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Original Research Article

Analyzing the Reasons for the Unconditioned Space in the Thermal Shell of the Apodyterium of Kashan Bathhouses

Ali Hashemi [1], Ali Asgari [2*]

1. Master of Project Management and Construction, Faculty of Architecture and Urban Planning, University of Arts, Tehran, Iran.
2. Department of Architecture, Shahr-e-Qods Branch, Islamic Azad University, Tehran, Iran.

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Abstract

Problem statement: Various estimates have been presented regarding effective strategies for reducing heat loss and energy storage in the body of traditional Iranian bathhouses. However, the efficiency level has not been determined due to the impossibility of calculating the function of each one.

Research objective: This study attempts to the efficacy of three common strategies in the body of bathhouses, including "compactness in the texture and neighborhood", "entering the ground" and "surrounding the apodyterium among unconditioned spaces" to see which is the most effective in preventing heat loss from the shell in traditional Kashan bathhouses.

Research method: The present study uses a quantitative paradigm and energy simulation strategy. In this study, Design Builder software was used for its calculations. It is based on evidence obtained from the physical reading of the spatial structure of traditional bathhouses in Kashan City. They were selected using a non-random sampling method.

Conclusion: Surrounding the apodyterium spaces among the unconditioned spaces in Kashan bathhouses has had different results which can be explained by their centrality in the bathhouse plans. However, in its minimum state, the space has been effective with a mean of 13.94% per year in Sultan Ahmed Bathhouse and 46.74% in Khan Bathhouse. This figure has reached 33. 18 percent compared to all four bathhouses. It shows the significance and efficiency of this strategy compared to the insignificant efficiency share of the strategies of inserting the bathhouse inside the ground and "compact urban texture to use the neighborhood" with values of 5. 44 and 0.6, respectively.

Keywords: *Bathhouse, Traditional architecture, Heat loss, unconditioned space, Climatic design.*

Introduction and Problem Statement

In traditional architecture literature, bathhouses are considered one of the significant urban places on the path of city and village markets. They follow an almost common pattern due to the low effect of climatic factors on their establishment, physical shape, and division of interior spaces (Ghobadian, 2009, 167). These buildings are distinct compared to other historical works of Iran due to the architects' attention to the heating system used in them (Pirnia, 1992, 198).

Several material and spiritual factors have been effective in diversifying the bathhouses. This issue has caused extensive physical (such as architectural

* +989122546292,ali.asgari@iau.ac.ir

space and structure, hierarchy, materials, and decorations) and functional (such as multiplicity, species diversity, and physical plan) changes in the built bathhouses (Tabasi, Ansari, Tavousi & Fakhar Tehrani, 2007, 52). Generally, bathhouses are made up of various components appropriate to the size and function of the bathhouse. Apodyterium, tepidarium, and middle space are among the most common spaces of bathhouses (Ghobadian, 2009, 168). Since users lack a cover in the apodyterium spaces, special attention has been paid to them in terms of heat exchange and ventilation.

The control of ventilation and air current with the help of breaking the paths and reducing the height of the movement paths (Haji Ghasemi, 2004, 98), lowering the whole building to the ground (Sadeghi, Shahbazi Shiran & Feizi, 2019, 177; Pirnia, 1992, 198), the compactness of the plan (Zarei, 2012, 77-78), and the thermal mass above the bathhouses (Zarei, Vahidi & Razani, 2017, 10) are among the various solutions proposed for heat loss control system in traditional bathhouses. The passion for studying native architecture and identifying sustainable strategies in traditional buildings is admirable both scientifically and nationally. However, the effect of each of the mentioned estimates in the simulation space has not been examined so far and factors such as "little information about materials and technology used in the construction of walls", "the accurate amount of air circulation", "openings", "the frequency of using building", and "the few remaining buildings due to the variety of periods and different climates in each region have reduced the validity of studies on the subject".

The present study seeks to answer the question of what strategies are used to reduce heat transfer through the shell in the apodyterium and to what extent has this issue been considered in the bathhouses of Kashan due to the extreme temperature fluctuation. This question on the role of unconditioned spaces in the apodyterium of traditional bathhouses in comparison with the effect of the exterior and interior compact texture of the bathhouses and lowering the whole building inside the ground can emphasize the significance of this neglected strategy in the studies. In this regard, the primary hypothesis of the study emphasizes the role of the arrangement of unconditioned spaces around apodyteriums to prevent heat loss through their shell in the climatic conditions of Kashan City. In other words, the present study hypothesizes that unconditioned spaces play a significant role in preventing heat loss in the apodyterium.

Although several studies have been conducted regarding thermal load or energy loss, very limited quantitative studies have been conducted on the heat loss of traditional bathhouses. Given the emphasis of previous studies on non-measurable or estimated strategies, the primary aspect of the innovation on the current subject in the article is its emphasis on the role of unconditioned spaces. In other words, this study seeks to identify the effect of placing apodyterium space as a conditioned space among other unconditioned spaces by comparing the strategies of tissue compactness and the neighborhood of the bathhouses and lowering the building into the ground.

