AN INVESTIGATION ON THE WATER SUPPLY AND DRAINAGE SYSTEMS OF HISTORICAL TURKISH BATHS

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ABSTRACT

AN INVESTIGATION ON THE WATER SUPPLY AND DRAINAGE SYSTEMS OF HISTORICAL TURKISH BATHS

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Historical Turkish baths still keeping their functional systems represent their original architectural and building technologies. Studies on the functional systems of historical baths are therefore needed to discover such technologies and to maintain them in working order.

This study was conducted on a 15th century historical Turkish bath, Şengül Hamamı, in Ankara for assessment of its water supply and drainage systems. These systems comprised of hot and cold-water supply, wastewater and rainwater drainage, were examined in terms of their adequacy, capacity and faults.

Comparisons were made with certain other historical Turkish baths to determine their original water storage and consumption capacities. The investigations were made by using non-destructive methods. Among them, the calculation methods used for discharge capacity assessment of drainage systems in Şengül Hamamı and consumption capacities of its water supply system were adapted and developed from the calculation methods used for contemporary buildings.

Serious dampness problems arising from certain roof drainage faults were identified in the building. The wastewater collection and discharge system was found to have serious problems due to improper grading and inadequate flow dimensions of drains and wastewater channels. The ideal situation for the improvement of discharge systems was discussed together with some suggestions on the urgent remedial interventions, preventive measures and future improvements.

The methods developed in this study were considered useful for the calculation of adequacy and capacity of wastewater and roof drainage systems and of water storage and consumption capacities of water supply system for the other historical baths.

Keywords: Water Supply and Drainage Systems, Drainage Calculations, Non-Destructive Testing, Historical Turkish Baths, Şengül Hamamı

ÖZ

TARİHİ TÜRK HAMAM YAPILARININ TEMİZ VE ATIK SU DÜZENEKLERİ ÜZERİNE BİR İNCELEME

Dişli, Gülşen
Yüksek Lisans, Mimarlık Bölümü, Yapı Bilimleri
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İşlevsel sistemlerini halen korumakta olan tarihi Türk hamam yapıları, kendilerine özgü mimari ve yapım teknolojilerini temsil etmektedirler. Bu nedenle tarihi hamamların özgün işlevsel sistemlerini ve çalışma prensiplerini iyi anlamak, bu yapıların performanslarını devam ettirmeleri ve buna yönelik koruma çalışmaları açısından önem taşımaktadır.

Bu çalışmada, Ankara'daki bir 15. yüzyıl Osmanlı dönemi hamam yapısı olan Şengül Hamamı, tahribatsız yöntemler kullanılarak incelenmiş; temiz ve atık su düzenekleri, yüzey eğimleri, yeterlilikleri, boşaltma kapasiteleri ve aksaklıkları/sorunları bakımından ayrıntılı olarak çalışılmıştır.

Tarihi hamam yapılarının özgün durumlarındaki su depolama ve su tüketimi kapasitelerini belirlemek amacıyla birçok tarihi Türk hamam yapısı incelenmiş;

bu yapıların sıcak ve soğuk su depoları ve gün içerisinde tüketilen azami su miktarı hesaplanmıştır.

Çalışma kapsamında, kızılötesi ısıl görüntüleme, malzeme bozulmalarının görsel analizi gibi yapıya zarar vermeyen tahribatsız yöntemler kullanılmıştır. Bu yöntemlerden, su deposu boyutları, temiz ve atık su/akaçlama düzeneklerinin değerlendirilmesi amacıyla kullanılan kapasite ve yeterlilik hesaplamaları, günümüz yapılarında kullanılmakta olan hesaplamaların, Şengül Hamamı'nın özelliklerine göre geliştirilmiş ve uyarlanmış halidir.

Şengül Hamamı'nın çatı akaçlama sisteminin, bilinçsiz müdahaleler ve bakımsızlık neticesinde günümüz koşullarında yetersiz olduğu gözlenmiştir. Ayrıca su akışına ters olan yüzey eğimleri, yetersiz gider ve toplama kanalı boyutları nedeniyle, yapının atık su toplama ve akaçlama sisteminde ciddi problemler gözlenmiştir. Akaçlama sistemlerinin iyileştirilmesi için uygun koşullar belirlenmiş; acil müdahale gerektiren durumlar ve kapsamlı onarım ve bakım programlarının geliştirilmesi için önerilerde bulunulmuştur.

Bu çalışma ile geliştirilmiş olan hesaplama yöntemleri, diğer hamam yapılarının temiz ve atık su/akaçlama düzeneklerinin yeterlilik ve kapasitelerinin değerlendirilebilmesi açısından önem taşımaktadır.

Anahtar Kelimeler: Temiz ve Atık Su Düzenekleri, Akaçlama Hesaplamaları, Tahribatsız Yöntemler, Tarihi Türk Hamam Yapıları, Şengül Hamamı

To My Parents

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Last but not least, I would like to thank my family for their endless support, great sacrifices, never-ending love and encouragement not only during my thesis study, but also throughout my life so far.

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NOTATIONS

A	Cross-sectional area of flow at the inlet opening (mm^2)
A_b	Effective plan area per basin in caldarium and tepidarium sections of the structure (m^2/basin)
A_R	Discrete effective area of each roof under study (m^2)
A1	timber pitched roof covered with roof tiles above the women's frigidarium section
A2	Timber pitched roof covered with roof tiles above the men's frigidarium section
A_T	Total effective area of each roof under study (m^2)
B	Surface width of water flowing through the inlet opening taken as the width of the spout opening due to its rectangular cross-section (mm)
B1	Mesh-reinforced concrete roof above the caldarium and tepidarium sections
B2	Mesh-reinforced concrete roof above the hot water storage room and the fire wood storage room
C1-13	Wastewater channels
D_O	Gutter depth including freeboard (mm)
DU	Rate of consumed water from the basins feeding the discharge channels (L/s)
f	Factor relevant to the slope
H_F	Height of freeboard (mm)
H_O	Depth of water at outlet (mm)
K	Frequency factor (unitless)
N_{LU}	Loading units: the total number of basins feeding each

	individual waste water channel
R_{LU}	Loading unit rate (L/s)
N_{basin}	Total number of original basins
Q_O	Flow capacity of the discharge units (L/s)
Q_{O1}	Flow capacity of O_1 (outlet in caldarium section) (L/s)
Q_{O2}	Flow capacity of O_2 (outlet in tepidarium section) (L/s)
Q_R	Rate of roof runoff (L/s)
Q_{TR}	Total runoff from each roof under study (L/s)
Q_{TO}	Total discharge capacity of spouts serving each roof area (L/s)
Q_{Rww}	Waste water run off rate of channels caldarium and tepidarium sections (L/s)
Q_{WCmax}	Maximum amount of hot water consumption per basin in a day (m^3/basin/day)
Q_{WW}	Free discharge of each waste water channel (L/s)
t	Period of working hours (s)
r	Rate of rainfall (mm/s)
Ψ	Weighted mean of the discharge coefficient for the roof.
$V_{HWSRmax}$	Maximum usable volume of hot water storage room (m^3)
$V_{CWSRmax}$	Maximum usable volume of cold water storage room (m^3)
V_{WSRmax}	Maximum usable volume of water storage room (m^3)

CHAPTER 1

INTRODUCTION

In this chapter is first presented the argument for and the objectives of the study, under Sections 1.1 and 1.2, respectively. It continues with Section 1.3, “Procedure”, where the basic steps of the study are outlined and conclude with Section 1.4, “Disposition”, in which a preview of what is embodied in subsequent chapters is introduced.

1.1 Argument

Historical structures present the architectural, constructional, cultural and economic features of their time. In other words, they are the basic documents for their constructional technologies and performances. Among these structures, the historical baths are qualified structures providing evidences about the original technologies of functional systems of their time. In the history of Anatolia, which extends up to the 7000 B.C., the historical baths occupy an important place, responding to different demands of mankind according to the geographical conditions. In addition to some archaic baths maintaining their presence partially or wholly up to this time, standing historical Turkish baths represent old traditions and technologies related with water.

There are some studies on the baths and bathing culture in the history (Işık, 1995; Yegül, 2006; Yegül, 1992). However, there is only a limited number of studies on the definition of historical water supply, heating, rainwater and wastewater drainage systems of historical baths and their assessment in terms of adequacy, capacity and faults (Başaran and İlken, 1998; Başaran, 1995; İpekoğlu, *et al.*, 2004; Önge, 1995; Önge, 1988; Önge, 1981 Temizsoy, *et al.*, 2003) and on the non-destructive testing methods to do these investigations (Tavukcuoğlu, Düzgüneş, Demirci and Caner-Saltık, 2007; Tavukçuoğlu, Düzgüneş, Demirci and Caner-Saltık, 2005). However, the discovery of functional systems, the well understanding of their technologies and performances are essential for the maintenance/conservation of historical baths.

In most historical Turkish baths, the traces of the architecture, construction and functional systems can only be observed from the foundations remained as the original part of the structure (Önge, 1981). As Önge stated (1981), although the plan organization of those structures remained almost unchanged through the centuries, due to the unconscious interventions, such as the use of incompatible contemporary materials for repairs, most historical baths have lost their inherent functional technologies contributing to the efficient use of energy and water sources and efficiently functioning drainage systems. The modifications on the water supply and drainage systems of historical baths by adapting the modern central running water system during restorations and the reconstructions of the structures caused the loss of functional systems.

The study was conducted on a 15^{th} century Ottoman bath, Şengül Hamamı, located in the province of Ankara, Turkey. This structure is a typical double bath, still keeping its original architectural features and heating system and presenting the original bathing culture. It was therefore selected in order to examine the original functional systems in terms of rainwater drainage system, hot and cold water supply systems and wastewater collection and discharge systems.

Some other historical Turkish baths keeping their original hot and cold water storage rooms were also selected to discover the ranges of maximum water storage and consumption capacities for the historical Turkish baths.

The use of non-destructive testing methods has a vital importance for historical structures since they allow the analyses of structure without giving any damage. The study is composed of consumption and capacity calculations for water supply and drainage systems of historical baths and supported by other non-destructive testing methods, such as mapping of decay forms and infrared thermography. In brief, the study was considered as a non-destructive study since all investigation techniques that allowed producing data and their analyses were done by using non-touching methods.

1.2 Objectives

The research was conducted to better understand the original characteristics of functional systems in historical Turkish baths, their technologies and performances in terms of their capacity, adequacy and faults. This knowledge is, without doubt, essential to keep their proper functioning for long periods of time and to plan appropriate maintenance/conservation programs developed by the experts from different disciplines for their survival. Therefore, the responsibility of experts in regard to safeguarding and a full understanding of the architectural heritage of those structures are of great concern.

In the light of these concerns, the specific objectives of the study were:

1. To discover the original technologies of some functional systems of historical baths, such as, water supply, waste water drainage systems, roof and surface water drainage systems.

2. To get knowledge on the hot and cold-water storage and consumption capacities of historical baths and ranges of these capacities for the historical Turkish baths between 12th and 19th centuries, belonging to the Seljuk, Principalities and Ottoman periods.

3. To develop capacity calculation methods particular to the historical baths by adapting the contemporary methods to the original characteristics of those structures.

4. To improve the use of non-destructive investigation methods for in-situ analyses, such as infrared thermography, leveling survey and mapping of decay forms. These are practical in-situ methods that their commonly-use is useful for the examination of functional systems of historical structures.

It was finally deemed that results emanating from the methods used in the case of Şengül Hamamı could be applied to the other historical structures in similar conditions for the assessment of their adequacy on a quantitative basis and in order to make suggestions for their improvement and maintenance, such as urgent remedial interventions, preventive measures, and future repair works.

1.3 Procedure

The study was designed to evaluate the functional systems of historical baths by using non-destructive testing methods. Apart from a literature survey conducted on library databases, several field observations of the author and a visual documentation of functional systems gathered from those observations were depicted to obtain required background information. Contact with the General Directorate of Pious Foundations through interviews for the measured drawings was the other sources for this as well as for the interpretation of the results.

A set of non-destructive testing methods was used for the evaluation of functional systems of Şengül Hamamı. The study consisted of the mapping of decay forms, leveling survey, infrared thermography and capacity and adequacy calculations of the water supply and drainage systems. Infrared thermography views were taken by the staff of Middle East Technical University Materials Conservation Laboratory. Information on the method used for the drainage calculations was based on a contemporary method modified and developed according to the characteristics of the building at hand. The relevant standards used for these calculations were obtained from the Turkish Standards Institution.

After gathering all related documents, whole information was analyzed to evaluate the water supply and storage capacity of the bath, wastewater discharge system and the adequacy of the roof and surface water drainage systems. The water storage capacities and number of basins/clients of the bath at hand, were also compared with some other historical Turkish baths belonging to 12^{th} – 19^{th} century in order to assess the daily water consumption rate of the historical baths and also to discuss the relation between the water consumption, number of basins, clients and effective floor area of these structures. Thereafter, whole analyze results were combined in comparison charts.

1.4 Disposition

The study is presented in five chapters, of which this introduction is the first.

In the second chapter, a brief literature survey is given basically on the general description of the historical Turkish baths together with their water supply system, rainwater drainage system, wastewater collection, and discharge systems.

In the third chapter, are given the descriptions of the material, that is, Şengül Hamamı. Its hot and cold water supply system, wastewater discharge system, roof and surface water drainage system are defined in this chapter. Also the non-destructive testing methods conducted on Şengül Hamamı are clearly described.

In the fourth chapter, the results obtained from non-destructive testing methods are presented in tables, figures, drawings, and charts. In the fifth and last chapter, the results are evaluated and discussed in terms of the adequacy, capacity, and faults of the service systems of the bath at hand. Some suggestions for the improvement of these systems and for the maintenance and conservation programs are also explained at this part of the study. Besides, at the end of this chapter the conclusion is drawn summarizing the findings of the study and offering recommendations for further research work.

CHAPTER 2

LITERATURE SURVEY

In this chapter are presented the literature survey with the following headings.

2.1 Historical Turkish Baths

Historical Turkish baths represent the continuous experience of bathing culture in Anatolia. They keep their original architectural and building technologies reflecting the achievements of the past in terms of building materials, functional systems and their design.

Yegül (1992) says that the historical Turkish baths are the continuation of the Roman baths and bathing culture, which started with Classical prototypes of antiquity. The Turks confronted with the bathing tradition of Romans and Byzantines when they arrived in Anatolia. Yegül (2006) also states that Turkish baths developed especially in Ottoman period serving for public needs of cleanliness and such kind of ceremonies as wedding, soldiery and circumcision. The study of Temizsoy, Esen, Şahlan, Tunç and Telatar (2003) supports that statement and describes Turkish bath as a unique synthesis of bathing tradition of Turks by adding their own bathing culture of Muslim concerning for cleanliness and for water usage, on the existing cultural, architectural and technological bathing tradition. Hence, to identify the baths constructed in the land of Anatolia under the influence of Muslim rules, the term Turkish bath is used.

Işık stated (1995) that Turkish baths in Anatolia could be classified into two as the public and private ones. Public baths are called as *halk hamamı* or *çarşı hamamı* that served for the people living in a village, a district or a part of a city. The private baths served for the people living in the palaces, military barracks, caravanserais and the like. Turkish baths represent the typical features of the urban fabric that they were constructed in. In Ottoman period following the Seljuk era, public baths developed both architecturally and culturally reaching a mature state especially in the 16^{th} century.

2.2 Service Areas of Historical Turkish Baths

In historical Turkish baths there are mainly three sections: changing section, bathing section and service section. These sections were explained under respective headings. The plan of a typical historical Turkish bath was given in Figure 2.1.

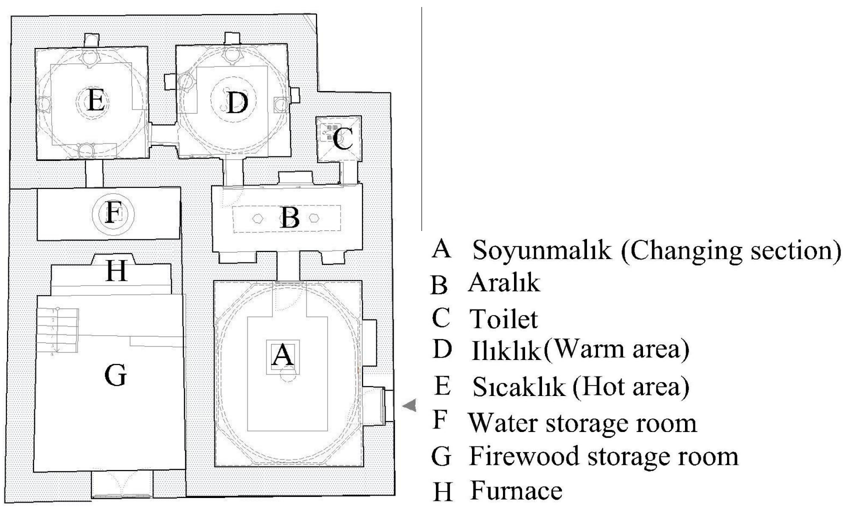

Figure 2.1. An example of a historical Turkish bath: Hacı Hamza Menzil Hamamı, in Çorum.
Source: Archives of The General Directorate of Pious Foundation, 2008

2.2.1 Changing Section (*Soğukluk, Soyunmalık, Camekan, Camegah*)

Başaran (1995) describes the changing section, which is called as apodyterium in Roman baths as the part of the bath used for changing clothes, waiting and resting near the entrance and sometimes it includes the entrance. It is usually the largest section of the bath. The bath is entered from this section directly or from a preliminary entrance space attached to this section. Temizsoy, *et al.*, (2003) state that the space is either covered with a timber pitched roof or with a dome with the illumination by lantern windows (*fener*) placed in the middle. Also as Işık (1995) states, in this section there are usually raised balconies with wooden cubicles, placed for the clients to change their clothes inside. A coffee house functioned for serving coffee for the clients after their hot bath and a small pool, that is, fountain *(şadırvan)* with water jet *(fiskiye)* for enjoying with the sound of water, were the indispensable parts of the changing section of the historical Turkish baths.

2.2.2 Bathing Section

In the study of Önge (1995) it is explained that bathing section is mainly composed of two parts; warm area and hot area, which are called as tepidarium and caldarium in Roman baths, respectively. Warm area called, as *Ilıklık* is the space entered from the changing section and constitutes the first part of the bathing section. Here the body is gradually adapted to heat, before entering hot area. It is usually composed of a main space, toilet and depilatory room. Skylights on the dome illuminate the main space and the walls are surrounded with marble platforms, which are called as *seki* in most of the examples.

Temizsoy, *et al.* (2003) also explains the hot area*, which* is called as *sıcaklık* as the second part of the bathing section. It is the hottest part of the hamam in which the bathing action takes place mostly. It is usually composed of a central space with a marble slab (*göbektaşı*) in the center and of iwans (*eyvan*) and cells (*halvet*s) surrounding this central space. The central space, halvets and iwans are illuminated by the skylights either on the domes or vaults.

Temizsoy, *et al.* (2003) further says that in early examples of Turkish baths, an additional space is observed between changing and bathing sections, which is composed of toilet(s) and depilatory room *(tıraşlık)*, called as intermediate room *(aralık)*. As Işık (1995) states, intermediate room functioned to prevent the changing section from the leakage of hot air and vapor of the bathing section, in later examples, is replaced with a space, which is located between warm area *(ılıklık)* and hot area *(sıcaklık)* thus toilet(s) and depilatory room *(tıraşlık)* become part of the bathing section.

2.2.3 Service Section

Hot and cold water storage rooms; firewood storage room and furnace together with the hypocaust section *(cehennemlik)* constitute the service section of the hamams. Water storage rooms are the spaces where water needed for the cleaning purpose is stored. The hot water storage rooms are generally covered with pointed or barrel vaults. Examples of water storage rooms are photographed in the fieldwork during the study (Figures 2.2, 2.3 and 2.4).

In the study of Önge (1995) it was stated that in order to control amount of water in these rooms, to benefit from the vapor heated there and to be able to do necessary repairs in these rooms, a window opening called as "*observation window*" is located in one of the iwans or halvets of hot area adjacent to the water storage room of the bath (Figures 2.5 and 2.6).

Firewood storage room is another part of service section in historical Turkish baths as Önge (1995) explaines, in which the wood, necessary for heating of the bath is stored. Furnace is the part in fire wood storage room in which the heating of hot water storage room and bathing spaces take place. In this part, there is generally an arched opening in the form of a fireplace opens outside for lighting the fire. Just over the fireplace, in the middle, there is mostly a concave copper boiler for heating water in the water storage room by the fire in the furnace, which is photographed in various examples during fieldwork of the study (Figures 2.7 and 2.8)

Önge (1995) further explaines that, the bathing section of the bath is generally heated by the circulation and dispersion of flame *(alev)* and smoke *(duman)* that result from the burning up of firewood inside the furnace. This circulation and dispersion take place inside the *cehennemlik,* all through the underground of hot and warm area of bathing section, examples of which photographed during the fieldwork of the study are given in Figures 2.9, 2.10 and 2.11.

