THE WINDCATCHERS OF YAZD

Susan Clare Roaf

A Thesis submitted in partial fulfilment of the requirements of Doctor of Philosophy, to the Council for National Academic Awards, undertaken at the Post-graduate Research School, of the Department of Architecture at Oxford Polytechnic.

November, 1988.

FOR JOHN MALCOLM AITKEN ROSS

DECLARATION

1. The candidate, Susan Clare Roaf, while registered for the Degree of Doctor of Philosophy, was not registered for another award of the Council for National Academic Awards, or of a university during the research programme.

2. The candidate, Susan Clare Roaf, while registered for the degree of Doctor of Philosophy, did undertake and complete advanced studies in connection with the programme of research in partial fulfilment of the requirements of the degree.

Susan Roaf

4.11.88.

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THE WINDCATCHERS OF YAZD

Susan Clare Roaf,

Post-graduate Research School,
Department of Architecture,
Oxford Polytechnic.

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ABSTRACT

Windcatchers are built on the roofs of houses of hot areas of the Middle East to ameliorate the internal summer climate. The archaeological and historical record shows them to have been used since antiquity, and although they are still widely found in the region today, and regularly mentioned in the modern works on architecture of the region, no detailed study of their types or operation has been published. Rather architects refer continually to an accepted stereotype of their form and performance on which modern architects have to rely as a design model.

This study makes an original contribution to the published record. In it the badgirs, or windcatchers of a single region, Yazd, on the Persian plateau, are described; and the distribution of their types in the villages of the area, and city of Yazd are reviewed in relation to the climatic and historical influences on their design and use. The functions of badgirs in the houses of Yazd, as air-conditioners and ventilators, are investigated. General temperature limits of their summer performance in the context of the life-style of the Yazdi, are established and reviewed in relation to comfort and the physiology of the human body and the climatic results used to interpret the distribution of windcatchers types in the wider area of the Middle East.

The research provides a unique historical record of the badgirs of Yazd, illuminates the complexity of the climatic and historical influences in their distribution, and, through analysis of their performance, provides a general climatic guide that may assist contemporary designers wishing to incorporate windcatchers in modern houses in hot areas.

ACKNOWLEDGEMENTS

For funding of fieldwork my thanks go to The Michael Ventris Award, The Anthony Pott Memorial Award, The British Institute of Persian Studies, The Royal Institute of British Architects, The Ancient Monuments Department of Iran, and John and Shirley Ross.

My stay in Yazd would not have been possible without the generosity of Mr. Mahmood Mashrouteh and his kind family, and all the Yazdis who allowed me into their homes with unfailing hospitality. Particularly to Mr. Rashdi. In Yazd the Ancient Monuments Department provided me with full use of the facilities at the Bagh-e Dowlatabad Office and Mohendiz Talaie gave freely of his time and knowledge to assist the project. My thanks also go to all those at the Ancient Monuments Department of Iran at Khiaban-e Larestan, Tehran, who encouraged and supported the work in Iran at every stage. A particular debt of gratitude is owed to Mohendiz Pirnian, whose knowledge of Iranian vernacular architecture is profound and who provided many valuable insights into its mysteries. In Tehran Mahmood Tavassoli was also a great help with his knowledge of the architecture of the Plateau. To all in Iran who so kindly helped go my heartfelt thanks.

During periods of fieldwork in Iran I was also assisted by a number of friends who visited me in Yazd including David Bradshaw, Dr. Eimo and Kiki Heeren, William Egan, Dr. Shirley Jarman, William Milner and Duncan Harvey. My thanks go to them for making field trips so enjoyable. In Tehran I was given invaluable assistance by David Stronach, O.B.E. to whom I am particularly grateful for the use of landrovers on field trips.

. The Architectural Association, London were very good in helping to find funding for the field work. Help at various stages of the work also came from Dr. John Wills of the national Physical Laboratory, Teddington, Dr. Peter Andrews, Dr. Michael Roaf, and Dr.R. Farhadi, of Berkley University, who provided invaluable references on the history of the aivan and talar.

For supporting me during writing up I am grateful to John and Shirley Ross, Dr. and Mrs. D. Roaf and of course Michael, my husband. My thanks, for encouragement during the years of the thesis also go to Miss B.Gosset, Mr. Duncan Ross, Charles Knevitt, Sylvia Beamon, Anneke Sandel, and Kiki Heeren.

At the Oxford Polytechnic Dr. Michael Jenks has been very good in supervising a thesis that has been compliled in fits and starts in different countries and to Mrs. Margaret Ackrill I own a considerable debt for her patience and support during the process of writing of this thesis.

Finally I would like to pay a tribute to Elizabeth Beazley, who first took me into the deserts of Iran to show me the badgirs of Yazd, and without whose interest in the vernacular architecture of the central plateau of Iran this thesis would never have been written.

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GLOSSARY OF PERSIAN TERMS

abanbār - water cistern

aivān - vaulted, reception room, with three walls and open to the courtyard (see appendix A)

andāruni - main family courtyard of the house

bādgīr - windcatcher

bāgh - garden

bālā khāneh - room on roof

biruni - guest courtyard of the house

bistan - garden

dārbandeh - closed door, used of a house with several courtyards and a single main entrance

hashti - eight sided - often used to describe octagonal entrance hall to Yazdi houses

hāwā kesh - ventilator on roof

hōz - pool

kavir - desert

khāneh - house or room

nīmiyeh - blank east wall of courtyard, with no rooms facing the hot western sun

qanāt - subterranean water channel

shahr - city

tākhta - large wooden couch, bed

tālār - vaulted reception room with walls on three sides and open to the courtyard (see appendix A)

The words above are used a number of times in the text. Where a term is used once it is followed by the English translation. Diacritical marks have been omitted from the text, except in appendix A. Generally the use of Persian terms is kept to a minimum and Persian script omitted. been

CHAPTER 1

1.1 Introduction

The houses of the Middle East have been well documented throughout modern history. The British awareness of the Middle East dates back to the Crusades. Since the 11th century travellers have been bringing back vivid descriptions of the way of life and architecture of the area. Notable accounts of Persia, for instance, came from Marco Polo (13th century) and later from Tavernier and Chardin, (17th century) Morier and Ouseley (19th century). Full bibliographies of travellers accounts can be found in books such as The British in the Middle East by Sarah Seawright (1979), or The Persians amongst the English, by Sir Denis Wright (1985).

In the 18th and 19th centuries to travellers accounts were added a vast corpus of written works including academic studies, biographies, and economic, political, military, and administrative reports. Such publications are well documented in numerous bibliographies of the area (Hennings, 1950; Afshar, 1961; Haghighi, 1970; Mossalla, 1952; Gedes,1985; Pearson, 1958; Behn, 1982-1987).

Written images of the Middle East have also been brought to life by the paintings of 19th century artists such as David Roberts (Perowne, 1979, pp.23-27), Frank Dillon (Llewellyn, 1984, pp.3-10), and John Frederick Lewis (Danby, 1983, p.201), all of whom achieved considerable success in Britain with their exotic paintings of the architecture of the Near East (Ur,vol.3,1984,pp.3-10)

The experience of the British in the Middle East has been enriched in the the last three centuries by men and women who lived in the area in the service of the Empire and in this century by the thousands of soldiers who served on the North African, the Mesopotamian or the Palestinian fronts in the two World Wars. There resulted from such works and experiences, added to by the vast body of fiction and media reporting on the area in the 20th century, very deeply entrenched cultural stereotypes, including those on the subect of the vernacular houses of the area, shared from the expert to the man in the street in Britain. The whole concept of such stereotypes is dealt with by authors such as Kuban (1983,pp.1-5), Said (1978) and Haddawy (1982-1985).

The relevance of these house stereotypes, centred superficially on the cool luxuriance of the central courtyard with pool, rich carpets, and coloured glass, and the mystery of the Hareem, to this present work is that they have influenced much of the thinking of modern historians and architects writing on the traditional architecture of the Middle East. Many authors write in cliches of the following vein:

> The courtyard house is of paramount importance in fostering the physical setting for Islamic family life because it permits the orientation of rooms towards the interior of the site. This introverted focus for family life enhances the sense of privacy demanded by Islam. In addition, the courtyard house is extremely well adapted to the climatic conditions of the hot, arid Arabian environment (Moustapha and Costa, 1983,p.246).

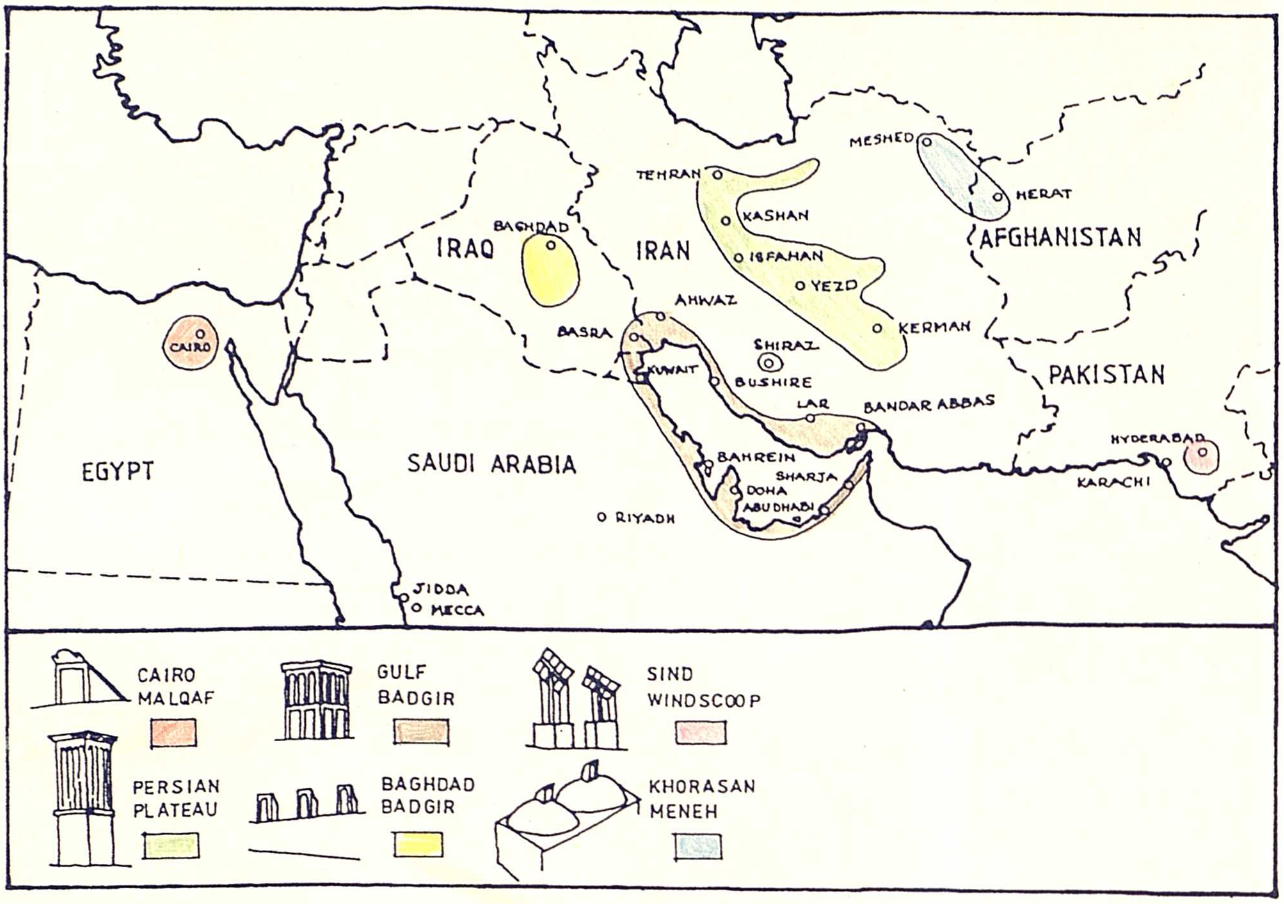
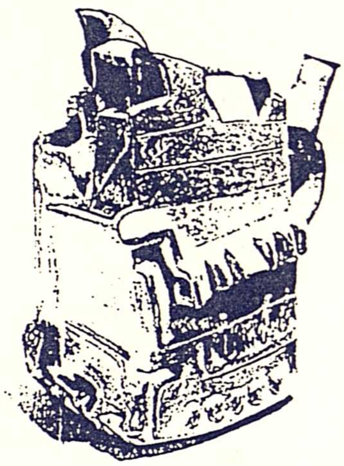


Figure 1.1. Map showing the location of the main types of windcatchers found in the Middle East.



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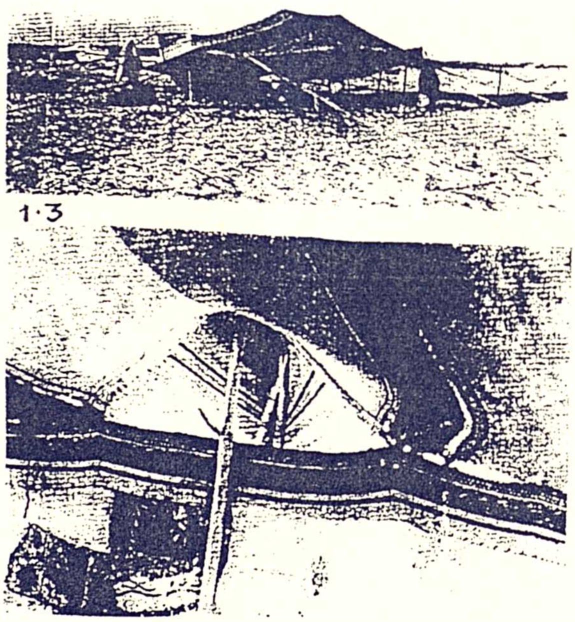

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Figure 1.2. A pot representing a three storey house with windcatchers on the roof, made by the Mochica Indians of Peru (200 B.C. to 700 A.D.). (Von-Hagen, 1978, p.288)

Figure 1.3 A) Cyrenaican Bedouin tent showing two raised windcatchers made from the tent cloth.
B) Interior of the Bedouin tent showing the stick supports of the tent cloth windcacther. (both photographs lent by Emrys Peters, Manchester University, 1976)

Fortunately this general form of cultural and architectural stereotype has been supplimented by a wealth of regional studies (eg. Ragette,1974; Khammash, 1986; Yagi,1983,pp.343-362; Fadan,1983,pp.295-323; Talib, 1984; Lewcock,1978) and technical studies (eg. Noor,1975; Mohsen,1978; Abdin,1982; Tappuni,1974) done in the last twenty years. These give a much more precise idea of the domestic architecture of the region and how it functions climatically.

Such regional studies show that within the Middle East there are a wide variety of different house types. Some house types in specific areas of the Middle East are characterised by the inclusion on their roofs of structures called windcatchers.

Windcatchers are built on the roofs of buildings from Pakistan to Egypt, Afghanistan, Iran, the Gulf region, and Iraq. However few windcatchers are built in the heartlands of Arabia, on the temperate Mediterranean coastlands of Syria, Lebanon, Palestine or Israel, or in Turkey, or the Jezira of Mesopotamia (figure 1.1).

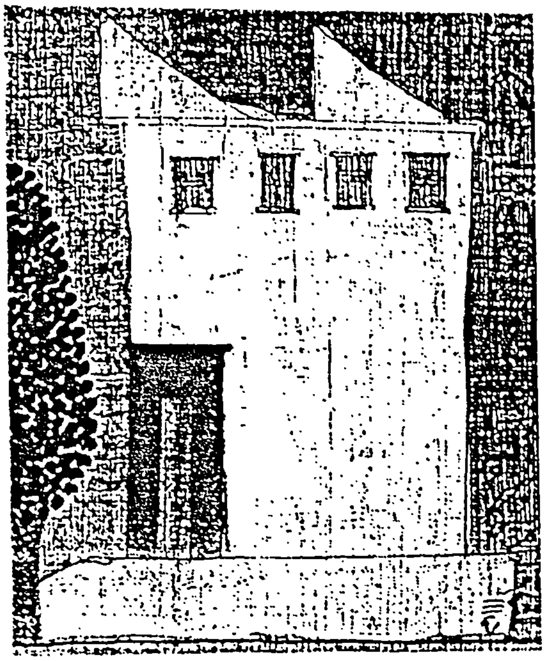
Windcatchers consist of an open vent, raised above the roof level of the building, facing either into or away from the prevailing wind. This vent is connected, either by a vertical shaft or a direct opening in the roof and ceiling, to the rooms below. The windcatcher acts as a high level, indirect view-less window through which air is introduced into or expelled from the room. Thus it enables air movement through the room whilst minimising the introduction of solar radiation and air borne debris into it.

The quality of the air introduced has also been thought important because the air streams above the roofs are cool and clean (Cain et.al.,1978,p.50) or 'cooler and stronger', and 'since masses of buildings reduce the wind velocity at street level and screen each other from the wind, the ordinary wind is inadequate for ventilation.' (Fathy, 1986, p.56).

The effectiveness of this apparently simple climatic device is demonstrated by its use in many different parts of the world, since antiquity. The Mochica Indians of Peru (200 B.C. - 700 A.D.) built windcatchers facing towards the sea on top of their houses (figure 1.2); a design feature included in the vernacular houses of Peruvians until the present century (Von Hagen, 1978, p.288).

Similar in conception are the simple vents on the tents of the Bedouin of Cyrenaica consisting of a woven extension of the tent cloth supported on sticks to protrude above the roof (figure 1.3). Thus while the tent is erected facing away from, with the back wall closed to the wind, the vent enables a small current of air to be directed through the centre of the tent (Peters, 1976). These two types of windcatcher exemplify the simplest form of the structure.

In the Middle East today windcatchers are generally called by two different names, the Persian <u>badgir</u>, from 'bad', wind, and 'gir' to take , seize, hold or catch; the second word is the Arabic 'malqaf', or wind-catch (Fathy, 1986, p.56). The latter term is used only in Egypt and



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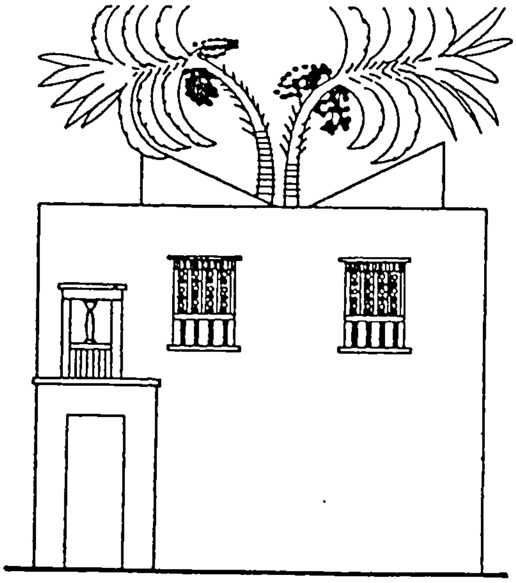

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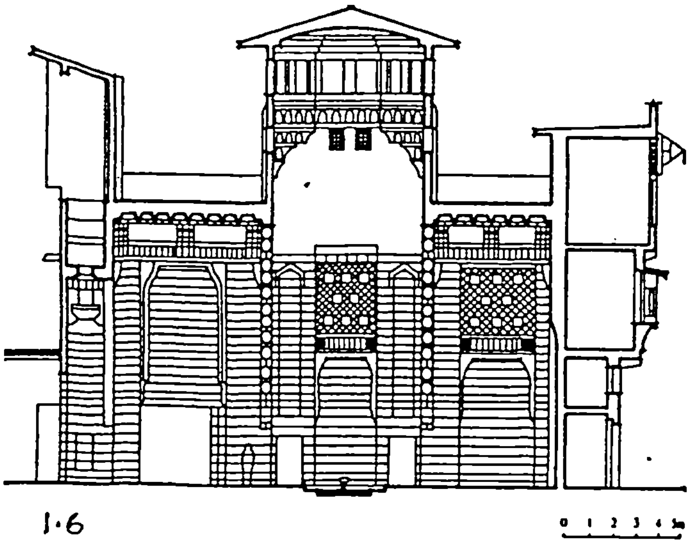
Figure 1.4. Windcatcher on the Pharonic house of Neb-Amun, from a painting on the wall of his tomb (19th Dynasty, c.1300 B.C.). (Fathy, 1986, fig.50)

Figure 1.5. The house of Nakht at 'Amarna (New Kingdom), wall painting showing paired windcatchers on the roof. (British Museum; illustration from Von-Hagen, 1978, p.289)



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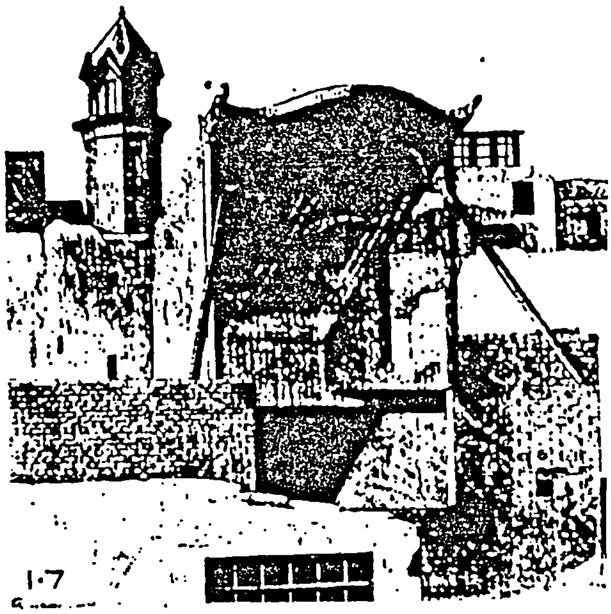

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Figure 1.6. Section through the Qa'a of Muhib Ad-Din Ash-Shaf'i Al-Muwaggi, showing the position of the malqaf.
(Fathy, 1986, p.116)

Figure 1.7. Turkish style malqaf in Cairo.
(Fathy, 1986, p.126)

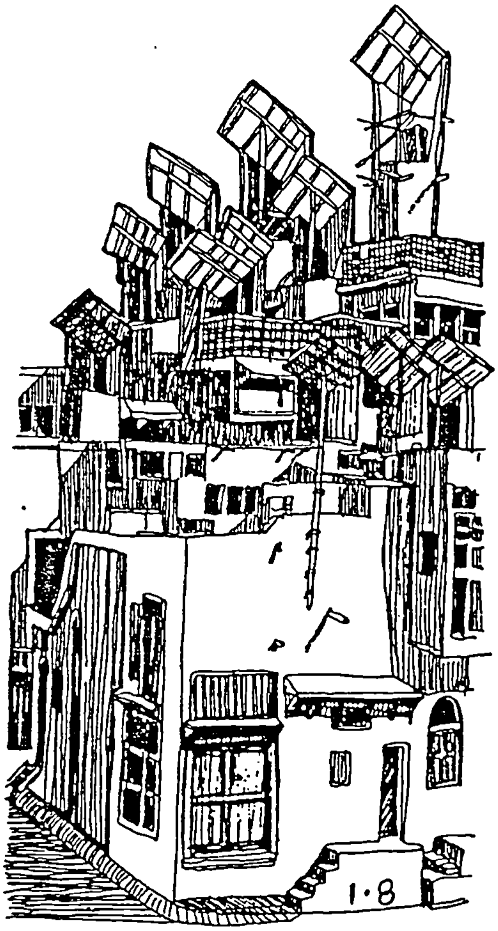
North Africa, while the former is used throughout Persia, Iraq and the Gulf region. In the Gulf area wall ventilators, 'badkesh', serve a function, similar to the windcatcher, introducing air through the summer rooms. There are in the region many different types of windcatcher with very different forms and functions and the review below of the main types of the Middle East demonstrates this variety.

1.2 THE MALQAF OF EGYPT

There are depictions of windcatchers, or 'malqaf' on Egyptian houses since the second millenium B.C.(Badawy, 1958,p123). Sceptics (Roaf,M., 1988) suggest that these may be stair well roofs, but certainly examples where the apex of the angular roof co-incides with an outer wall are more likely to be windcatchers.

On a tomb wall at Thebes is an illustration of the Pharonic house of Neb-Amun (figure 1.4), which dates from the Nineteenth Dynasty (1300 B.C.) on which it is suggested there are two windcatchers facing in opposite directions (Davies, 1923, p.30). Depictions of summer houses or land houses of the wealthy of the New Kingdom (c.1500 - 300B.C.) show that they commonly had two vents, triangular in shape from the side view, set on top of the terrace roof (figure 1.5) (Badawy, 1948, p.86).

Larger houses of Cairo in the 14th century characteristically had windcatchers above their summer quarters, often in conjunction with a high covered hall called a Qa'a (figure 1.6), at the apex of which was an open



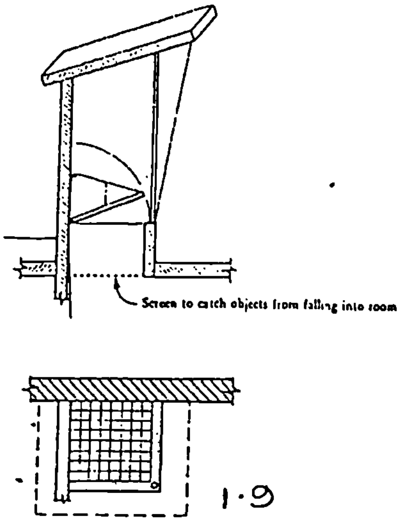


Figure 1.8. Windscoops in Hyderabad, Sinde, Pakistan. (Sketch from Kubba, 1987, vol. 2, figure 266)

Figure 1.9. Section and plan of Hyderabad windscoop showing the trap-door below the scoop. (Von Hagen, 1978, p.290)

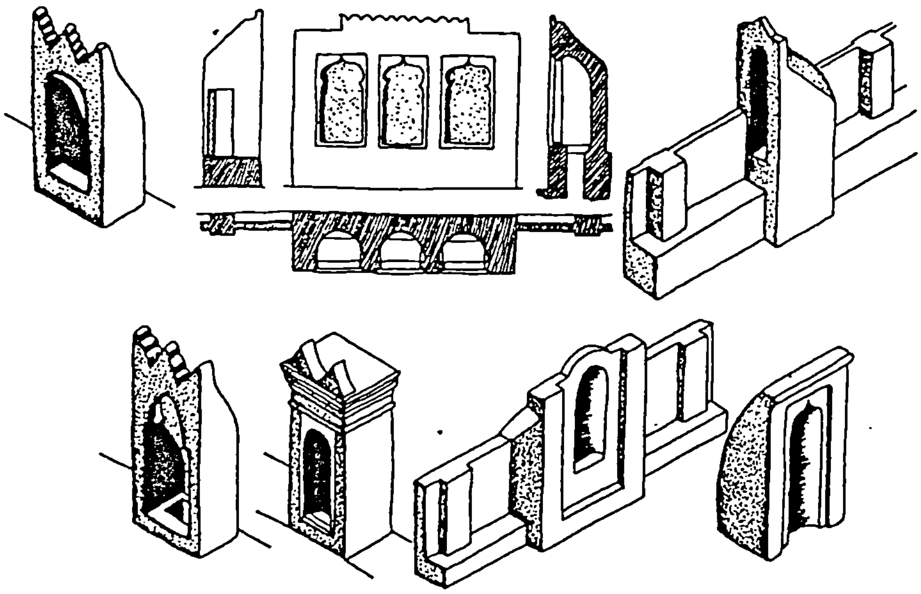


Figure 1.10. Badgir vents on the houses of Baghdad. (Warren and Fethy, 1982, pp.85, 86, and 87,from Langenegger; redrawn by Kubba, 1987, vol.2, figure 283)

vent, which provided the inlet or outlet for the air drawn through the malqaf (Creswell, 1929, p152, ff.). While the majority of Eqyptian malqaf vents are linked to the rooms below through a shaft, some examples of nineteenth century Turkish malqaf in Cairo introduce air directly through a hole in the ceiling of the room below (figure 1.7) (Petherbridge, 1984, p.203).

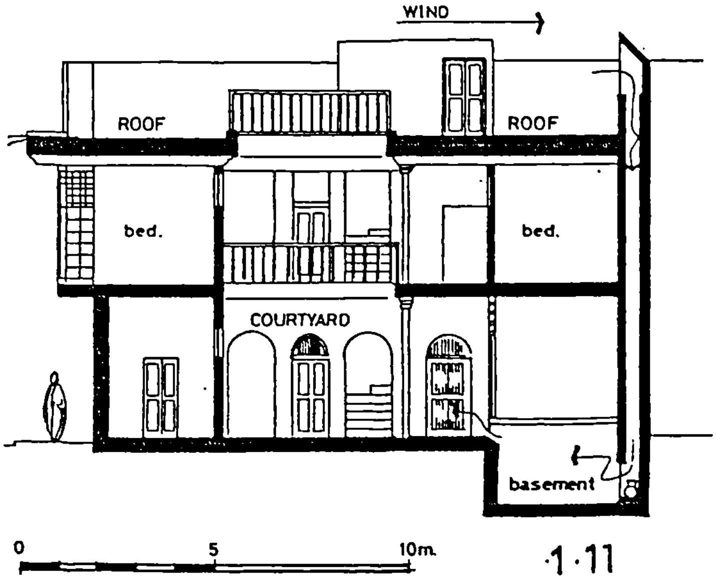
There is no doubt that a detailed study of the Egyptian windcatchers needs to be done, which may demonstrate the various types of windcatcher in Eqypt that have been described here under the one name of Malqaf.

1.3 THE WINDSCOOPS OF SIND, PAKISTAN

The modern city of Hyderabad, in the Sind province of Pakistan, was founded by Ghulam Shah Kalhora in 1768 and was the capital of Sind until 1843 when the British captured it and moved the capital to Karachi (Encyclopaedia Britannica, Micropaedia, 1974, vol.5, p235).

In 1815 Pottinger(1816, p.57), an English traveller wrote of Hyderabad that every house from 'the Governor's palace to the lowest hovel', had a windcatcher.

Figure 1.8 shows the multiplicity of the vents on the houses of the traditional quarter of the city. The vents are roofed in timber and plaster, or in modern examples corrugated metal sheeting supported on a timber frame with masonary walls (Petherbridge, 1978, 203). The Sind examples are situated above 'wind-rooms' from which they may be separated by trap-doors which are generally closed during



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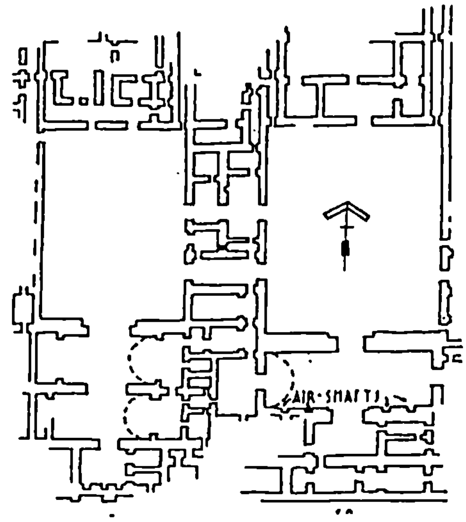

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Figure 1.11. Section through a Baghdadi house showing the badgir shaft descending into the basement room. (Kubba, 1987, vol.2, figure 279)

Figure 1.12. Plan of Nabupolassar's summer palace at Nimrud showing wind shafts identified by the excavator. (Koldewey, 1925, Abb.100A.101).

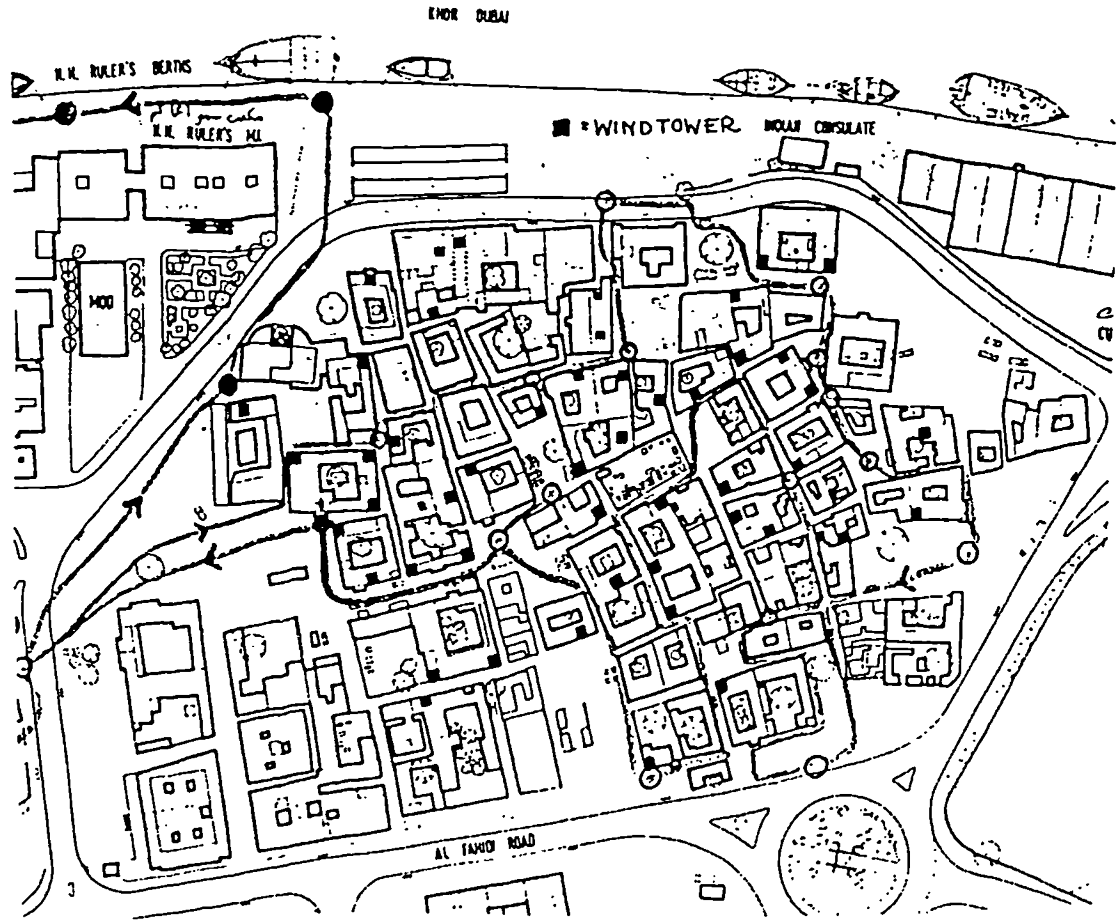


Figure 1.13. Plan showing the location of wind-towers in the old quarter of Bastakia, Dubai. (Harris, 1978)

the winter (figure 1.9) (Bourgeois, 1983, p.54).