Literature Review

Limited studies have investigated bathhouses climatically. One of these studies has examined the effect of climate on the design and construction of Iran's bathhouses. The present study hypothesizes that diverse climates in Iran have caused significant impacts despite physical commonalities in traditional bathhouses (Tabasi, Ansari, Tavousi & Fakhar Tehrani, 2006). The construction of a basin space, the use of tiles in decorations in hot and dry climate bathhouses with a larger area, shortening the height of the apodyterium, the use of limestone decorations, brickwork in cold and mountainous climates, building a mansion on sleeper wall, using a sloped cover, providing light from the vestibule of the body, using wood and not using decorations in a moderate and humid climate, and building small bathhouses, using coral stones, not decorating the body in a hot and humid climate were the achievements of the study (same). Another study entitled "Analysis of architectural and spatial characteristics of Qajar bathhouses in Fars region", investigated the body of bathhouses in the province in addition to testing the previous achievements. It showed that bathhouses in hot climates have more than 0.04% elongation in length-to-width ratio. The apodyterium is shorter but larger than the tepidarium in a cold climate. This article also revealed that apodyterium and tepidarium spaces occupied almost 30 to 40% of the total area of bathhouses in different climates of the Fard Province (Zarei, Vahidi & Razani, 2017, 13) (Fig. 1).

Sohrabi and his colleagues compared the internal geometry of the apodyterium and the tepidarium spaces of bathrooms in hot and dry climates of Iran. They reported that in the bathhouses of hot and dry climates, physical design reduced the thermal fluctuation first by lowering the building into the ground and then by increasing the thermal mass of the building. Due to the structure of the tepidarium and apodyterium established among the unconditioned spaces, they have little direct connection with the surrounding environment. The results showed that tepidarium by 66% and apodyterium by 67% are in interaction with spaces with fewer temperature differences (Sohrabi, Asgari & Ghaffari, 2023).

Regarding the foreign studies conducted about bathhouses, we can refer to a study that measured the thermal-humidity behavior of Roman thermal buildings, Indirizzo" baths of Catania, Sicily. In the mentioned study, knowing the building performance, the researcher investigated the primary building of the Indirizzo" Baths of Catania – Sicily with the help of 3D laser scanning and computational fluid dynamics while emphasizing the indecisiveness in the analysis due to the lack of knowledge of the temperature and relative humidity in the apodyterium, the thermal level, and the process of emission of hot chimney gases, and the presence of window panes and coverings. The results indicated that the temperature between 90 and 125 °Cof the gases in the chimneys below the surface of the bathhouse causes a temperature between 30 and 35 °C and a relative humidity of 60 to 70 percent. By dynamic modeling of the fluids inside the old bathhouse, this study showed that the relative humidity and air temperature decrease and increase, respectively, as the height of the apodyterium increases. This value is about 10 °C and 10% (Gagliano, Liuzzo, Margani & Pettinato, 2017).

Although limited studies have been conducted on the structure of traditional Iranian bathhouses focusing on heat loss, several views have been provided about the effectiveness of strategies such as plan arrangement, compactness of the plan structure, and surrounding texture, which generally have a small contribution to the bathhouse literature. This issue has been stated as an estimate in the form of studies about the bathhouse (looking at decorations, general geometry, social relations, etc).

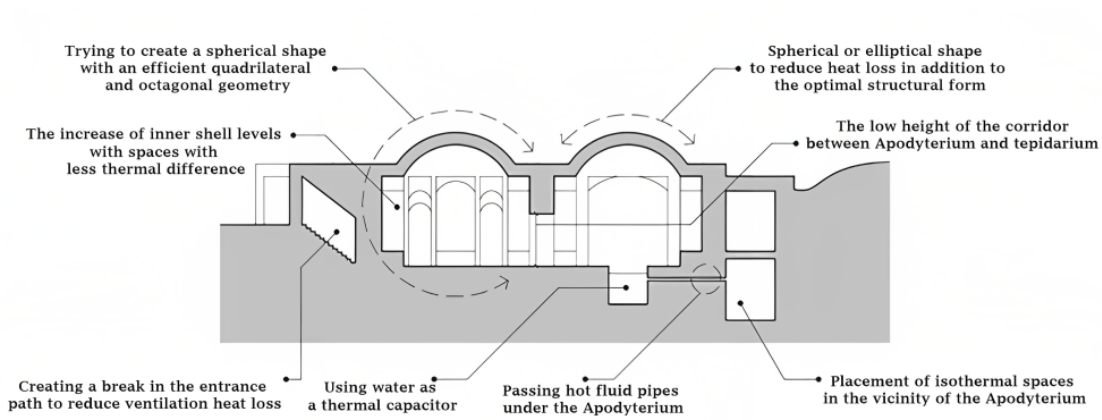

Fig. 1. The general solutions used in traditional bathhouses in the hot and dry climates of Iran. Source: Sohrabi et al., 2023, 34.

No study has used energy simulation in this regard due to the lack of access to documented information about the buildings, the small number of samples available in a climate context, and the lack of full functionality of the bathhouse due to the lifestyle change. Thus, this issue is considered one of the primary innovation aspects of the present study. In this regard, the issue of «unconditioned spaces», «the effect of compactness of the plan in the structure and the building», and «the lowering of the building to the ground» in reducing the heat loss of the building have been considered in other traditional buildings and new buildings.

Regardless of the studies that define this space, as national standards and regulations, various studies have been conducted about unconditioned spaces regarding the level of functionality and their positive impacts. In this regard, one study analyzed the effect of defining the internal temperature of the house on determining the coefficient of heat loss through remote environmental sensing with a focus on comparing different types of factors affecting heat loss in conventional buildings in Switzerland. It reported that unconditioned spaces can be effective in reducing heat loss through shells by up to 30% (Senave, Roels, Verbeke & Saelens, 2020).