Temizsoy, *et al*. (2003) states that, there are vertical stacks, called as *tüteklik*, which are the parts of service section designed to support and interrelate hot water supply system in the baths. Vertical stacks *(tüteklik)* are constructed as a hole inside the massive rubble stonewalls but there are terracotta vertical pipes (*künk*) inside them (Figures 2.12 and 2.13). Besides heating, *tüteklik* on the exterior walls provides control of heat loss or transfer while ones on the interior walls keep hot water circulating at a certain temperature inside the bath.

Figure 2.2 A view of the water storage room with brick barrel vault covering above and concave boiler below in Yıldırım Beyazıt Hamamı in Mudurnu, Bolu. *Source : Archives of the Author*

Figure 2.3 A view of the water storage room in Paşa Hamamı, in Beypazarı, Ankara. *Source : Archives of the Author*

Figure 2.4 A view of the water storage room in Yalı Hamamı, in Tekirdağ.

Source: Archives of The General Directorate of Pious Foundation, 2008

Figure 2.5 A view of observation window in Paşa Hamamı, in Beypazarı, Ankara.
Source : Archives of the Author

Figure 2.6 A view of observation window in Yarhisar Köyü Hamamı, in Bursa.
Source: Archives of The General Directorate of Pious Foundation

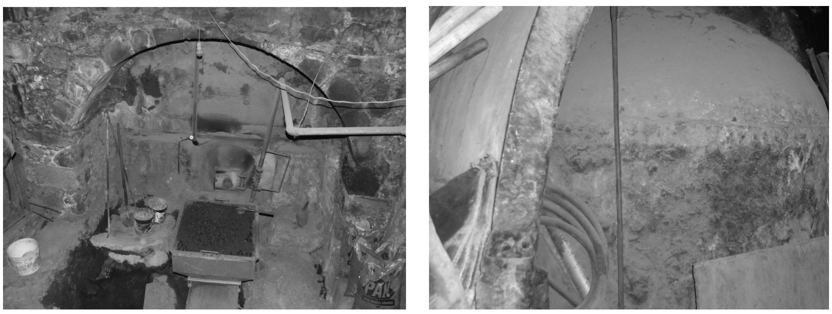

Figure 2.7 Views of furnace section in Şengül Hamamı, in Ulus, Ankara. *Source : Archives of the Author*

Figure 2.8 Views of furnace section in Yıldırım Beyazıt Hamamı in Mudurnu, Bolu.
Source : Archives of the Author

Figure 2.9 Views of hypocaust section *(cehennemlik)* in Paşa Hamamı, in Beypazarı, Ankara.
Source : Archives of the Author

 

Figure 2.10 Views of the hypocaust section in Yıldırım Beyazıt Hamamı, in Mudurnu, Bolu.
Source : Archives of the Author

Figure 2.11 A view of the entrance part to the hypocaust section in Yıldırım Beyazıt Hamamı, in Mudurnu, Bolu.
Source : Archives of the Author

Figure 2.12 A view of *tüteklik* rising inside the wall up to the roof in Yıldırım Beyazıt Hamamı, in Mudurnu, Bolu.
Source : Archives of the Author

Figure 2.13 A view of *tüteklik* in Paşa Hamamı, in Beypazarı, Ankara.
Source : Archives of the Author.

2.3 Water Supply and Drainage Systems of Historical Turkish Baths

A brief literature survey is given below under respective headings on the water supply system and drainage systems of historical Turkish baths through references from selected sources. Due to the fact that there is considerable lack of knowledge in literature on those systems of historical Turkish baths, the data hereunder was supported with the field observations and photographs of the author.

2.3.1 Water Supply System

Önge (1995; 1981) and Yegül (1992; 2006) conducted the most comprehensive studies related with the water supply systems of historical baths. The authors described and visually documented the service systems of most of the historical baths.

Yegül (2006) states that existence of abundant water was necessary to be able to construct a bath in a province. In Ottoman period people was to bring water that would be used in the bath, to the point of city where the bath was built. Then this source of water was connected to the city network and from there to the water storage room of bath with the help of large diameter terracotta pipes. Thus, with the help of the construction of a bath in a region, amount of water brought to a city was increased. How much water could be consumed was written on the title deed, that is, *tapu* of each bath. The amount of water was measured with *masura* and then that water became the right of that bath. One *masura* equalized to $14.5m^3$ and each bath could consume 1.5-2 *masura* water per day. The operators of the bath did not pay any money for the water consumed in the building

Yegül (1992) further states that, before aqueducts became common, wells, cisterns and roof tanks were the components of the water supply system of Roman baths. They continued to be used as the supply of water in small-sized ones even after the development of water distribution system. Similarly, Önge (1981) points out that in historical Turkish baths, like Roman baths, the needed clean water was supplied from natural water sources like stream, lakes and springs or from wells and cisterns. Dissolved snow and rainwater gathered on the roof of the structure was also used as the supply of water.

Onge (1995) says that, the water storage room, terracotta pipes *(künk)* and basins *(kurna)* are the elements of the water distribution system in historical Turkish baths. The hot and cold water is distributed from the water storage rooms to the bathing spaces by means of terracotta pipes and then converted to the taps of the basins. Most of the basins are made of stone. According to the literature survey and field observations, it has been seen that, for the typical historical Turkish baths having iwans and halvets surrounding the center of caldarium section, there are usually two basins placed in halvets and three basins in iwans in original (Temizsoy, *et al*., 2003; Önge, 1995).

İpekoğlu, *et al*. (2004) explains that basins are generally in circular, semi-circular, semi-octagonal or in such similar forms some of which with geometrical or muqarnas decorations (Figures 2.14, 2.15 and 2.16). Önge (1995) claims that the terracotta pipes which are also called *merbah* or *pöhrenk* are placed along the walls of bathing section (Figure 2.17). The author defines those pipes as cylindrical in form and one end is larger than the other to be connected to each other. One end is approximately 9cm, the other is 13cm in diameter, 1.5cm in thickness and 25-38cm in length. They are embedded with a waterproof mortar called *lökün* along the walls Önge (1981) further claims that, in historical Turkish baths, these terracotta pipes are usually connected to the *maslak* or *maksem,* which is in the form of a perforated stone coffer placed in a niche in the height of a person in the wall of the water storage room.

Önge (1981) explains that, the terracotta pipes could be either in two rows both for hot and cold water or in one row only for hot water according to the necessity or the size of the bath. From the field observations the author concludes that only hot water run through the taps of bathing section in most of the historical baths between 12th and 15th century even in the 16th century. In Paşa Hamamı, in Beypazarı, Ankara; in Şengül Hamamı, in Ulus, Ankara; in Yıldırım Beyazıt Hamamı, in Mudurnu, Bolu; in Yarhisar Köyü Hamamı, in Bursa; in Çukur Hamam, in Manisa, and in Kamanlı Hamamı, in Urla, İzmir terracotta pipes are placed in two rows both for hot and cold water (Figures 2.18, 2.19 and 2.20), while as İpekoğlu, *et al.* (2004) states, in Büyük Hamam and Küçük Hamam, in Seferihisar; in Kaleiçi Hamamı, in Sığacık and in Özbek Hamamı, in Düzce terracotta pipes are placed in one row for hot water only.

Figure 2.14 A view of a stone basin in tepidarium section of Yıldırım Beyazıt Hamamı, in Eskiçağa, Bolu.
Source: Archives of the Author

Figure 2.15 A view of a basin in Çukur Hamam
Source: Temizsoy, et al., 2003, pp.8

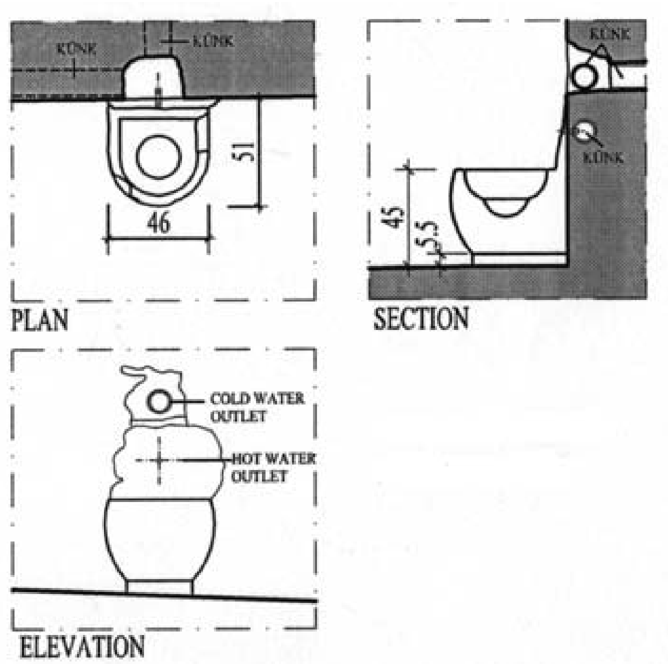

Figure 2.16 Detail of a basin in Çukur Hamam
Source: Temizsoy, et al., 2003, pp.8

Figure 2.17 A view of a terracotta pipe in Paşa Hamamı, in Beypazarı, Ankara.
Source: Archives of the Author

Figure 2.18 Teraces of terracotta pipes observable as the horizantal bant on the wall of Yıldırım Beyazıt Hamamı in Mudurnu, Bolu.
Source: Archives of the Author

Figure 2.19 Terracotta pipes arranged in two rows on top of each other carrying hot and cold waterYarhisar Köyü Hamamı, in Bursa.
Source: Archives of The General Directorate of Pious Foundations, 2008

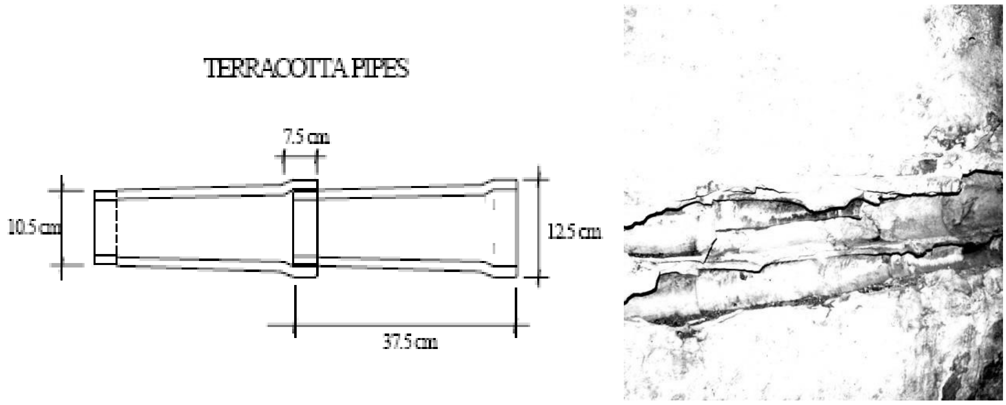

Figure 2.20 Detail of terracotta pipes arranged in two rows in Kamanlı Hamamı, in Urla, İzmir.
Source: İpekoğlu, et al., 2004, pp.8

In an investigation pertinent to the service systems of historical Turkish baths, a 14th century *Beylikler* period hamam, Çukur Hamam, in Manisa was examined in terms of its original water supply system, surface water drainage system and heating system (Temizsoy, *et al.* (2003). In this study, both hot and cold water supply systems of the structure were analysed, in terms of their original slopes and levels. The authors found that in Çukur Hamam, a certain slope was used to carry the water by terracotta pipes and gravity was used for the distribution of water. In the study the terracotta pipes on the walls were observed to be arranged in two lines parallel to each other to carry hot and cold water where hot water pipe line was below the cold water pipe line as shown in Figure 2.21. Both hot and cold water pipe lines were found to have seperate stoppers. The hot and cold-water supply system and wastewater discharge system of Çukur Hamam is given in Figure 2.22.

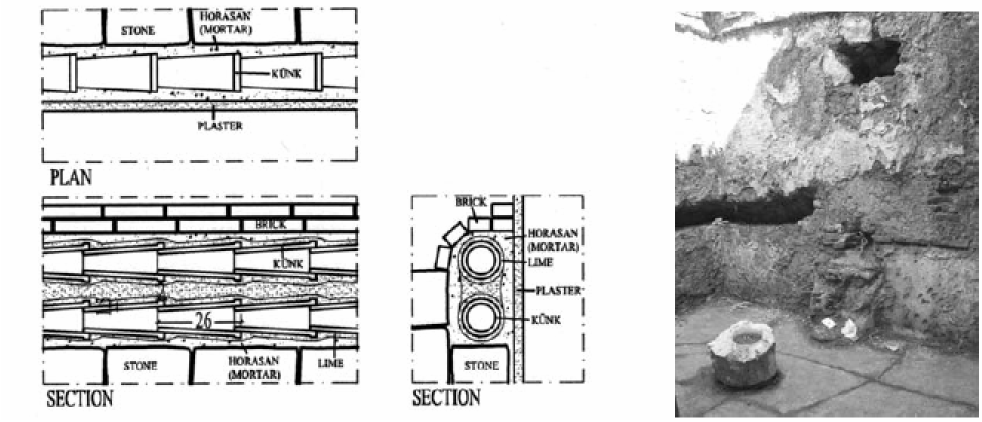

Figure 2.21 Detail of terracotta pipe in Çukur Hamam.
Source: Temizsoy, et al., 2003, pp.4

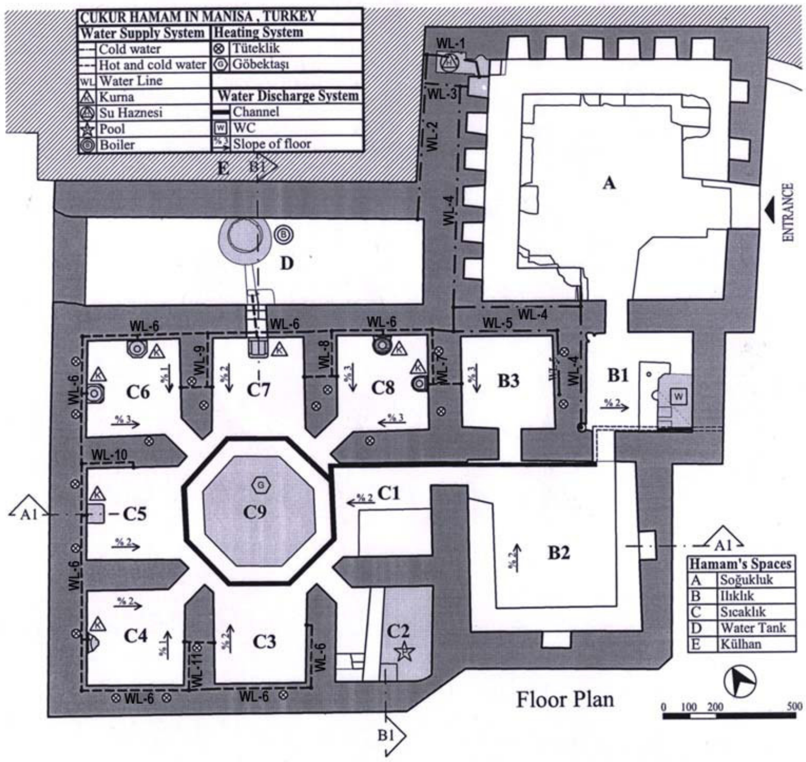

Figure 2.22 Plan of Çukur Hamam showing the hot and cold-water terracotta pipelines which carry water in two lines at a certain slope with a gravity arrangement.
Source: Temizsoy, et al., 2003, pp.4

In another study, İpekoğlu, *et al.* (2004) investigated the water distribution system in a group of Ottoman baths. In that study the authors found that the cold water could was distributed to the bathing spaces after collecting in a cold-water storage room or it could be distributed by terracotta pipes without collecting in a cold-water storage room. In the first case, after collection of clean water in cold-water storage room sufficient quantity was transmitted to the hot water storage room and the rest was distributed to the bathing spaces by terracotta pipes. The authors observed such an arrangement in a double bath in Urla, İzmir. In the second case, clean water was brought to the hot water storage room from the cistern or well either by stone channels or terracotta pipes at the upper level of the hot water storage room. In this arrangement, cold water supplies of both the hot water storage room and the bath were directly transmitted to the taps running in the basins and to the fountain. The authors observed such an arrangement in Ulamış, Düzce and Kamanlı Hamamları (Figure 2.23).

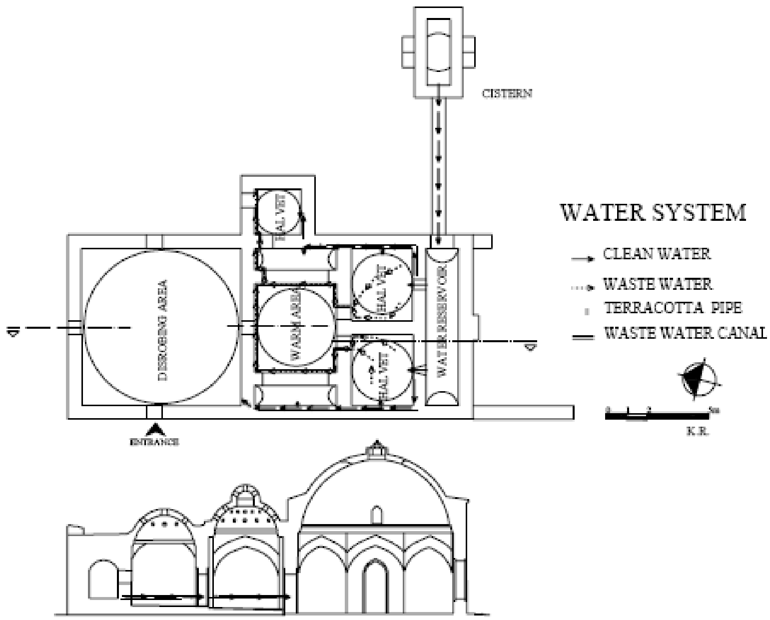

Figure 2.23 Plan and section drawings of Düzce Hamamı showing the water supply system of the structure.
Source: İpekoğlu, et al., 2004, pp.3

In another study, related with the heating of hot water supply of the historical baths, Başaran and İlken (1998) investigated the thermal analyses of the heating system of a small bath in Ancient Phaselis. The authors calculated the heat loss from the reconstructed bath and determined the mass flow rate of the fuel and gas by making the gas analyses. Following the determination of the required design temperature, humidity and thermal conductivity values, a computer program based on the finite difference method was prepared. Thus the temperature distributions, heat transfer to the bath and the change of chimney's gas temperature was calculated by using this program. It was found that there was a rather small amount of heat transfer from the hypocaust section of the bath to the bathing section, which made it impossible to provide necessary temperature conditions in winter times. Başaran (1995) calculated the transfer of heat to be less from the floor and walls than from the roof and unheated walls. The author also found that there were not very big differences in the surface temperatures of floor areas between the caldarium and tepidarium sections since the floor thicknesses were similar to each other though it might be more in caldarium. There are some studies done on the historical water supply systems of Turkey (DSI, 1984; Özand, 1967; Öziş, 1994). In these studies mostly the pipelines of the water supply system were described visually as seen in Figure 2.24 but their capacities were not analyzed.

Figure 2.24 The terracotta pipes carrying hot and cold water to the bath in two lines, in Milet. *Source: Öziş, 1994, pp.63*

Özand (1967) claimed that, though, from the excavations, it was known that the city Ankara was constructed in 2000 B.C. by the Hittite civilization, because of the invasions throughout the history, the earliest traces of water supply system in Ankara could only go back to Roman period. The Romans built so many temples, bazaars, fountains and baths in the cities that they settled. As a result they constructed large water supply installations to bring water to the city and thus to those structures built inside that city.

Özand (1967) did the most detailed study on the history of Ankara city water. The author gave information about the water installations of the city, which had been constructed in the history. The plan of historical water reserves and pipelines of Ankara was given in Figure 2.25. The author also described the water supply planning of Ankara in 1936, which was shown in Figure 2.26.

There were four water supply installations built in Ankara in Roman period which were in Kayaş and Elmadağ (Figure 2.25), (DSI, 1984; Özand, 1967). Özand (1967) stated that, in Ankara, the water needed for the Roman bath was supplied from the water reserve in Kayaş, built in Roman period (Figure 2.25). But only low parts of the city could use that reserve, so another reserve in Elmadağ that was 1000 m high from Ankara was constructed in Roman period (Figure 2.25). Through terracotta pipelines laid underneath, the water needed for high parts of the city was provided. The water supply of Şengül Hamamı might be provided from the water reserve in Elmadağ with terracotta pipes since the hamam was construcuted at a high point of the city. Özand (1967) further stated that the earliest written information about the water supply system of Ankara started in the period of the Governor Abidin Pasha. In that period, the water sources of Elmadağ were repaired to a large extent and the water in these reserves was poured to a water storage located in Cebeci, Abidinpaşa. The water supply of Ankara Castle was also provided with the help of cast iron pipes laid underneath, started from that water storage. Thus the use of cast iron pipes in addition to the terracotta pipelines was observed for the first time in Ankara, in late 19th century.

