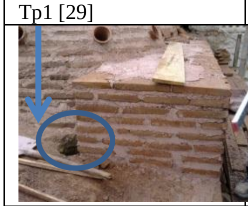
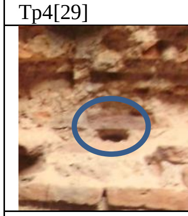
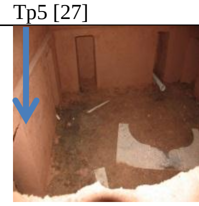
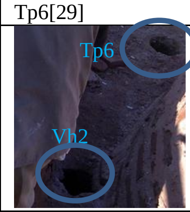
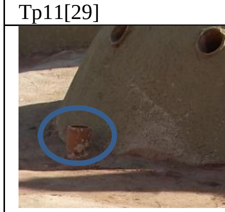
In addition to hypocaust underfloor heating, the bath of Suleymaniye Hospital is also heated indirectly with in total eleven vertical *tüteklik* pipes (Tp) located inside the walls. They are made up of terracotta material, circular in section with a diameter of ≈0,15 m and located ≈0.15 m distant from the surface of the interior walls. Among them five are situated inside the walls of halvet section, three are inside the walls of caldarium and three are located inside the walls of tepidarium section. There are also two ventilation holes (Vh) above the door openings rising up to the roof level. Thus, there are in total thirteen vertical *tüteklik* pipes and ventilation holes located inside the walls of the bath. Vertical *tüteklik* pipes begin from the underfloor hypocaust section and lie up to the roof level. Hence, they both contribute to the heating of the space by means of the circulation of hot smoke inside the walls, and emit the excess hot smoke in the hypocaust section by means of chimney extensions on the roof level. Ventilation holes, on the other hand provide the emission of excess water vapor formed during the cleaning process inside the bathing spaces.

Table 3 Data on the *tüteklik* pipe (Tp) and ventilation holes (Vh) inside the walls of the bath

Tüteklik pipe-Tp Ventilation hole- Vh#	Diameter ≈ (D) m	Material
Tp1	0,15	Terracotta
Tp2	0,15	Terracotta
Tp3	0,15	Terracotta
Tp4	0,15	Terracotta
Tp5	0,15	Terracotta
Tp6	0,15	Terracotta
Tp7	0,15	Terracotta
Tp8	0,15	Terracotta
Tp9	0,15	Terracotta
Tp10	0,15	Terracotta
Tp11	0,15	Terracotta
Vh1	0,15	Terracotta
Vh2	0,15	Terracotta

Key Drawings -(a) Site plan of the hospital- Archives of Directorate General of Foundations [30] ,(b-c)- ground floor and roof level drawings of the bath [27].



a- Hospital Site Plan (bath is on the northwest corner)	b-Ground Floor Plan Drawing of the Bath	c- Roof Level Plan Drawing of the Bath
Tp1 [29]	Tp2[29]	Tp3[29]
		
Tp4[29]	Tp5 [27]	Tp6[29]
		
Tp7 [27]	Tp8-Tp9[29]	Tp10[29]
		
Tp11[29]	Vh1[29]	Vh2[29]
		

CONCLUSIONS

The study has shown up the characteristics of original heating system elements for the Bath of Suleymaniye Hospital (Darüşşifa). It was seemed that the structure had originally well-designed functional heating systems all of which composed a well-functioning structure producing, using, running, collecting and emitting the hot smoke in its hypocaust section and inside the walls by means of vertical *türteklik* pipes in an efficient way. However, those functional heating system elements have not been able to properly function at present due to the inappropriate intervention and lack of maintenance and passing of time. Further studies are needed to discover the thermal performance characteristics of original heating system elements. Further studies are also needed to better understand the relationship between the effective volumes of hypocaust section, as part of hot smoke circulation area, in this case study bath.

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