Some other studies have analyzed one of the building spaces as a common but unconditioned space in the common body of buildings. For example, in a study entitled "Effect of space under the gable roofs on the energy performance of old buildings", Fabbri and Brunetti criticized the model of restoration of houses in the village of Borgo Maricchia, Italy, and investigated the effect of the gable roofs of traditional houses compared to the insulation of restored buildings without gable roofs. The simulation performed in this study indicated the higher efficiency of the traditional model despite the updated insulation of the upper level of the restored buildings. This value, which shows about 10% higher performance in cold months, is another example of the efficiency of unconditioned space in architectural design (Fabbri & Brunetti, 2015, 1282).

Similar to the previous study, a study by Hoffmann and Geissler about the conditioned space in the basement reported that walls without insulation were considered effective in controlling heat loss by 10% (Hoffmann & Geissler, 2017, 37). Many studies, such as the study of Bergero & Chiari, have been conducted to calculate unconditioned spaces more accurately in the prescriptive and functional methods in the new English standards. For example, in this study entitled "Heat transfer in unconditioned spaces: method of evaluating the adjustment index", the researchers observed new values instead of the coefficients of common standards, and they realized that the contribution of the thermal bridge in analytical calculations is negligible (Bergero & Chiari, 2019).

Theoretical Foundations

Unconditioned space or unheated space refers to parts of the building space that do not have heating and cooling terminals such as air-locked separation joints, stairways, corridors, and parking lots (Building and Housing Research Center, 2009, 10). This definition, expressed generally in comparison with the conditioned space in the building audit, is used in both functional and prescriptive methods in building calculations due to the lower temperature difference on the two sides of the wall, with coefficients extracted from national regulations or current standards in the region.

In other words, this issue should be considered in the calculations using a reduction factor considering that the temperature difference between the interior space and the unconditioned space is less than the temperature difference between the interior and exterior space, and thus, the rate of heat transfer from the adjacent walls of the unconditioned space is less than the rate of heat transfer from the adjacent outside walls (ibid.). In the functional analysis of the thermal cover, the building is divided into conditioned and unconditioned compartments. The wall between these two spaces prevents the integration of conditions as a physical barrier. It is difficult to accurately estimate unconditioned space temperature for energy audit purposes. However, it can compensate for the non-constant effects of temperature for measuring long periods and allow the use of average values in sustainable design (Nepomuceno, Martins & Pinto, 2022).

Methods

The present study used the post-positivism approach and processed the physical structure of the inner shell of the apodyterium of Kashan bathhouses with the modeling and simulation approach. To identify the physical characteristics of Kashan bathhouses, four bathhouses were selected as samples using a non-random sampling method (Table 1). In the stage of identification, organization, and analysis of the data collected from the documents of the bathhouses, affected by the pictures and maps taken from them before destruction or the possibility of observing the works during writing the article, physical spaces were abstracted. The inclusion criteria were as follows: "having complete physical information about the subject", "possibility of re-sampling to measure the quality of the space", "popularity of bathhouses in the architectural literature of Kashan", and "the health of the building in terms of changes until the time of documentation" in the hot and dry climate of Kashan.

It is necessary to study the calculation logic and identify the parameters affecting the thermal behavior of the walls to evaluate the studied samples regarding the comparative investigation of the thermal behavior of the external shell of bathhouses in hot and dry regions. Thus, after selecting the samples of this study and referring to the calculation principles of the behavior of the outer shell of the building, the performance of the walls of the desired spaces in the bathhouse was analyzed. For this purpose, to model the physical space of bathhouses, after the field sampling of the surfaces, selected samples were measured in terms of "adjacent and neighboring surfaces", "going down in the ground", "materials used in the building", "extent of surfaces", " North orientation" and "apodyterium location" in four prototypes in Design Builder software. This software is one of the analytical programs that will perform defined calculations with its internal processor, with energy knowledge and input variables, which surely has higher speed and accuracy than normal calculations (Asgari & Fathi, 2022, 106). To match the thermal performance of the shells, in this study, the weather information of Kashan City was obtained from the Ladybug International Meteorological Database in the form of a file related to Builder software, extracted from thirty years (Figs. 2 to 4).

In this regard, each of the case samples was first summarized in terms of overall area, dimensions, and alignment, as shown in Fig. 5. In this case, the area of the bathhouse with the value (S), the general alignment angle relative to the geographical alignment of the north with the value (a), the length and width in the case, in which the area of the abstract shape is equal to the real plan, were simulated with values (l) and (d), respectively.

Also, in the sections related to the heating conditions of the software, the general heating of the space, according to the results of previous studies regarding

Table 1. Samples studied in this study. Source: Haji Ghasemi, 2004.