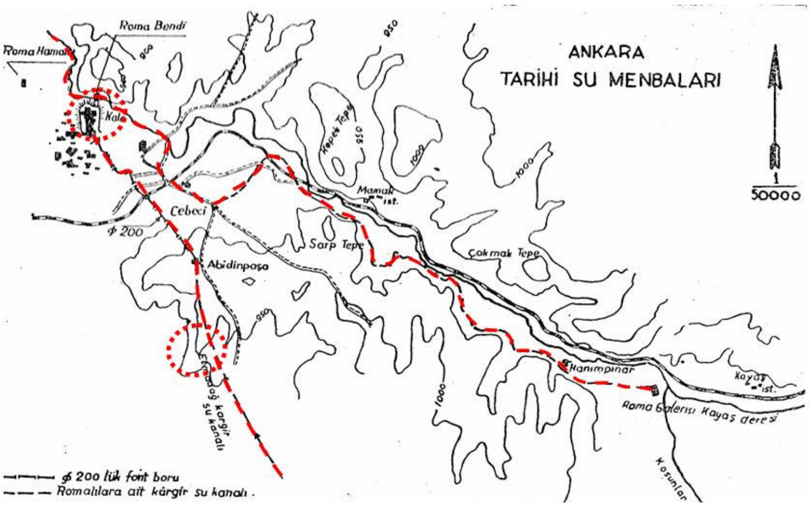

Figure 2.25 The historical water reserves and pipelines of Ankara.
Source: Özand, 1967 pp.5

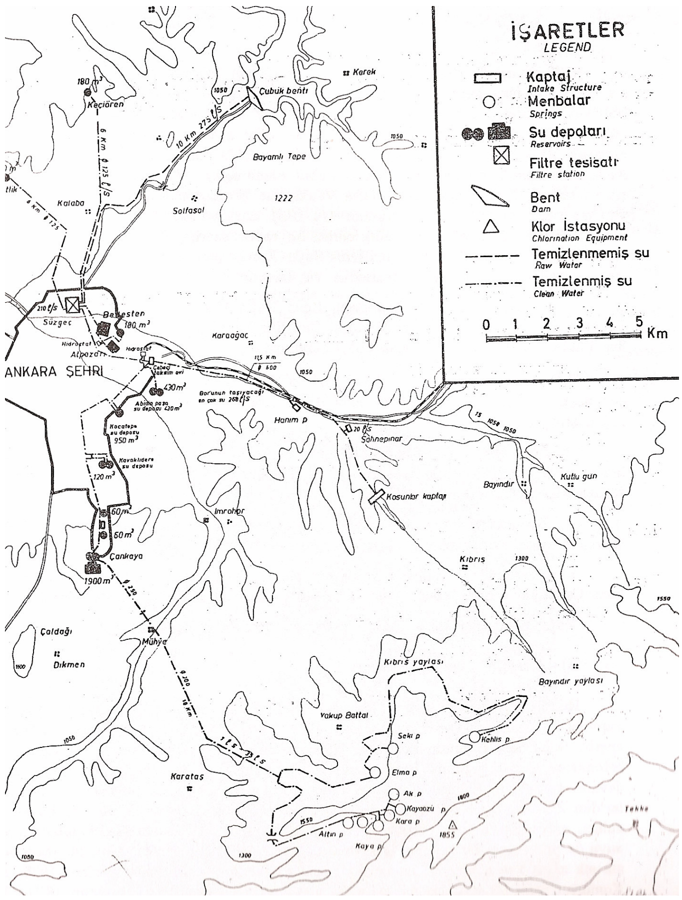

Figure 2.26 Water Supply Planning of Ankara in 1936. *Source: Özand, 1967, pp.9*

2.3.2 Waste Water Collection and Discharge System

In this section are presented the results of various studies conducted on the waste water collection and discharge systems of historical Turkish baths mostly obtained from the field observations of the author, since there is limited study done on that subject.

İpekoğlu, *et al*. (2004) explains that the open channels; arranged on the floors of the caldarium and tepidarium sections of the baths, toilets; discharging the waste water collected through these channels to the outside, floor drains and the outlets constitute the waste water collection and discharge system of historical Turkish baths. The authors further explain that the open wastewater channels are generally located along the walls and/or along the bottom edges of the elevated platforms, which are generally covered with marble. The waste water is directed towards these channels with the help of the inclined floor arrangements of the bathing spaces and discharged either from the toilet or from the corner of the one wall of the structure to the outside (Figure 2.27).

Figure 2.27 A view of the waste water collection and discharge system in Büyük Hamam, in Seferihisar.
Source: İpekoğlu, et al., 2004, pp.7

In a field observation of the author, Yıldırım Beyazıt Hamamı, in Eskiçağa, Bolu was examined in terms of its wastewater collection and discharge system. In that structure waste water coming from the two *halvet* of caldarium section and from the tepidarium section was observed to be transmitted to the outlet located on the west wall of tepidarium section and from there discharged to the outside of the structure.

On the other hand, the wastewater collected on the elevated platform of the caldarium section was directed towards the toilet with a slope arrangement of 2% and discharged from a floor drain located in the toilet. It was found that the dimensions of waste water channels were not the same all through the bath, such that, their dimensions were observed to vary in the range of 7.5-15cm in width and 7-8cm in depth. It was also found that there was a slope arrangement in the bath to direct the wastewater to the wastewater collection channels. At floor level of *halvet* sections, the wastewater was found to be directed towards the caldarium where there was a central wastewater collection system along the wall edges (Figure 2.28). These channels were observed to collect wastewater by means of a slope arrangement varying in the range of 1-3%. However, the slopes in tepidarium were found to be 2 %.

Figure 2.28 A view of waste water collection and discharge channels in Yıldırım Beyazıt Hamamı, in Eskiçağa, Bolu. *Source : Archives of the Author*

In another field observation, wastewater collection and discharge system of Paşa Hamamı, in Beypazarı, Ankara was investigated. In this structure the wastewater was observed to flow from the elevated platforms to the lower levels, and then, it was directed towards the open channels surrounding the wall edges of caldarium section. Their dimensions were observed to vary in the range of 6-12cm in width and 7-20cm in depth. The wastewater collected in these channels was discharged by means of a floor drain with the dimensions of 16.5cm x 19.5cm in width to depth, located in the middle of entrance of the caldarium section (Figure 29).

Figure 2.29 Views of wastewater collection and discharge channels and floor drain in Paşa Hamamı, in Beypazar, Ankara
Source: Archives of the Author

In Yalı Hamamı, in Tekirdağ the open wastewater channels were observed to be arranged along the bottom edges of the elevated platforms and along the wall edges of the caldarium and tepidarium sections (Figure 2.30).

Figure 2.30 Wastewater channels in Tekirdag, Yalı Hamam.
Source: Archives of The General Directorate of Pious Foundations, 2008

As seen in Figure 2.31, İpekoğlu, *et al*. (2004) investigated Özbek Hamamı, in Urla, İzmir and observed that waste water coming from *halvet,* was separately transmitted to the channels lying along the bottom edges of the elevated platforms in the caldarium section and sent to the outside from the corner of one wall. Also as seen in Figure 2.32, in Kamanlı Hamamı, in Urla, İzmir, the authors observed that, the wastewater coming from *halvets* was discharged through the open channels in the main space of the caldarium and was carried from the corner of one wall of the tepidarium to the outside.

Figure 2.31 A view of waste water collection and discharge channels in Özbek Hamamı, in Urla, İzmir.
Source: İpekoğlu, et al., 2004, pp.6

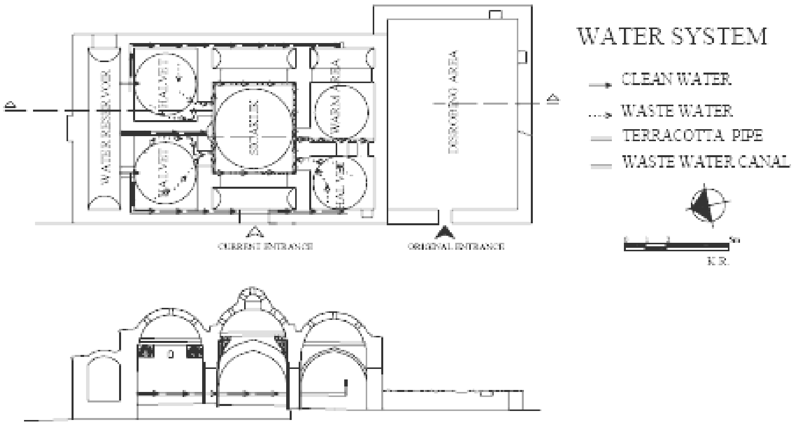

Figure 2.32 – Analyses of the wastewater collection and discharge system in Kamanlı Hamamı, in Urla, İzmir
Source: İpekoğlu, et al., 2004, pp.6

In another study, Temizsoy, *et al.* (2003) examined the surface water discharge system in *Çukur Hamam.* The authors found that the wastewater was directed towards the wastewater channels by means of inclined floor surfaces with the slope arrangement of 2% or 3% from caldarium to tepidarium as shown in Figure 2.22.

2.3.3 Rainwater Drainage System

The study done by Önge (1995) showed that the frigidarium section of historical Turkish baths of 11th and 12th centuries was generally covered with timber frame upper structure with earth covering. After 16th century, most of those earth roofs were replaced with timber pitched roofs with tile covering. However, the author further states that in historical Turkish baths of 12th and 13th centuries, different roof types with different materials are observed. Stone and/or brick vaults and domes were seen in most of those structures to cover the caldarium and tepidarium sections of the roof on which proper roof plasters were coated or even left grouted. The use of lead to cover those stone and/or brick domes and vaults of the structures was started in 15th century with the mud plaster coating underneath.

Although there are some studies on visual descriptions of superstructures and roof types of historical Turkish baths, there is not any study done before on rainwater drainage systems of those structures. However, there is a limited study conducted on the assessment of rainwater drainage systems for historical buildings (Tavukçuoğlu, *et al.*, 2007; Tavukçuoğlu, *et al.*, 2005; Tavukçuoğlu, 2001). In these studies, the dampness problems of Ağzıkarahan (Aksaray) and their sources were examined in terms of rainwater drainage system characteristics, faults occurred in time, material weathering related to these faults and the interaction of climate. A method for the adequacy assessment of roof drainage system was also introduced. In that structure the surface conditions of the roof were found to be unacceptable due to the high propensity for absorption of rainwater and the ideal dimensions for the spout openings were suggested to cope up with the roof runoff.

There are also studies on the roof covering plasters of historical baths (Caner, *et al.,* 2005; Caner-Saltık, *et al.,* 2005; Caner-Saltık, *et al.,* 2004). Investigations showed that there was an advanced plaster technology in history. For instance for two 15th century baths, namely, Hersekzade Ahmet Paşa Hamamı and Yahşi Bey Hamamı, it was understood that, the lime-based roof covering plasters applied in layers, had high water vapour permeation and water proof feature.

In another investigation, Böke and Akkurt (2003) examined two types of historic hydraulic plasters from a selected Ottoman bath; the first of which was original and structurally sound, while the second one was repair plaster and deteriorated. No significant differences were found between the raw material compositions and the pozzolanic activities of them. But ettringite crystals were detected in the historic repair plaster by XRD, FTIR, and SEM-EDS analysis. Then it was claimed that, the repair plaster might be deteriorated due to the expansion generated by the growth of ettringite crystals in the plaster.

In another study Esen, *et al.* (2004) examined the material properties of historic plasters, brick and stone mortars of Çukur Hamam, in Manisa. It was found that the contemporary building materials such as factory brick and cement-based platers/mortars were incompatible with historic ones so could not be used for repair purposes.

Finally, Uğurlu (2006) investigated the material characteristics of *horasan* plasters used in some historical baths belonging to Ottoman period in Urla and Seferihisar (İzmir) by using XRD, SEM- EDX, AFM and chemical analyses. All of the plasters are porous and low dense. Multi-layered *horasan* plaster application with the less porous one as interior finishing layers provide a waterproof surface to the levels beneath.

2.4 Use of non-destructive testing methods

The non-destructive testing methods used during the study are described below.

Mapping of decay forms is one of the methods used during the study. Mapping is the classification, documentation, and presentation of visual deterioration types on a building, its façade, or on the objects. In other words, it is a preliminary on-site visual survey to reveal the salient features and the problem areas of the subject matter. By this method, an historic object or building may be accurately analyzed, non-destructively, and its damage is diagnosed. In this method the amount and distribution of deterioration types of the materials of the structure was surveyed by field drawings. The most common way for the determination of decay forms is the use of Fitzner's method in which the type of decay present in every point of the surfaces and the global extension of each typology of degradation are specified from less severe to severe according to color, deposits, detachments, loss, cracks and so on (Fitzner, Heinrichs and Kownatzki, 1997; Fitzner, Heinrichs and Volker, 1996; Fitzner, Heinrichs and Volker, 1995).

Leveling survey is another method used during the studies, which is a planimetric survey, conducted to record the topographical features of the interior floors, roof, and the immediate grounds of the building periphery at hand. In this method readings are then converted into the detailed maps of the interior floors and the roof, both of which indicating the surface slope arrangement in reference to discharge components, such as wastewater collection channels at interiors of the building or waterspouts of the roof. The maps are used to determine the directions and rates of surface falls and their extents, which make it possible to locate the areas having a potential risk of ponding due to the insufficient and/or reverse slopes (Tavukcuoglu et al, 2005; 2007; 2001).

Infrared thermography method, used mostly for the topics of fuel and energy, is another method used during the study. This method was used in order to investigate the distribution of damp zones in the bath structure and to determine the failure zones, especially where thermal and moisture bridges were observed. The use of this method for the examination of historical buildings is highly increased at present, which gives possibility to produce thermal maps showing the temperature distribution on building surfaces in colors corresponding to a temperature scale (Avdelidis and Moropoulou, 2004; Burnay, Williams and Jones, 1988; Clark, McCann and Forde, 2003; Grinzato, Bison, Marinetti, Concas and Fais, 2004; Grinzato, Bressan, Marinetti, Bison and Bonacina, 2002; Grinzato, Bison and Marinetti, 2002; Grinzato, Vavilov and Kauppinen, 1998; Kandemir-Yücel, Tavukçuoğlu and Caner-Saltık, 2007; Meola, Di Maio, Roberti and Maria Carlomagno, 2005.; Tavukçuoğlu, *et al.,* 2005; Tavukçuoğlu and Caner-Saltık, 1999).

During the thesis study some capacity and adequacy calculations were used. The roof drainage calculations were made to assess the discharge capacity of the roof discharge components and their adequacy whether they provide acceptable rates of water evacuation from roof surfaces. The ideal situations were also examined to achieve a proper roof slope arrangement providing roof areas feeding each discharge component and to determine satisfactory flow dimensions for these components. The roof drainage calculations were based on the methods explained in the literature (Barry, 1988; BRE Part 1, 1976; BRE Part 2, 1976; ISISAN, 1997; Griffin and Fricklas 1995; Hall, v.3, chapter 5, 1996; Hall, v.1, chapter 8, 1994; Tavukçuoğlu, *et al.* 2007; TS EN 12056-3, 2005), and adapted to the characteristics of the roof at hand.

The hot and cold-water storage capacities are examined by calculating the usable volume of storage room. There are some calculation methods defined in the standards in order to calculate the rate of wastewater run off from the taps and the flow dimensions of discharge components for a proper drainage of wastewater (Hall, v.1, chapter 8, 1994; TS EN 12056-1, 2005; TS EN 12056-2, 2005; TS EN 12056-3, 2005).

The water storage/consumption and wastewater drainage calculations based on the methods/standards explained in the literature were adapted and developed for the case of historical bath structures in this study.

CHAPTER 3

MATERIAL AND METHOD

Here are presented the material and method of the study. The former describes the hot and cold water supply systems; wastewater collection and discharge systems and rainwater drainage systems of Şengül Hamamı. The latter presents a detailed account of the various non-destructive investigation methods. These methods covered the mapping of decay forms, leveling survey, infrared imaging, and storage capacity calculations for hot and cold water supply systems and discharge capacity calculations for the wastewater and rainwater drainage systems.

3.1 Material: Şengül Hamamı

Şengül Hamamı is a typical Ottoman double bath (Figures 3.1 and 3.2). It was constructed with stone masonry walls with brick transitions and brick upper structure. The floors of the bath were covered with marble tiles at interiors and the immediate periphery of the building surrounded with asphalt-paved streets at the north, west and south.

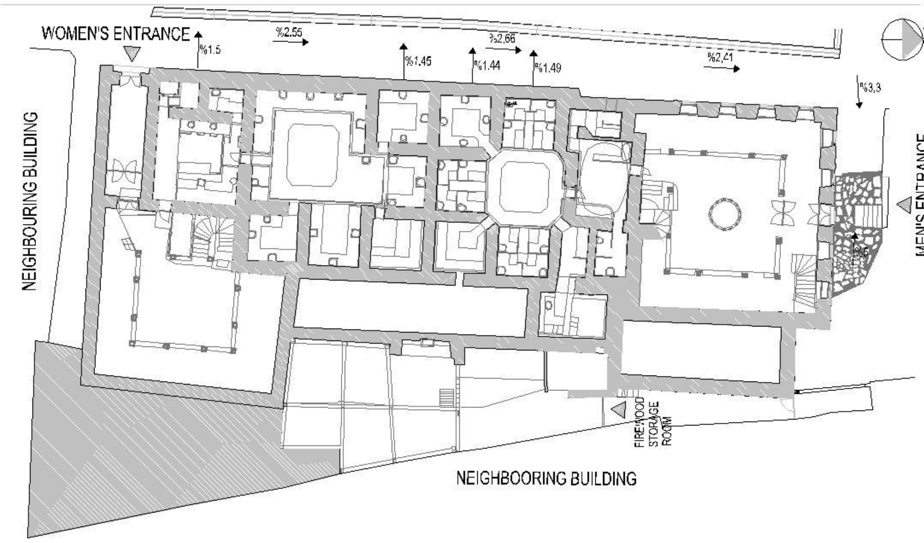

Figure 3.1 Plan of Şengül Hamamı
Source : Archives of the General Directorate of Pious Foundations, 2008

Figure 3.2 Views of Şengül Hamamı: the north façade entrance to the men's part (at the left); the west façade - entrance to the women's part (at the right) and the immediate periphery of the building surrounded with asphalt-paved streets at the north, west and south.
Source : Archives of the Author

The bath is composed of basically three sections: Frigidarium (F), Tepidarium (T) and Caldarium (C). There are also spaces serving for both parts, such as cold-water storage room (CWSR), hot water storage room (HWSR), firewood storage room (FWSR) and furnace (Fu). These sections both for the women and men's part were presented in Figure 3.3. Both sections are heated from underneath the floor. At the center of the caldarium an elevated marble platform, *göbektaşı,* is located, which is the hottest surface of the bath. There are stone basins *(kurna)* in which hot and cold water were mixed to achieve a desired temperature for bathing. In as-is case, there are 43 basins in total: 24 basins in women's part and 19 basins in men's part. The firewood storage and hot and cold-water storage rooms are located at the east side of the building as shown in Figure 3.3. The furnace is located at the bottom of hot water storage room.

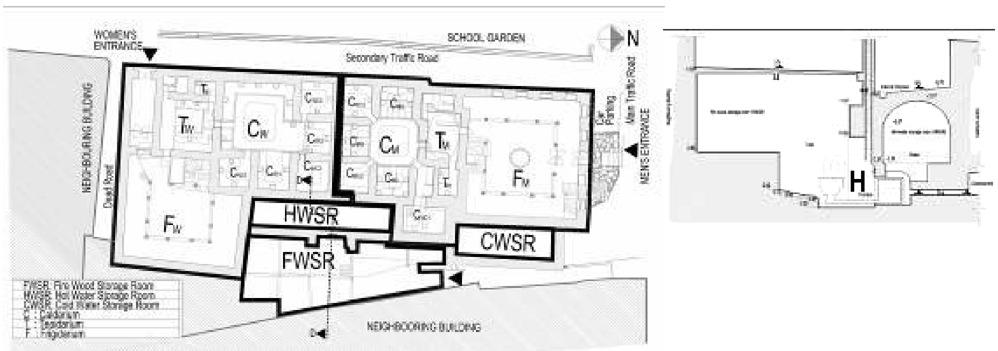

Figure 3.3 Plan of Şengül Hamamı showing the sections for women and men's parts and the section DD showing the locations of furnace and hot water storage room.
Source : Archives of the General Directorate of Pious Foundations, 2008

3.1.1 Hot and Cold Water Supply of Şengül Hamamı

As cited in the literature survey section, according to the operators of Şengül Hamamı, the cold-water was supplied to the structure from the mountain Elmadağ, located 41 km at the east of Ankara.