Only one study of these wind-scoops has been attempted, by Sharma, at the Development Planning Unit in London, but this thesis was never completed (Sharma, 1971).

1.4 THE BADGIRS OF BAGHDAD

The badgirs of Baghdad and southern Iraqi cities are rather different in form and function from these simple 'wind scoops'.

Into the thick mud brick or baked brick walls at the rear of the summer living rooms are vertical shafts that link the vents on the roof, built into and just higher than the parapet walls (figure 1.10), with the full basements and half basements and above ground living rooms. The shafts most commonly terminate over narrow recessed niches in the back and side walls of the basements (figure 1.11)(Warren and Fethy, 1984, p.84-88). The warm dry air introduced through them circulates and is expelled through openings, which can be small high metal grill windows in full basements or half storey height window openings along the courtyard wall in a half basement (Al Azzawi, 1985,vol.1, p.10). Badgirs do not generally supply air to ground floor and first floor rooms in Baghdad.

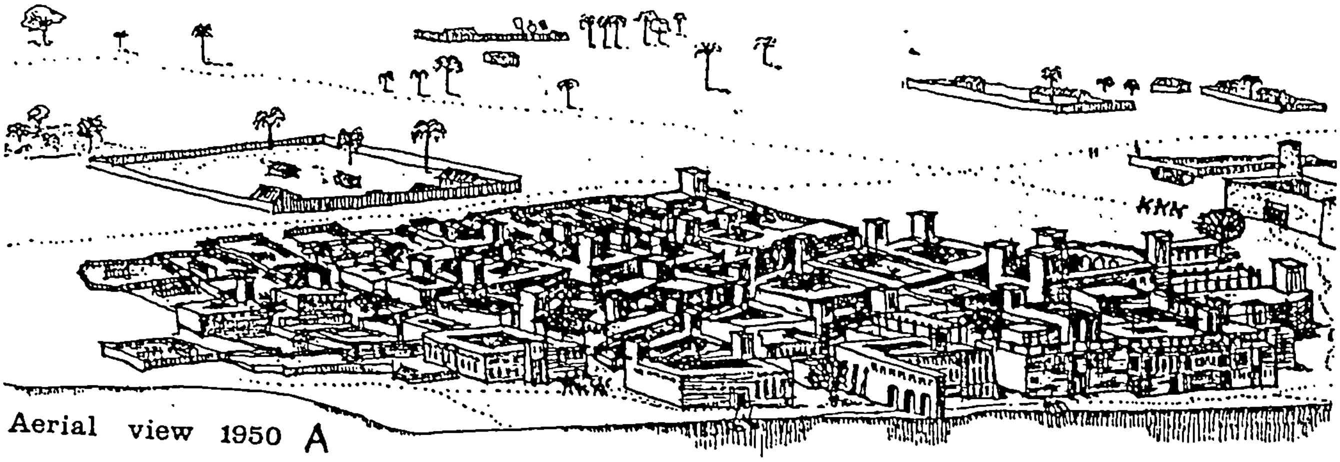
It has been postulated that similar structures, located in the rear walls of the throne rooms of the palaces of Assyrian, and Babylonian (Koldewey, 1914, pp.72-118) kings in Nimrud and Babylon in Iraq, were also used for ventilation (figure 1.12). While such speculations, developed by Kubba (1987, vol.1,pp.155-158) who claims that virtually any niche in an excavated building was below a badgir, are interesting and provocative, there is no actual proof for such theories; only the bases of the walls of these rooms were excavated. Half or full height niches in the walls of living rooms of traditional buildings in the Middle East was fairly ubiquitous throughout the region for at least six thousand years.

Convincing evidence from texts, building models, or excavated roofs is still lacking to provide support for such theories.

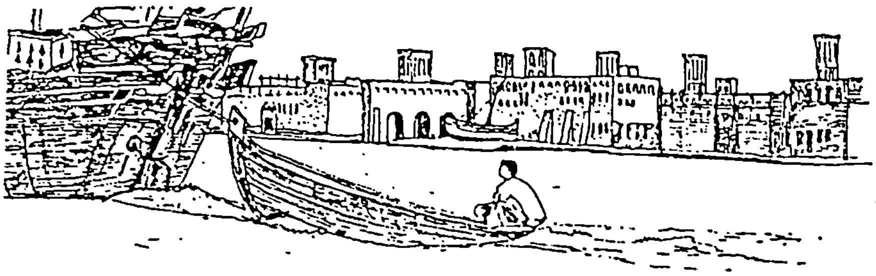
1.5 WINDCATCHERS OF THE GULF

Settlements along the Gulf in Iran, Iraq, Kuwait, Bahrain, Saudi Arabia and in the Emirates have windtowers of several types, built by the Persian, Iraqi and Arab dwellers of the area. One Gulf port with excellent preserved windcatchers is in Bastakia (figures 1.13 - 1.15), now a downtown suburb in the heart of modern Dubai.

> In the past, a sense of community existed across the shores of the Gulf. During the nineteenth century the Qawasimi Sheikhs of Arab origin administered the Persian coast opposite Dubai. Many of the inhabitants of the coastlands were predominantly Sunni Moslems in contrast to the predominantly Shiite sect of Persia. After 1883, the central Persian government began to extend their authority to the coastlands and consequently the merchants whose trade was threatened settled across the water in the Bastakia area of Dubai.
>
> The merchants formed a compact community for environmental, social and security reasons. These prosperous merchants introduced the concept of the masonry windtower house but adapted it in response to the specific local conditions of Dubai. In Persia the principle of the windtower has been highly developed in such towns as Yazd, Bastak and Lingeh. Many of the



Aerial view 1950 A



The creek frontage 1955 B.

Figure 1.14. Sketches of Bastakia based on A) a 1950 aerial photo, and B) 1955 photograph. (Harris, 1978)

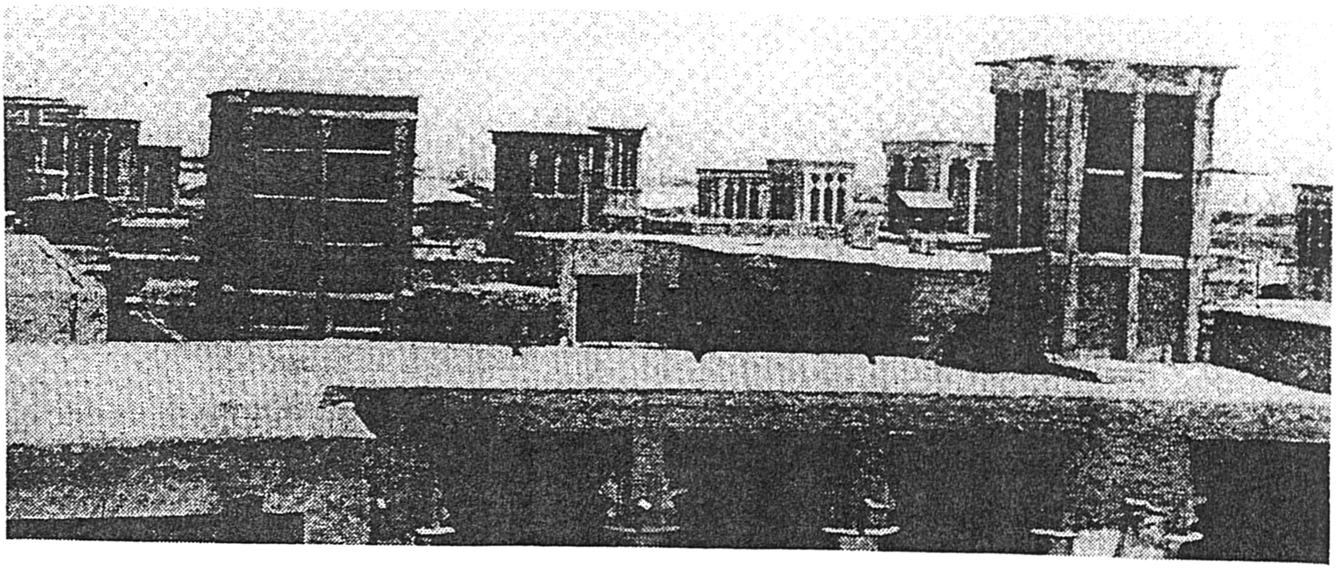


Figure 1.15. Wind-towers on the roofs of Bastakia. (Jackson and Coles, 1975, p.51)

> Merchants came from Bastak, from which Bastakia is derived. As Lingeh began to decline so Dubai began to prosper. (Harris, 1978)

The success of the badgir in these coast lands was due to strong on-shore sea breezes that arise on summer afternoons. The cool, humid air currents are strongest in mid-afternoon when the warm air rising from the heated land mass draws the air currents inland from the sea. Coles and Jackson make this point in their article about a wind tower house in Dubai (1975a, p.13).

> The windtowers are open on four sides. They are thus multi-directional and able to catch the breeze from which ever direction it may come. The land breeze is from the desert; its air is light dry and often hot. In contrast, the sea breeze which blows in the afternoon is both cool and strong, although it is humid and tangy with the smells of the sea-shore. These wind towers only work if a wind is blowing; there is quite often a period of calm from about 7pm. to 2am.

There are three different types of windcatcher in the Gulf settlements:

1) The wind tower (figure1.16.b)

2) The Arabian badkesh, wall ventilators (figure1.16.c)

3) The simple ventilator (Figure1.16.a)

These are described in turn below.

1.5.1 Windtowers in the Gulf

The high square windtowers, generally facing in four directions, are typical of the ports of Basra, Bushir, Kuwait, Bahrain and Dubai (figure 1.17). These towers stand above the summer living quarters of merchants houses and, despite their Persian origin, have developed perhaps in the short space of a hundred years details at the vent head and

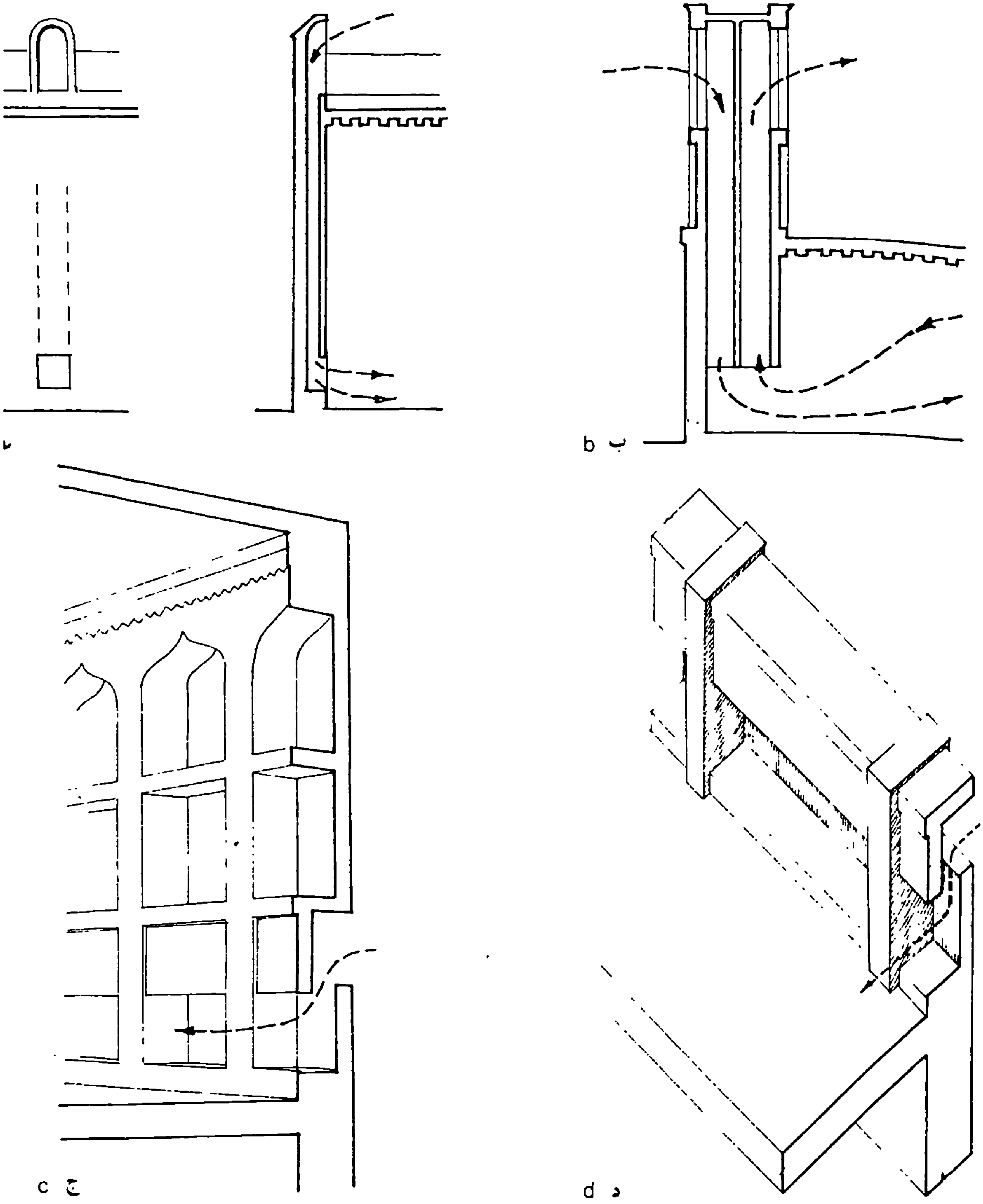


Figure 1.16. Three types of ventilators found in the Gulf:
A) Simple windcatchers B) Windtowers
C) Wall ventilators D) Parapet ventilators
(Lewcock, 1973, p.119)

on the tower sides that display a distinct Gulf Style'(figure 1.18a), that is neither Persian nor purely Arabic.

Often in the Gulf settlements, where living rooms were used in summer and winter, the wind towers were blocked off in the cool season:

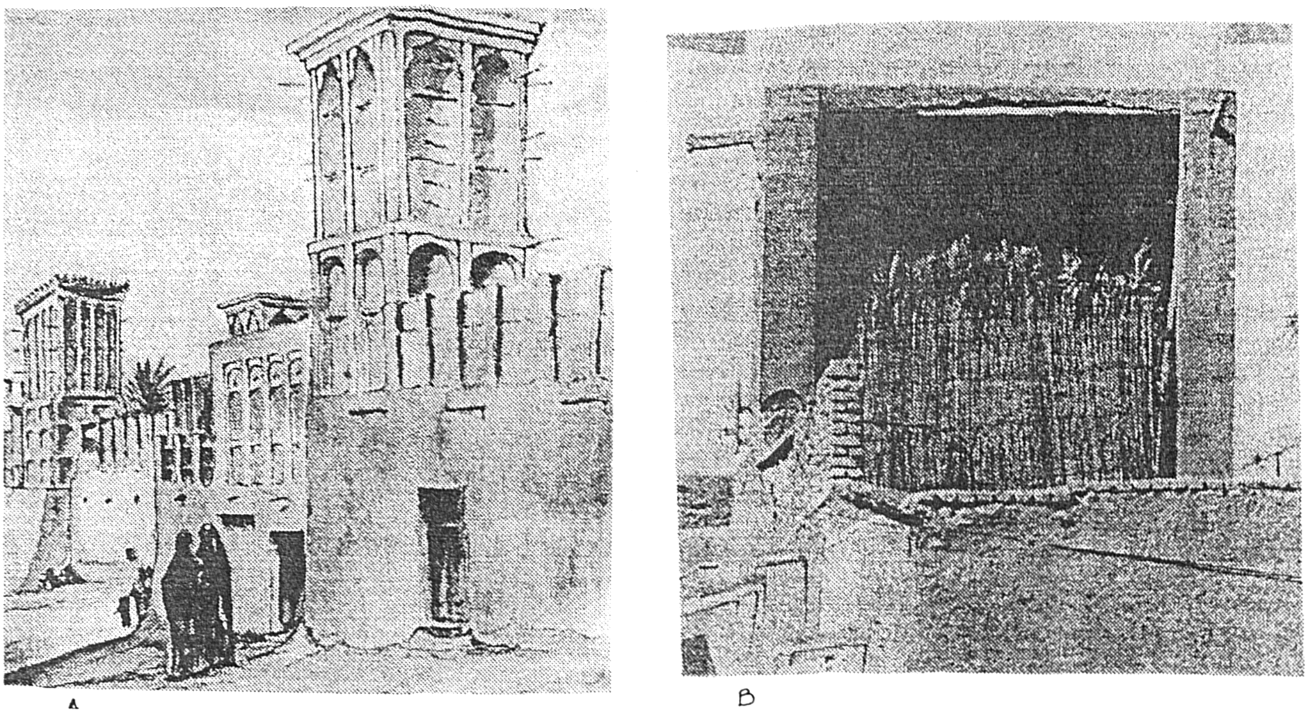
> The vents of the windtower are blocked off in the cool season when the additional ventilation is not desirable. Eight numbered wooden triangles slot into the base of the tower. Near the top of the tower there is a metal grille which prevents pigeons flying in. (Coles and Jackson, 1975a, p.13)

In Bandar Abbas the square towers were modified and the entire tower was reduced to one deep vent facing towards the sea. It was a common practice in the town to place loosely woven reed or bamboo mats partially across the vents and to throw water over them on summer afternoons to further humidify the air and thus cool it evaporatively, in the same fashion as does the mechanical swamp cooler (Roaf, 1983, p.266) (figure 1.18b).

1.5.2 Badkesh (wall ventilators) in the Gulf

Badkesh means literally wind expeller (Talib, 1984, p.89) or puller in Persian, like the 'dudkesh' (smoke expeller), or a chimney.

Badkesh are short shafts built into the wall to allow air movement through the wall while obsuring the view into the room and excluding direct solar radiation entry. They are built either on the roof where they are incorporated into the parapet walls adjacent to the sleeping areas, or in first floor living rooms, where they are built into the



A B

Figure 1.17.A) Sketch of a domestic wind-tower in Bahrain. (Painting by a member of the Bahrain Historical and Archaeological Society, from the St.John Simpson collection)
B) Photograph of a reed mat placed over the vent to a wind-tower in Bandar Abass. (Roaf, 1983, p.266)

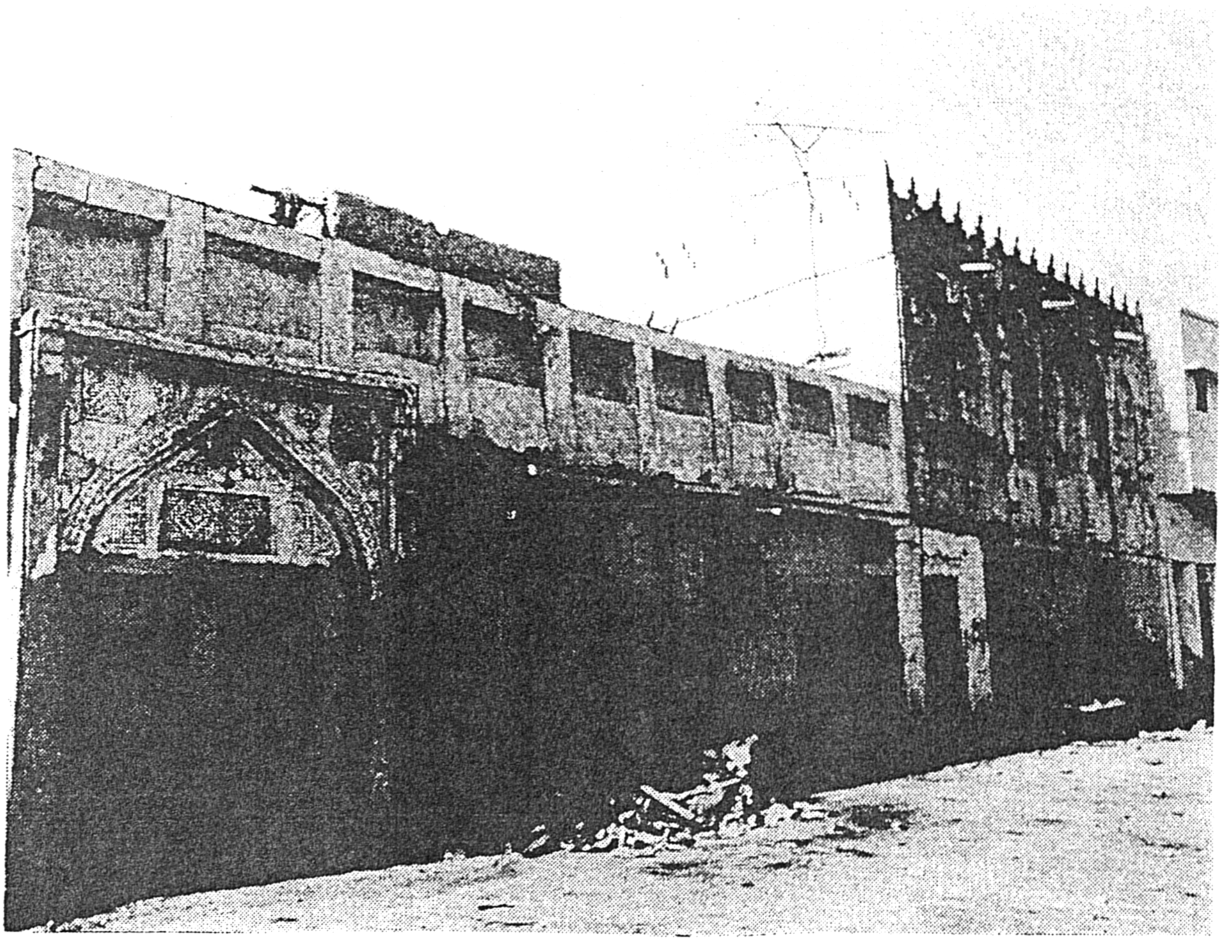


Figure 1.19. Photograph of the outside wall of a house in Bahrain showing wall and parapet ventilators. (Lewcock, 1973, p.103)

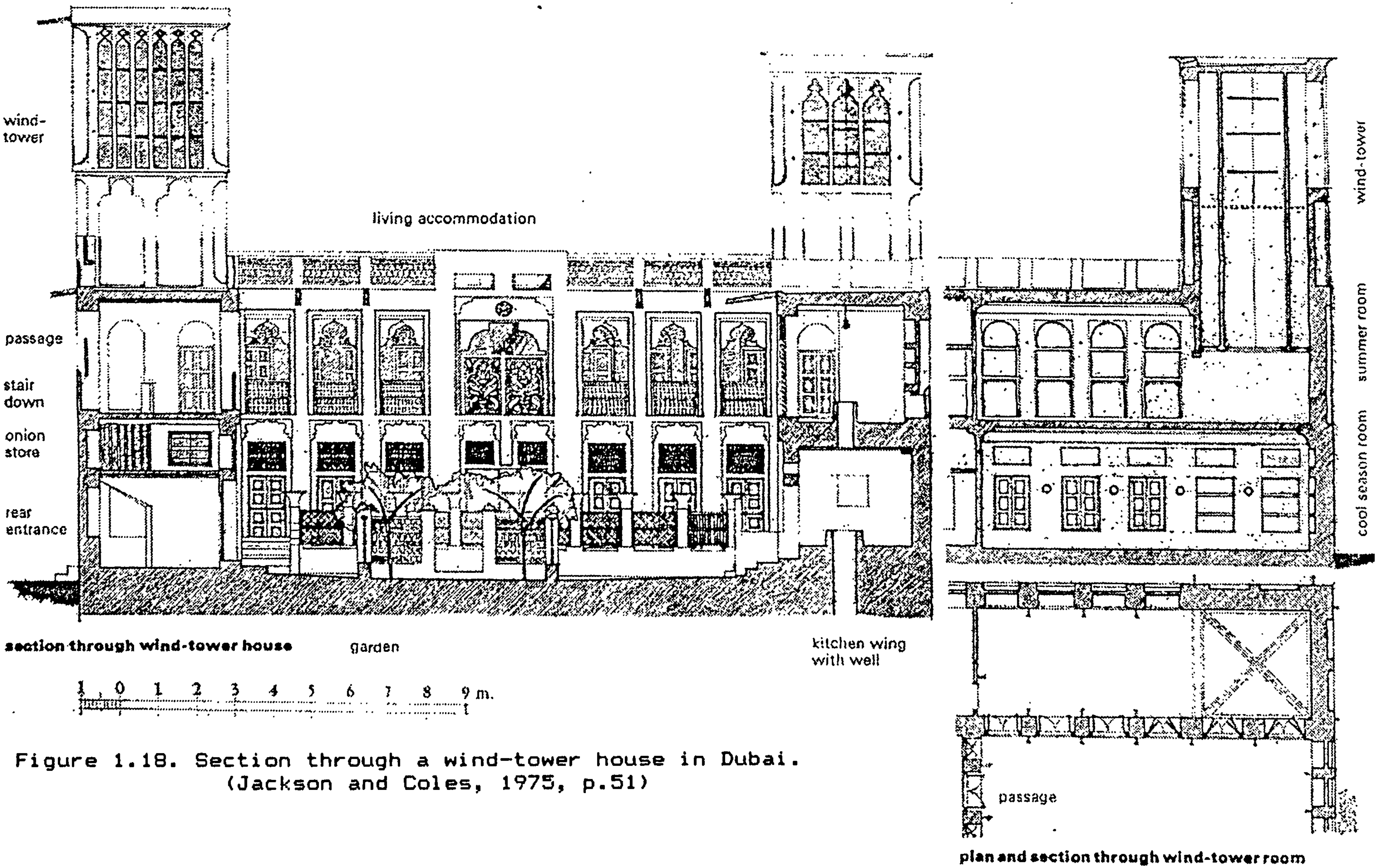


Figure 1.18. Section through a wind-tower house in Dubai.
(Jackson and Coles, 1975, p.51)

windward and the leeward walls of the living rooms (Lewcock, 1984. pp.40-42), to maximise the movement of air through the living areas of the house in summer.

In origin they appear to have been derived from windows in the walls rather than vents on the roof but they effectively introduce the strong prevailing air streams of the onshore sea breezes through the house, whilst excluding direct sunlight and vision into the living rooms. (Figure 23)

Wall ventilators are used in the Gulf settlements with their humid climates because in such conditions.

> movement of the air is the only available relief from climatic stress, therefore vital to indoor comfort, the building will have to be opened up to breezes and oriented to catch whatever air movement there is. Failure to do this would produce indoor conditions always warmer than a shaded external space which is open to air movement (Koenigsberger et. al., 1974, p.217).

1.5.3 The simple ventilator

One further type of wind catcher that exists throughout the Middle East claims no allegience to a particular style. This is the simple uni-directional roof ventilator facing either into or away from the wind. It serves the ground floor rooms in the Gulf and is built crudely of the local building materials and represents a very simple and widely used technology (Lewcock, 1978, p.102).

1.6 THE PERSIAN BADGIR

As in Egypt, the windcatcher may well have been used in Persia since the earliest times.

A very early example of what may have been a windcatcher

Figure 1.20. Illustration showing a high four-square badgir in central Kashan (Jean Chardin, 1686). A conical ice-house is in the foreground.

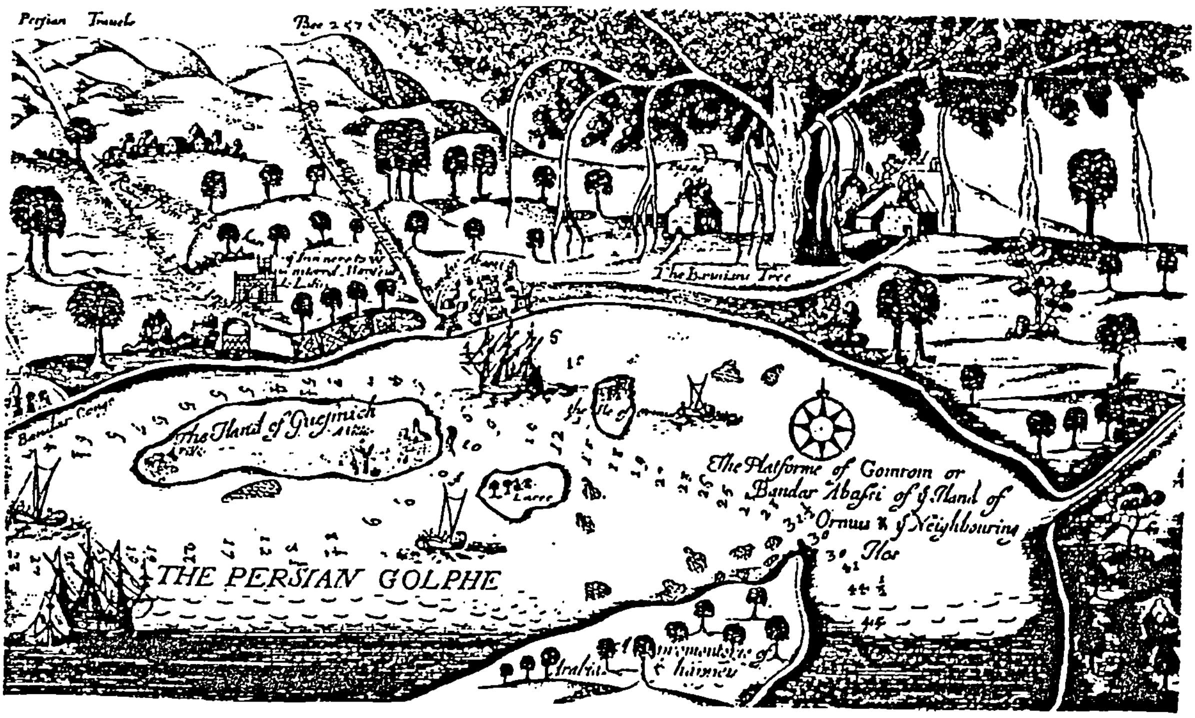


Figure 1.21. Map of the Gulf included in Taverniers' book of 1678. Note the inn to the west of Bandar Abass with what might be a windcatcher on the roof.

was excavated in Iran by a Japanese expedition. It comes from the site of Tappeh Sangh-e Caxmaq, some 8 kms north of Shah Rud, on the southern slopes of the Elborz mountains in north eastern Iran (Masuda, 1984):

> A clay house-model with a flat roof was uncovered from Level III of the East (4th millenium B.C.). Its windows are set in rather high position. Equipment of air-ventilation is on the roof.

The earliest description of windcatchers found in Iran was written by Marco Polo in the 13th century A.D.

> There are a good many cities and towns belonging to Hormos, and the people are Saracens. The heat is tremendous, and on that account their houses are built with ventilators to catch the wind. These ventilators are placed on the side from which the wind comes, and they bring the wind down into the house to cool it.. But for this the heat would be utterly unbearable (Yule: book III, p.452).

In 1595 Pietro della Valle wrote at length of the windtowers at Lar and of the possibility of using such structures to cool houses in Italy (della Valle, 1843, vol.2, pp.333-336).

17th century travellers frequently commented on the windcatchers in the towns of southern Persia.

> 1633-67 - At SCHIRAS, LAR, and in other hot Countries, they have upon the tops of their Houses an invention for catching the fresh Air: It is a wall one or two fathom high, and about the same breadth, to which at the intervals of about three foot, other Walls about three foot broad and as high as the great Wall, joyn in right Angles: there are several of such on each side of the great Wall. and all together support a Roof that covers them: The effect of this is, that from whatever corner the Wind blows, it is straightened betwixt three Walls and the Roof over head, and so easily descends into the house below, by a hole,that is made for it.' (Thevenot, 1686, Part II, p.87)

> 1665 - Illustration of a square four directional badgir in Kashan by Chardin (1686.p.410) (figure 1.20).