No	Bathhouse	Construction period	Registration number	Registration date	Address
1	Sultan Mir Ahmad	Qajar	1351	1976	Alavi Street, Sultan Mir Ahmad Alley
2	Khan	Zand	3627	2002	Feyz Square, Grand Bazaar
3	Mohtasham	Qajar	3319	2000	Kamal-Ol-Molk Square, Mohtsham St., Mohtsham Alley
4	Fin	Safavid	238	13935	Amirkabir St

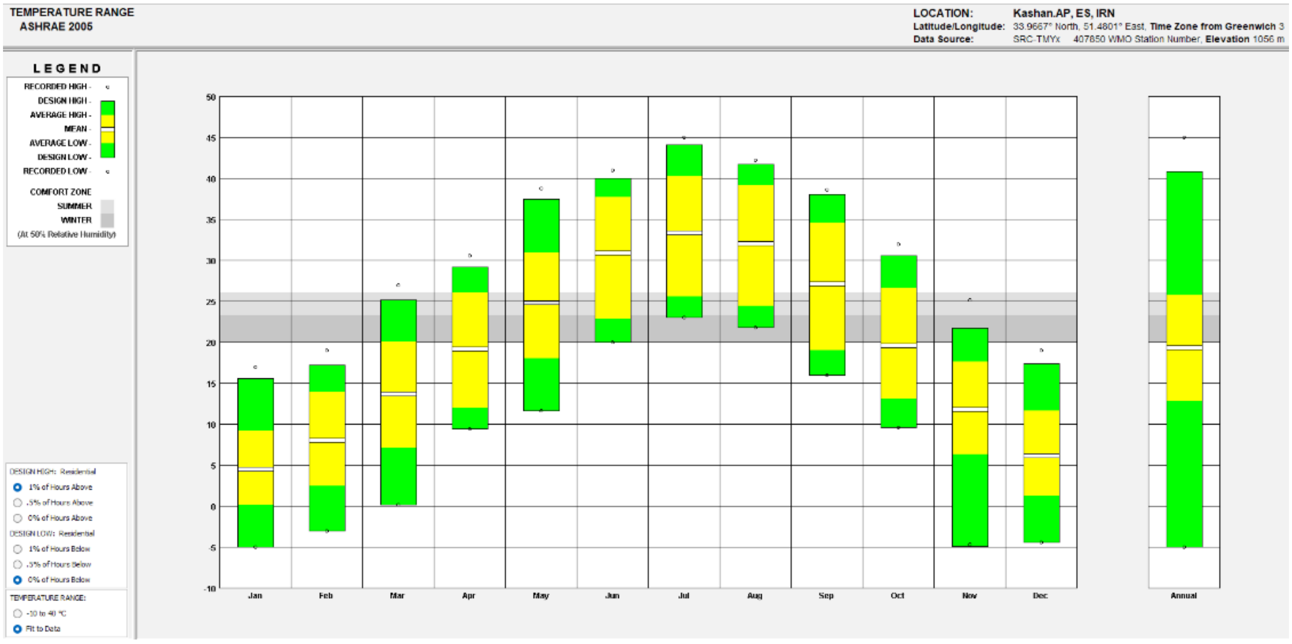

Fig. 2. Dry temperature fluctuation in Kashan City compared to the thermal comfort conditions in the ASHRAE standard, extracted from the climate consultant software. Source: Authors.

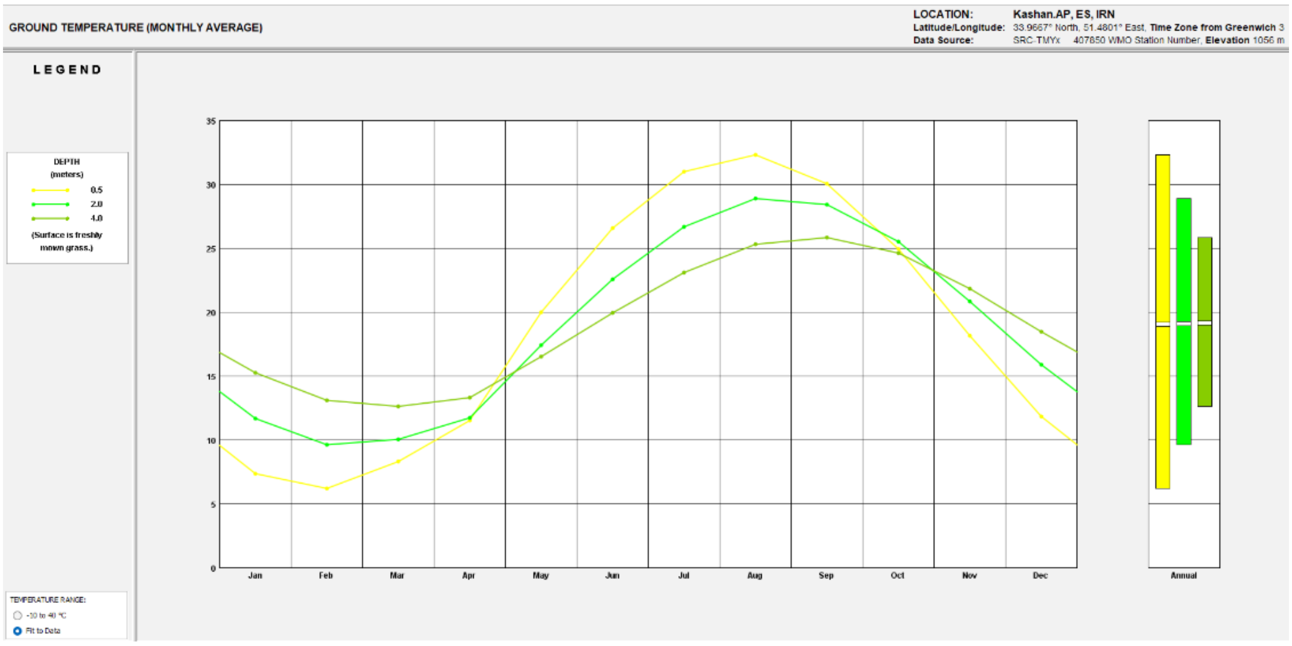

Fig. 3. Ground temperature fluctuation in Kashan City at the depths of 0.5, 2, and 4 meters from the ground surface, extracted from the climate consultant software. Source: Authors.

the origin of heating in traditional bathhouses and existing documentation, was considered the passage of smoke in the chimney path after the burning of fossil fuels, coal or renewable fuels of animal excrement from under the catwalks below the bathhouse floor (Fakhari Tehrani, 2000, 102-103). The activity information in the software, according to the documents, was given from 6 am to 9 pm for seven days of the week and the expected temperature range was from 18 to 24 °C. The average clothing in this section was calculated at 0. 5 Clo (Clothing and Thermal Insulation).