The potable water has been carried to the cold water storage room of the structure, by means of large-sized terracotta piping system, called as *"maslak"* or *"maksem"*, which is the main branch of cold water supply to the structure (Önge, 1995; Önge, 1981). Terracotta pipes buried in the masonry wall in two lines provided the water distribution in the structure: the first line was for the cold-water (unheated water) and the other one was for the hot water (heated water) supply. The original water supply system is not visible at present, however, the traces of terracotta piping is still observable in Şengül Hamamı, carrying cold water from the cold water storage room to the hot water storage room (Figure 3.4). At the interiors, the stoppers of the historical water supply system feeding the taps of stone basins were also visible on the wall (Figure 3.5). The old water supply system is out of usage at present. Instead, a cast iron piping system functions and runs horizontally on the wall at a level above the historical one hidden in the wall. The usable volumes of hot and cold-water storage rooms, in other words, their maximum water storage capacities, Q_{WC}, were 45m^3 for hot water storage room and 62m^3 for cold-water storage room. Since the cold water storage capacity of the bath is larger than the hot water storage capacity, carried water must have been used at the first centuries of its construction that is before the water source of Elmadağ was connected to the bath to feed the storage rooms. The values found for the water storage room capacities were the original capacities of the bath since the dimensions of the storage rooms and overflow and outlet levels were not changed in time.

Figure 3.4 Views of the traces of the historical terracotta piping in Şengül Hamamı, running at the west wall of the firewood storage room.
Source : Archives of the Author

Figure 3.5 Views of the stoppers belonging to the old water supply system located close to the level of present piping system.
Source : Archives of the Author

3.1.2 Wastewater Drainage of Şengül Hamamı

The waste water flows from the elevated platforms to the lower levels, and then, by means of cross falls, it is directed towards the center of caldarium where there is a central waste water collection system surrounding the elevated marble platform (Figure 3.6). The discharge components of the wastewater collection and discharge system were the open channels and floor drains. Their dimensions were observed to vary in the range of 6-4cm and 14-18cm in width and depth, respectively. The wastewater collected in these channels was discharged by means of floor drains located in the toilets and then towards the wastewater manholes located on the street (Figure 3.7). All floors of Şengül Hamamı were recently repaired with new marble tiles and the historical surface grading together with the discharge systems seemed to be renewed.

Figure 3.6 Views of wastewater collection and discharge system in Şengül Hamamı.
Source: Archives of the Author

Figure 3.7 Views of waste water channels and of floor drains in Şengül Hamamı.
Source: Archives of the Author

3.1.3 Roof and Surface Water Drainage of Şengül Hamamı

The roofs above the tepidarium and caldarium sections, hot water storage and firewood storage rooms of the bath, including the dome surfaces, were repaired with an addition of 8 cm thick mesh-reinforced concrete layer (Figure 3.8). The roofs of the frigidarium sections at the north and south are timber pitched roofs covered with fired-clay roof tiles (Figure 3.9). The immediate periphery of the structure was totally surfaced with asphalt pavement.

Figure 3.8 General views of the mesh-reinforced concrete roof above the caldarium and tepidarium sections.
Source: Archives of the Author

Figure 3.9 Views of the pitched roof, A1, over the frigidarium of women's part (at left) and the pitched roof, A2, over the frigidarium of men's part (at right) with their discharge components: gutters and downpipes *Source: Archives of the Author*.

The roof areas under study were presented in Figure 3.10. These areas were composed of four roof areas; A1, A2, B1 and B2, having different geometry and drainage systems (Figure 3.10). The roofs A1 and A2 were pitched roofs similar with each other, consisted of two parts; the four-sided pitched roof covering the square area and the lantern roof at its top. A peripheral drainage system was provided by means of zinc eaves gutters and fourteen down pipes, some of which discharge water directly onto the concrete-clad roof, B1 (Figure 3.11).

The roof B1 was a low-slope roof including domes, configured to provide peripheral drainage, with flows from elevated interior edges to lower exterior ones, and then, to waterspouts located at the eaves level along the west side of the roof (Figure 3.11). There were nine spouts, with similar dimensions, serving this roof area.

The roof B2 was a flat roof configured to provide an internal drainage, with flows towards an internal gutter located at the middle of the roof area (Figure 3.11). The water collected in the gutter was discharged through a grilled outlet located at its north end, and then, carried by a drain line (buried in the garden) to the rainwater drainage network (buried under the street) (Figure 3.12).

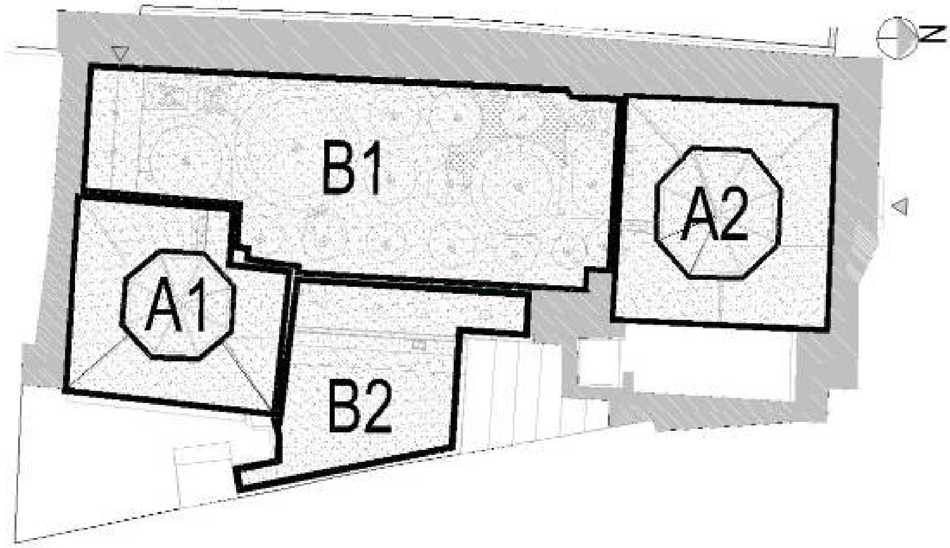

Figure 3.10 Plan of the building, showing the roof areas under study and immediate grounds: **A1–**timber pitched roof covered with roof tiles above the women's frigidarium section; **A2-**timber pitched roof covered with roof tiles above the men's frigidarium section; **B1–**mesh-reinforced concrete roof above the caldarium and tepidarium sections; **B2–**mesh-reinforced concrete roof above the hot water storage room and the fire wood storage room; **Grey-shaded areas–** immediate grounds of the building.
Source: Archives of The General Directorate of Pious Foundations, 2008

Figure 3.11 Views of the building, showing the roof areas under study.
Source: Archives of the Author

Figure 3.12 Views of the interior gutter and the drain discharging water from concrete clad flat roof, B2 and view of the drain line (buried in the garden) towards the drainage network (buried under the street).
Source: Archives of the Author

3.1.4 Other Historical Baths Examined For Comparison

In order to make comparison between the hot and cold-water storage and consumption capacities of Şengül Hamamı with the other historical baths, the study was carried out on some other historical Turkish baths as well. There were, in total, 28 baths; 13 double baths and 15 single baths under study, belonging to the periods between 12th and 19th centuries. Their names, types, periods and regions were given in Table 3.1.

Table 3.1 Names, types, periods and regions of historical baths under study.

Number	name of the hamam	Bath type	Century	Region	Number	Name of the hamam	Bath type	Nentury	Region
1	Kurtuluş Hamamı	Single	16th	Hatay	15	Valide Sultan Hamamı	Double	17th	Manisa
2	Hacı Hamza Menzil Hamamı	Single	16th	Çorum	16	Tekirdağ Yalı Hamamı	Double	19th	Tekirdağ
3	Eski Hamam	Single	16th	Kilis	17	Yıldırım Beyazıt Hamamı	Double	14th	Bolu
4	Orta Hamam	Double	14th	Bolu	18	Hacı Hekim Hamamı	Double	16th	İzmir
5	Pertev Paşa Hamamı	Double	16th	Kocaeli	19	Karataş Hamamı	Double	17th	Çankırı
6	Paşa Hamamı	Single	13th	Ankara	20	Yıldırım Beyazıt Hamamı	Single	14th	Bolu
7	Orhangazi Gürle Köyü Hamamı	Single	14th	Bursa	21	Yarhisar Köyü Hamamı	Single	14th	Bursa
8	Çayırcık Hamamı	Single	N/A	Kastamonu	22	Yıldırım Emir Sultan Hamamı	Single	15th	Bursa
9	Cinci Hamamı	Double	17th	Karabük	23	Paşa Hamamı	Single	17th	Amasya
10	Aksu Hamamı	Single	N/A	Bursa	24	Vakif Hamamı	Single	12th	Kastamonu
11	Gazi Süleyman Paşa Hamamı	Double	14th	Bolu	25	Tabaklar Hamamı	Double	16th	Bolu
12	Şengül Hamamı	Double	15th	Ankara	26	Gölyazı Köyü Hamamı	Single	N/A	Bursa
13	Eynebey Hamamı	Single	16th	Ankara	27	Saray Hamamı	Double	15th	Edirne
14	Sahip Ata Hamamı	Double	13th	Konya	28	Gülgün Hatun Hamamı	Single	14th	Manisa

3.2. Methods

The hot and cold water supply systems, waste water collection and discharge system and rainwater drainage system of Şengül Hamamı were examined by non-destructive testing methods. The methods used, were summarized below under respective headings.

3.2.1 Mapping of Visual Decay Forms

The maps of visual decay forms, observed on building facades were produced in three groups by using Fitzner method as cited in the literature survey section. These were the maps showing material loss; material detachment and discoloration; deposits and cracks on building surfaces. The 1/50-scale north and west elevation drawings of the building were used during the fieldwork on site. Damages were then recorded as damage classes with legends and color was used to identify those classes. The image file was then converted to 256-color bitmap file by using Photoshop 8.0 program. A style and color for each damage type and category was then established and applied in the final drawings.

The method of mapping of visual decay forms was also adapted to the roof to determine the roof drainage faults of the structure. The failures on the roof were mapped to identify the lack of discharge components, ponding areas on roof surfaces; parapets obstructing the free flow of rainwater and deteriorated discharge components. The results of the roof faults determined by the other methods were also included in these roof failure maps.

3.2.2 Leveling Survey

Topographical measurements were taken at all building corners, both internal and external, and at points immediately below the centerlines of roof drainage spouts along wall surfaces. At the exteriors, the leveling survey was designed to cover the overall roof surfaces and the strip of ground on the building periphery in the range of 1.5-2.5m wide. At roof, level measurements were taken at all parapet and chimney corners and the edges of dome skirts, at critical points of ridges, valleys and gullies and at the inlets of discharge spouts. All spot height readings and lateral distances were taken with a “SOKKIA 520V Total Station” optical surveyor’s instrument consisting of an electronic theodolite, an electronic distance measuring device and its software for calculations of readings.

3.2.3 Infrared Thermography (IRT) Survey

The infrared thermography survey of the structure was conducted on the exterior surfaces of the roof and walls. Special attention was given to the lower parts of the walls at points where a roof drainage component existed overhead. Damp zones were compared with the risky areas for ponding.

The study was carried out once in July at night and once in November at night by using the “AGEMA ThermaCAM 550” and “FLIR ThermaCAM E65” thermographic equipments, respectively. The cameras were given inputs on ambient temperature, relative humidity, and distance to target area and on emissivity of target surfaces to obtain accurate on-site measurements. Climatic data were recorded by using an environmental meter, “Kestrel 3000”. The moisture content of some problem areas, where necessary, was measured by means of a protimeter, “Surveymaster SM”. Images were then analyzed by using the software of "ThermaCAM Reporter 2000". Infrared images of wall and roof surfaces were taken in segments together with their visible-light photographs.

3.2.4 Roof Drainage Calculations

The calculations were based on a rainfall rate of 0.03 mm/s, which corresponds to the maximum rainfall rate in that region according to the long-term meteorological data, and on the equation given below (Tavukçuoğlu, *et al.,* 2007; TS EN 12056-3, 2005);

$$(Q_R = r \text{ x } A_R \text{ x } \Psi) \qquad (1)$$

where Q_R is the rate of roof runoff (L/s), r the rate of rainfall noted above (mm/s), A_R the effective roof area (m^2) and Ψ the weighted mean of the discharge coefficient for the roof. The value of Ψ indicates the ratio of unabsorbed water running over surfaces and varies according to surface conditions.

The weighted mean of the discharge coefficient, Ψ, was taken as "0.8" for the roof surfaces with a slope arrangement less than 15°, such as flat surfaces of roof B1 and B2 and low-sloped domes of roof B1 (ISISAN, 1997; Hall, v.3, chapter 5, 1996; Tavukçuoğlu, *et al.* 2007), "0.3" for earth covered roof area in roof B1 (Hall, v.1, chapter 8, 1994; Tavukçuoğlu, *et al.* 2007) and "1.0" for the roof surfaces with a slope arrangement greater than 15°, such as high-sloped domes of roof B1, pithched roofs of A1 and A2, wall surfaces surrounding the roof areas and for the drums of the domes (ISISAN, 1997; Tavukçuoğlu, *et al.* 2007).

The effective roof areas A_R were calculated by the following equation;

$$A_R = (A \times f) \quad (2)$$

where, *f*, is the factor relevant to the slope and *A* is the plan areas of the roof (Barry, 1988; Tavukçuoğlu, *et al.,* 2007),

The factor relevant to the slope *f* was taken as "1.0" for the roof surfaces with a slope arrangement less than 30° such as flat surfaces of roof B1 and B2 and low-sloped domes of roof B1, "1.15" for the roof surfaces with a slope arrangement between 30° and 45°, such as pitched roofs of A1 and A2, "1.4" for the roof surfaces with a slope arrangement between 45° and 60° such as high-sloped domes of roof B1 and as "0.5" for the roof surfaces with a slope arrangement above 70° such as the wall surfaces surrounding the roof areas and the drums of the domes (Barry, 1988; Tavukçuoğlu, *et al.,* 2007).

The walls surrounding the north and southeast of the concrete-clad roof, B1, the drums of the main domes above the caldarium sections and the walls surrounding the east, west and south of the concrete-clad roof, B2, were added to the effective roof area, due to their considerable amount of surface areas. Dimensions of all spout outlets, eaves gutter and downspouts were also taken to facilitate capacity calculations (Tavukçuoğlu, *et al.,* 2007).

A typical peripheral drainage system, consisted of eaves gutter and downspouts, was configured for the pitched roofs, A1 and A2. The discharge elements for the concrete-clad roof, B1, were only the spouts at the eaves level while a different system composed of a concealed channel connected to a drain were used to discharge water from the concrete-clad roof, B2. The flow dimensions of all discharge components had to provide a discharge rate that would not cause water back up. The effectiveness of each component, therefore, was checked individually. Their flow capacities, *Qo,* for a free discharge was calculated from the following equation (BRE Part 1, 1976; BRE Part 2, 1976; Griffin and Fricklas 1995; Hall, v.3, chapter 5, 1996; Tavukçuoğlu, *et al.,* 2007; TS EN 12056-3, 2005),

$$(Q_O = (A^3 / B)^{1/2} \text{ x } 10^{-4}) \qquad (3)$$

where Q_O is the flow capacity of the outlet (L/s), A the cross-sectional area of flow at the inlet opening (mm^2), B the surface width of water flowing through the inlet opening (mm) taken as the width of the spout opening due to its rectangular cross-section (Figure 3.13) (Tavukçuoğlu, *et al.,* 2007). In these calculations height of freeboard H_F, was accepted to be the 4/5 H_O, which is the depth of water at outlet (Tavukçuoğlu, *et al.,* 2007). Values of Q_O were found from Equation (3) with A and B determined from dimensions of spouts openings measured on-site.

A = area of flow at outlet
B = width of water surface at outlet
D_O = gutter depth including freeboard

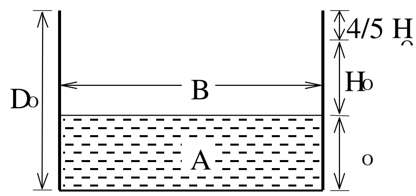

Figure 3.13 Dimensions of spout openings.
Source: BRE Part 1, 1976; Tavukçuoğlu, et al., 2007, pp.2702

3.2.5 Water Supply Capacity Calculations

The hot and cold water storage and consumption capacities were examined by taking into account the usable volume of the hot and cold water storage rooms (m^3), number of basins, maximum amount of water consumption per basin in a day (m^3/basin/day), Q_{WCmax}, and effective plan area per basin (m^2/basin) in caldarium section, A_b, of the structure. This examination was conducted on the other historical Turkish baths in order to discover the ranges of maximum water consumption per basin in a day for those structures.

The water storage and consumption capacities of the bath was found on an assumption that the water heated in the hot water storage room should be consumed in one day. This assumption also corresponds with the contemporary regulations and standards for water storage tanks (BS 6700, 1997; Hall, v.3, chapter 13, 1996; TS 1258, 1984). The maximum amount of hot water consumed by one basin in working hours of a day, Q_{WCmax}, was calculated by taking into account the original water storage capacities of the building and number of original basins. The water storage capacity could be determined since the dimensions of the storage rooms and overflow and outlet levels were not changed in time.

The maximum depth of water accumulated in the storage room, was assumed to be the height between the level of 10cm above the ground level of the storage room-where the drain was located-and the bottom level of observation window-placed between the hot water storage room and caldarium section acting as an overflow valve. Certain assumptions and acceptances were also necessary for the calculations of water storage and consumption capacities. The original number of basins was accepted to be 15 in total for the men’s part and 21 in total for women’s part by taking into consideration the later interventions, such as addition of new basins and removal of original ones. This means that the existing number of basins, which was 43 at present, was accepted to be 36 in the past (Table 4.3). The working period in the past was assumed to be 12 hours while this period is longer today, such as reaching to 18 hours for men's part and 13 hours for women's part. Thus, the Q_{WCmax} was calculated by dividing the maximum usable volume of hot water storage room, $V_{HWSRmax}$, in m^3, to the total number of original basins, N_{basin}, as shown in the equation given below,

$$(Q_{WCmax} = V_{HWSRmax} / N_{basin}) \tag{4}$$

3.2.6 Wastewater Discharge Calculations

The adequacy of wastewater discharge system for the women's part of Şengül Hamamı was investigated in terms of surface grading and flow capacity of drains and water channels, whether being or not, in acceptable ranges. A leveling survey was used to define the overall wastewater drainage system at present in terms of surface slope arrangement in reference to discharge components, such as wastewater collection channels and floor drains. This made it possible to locate the areas having a potential risk of ponding due to the insufficient and/or reverse slopes.

Wastewater drainage calculations were made to assess the discharge capacities of discharge components at the interiors and their adequacy whether they provide acceptable rates of water evacuation from interior floor surfaces.

Two different methods were used during the study for the capacity and adequacy calculations of wastewater collection and discharge system. The first method was based on the logic that the water was collected and discharged from the wastewater collection and discharge channels without interruption all through the working hours of the bath. The parameters of this method are period of working hours in a day, number of basins and maximum hot water consumption capacity of the bath. This method was used for the wastewater drainage calculations. These calculations were based on the equations given in the literature and necessary adaptations have been done according to the characteristics of Şengül Hamamı (Hall, v.1, chapter 8, 1994; TS EN 12056-1, 2005; TS EN 12056-2, 2005; TS EN 12056-3, 2005). The second method was based on the standard TS EN 12056-2 (2005) whose parameters are the frequency factor, number of loading units and type of appliances**.** In this method loading units were accepted as basins instead of taps. The type of appliance was chosen as showers without stoppers for the historical bath structures (Table 3.3). By using the second method the adequacy of wastewater channels was calculated by adapting circular cross-sections of the pipes to rectangular cross-sections of the open wastewater channels.

Using the first method, the waste water run off rate of each channel in caldarium and tepidarium sections, Q_{Rww}, was calculated separately by multiplying the Q_{WCmax} for each basin in L/s by the number of basins, N_{basin}, and period of working hours, t, in seconds as shown in the equation given below,

$$(Q_{Rww} = Q_{WCmax} \times N_{basin} \times t) \qquad (5)$$

The flow capacity of the outlets discharging wastewater collected in the channels was calculated by using the Equation 3, explained in Section 3.3.4.