> 1668 - All the Houses from LAR to ORMUS are built after one manner. For there is a kind of Pipe, like a Chimney,

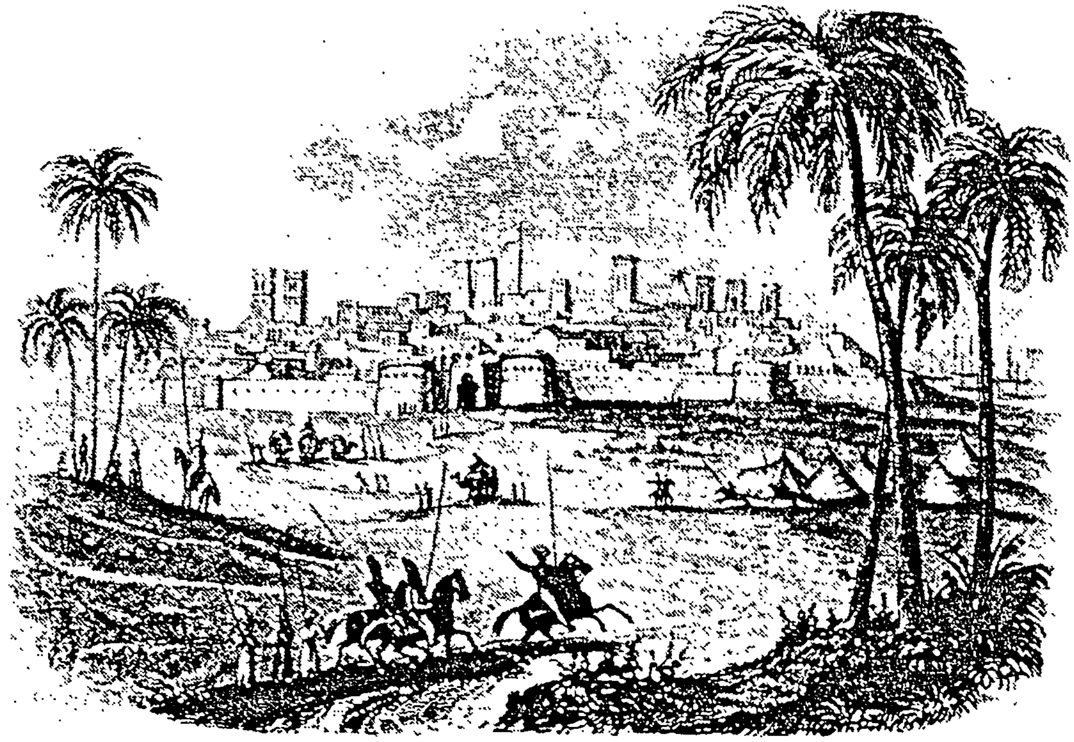


Figure 1.22 Windcatchers on the skyline of Bushir, Iran; illustration from J.S. Buckingham, Travels in Assyria, 1829. (Seawright, 1979, p.147)

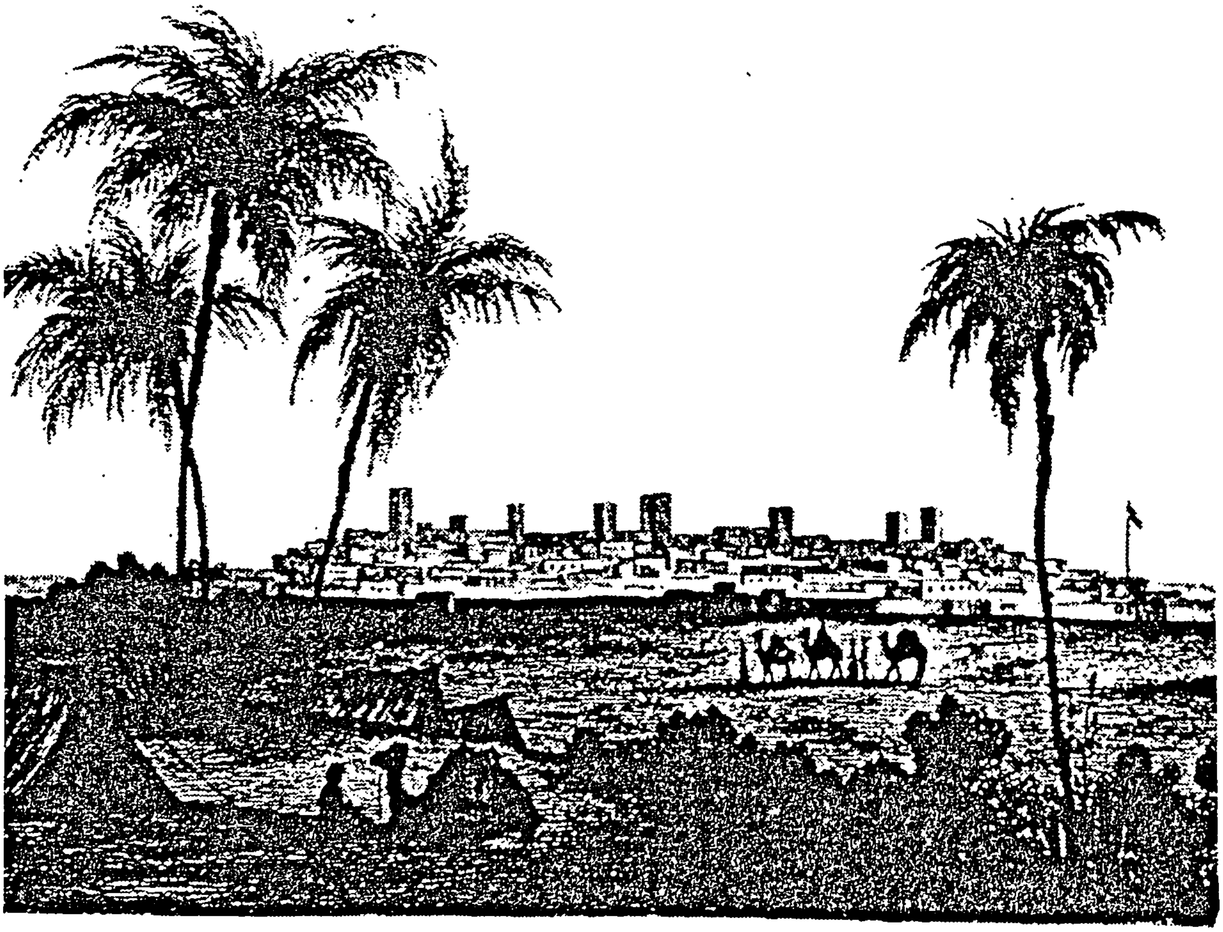


Figure 1.23. Wind-towers rising over Bushir. (from Malcolm, 1815, reproduced by Dubeux, 1841).

that runs from the bottom to the top to gather wind. (Tavernier, Book V,p.254) (figure 1.2.1).

> 1672-1681: in Bandar Abbas:
> The structures are all plain atop, only VENTOSO'S, or funnels, for to let in the Air, the only thing requisite to living in this fiery Furnace with any comfort; wherefore no House is left without this contrivance; which shews gracefully at a distance on Board Ship, and makes the Town appear delightful enough to Beholders, giving at once a pleasing Spectacle to Strangers, and kind Refreshment to the Inhabitants; for they are not only elegantly Adorned without but conveniently Adapted for every Apartment to receive cool Wind within (John Fryer, 1698, p.222).

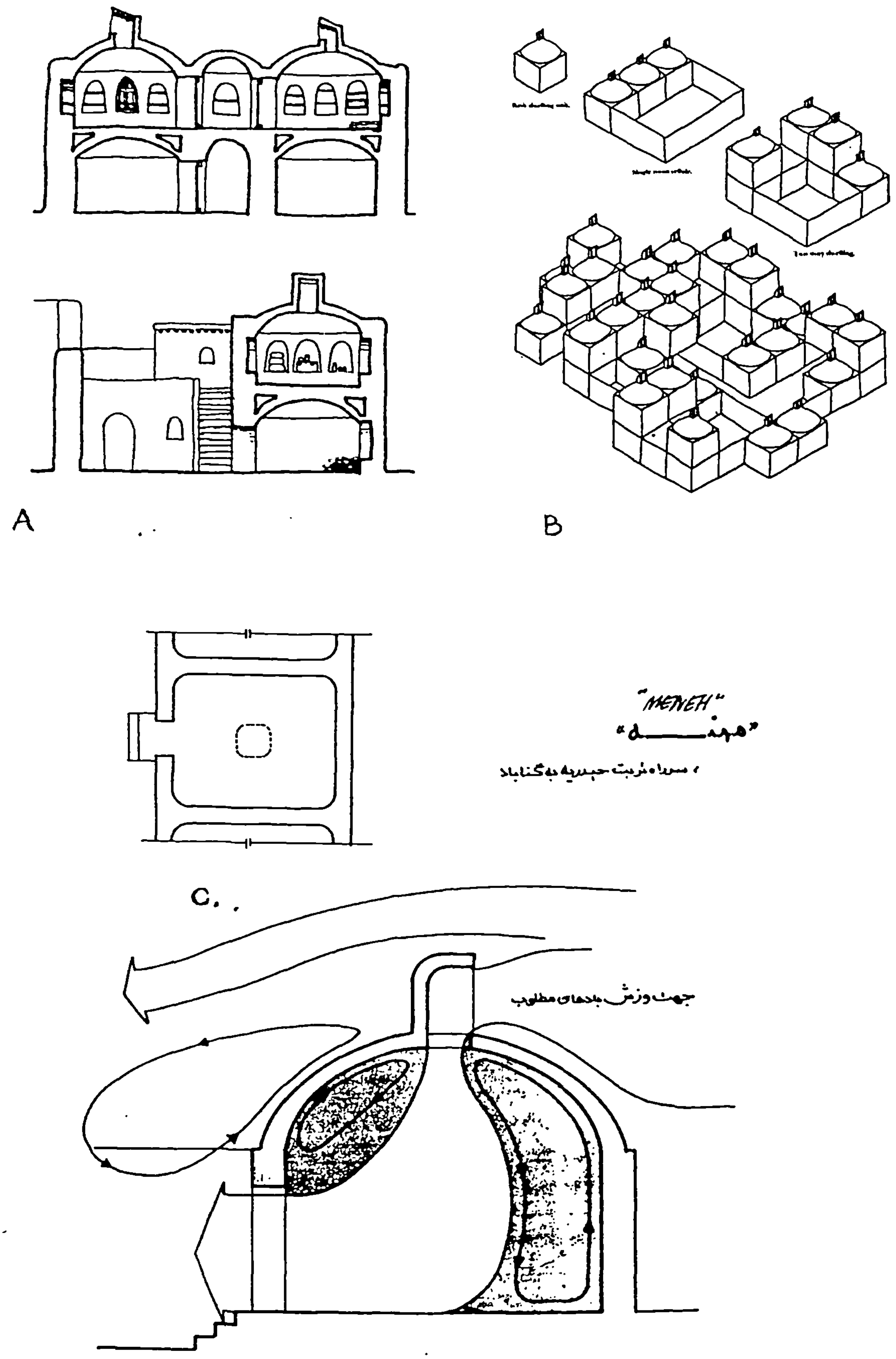
In the 18th century Persia was visited by few European travellers but by the 19th century its doors were again opened and many good descriptions of <u>badgir</u> by travellers survive (figures 1.22 and 1.23).

> 1808-1809 - A great man's dwelling (there are nine in Bushire) is distinguished by a wind chimney. This is a square turret on the sides of which are perpendicular apertures, and in the interior of which are crossed divisions, which form different currents of air, and communicate some comfort to the heated apartments of the house. But comfort is not wholly without danger; as in an earthquake some years ago the turrets were thrown down to the great damage of the surrounding buildings (Morier, 1812, p. 57).

> 1815: in Shiraz - To promote free circulation of air in summer, every house of this description has a high triangular building*, which rises far above the terraced roof, and is open at the top; it received the wind from whatever direction it blows, and by this means the different apartments are ventilated:

> * This ventilator is termed in Persian Baudgeer, which literally signifies "a windcatcher."(Malcolm, 1815, chapt.24,p.525)

> 1857: Bushir - The roofs of the larger houses are flat; and many have tall BADGEERS or wind-towers rising high above. The badgeer merits particular description. It is a large square tower covered on the top, but opening below in to the apartment above which it is erected. The four sides are laid open in long perpendicular apertures, like narrow windows; and within there are partitions or walls, intersecting each other, so as to form four channels in the tower. By this contrivance, from whatever quarter



'igure 1.24. Cowl ventilators or <u>meneh</u> in Khorasan.
A) and B) from Hallet and Samizay, 1980 (Kubba, 1987, part ii, figs. 288 and 289)
C) from Tavassoli, 1976, p.49.

> the wind blows it is caught and conveyed into the room below, so that a constant draught of air is kept up, except when it happens to be a dead calm. At this season of the year, people do not think of seating themselves under the badgeer, but in the heat of the summer, it is a most refreshing, and to many, indispensible comfort. (Binning, vol.I, p. 141)

On the Central Persian Plateau badgirs were used from at least the fifteenth century onwards (O'Kane, 1976, p.85).

The wide variety of types and sizes of ventilation devices found on the Plateau is remarkable. These vary from the small and simple <u>meneh</u> (Tavasoli, 1975, p.49) or cowl ventilators of Khorasan (Hallet and Samizay, 1980) (figure 1.24) to the modest windtowers of Shiraz, Isfahan, Sirjan, Semnan and Tehran, and the massive and complex towers of the settlements on the southern fringe of the Dasht-e Kavir, the central desert of Persia.

The cities of Kashan, Nain, and Kerman have some surviving windcatchers, but one city on the Plateau, Yazd, exceeds all others in the quality and quantity of its windcatchers, for which it is known as 'Shahr-e Badgirha', the city of the windcatchers.

Yazd has the greatest variety of types and sizes of windtowers and for this reason it was chosen as the core area for this study.

1.7 THE FUNCTION OF WINDCATCHERS

1.7.1 The function of windcatchers in the Middle East

Dr. Lewcock (Lewcock, 1978, p.40) writes of the windcatchers in the Gulf region that:

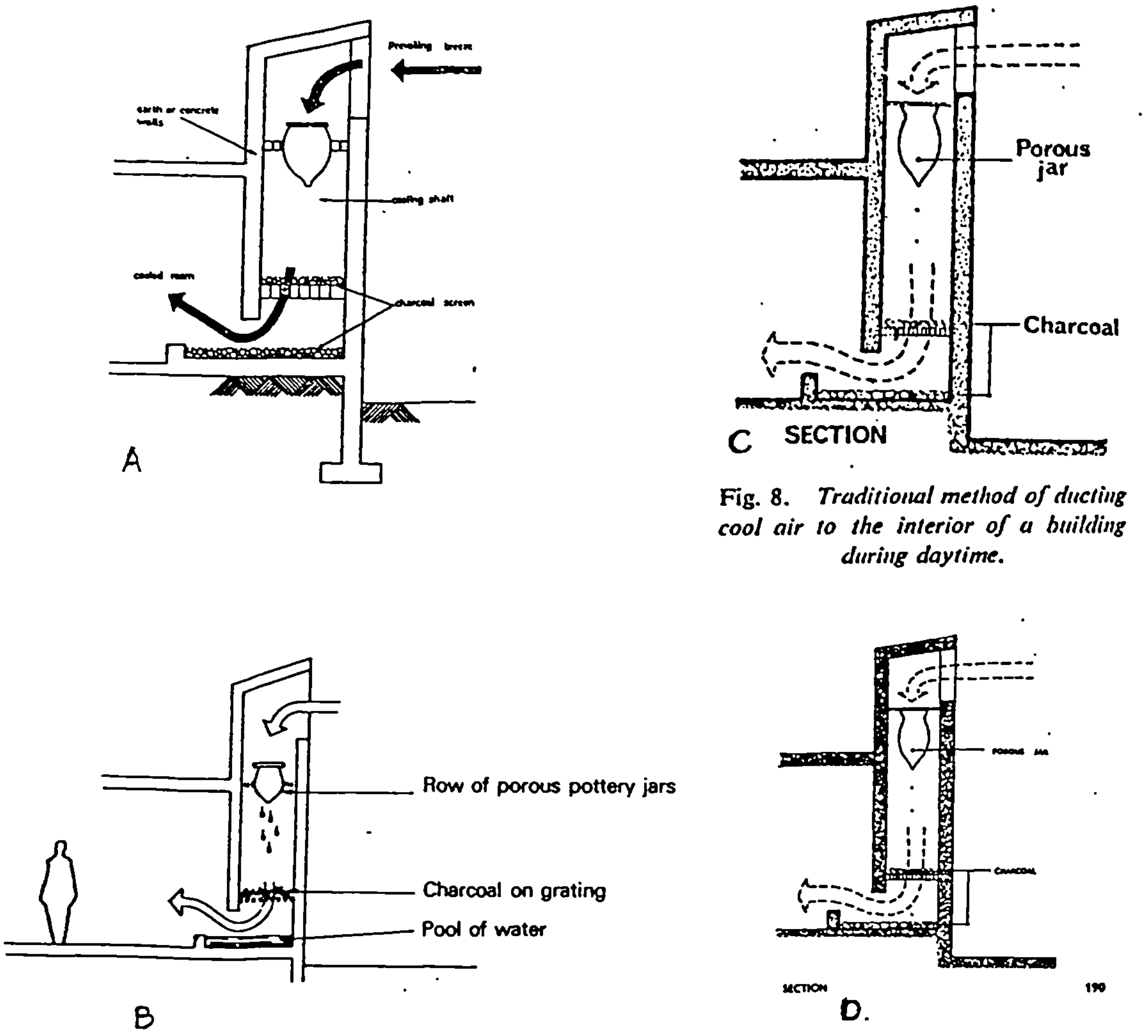


Figure 1.25. The windcatcher diagram. A) First published by Oakley in 1962, and subsequently published by many others including B) Koenigsberger et. al., 1973, p. 103, C) Danby, 1963, p.190 D) Danby, 1978, p.67.

There are two basically different types of ventilator, those which face into the prevailing wind, and those which face away from it and exhaust stale air and smoke.

Interestingly some authors, usually indigenous Arab writers, describe the function of the windcatcher as a ventilator (Fathy, 1986, p.60) or a 'selective ventilator' (Talib, 1984, p.89). Others envisage the role of the windcatcher as either that of an air-conditioner (Danby, 1968, p.208) or a swamp cooler (Bahadori, 1977, p.8) a structure that supplies cooled breezes to rooms.

It has generally been believed that 'cool air' is introduced down through the badgir. The following descriptions are typical of the perceived modus operandi of the <u>badgir</u>:

> The wind-catch tower is found in innumerable shapes and sizes from North Africa, through the Middle east to the Sind Region of Pakistan. Its design often follows closely aero-dynamic principles in order to draw cool, clean air found well above ground level, down into the living spaces of the house. (Cain, Afshar, Norton, Daraie, 1978, p.50)

> However in these regions(Central Persian plateau), the cities are built on level lands and are very compact and the cooling winds are cut off from much of the city. In an effort to "breath" cool air, the bad-gir or wind tower was devised to catch some of the cooling winds and direct them into the living spaces. (Tavasoli, 1975, p.3)

> They are normally oriented to catch favourable winds, such as daytime sea winds in maritime desert locations. In inland locations the cooler outside air at night is coaxed downwards to enter the building and thus cools it sufficiently for it to make it comfortable during the hot daytime conditions of the following day. (Saini, 1980, p.61.)

A number of authors, when describing the <u>badgir</u>, provide a single diagram, '<u>The Windcatcher Diagram</u>', to illustrate the concept (figure 1.25).

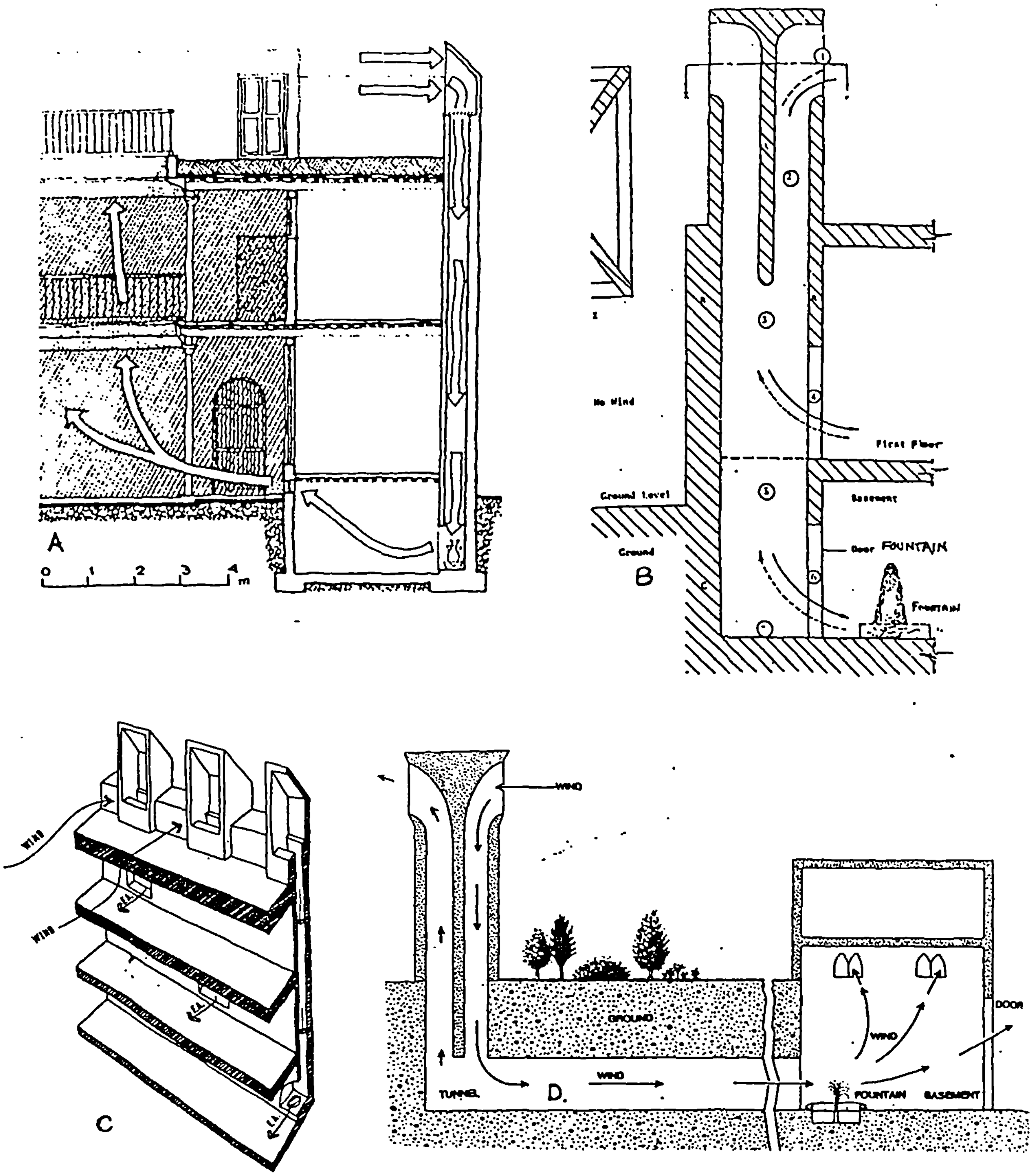


Figure 1.26. Pots and pools in the basement. Are they really there? A) Azzawi, 1969, p. (reproduced in Konya, 1980, p.56) D) Bahadori, 1978, p.147 C) Kubba, 1987, volume 2, figures 278 and 279 B) Bahadori, 1977, p.17.

'The Windcatcher Diagram' was first produced as an illustration of the windcatcher designed by Hassan Fathy in the new school in Gourna in 1958. This was in turn reproduced in a report, in Washington D.C. U.S.A. and was subsequently copied and published in England, in a book by Oakley, Tropical Architecture, in 1961 (p.127-128). It was at this point that the diagram was widely seen and copied repeatedly, generally masquerading as a genuine traditional, vernacular, indigenous device. However, not only was this diagram not a measured drawing of a traditional design but also the characteristic behaviour of the structure had been altered by Fathy by including the charcoal tray and suspended pots. A confusing factor was perhaps that Fathy built this structure on a pseudo-traditional school building.

As a result of this diagram a number of articles and books have appeared purporting that this diagram is actually of a traditional structure, and usually naming locations where it is found. Also, and perhaps understandably, water pots have begun to appear in the drawings of the shafts of traditional windcatchers, where they were never found in reality (Bahadori, 1977, p.147; Azzawi, 1969, pp.91-102; Konya, 1980, p.56; Kubba, 1987, vol.2, figures 278 and 279; Petherbridge, 1978, p.204; Tappuni and Rassam, 1981, p.2; Moore, 1983, p.233; etc.) (figure 1.26).

Fathy claimed that the windcatcher in the school in Gourna reduced the temperature of the air by up to 7f (3.9c)(Oakley,1961, p.126). This difference has risen to as much as 10c in an account of the performance of this single tower by a later authors (Saini, 1980, p.61).

A subsequent work on the performance of windcatchers in Yazd, by Professor Mehdi Bahadori, who did some field measurements over a period of three days in Yazd with the assistance of three students in 1976, gives figures also for the degrees that the air is cooled by in its descent down the shaft of the wind tower: (figure 1.26b)

> The air is cooled sensibly by about 5-10c as it passes through portions (2) and (3) of the wind tower (ie. the base of the shaft) and may be let out at the first floor through the door or at the basement through the door.(1977, p.7)

However Bahadori gives no actual readings taken in Yazd of temperature, humidity or windspeeds, and leaves one without any real evidence of badgir performance. He also reinforces the idea of the importance of the use of water, associated, as a result of the the windcatcher diagram, with the windcatchers in the traditional houses (Bahadori, 1978, p.147.).

Thus one might summarise a very general stereotype of the functioning of the windcatcher in the Middle East, influenced largely by the very profound impact of Hassan Fathy's pioneering work in the Egypt, as follows:

1) Windcatchers, from Pakistan to Eqypt look, in general like 'The Windcatcher diagram' (figure 1.25).

2) A primary function of a windcatcher is to circulate cool air through summer rooms - either air that is cooler because taken from a greater altitude, or air that has been cooled

by its descent down the shaft - thus cooling the occupants of the summer rooms.

3) Windcatchers are commonly associated with water, usually contained in jugs or pools, at, or near, the base of the windcatcher shaft.

It should be noted that in the last ten to fifteen years studies of regional vernacular architecture in the Middle East, such as Lewcock's work on Kuwait (Lewcock, 1978, pp.40-41) show a variety of fundamentally different forms within one area and such publications are gradually changing the level of awareness concerning the range of badgir types and their location in the Middle East.

1.7.2 <u>The function of windcatchers on the Persian Plateau</u>

Little has been written on the actual operation of the windcatchers of the Persian Plateau.

On the plateau the winds, coming as they do from the desert floor are hot. Hans Wulff, in his book on the <u>Traditional Crafts of Persia</u>' (1966,p.106), implies that the daytime winds on the plateau may be unsuitable for cooling purposes, by emphasising that only the night-time winds are cool and refreshing:

> Ventilation towers or wind catchers (bad-gir) are a feature peculiar to the houses of Central Persia. They lead the cool, refreshing night winds into the living room in the basement (zir-e zamine).

To the south of the Central Persian Desert the strongest winds blow in from the desert floor from the north and north west and are in absolute terms hot winds'. Mahmood

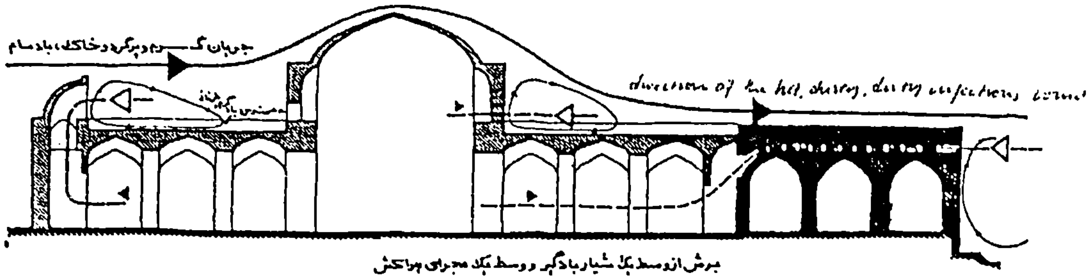


Figure 1.27. Section through a windcatcher in Iran showing the direction of the hot, dusty and dirty winds which are excluded from the tower. (Tavasoli, 1976,p.52)

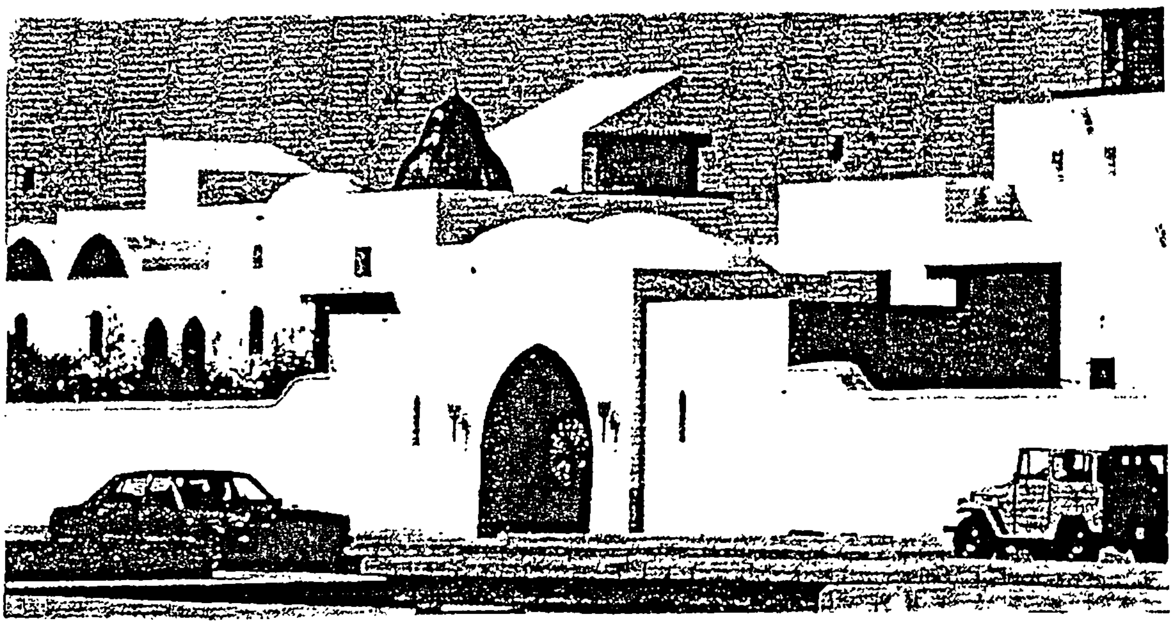


Figure 1.28. The palace of Al-Sulaiman in Jeddah, designed by Abdel Wahed El-Wakil showing two windcatchers on the roof-line. (Antoniou, UR, no.2, 1984, p.29)

Tavasoli stressed in his book on Architecture of the Arid Region, the importance of excluding the 'infectious, dusty and hot winds' from the badgir in areas where there are two strong prevailing winds (Tavasoli, 1975, p.52) (figure 1.27).

The above descriptions emphasise the importance of drawing 'cool' wind through the wind towers and buildings, and this is also the central concept around which building technologists have built their descriptions of the function of windcatchers in the Middle East region in general.

1.8 REGIONAL DIVERSITY IN BADGIR DESIGN IN THE MIDDLE EAST

Despite the recent general consensus on the badgir stereotype, it has been seen that there is a wide variety of forms and sizes, and reasons for this variety have been considered by a select number of authors.

Hassan Fathy suggested that:

> The size of a malqaf is determined by the external air temperature. A larger size is required where the air temperature at the intake is low, and a smaller size where the ambient air temperature is higher than the limit for thermal comfort, providing that the air flowing through the MALQAF is cooled before it is allowed to circulate through the interior. In Iraq, where the air temperature in summer rises to above 45c.(113f), the typical MALQAF shaft is very narrow. It is placed in the northern wall with a small inlet allowing the air to cool before it flows into the interior,... This is very similar to the shape of the human nostrils, which are narrower in colder climates so that cold air will not reach the lungs before it has been heated by contact with the trachea, which is at body temperature. (1986, p.59)

Shamal Kubba suggested that:

> Their form and size is chiefly dictated by the velocity and direction of the prevailing winds, and whether the wind is multi-directional or uni-directional. Available materials and tradition can also influence the design.
>
> For example, near the Afghanistan - Iran Border, the prevailing wind is quite strong and blows from one direction only. Therefore small windscoops are sufficient to cool the interior spaces. In Egypt and Pakistan on the other hand, the summer wind is quite mild, and large openings are required (Kubba, 1987, vol.1, p.155).

Ron Lewcock wrote on the subject

> Internally the turret (of the wind tower) is normally divided into four vertical shafts. This may be done in two ways. In northern and western Persia, Iraq and Kuwait, it seems normally to have been done by creating four rectangular shafts with cross walls built parallel to the outer walls of the wind-tower; ... While the turret using diagonal cross walls is common in the central and southern Gulf, a number of examples of it may also be seen in Kuwait, notably on the big houses built by Sheikh Khazal al-Khan (1978, p.41)

Thus Lewcock suggests that there are different local building blueprints for badgirs in different regions.

These three authors, amongst the few who deal with divergence in form and size, have suggested a number of different factors that may influence regional forms of badgirs, including historical factors (local building traditions), and climatic factors including velocity, direction, and temperature of local winds.

1.9 THE NEED FOR FURTHER WORK

The review above of the published literature on the subject of windcatchers emphasises two important topics that have not been covered to date:

A) There is no detailed local study of the windcatchers of one area, describing the range of their types and sizes and and the buildings with which they are associated, in rural or urban settings. Only by using primary data from such a local study can progress be made in understanding the reasons, climatic or historical, for the differences in regional windcatcher types and their distribution.

B) There is no detailed published study of the actual functioning of the windcatcher in any region of the Middle East, with measurements of temperature, humidity and air flow; so while theories abound on their function, these are based on conjecture rather than factual observation.