In the simulation stage, the defined rectangular cube was drawn on behalf of the primary volume, in

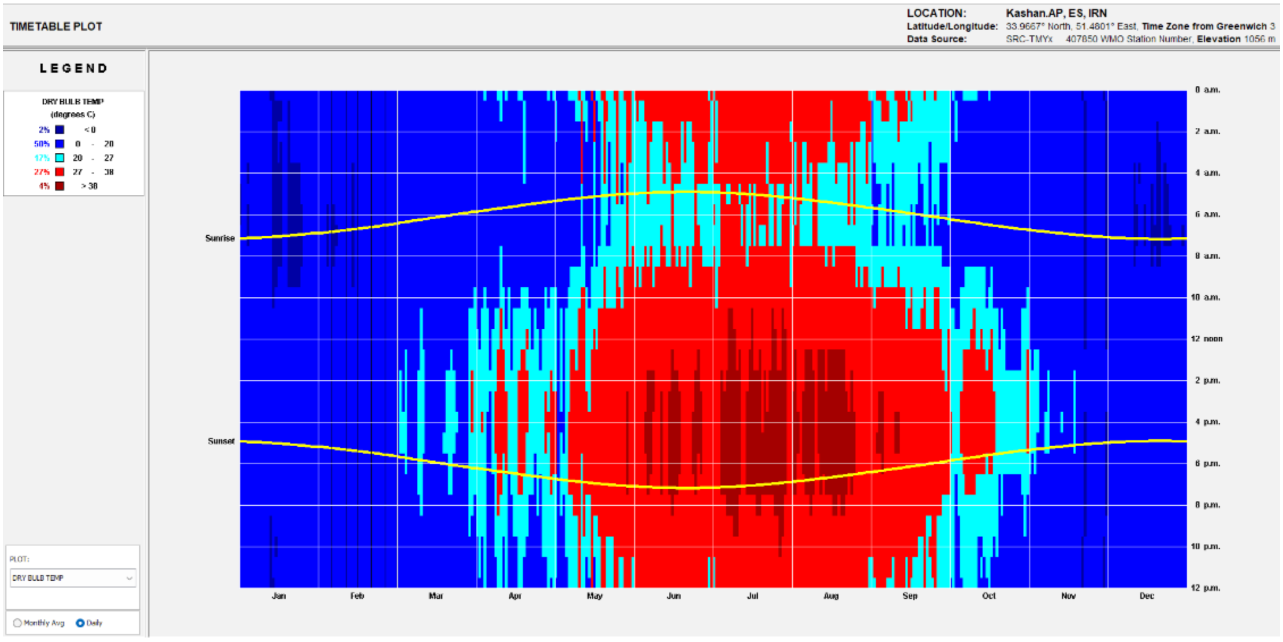

Fig. 4. The hourly temperature fluctuations during the year in Kashan City, extracted from the climate consultant software. Source: Authors.

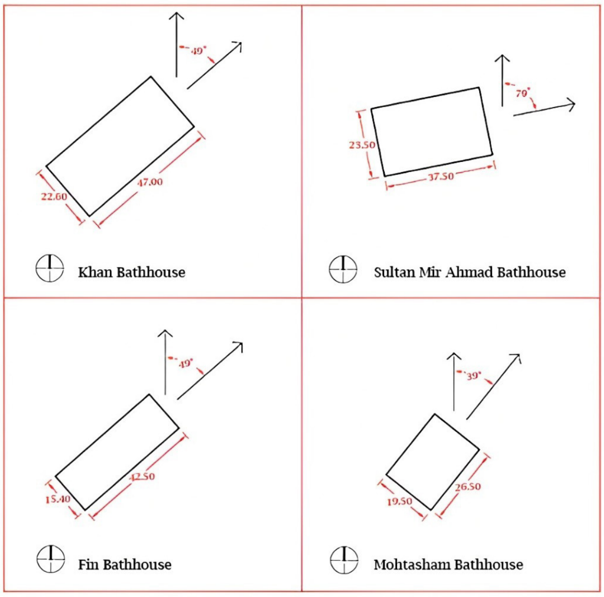

Fig. 5. General alignment and deviation from the north axis in selected samples. Source: Authors.

terms of the environment involved with neighboring spaces (walls of neighboring buildings) and the mean depth inside the soil. The information derived from the dimensions and area according to the documents provided in the research results has been included in the modeling. The modeling was finally done in the first stage of the whole-year period. However, due to zero amount of loss between April to September and a negligible amount in October, the heat loss is shown in the tables only for the months that require heating (five cold months of the year: November to March).