The equations given in TS EN 12056-2 (2005) were also used to calculate flow capacity of the outlets in order to clarify whether the above-mentioned second method is adaptable for the discharge capacity assessment of wastewater channels in historical baths. By this way, the adequacy of flow capacities for discharge channels and outlets can be evaluated in relation to using frequency of the basins.

Here, the free discharge of each waste water channel, Q_{WW} (L/s) was calculated by multiplying the consuming rate of water from the basins that totally feed the related discharge channels, *DU* in L/s (Table 3.3) with the frequency factor, *K* (unitless) (Table 3.2). The equation used is given below (TS EN 12056-1, 2005; TS EN 12056-2, 2005);

$$(Q_{WW} = K x \sqrt{\sum DU}) \quad (6)$$

The value of *DU* varies according to system types that are related with the usage of sanitary installations, which changes from one country to another, and technical traditions of the countries.

Here, the historical baths are considered as showers without stoppers and categorized as System III that is the high radius secondary waste water discharge system designed for intense usage, and the value of 0.4 L/s is taken for calculations (Table 3.3). The *ΣDU* value was calculated by multiplying the loading units, N_{LU}, that was the total number of basins feeding each individual waste water channel with the loading unit rate, R_{LU}, in L/s (Table 3.3). The value of R_{LU} changes according to System type and type of sanitary appliances. The equation used is given below,

$$(\Sigma DU = N_{LU} \text{ x } R_{LU}) \quad (7)$$

The typical frequency factors, *K*, are given in Table 3.2. It indicates how often sanitary installations are used in different building types. The frequency factor, K, of intense usage that is “1.0” was taken for historical baths in calculations as seen in Table 3.2. Also in order to evaluate effect of the frequency factor on the rate of wastewater run off and to evaluate the adequacy of flow capacities of wastewater channels, the Q_{WW} was calculated with a frequency factor K of frequent usage, 0.7 (Table 3.2). In this case, R_{LU} of System type II, 0.4L/s, was obtained (Table 3.3). The results were compared with each other and given in Chapter 5.

Table 3.2 Typical frequency factors, *K*.
Source: TS EN 12056-2, 2005, pp.12

Periodic usage (i.e., house, guest house, work place)	0.5
Frequent usage (i.e., hospital, school, restaurant, hotel)	0.7
Intense usage (i.e., public toilets and/or baths)	1.0

Table 3.3 Loading unit rates for various appliances, R_{LU}, according to the System types I, II, III and IV.
Source: TS EN 12056-2, 2005, pp.11

Type of appliance	System I	System II	System III	System IV
	R_{LU} L/s	R_{LU} L/s	R_{LU} L/s	R_{LU} L/s
Washbasin, bidet	0.5	0.3	0.3	0.3
Shower without stoppers	0.6	0.4	0.4	0.4
Shower with stoppers	0.8	0.5	1.3	0.5
Urinal with siphon	0.8	0.5	0.4	0.5
Urinal with water wash valve	0.5	0.3	-	0.3
Paka urinal	0.2*	0.2*	0.2*	0.2*
Bathtub	0.8	0.6	1.3	0.5
Kitchen sink (house type)	0.8	0.6	1.3	0.5
Dish washer	0.8	0.6	0.2	0.5
Washing machine(up to 6 kg)	0.8	0.6	0.6	0.5
Washing machine(up to 12 kg)	1.5	1.2	1.2	1.0
Toilet with 4.0l reservoir	**	1.8	**	**
Toilet with 6.0l reservoir	2.0	1.8	1.2-1.7***	2.0

Table 3.3, continued

Type of appliance	System I	System II	System III	System IV
	R_{LU} L/s	R_{LU} L/s	R_{LU} L/s	R_{LU} L/s
Toilet with 7.5l reservoir	2.0	1.8	1.4-1.8***	2.0
Toilet with 9.0l reservoir	2.5	2.0	1.6-2.0***	2.5
Floor drain DN 50	0.8	0.9	-	0.6
Floor drain DN 70	1.5	0.9	-	1.0
Floor drain DN 100	2.0	1.2	-	1.3

* Per person ** not allowed - out of use or no data
*** Fixed to the type (only valid for toilets with water wash reservoirs)

CHAPTER 4

RESULTS

The results of all non-destructive testing methods and the calculations are given in this section under respective headings, presented in succession with figures and tables.

4.1 Mapping of Visual Decay Forms

In this section are presented the experimental results on mapping of visual decay forms of building facades and roof. The maps were analyzed to determine the problem areas in the structure, their distribution, as well as the probable sources of those problems. The maps showing the material loss, material detachment & cracks and discoloration & deposits were given in Figures 4.1, 4.2, 4.3 and 4.4.

In Şengül Hamamı, material loss was categorized into three types: light, intermediate and severe. Severe material loss was mostly observed where the rainfall swept over the wall surfaces as the loss of jointing material or as surface abrasion of the masonry stones (Figure 4.1).

Material detachments observed in Şengül Hamamı, were classified into three types: flake to granular disintegration, scale and the detachment of cement-based repointings. With respect to the severeness of the dampness problem, the size of the material detachment varied between granular disintegration and scales. The more severe the dampness problem was, the higher the size of the material detachment from the original masonry stone was.

The cement repointings also tend to detach from the structure presenting the highest size material detachments among all (Figure 4.2). In west façade of the structure a severe crack was also observed as seen in Figure 4.2.

The deteriorations in the form of discoloration and deposits were again categorized into three types: gray to black discoloration (crust formation), yellowing and whitening (salt crystallization) (Figure 4.3). Biological growths were encountered on the wall surfaces mostly wherever there was the rising damp problem. The biological growth in the form of moss signaled the active deterioration zones where there was the continuity of the dampness problem, which was mostly observed on the south elevation of the structure (Figure 4. 4).

Figure 4.1 Elevations showing the distribution of the severe material loss at the north and west façade of the building. *S1, S2, S3, S4, S5 and S6 show the location of material samples taken from the west façade.* The severe loss and detachment on surfaces was observed together with white staining and salt deposits, especially at the lower parts of the rainwater pipes at both sides of the façade and stone courses at the top, underneath the eaves gutter.
Source: Archives of The General Directorate of Pious Foundation, 2008

Figure 4.2 Elevations showing the distribution of the material detachment and cracks at the north and west façade of the building.
Source: Archives of The General Directorate of Pious Foundations,2008

Figure 4.3 Elevations showing the distribution of discoloration and deposits on surfaces of the north and west façade of the building.
Source: Archives of The General Directorate of Pious Foundations, 2008

Figure 4.4 Views of biological growth as active deterioration zones together with white staining and/ or salt deposition & material loss in relation with cement repointing on surfaces of the south façade of the building.
Source: Archives of The General Directorate of Pious Foundations, 2008

4.2 Leveling Survey

The roof drainage system of Şengül Hamamı was evaluated in terms of its surface grading, discharge capacity and adequacy. The map showing the surface slopes, their directions, and extents on roof surfaces in reference to roof drainage components was given in Figure 4.5.

The slopes of the pitched roofs, A1 and A2, were found to be in the range of 32-42%. For the roof B1, the primary slopes from east to west were in the range of 3-6% and the secondary slopes towards the spouts along the west side (eaves level) of the roof were, in the range of 3-5%. The roof B2 was found to have slopes in the range of 3-10%, towards the interior gutter located in the middle (Figure 4.5). The roof map of as-is case prepared according to the results of leveling survey, showed that the discrete effective areas feeding the individual discharge components were not evenly distributed (Figure 4.7).

As the continuation of roof drainage system, there is a site grading to provide the surface-water removal from the immediate grounds of building. At the west, it followed the overall slope of the asphalt-paved street with an average value of 3% from south to north together with the secondary slopes, around 2%, running away from the walls. On the other hand, at the north, the entrance to the men's part was provided at a lower level, -0,90 m than the street level, which causes the risk of ponded area in the immediate vicinity of the building. This problem was seemed to be solved by means of an area drain, acting like a gully with the slopes varying between 3% and 5% towards the drain, collecting and then, discharging water to the city network (Figure 4.5).

The results of the leveling survey at the interiors were summarized in the map showing the overall surface slopes, their extent and direction as well as the flow pattern of the wastewater discharge channel towards the manholes (Figure 4.6). The wastewater was observed to flow from the elevated platforms to the lower levels by means of slopes varying in the range of 1-3%. At floor level, the wastewater was directed towards the center of caldarium where there was a central waste water collection system surrounding the elevated marble platform. These channels were observed to collect wastewater by means of cross-falls. These falls were found to vary in the range of 0-4%. However, most slopes were found to be below 1%, which is not acceptable according to the standards (Griffin and Fricklas, 1995)

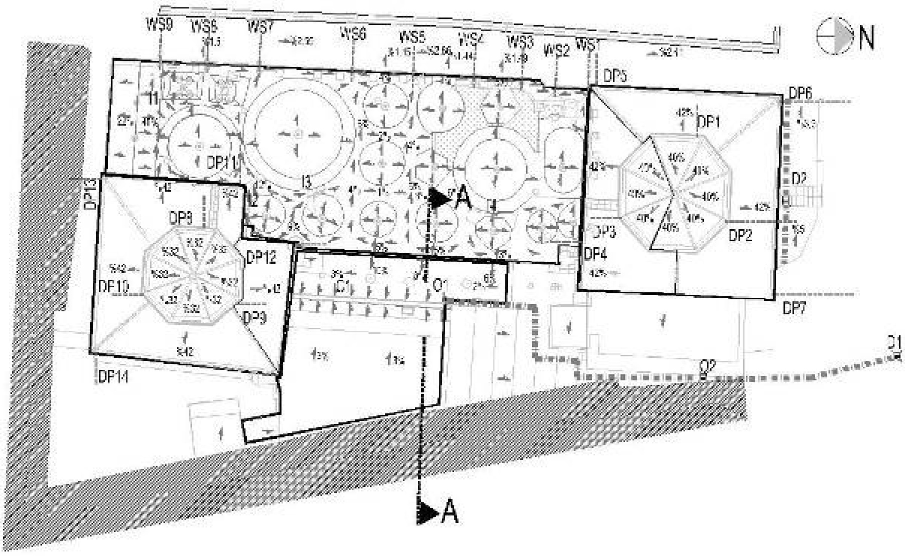

Figure 4.5 The map showing the direction and extent of surface slopes on the roofs of Şengül Hamamı and its immediate periphery.
Source: Archives of The General Directorate of Pious Foundations, 2008

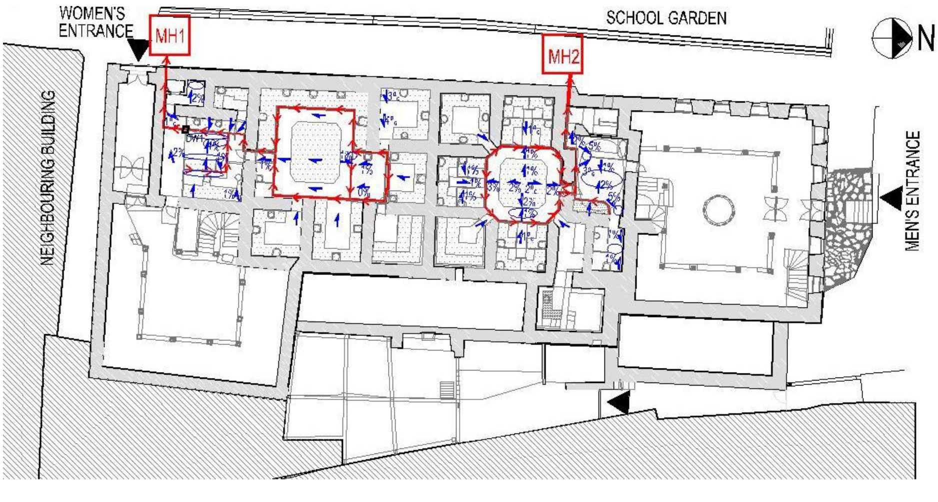

Figure 4.6 The map showing the water flow pattern of the waste water discharge channel towards the manholes and the surface gradients of floors.
Source: Archives of The General Directorate of Pious Foundations, 2008

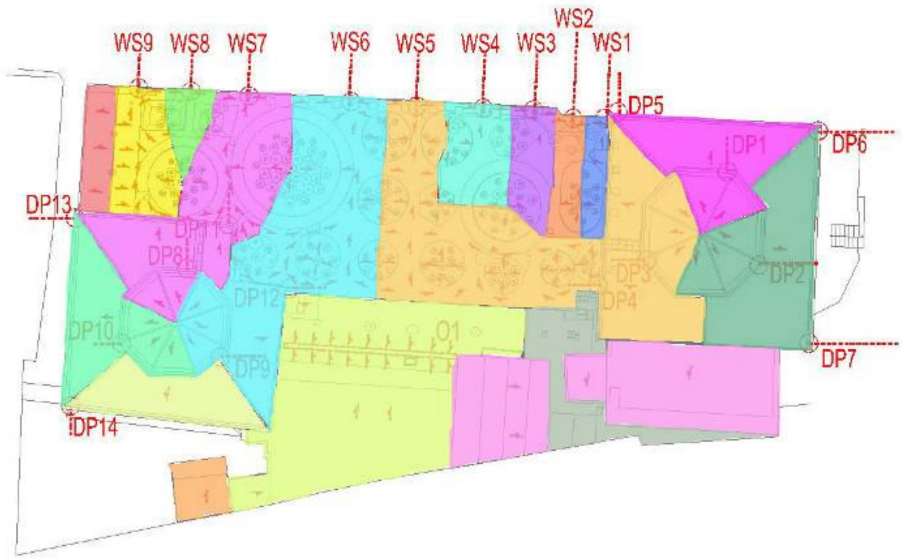

Figure 4.7 The roof map of the as-is case, showing the uneven distribution of discrete effective areas feeding the individual discharge components.

Source: Archives of The General Directorate of Pious Foundations, 2008

4.3 Infrared Thermography

The infrared images together with mapping of decay forms, showed the problem areas of continuous rainwater penetration and their location in the structure. In the infrared images, the severe material loss on masonry surfaces together with staining and salt deposits was observed to correspond with the damp zones (Figures 4.8 and 4.9). Those surfaces were exposed to rainwater, overflowing from the eaves gutter, down pipes and waterspouts. Hence, the lower parts of the walls on the axis of down pipes and waterspouts were found to be damp and cold in the infrared images (Figures 4.9 and 4.10). The height of cold areas was detected to extend towards the discharge components above (Figure 4.10). The periodical wetting and drying at those damp zones must have caused such severe deterioration on wall surfaces. The recent repairs with cement mortar also introduced salt problems, which accelerated the deterioration mechanisms at the presence of dampness.

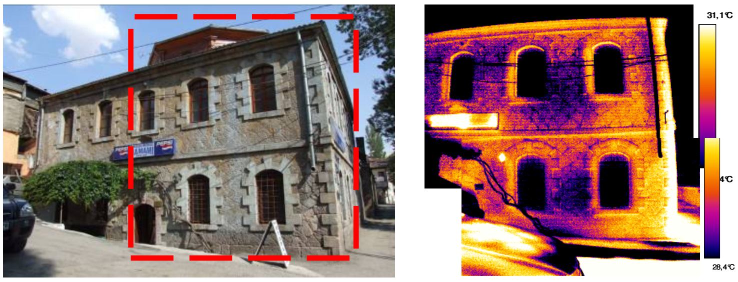

Figure 4.8 The infrared image of the selected region at the north façade, showing the severe material loss as warmer areas and the detachments which were not observed visually as colder areas, both suffering from the roof drainage faults.

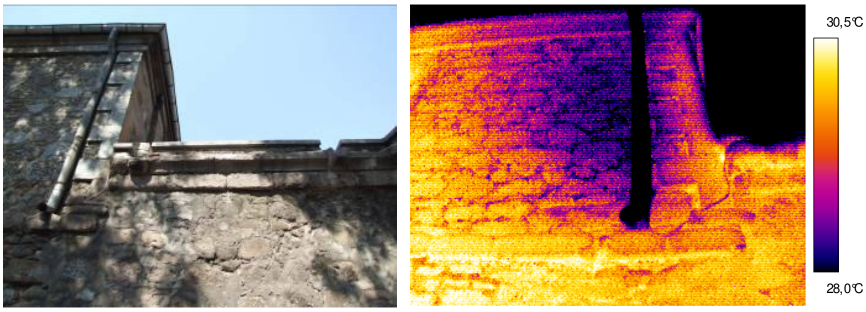

Figure 4.9 The infrared image of the selected region in which the detached areas close to the rainwater down pipes were detected as colder areas.

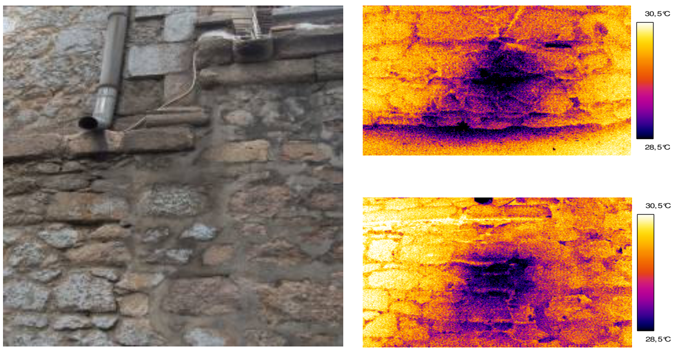

Figure 4.10 The infrared image of the selected region in which the lower parts of the wall corresponding to the axis of the down pipe and the water spouts were found to be cold and damp

4.4 Roof Drainage Calculations

In as-is case, the flow dimensions of the spout outlets were measured in the range of 6-12cm in width and 6-11cm in depth (Table 4.1). Among all, the original spout WS6, having flow dimensions of 10cm x 7cm in width and depth, seemed to be the mostly-preserved one (Figure 4.11). The eaves gutters used for the pitched roofs were measured to have the diameters in the range of 14-16cm connecting to the down pipes with diameters in the range of 8-10cm. In as-is case the overall roof runoff rate of the concrete-clad roof B1 was calculated to be 18.2 L/s. On the other hand total discharge capacity of the waterspouts was calculated to be 10.2 L/s. The total roof runoff rate of the concrete-clad roof B2 was found to be 9.7 L/s and the discharge capacity of the drain O1 was found to be 5.4 L/s (Table 4.1).

As it can be seen from Table 4.1 and Figure 4.7, as a result of the leveling survey and roof drainage calculations the spouts WS5, WS6, WS7, WS9 and the down pipe DP7, were found to be overloaded with the roof run off rates of 5.8 L/s, 4.6 L/s and 3.6 L/s, 1.4 L/s and 1.85 L/s, respectively. On the other hand, the spouts WS1, WS2, WS3, WS4 and WS8 were found to have rather small roof run off rates with 0.68 L/s, 0.42 L/s, 0.62 L/s, 0.82 L/s and 0.38 L/s, respectively (Table 4.1) (Figure 4.7).

Roof drainage calculations were also made to identify the flow dimensions of the spout outlets, eaves gutters and down pipes in ideal case. The results of roof drainage calculations for the ideal-case of roof A1, A2, B1 and B2 were given in Table 4.2 and Figures 4.12. The ideal dimensions of the spouts WS6 and WS7 were calculated to be 11cm x 11cm in width and depth, respectively (Table 4.2).

For as-is case, the pitched roofs of the frigidarium sections were observed to discharge rainwater directly onto mesh-reinforced concrete roofs while, for the ideal case, it was assumed that the rainwater from the pitched roofs was discharged separately. The dimensions of eaves gutters used for the pitched roofs A1 and A2 were calculated to have the diameters in the range of 20-25cm connecting to the down pipes with diameters in the range of 6-7cm. In ideal case the overall roof runoff rate of the concrete-clad roof B1 was calculated to be 13.77 L/s. On the other hand total discharge capacity of the waterspouts was calculated to be 19.96 L/s. The total roof runoff rate of the concrete-clad roof B2 was found to be 16.7 L/s and the discharge capacity of the drain O1 was found to be 8.35 L/s (Table 4.2). The roof map for the ideal case showing the location of each individual discharge component and discrete effective areas feeding individual discharge component, which provides even rainwater loading for each component were given in Figures 4.12 and 4.13, respectively.

Table 4.1 The results of roof drainage calculations for the as-is case: The lines in red show the as-is flow capacities of the discharge components (Q_O) not enough to cope up with the individual roof runoff rate (Q_R).