While Fathy and Bahadori have provided readings of the difference in air temperature between the top and the bottom of the windcatcher shaft, neither give the ambient outside and inside temperatures, so conclusions cannot be drawn as to what such temperature differences mean in terms of internal wet and dry bulb temperatures.

Danby has published some findings of a study on temperatures in a research building in Khartoum, built of mud with a flat roof. The graph of indoor temperatures for a room ventilated only at night and closed during the day (Danby, 1973, p.65), at 3pm in summer, shows an outdoor temperature of around 40c and an indoor temperature of 30c. If these are indicative of general temperatures in the area then the addition of a malqaf to the room would be introducing air, cooled in its descent down the tower by only 3.9c (Oakley,1962,p.126), into the room that was about 6c cooler than the new air.

Nobody suggests the possibility that warm air is introduced into summer rooms by windcatchers in any of the literature published on the subject.

1.10 THE IMPORTANCE OF FURTHER WORK

Intuitive assumptions are being made about the function of the wind tower in the Middle East on which are based blue-prints for windcatchers in rationalised traditional houses now being built in the Middle East today.

Abdel Wahel El-Wakil,in a brave attempt to transfer the technology between different areas in the Middle East, has used an Egytian malqaf on the palace of Al Sulaiman in Jeddah, Saudi Arabia (Muqarnas, vol.I, 1981,pp.48-55) (figure 1.28). In the Jeddah area, due possibly to high summer temperatures, the windcatcher, although perhaps used in the area in antiquity, was not used in the recent past when traditional houses were commonly four stories high without badgir (Talib, 1984,pp.67-77). The advisability of transfering the windcatcher freely between very different geographical and climatic regions in the Middle East is difficult to guage as there is no existing published yard stick, however rudimentary, with which we can begin to answer such questions.

Fathy used a rationalised form of malqaf early in his work, on the school in Gurna, attempting to improve the performance of the traditional tower by using porous pots and a charcoal mat at the base of the tower (Oakley, 1962, p126). His more recent work, the 1986 book Natural Energy and Vernacular Architecture, demonstrates a decreasing confidence in the usefulness of the traditional malqaf by including two increasingly complex rationalisations of the malqaf.

Tappuni and Rassam of Baghdad University claim a clear failure of the system' because of the non-use of the windcatcher in modern houses of Baghdad (1981,p.2). They conclude their paper with two rationalised forms of the windcatcher for use in modern houses. They claim also that observation and evidence prove that the vernacular passive systems of the courtyard house do not 'provide the convenience level of comfort required by contemporary man' (Tappuni and Rassam, 1981,p.9) and yet they acknowledge that no systematic worthwhile attempt has been made in monitoring the efficiency of this vernacular system' (Tappuni and Rassam, 1981, p.2).

The importance of further research on the windcatchers of the Middle East has been recognised by the Architectural Department at King Fahad Universty in Damman, Saudi Arabia, which has incorporated a wind-tower in the centre of the test home constructed on the university campus in 1986 (Bajwa, Aksugur and Al-Otaibi, 1987, p.4).

1.11 THE CHOICE OF FIELD STUDY LOCATION

Two main questions have been raised in the review of literature on the subject:

1) What are the reasons for the differences in windcatcher form and design in different areas of the Middle East?

2) How do windcatchers function?

This study is based primarily on fieldwork in the city and region of Yazd. Due to the impossibility of investigating every city with windcatchers in the Middle East a single area was selected for study. The choice of the city of Yazd on the central Persian plateau was made because, of all the cities in the Middle East Yazd has more, and more varied, windcatchers than any other. There are seas of windcatchers rising above the roofs of the city and surrounding villages. This area potentially offered the richest variety of wind-tower types, a key consideration in the study of their diversity.

1.12 THE AIMS OF THE STUDY

Given the general questions raised the particular aims of the thesis are:

1) To provide a detailed case study of the types of windcatchers in the city, towns, and villages in the Yazd province, with a view to understanding the impact of climatic and historical influences on the variety of types and their distribution in the area.

2) To investigate the functions of the windcatchers in the city of Yazd in order to understand within what range of climates the windcatchers of Yazd function best and why.

3) To relate the findings of this local study to questions of the wider distribution of windcatchers in the Middle East, and the potential for the use of the windcatcher in modern houses of the area.

1.13 THE STRUCTURE OF THE THESIS

In order to address these questions and fulfill these aims the thesis is divided into three parts. The first part provides a regional approach to the questions of the distribution of badgirs in the Yazd area in terms of the relative importance of climatic and historical as influences on badgir form and distribution, as a background to the more detailed study of the badgirs of the city.

The second part focuses on the historical development of the badgirs in the city of Yazd, the evolution of the domestic badgir, the physical attributes of the badgirs ; their types, sizes, decoration and location, and finally on their distribution in the city in relation to date.

Part III of the thesis deals with the functions of the badgirs of the city in relation to the summer use of the badgirs in the house, and the implications of the findings on function in terms of the distribution of windcatchers in the Middle East.

Part I, chapters 2 - 4, of the thesis begins with an investigation into the geography and climate of Yazd (chapter 2), arguing that, as suggested by several authors (1.8), climate may be a key factor in determining the distribution of badgirs in the Middle East. As no easy answer is forthcoming, chapter 3 looks at the settlements of the Yazd region (3.1), rural badgirs in the area, the buildings on which badgirs are built (3.3), and the distribution of rural bagdirs (3.4), considered in relation to climate (3.5).

Chapter 4 deals with the possible historical influences on the distribution of badgirs in the study area, particularly the Yazd basin. It begins with an investigation of who builds badgirs (4.2), the materials required to build badgirs and where they are purchased in the region (4.3). Then, having isolated the two regional centres to the east of the Yazd basin, the history of the evolution of these two main market centres at Ardakan / Maibud (4.4) and Yazd city (4.5) are investigated in general, with reference to the different badgir types used in the different areas of the Yazd basin.

Chapter 5 reviews the historical and climatic findings of part I of the thesis and outlines the resulting questions raised which will be addressed in parts II and III. In chapter 5 the methodologies adopted for the survey of badgirs in Yazd city and the technical study of the function of badgirs in the city are outlined.

Part II is divided into 3 chapters. In chapter 6 the evolution of the houses of Yazd is discussed in relation to the development and use of different badgir types at different dates. In chapter 7 the badgirs of Yazd city are described and classified, using the results of a survey of the badgirs of the city. In chapter 8 the findings of this survey are related to the location of individual badgirs within datable suburbs of the city. In so doing some evidence is provided to establish the use of different badgir types at different dates, the fashion for high towers in the late 19th century and the idiosyncracies of individual badgir builders at that period, who may well have fostered the fashion for high towers in the city.

Having established that fashion in badgir building was a determining influence in the use of different badgir types at different periods, a further finding of part II of the thesis is that a wide range of badgir types were built at all periods in all parts of the city. This leads back to the question of the suitability of the local climate to the use of badgirs.

In part III, chapters 9 - 11 of the thesis, the function of the badgirs in Yazd is investigated. Chapter 9 provides a general range of internal climates experienced in houses with and without badgirs. In chapter 10 the summer use of space in the typical house is described and an outline of the diurnal climate of occupied spaces is given. In chapter 11, the general range of climates occupied in summer in Yazdi houses is discussed briefly in relation to Western comfort standards, and more fully, due to the high temperatures involved, in relation to the physiology of man's responses to high temperatures and the mechanism for heat loss of which the badgir takes advantage. In conclusion the study suggests that these temperature limits, defined in chapter 11, may provide an indication of the reasons why some climates prove to be unsuitable for the use of badgirs, and more generally, the climatic criteria that determine the distribution of windcatchers in the Middle East.

Chapter 12 summarises the conclusions of the study.

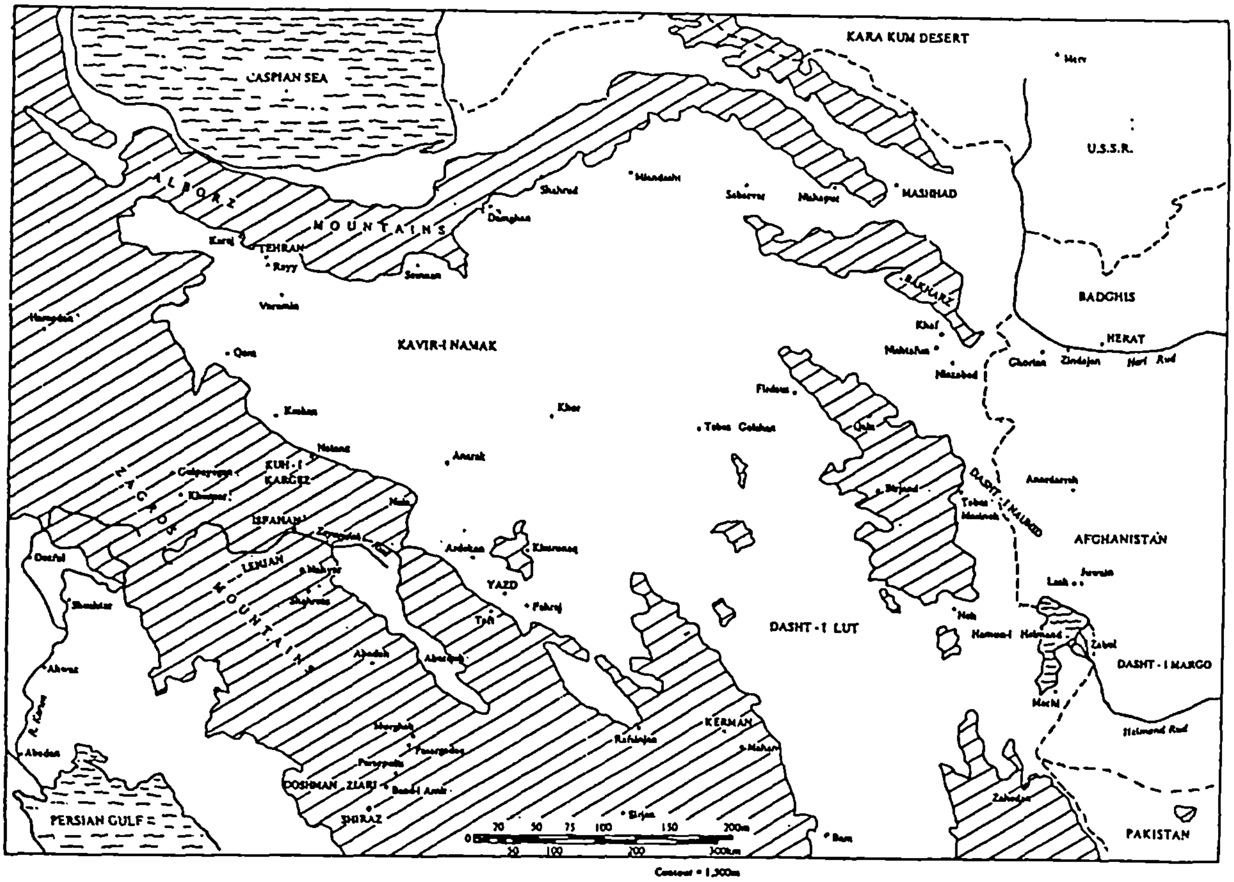
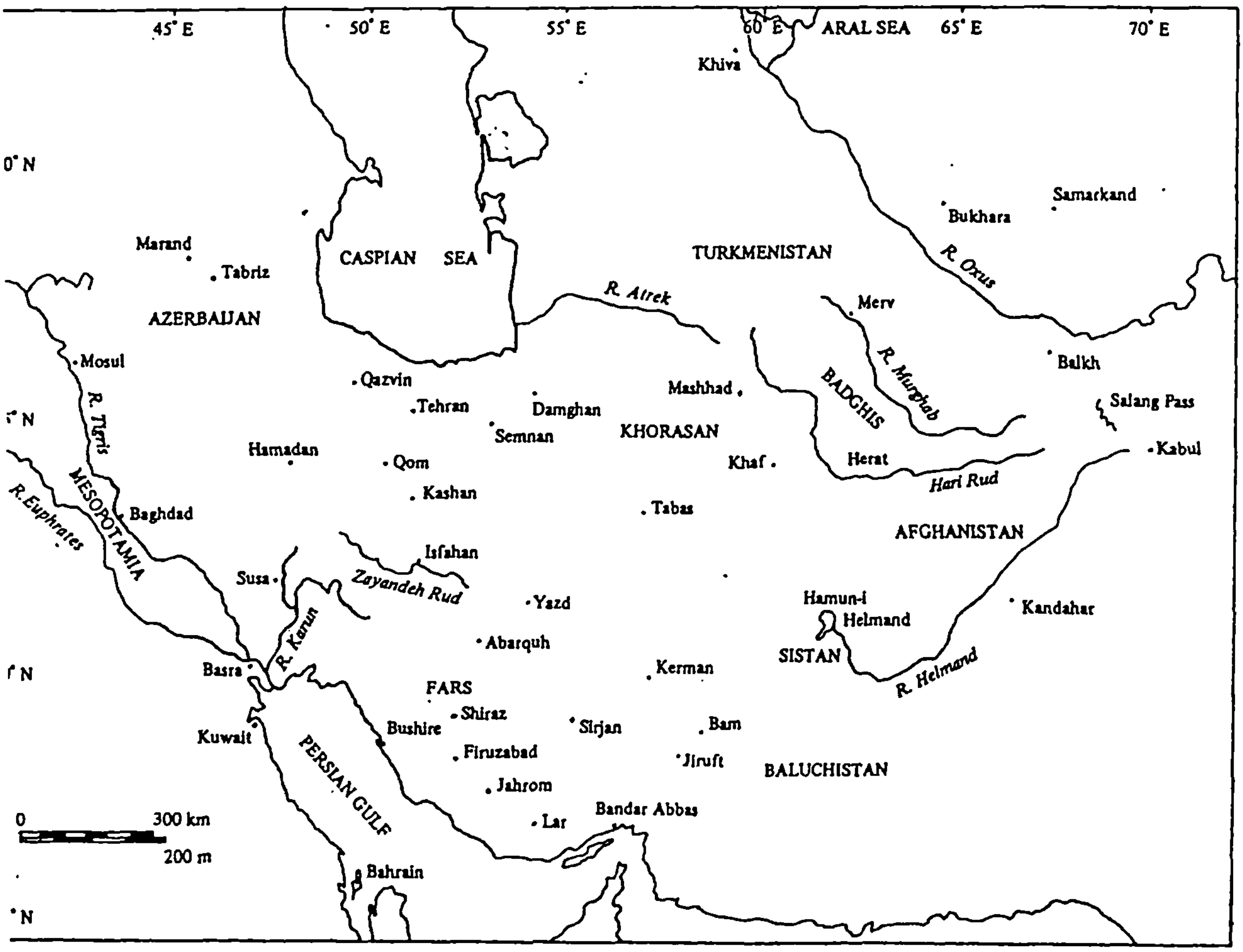


Figure 2.1. Map showing the geographical location of Yazd on the central plateau of Iran. (Beazley and Harverson, 1982)



1: *Iran and neighbouring areas, with settlements, rivers and regions mentioned in this book.*

Figure 2.2. Map showing the main cities in Iran and neighbouring countries. (Beazley and Harverson, 1982)

CHAPTER 2

THE CLIMATE OF YAZD

2.1 INTRODUCTION

The reasons for the wide variety of types and the distribution pattern of windcatchers in the Middle East, it has been claimed by a majority of authors writing on the subject (see 1.8), is due to differences in climate between areas.

In this thesis the investigation is focused on the distribution of types in the region of Yazd. If climate is a critical factor in incidence and distribution of windcatchers then a general study of the geography and climate of Yazd may clearly indicate why this city and its hinterland has more windcatchers than any other region of the Middle East. Comparison between climates in the neighbouring cities of Kerman and Kashan, similarly located on the southern shore of the Central Desert of the Iranian Plateau, may highlight why these two geographically comparable cities have relatively few badgirs. Wider conclusions may be drawn on the distribution of windcatchers in the Middle East.

2.2 YAZD - THE GEOGRAPHY OF ITS LOCATION

The centre of Persia consists of a high plateau, surrounded by mountains, at the heart of which is a great desert, the dasht-e kavir (figures 2.1 and 2.2). At the southern limit of the desert are a number of large cities lying on a trade route skirting the desert, to the south of which the Zagros mountains rise steeply. From the north west to the south east along the trade route the larger cities are Qom, Kashan, Nain, Yazd and Kerman.

The city of Yazd is situated in the province of Isfahan-Yazd, and is located at 31 54' N. latitude, 54 24' E. longitude, at an elevation of 1225m. above sea level (Iran Meteorological Office statistics).

Yazd is placed centrally on the trade routes that connect Tehran and Isfahan to the west and Mashad and Khorasan in the north-east, and Bandar Abbas on the Gulf coast, and Zahedan and Pakistan in the south east of the country. It was a main trading centre on the routes between Europe and the Near East, to the west, and China and India to the east.

Yazd is 170 kms from Nain to the north west, the nearest city. Until the 1920s and the introduction of motor vehicles into the area, it lay five days ride or caravan stages from Nain, (Curzon, 1892,vol.2,pp.265-267) now only 2-3 hours away by car. Yazd has a present day population in the region of 250,000 and is an administrative as well as an industrial and market centre, with important local textile and mining industries. It was also an important grain producing area (Cambridge History of Iran, 1968, pp.502,543,548 and 516). However in recent years grain production has declined considerably (Ibid, 1968, p.567)

2.2.1 Physical geography of the area

Physically Iran consists of a complex of mountain chains enclosing a series of interior basins that lie at altitudes of 300m to 1200m above sea level. The whole country has been likened to a bowl with a high outer rim surrounding an irregular, lower, but still not low-lying, interior. At the heart of this interior plateau are a number of basins, the largest of which is the Kavir-i Bozorg, or the Great Kavir (Fisher, 1968, p.3) an inhospitable tract of stone, mud and salt desert; the Kavir-i Bozorg is bordered by smaller desert basins, of which the Yazd basin forms the southern part (Curzon, 1892,vol. 2,p.246-253).

The Yazd basin is an area of closed drainage, one of several along the eastern flanks of the Zagros mountains, formed of long narrow basins enclosed between high narrow mountain ridges that trend mainly north west and south east and lie 30-40 miles apart.

The Yazd basin extends from Ardistan in the north west, through Nain and Yazd and down almost to Kerman in the south east and it has small but fairly numerous expanses of both sand desert alternating with kavir surfaces, formed largely of gravels and other sedimentary material (Breckle,1983, pp.274).

The north east and south west sides of the basin are flanked by mountain ridges formed largely of rocks of the Cretaceous and Jurrassic periods, with the highest peak being Shir Kuh, or Lion Mountain', to the south of Yazd, formed of an acidic igneous intrusion and rising 1244m.

above sea level. An outcrop of mountains to the north west of Yazd provides some wind shelter from the prevailing north west wind that flows in off the desert floor.

The three main cities in the heart of the basin, Yazd, Nain and Ardakan lie in well watered oases.

2.2.2 Water supply

The traditional system of qanats, subterranean water channels tapping deep aquifers in local upland areas (Wilkinson, 1974; English, 1976, figs. 6,7 and 8) provides water for a large number of settlements in the area. It is these qanats that are responsible for the existence of well established oases in the Yazd Basin. Qanats vary in length from 1 mile to 18.3 miles in the Kerman district (English, 1975, fig.8.; see also Wulff, 1966,pp.66-68; Wulff, 1968, pp.94-105; and McLachlan, in press).

Other sources of water for the settlements of the area include springs, domestic wells with water drawn by windlass, and motor pumped deep wells and rain fed cisterns (Beazley and Harverson, 1982, p.39-45). In the upland areas of the region rainfall is sufficient to support some dry farming but crops grown on the desert floor require extensive irrigation.

2.2.3 Soils of the plateau

The soils of the plateau are typically sandy earth with clay. It is often greyish, being calcareous throughout, with an accumulation of soluble salts; or it may be a crumbly brown soil which grades into a pale brown or greyish, highly calcareous clay 15 - 30cms below the surface (Breckle, 1983, pp.274). There is very little organic matter in either type of soil, and it makes excellent mud bricks.

Two excellent studies of the building techniques and materials on the plateau have been published by Wulff (1966) and Beazley and Harverson (1982).

2.3 VEGETATION OF THE REGION

Vast areas of central Iran appear completely barren, being saline plains with a very high salt content, and often, where vegetation does begin, it takes the form of salt tolerant low scrub bushes. These develop into a sporadic climax of low xerophytic tree species including artemisia species and a remarkable variety of Tamarisk species, numbering over 40 (Breckle, 1983, pp.281-308).

When driving over the desert plains it is a rare sight to see trees clustering around a settlement, a deep well basin, or a qanat outlet, although in the region of Khur, Chupanan and Mehrjan the government has been experimenting since 1975 with plantations of tamarisk watered by tanker lorries. On the road between Chupanan and Baiyazeh, on the very edge of the central desert, a number of oasis settlements, of which Khur is the largest, grow date palms, although in 1970 many trees became diseased and died. [Homan, 1971]

The area is one of intermittent depopulation, due mainly to the drying up of local qanats, or the loss of settlements to the desert sands.

In well established communities fruit trees are often grown in walled garden areas. This is particularly true of the villages in the mountain areas to the south of Yazd, which are famous for their fruit crops such as apples, cherries, apricots, and citrus fruits. Mulberry is a popular species, much more widely grown when the silk worm industry flourished locally. There are many pistachio orchards around the settlements on the roads from Yazd to Nain. Nuts from Ardakan and Nain are famous throughout Iran for their size and excellence.

One tree type which occasionally stands out in the area is the cypress which is classed as a ziarat', or pilgrimage vegetation, as it is grown by the Zoroastrians at or near their shrines.(Breckle, 1983, pp.281-308)

It is unusual to see any vegetation other than low scrub bushes less than 40cms. high outside the settlements and the associated farm lands of the area. The limited amount of available timber has obviously influenced the brick dominated architecture of Yazd.

Vegetation patterns may affect the operation of the badgir in a number of ways. The existence of gardens or orchards, and pools of water, increases the relative humidity within the settlements and decreases the temperature of the air above them (Lesiuk, 1983, pp.215-230). On a larger scale the existence of a belt of gardens or date or tamarisk plantations around a settlement may also

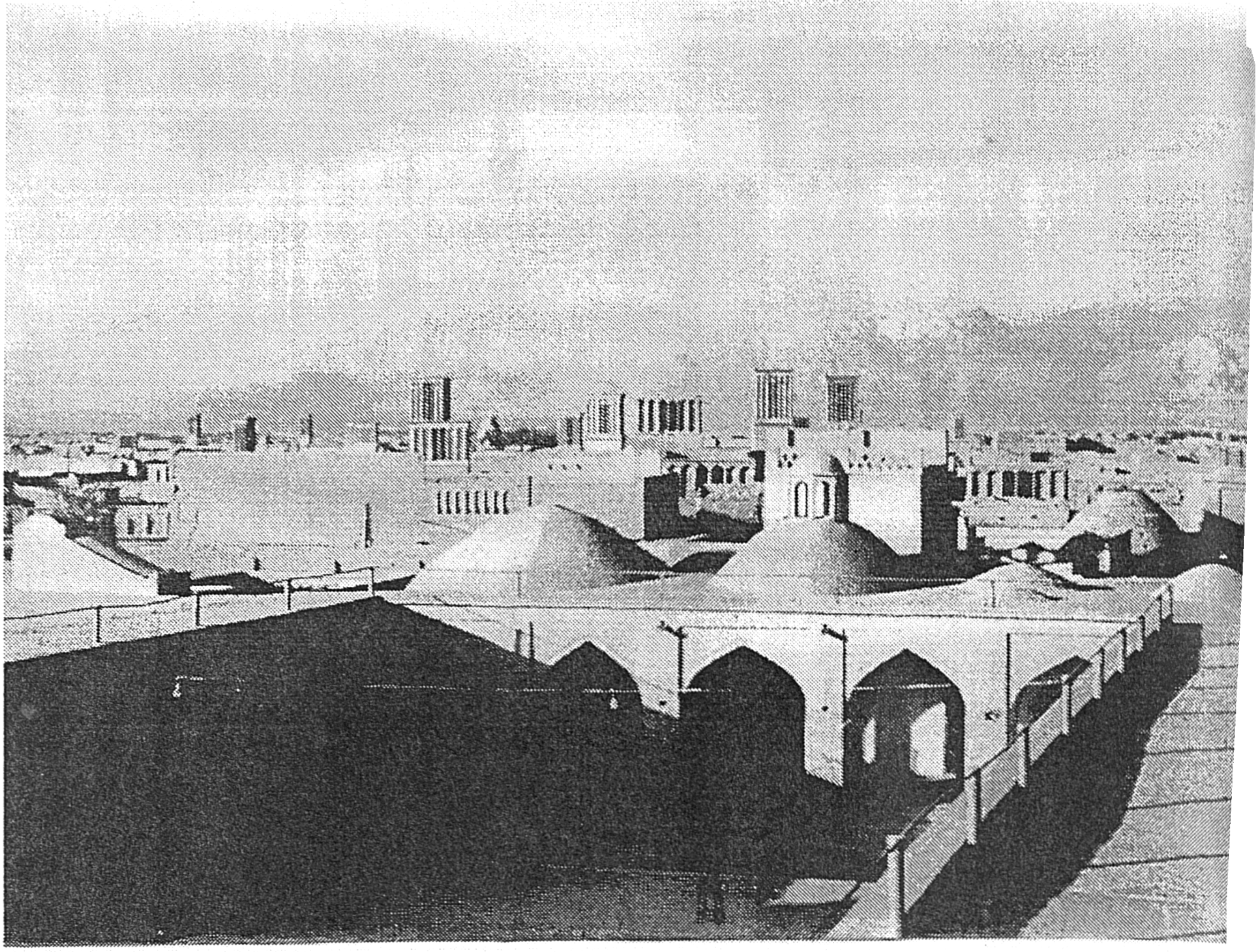


Figure 2.3. Windcatchers on the skyline of Yazd, located to the east of the Friday mosque.

Figure 2.4. Sandy desert by the road north of Mehrjan.

condition', by cooling, humidifying, and removing dust from the air before its arrival at the settlement. Most cities on the plateau including Yazd, Kerman and Kashan have surrounding belts of gardens and orchards, and the roof level climate of settlements without surrounding gardens. The actual effect of vegetational air-conditioning' on the distribution of badgirs in the Province of Yazd is summarised in 3.6.

As most of the structure of the windcatchers is mud-brick the limited amount of timber available in the Plateau cities probably does not affect the incidence of badgir. Timber is used in scaffolding poles and to support the lintels of the ground floor outlet, and internal partitions of the shaft. The woods most commonly used in constructing badgirs in Yazd are poplar, plane and fruit woods (Wulff, 1966,pp.75-78 and Khalaf, 1985, chapter 3).

2.4 THE CLIMATE OF YAZD

Yazd has an arid, continental climate due to its interior plateau location. In the Yazd area the highly accentuated surface relief results in a great variety of local climates and vegetation, from the upland grasslands and fruit-growing areas of Shir Kuh region to the deserts around Yazd itself (Figures 2.3 and 2.4). In the city of Yazd however the lowland location on the plain ensures a true desert climate. The data that follows is taken from that provided by the Tehran Meteorological Bureau (figure 2.5).

AHWAZ

Lat. 31° 20' " ; Long. 48° 40' " ; Elevation 18 meters ;
Years of Observation 1956 to 1971 ; Koeppen Symbol :

Month of the Year	TEMPERATURE					PRECIPITATION				Rel. Hum			Other Data				
	Av. Max.	Av. Min.	Abs. Max.	Abs. Min.	Average	Total	Days≥1 mm	Days≥10 mm	Max. in a Day	03 GMT	09 GMT	AVERAGE	Sunshine	Wind Prev.	Wind Max.	58-70 Frost	PRESSURE
			54.0	-7.0		186.0			83.5								1012.6
Jan.	17.8	6.9	27.0	-7.0	12.3	49.7			71.5	83	59	71	165.8	W/12		1.1	1018.6
Feb.	20.6	8.3	30.6	-5.4	14.4	27.4			31.7	80	53	66	186.2	W/15		–	1016.5
Mar.	25.7	12.5	34.0	2.0	19.1	14.6			29.0	73	40	56	191.0	W/16		–	1013.6
Apr.	31.6	16.4	42.6	7.0	24.0	17.1			43.3	67	34	50	179.2	SW/16		–	1009.8
May	38.7	21.9	47.8	13.0	30.3	7.2			43.4	55	22	38	267.3	W/15		–	1005.6
June	44.1	24.4	51.0	15.0	34.2	0.0			0.0	46	16	31	316.8	W/20		–	999.9
Jul.	45.8	26.6	54.0	19.8	36.2	0.0			0.0	50	18	34	320.2	W/15		–	995.6
Aug.	45.3	25.8	50.3	19.4	35.5	0.0			0.0	53	20	36	320.6	W/18		–	997.4
Sep.	42.1	21.6	48.0	14.0	31.8	0.0			0.2	54	21	37	297.7	W/15		–	1003.[illegible]
Oct.	35.6	17.6	42.9	7.6	26.6	6.0			37.0	64	29	46	255.0	W/15		–	1011.1
Nov.	26.4	12.4	35.0	0.0	19.4	31.2			83.5	73	42	57	197.0	W/16		0.1	1016.0
Dec.	19.4	7.5	29.0	-3.0	13.4	30.8			31.7	81	60	70	169.6	W/15		0.3	1018.[illegible]

YAZD

Lat. 31° 54' " ; Long. 54° 24' " ; Elevation 1230 meters ;
Years of Observation 1953 to 1971 ; Koeppen Symbol :

Month of the Year	TEMPERATURE					PRECIPITATION				Rel. Hum			Other Data				
	Av. Max.	Av. Min.	Abs. Max.	Abs. Min.	Average	Total	Days≥1 mm	Days≥10 mm	Max. in a Day	03 GMT	09 GMT	AVERAGE	Sunshine	Wind Prev.	Wind Max.	58-70 Frost	PRESSURE
			45.0	-16.0		56.1			26.0								881.5
Jan.	12.8	-0.5	27.2	-14.0	6.1	10.7			23.2	66	38	52	153.0	NW/7		19.4	879.3
Feb.	15.9	2.2	27.2	-8.6	9.0	6.9			12.0	59	30	44	194.0	NW/7		9.1	877.5
Mar.	20.5	7.0	32.4	-5.4	13.7	8.2			12.0	47	22	35	195.0	NW/10		1.5	875.8
Apr.	25.8	11.8	36.6	0.2	18.8	10.1			15.0	46	23	34	237.0	W/11		–	875.7
May	31.9	17.1	41.2	8.0	24.2	4.7			18.6	32	16	24	278.0	NW/7		–	875.2
June	37.0	21.9	44.6	11.2	29.4	0.4			5.0	21	11	16	336.0	NW/7		–	871.3
Jul.	39.5	23.9	45.0	16.0	31.7	0.6			5.0	19	11	15	368.0	NW/7		–	870.1
Aug.	37.9	21.8	44.6	12.6	29.3	0.0			0.1	20	10	15	317.0	NW/10		–	871.5
Sep.	33.8	16.9	41.6	1.8	25.3	0.0			0.1	24	11	17	312.0	NW/7		–	875.4
Oct.	27.4	10.9	38.0	-3.0	19.1	1.0			7.3	34	16	25	298.0	NW/6		0.2	880.1
Nov.	19.0	4.2	28.4	-9.8	11.6	8.0			26.0	53	25	39	212.5	NW/6		7.3	883.5
Dec.	13.9	-0.4	24.2	-15.0	6.7	5.6			9.0	61	32	46	204.0	NW/8		19.4	884.3

KERMAN

Lat. 30° 15' " ; Long. 56° 58' " ; Elevation 1749 meters ;
Years of Observation 1950 to 1971 ; Koeppen Symbol :

Month of the Year	TEMPERATURE					PRECIPITATION				Rel. Hum			Other Data				
	Av. Max.	Av. Min.	Abs. Max.	Abs. Min.	Average	Total	Days≥1 mm	Days≥10 mm	Max. in a Day	03 GMT	09 GMT	AVERAGE	Sunshine	Wind Prev.	Wind Max.	58-70 Frost	PRESSURE
			42.8	-24.8		163.7			36.0								825.3
Jan.	12.4	-3.1	24.0	-24.4	4.6	24.7			32.5	70	41	55	196.6	SW/12		21.1	826.[illegible]
Feb.	15.2	0.1	25.0	-20.0	7.6	28.8			30.4	68	33	50	193.1	W/15		13.1	825.2
Mar.	19.2	4.5	29.0	-7.6	11.8	31.9			33.4	57	26	41	242.7	W/15		6.6	824.[illegible]
Apr.	23.7	8.5	33.8	-5.4	16.1	24.1			34.0	53	22	37	214.4	W/17		0.8	823.[illegible]
May	29.6	12.8	39.0	1.2	21.2	14.4			23.0	41	17	29	289.0	W/13		–	823.[illegible]
June	34.1	16.7	42.8	6.5	25.4	1.7			8.4	29	12	20	312.2	W/16		–	821.6
Jul.	35.8	18.3	41.1	9.0	27.0	3.2			20.6	28	12	20	308.3	W/14			819.[illegible]
Aug.	34.5	15.6	41.1	2.4	25.0	0.3			3.2	29	12	20	325.0	W/14		–	820.[illegible]
Sep.	31.5	10.9	38.0	-1.5	21.2	2.3			35.0	34	14	24	286.7	W/15		–	824.[illegible]
Oct.	26.2	5.5	33.3	-8.0	15.8	1.7			18.2	43	17	30	264.7	W/19		2.8	827.[illegible]
Nov.	18.9	0.1	27.8	-14.8	9.5	6.2			19.8	57	26	41	239.3	W/8		16.8	828.[illegible]
Dec.	14.1	-2.9	26.7	-24.8	5.6	20.0			26.0	63	33	48	221.8	W/12		26.2	826.[illegible]

KASHAN

Lat. 33° 59' " ; Long. 51° 27' " ; Elevation 955 meters ;
Jars of Observation 1966 to 1971 ; Koeppen Symbol :

Month of the Year	TEMPERATURE					PRECIPITATION				Rel. Hum			Other Data				
	Av. Max.	Av. Min.	Abs. Max.	Abs. Min.	Average	Total	Days≥1 mm	Days≥10 mm	Max. in a Day	03 GMT	09 GMT	AVERAGE	Sunshine	Wind Prev.	Wind Max.	57-70 Frost	PRESSURE
			47.8	-10.4					38.0								913.3
Jan.	9.7	-0.2	18.6	-10.4	4.7	31.4			35.6	73	50	61	140.8			9.5	911.1
Feb.	13.2	1.7	23.2	-6.6	7.4	19.7			16.8	74	47	60	160.1			7.5	909.5
Mar.	20.2	7.6	32.2	-1.0	13.7	21.5			15.0	62	40	51	180.6			0.2	907.1
Apr.	25.4	12.5	36.5	-1.0	18.9	17.1			11.0	59	34	46	203.3			–	906.6
May	33.7	18.8	42.2	11.0	26.2	9.7			7.6	53	31	42	251.8			–	905.7
June	36.9	22.7	47.6	14.6	29.8	0.3			1.0	39	24	31	284.6			–	899.2
Jul.	40.9	25.4	47.8	19.4	33.1	0.7			3.6	38	22	30	306.6			–	899.6
Aug.	40.5	24.3	46.4	18.8	32.4	0.2			0.6	36	21	28	303.2			–	900.9
Sep.	34.8	18.6	41.2	11.0	26.7	0.1			0.6	40	22	31	308.5			–	906.1
Oct.	27.5	13.4	36.6	7.6	20.4	6.2			9.6	52	31	41	219.5			–	909.2
Nov.	18.5	7.4	27.0	-1.0	12.9	17.1			38.0	65	43	54	174.5			1.2	913.3
Dec.	12.5	2.5	26.6	-5.2	7.5	9.2			7.0	71	46	58	145.4			6.0	911.4

Figure 2.5. Climatic data from the Iranian Metereological Office for A) Yazd and Kerman, and B) Kashan and Ahwaz.