Discussion

As stated in the method section, in the initial stage, the samples taken from the four historical bathhouses of Kashan were used as the basic documentation of this study. The apodyteriums of these bathhouses, marked with orange colors in fig 6 can be identified in rectangular and octagonal shapes. The general alignments of the plans are shown in Fig. 7 considering the geographical north on the top of the paper. In all bathhouses, the structure of the walls of the apodyterium space is covered by other unconditioned spaces, such as the tepidarium, the treasury, the vestibule, the closet, the middle space, the basin, and so on. This issue is shown in Table 2 in the form of space syntax graphs.

As shown in Fig. 8 the space syntax in the selected bathhouses of the study had a similar pattern.

The space of the apodyteriums in contemporary conditions has become useless due to the destruction of some neighbors of the bathhouse from the coverage of the adjacent unconditioned space. This issue has been considered based on the overall

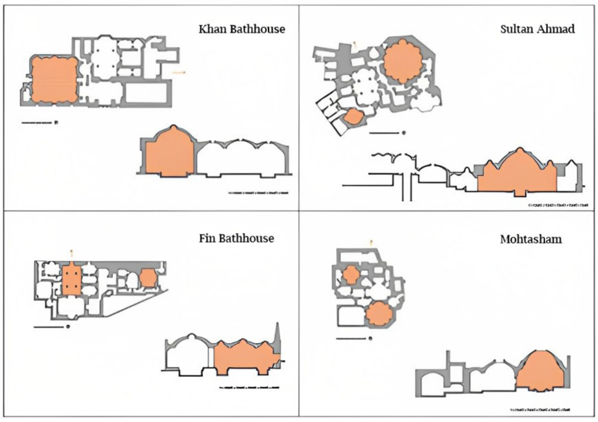

Fig. 6. Apodyterium in plan and section of Kashan bathhouses. Source: Sohrabi et al., 2023, 28.

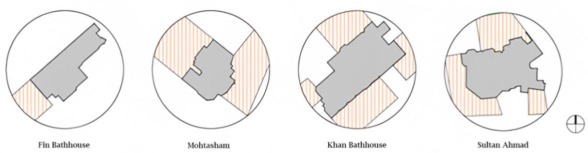

Fig. 7. Adjacencies with emphasis on the neighborhood and empty spaces in the surrounding texture of selected research samples. Source: Authors.

contribution of the available spaces in the research calculations and the score of the non-measurable old neighborhoods has not been considered in the results. The secondary sample taking and the use of field visits of the bathhouses of the initial stage helped to make the dimensions of the spaces in all bathhouses regular. The initial modeling of the maps made it possible to measure the total area and empty spaces of the bathhouse for comparison. In this regard, to simulate the summarized model of each of the bathhouses in the Design-Builder simulator software, it is necessary to estimate the environment involved with the neighborhood, the mean depth of the space buried in the soil, and the surrounding area, and the general alignment regarding the amount of sunlight received through the roof and the average dimensions of the apodyterium. Tables 2 & 3 show this issue. To reduce modeling, the mean dimensions of apodyteriums in bathhouses that have two separate sections were considered.

Data analysis

In the initial simulation of the bathhouses, considering all three strategies, i.e. "using the neighborhood and compact texture", "inserting the building into the ground to use the thermal capacitor of the ground" and "placing the apodyterium space in a layer of controlled spaces", the results extracted from the software showed (Fig. 9 to 12) showed that in all four bathhouses, the lowest heat loss is in the walls of the bathhouses and the highest is in the roof. Then, to find the contribution of each of the strategies in preventing heat loss, the conditions of the three strategies were removed step by step and the heat loss in the five cold months of the building (from November to March), as shown in Tables 4 to 7 was simulated and calculated.

Based on the level of reduction in heat loss in each row and comparing the values of Tables 4 to 7 the contribution of each of the strategies in reducing heat loss from the shell in each of the bathhouses is shown in Table 8.

Conclusion

As stated in the background of the study, the lack of stimulation of energy in the traditional bathhouses, which was not possible for various reasons, suggested various strategies regarding the prevention of heat loss in bathhouses in hot and dry areas in contemporary literature. The strategies of "going down into the ground", "locating in compact urban texture" and "using unconditioned spaces" in the physical designs of Kashan bathhouses were effective in reducing heat through the shell. However, in contrast to the research literature in this regard, it was observed that the "use of unconditioned spaces" is more effective than the other two general strategies. Consistent with the primary question of the study, the results revealed that the selected bathhouses in Kashan, the unconditioned space in the cold months of the year in this region were effective in reducing the heat loss from the shell of apodyteriums by 33.18% on average. This figure compared to the strategy of "going down into the ground" and "locating in the compact urban texture", which were 5. 44 and 0. 6 percent,

Table 2. The height and depth of the space buried in the ground of the bathhouses. Source: Authors.

No.	Bathhouse name	Bathhouse height (cm)	Depth of the space buried in the ground of the bathhouses (cm)	Adjacent surface length of neighborhoods (m)	The ratio of the adjacent surfaces of the neighboring space to the total length of the building in percentage	The average width of the equated building	The average length of the equated building	Average length and width of the equated apodyterium
1	Sultan Mir Ahmad	470	140	105	60	37.5	23.5	9
2	Khan	520	410	35	21	48.5	21.5	10.5
3	Mohatasham	480	120	70	63	20.5	25	6
4	Fin	410	130	13	10	43	15	9
Mean		470	200	56	39	37	21	8.5

Table 3. Distribution of surrounding walls based on the ratio of the apodyterium area to the area of unconditioned lateral spaces of Kashan bathhouses. Source: Authors.