Q_O: the flow capacity of an outlet;

Q_{TO}: the total discharge capacity of the spouts serving each roof area;

A_I: the discrete effective areas feeding individual spouts;

A_T: the total effective area of each roof under study;

Roof Spouts	A_R	A_T	Sizes width x height	Qo	Q_{TO}	Q_R	O_{RT}
	(m²)	(m²)	(cm)	(l/s)	(l/s)	(l/s)	(l/s)
WS1	24	657	8.5 x 7.5	1,18	**10,20**	0,68	**18,22**
WS2	17		9.0 x 7.0	1,13		0,42	
WS3	26		8.5 x 5.5	0,74		0,62	
WS4	35		9.5 x 6.5	1,06		0,82	
WS5	206		6.0 x 11.0	**1,48**	**<**	**5,79**	
WS6	162		10.0 x 7.0	**1,25**	**<**	**4,56**	
WS7	124		12.0 x 6.5	**1,34**	**<**	**3,55**	
WS8	14		9.0 x 6.5	1,01		0,38	
WS9	49		9.0 x 6.5	**1,01**	**<**	**1,4**	
DP7	62		Φ=10	**1,79**	**<**	**1,85**	1,85
IG1	325	325	28 X 12.5	**8,35**	8,35	**9,74**	9,74
O1	325	325	18 X 12.5	**5,37**	5,37	**9,74**	9,74

Figure 4.11 The front and top views of the original water spout, WS6, having flow dimensions of 10cm x 7cm in width to depth, respectively.

Table 4.2 The results of roof drainage calculations for the ideal-case of the roofs B1 and B2 (at the left); and the roofs A1 and A2 (at the right)

Roof Spouts	A_R	A_T	Sizes width x height	Qo	Q_{TO}	Q_R	O_{RT}
	(m²)	(m²)	(cm)	(l/s)	(l/s)	(l/s)	(l/s)
WS1	35	501	10.0 X 9.0	1,82	19,96	0,99	13,77
WS2	19		10.0 X 9.0	1,82		0,49	
WS3	51		10.0 X 9.0	1,82		1,36	
WS4	65		10.0 X 9.0	1,82		1,76	
WS5	58		10.0 X 9.0	1,82		1,58	
WS6	93		**11.0 X 11.0**	2,7		2,54	
WS7	101		**11.0 X 11.0**	2,7		2,79	
WS8	14		10.0 X 9.0	1,82		0,38	
WS9	47		10.0 X 9.0	1,82		1,34	
WS10	18		10.0 X 9.0	1,82		0,54	
IG1	288	288	28 X 12,5	8,35	8,35	8,25	8,25
O1	288	288	28 X 12,5	8,35	8,35	8,25	8,25

Q_O: the flow capacity of an outlet; **Q_{TO}**: the total discharge capacity of the spouts serving each roof area; **A_I:** the discrete effective areas feeding individual spouts; **A_T**: the total effective area of each roof under study; **Q_R**: the rate of runoff from each effective area feeding individual spouts; **Q_{TR}**: the total runoff from each roof under study.

Roof downpipes and gutters	A_R	A_T	Sizes Downpipe	Sizes Gutter	Qo	Q_{TO}	Q_R	O_{RT}
	(m²)	(m²)	(cm)	(cm)	(l/s)	(l/s)	(l/s)	(l/s)
DP1	14,9	460,5	Φ=6	Φ=20	1,1	34,3	0,51	15,9
DP2	13,58		Φ=6	Φ=20	1,1		0,47	
DP3	14,24		Φ=6	Φ=20	1,1		0,49	
DP4	13,63		Φ=6	Φ=20	1,1		0,47	
DP5	16,47		Φ=7	Φ=25	1,7		0,57	
DP6	19,54		Φ=7	Φ=25	1,7		0,67	
DP7	32,49		Φ=7	Φ=25	1,7		1,12	
DP8	10,23		Φ=6	Φ=20	1,1		0,35	
DP9	10,24		Φ=6	Φ=20	1,1		0,35	
DP10	10,75		Φ=6	Φ=20	1,1		0,37	
DP11	25,6		Φ=7	Φ=25	1,7		0,88	
DP12	27,77		Φ=7	Φ=25	1,7		0,96	
DP13	15,98		Φ=7	Φ=25	1,7		0,55	
DP14	17,75		Φ=7	Φ=25	1,7		0,61	
DP15	10,56		Φ=6	Φ=20	1,1		0,36	
DP16	5,51		Φ=7	Φ=25	1,7		0,19	
DP17	30,27		Φ=7	Φ=25	1,7		1,04	
DP18	17,86		Φ=7	Φ=25	1,7		0,62	
DP19	31,7		Φ=7	Φ=25	1,7		1,09	
DP20	32,35		Φ=7	Φ=25	1,7		1,12	
DP21	15,96		Φ=7	Φ=25	1,7		0,55	
DP22	30,55		Φ=7	Φ=25	1,7		1,05	
DP23	42,61		Φ=7	Φ=25	1,7		1,47	

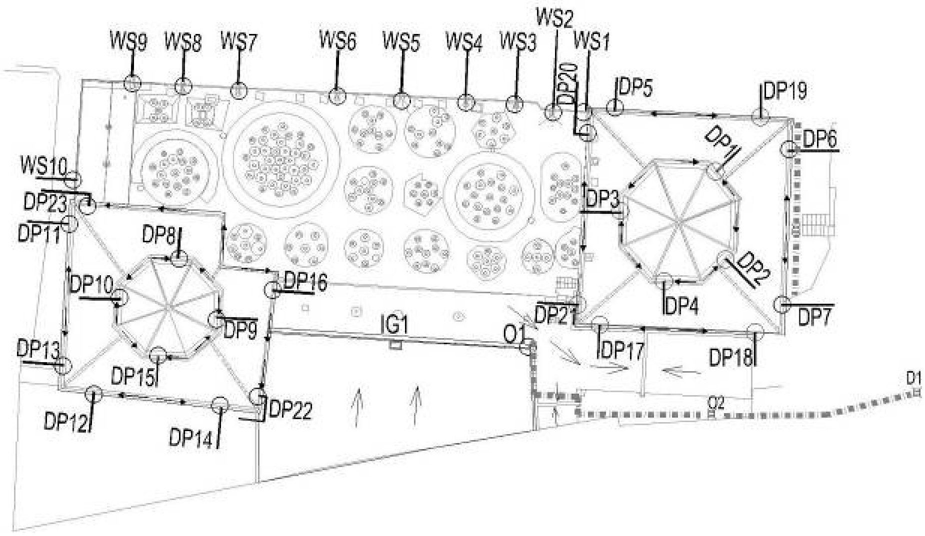

Figure 4.12 The roof map of the ideal case showing the location of each individual discharge component.

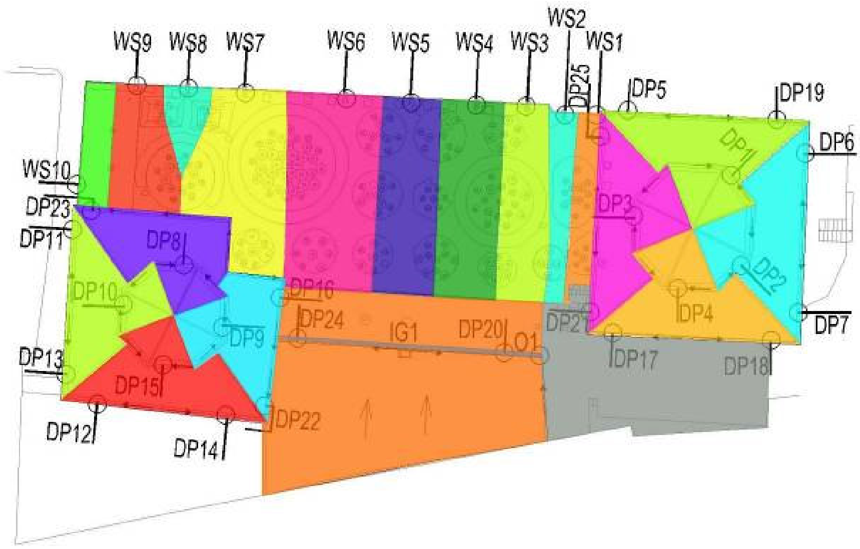

Figure 4.13 The ideal roof map showing the discrete effective areas feeding individual discharge component which provides an even rainwater loading for each component.

4.5 Mapping of Roof Drainage Faults

The faults of the roof drainage system were summarized as follows: -

– All discharge components serving the roof areas, in one way or another, had become disfunctional (Figure 4.14): All spouts were observed to suffer from the accumulation of soil deposits and plant growth, obstructing the free discharge of rainwater from the roof. In addition, all spouts, zinc gutters and down pipes were observed to be severely deteriorated due to the wrong restoration practices, such as repairs with cement-based mortars as shown in Figure 4.15. Almost all metal components were observed to have corroded and lost their functions.

– The reverse or nil falls were found to cause local ponded areas on the concrete-clad roofs, B1 and B2 (Figure 4.14). Some waterspouts, particularly the spouts WS5, WS6 and WS7, were determined to be overloaded due to the improper surface slopes and direct discharge of rainwater from the timber pitched roofs to the concrete-clad roof B1 and then causing discrete roof areas feeding each spout unevenly (Figure 4.7). The overloaded spouts could also be detected in their infrared images (Figure 4.16).

– A later addition of parapets on the roofs B1 and B2 were observed to cut the water flow of the rainwater towards the discharge components, causing ponding and soil/dirt accumulation on their fronts (Figures 4.14 and 4.17).

– The regions at the south of the roof B1 and at the north of the roof B2 were also the risky areas due to the lack of discharge components (Figure 4.14). Overflowing and/or ponding from the eaves level, therefore, were inevitable for those regions.

– It was observed that rainwater collected on the neighboring building, at the east of the building was discharged directly onto the roof B2, above the firewood storage of Şengül Hamamı (Figure 4.18).

– As a recent unconscious addition, a green garden with 22m^2 area was observed on the roof B1 (Figure 4.14). This garden was attached for growing some vegetables by taking advantage of the heat and rainwater of the roof. This garden area was surrounded by a concrete parapet of 40cm height without any discharge component, acting like a pool entrapping the rainwater and causing serious dampness problems at both interiors and exteriors.

Some cracks were also observed on the mesh-reinforced concrete surfaces following the slopes, inevitably causing water leakages into the sub layers and heat loss from the interiors.

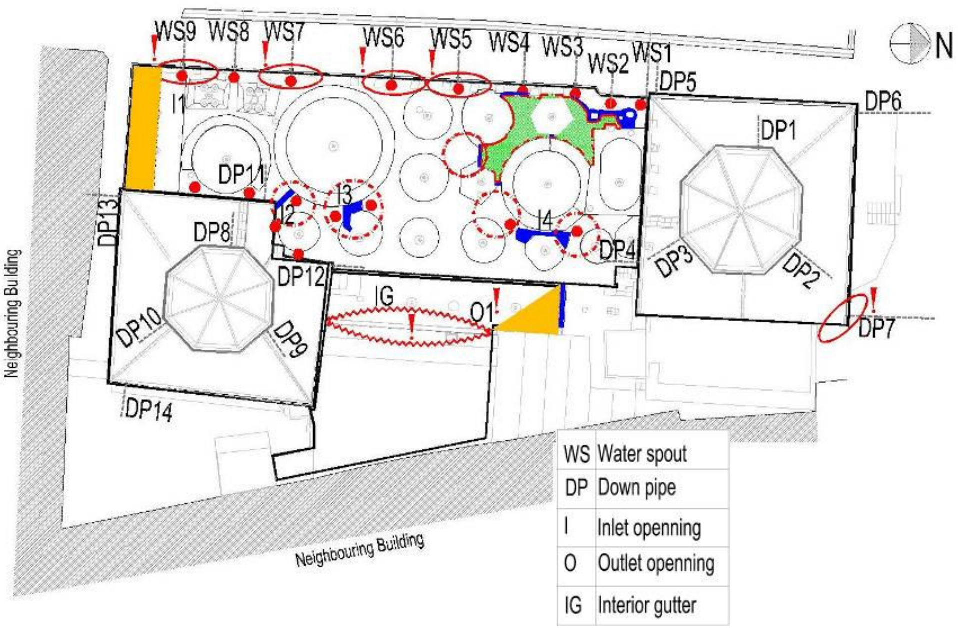

Figure 4.14 The map showing the faults of the roof drainage system and their location.

Figure 4.15 Views of the spouts, WS1, WS4, WS5 and WS7 (from left to right, respectively) showing the severely deteriorated sluiceways due to cement-based mortar repairs.

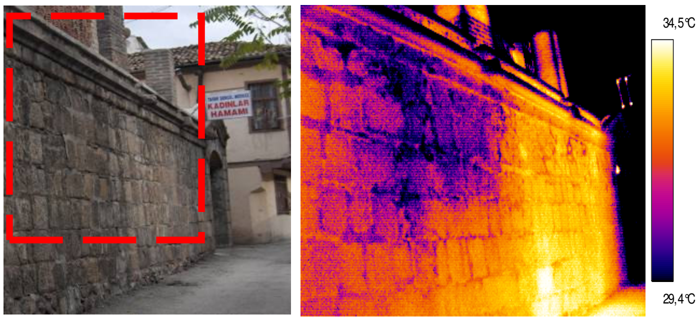

Figure 4.16 The infrared image of the selected region in which the darker areas indicate the damp zones at the upper parts of the wall due to the overflowing from the roof eaves level between the spouts WS6 and WS7; severe material loss together with salt deposits and biological growth overlap with the colder areas.

Figure 4.17 The infrared image of the parapet cutting the water flow and causing soil/dirt accumulation in front of its outlet; the gradual decrease of surface temperatures towards the outlet exhibited the potential for absorbing and retaining rainwater.

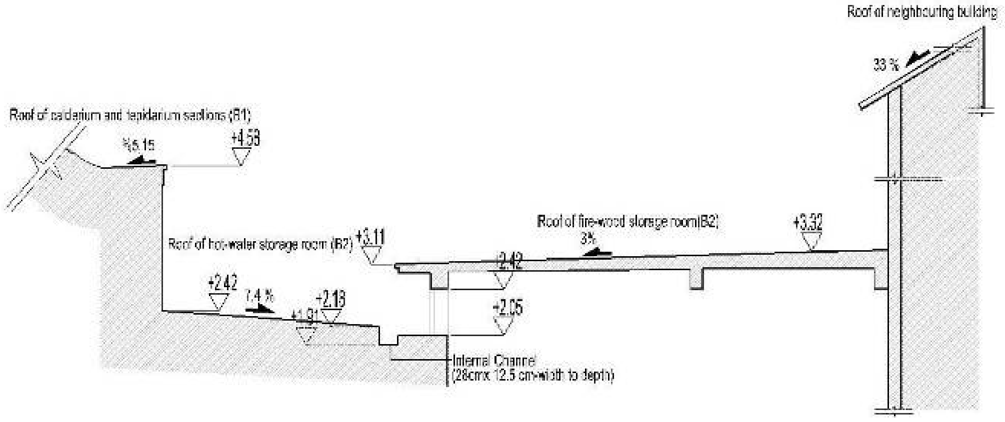

Figure 4.18 The cross section A-A from the roof B2 showing the roof slope arrangement towards the interior gutter and additional rainwater loading from the neighboring building.

4.6 Water Supply Capacity Calculations

The storage capacities of hot and cold-water storage rooms of Şengül Hamamı were $45m^3$ and $62m^3$, respectively. The maximum hot water consumption capacity, Q_{WCmax}, was calculated to be $1.25m^3$/basin/day.

The analysis of water storage and consumption capacities of different Turkish baths was summarized in Table 4.3. The results were compared with each other in terms of their hot and cold-water storage capacities, hot water consumption capacities, total number of original basins and effective plan area per basin in caldarium section. It was observed that some baths had both hot and cold-water storage rooms while some others had only hot water storage room (Table 3.1 and Figure 4.19). Among the historical baths having both, except for Eski Hamam (Kilis) and Şengül Hamamı (Ankara), the cold-water storage capacities of the baths seemed to be lower than their hot water storage capacities. Şengül Hamamı also seemed to have the largest cold-water storage capacity ($62m^3$), which could be resulting from the scarcity of water source of that region.

The Q_{WCmax} of the historical baths were found to be in the range of 0.61-2.78m³/basin/day with an average of 1.56±0.60m³/basin/day (Table 4.3 and Figure 4.20). In this range, three groups were observed in terms of $Q_{WCmax.}$ The first group has, Q_{WCmax} with the value of 0.81± 0.14m³/basin/day. The baths falling in this group are Kurtuluş Hamamı, Hacı Hamza Menzil Hamamı, Eski Hamam and Orta Hamam.

The second group having the Q_{WCmax} values of 1.56±0.60m³/basin/day seemed to have the Q_{WCmax} in average ranges. Şengül Hamamı was in this group with its Q_{WCmax} value of 1.25m ³/basin/day. Pertev Paşa Hamamı, Paşa Hamamı in Ankara, Orhan Gazi Gürle Köyü Hamamı, Çayırcık Hamamı, Cinci Hamamı, Aksu Hamamı, Gazi Süleyman Paşa Hamamı, Eynebey Hamamı, Sahip Ata Hamamı, Valide Sultan Hamamı, Tekirdağ Yalı Hamamı, Yıldırım Beyazıt Hamamı, Hacı Hekim Hamamı, Tabakhane Karataş Hamamı, Yıldırım Beyazıt Hamamı, Yarhisar Köyü Hamamı and Yıldırım Emir Sultan Hamamı are also in this group (Table 4.3 and Figure 4.20).

The third group seemed to have Q_{WCmax} values above the average range, 2.48±0.21m³/basin/day. The baths falling in this range are the Paşa Hamamı in Merzifon, Amasya, Vakıf Hamamı, Tabaklar Hamamı, Gölyazi Köyü Hamamı, Saray Hamamı and Gülgün Hatun Hamamı (Table 4.3 and Figure 4.20). In addition, it seemed that both double and single baths had Q_{WCmax} values in different amounts and no relation was observed between the types of historical baths and their Q_{WCmax} values (Table 3.1; Figure 4.21).

The relations between the Q_{WCmax} values of historical baths with the total number of original basins, N_{basin}, and with the effective floor area of caldarium and tepidarium sections per basin, A_b, were examined (Figures 4.20 and 4.22). The effective floor area per basin in caldarium section of the historical Turkish baths was found to vary in the range of 3.21-11.04m^2/basin with an average of 5.7±1.7m^2/basin.

The increase in Q_{WCmax} was observed to have no relation with effective floor area per basin, as shown in Figure 4.22. Further studies are therefore needed to understand the reasons of higher or lower Q_{WCmax} capacities than expected. Also it seemed that the total number of original basins had no effect in the increase of Q_{WCmax} values for the historical baths as seen in Figure 4.21. For instance, some baths have less number of original basins having higher Q_{WCmax} values when compared with the ones having more basins with smaller Q_{WCmax} values.

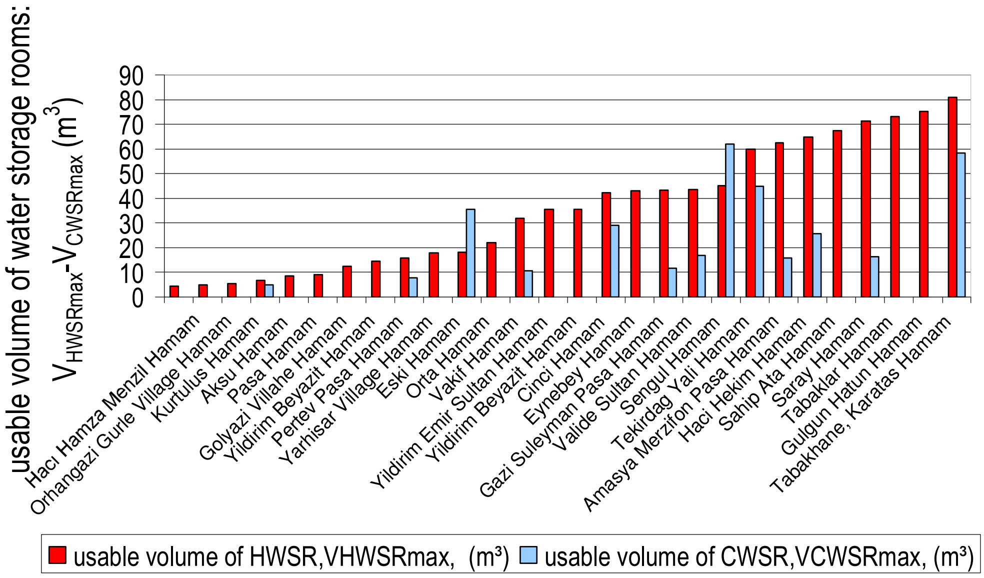

Figure 4.19 The chart showing the maximum hot water storage capacities, $V_{HWSRmax}$, and cold water storage capacities, $V_{CWSRmax}$, of historical baths.