2.4.1 Temperatures

The altitude and latitude of the plateau contribute to the diurnal and annual temperature variations experienced. Monthly mean temperatures show annual fluctuations varying from 25-28c, and absolute fluctuations over the year reach 70c. in some places. In Yazd itself temperatures vary from -16c to + 45c during the year, a fluctuation of 61c.

Very high diurnal fluctuations are also characteristic of the inland continental climate, and are commonly in the region of 15c in the dry summer months and may be as much as 20-25c in exceptional instances.

2.4.2 Precipitation

Yazd experiences four months of the year with virtually no rainfall, from June to September, although within the winter months up to 26mm. can fall on a single day. Although rainfall figures are generally low they do exhibit a great deal of variety over a period of years.

Precipitation varies considerably in the area, depending on the altitude and location of a site. Figures are generally low in the desert basins; Kerman, in the south west of the central desert, and Kashan on its south eastern shore, receive annual average figures of 163.7mm and 133.7mm. respectively, while Yazd receives only 56.2mm p.a. with frost occurring in six months of the year.

2.4.3 Relative humidity

Relative humidity of the area is low, peaking in January at 66% at 03 GMT. and 38% at 09 GMT. (7am. and 1pm. local time). January is the month of the highest average precipitation in Yazd and it falls below 20% relative humidity for entire months during the driest periods of the year.

Monthly summer daytime averages in Yazd, Kerman and Kashan fall below 15%, 20% and 30% relative humidity, respectively and Yazd has a monthly average mean relative humidity as low as 30%.

2.4.4 Winds

The measurements pertaining to wind speed and direction available for the area are very general. In Yazd there is a strong prevailing north westerly wind varying in force over the year from 11 to 16 knots.

2.4.5 Solar radiation

Solar radiation levels received in these desert settlements are very high, with a large number of sunshine hours per annum recorded, due to the cloudless skies of the area. In some months no cloud cover at all is recorded, and in Yazd the average number of sunshine hours per annum is 3105.5.

2.5 COMPARISON BETWEEN THE CLIMATES OF YAZD, KASHAN AND KERMAN, CITIES TO THE SOUTH OF THE CENTRAL DESERT

Kashan and Kerman are similarly situated to Yazd, south of the central desert and yet both cities have few <u>badgirs</u> and exhibit none of the proliferation of the high towers found in Yazd. Climatic reasons for this are not immediately apparent. All three cities have hot dry climates with considerable wind from the north west in summer.

Yazd is noticeably the driest climate of the three, but it is neither the hottest or the coldest, with Kerman being cooler in July and Kashan being slightly warmer.

In terms of wind incidence, Kashan alone of the three cities is unsheltered by mountain masses to the north and north west, the direction of the strong prevailing wind from the desert floor.

In Kerman the wind varies in direction from the west in the winter months to the north in the summer months as it is much stronger than that in Yazd with wind speeds of up to 17 knots in March. Seistan Province to the north of Kerman is famous for its wind of 180 days which reaches speeds of over 120 miles an hour after its unimpeede course across the deserts of central Iran. Figures are not available for Kashan but it is subject in summer to strong, dust-laden, northerly winds - the 'shomal' - blows almost unceasingly for about four months, causing twisters or dust-devils.

Kashan, despite being the hottest city of the three, has the highest humidity, twice that of Yazd which has a mean humidity of only 15% in the summer months. Kashan, surrounded by well-watered gardens, orchards and fields of the Bagh-e Finn neighbourhood, is considerably smaller than Yazd and in closer proximity to the surrounding gardens.

No outstanding feature of the general climatic data available appears to single Yazd out as a climatically advantageous location for the use of badgirs.

2.6 COMPARISON OF YAZD'S CLIMATE WITH OTHER WINDCATCHER CITIES IN THE MIDDLE EAST

<u>CHART TO SHOW THE GENERAL CHARACTERISTICS OF WINDCATCHER CITIES AND THE MAIN CHARACTERISTICS OF THEIR WINDTOWERS</u>

		TEMPERATURES				
PLACE:	BADGIRS	AV.MAX.	ABS.MAX.	MEAN	LOCTN	%R.H.
Yazd	many,big	39.5	50	35.5	U.I.P.	15
Kerman	few	35.8	41.1	27	U.I.P.	20
Kashan	few	40.9	47.8	33.1	U.I.P.	30
Isfahan	some, modest	37.0	42.0	28.0	U.I.P.	28
Tehran	few	37.0	43.0	29.5	U.I.P.	45
Baghdad	many, small	43.9	50	35.5	Interior	23
Cairo	big	35.8	45.5	35.5	Interior	30
Ahwaz	big	45.8	54	36.2	I.C.P.	34
Hyderabad	many				I.C.P.	
Basra	few,modest	39.8	51	33.8	C.P.	49
Bushire	some,big	35.0	44.0	32.0	Gulf	73
Bahrain	some,big	37.0	44.0	33.0	Gulf	68
Kuwait	few,modest	39.0	48.0	34.5	Gulf	43
U.A.E.	some,big	38.0	47.0	33.0	Gulf	64
Jidda	none	37.0	42.0	32.0	Coast	53
Riyadh	none	42.0	45.0	34.0	I.U.P.	27

LOCTN= location: U.I.P.= upland interior plateau
I.C.P.=inland on coastal plain
C.P.=coastal plain

(figures taken from the Iranian Meteorological office and Pearce and Smith, The world weather guide, 1984)

2.61 Comments on the general distribution of badgirs in the Middle East

As suggested by Fathy (1986, p.59) the cities, such as Baghdad (and Kashan perhaps) with very hot (av. mean maximum above 40c) climates have few, or small windcatchers, probably serving basements usually, if the mean July relative humidity is below 30%. Riyadh appears to be an exception.

In areas where the relative humidity is very high, even with mean maximum temperatures exceeding 40c, the wind towers are large, presumably to relieve climatic stress (Koenigserger et al., 1974,p.217).

It appears that within the wider framework of the climate of the Middle East Yazd does stand out as having an unusual climate in that combined with being hot (not excessively hot with a av.max temp above 40 c) it is also the driest climate listed. Is the key to the suitability' of Yazds climate in the low relative humidity or do the temperature ranges of the summer climate play a role in the proliferation of badgirs in the Yazd region?

This question may be answered by investigating the badgirs in the Yazd region to see if local variations in temperature or humidity of the summer climate affect the distribution of bagdirs in the area. This is the subject of chapter 3.

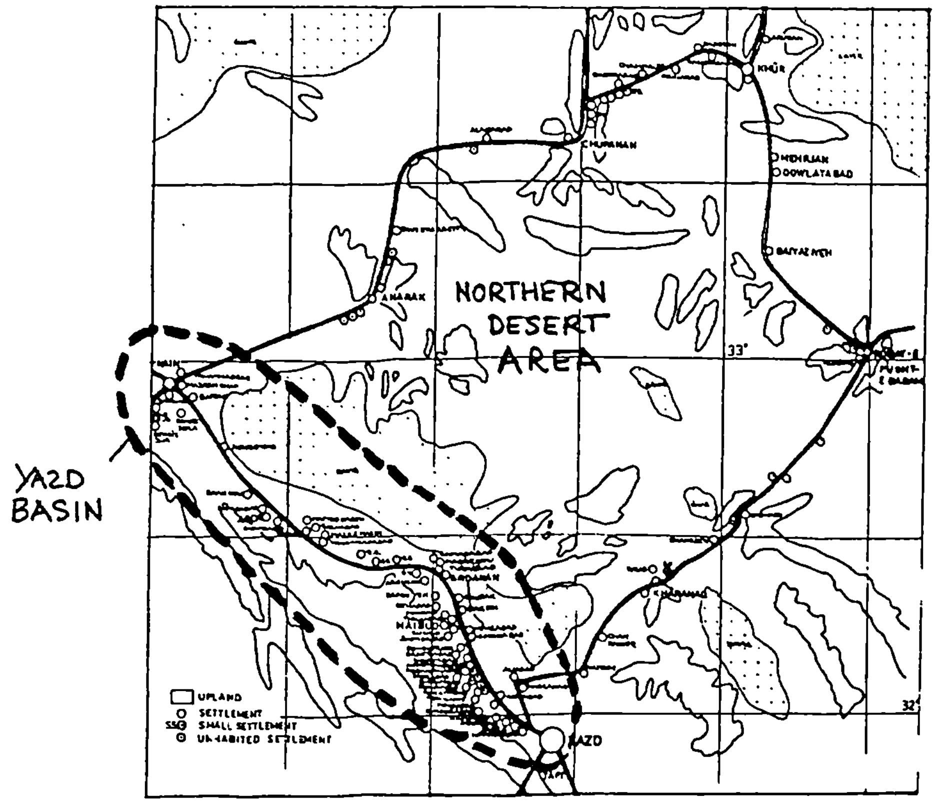


Figure 3.1. Map of the survey area showing the road through the Yazd Basin and the northern desert loop.

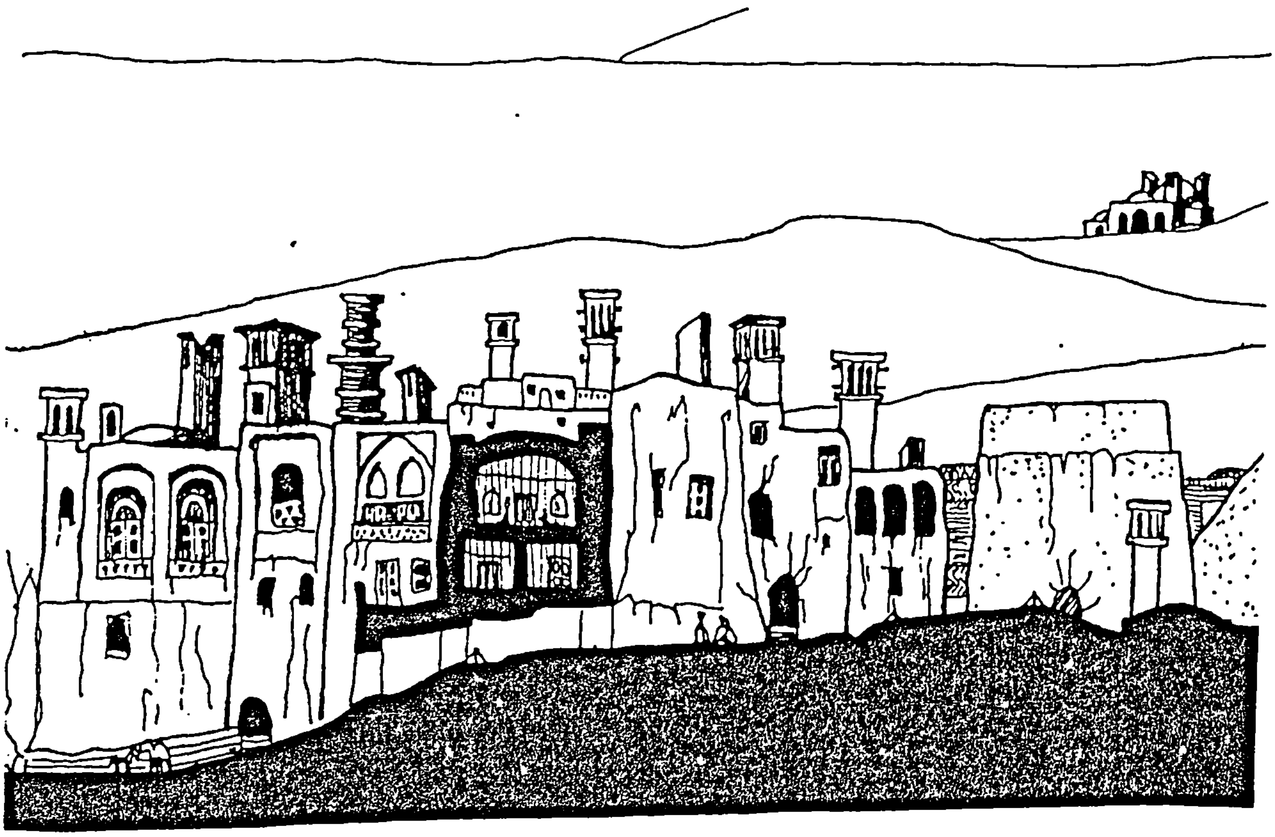


Figure 3.2. Sketch section through the citadel town of Kharanaq, showing the windtowers rising above the dense ant-hill of dwellings.

CHAPTER 3

SETTLEMENTS, HOUSES, CLIMATE AND THE DISTRIBUTION OF BADGIRS IN THE PROVINCE OF YAZD

3.1 INTRODUCTION

The hot dry climate of Yazd may be assumed to be suitable, to some degree, for the use of badgirs to judge by their proliferation in the area. In this chapter the importance of climate - temperature, humidity and prevailing wind - are considered in relation to the distribution of badgirs in the Yazd region, and against a background description of the settlements and buildings on which they are found..

The chapter is arranged in five parts, firstly a description of the study area and its settlements; secondly a description of the badgir types in the area; thirdly a description of the buildings on which they are built; fourthly, the distribution pattern of badgirs in the study area; and fifthly, an investigation of the distribution pattern of badgirs in relation to the micro-climates of different areas in the region.

3.1 THE STUDY AREA IN THE YAZD REGION

The areas in which the rural badgirs of the Yazd region were studied lies to the north, north-west, and west of the city of Yazd (figure 3.1).

3.1.1 The field survey

The data on the badgirs and buildings of the Yazd region included in chapters 3 - 5 was collected during three village surveys carried out between 1975 and 1978, in which buildings and badgirs of the settlements flanking the two main highways of the province were recorded.

The first area surveyed skirted the main road between Nain and Yazd, running through the centre of the Yazd basin. Today this road is a two to four lane highway which runs through the prosperous agricultural areas of Ardakan and Maibud. Much of the population in the Yazd basin lives in large to medium sized settlements, either surrounded by cultivation, or in one of the three large oases of the area, those of Yazd, Ardakan / Maibud or Nain.

The second string of villages surveyed are situated beside the northern desert loop' road from Nain, to Yazd via Anarak, Khur, Robat-e Pusht-e Badam. This route is in many places little more than a dirt track traversing sand, stone and mud deserts of the Kavir. The occupations of the inhabitants of this remote area are largely mining, herding goats, sheep and camels, date cultivation, and posts in administration and service industries, in particular those involved with trade and communications. The bulk of the population live in the large oasis settlements of Khur, Baiyazeh and Mehrjan or the mining town of Anarak (Wulff, 1973, p.14-16)

3.1.2 Settlements of the Yazd region

The Yazd Basin has been well documented by Michael Bonine, a geographer, in his Central Place study of Yazd and its Hinterland (Bonine, 1980,pp.26-57).

In November 1966 the census recorded a population of 281,1548 for Yazd Shahrestan (Bonine,1978, p.52).

AREA	POPULATION	PERCENTAGE OF TOTAL
Yazd city	93,241	33%
towns > 5000	52,815	19%
villages < 5000	135,102	48%
TOTAL POPULATION	281,158	

48% of the population live in villages of less than 5000 people. Of these:

40%	live in settlements with	1000 - 5000 people
20%		500 - 1000
20%		100 - 500
20%		less than 100 people

Bonine divided the settlements of the Basin into six towns, 15 primary villages, 62 major villages, 60 minor villages and 19 hamlets. His findings emphasise that up to 50% of the settlements in the Yazd basin could be deemed to be moderately large settlements with populations of more than 100 people.

The survey of 131 villages completed by this author in the Yazd region highlighted the dramatic difference between the settlements of the Yazd basin and those along the northern desert route. In the Yazd Basin 80% of the settlements had a population of more than 100 inhabitants, about 20 households. Of the settlements on the northern desert route 79% had less than 150 households and 64% less than 10 households, and a remarkable 50% are abandoned or only temporarily occupied during the year.

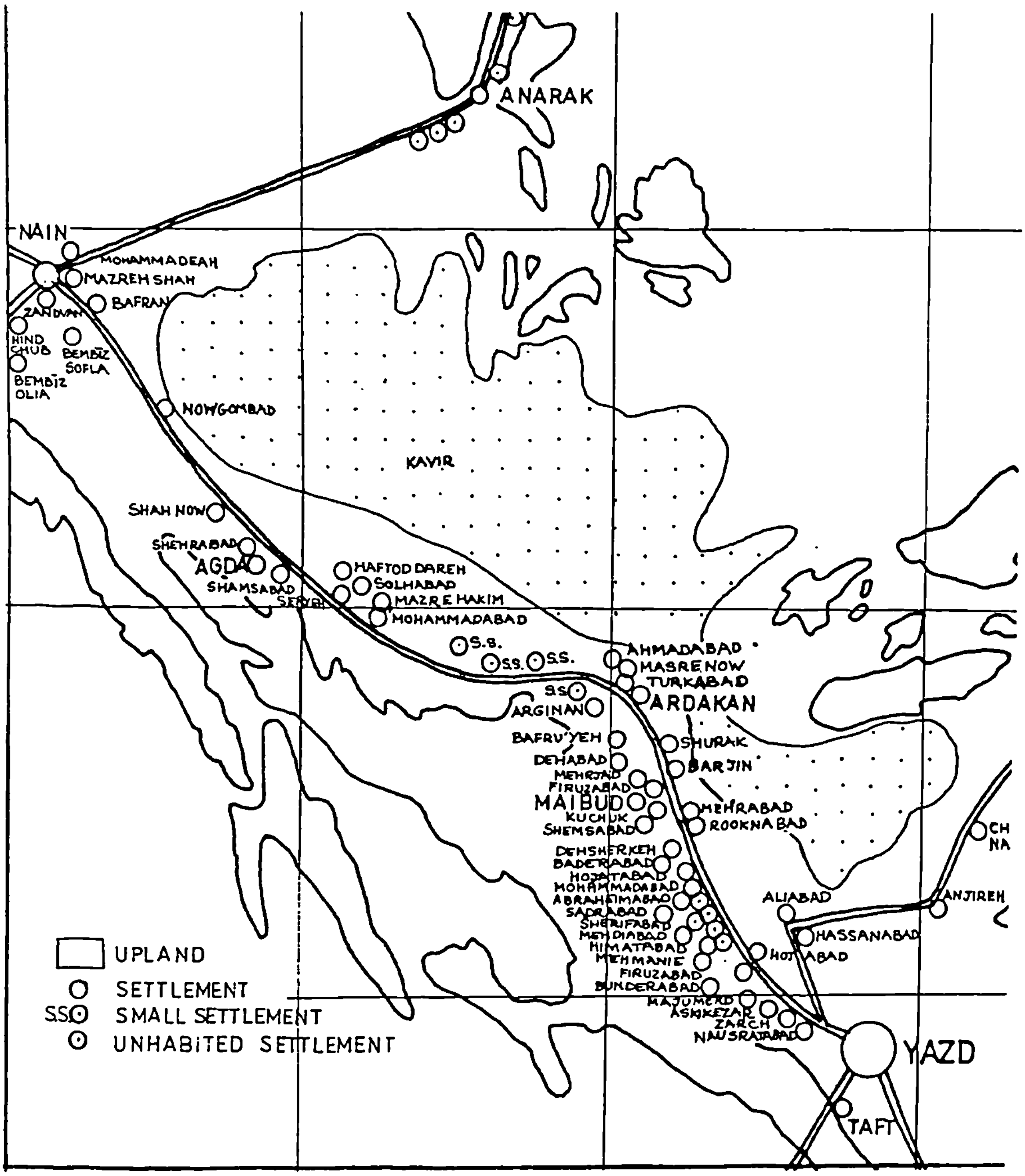
3.1.3 Form of settlements in the area

Settlements in the Yazd region are most commonly compact, clustered around the water source, either a pool or an open water channel. Very occasionally a settlement is linear, situated along a surface water channel fed by qanat, usually beside the main road. The use of water from the qanat, along the channel, is strictly controlled (Roaf, 1988), and there is a preference for a location closer to the drinking water supplies in the settlement.

The network of open water channels to a degree determines the location of gardens, which are built on as the village expands (Bonine, 1980, pp.193-219, and Bonine, 1979, pp.208-224).

The majority of the settlements of the area are composed of houses, with a scattering of service buildings towards the centre. They cannot necessarily be defined as nuclear settlements, as services are scattered along the length of the main water channel or road.

In the larger villages these public buildings include a mosque, public bath (hammam), flour mill (asiab) water cistern (abambar), public open squares (husseineah) and shops(dukan).(Bonine, 1978, pp.) A number of the villages have surrounding defensive walls and defensive towers.



3·3 B) Enlargement of Yazd basin showing settlements.

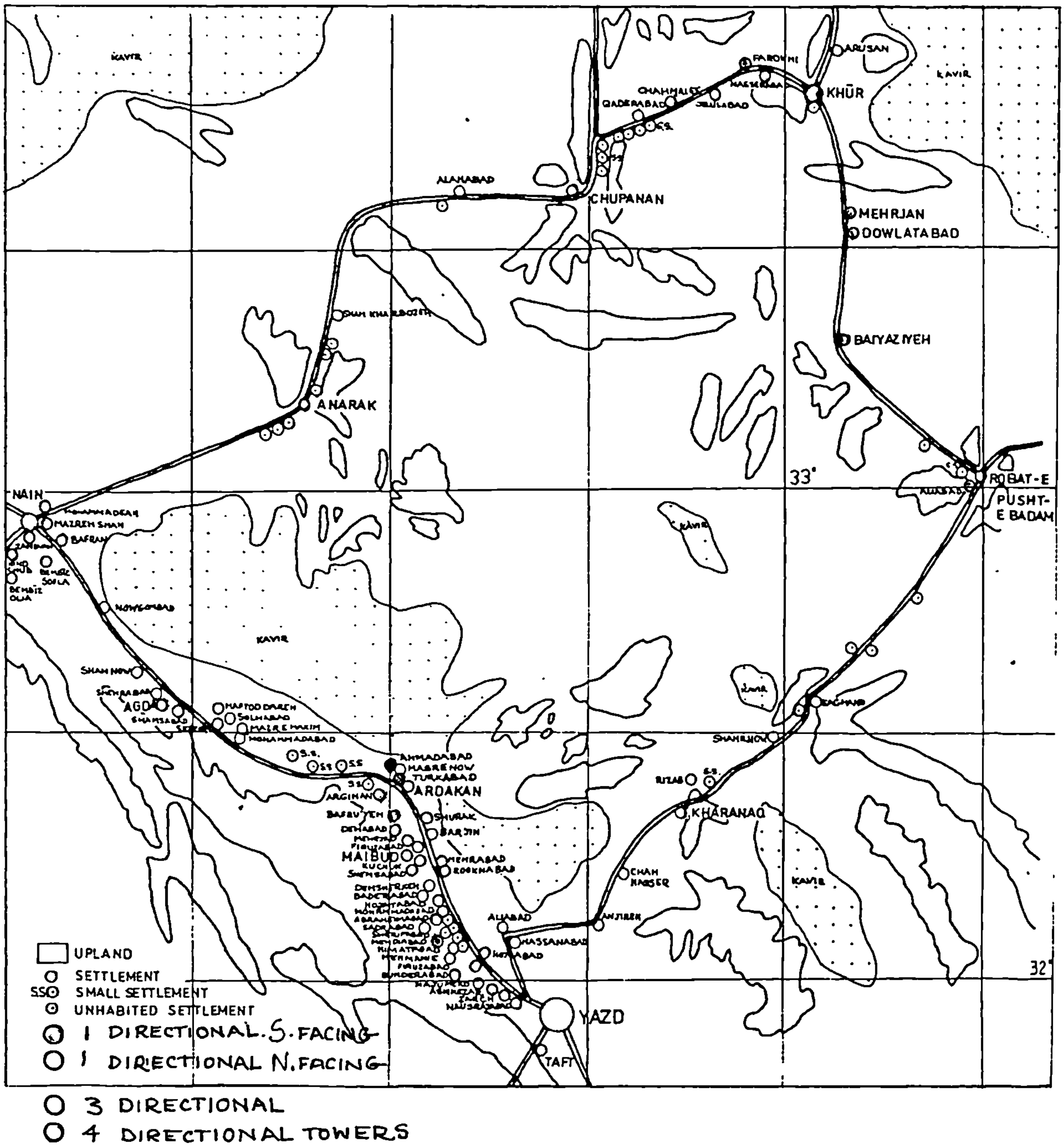


Figure 3.3.A) Map showing the distribution of the main badgir types in the survey area.

Occasionally rural settlements consist of a single palace' complex, described below in 3.3.5 4). A number of villages have had surrounding walls built around them and in the most extreme situations, in the exposed isolated settlements in the north of the province, the necessity of constricting the population within the walls has led to the upward expansion of the village, creating citadel settlements such as Mehrjan, Baiyazeh, Khoranaq and Dowlatabad.

A good example of a citadel settlement is Khoranaq (figure 3.2) where the routes of the village take the form of the branches of a tree, winding and twisting up towards the light. At the end of each branch is a residence and the core of the mud brick mountain is occupied by stables and store rooms. The private open space of each house is restricted to tiny courtyards, balconies and roofs with parapets (S.Roaf, in press). There are many badgirs on these high citadel settlements.

In conclusion it is suggested that the three main settlement forms of the area are Compact, Linear and Citadel, of which the two former types are found in the north and south of the are while the main Citadel settlements of Khoranaq, Dowlatabad, Mehrjan and Baiyazeh are isolated towns in the north of the area.

3.2 RURAL BADGIR TYPES IN THE YAZD REGION

Figure 3.3 shows the distribution of the four main types of domestic badgir recorded in the area.

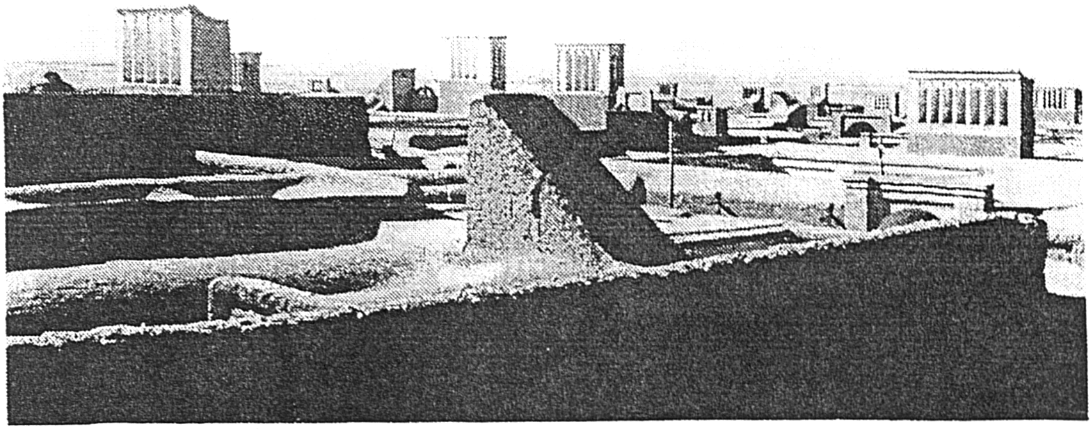


Figure 3.4. Badgirs on the roofs of *Chupanan*. (Beazley, 1975)

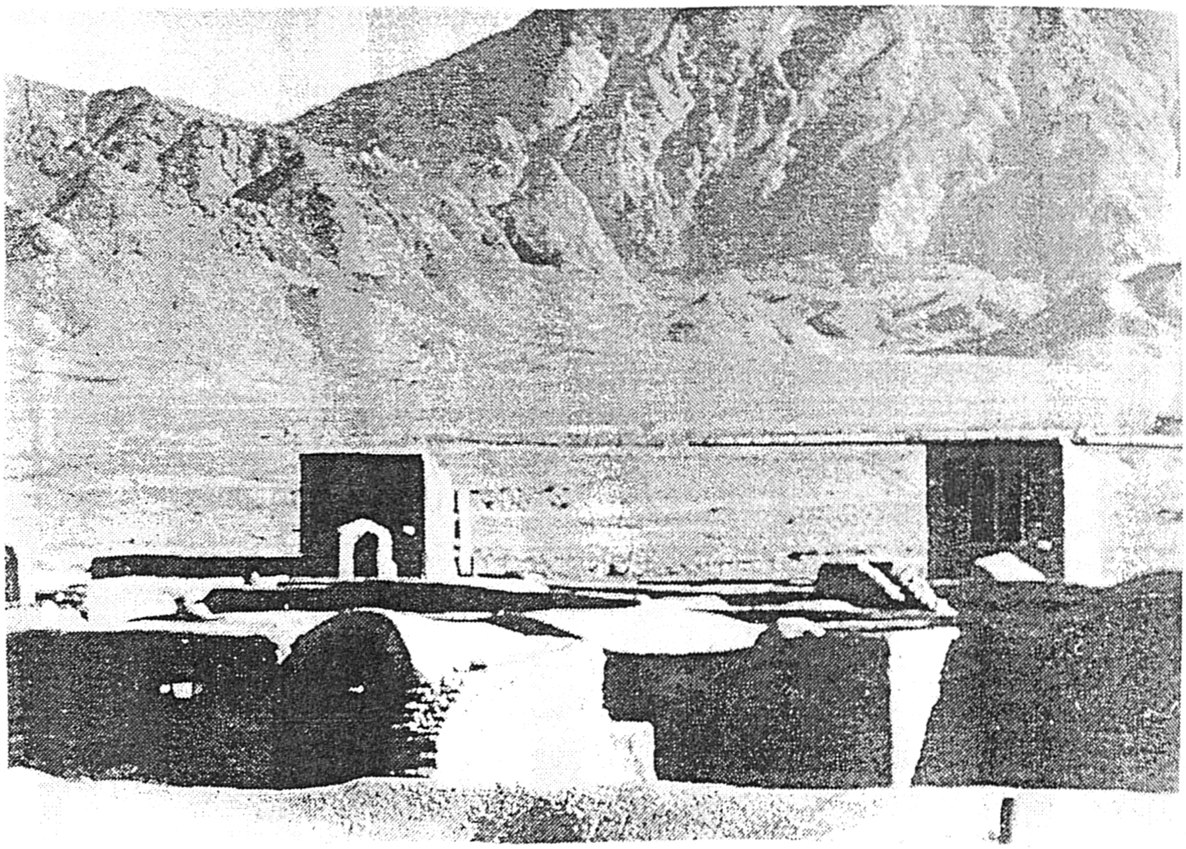


Figure 3.5. Badgirs on the roofs of Robat-e Pusht-e Badam.

The four types are:

1) uni-directional badgirs facing in one direction, towards the prevailing winds, to the north (figures 3.4 and 3.5)

2) uni-directional badgirs that face away from the prevailing wind

3) three directional towers, facing east, west and north

4) four directional towers (figures 3.6 and 3.7)

Where a settlement has roughly equal numbers of two types their presence is noted, but where one type predominates that type only is shown. The incidence of badgir types was visually estimated except where only a few were found on settlements. These were counted.