No.	Bathhouse name	The total area of the building (m2)	The total area of walls (m2)	Apodyterium area (m2)	Area of unconditioned spaces (m2)	The area of the surrounding walls of the apodyterium (m2)	Area of inner walls (m2)	The total area of the building (m)
1	Sultan Mir Ahmad	881	341	84	540	33	308	175
2	Khan	1064	299	109	765	31	268	168
3	Mohatasham	518	184	37	334	13	171	111
4	Fin	655	231	87	424	31	200	131
Mean		780	264	79	516	27	237	146

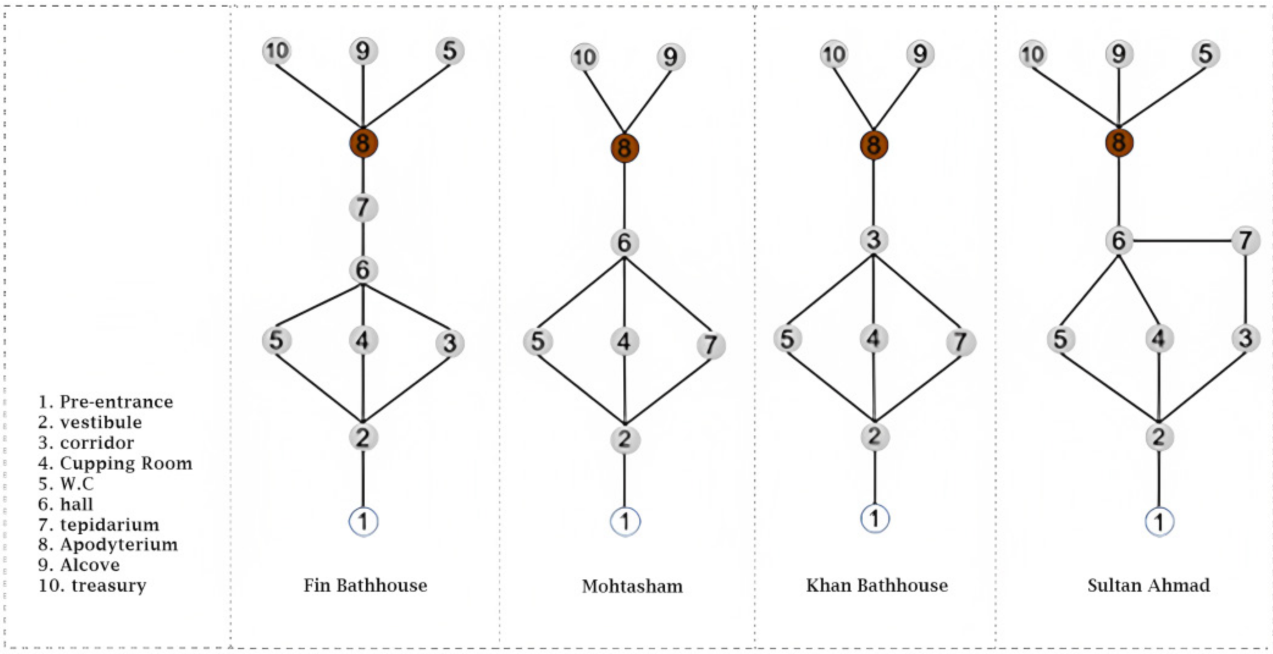

Fig. 8. Examining the space syntax in the selected bathhouses of the research. Source: Authors.

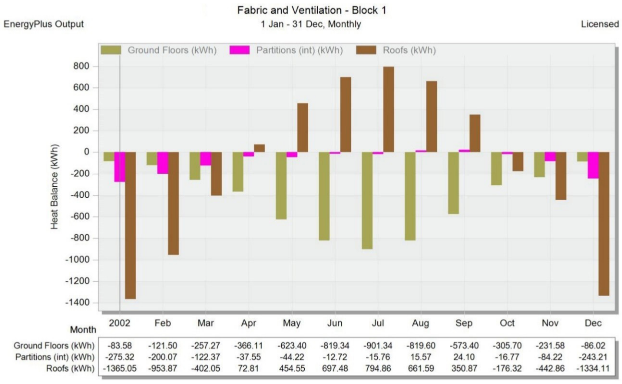

Fig. 9. A comparison of heat loss through the floor, roof, and walls in the Sultan Mir Ahmed bathhouse – output of Design Builder software. Source: Authors.

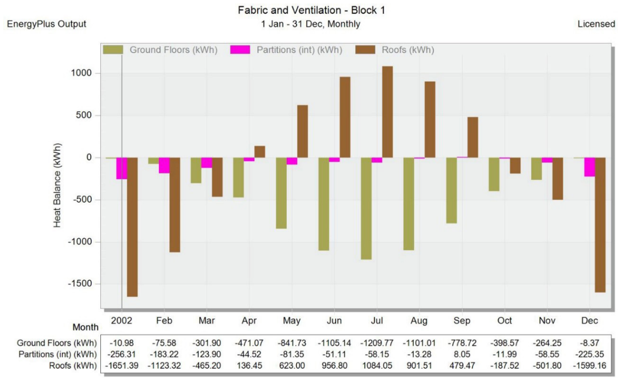

Fig. 10. A comparison of heat loss through the floor, roof, and walls in Khan bathhouse- output of Design Builder software. Source: Authors.