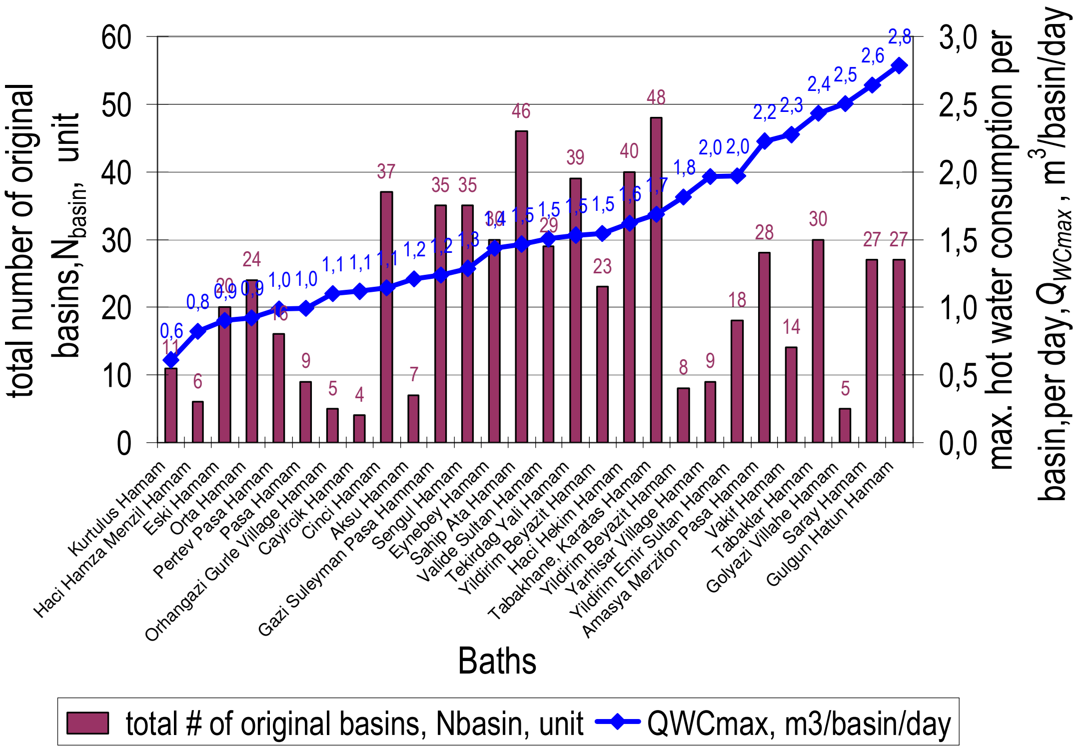

Figure 4.20 The chart showing the Q_{WCmax} values versus number of original basins, N_{basin}, for each historical bath; the Q_{WCmax} varied in the range of 0.61-2.78m³/basin/day.

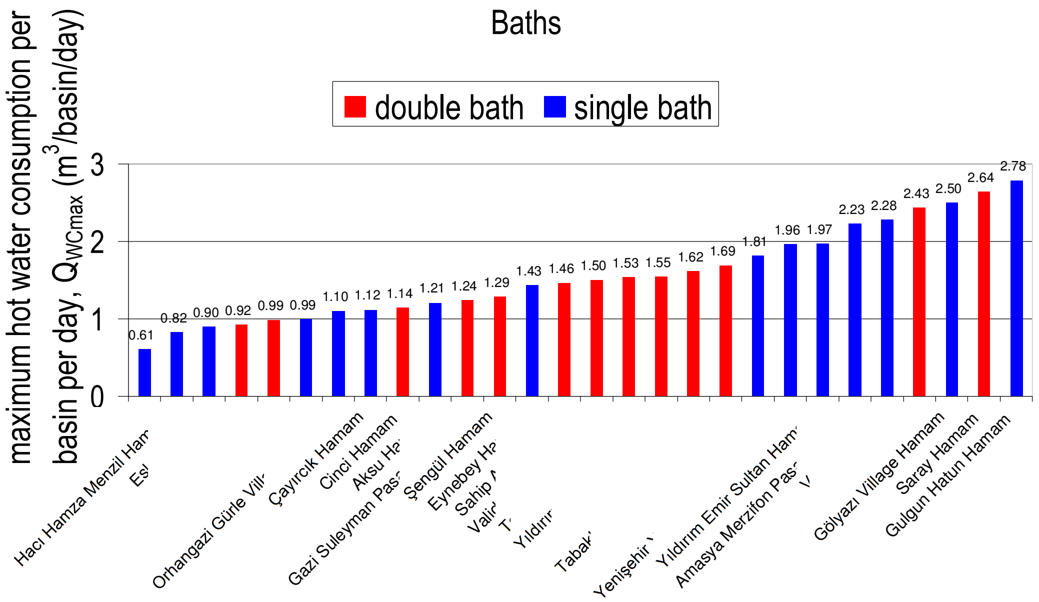

Figure 4.21 The chart showing Q_{Wcmax} values versus the type of historical baths; there is not a visible effect of type of the bath to the Q_{WCmax} value.

Table 4.3 The results of the calculations for each historical Turkish bath, sorted according to maximum hot water consumption per basin in a day, Q_{WCmax}.

name of the hamam	N_{basin} **(basin)**	$V_{CWSRmax}$ **(m³)**	$V_{HWSRmax}$ **(m³)**	V_{WSR} **(m³)**	Q_{WCmax} **(m³/basin/day)**	N_{basin} **in caldarium (basin)**	**A (m²)**	A_b, **(m²/basin)**
Kurtuluş Hamamı	11	4.83	6.72	11.55	0.61	10	45.71	4.57
Hacı Hamza Menzil Hamamı	6		4.94	4.94	0.82	6	21.98	3.66
Eski Hamam	20	35.36	18.00	53.36	0.90	17	99.92	5.88
Orta Hamam	24		22.05	22.05	0.92	15	77.67	5.18
Pertev Paşa Hamamı	16	7.65	15.76	23.41	0.99	14	116.54	8.32
Pasa Hamam in Ankara	9		8.94	8.94	0.99	9	34.01	3.78
Orhangazi GürleKöyü Hamamı	5		5.50	5.50	1.10	3	18.46	6.15
Çayırcık Hamamı	4		4.46	4.46	1.12	4	15.94	3.99
Cinci Hamamı	37	29.13	42.26	71.39	1.14	32	188.37	5.89
Aksu Hamamı	7		8.46	8.46	1.21	6	25.06	4.18
Gazi Süleyman Paşa Hamamı	35	11.53	43.27	54.80	1.24	28	128.17	4.58
Şengül Hamamı	36	62.00	45.00	107.00	1.25	32	231.21	7.23
Eynebey Hamamı	30		43.00	43.00	1.43	23	152.45	6.63
Sahip Ata Hamamı	46		67.37	67.37	1.46	42	229.25	5.46
Valide Sultan Hamamı	29	16.95	43.62	60.57	1.50	27	298.05	11.04
Tekirdağ Yalı Hamamı	39	44.77	59.76	104.53	1.53	32	220.68	6.90
Yıldırım Beyazıt Hamamı	23		35.54	35.54	1.55	17	124.87	7.35
Hacı Hekim Hamamı	40	25.49	64.80	90.29	1.62	34	127.41	3.75
Tabakhane Karataş Hamamı	48	58.28	80.94	139.22	1.69	36	115.50	3.21
Yıldırım Beyazıt Hamamı	8		14.50	14.50	1.81	8	54.86	6.86
Yarhısar Köyü Hamamı	9		17.68	17.68	1.96	9	52.64	5.85
Yıldırım Emir Sultan Hamamı	18		35.45	35.45	1.97	13	63.52	4.89
Amasya Paşa Hamamı	28	15.67	62.33	78.00	2.23	25	178.69	7.15
Vakıf Hamamı	14	10.42	31.85	42.27	2.28	13	96.29	7.41
Tabaklar Hamamı	30		73.02	73.02	2.43	22	117.43	5.34
Gölyazı Köyü Hamamı	5		12.51	12.51	2.50	4	15.18	3.80
Saray Hamamı	27	16.43	71.24	87.67	2.64	25	135.66	5.43
Gülgün Hatun Hamamı	27		75.19	75.19	2.78	21	117.48	5.59

N_{basin}**(basin)-** total number of original basins; $V_{CWSRmax}$ **(m^3) –** maximum usable volume of cold water storage room; $V_{HWSRmax}$ **(m^3) –** maximum usable volume of hot water storage room; V_{WSR} **(m^3)-** total usable volume of water storage rooms; Q_{WCmax} **(m^3/basin/day) -** maximum hot water consumption capacity per basin in a day; A **(m^2)-** effective plan area of caldarium and tepidarium; A_b **(m^2/basin) -** effective plan area of caldarium and tepidarium per basin.

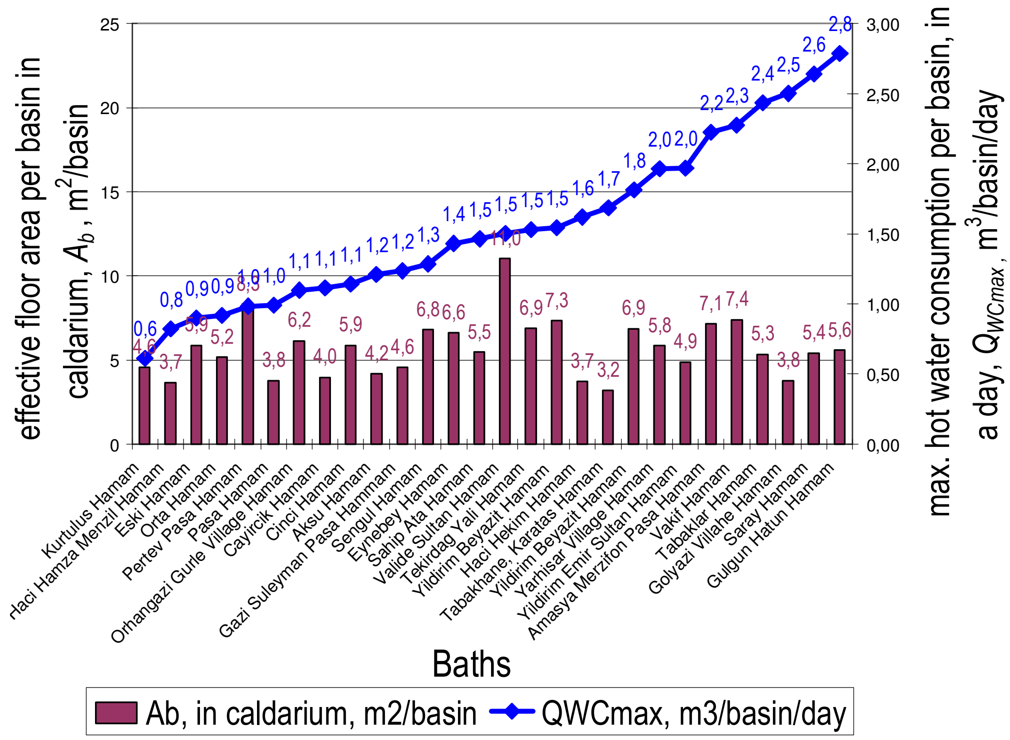

Figure 4.22 The chart showing the Q_{WCmax} as a function of A_b, showing that there is not a visible effect of A_b in the increase of Q_{WCmax} of the bath.

4.7 Waste Water Drainage Calculations

In as-is case, the flow dimensions of outlet O_1, in caldarium section and outlet O_2, in tepidarium section were measured to be 13cm x 9cm and 13cm x 12cm in width and depth, respectively (Table 4.4).

The flow dimensions of wastewater collection and discharge channels were observed to be different in the hamam, as shown in Table 4.5, Table 4.6 and Figure 4.23. Those dimensions of wastewater channels in caldarium section of women's part were found to be in the range of 6-14cm in width and 4-12cm in depth (Table 4.6). In tepidarium section this range was found to be 9-14cm in width and 6-18cm in depth (Table 4.5). The Q_{Rww} for the tepidarium and caldarium sections of the women's part were calculated to be 3.65 L/s and 3.12 L/s, while the discharge capacities of the floor drains at tepidarium and caldarium were 3.65 L/s and 2.35 L/s, respectively (Table 4.4). The result of rate of wastewater run off calculations for the women's part of Şengül Hamamı according to the Equation 5 (Section 3.2.6) using Q_{WCmax} value of 1.25 L/s was presented in Table 4.7. In this method, the rate of free discharge of waste water channels (Q_O) for C1-13 were found to be in the range of 0.17-4.17 L/s in as-is case and 0.17-3.65 L/s in ideal case with the discharge capacities changing in the range of 1.06-3.65 L/s in as-is case and 1.06-4.11L/s in ideal case (Table 4.7).

By using the Equations 6 and 7 (Section 3.2.6), free discharge of wastewater channels, $Q_{Rww,}$ was calculated and the results were compared with the values of $Q_{Rww,}$ calculated using Equation 5 and the results were presented in Tables 4.8 and 4.9.

As seen in Figure 4.24 and Table 4.8 and Table 4.9, the waste water channel 1, C1, was loaded with four basins; basins 1-4. Channel 2, C2, was loaded with the basins 1-5. Chanel 3, C3, was loaded with the basins 1-8. Channel 4, C4, was loaded with the basins 1-9. Channels 5 and 6, C5 and C6, were loaded with the basins 10, 11 and 12. Channel 7, C7, was loaded with the basins 10-15. Channel 8, C8, was loaded with the basins 10-18. Channel 9, C9, was loaded with basins 10-19. Channel 10, C10, was loaded with the basins 1-19, C11, was loaded with the basin 20. Channel 12, C12, was loaded with the basin 21 and the channel 13, C13, was loaded with the basins1-24.

In as-is case, with the frequency factor, *K,* of 1.00, the rate of waste water run off, Q_{ww} was calculated to be in the range of 1.10-2.76 L/s for the channels C1-C10 in caldarium section; and 0.63-3.10 L/s for the channels C11-C13 in tepidarium section. Considering the ideal wastewater runoff and the original wastewater channel dimensions, it was calculated that Q_{ww} changed in the range of 0.89-2.68 L/s for the channels C1-C10 and 0.63-2.90 L/s for the channels C11-C13 with the dimensions in the range of 9-14cm in width and 6-12cm in depth, respectively (Table 4.8). On the other hand it was calculated that for the channels C1-13, the Q_{ww} was found to be in the range of 0.77-2.77 L/s in as-is case and 0.63-2.03 L/s for the ideal case with the frequency factor *K,* of 0.7 (Table 4.9).

Table 4.4 The results of rate of waste water run off calculations for the women's part of Şengül Hamamı

Q_{WCmax} m3/basin/ day	Q_{WCmax} L/ basin /s	Period of work hours	Q_{RWW} for cald.	Q_{RWW} for tepid.	Q_{O1} AS-IS (13x9 cm) L/s	Q_{O2} AS-IS (13x12cm) L/s	Q_{O1} IDEAL (13x11 cm) L/s	Q_{O2} IDEAL (13x13 cm) L/s
1.25	0.01447	(12x 3600)	3.12	3.65	2.37	3.65	3.20	4.11

***Q_{WCmax}* (m^3/basin/day) -** maximum hot water consumption capacity per basin in a day, in m^3; ***Q_{WCmax}* (L/basin/s) -** maximum hot water consumption capacity per basin in a second, in liter, L; ***Q_{Rww}* (L/s) -** rate of original waste water run off; ***Q_{O1}* (L/s)-** the flow capacity of O_1 (outlet in caldarium section); ***Q_{O2}* (L/s)-** the flow capacity of O_2 (outlet in tepidarium section).

Table 4.5 The width and depth values of the sections taken from the tepidarium.

Sections in Tepidarium	Sizes width x height (cm)
Section A-A	14.0 X 18.0
Section B-B	9.0 X 7.0
Section C-C	12.0 X 9.0
Section D-D	11.0 X 6.0

Table 4.6 The width and depth values of the sections taken from the caldarium

Sections in Caldarium	Sizes width x height (cm)	Sections in Caldarium	Sizes width x height (cm)	Sections in Caldarium	Sizes width x height (cm)	Sections in Caldarium	Sizes width x height (cm)
Section E-E	13.0 X 9.0	Section I-I	13.0 X 7.0	Section M-M	12.0 X 6.0	Section R-R	12.0 X 7.0
Section F-F	14.0 X 12.0	Section J-J	14.0 X 5.0	Section N-N	13.0 X 12.0	Section S-S	14.0 X 7.0
Section G-G	12.0 X 7.0	Section K-K	6.0 X 4.0	Section O-O	12.0 X 7.0	Section T-T	14.0 X 11.0
Section H-H	14.0 X 9.0	Section L-L	12.0 X 7.0	Section P-P	14.0 X 7.0	Section U-U	13.0 X 11.0

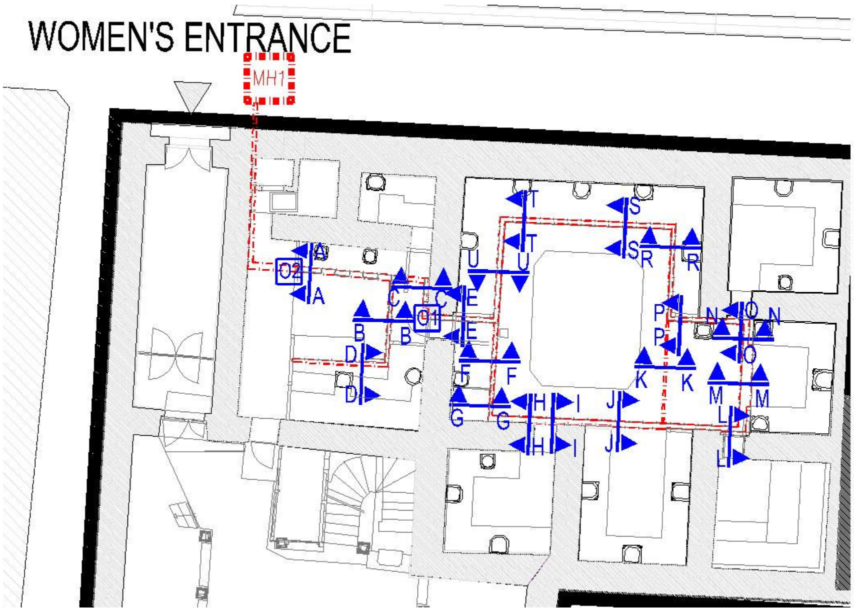

Figure 4.23 The map showing the direction and name of the sections taken from the wastewater discharge channels in caldarium and tepidarium sections of the women's part in Şengül Hamamı.

Figure 4.24 The map showing the name of the basins feeding each channel in caldarium and tepidarium sections of the women's part in Şengül Hamamı.

Table 4.7 The result of rate of waste water run off calculations for the women's part of Şengül Hamamı, according to the Equation 5 (Section 3.2.6) with a Q_{WCmax} value of 1.25 L/s.

	AS-IS						ORIGINAL					IDEAL			
	N_{LU}	Sizes		A	Q_O	Q_R	N_{LU}	Sizes		Q_O	Q_R	Sizes		Q_O	Q_R
channels	loading units	width	depth	Area	discharge capacity of each channel	free discharge of channel	loading units	$width_{as\text{-}is}$	depth	discharge capacity of each channel	free discharge of channel	width	depth	discharge capacity of each channel	free discharge of channel
	(unit)	(cm)	(cm)	(cm^2)	(L/s)	(L/s)	(unit)	(cm)	(cm)	(L/s)	(L/s)	(cm)	(cm)	(L/s)	(L/s)
C1	4	14	7	35	1.75	0.69	2	14	7	1.75	0.35				
C2	5	12	7	30	1.50	0.87	3	12	7	1.50	0.52				
C3	8	14	11	55	3.45	1.39	6	14	11	3.45	1.04				
C4	9	13	11	51.1	3.20	1.56	7	13	11	3.20	1.22				
C5	3	12	6	25.7	1.19	0.52	3	12	6	1.19	0.52				
C6	3	12	7	30	1.50	0.52	5	12	7	1.50	0.87				
C7	6	14	5	25	1.06	1.04	8	14	6	1.39	1.39				
C8	9	14	9	45	2.55	1.56	10	14	9	2.55	1.74				
C9	10	14	12	60	3.93	1.74	11	14	12	3.93	1.91				
C10	**19**	**13**	**9**	**41.8**	**2.37**	**3.30**	**18**	**13**	**9**	**2.37**	**3.13**	**13**	**11**	**3.20**	**3.13**
C11	1	11	6	23.6	1.09	0.17	1	11	6	1.09	0.17				
C12	2	9	7	22.5	1.13	0.35	2	9	7	1.13	0.35				
C13	**24**	**13**	**12**	**55.7**	**3.65**	**4.17**	**21**	**13**	**12**	**3.65**	**3.65**	**13**	**13**	**4.11**	**3.65**

C1-13- wastewater channels; ***N_{LU} (unit)-*** Loading units-total number of basins feeding each channel; ***A (cm^2)-*** area of flow at each channel ***Q_O (L/s) –*** discharge capacity of each channel; ***Q_R (L/s)-*** free discharge of each channel.