The two types most commonly found in the region are the simple uni-directional badgir, with one to seven vents facing generally towards the prevailing winds from the north, north-east or north-west, and the badgirs that face in four directions. The latter may have rectangular internal air shafts formed by partitions placed at right angles to each other and to the outer walls of the badgir, or alternatively have a square tower divided into four equal shafts, triangular in cross-section, by diagonal partitions across the tower (see 7.3.4).

Unusual badgirs are found in a number of villages including several with small hexagonal and octagonal shafts in Nausratabad some 8 kms west of Yazd.

Figure 3.6. Badgirs above the 20th century town of Anarak.

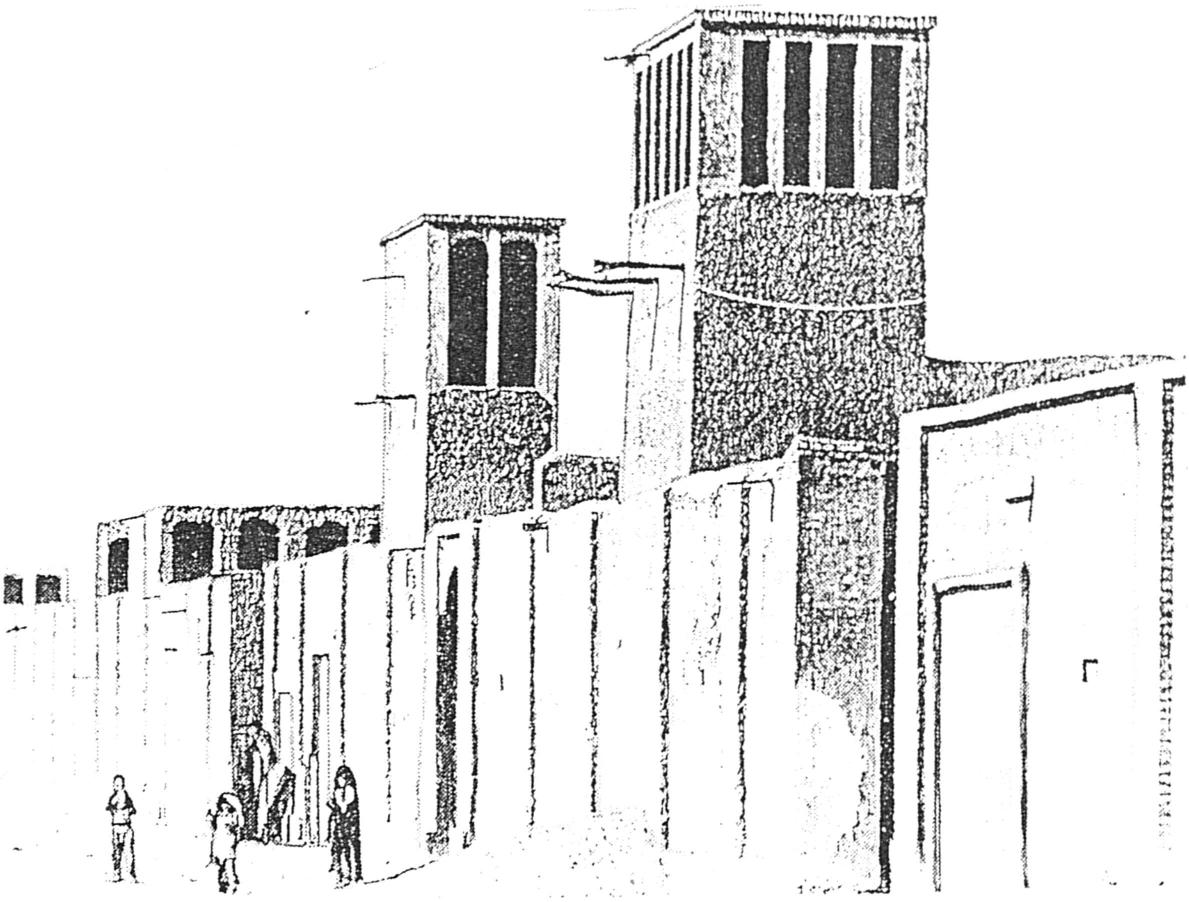


Figure 3.7. Badgirs on the roofs of Chah Malek.

3.3 BUILDINGS WITH BADGIRS IN THE YAZD REGION

Badgirs are most usually found on five types of buildings in the province: water cisterns, caravanserais, mosques, mines and houses.

3.3.1 Water cisterns

Numerous examples of badgirs on water cisterns are found in the province and elsewhere on the plateau. In Yazd province, cisterns are served by one to five badgirs. If a cistern has a single badgir, it is generally placed over the apex of the dome of the cistern, and on domes with two to five badgirs they are generally placed equidistantly around the base of the hemisphere of the dome. The towers may have vents facing in one to four, six or eight directions. The badgirs around some cisterns have single vents but each individual tower, if there are three or four towers around the cistern, faces in a different direction (figures 3.8 and 3.9).

Towers with vents in more than one direction occasionally have no central dividing partition so the tower shaft works on the Venturi principle with the air moving across the neck of the shaft, thus drawing air up from the interior of the cistern. The one example of this tower type in Mohammadiyeh, outside Nain, was paired with a second tower on the opposite side of the cistern with a badgir that had vents facing in four directions and had internal partitions. Thus one shaft channels air into the cistern while the second tower draws air out of it.

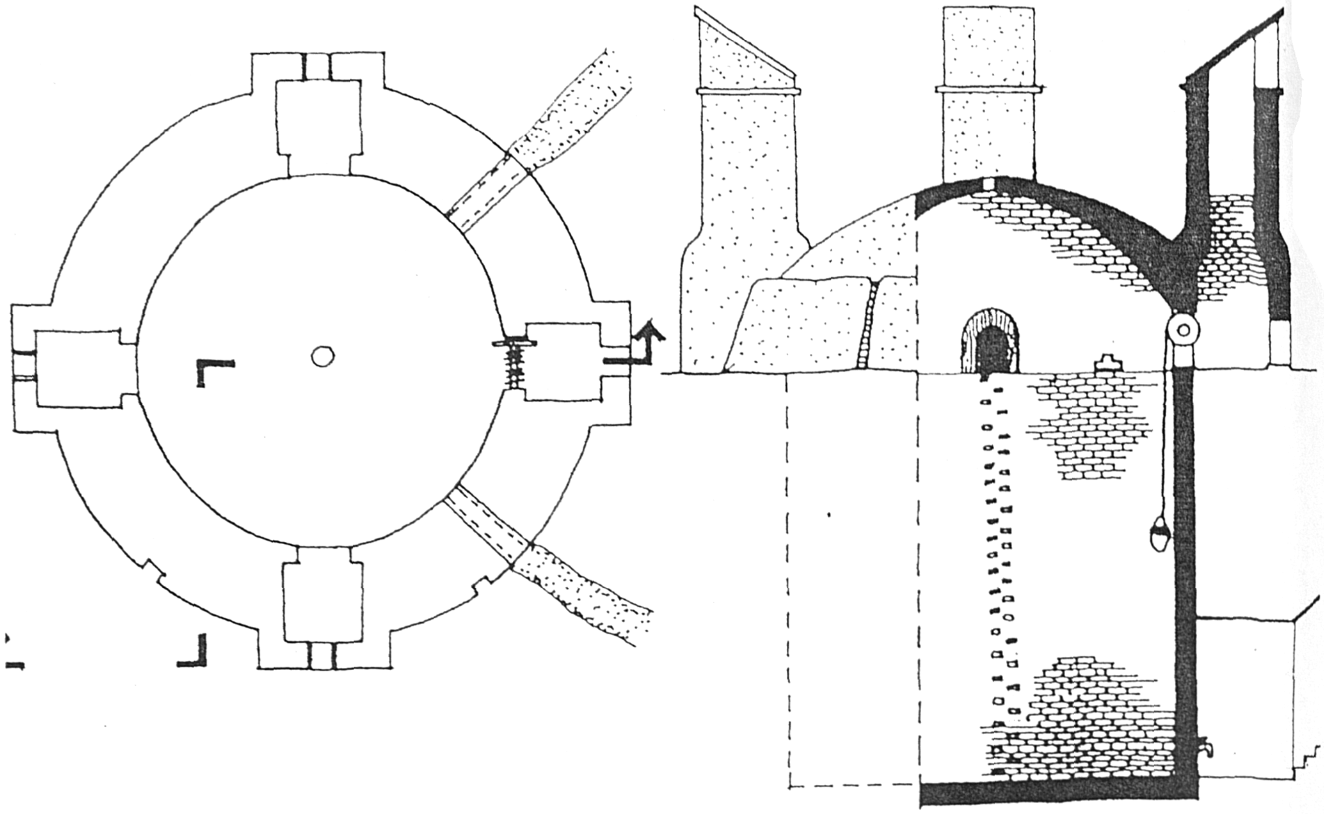


Figure 3.8. Plan and section of a four badgir water cistern fed by a qanat chanel, with a bucket on a pulley for cleaning and steps to a tap at the base of the tank from which water is collected.

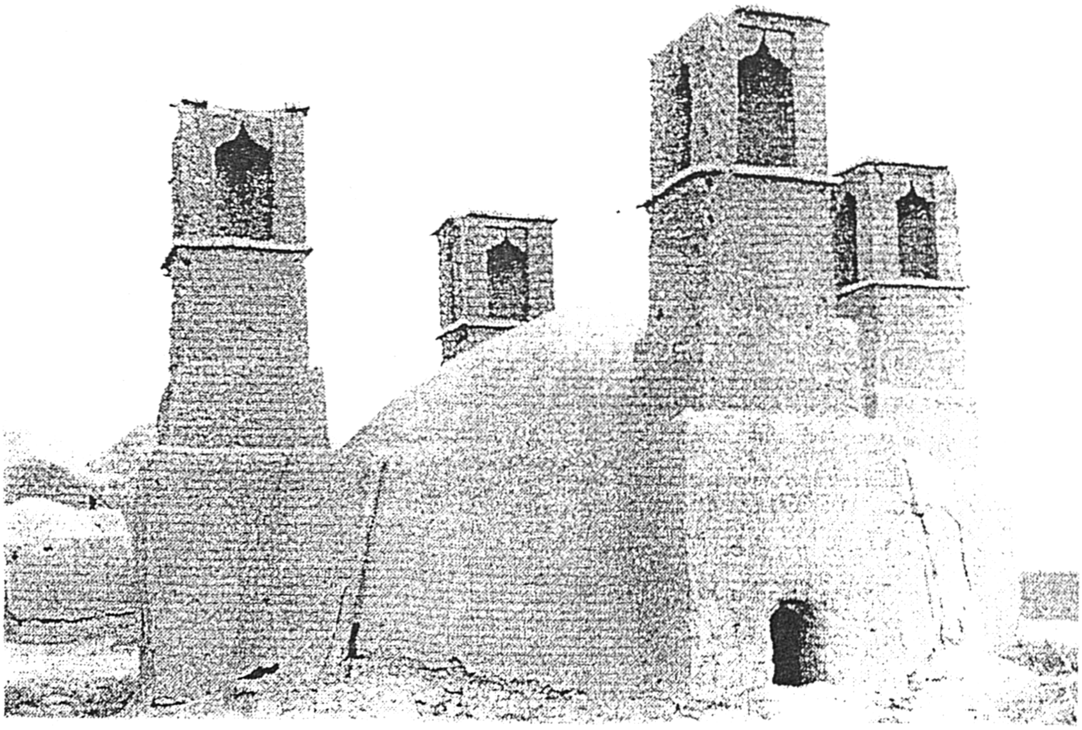


Figure 3.9. Photograph of the cistern at Nausratabad.

A common arrangement of badgirs around a cistern, particularly in the Ardakan region, is that of three equidistantly spaced towers with single vents facing away from the cistern. This arrangement ensures the passing of air over the water, whichever direction the wind is coming from.

Uni-directional badgirs with angled roofs, such as are found on many cisterns, particularly of the Ardakan region, are called locally Kermanis' (figure 3.10). Occasionally this term is taken to mean those towers of this type that face south east towards Kerman only (see 7.3.3).

The badgirs on cisterns perform three vital functions; cooling the water, providing ventilation without direct solar radiation, and oxygenation of the water. They chill the water by evaporative cooling. Differences between summer mid-day external air temperatures and the temperature of cistern water have been recorded as great as 22c. So effective are the cisterns in chilling water that they are still widely used in the villages and the city of Yazd because of the coolness and quality of the water they provide. Badgirs enable air to enter the cistern while minimising the entry of light and dust, both of which are potential contaminants for the water within. The constant and perceptible air stream that is passed over the water is also important in oxygenating the water (Beazley and Harverson, 1982, pp.39-45).

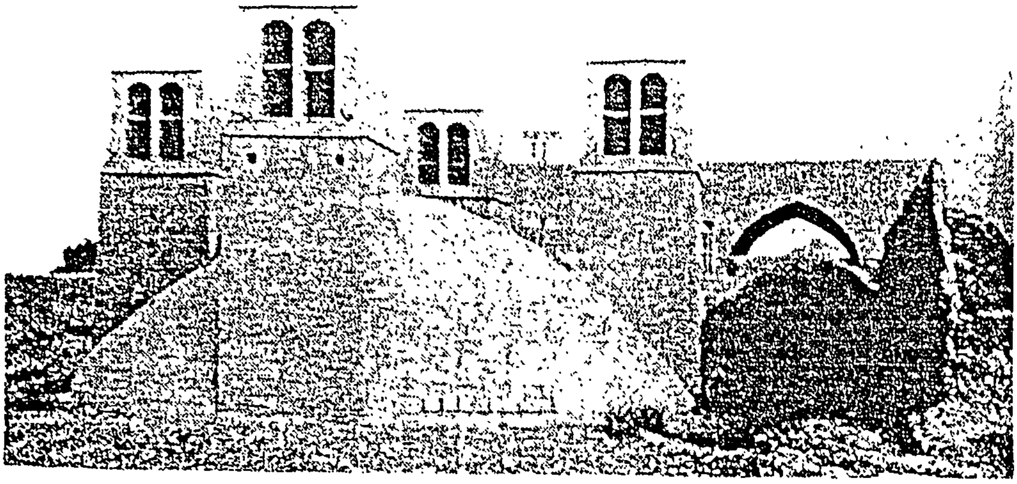


Figure 3.10. Photograph of the water cistern at the Bagh-e Khan, used by the residents of the garden and also by travellers on the Taft road. (Fathy, 1986, fig.68)

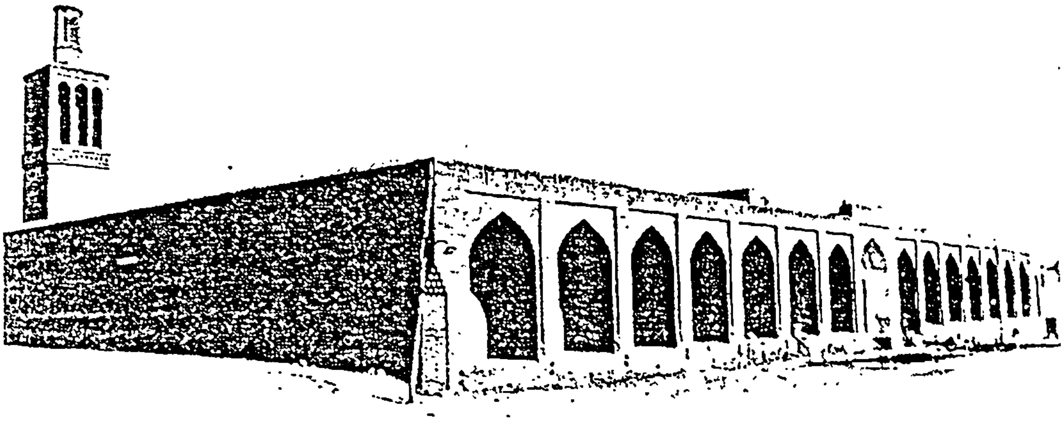


Figure 3.11. The caravanserai at Agda with two-storey badgir over the south aivan.

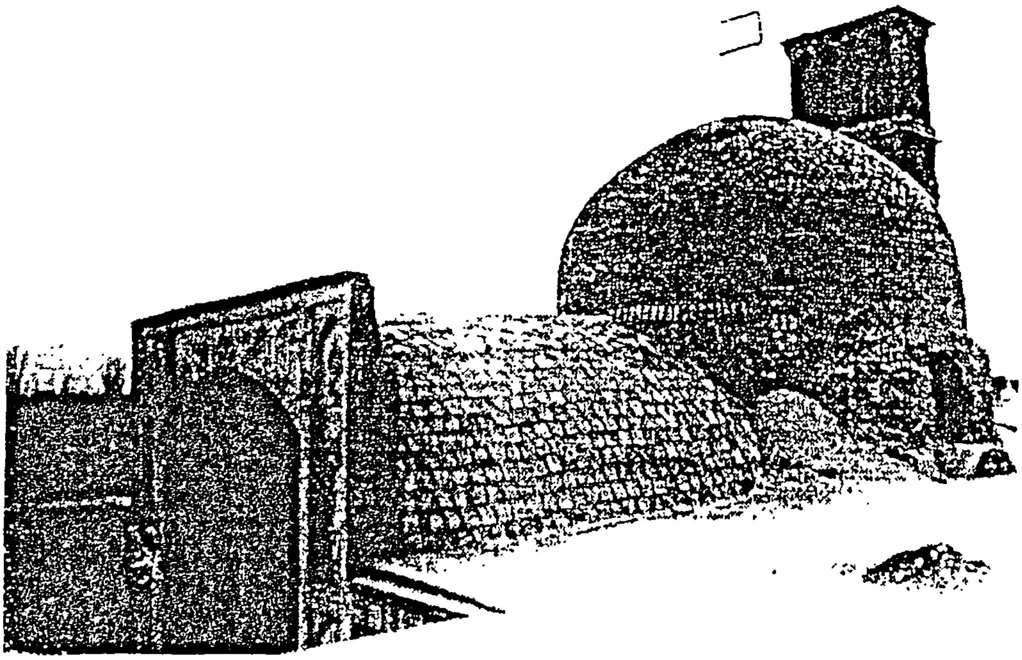


Figure 3.12. The single badgir behind the dome of the mosque of Haggi Malik, Bafru'iyya, near Maibud. This badgir appears later than the 15th mosque dome as it is appended to the dome rather than being built as an integral part of it.

3.3.2 Caravanserai

Badgirs were built on several caravanserai in the area and two notable examples are at Agda and Aliabad. On both caravanserais the badgir is built over the central room on the south wall of the courtyard which serves as the principal summer living area.

The Aliabad caravanserai was built in c. 1800:

> Illahabad ...; this village is situated in the desert, has a new Surae, and supplies are procurable. (Pottinger, 1816, p.420)

The serai has a four aivan courtyard with a hoz khaneh, a pool room, in the centre of the south wall. This is a large summer living room with a pool in the centre around which travellers sit or sleep in summer. At the rear of this room on the south wall of the serai is the stump of a four-directional badgir.

The serai at Agda was noted in 1880: (figure 3.11)

> Agda is remarkable for its noble caravansarai and abambar, built by a merchant of Rasht thirty years ago, and for a large spring in a hollow under the fort. (Stack, 1882, vol.II, p.8)

But Captain Christie who passed through the area in 1810 noted:

> Oogda is a small village of about one hundred and sixty houses, with a good Surae,.. (Pottinger, 1816, p.422)

Stack is probably describing a later building. The badgir at Agda was built over the summer living room and is unusual in that it is a two story badgir with a rectanglar plan for the lower tower and an upper, narrow hexagonal tower.

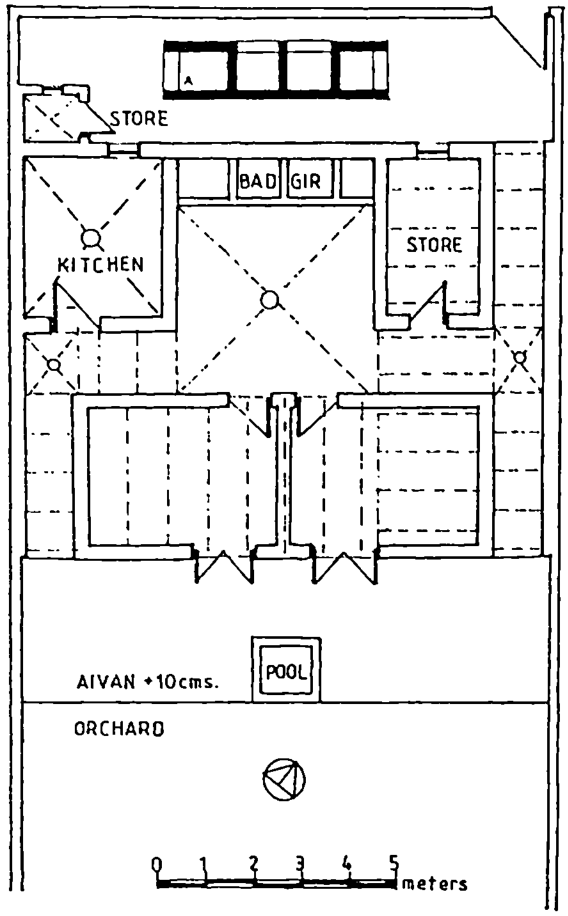


Figure 3.13. Plan of the compact house at Bunderabad, with A) inset showing plan of badgir at vent level.

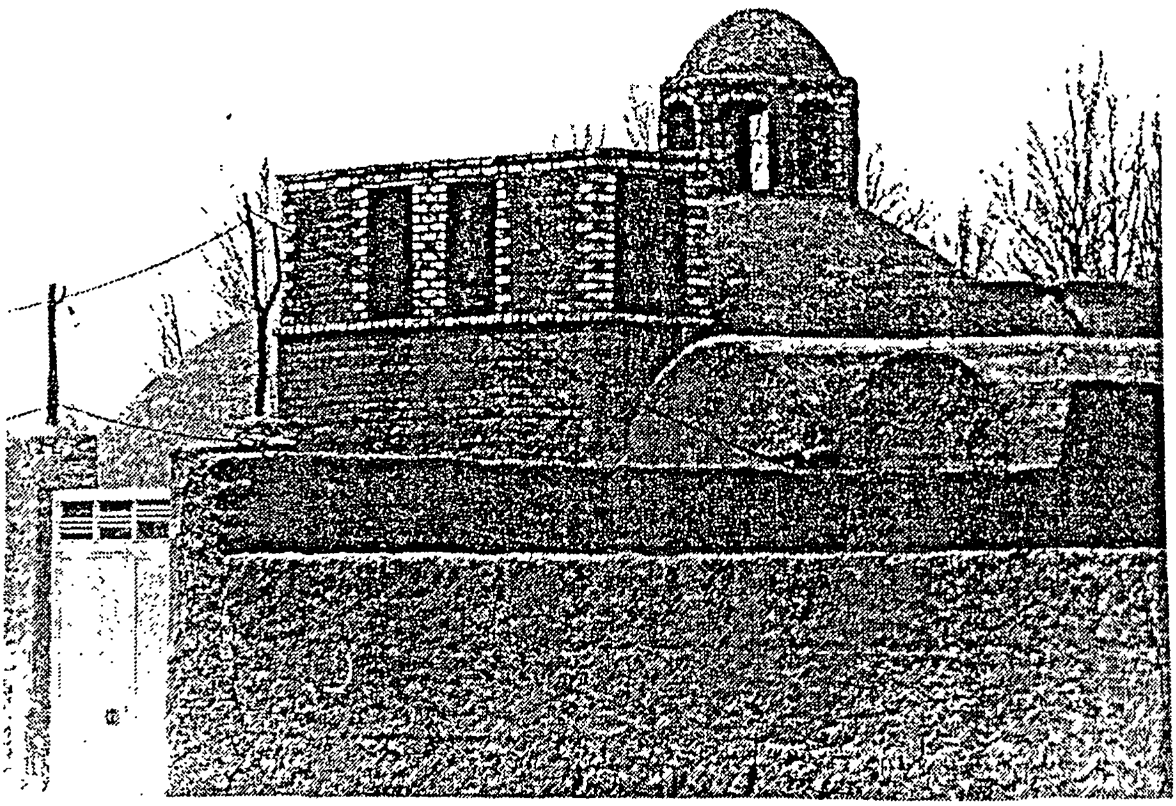


Figure 3.14. Photograph of the house at Bundarabad.

3.3.3 Mosques

On mosques in the Yazd province badgirs were built in two positions, and have been since the Timurid period (15th century). On the Timurid mosque of Firuzabad a pair of uni-directional badgirs were built directly above the upper storey prayer balconies flanking the central prayer chamber of the mosque. On the Timurid mosque of Kuchuk, a single uni-directional badgir was built directly above the mihrab, so passing air from the tower above worshippers into the body of the main prayer hall. Similarly located badgirs are found in the mosques of Amir Chaqmaq and Bafru'iyya (figure 3.12).

3.3.4 Mines

Hans Wulff, in his book on the Traditional Crafts of Persia, (Wulff, 1973, p.15) gives the following description of badgirs on mines in the province:

> Still another way of getting fresh air into the mine was the building of so-called wind catchers (bad-gir) on top of an old shaft outlet, thus forcing the air from the continuously blowing desert wind into the mine. The copper mountain of Anarak is studded with these wind catchers; some of them are over 60 feet high.

3.3.5 Domestic badgirs

The majority of badgirs in the area are on houses. The possibility that regional differences in house types may influence the distribution of rural badgirs will be briefly investigated by outlining the findings of the rural survey on house types and their distribution in the area.

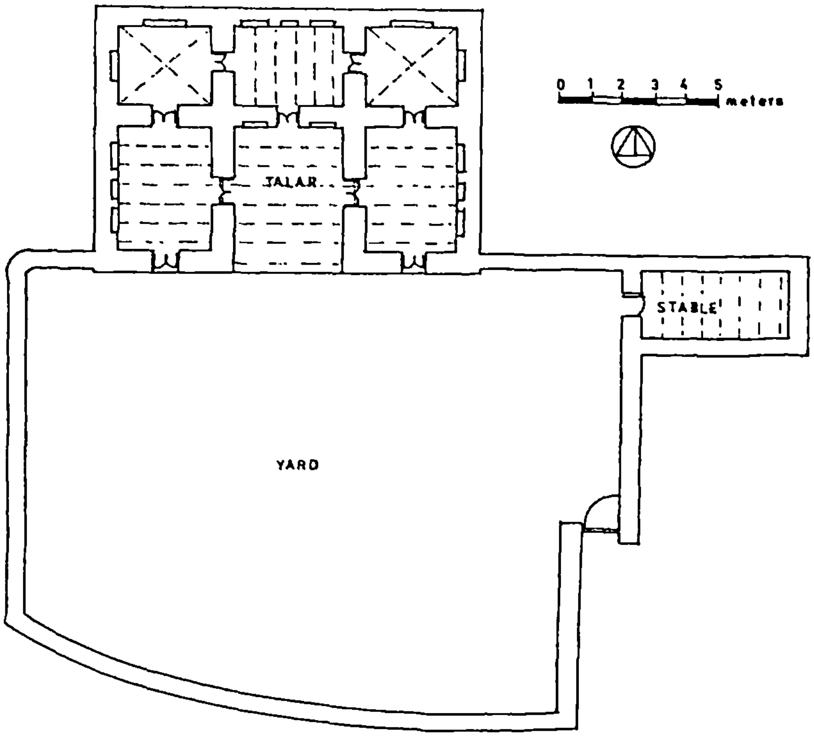


Figure 3.15. Plan of the compact house at Aliabad.

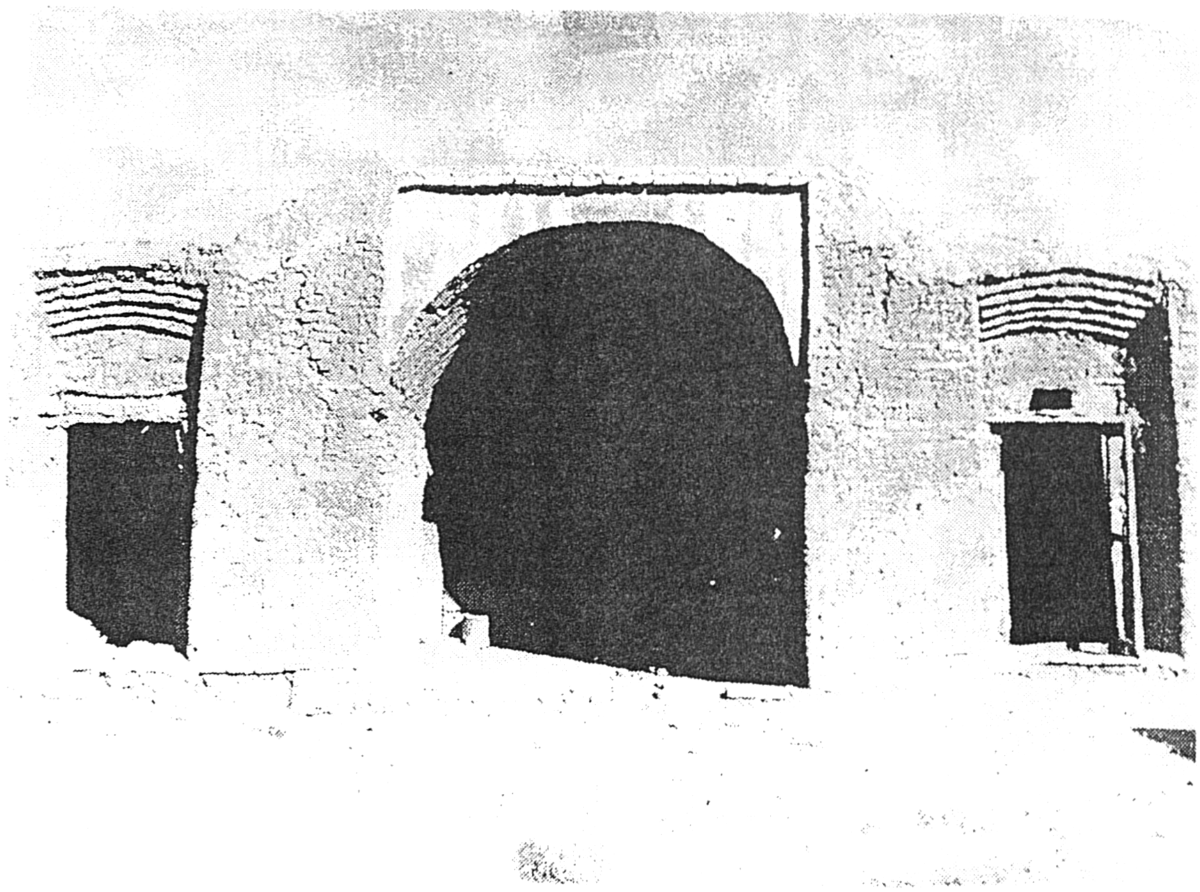


Figure 3.16. Photograph of the house at Aliabad.

On the survey five main house types were identified:

1 - The COMPACT house.
2 - The COURTYARD house.
3 - The COMPOUND house.
4 - The GARDEN PAVILLION.
5 - The ZOROASTRIAN house.

The main rooms of such houses are:

1) Winter living rooms - one to two rooms with glass doors and /or windows facing south.

2) Summer living rooms - either open to the north with high vaulted ceilings, or facing north with French windows onto the courtyard. On these rooms are built the badgirs.

3) Store rooms - for food, utensils or clothing. Usually placed in the north-west or north-east corner of the house.

4) Kitchen - This may be an internal room in the same position as a store or a separate building near the house. Much cooking is done in the open.

5) Lavatory

6) Bathroom - these are unusual if not absent from the village houses as the family either wash in the pool in the yard, or, more commonly, in the local village public bath house.

Each house type will be briefly described and illustrated below. Only a few of the largest village houses have basements, except in the Zoroastrian villages.

1) The compact house

The compact house has no internal courtyard but has an adjacent yard or garden surrounded by a high mud or mud brick wall. It is generally a rectangular building, built on a 3x3 or 3x2 grid (Figures 3.13 to 3.16) containing 5-6 rooms. It appears to be based on a tripartite plan. It is oriented with the summer rooms on the north side, and the winter rooms facing south.