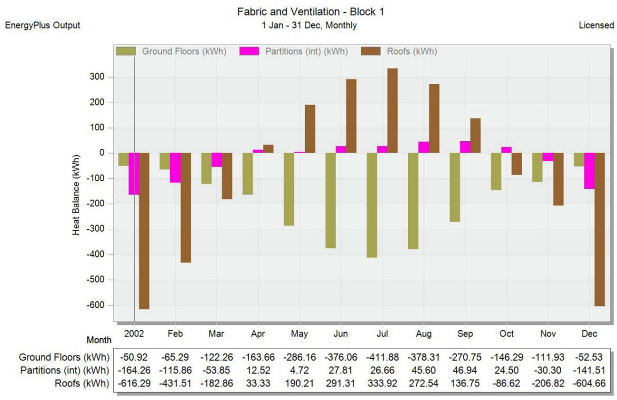

Fig. 11. A comparison of heat loss through the floor, roof, and walls in Mohtasham bathhouse – output of Design Builder software. Source: Authors.

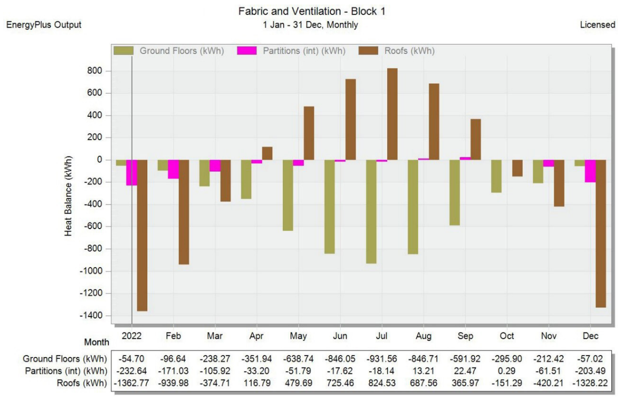

Fig. 12. A comparison of heat loss through the floor, roof, and walls in the Fin bathhouse -output of Design Builder software. Source: Authors.

Table 4. Calculation of the level of heat loss in watts from the shell in the apodyterium of Sultan Ahmad bathhouse of Kashan. Source: Authors.

Heat loss/month of the year	November	December	January	February	March
Without strategy	525.9	1749.58	1861.46	1298.71	618.91
Having uncontrolled space	498.71	1485.55	1549.99	1084.85	518.46
Having uncontrolled space + access to ground	493.06	1389.81	1451.38	1035.85	513.82
Having unconditioned space + access to ground+ neighborhood	495.55	1386.92	1447.57	1032.26	511

Table 5. Calculation of the level of heat loss in watts from the shell in the apodyterium of Khan bathhouse of Kashan. Source: Authors.

Heat loss/month of the year	November	December	January	February	March
Without strategy	872.19	2506.52	2647.25	1921.57	985.82
Having uncontrolled space	423.97	1431.09	1535.06	1023.36	485.72
Having uncontrolled space + access to ground	426.48	1401.08	1495.59	999.57	483.35
Having unconditioned space + access to ground+ neighborhood	414.53	1380.22	1467.99	981.24	473.24

respectively, indicate the high significance of this strategy for controlling heat loss. As shown in Table 8, the minimum efficiency of the unconditioned space in February in Sultan Ahmed bath is more than five times more effective than the other two strategies due to the proximity of the apodyterium to

Table 7. Calculation of the level of heat loss in watts from the shell in the apodyterium of fin bathhouse of Kashan. Source: Authors.

Heat loss/month of the year	November	December	January	February	March
Without strategy	425.92	1198.98	1264.72	927.02	482.29
Having uncontrolled space	245.85	717.18	752.77	540.62	262.23
Having uncontrolled space + access to ground	228.1	677.32	710.80	508.43	243.22
Having unconditioned Space + access to ground+ neighborhood	230.27	672.19	704.78	500.57	237.57

Table 8. The contribution of each of the compared strategies in Kashan bathhouses in reducing heat loss from the shell. Source: Authors.

Bathhouse Name	Strategy	Strategy share in the months of the year					Mean
		November	December	January	February	March	
Sultan Ahmad	Unconditioned space	5/2	15/1	16/7	16/5	16/2	13/94
	Access to ground	1/1	5/5	5/3	3/8	0/7	3/28
	Neighborhood	-0/5	0/2	0/2	0/3	0/5	0/14
Khan	Unconditioned space	51/4	42/9	42/0	46/7	50/7	46/74
	Access to ground	-0/3	1/2	1/5	1/2	0/2	0/76
	Neighborhood	1/4	0/8	1/0	1/0	1/0	1/04
Mohtasham	Unconditioned space	42/3	40/2	40/5	41/7	45/6	42/06
	Access to ground	4/2	3/3	3/3	3/5	3/9	3/64
	Neighborhood	-0/5	0/4	0/5	0/8	1/2	0/48
fin	Unconditioned space	25/8	31/7	31/4	29/8	30/4	29/82
	Access to ground	20/7	9/7	9/4	11/6	19/2	14/12
	Neighborhood	1/3	0/5	0/4	0/8	1/1	0/82
Mean	Unconditioned space	31/2	32/5	32/7	33/7	35/8	33/18
	Access to ground	6/4	4/9	4/9	5/0	6/0	5/44
	Neighborhood	0/4	0/5	0/5	0/7	0/9	0/6

the final wall of the bath. The maximum efficiency of this space in the space arrangement of Khan and Mohtasham bathhouses has reached about 50% due to the placement of the apodyterium among the bathhouse spaces, which is significant.

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