Table 4.8 The results waste ater run off calculations according to Equation 6 for intense use (*K=1.00*) and for loading unit rate of System III; (*R_{LU}= 0.4 L/s)*

	AS-IS						ORIGINAL					IDEAL			
	N_{LU}	Sizes		A	Q_O	Q_{WW}	N_{LU}	Sizes		Q_O	Q_{WW}	Sizes		Q_O	Q_{WW}
channels	loading units	width	depth	Area	discharge capacity of each channel	free discharge of channel	loading units	$width_{as-is}$	$depth_{as-is}$	discharge capacity of each channel	free discharge of channel	width	depth	discharge capacity of each channel	free discharge of channel
	(unit)	(cm)	(cm)	(cm^2)	(L/s)	(L/s)	(unit)	(cm)	(cm)	(L/s)	(L/s)	(cm)	(cm)	(L/s)	(L/s)
C1	4	14	7	35	1.75	1.26	2	14	7	1.75	0.89				
C2	5	12	7	30	1.50	1.41	3	12	7	1.50	1.10				
C3	8	14	11	55	3.45	1.79	6	14	11	3.45	1.55				
C4	9	13	11	51.1	3.20	1.90	7	13	11	3.20	1.67				
C5	3	12	6	25.7	1.19	1.10	3	12	6	1.19	1.10				
C6	3	12	7	30	1.50	1.10	5	12	7	1.50	1.41				
C7	**6**	**14**	**5**	**25**	**1.06**	**1.55**	**8**	**14**	**5**	**1.06**	**1.79**	**14**	**8**	**2.14**	**1.79**
C8	9	14	9	45	2.55	1.90	10	14	9	2.55	2.00				
C9	10	14	12	60	3.93	2.00	11	14	12	3.93	2.10				
C10	**19**	**13**	**9**	**41.8**	**2.37**	**2.76**	**18**	**13**	**9**	**2.37**	**2.68**	**13**	**10**	**2.77**	**2.68**
C11	1	11	6	23.6	1.09	0.63	1	11	6	1.09	0.63				
C12	2	9	7	22.5	1.13	0.89	2	9	7	1.13	0.89				
C13	24	13	12	55.7	3.65	3.10	21	13	12	3.65	2.90				

C1-13- wastewater channels; ***N_{LU} (unit)-*** Loading units- total # of basins feeding each channel; ***A (cm^2)-*** area of flow at each channel ***Q_O (L/s)*** discharge capacity of each channel; ***Q_{WW} (L/s)-*** free discharge of each channel.

Table 4.9 The results of wastewater run off calculations according to Equation 6 for frequent use (*K=0.7*) and for loading unit rate of System II (R_{LU}= 0.4 L/s)

	AS-IS						ORIGINAL					IDEAL			
	N_{LU}	Sizes		A	Q_O	Q_{WW}	N_{LU}	Sizes		Q_O	Q_{WW}	Sizes		Q_O	Q_{WW}
channels	loading units	width	depth	Area	discharge capacity of each channel	free discharge of channel	loading units	$width_{as\text{-}is}$	$depth_{as\text{-}is}$	discharge capacity of each channel	free discharge of channel	width	depth	discharge capacity of each channel	free discharge of channel
	(unit)	(cm)	(cm)	(cm^2)	(L/s)	(L/s)	(unit)	(cm)	(cm)	(L/s)	(L/s)	(cm)	(cm)	(L/s)	(L/s)
C1	4	14	7	35	1.75	0.89	2	14	7	1.75	0.63				
C2	5	12	7	30	1.50	0.99	3	12	7	1.50	0.77				
C3	8	14	11	55	3.45	1.25	6	14	11	3.45	1.08				
C4	9	13	11	51.1	3.20	1.33	7	13	11	3.20	1.17				
C5	3	12	6	25.7	1.19	0.77	3	12	6	1.19	0.77				
C6	3	12	7	30	1.50	0.77	5	12	7	1.50	0.99				
C7	**6**	**14**	**5**	25	**1.06**	**1.08**	**8**	**14**	**5**	**1.06**	**1.25**	**14**	**6**	**1.39**	**1.25**
C8	9	14	9	45	2.55	1.33	10	14	9	2.55	1.40				
C9	10	14	12	60	3.93	1.40	11	14	12	3.93	1.47				
C10	19	13	9	41.8	2.37	1.93	18	13	9	2.37	1.88				
C11	1	11	6	23.6	1.09	0.44	1	11	6	1.09	0.44				
C12	2	9	7	22.5	1.13	0.63	2	9	7	1.13	0.63				
C13	24	13	12	55.7	3.65	2.17	21	13	12	3.65	2.03				

C1-13- wastewater channels; ***N_{LU} (unit)-*** Loading units- total # of basins feeding each channel; ***A (cm^2)-*** area of flow at each channel ***Q_O (L/s)*** discharge capacity of each channel; ***Q_{WW} (L/s)-*** free discharge of each channel.

CHAPTER 5

DISCUSSIONS AND CONCLUSION

In this chapter, the surface slopes, discharge capacity and faults of the roof of the structure were evaluated. The maximum water storage and consumption capacities and wastewater discharge system were assessed in terms of their adequacy and improvement. The recent interventions done with incompatible materials were also discussed. At the end are given the conclusions followed by the suggestions for further studies.

5.1 Rain Water Drainage System

In this section of the study *the faults of the rain water drainage system*, *adequacy of the rainwater drainage system* and *suggestions for the improvements of the rainwater drainage system* were evaluated under respective headings.

5.1.1 Faults of the Rain Water Drainage System of Şengül Hamamı

The present condition of the roof was determined to be unsatisfactory due to unconscious interventions and poor maintenance as presented in the map showing the roof faults given in previous chapter (Figure 4.14). It appeared that the roof drainage system is not possible to function properly anymore due those faults and due to the presence of unacceptable mesh-reinforced concrete layer. This incompatible layer definitely accelerates the soluble salts and dampness problems and destroys the functioning of roof drainage system. The recent studies also showed that the concrete/reinforced-concrete repairs destroy the structural stability of the historic masonry structures and weaken the structures against the lateral stresses (Aktaş, 2006). Most faults observed on the roof surfaces described in the previous chapter in detail, were inevitably the result of this concrete layer.

5.1.2 Adequacy of the Rain Water Drainage System of Şengül Hamamı

The roof drainage calculations clearly exhibited the inadequacy of the roof drainage system in as-is case on quantitative basis (Table 4.1). For instance, the overall roof runoff rate of the concrete-clad roof B1, 18.2 L/s, was almost twice of the total discharge capacity of the waterspouts, 10.2 L/s. Similarly, the total roof runoff rate of the concrete-clad roof B2 was calculated to be 9.7 L/s which is considerably higher than the discharge capacity of the drain O1, 5.4 L/s. This drain O1 was the only discharge component of the roof B2 and in case of it's partially or completely blockage, the roof B2 seemed to suffer from rainwater accumulation in considerable amounts.

Although the hamam is seemed to have some surface slopes providing water flow, the slope arrangement was far away from a satisfactory removal of rainwater from the concrete-clad roof surfaces. The as-is case of the roof drainage system was inadequate and not allowing free discharge of rainwater due to the unconscious interventions of mesh-reinforced concrete layer with improper surface grading, parapets and green garden. But, as the continuation of roof drainage system, the site grading of the surface drainage system seemed to be acceptable for a proper surface water removal from the immediate grounds of the building.

The calculations also presented the uneven distribution of rainwater loading for each discharge components. For instance, the spouts WS5, WS6, WS7, WS9 and the down pipe DP7, were found to be overloaded considerably while the spouts

WS1, WS2, WS3 and WS8 were found to work under capacity (Table 4.1)(Figure 4.7). This corresponds with the results of the map showing the discrete roof areas feeding each waterspout (Figure 4.7). According to the calculations, the spouts WS5, WS6 and WS7 were extremely-loaded with the roof run off rates of 5.8 L/s, 4.6 L/s and 3.6 L/s, respectively, even reaching to the four times of their as-is discharge capacities (Table 4.1).

The discharge coefficient, Ψ, for the low-sloped surfaces of the roof B1 was also discussed according to the results of drainage calculations. The discharge coefficient of the dome surfaces was accepted as '1.0' because of their high slope (Hall, 1996; TS EN 12056-1, 2005; TS EN 12056-2, 2005). Considering the ideal roof fall arrangement and the original spout dimensions, 10cm x 9cm in width and depth, the surface conditions for the low-sloped surfaces at the past could be calculated. The discharge coefficient was found to be in the range of 0.2-0.3 for the low-sloped surfaces signaling a considerably high water absorption capability of the surface, such as soil.

5.1.3 Suggestions for the Improvement of the Rain Water Drainage System of Şengül Hamamı

The study has shown up the priorities for the improvement of the roof drainage system and maintenance program particular to the building. Above all, it is essential to correct the surface grading of the roof surfaces but it is not possible to repair these surfaces with additional concrete layers. That is, the present roof drainage system of the mesh-reinforced concrete roofs could not be improved by usual remedial measures. The mesh-reinforced concrete layer, therefore, should definitely be removed from the structure and then the roof should be covered with the layers of compatible roof plasters in the context of a well-planned conservation program developed by the structural engineers and conservation experts. The ideal case for the improvement of the roof drainage system was suggested as follows: -

(a) As much as the present surface geometry allowed, an even distribution of rainwater loading for each discharge component should be achieved as suggested in Figure 4.13. The arrangement of roof slopes should be corrected accordingly for a pond-free drainage system. Special care should be given to level the reverse falls in front of spout openings properly for a fast water runoff,

(b) The extreme loading from the roof of neighboring building at the east of the roof B2 should be prevented, without doubt, by a separate roof drainage of the neighboring building,

(c) The discharge capacities of the waterspouts should be improved by increasing their flow dimensions. For a rainwater discharge in acceptable ranges, the ideal flow dimensions for the spouts, WS1, WS2, WS3, WS4, WS5, WS8 and WS9 were calculated to be 10cm x 9cm in width and depth, having the discharge capacity of 1.8 L/s. A larger discharge capacity of 2.7 L/s was needed for the spouts WS6 and WS7 with the flow dimensions of at least 11cm x 11cm in order to cope up with the roof runoff rates of 2.5 L/s and 2.8 L/s, respectively (Table 4.2). The as-is dimensions of O1, 12.5 x 18.0cm in width and depth, needed to be increased to 12.5 x 28.0cm to cope up with the free discharge of the rainwater from the roof area,

(d) The internal gutter IG1 should be extended to cover the whole length of the roof B2, 17.40 m, where it suffers from the lack of drainage component (Figure 4.13). An alternative drain may be suggested which may act as an overflow drain in case of any partial/complete blockage of O1,

(e) There is a necessity of an additional waterspout WS10 at the south of B1, suffering from the uncontrolled overflow and severe dampness problems on the wall surfaces (Figures 4.12 and 4.13)

Some urgent interventions related to the timber pitched roofs were also recommended to improve their existing conditions: -

(f) The timber pitched roofs should be repaired to let it properly function as a four-sided pitched roof/hipped roof as suggested in Figures 4.12 and 4.13. The eaves gutter and down pipes forming the peripheral drainage system for these pitched roofs should be replaced with the properly sized ones. The drainage systems for the pitched roofs and low-sloped roofs should be separated. The direct discharge from the pitched roofs onto the roofs B1 and B2 should definitely be prevented by the addition of downspouts diverting rainwater to the surface-water drainage system at the immediate periphery of the structure. The placement of these down pipes was shown in Figure 4.12 and the ideal sizes for each down pipe and eaves gutter were presented in (Table 4.2). The 23 down pipes located at four sides of the roofs should be recommended with diameters of 70mm for the down pipes and of 250mm for the eaves gutters while smaller diameters could be enough for the lantern part of the pitched roofs as presented in Table 4.2.

Such improvements summarized above are essential for a pond-free drainage system and for the survival of the structure. In addition, some preventive measures were also suggested, such as the cleaning of discharge components from soil and plant deposits regularly/seasonally/frequently especially at rainy seasons.

5.2 Water Supply and Waste Water Discharge System

In this section of the study *the hot and cold-water storage and consumption capacity of the Şengül Hamamı, the adequacy of waste water discharge system of Şengül Hamamı and suggestions for the improvement of waste water discharge system of the structure* were discussed under respective headings.

5.2.1 Hot and Cold Water Storage and Consumption Capacities of Şengül Hamamı

The capacity of hot water storage room ($45m^3$) corresponds to the maximum capacity of hot water consumption in Şengül Hamamı. Bathing water with sufficient temperature can be obtained by mixing four volume of hot water and one volume of cold water. With this assumption overall/total water consumption in a day should be $56m^3$, including all activities of cleaning. The contemporary standards, such as TS 1258 (1983) and BS 6700 (1997) require the cold-water storage to cover 24 hours of interruption-supply. The water storage capacity of $62m^3$ for cold-water storage room seemed to satisfy this requirement since that capacity was slightly larger than the assumed value of $56m^3$. This meant that the cold water storage capacity of Şengül Hamamı appeared to cope with all activities consuming water, such as bathing, general/routine cleaning of the bath, washing towels and cloths toilet cleaning and etc., for a day in case of no water supply.

5.2.2 Adequacy of Waste Water Collection and Discharge System of Şengül Hamamı At Present

The map showing the surface slopes on floors exhibited the presence of a surface water flow arrangement in the tepidarium and caldarium sections of Şengül

Hamamı. Most slopes were found to be below 1%, even being nil at some places, which are inadequate for a proper surface water removal and cause local ponding areas on marble floors.

The outlet O_1, in the caldarium section with the discharge capacity of 2.37 L/s was not able to withstand the run off rate of 3.12 L/s. The outlet O_2 in the tepidarium section with the discharge capacity of 3.65 L/s seemed to cope up with the run off rate in as-is case with its flow dimension of 13cm x 12cm in width to depth (Table 4.4)(Figure 4.23).

The wastewater discharge capacity calculations clearly exhibited the inadequacy of the wastewater discharge system on quantitative basis especially for the caldarium section of the women's part of the structure in as-is case (Tables 4.7, 4.8 and 4.9). For instance, as seen in Table 4.7, the results of first method explained in Equation 5 (Section 3.2.6) clearly exhibited that, the channels C10 and C13 were found to be overloaded with the 13cm x 9cm and 13cmx 12cm in width and depth dimensions and with the discharge capacities of, Q_O, of 2.37 L/s and 3.65 L/s, respectively. Also in the second method explained in Equation 6 (Section 3.2.6), with the frequency factor, K**,** of intense use, 1.00, the wastewater channels C7 and C10 were found to be overloaded with the discharge capacities of, Q_O, 1.06 L/s and 2.37 L/s, respectively, due to the larger quantities of run off rates at 1.55 L/s and 2.76 L/s, respectively (Table 4.8) (Figure 4.24). When K was taken as frequent use, the discharge capacities of all channels except for the channel C7 seemed to be highly adequate to provide a free flow of wastewater (Table 4.9).

5.2.3 Suggestions for the Improvement of Waste Water Collection and Discharge System of Şengül Hamamı

The suggestions for the improvement of the wastewater discharge system were summarized below: -

(a) For pond-free floor surfaces the wastewater floor arrangement on marble clad floors considering the rate of surface slopes and their direction should be corrected according to the surface slopes recommended by the standards (Barry, 1988) such as 2 % for smooth impermeable surfaces.

(b) The discharge capacities of the overloaded wastewater channels and their outlets should be improved by increasing their flow dimensions (Table 4.4 and Table 4.8). For a wastewater discharge in acceptable ranges, the ideal flow dimensions for the channel, C7 were calculated to be at least 14cm x 8cm with the flow capacity of 2.14 L/s (Table 4.8), while it seemed to be adequate with the 14cm x 6cm flow dimensions in width to depth when the frequent use of K value was taken, that was 0.7(Table 4.9).

The ideal flow dimensions for the channel C10, was determined to be 13cm x 10cm with the discharge capacity of 2.77 L/s when the intense use of K value was taken, that was 1.0 (Table 4.8), though it was again adequate with 13cm x 9cm width to depth dimensions, when K value was taken as 0.7 (Table 4.9).

The ideal flow dimensions and flow capacities, Q_O, were determined to be at least 13cm x 11cm with 3.20 L/s for the floor drain O_1 and 13cm x 13cm with 4.11 L/s for the floor drain O_2, in order to provide water evacuation in acceptable ranges (Table 4.4).

The ideal flow dimensions for the channel C13 was found to be at least 13cm x13cm in width to depth dimensions for a free flow of wastewater according to the method in Equation 5 (Table 4.7), though 13cm x 12cm flow dimensions seemed to be highly enough according to the method in Equation 6 (Table 4.8 and 4.9).

5.3 Conclusions

The study has shown up the characteristics of hot and cold-water storage capacities, water consumption, and wastewater and rainwater drainage systems for Şengül Hamamı. It was seemed that the structure had originally well-designed functional systems all of which composed a well-functioning structure using, running, collecting and discharging water in its spaces in an efficient way. However, those functional systems have not been able to properly function at present due to the inappropriate intervention and lack of maintenance and passing of time.

At present, the roof drainage system failed to provide rainwater collection and discharge in acceptable ranges. There were serious dampness problems arising from unconscious recent repairs, mainly the 8 cm thick mesh-reinforced concrete layer causing considerable roof drainage faults. For a well functioning roof drainage system and for the health of the structure, the mesh-reinforced concrete layer covering the overall roof area should be removed. Then this roof area should be clad with layers of protective roof plasters. The plasters should be compatible with the historic dome masonry. Therefore, these works should be done in the context of a well-planned conservation program developed by the conservation experts and structural engineers.

The suggestions for the improvement of the roof drainage system were made in terms of roof fall arrangement, flow dimensions of discharge components and their placement on roof area. Some preventive measures were also pointed out.

Şengül Hamamı seemed to have enough cold-water storage capacity for its proper functioning during the 24 hours of interruption-supply, including all activities consuming water. Şengül Hamamı was found to have maximum hot water consumption capacity, Q_{WCmax} (1.25 m^3/basin/day) that seemed to fall in the average values for the historical Turkish baths belonging from 12^{th} to 19^{th} centuries. The effective floor area per basin in caldarium section of the historical Turkish baths, A_b, was found to vary in the range of 3.21-11.04m^2/basin with an average of 5.7±1.7m^2/basin. The A_b value of Şengül Hamamı again falls in the average range with the value of 7.23m^2/basin among the other historical Turkish baths.

No significant relation was found between the hot water consumption capacity (Q_{Wcmax}) values of historical Turkish baths and their effective floor areas of their caldarium sections per basin (A_b). The waste water discharge system of Şengül Hamamı had become disfunctional due to inadequate and reverse falls and inadequate flow dimensions of water channels/outlets, in turn causing ponded areas on the slippery marble surfaces.

The results obtained from the calculation methods using the Equations 5 and 6, (see Section 3.2.6) showed that both methods were useful to evaluate the adequacy and capacity of wastewater discharge system in historical Turkish baths. The comparison of the values Q_R and Q_{WW} showing the discharge capacity of a wastewater channel presented that the *K value* for Şengül Hamamı was 0.7. Knowing this information, from now on, allowed us to calculate the ideal flow dimensions for the wastewater discharge components of Sengul Hamamı, only by using the calculation method using Equation 6, described in the standard, TS EN 12056-2 (2005). The *K value* may differ for the other historical baths The *K value*, indicating the use-frequency of sanitary installations in buildings types, should be defined for the historical baths, and then, included in the standards as a certain frequency factor, or within a range, especially for the basin taps of those structures. A similar study on the determination of rate of water run off of each basin, R_{LU}, and the type of appliances is also required for adapting the Equation 6 for the capacity calculations of historical baths. These data is essential for the development of standards, specifically for the assessment of wastewater discharge systems of historical baths.

The calculation methods developed in the study seemed to be useful for the assessment of water storage and consumption capacities, the adequacy of discharge system and its improvement. These calculations should be done for the adequacy assessment of any intervention suggested for the water supply and drainage system of the historical structures. Any subsequent intervention of roof drainage system should be evaluated by means of roof drainage calculations used in this study.

The joint interpretation of non-destructive analyses, including mapping of the decay forms, infrared thermography analyses, leveling survey and capacity calculations, provided a good combination for the assessment of the water supply and drainage system of historical baths.

Further studies are needed to discover the drainage characteristics of original roof materials. The locations of the area drains and their capacity should be checked for the ideal case due to the additions of new down pipes directly discharging water to the surface-water drainage system of the immediate grounds.

Further studies are also needed o better understand the relationship between the storage capacities of historical baths and the availability of natural water sources nearby. In Şengül Hamamı the volume of cold-water storage room is greater than the volume of hot water storage room. Further studies are needed to clarify the reason for the need of larger-volume cold-water storage room construction in the building.

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