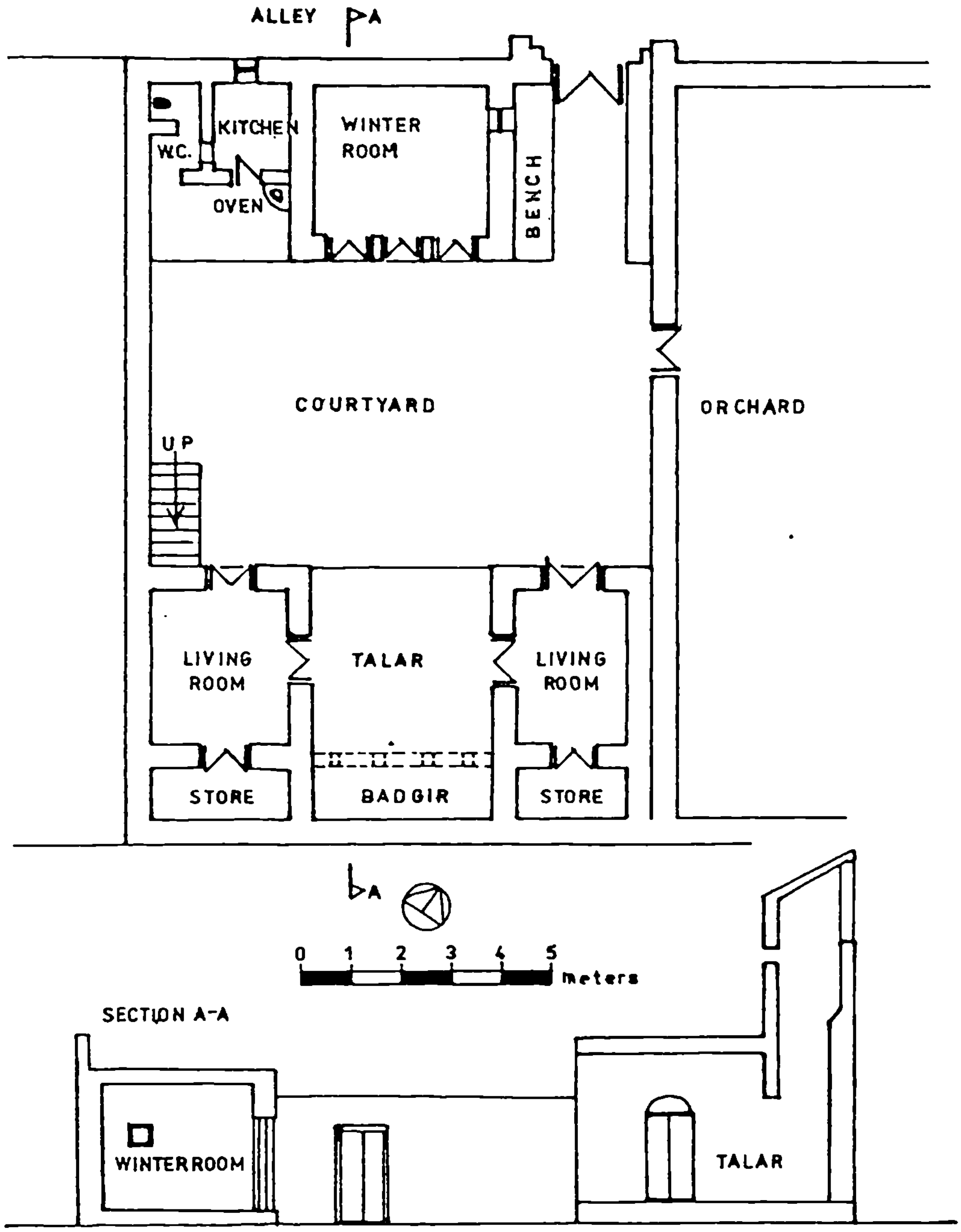


Figure 3.17. Plan of a courtyard house at Maibud with section through badgir and summer talar.

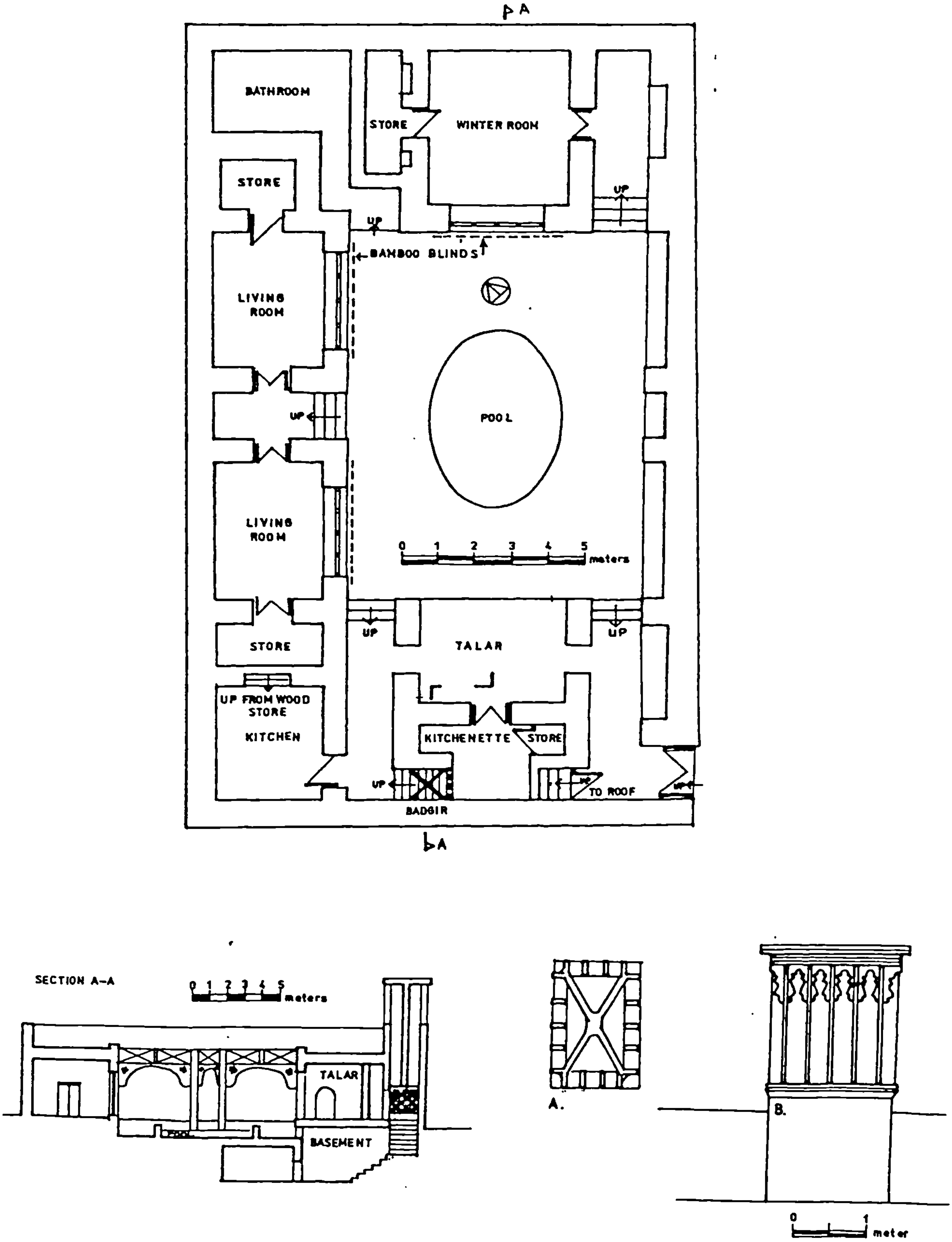


Figure 3.18. Plan and section of a courtyard house at Mohammadiyeh, with A) plan of badgir at vent level and B) south-west elevation of the badgir.

2) The courtyard house

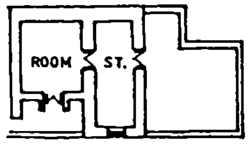
The courtyard houses of the Yazd region are generally built to a very rigid blue-print. Essentially the houses are tri-partite in form and elevation, with three rooms on each of the courtyard facades (figure 3.17 and 3.18). There is a single row of rooms around the courtyard. In its simplest form there may be rooms along the north and south walls of the court only. The north and south facades of the courtyard have a large central room flanked by smaller living or service rooms.

In the corners of the house the kitchens, store rooms, bathrooms, corridors and stairways are placed.

Two courtyard houses, both from the Yazd Basin, have been chosen to illustrate the wide variety in size and quality of courtyard houses with windcatchers built in the villages.

3) The compound house

The compound house has no internal formal courtyard but is built around a compound yard or garden. Its basic form is a high walled enclosure against which a number of single rooms are built (figure 3.19). Depending on the size of the yard, and the number of rooms around it, the yard may be partially or entirely surrounded by rooms and so may resemble a courtyard house. However these dwellings of randomly arranged living and service rooms bear little resemblance to the formal, tripartite courtyard house of the area and yet both are lumped together under the term of courtyard house by many authors who do not consider the very different



A.

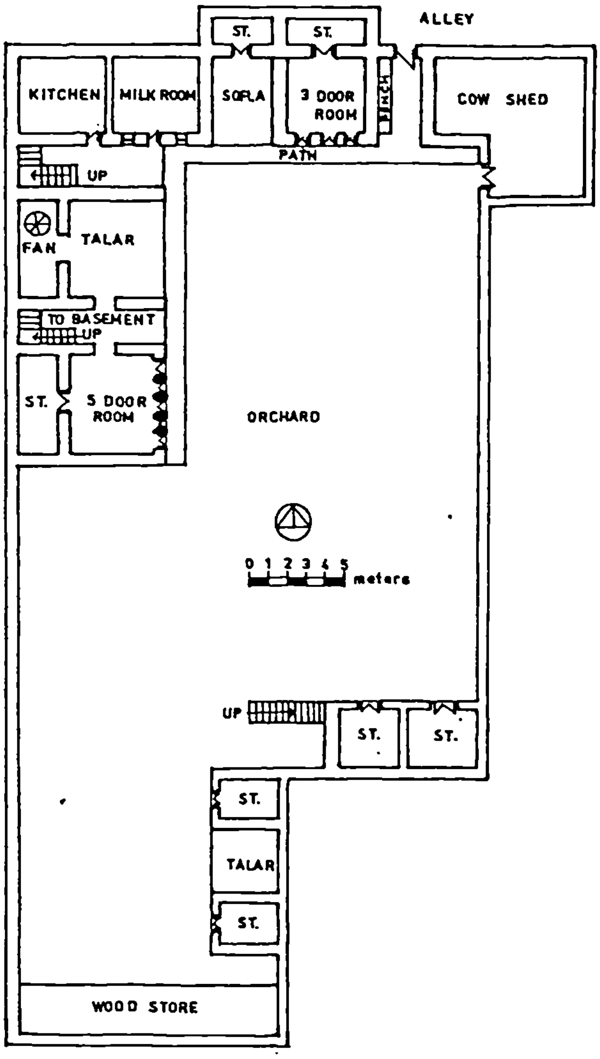


Figure 3.19. Plan of a compound house at Nausratabad, with inset A) showing plan of first floor rooms above entrance..

conceptual and functional nature of these building types.

The compound house is found throughout the Near and Middle East, and in the Yazd district compound houses are commonly built in the upland villages to the south and east of Yazd in the yeilak, or summer quarters. Here there are numerous gardens to which the Yazdis resort during the hot summer months (see 10.2.1). The garden houses are usually situated near the door of the garden and consist of a string of rooms around one, two or three walls of the compound.

The number of rooms around the walls of the compound may reflect the length of time the compound has been occupied, the prosperity of the occupants of the house, and/or the size of the extended family that occupies the house, with each new married couple building on a separate sleeping room.

4) <u>Garden pavilions</u>

Wealthy Yazdis occasionally build garden residences in villages which they own and where the summer may be comfortably spent. A small village is often associated with a garden and provides services for the residents. The main residence consists of one or more garden pavilions, of which one at least has a badgir, set in a high walled garden with the service settlement outside the walls (figure 3.20). The largest of the gardens include the Bagh-e Dowlatabad, built just outside the city of Yazd (see 8.5.2), and the Bagh-e Khan, built some 5 miles south of Yazd on the Taft road. This garden has a single pavilion, linked to a free standing

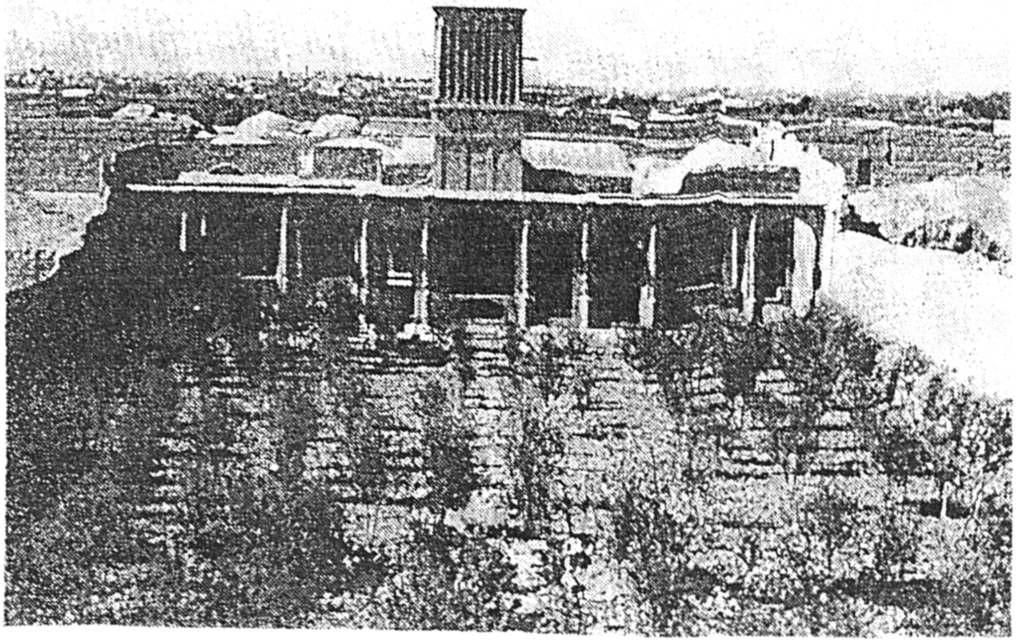


Figure 3.20. Garden pavilion of Abdul Rhakim Khan, just outside Yazd at Rhakimabad.(Afshar, 1969, vol.2, plate 11)

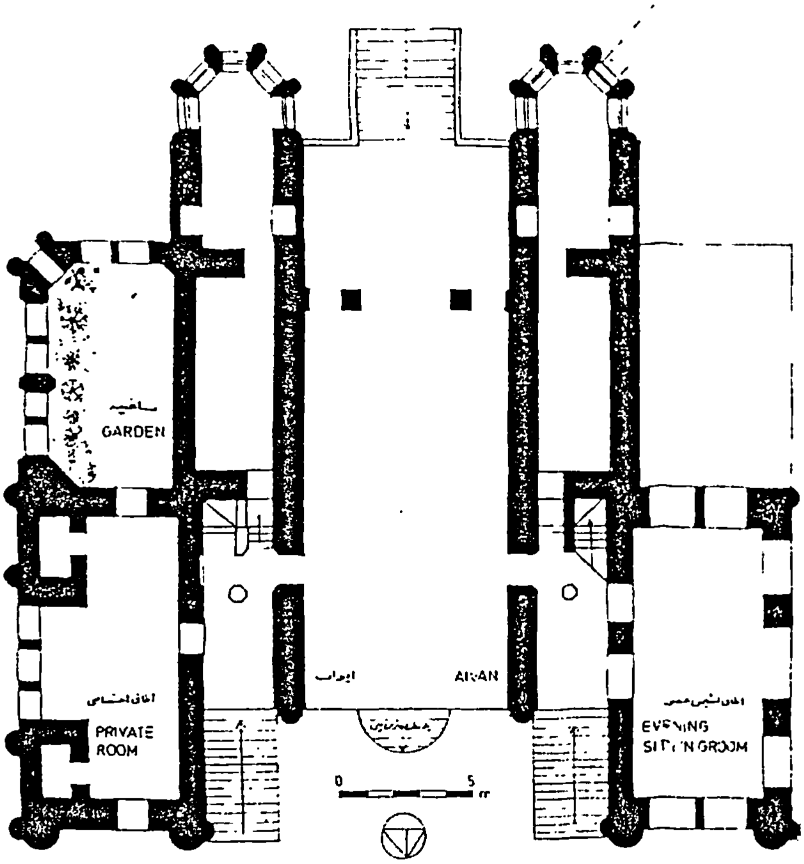


Figure 3.21. Ground floor plan of the pavilion at the Bagh-e Khan. redrawn from a plan by the Ancient Monuments Department of Iran)

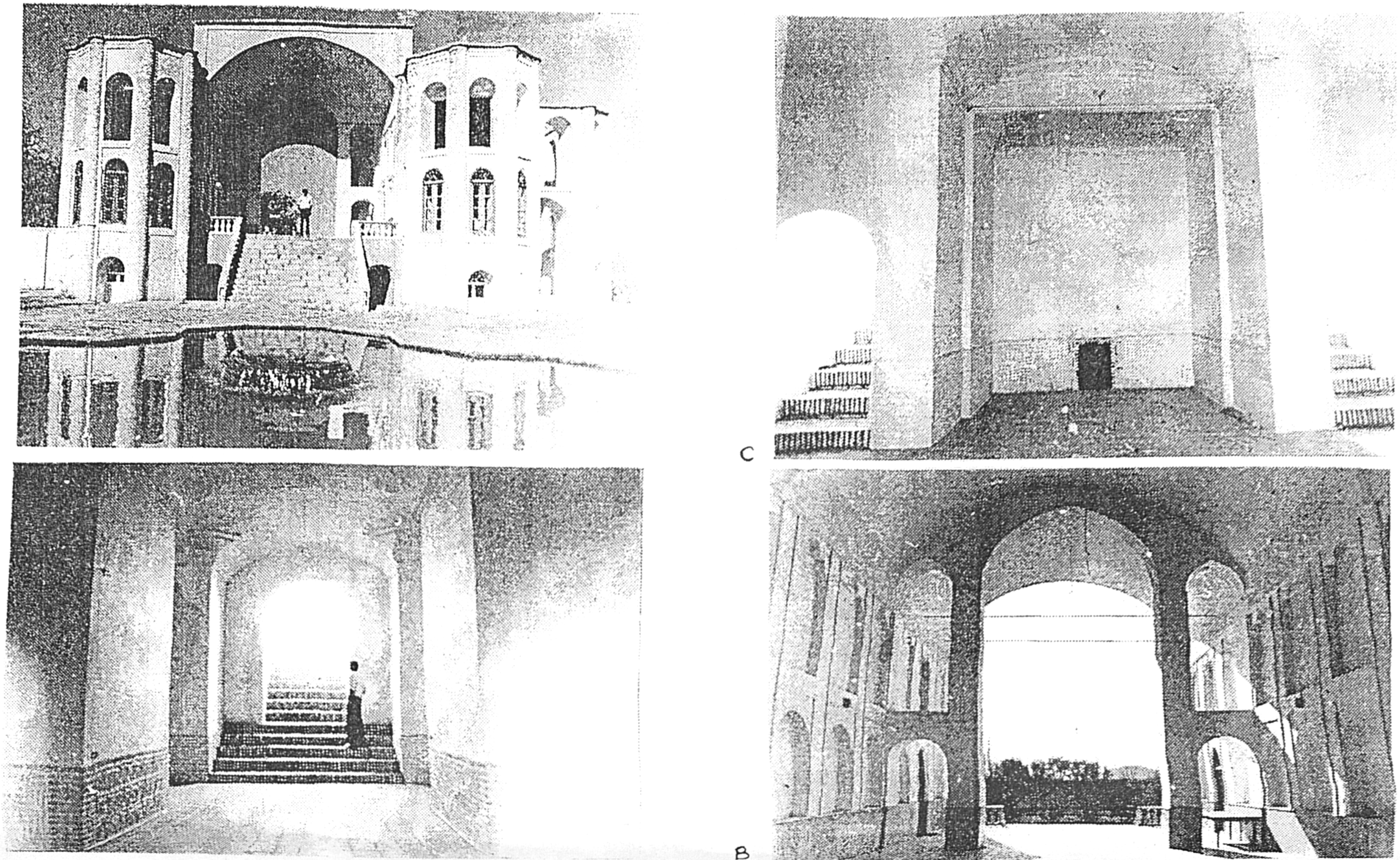


Figure 3.22. Photographs of the pavilion at the Bagh-e Khan.
A) The front elevation.
B) Looking from the aiwan [illegible] Yazd.

badgir some 50m from the dwelling by an underground channel from the basement that passes over a qanat stream so cooling and humidifying the air in its passage into the basement (see 12.6.2) (figure 3.21 and 3.22 and 3.10). Both gardens have main pavilions consisting of a compact tripartite building, with living rooms and originally all the services such as bathrooms, kitchens, water cisterns, ice houses, stables were located in separate buildings around the gardens.

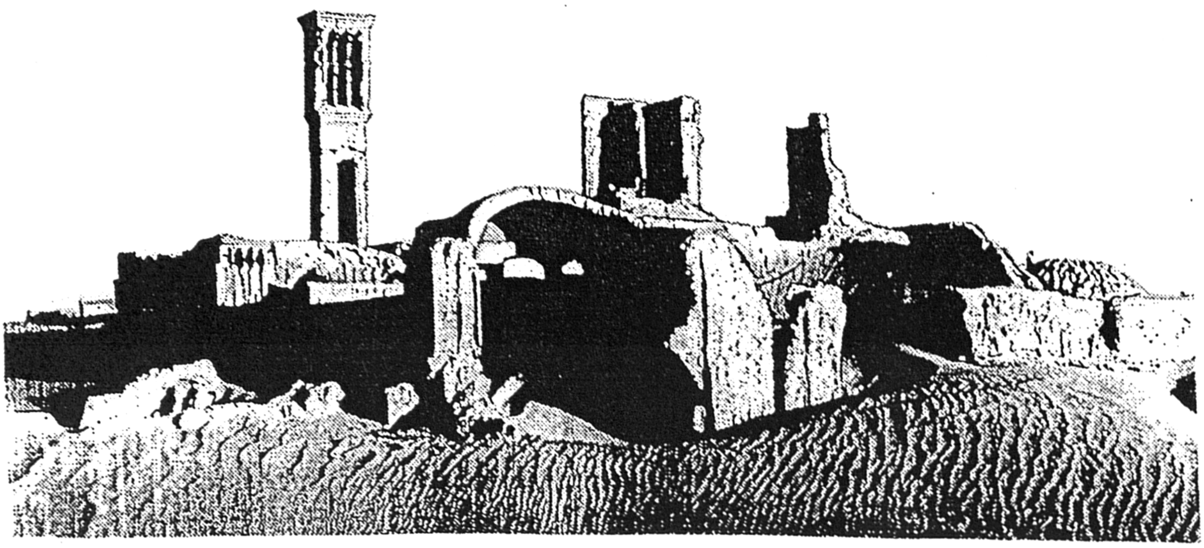
Another notable garden complex was built by Bibi Gol Khanum in the 19th century at Ruknabad, some 10 kms to the west of Yazd and it too has a remarkable, though sadly ruined badgir (figure 3.23).

Four of the finest of the provincial badgirs are located on these three garden pavilions.

5) <u>Zoroastrian village houses</u>

The traditional Zoroastrian house differs very substantially from the traditional Muslim urban courtyard house. An excellent study of the Zoroastrian houses of Yazd has been made by Mary Boyce in 1976 (Boyce, 1976, pp125-147) in which she writes: (figure 3.24)

> The traditional Zoroastrian houses of Yazd and its villages, which have never been described, are strikingly different in design, though made of the same materials (mud-brick, mud-plaster, and a little wood for doors). Like those of the Muslim poor, they are small and cramped in their proportions, for the Zoroastrians were held down in poverty, and restricted moreover in the scope of their building. There are two standard types of old Zoroastrian house, built until the last decades of the nineteenth century. These are called in their own speech <u>do-pesgami</u> house and cor-pesgami, that is house with two or four <u>pesgams</u>, the Dari' word for <u>talar</u>.



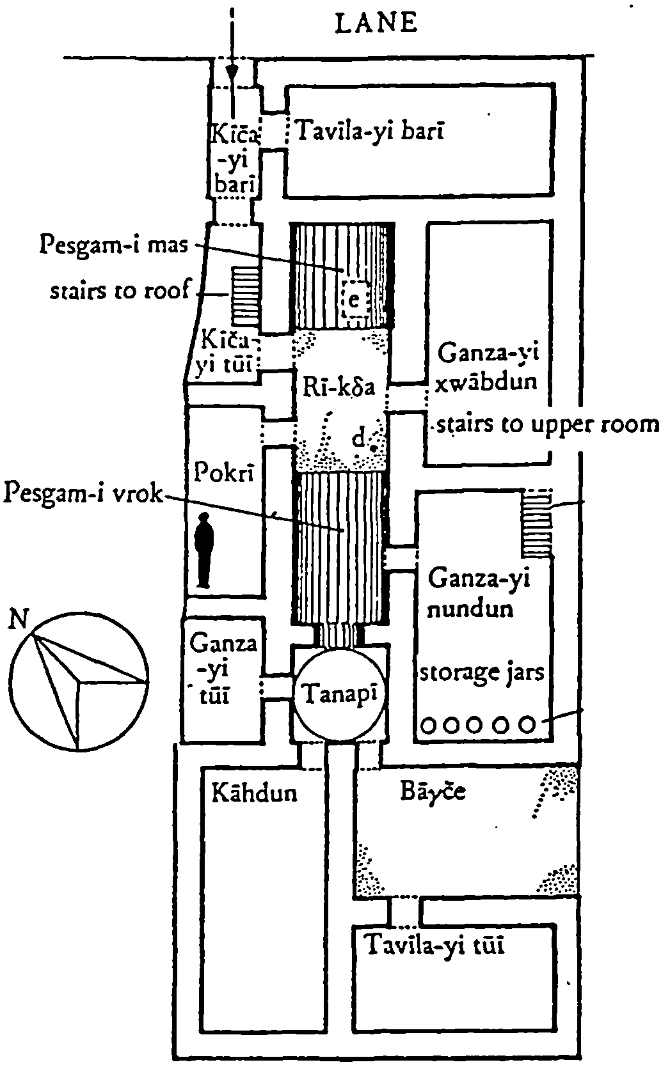


Figure 1. *Dō-pesgamī* house of Khodarahm Rashidi, Sharīfābād. Key: a. corn-store; b. hiding-place; c. door to *šiw-ʒwīn*; d. drainage hole; e. weaving-well; f. *šīrōk*; g. *ganʒa-yi pūnidun*; h. privy; i. wood-store; j. *taxt*.

Figure 3.24. Plan of a Zoroastrian house (Boyce, 1971, p.127)

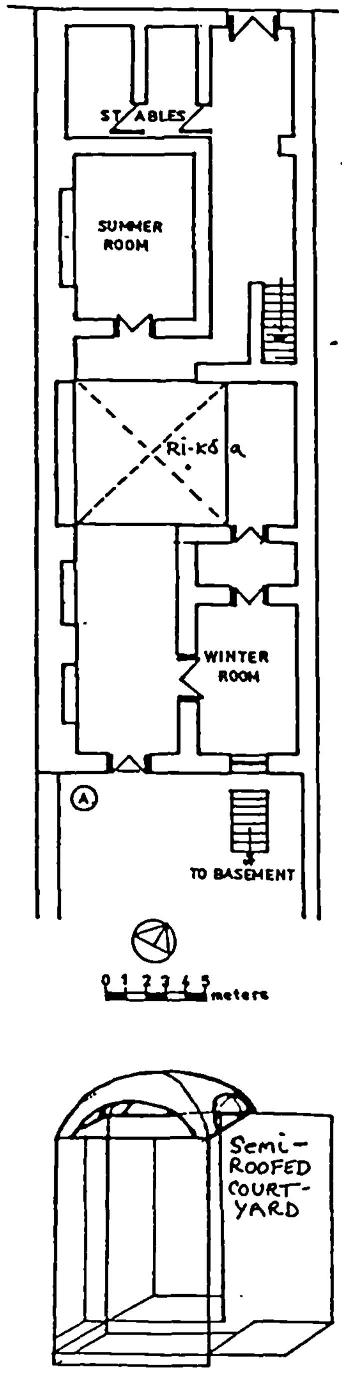


Figure 3.25. Plan of a Zoroastrian house in Mohammadiyeh.

Zoroastrian courtyards are called Ri-kda', and are small and generally cobbled with small round stones or trodden earth. Figure 3.25 shows a plan of a Zoroastrian house in Mohammadeah which has a sketch perspective of the ri-kda, showing the raised half roof facing north which acts as a very simple windcatcher.

The restrictions on building Boyce mentioned included, in the 1890s, Zoroastrians being (Napier, 1905,p.43):

A) Forbidden to build walls around their houses higher than a Muslim could reach with his hand. They could however build below ground.

B) Made to splash walls with white around the doors.

C) Forbidden the double, or french doors popular in Yazd at that period.

D) Forbidden to have badgirs.

E) As Parsis were forbidden to engage in trade, therefore, they had large cellars and store rooms to hide goods in secretly.

3.3.6 Conclusions on the influence of building types on the distribution of badgirs in the Yazd region.

From the outline of building types associated with badgirs in the region, provided as background data for the consideration of influences on distribution of badgirs in the region, several conclusions can be drawn:

1) While badgirs are built on five building types in the area, the distribution pattern of badgirs identified in the rural survey reflects largely the distribution of domestic badgirs.

2) On the survey five different dwelling types were identified but it was found that compact, compound, and courtyard houses were built in all parts of the survey area while garden pavillions and traditional Zoroastrian houses were found in the vicinity of Yazd only.

3) The only possible relationship between house type and incidence of village badgirs appears to be a historical one, with Zoroastrian villages before the turn of the century prohibited to use badgirs on their houses. As this prohibition was withdrawn by 1900 (Napier, 1905, p.43) the significance of this factor is negligable to the present survey.

3.4 DISTRIBUTION OF BADGIR TYPES IN THE YAZD REGION

The distribution of rural badgirs in the study area appears to fall into two distinct patterns, one in the Yazd Basin to the south of the area and the other in the more isolated desert settlements to the north of the area.

3.4.1 <u>In the Yazd Basin</u>

A distinct pattern of distribution of badgirs in the Yazd basin can be observed.

Villages in the vicinity of the cities of Nain and Yazd predominantly have badgirs facing in four directions while the villages in the vicinity of Maibud and Ardakan face predominantly in one direction only, to the north and north-west. An unusual exception is found in the villages of Turkobad and Ahmadabad to the north west of Ardakan, where the uni-directional towers face south to south east.

3.4.2 <u>In the north of the study area</u>

On the northern desert route the badgirs on settlements generally faced in four directions with the exception of those of two large villages, Chupanan and Robat-e Pusht-e Badam, in which one directional badgirs facing north and north-west predominate (Figure 3.4 and 3.5).

3.5 THE INFLUENCE OF CLIMATIC FACTORS ON THE DISTRIBUTION OF BADGIRS IN THE REGION OF YAZD

3.4.1 <u>Precipitation</u>

Rainfall figures for all areas of the survey area are uniformly low, as evidenced by the precipitation figures for Yazd, Ardakan (in the centre of the Yazd Basin) and Chupanan (in the heart of the northern desert area) shown in figure.

Rainfall figures, so low over the whole area, do not appear to be a contributary factor in the distribution pattern of the area on the scale of the macro-climate of the region. However relative humidities may vary considerably from settlement to settlement, due to factors such as altitude, and the extent of the orchards and gardens around a settlement (see 2.3).

3.5.2 <u>Temperatures</u>

The only available figures for temperatures in the province are those for the city of Yazd. Location, altitude, and proximity to the Kavir must influence the general range experienced in individual settlements.

3.5.3 Prevailing winds

Prevailing winds in the area are poorly recorded and meteorological records exist only for the largest settlements in the form of general readings. These show that in Yazd there are strong prevailing winds from the north west in all months of the year. In Ardakan the prevailing wind is from the north. The general pattern for all the settlements of the area is of strong prevailing winds year round from the north and north west, following the direction of the mid-latitude westerlies.

Each village in which inquiries were made about the direction of sweet' winds reported that the best winds come from the north and the north west. North of Robat-e Pusht-e Badam there is also a favourable wind from the east, from Khorasan, and due to the severe winds from the south, in some settlements the towers face roughly in three directions, north-east and west, with a blank wall to the south.

In some settlements the direction of the prevailing wind is written clearly on the face of the tower itself. Aliabad, 1.5 kms south of Robat-e Pusht-e Badam, provides such useful evidence. On north-west of the water cistern to the west of the caravanserai, is the stump of a hexagonal badgir. On inspection the north-west facade of the tower can be seen to differ from the other five sides in being heavily eroded by wind action. The other sides appear little scathed by wind erosion. The second badgir in this settlement, on the north facing pool room is a rectangular structure facing in four directions.

3.5.4 <u>The conditioned north wind in the north of the province</u>

The modern village of Robat-e Pusht-e Badam, 1.5 kilometers to the north of Aliabad (figure 3.5), was built after the Second World War, following changes in the position of the road. Of the approximately 21 badgir towers on the newer settlement, one faces in four directions and twenty examples face in one direction only, to the north-west (333 deg., = NNW), towards the mountains. The residents say that the wind from the mountains is cool but from the south it is bad, warm'.

In Chupanan, another settlement with a majority of north-west facing, uni-directional towers, there is a range of hills to the north west of the town, as there is to the north of Khur, over which the prevailing wind is cooled before its arrival at the settlement (figure 3.2). In Chupanan there were boards by most towers, at hand to close off the tower vents (figure 11.4). This may indicate the occurrence of unsuitable winds in summer, which need to be excluded, or that the rooms with badgirs are also used in winter when the badgir in closed off.

3.5.5 <u>The naked north wind in the north</u>

A reason why all settlements on the loop road do not have large uni-directional wind catchers facing north to the prevailing wind, may be that many of these settlements strung out along this desert track are exposed to the north wind which here is hot and dusty, straight off the desert floor, carrying sand and dust. In the settlements, mentioned in 3.5.4, airborne debris is deposited on highlands to their north. The highlands also moderate the temperature and speed of the wind before it arrives at these settlements.

In villages exposed to open desert to the north however, most of the wind towers have smaller vents and face in three or four directions, with only one vent facing in each direction.

3.5.6 South winds

The vast desert at the heart of the Persian Plateau inevitably has a considerable effect in altering the wind patterns in extreme conditions. The prevailing north-westerly wind in its unchecked path across the desert requires a major air system to alter its direction; and indeed the high pressure system that emerges over the baking desert floor at the height of summer, and in particular on summer afternoons, provides a powerful draw to air streams from the fringe of the desert. Thus it is that at the very hottest periods of the day and year the southerly, south-easterly and south-westerly wind predominates.

3.5.7 South winds in the Yazd Basin

This line of reasoning suggests that facing windtowers south leads to the introduction of excessively hot air into the house. Yet in two settlements, Turkobad and Ahmadabad to the north west of Ardakan, virtually all the badgirs are uni-directional and face south, and in a number of other settlements in the area individual windtowers also face south.

The reason lies in the micro-location and micro-climate of the settlements or particular houses concerned. Both Turkobad and Ahmadabad lie on the very edge of the desert to the north, a hostile, vegetationless kavir, and both are situated on the northern edge of the very fertile, well watered and treed oasis of Ardakan.

Thus air arriving from the north at these two settlements is the naked hot north wind, while that coming from the south is considerably conditioned by its passage over at least five miles of orchards and gardens. Thus the location of an individual village in relation to cultivated land, settlements and desert may dictate to a considerable extent the orientation of the badgir vents. The same may also be influential in the orientation of individual domestic badgirs to the south in a village where the majority of towers face north. That is, the houses concerned have a cultivated or settled area to their south, so ensuring that any south wind that enters them directly is conditioned before its arrival.

3.5.8 Special factors affecting the presence of uni-directional towers along the northern desert road.

If then, as the above discussion implies, either a hot north (Shomali), or an east wind (Khorasani), or a south wind

(Jenubi) after it has been conditioned, are considered suitable for badgirs, why then do many exposed settlements on the desert loop road have four directional towers?

One answer is to be found in the very different types of settlement on the road. Figure 33 shows that the larger settlements are spaced well apart and are generally one, two or three days' ride apart, that is approximately 30 to 90 kilometres apart. There are four different types of large settlement along this road. The first is the citadel town, with an old walled fort at its centre and often a walled town around it, surrounded in turn by date groves, or orchards and fields of crops. In Biayazeh, Dowlatabad and Mehrjan, the towns are surrounded by a belt of such cultivation. In Khoranaq there is cultivation on the north east and west sides only, but a range of low hills to the south. Thus this ring of cultivation and hills provides the mechanism for conditioning the south wind. The air is humidified, relieved of the larger sand and dust particles, and cooled as it travels over the hills and cultivation. Thus four directional towers in such settlements receive the south wind only after it has been conditioned.

A second settlement type is the oasis town such as Khur which has traditionally been a date growing centre for the region. Here the ring of date orchards around the old centre is being eaten into by the new suburbs that have sprung up on the revenue generated by the recent elevation of Khur into a important regional administrative centre. The four directional towers here also receive a well conditioned south wind.

Of the more modern settlements there are two types. The first type are grid settlements, such as Chah Malek and Chupanan, where the whole town has been laid out on a grid pattern of parallel roads adjacent to the water channels. Chah Malek is a town surrounded by tamarisk groves and has four directional towers, while Chupanan, with little or no medium level vegetation around it, has uni-directional towers.

The second type of modern settlement in this area is the ribbon settlement strung along a main road. Robat-e Pusht-e Badam is an example of the modern staging post', located where the Tabas road branches off. Its exposed location has resulted in the construction of uni-directional towers. Ghaderabad and Farroukhi are ribbon settlements with tamarisk and date groves surrounding them and have four-directional towers.

3.6 CONCLUSIONS

From the evidence available it appears likely that climate does play an important role in the nature and distribution of badgir types in the province of Yazd.

A key factor in type determination appears to be the form and location of the settlement itself. The following five conclusions are offered on the relationship between climate and badgir distribution:

1) Winds from the north or north west are considered uniformly acceptable to badgirs with the exceptions only of two villages, Ahmadabad and Turkobad, to the north-west of Ardakan. These then are the preferred winds for badgirs in the Yazd province.

2) Settlements exposed to the open desert on their north and protected by a vegetation belt to their south may have uni-directional towers facing south. This is the case with Ahmadabad and Turkobad.

3) Winds from the north are considered exceptionally favourable when modified (ie. cooled and humidified) by their passage over or around mountains or hills prior to their arrival at the settlement.

4) Winds from the south appear to be acceptable, if they have been modified by passage over or around hills or over high to medium level vegetation such as date and tamarisk groves and orchards

5) Settlements in exposed desert locations with a ring of cultivation, orchards or date groves around them to modify the wind before its arrival at the badgirs, may have windcatchers that face in four directions.

These conclusions may be reduced to a simple rule of thumb. A conditioned wind is preferable to a naked wind off the desert floor, which is likely to be higher in temperature during the day in summer. It may be deduced that some winds in the area are too hot for use in badgirs. This in turn suggests that temperature thresholds exist below which winds are 'suitable', and above which temperatures are 'unsuitable' for badgirs.

However climate alone cannot explain the distinctive distribution pattern of badgirs in the Yazd Basin, where areas with seemingly similar climates commonly use different badgir types. Further investigation of historical factors at play in the region may provide further insight into the range of influences affecting the distribution of rural badgirs.

3.7 WIDER CONCLUSIONS ON CLIMATE AND REGIONAL BADGIR DISTRIBUTION

The importance of wind-conditioning in explaining the distribution and types of badgirs in the Yazd province may have wider implications. One factor that emerged from chapter 2 was that Kashan as the only one of the three cities, Yazd, Kerman, and Kashan, that was not sheltered to the north by a mountain massif. It is also the warmest of the three cities. It could be suggested that the prevailing winds it experiences, straight off the desert floor, are hot and strong, which, in conjunction with marginally higher summer temperatures, may explain why the badgirs of Kashan are few and small.

CHAPTER 4

THE INFLUENCE OF HISTORICAL FACTORS ON THE DISTRIBUTION OF RURAL BADGIRS IN THE YAZD STUDY AREA

4.1 INTRODUCTION

The distribution pattern of badgir types varies considerably between those in the north of the study area and those in the Yazd basin to its south (figure 3.3). In the north the patterns appear random, in the Yazd basin around Yazd and Nain there appears to be a distinct pattern of four-directional towers predominating, while in the centre of the Yazd basin, around Ardakan and Maibud, the towers are uni-directional, facing generally north to north-west.

In chapter 3 it has been seen that, in the north of the study area, climate is possibly an important determinant on the incidence and type of badgir while in the Yazd basin to the south it was argued to have less importance.

In this chapter the historical influences on the distribution pattern will be investigated. Market centres in the region and their historical development in relation to the evolution of badgir types in the area will be traced firstly in the northern desert area, and secondly, in more detail, in the Yazd basin.

The chapter begins with a brief consideration of who builds badgirs in the towns and villages of the area, and then discusses the local market centres as sources for the materials and skills required for the building of rural badgirs. This leads to an outline of the development of the two main market centres of the region, those of Ardakan/Maibud, and of the city of Yazd itself (Bonine, 1980, p.161) in relation to the the occurrence and distribution pattern of badgirs types in the Yazd basin.

4.2 BADGIRS BUILDERS

From the survey undertaken by the author of this thesis it appears that badgirs are built by two groups; the patrons of public building, and the private house owner.

4.2.1 Patrons of Public building

Public buildings on which badgirs are found, such as water cisterns and caravanserai, were traditionally funded by local private patrons who paid for, and employed architects to design, the building. Today this function has been taken over by local government offices or local rural co-operative societies or sherkat- ta'avuni-i rusta'i, (Bonine, 1980, p.65). For example in Zandvan, five miles to the south-east of Nain, the local village co-operative raised the money for, and in 1978 built a new cistern, completely by itself, employing a well known master builder from Nain. He designed the cistern with two four-directional badgirs.

4.2.2 The private house owners.

The first group of house owners are wealthy house owners, usually landlords or merchants who have land in the villages, on which they then build a house. Such houses are usually designed by a builder/architect from the large town or city in which the well-to-do landowners have their town house. The Mohammadiyeh house (figure 3.1.8) is an example of a well constructed and detailed Zoroastrian merchant's house designed in a village by a well known Yazdi master builder, Hajji Ali Akbar. Garden pavilions are built only by wealthy landowners.

The majority of rural houses however are built by peasants, the second and larger group, who design and physically build their own houses with the help of skilled workmen, family or friends.

4.2.3 Influence of patronage on badgir design

The extent to which a peasant is influenced in the design of a badgir by elaborate badgirs built on public buildings, or on the houses of the wealthy in the village or local town, is difficult to assess from the available data. There is no known published study on the diffusion of designs from centres of population to the hinterland with which to compare or assess the impact of style on badgir design in relation to the present study.

Certain clear examples of rural badgirs not influenced by imported designs do occur in the area. For instance, two miles to the south of modern Robat-e Pusht-e Badam, is the caravanserai village of Howz-e Charfarsukh or Aliabad, which was in good condition when visited by Macgreggor in 1879 (p.88). The settlement includes two qanats, one caravanserai, a water cistern, a public bath, water mill, and several houses, all built in the mid-nineteenth century by Hajji Gaznovizi (Hajji Murza Mandale Tehrani). There are two fine windcatchers on the buildings. These are a hexagonal tower on the cistern and a four-directional tower on the north-facing aivan of the caravanserai. Both appear to be the work of a very skilled Yazdi ostad, and as fine examples may be expected to set a precedent for badgir design in the area. Yet in Robat-e Pusht-e Badam, 1.5 kms to the north, a settlement which has now completely replaced Aliabad in function, there are twenty-one windcatchers, of which only one faces in four directions, and is of very simple construction. In this example the disparity between the size, cost and elegance of the two imported designs and the very crude village badgirs may either suggest the climatic unsuitability of the imported design or highlight the discrepancies between the economic status of the peasant builders of Robat-e Pusht-e Badam and the wealthy Yazdi merchant. Such differences in aspirations or wealth however, may not exist between the local landowner and the wealthy peasant in the villages of Yazd. Further work on this subject may provide positive conclusions on the reasons for the dispersion, or otherwise, of design models.

4.3 THE IMPORTANCE OF MARKET CENTRES

While no work has been done on design diffusion influences, a useful study exists on the mechanism of marketing patterns in the Yazd region (Bonine, 1980) which illustrates the routes by which goods are moved through the Yazd area. Using this study some insight into the market centres for the building industry may be gained. It should be reitterated that by far the majority of rural badgirs in the area are located on the houses of peasants in the area, and thus it is in relation to these that the market imput into the building industry will be investigated.

4.3.1 Materials used in constructing a house

The typical village house is made of mud brick and has rough mud and straw plaster on external and internal surfaces, and mud-brick vaulted roofs. Fine white gypsum plaster is only used on the internal surfaces of the houses of wealthy owners. Timber is used traditionally in the doors, windows and badgir of a house. Today many of the better rural houses in the area incorporate cement, particularly in floors, and metal doors and windows in their construction.

In the building of village houses earth is excavated locally (Wulff, 1973, pp.102-171; Beazley, 1983, pp.11-30) and the main purchased requirements for the peasant builder are articles which include the following: shovels, a mason's spatula, some timber, nails, hammer, glass, electric wiring (only in some cases), some cement, and door and window hinges and locks.

4.3.2 Purchase centres for such items in the northern region of the study area

Despite the large distances involved and the poor quality of the roads, the primary markets for settlements in the vicinity of the main cities on the northern loop appear to be Nain and Yazd (Bonine, 1980,pp.111-140).

However, in the extreme north of the area, the town of Khur was in the last century a large village and important date-growing centre (Honan, 1971, pp.49-58):

> Khoor is a small oasis about two miles in diameter, in which there are 400 houses of Persians, Arabs, and Syuds, and a dense forest of date palms. '... The houses are of mud, but there are a few "badgeers" to relieve the monotony of the scene. (MacGreggor, 1879, pp.93-94)

By 1978 Khur was a rapidly growing administrative town, and the largest market centre in the north, containing a number of specialised shops selling equipment, hardware and materials. Local shops in other towns might sell items such as nails and shovels, but, in the isolated settlements north of latitude 33.5 degrees north, Khur would appear to be the main market centre for building supplies.

If any strong design influence was provided by this regional market centre in the north of the area, it would presumably appear as a centralised pattern of badgir types around Khur. This is not the case. The apparently random, perhaps rather idiosyncratic nature of the distribution pattern decries the importance of local market influences on the presence and orientation of badgirs of the northern loop road.

4.3.4 Local purchase centres for building materials in the Yazd Basin

For the purpose of this study in the Yazd basin between Nain and Yazd a major centre of population is identified, centred around Maibud (population c. 25,000 : Bonine, 1980, p.84) and Ardakan (population of villages in area -Torkobad, Ahmadabad, Arjinan - and town c. 20,000 : Bonine's statistics from 1966 Iranian census, 1980, pp.192-195) that is, a total population of around 45,000 people. It is argued that the markets of these two towns supply the building materials and skills of the area in the centre of this section of the Yazd basin.

In his thorough work on the economy of the Yazd Basin Michael Bonine has provided extensive diagrams of the paths of movement between settlements of the area to support his conclusions on the hierarchy of settlements in terms of their Central Place functions (Bonine, 1980).

Bonine describes Maibud as a composite town with an undeveloped bazaar and Ardakan as a compact town with a well developed bazaar. Of Ardakan Bonine states:

> ..many aspects of Ardakan's commercial structure resemble those of the city of Yazd. (Bonine, 1980, p.94)

> Ardakan as the only major town ... has a much greater centrality due to its greater number of functions and level of commercial development. Ardakan is an effective competitor to Yazd for all but the highest order goods and services (for example, purchase of copperware). (Bonine, 1980, p.143)

However Bonine states elsewhere that copperware can be bought in Mehrjerd, next to Maibud (1980, p. 85) and that radio repair shops are found in Maibud and Ardakan (1980, p.103 & 208).

Bonine demonstrates that all the required building materials <u>and</u> skills for a house, outlined above are available in Ardakan and in Maibud (Bonine, 1980, pp.203-

207), and the house builder will do much of the building himself. The expertise of a carpenter, for instance, is available in all the larger villages of the Maibud area (Bonine, 1980, p.103) and in Ardakan, and in both settlements there are brick-kilns and tile-makers (Bonine, 1980, p.207). Specialist products may be found in particular villages such as rope-makers in Bafru'iyya (Bonine, 1980, p.177). Ardakan however is the only town in the region in which the banks provide credit facilities for building and similar purposes (Bonine, 1980, p.159).

In terms of land ownership and water rights Ardakan and Maibud are independent of Yazd. The water rights for instance in both these settlements are in the hands of local landowners (Bonine, 1980, p.165), and Bonine also points out that in terms of the labour market Ardakan is likewise fairly independent (1980, p.170). It is a local market centre for the north-west of the Yazd province, and also traditionally dominated the district's retail market as well. (1980, p.161). To supply the market many shopkeepers travel to Tehran from Ardakan to purchase goods which are then sold to owners of local retail shops at a lower price than would be the case had they been bought in Yazd (Bonine, 1980, p.161). Bonine suggests that security was a prime consideraton in earlier periods when, especially before Reza Shah, bandits, robbers and brigands adounded in the area and villagers would organise small caravans to transport themselves to the local market (Bonine, p.161). This may have enhanced the traditional role of Ardakan as a rival market centre to Yazd for the population in the north-west of the province of Yazd.

Bonine provides convincing evidence that Ardakan, and to an extent its sister settlement of Maibud, are effective market centres for building materials and services, second only to Yazd in the entire region. It appears that, if these market centres serve their own immediate areas and the north-west of the province (Bonine, 1980, p.161) which extended traditionally to Aqda (Pottinger, 18160, pp.422) then the limits of the hinterland of the Ardakan / Maibud markets co-incide with the limits of the use of uni-directional badgirs.

Why is it that the limits of the two adjacent market hinterlands are associated traditionally with the use of different badgir types, with uni-directional towers in the Ardakan / Maibud area, while those built on villages in the immediate hinterland of Yazd are generally four-directional?

An investigation of the history of each centre may provide a clue to the disparity of badgir type distribution in the Yazd basin.

In the two following sections the history of the development of the Ardakan / Maibud oasis and of Yazd city are reviewed, from secondary sources, to isolate any factors that might shed light on this question.

4.4 HISTORICAL INVESTIGATION INTO THE ARDAKAN / MAIBUD AREA

The development of the population and market centres of Ardakan and Maibud, mid-way in the Yazd basin between Nain and Yazd, while influenced by the evolution of the city of Yazd, the dominant city in the region (Bonine, 1980, pp.183-184) nevertheless should be reviewed separately from that of Yazd in order to discover if any aspect of the historical evolution of each population centre provide, a clue to the discrepancies in the distribution patterns of badgirs in the Yazd basin.

In the Yazd basin the often poor agricultural land and lack of water of much of the basin, and the vulnerability of the exposed settlements, and caravans, to bandits (Abbott, 1853, FO.251/42/9059, pp.49-53; Bonine, 1980, p.161) means that the widespread settlement of the Basin is comparatively recent, occurring largely in the late 19th and 20th centuries. Prior to that there were only the two largest cities in the area, Yazd and Nain, and between them several large, well-fortified villages such as Haftodor and Aqdar, built in Sassanian times (6th century A.D.) (Bonine, 1980, p.12) and Bunderabad, built by the Atabegs in the 13th century (Bonine, 1980, p.13). All three settlements had a fort or caravanserai for times of attack. The only conurbation of settlements that existed in the centre of the basin was in the large oasis depression containing the Sassanian settlements of Firuzabad and Maibud. These later became much enlarged under the Muzaffarid dynasty of the 14th century who came from Maibud (Bonine, 1980, p13). Also in the Ardakan oasis directly to the north of Maibud, are the settlements of Turkabad, built by the Kakyids in the

12th century, and Ardakan built by the Atabegs in the 13th century (Bonine, 1980, p.13).

In the 15th century much of Persia fell under the rule of the Timurids and from this time there exist three badgirs in the Maibud area dated by Dr. O'Kane. In his article on the Timurid school at Khargird in Khorasan , built in 1417-1442, mentions five other Timurid buildings, all mosques, with windcatchers, and all of them in the Yazd area:

> Five other Timurid buildings possess bad-girs. They are the Masjid-i Sar-i Rik (828/1425) and the Masjid-i Mir Chaqmaq (840/1437) both in the Town of Yazd, and the Masjid-i Jami's of Kuchuk (c.865-70/1461-6), Firuzabad (866/1462) and Bafru'iyya (866/1462) in the Maibud district, some 55 kms. north of Yazd. In all the above, except the Kuchuk Masjid-i Jami', the bad-gir is situated directly in front of the mihrab, and the wind-tunnel except the Kuchuk Masjid-i Jami', the badgir is situated directly in front of the mihrab, and the wind-tunnel leading up from it emerges directly behind the sanctuary. In the Kuchuk Masjid-i Jami' there are two bad-gir, situated on either side of the sanctuary dome chamber. In view of the rarity of this feature (bad-girs) it may be possible to assume a direct influence from the mosques of Yazd in this case. On the other hand Qavam al-Din (the architect of the school at Khargird) may simply have been adapting a domestic constructional feature. In any case, considering the present-day preponderance of bad-gir in the towns of south and central Iran it is likely that Qavam al-Din Shirazi drew his inspiration from his native provinces. (O'Kane,1976,p.90) (figure 3.12)

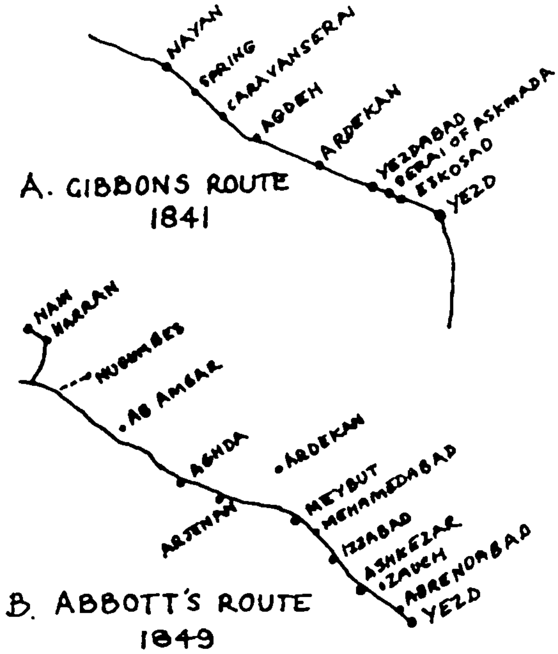
The authenticity of three of these Timurid badgirs is open to question. M. Pirnian, a leading Iranian architectural historian, considers the badgir on the Masjid-i Mir Chaqmaq to be Qajar (19th century), because of its style and the fact that the Timurid inscription is actually cut into by the addition of the badgir base, and the same he maintains to be true of the Masjid-i Sar-i Rik. He holds that there are no Timurid badgirs on the mosques of the area but that there is one on a house, the Faghighi house in Yazd, which still has the remains of a Timurid badgir above the summer living room (Pirnian,1976). Of the paired badgirs of Kuchuk, the eastern tower appears to be similar in type to that at Khargird, but the western tower may well have been replaced, judging by stylistic evidence, by a 19th century tower. Here one is dealing with speculation but this point could well be followed up by further field work in the area.

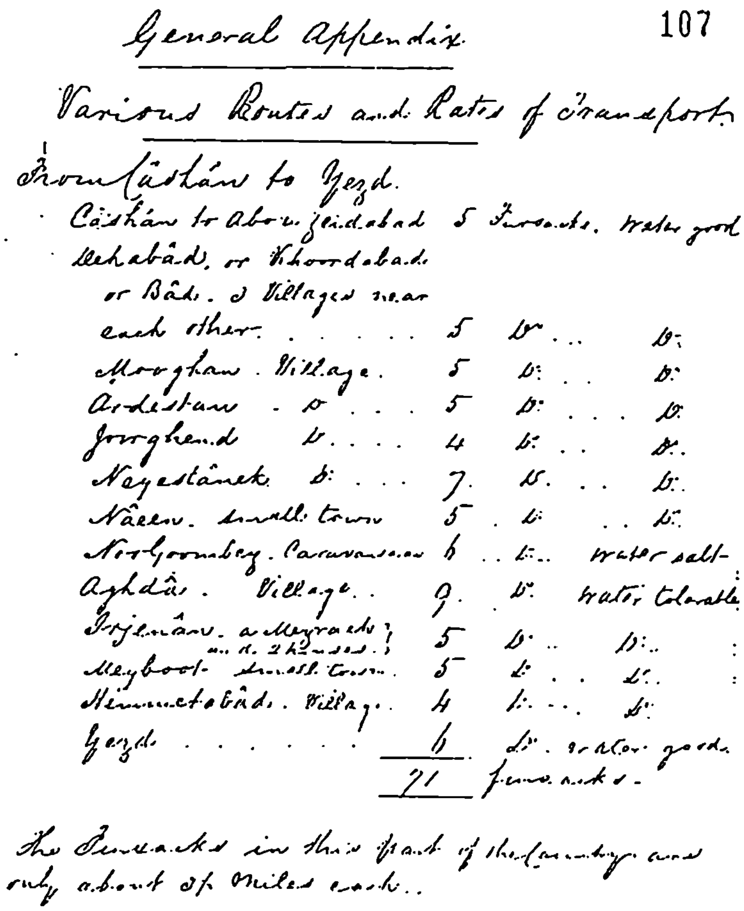
However the evidence is sufficient to suggest that in the Maibud area simple low uni-directional towers were built as early as the 15th century.

In 1816 Captain Christie published the following account of a journey from Yazd to Agda:

> 24th June (1810). Leaving Yezd this day, I marched westerly along the base of the hills over a deep sandy road. The gardens on each side extended for six miles. At fourteen miles I passed through a large village called Eshkidur, and winding over sandy hills altered my course more northerly. At twenty four miles arrived at Yezdawah, a small town, the country around well cultivated and affording plenty of water.
>
> 25th June. Twelve miles to the small village of Myboot, contiguous to a range of hills on the left; to the right the country is well cultivated. Eight miles hence is Ardakoo, a large village; and ten further, the village of Tafta. At thirty miles I arrived at Oogda.
>
> Oogda is small village of about one hundred and sixty houses, with a good surae, situated on the edge of the desert between two ranges of mountains running north-west and south-east. Here the authority of the governor of Yazd terminates. (Pottinger, 1816, pp.420-422)

This description, only 85 years after the Afghan invasion of the area, emphasises the very scattered nature of the villages in the basin. By the late 19th century there are many more villages built in the area of the Basin but the




General Appendix. 107

Various Routes and Rates of Transport.

From Cáshán to Yezd.

Cáshán to Aboo Zeidabad	5	Fursacks.	water good
Dehabâd, or Khoordabad or Bâd. 3 Villages near each other	5	Do.	Do.
Mooghan. Village.	5	Do.	Do.
Ardestan. Do.	5	Do.	Do.
Joorghend Do.	4	Do.	Do.
Nayestânek Do.	7.	Do.	Do.
Nâeen. small town	5	Do.	Do.
Noorgoombez. Caravanserai	6	Do.	water salt
Aghdâs. Village.	9.	Do.	water tolerable
Irjenân. a Meyrach and 2 houses	5	Do.	Do.
Meyboot small town.	5	Do.	Do.
Hemmetabâd. Village.	4	Do.	Do.
Yezd	6	Do.	water good.
	71	fursacks.	

The Fursacks in this part of the Country are only about 3½ Miles each.

Figure 4.1.A) Map of central Persia by Sergeant Gibbons in 1841 showing seven watering points between Yazd and Nain: Eskasad, Askamada, Ardekan, Ag Deh, spring, Nayan.
B) Map of the settlements recorded by Abbott in 1849, (Abbott, 1855, p.1) with itinery from Abbott

four main focuses of population, Yazd, Ardakan/Maibud, Aqda and Nain, still dominated the settlements of the area (figure 4.1). Many new villages and qanats were built in the 19th century in the Yazd area - by Mohammad Taggi Khan, his son Ali Taggi Khan, Mohammad Abdul Rahmin Khan, and Mohammad Vali Mirza early in the century. In the latter half of the century Mohammad Khan Vali and Mushir Mamalik were considerable builders (Bonine, 1980,p.15).

> There are signs of life and agricultural activity as Yezd is approached along the Kashan road. At Maibut.... In this neighbourhood are clusters of large villages , such as Ardekoh, Bafroh, Ahmedabad, Sarfabad, Turkabad.(Goldsmid, 1867, 276)

> Yuzd is situated in what might rightly be termed an oasis. In all directions, immediately outside of the city and surrounding villages, there is a howling wilderness, where the sand seems gradually to be encroaching on the cultivation. (MacGreggor, 1879, p.75)

> Within a few miles of Ardakan, the desert country commences, and in every direction there is nothing but barren, stony hills, and equally barren plains. (RGS,1881,p.515)

> Maibut is a large thriving village of one thousand houses, a considerable acreage of mulberry trees,(Floyer, 1882, p.359)

> Maibut itself lay embowered in trees on our left. In two hours more we were drawing near to Ardakan, and the town began to separate itself from its green suburbs, and to stand out as a small fenced city, enclosed within a wall with gates and towers, mud-built.
>
> Ardakan had a population of about 10,000. There is a saying that Yazd is a large village, and Ardakan a small city.(Stack, 1882, p.6)

This saying may provide a key to the present day distribution of the badgirs of the Yazd Basin. In 1882 the populaton of the walled city of Ardakan was 10,000 (Stack, 1882, p.6). Ardakan expanded beyond these walls only in the 20th century (Bonine, 1980, p.90) and despite expansion of

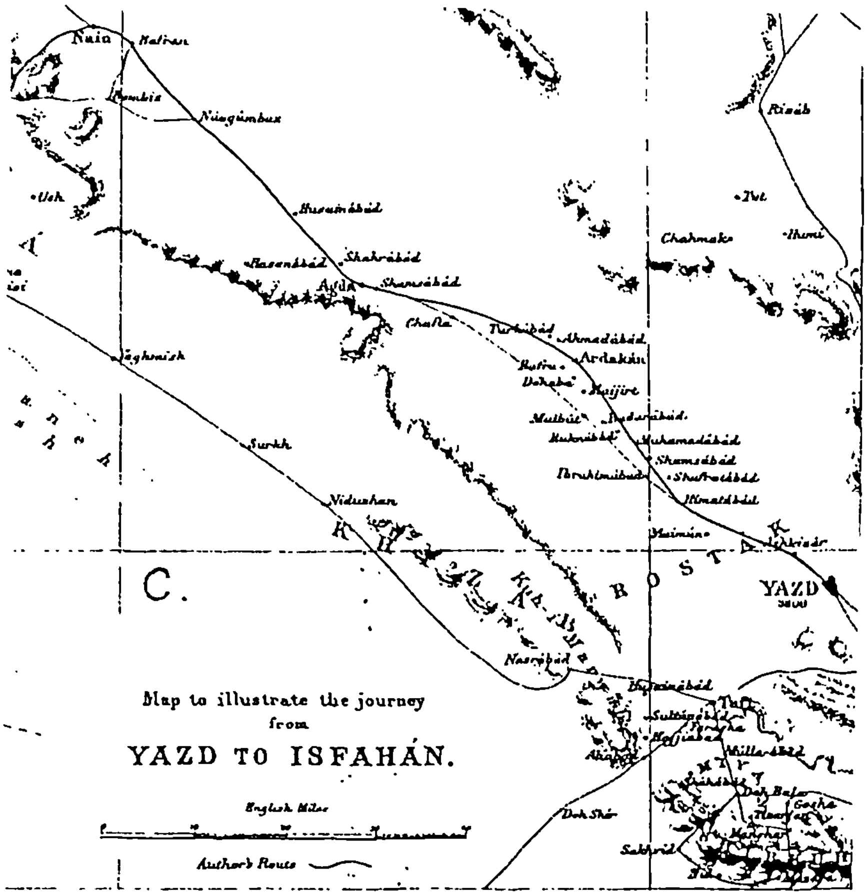


Figure 4.2. Map of settlements in the Yazd basin recorded by Stack, 1882.

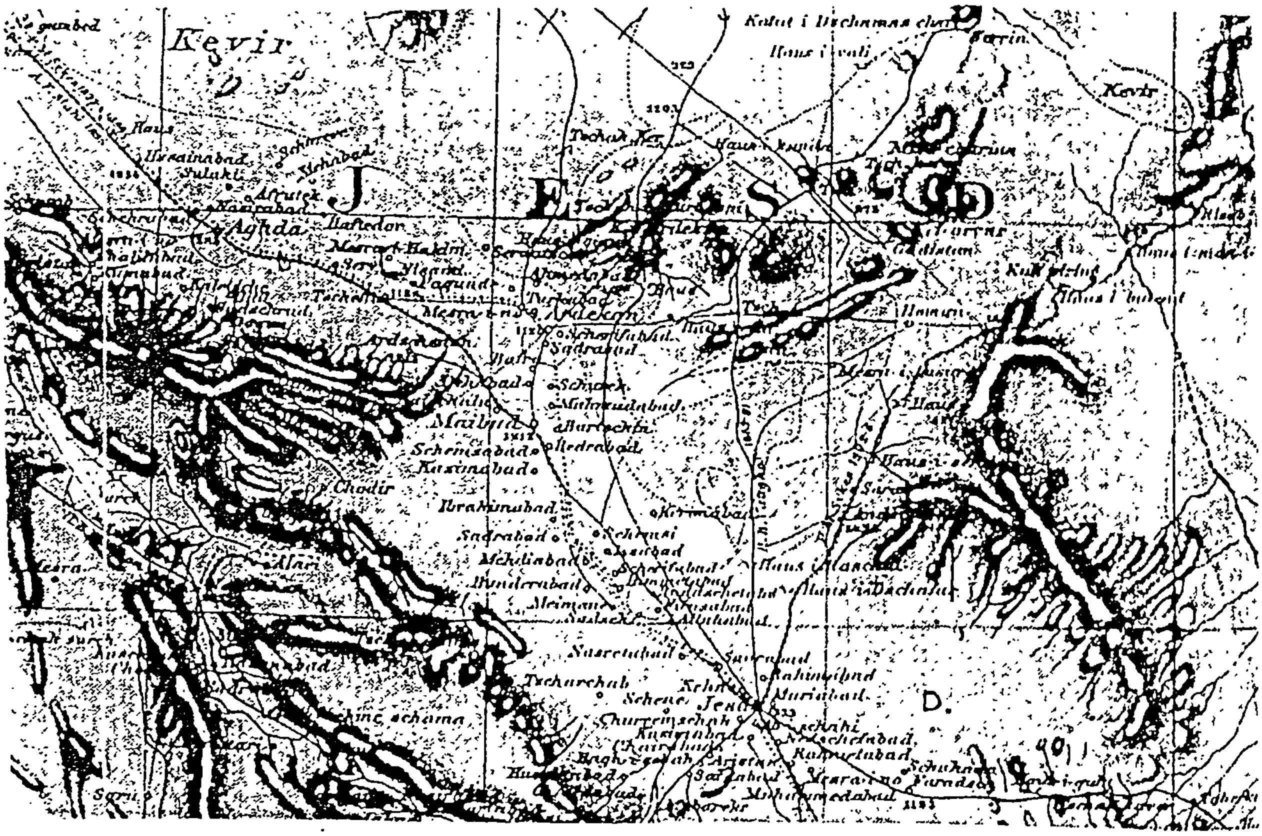


Figure 4.3. Map of the Yazd Basin by Sven Hedin, 1902, showing over double the number of villages between Yazd and Ardakan that were on Stack's map of thirty years earlier (Hedin, 1902).

the town after the building of a main road by the south and west wall of the city linking Yazd to Tehran in 1933, the population of Ardakan by 1966 was only 14,333 (Bonine, 1980, p.90). This suggests that Ardakan was not a centre of major expansion in the late 19th and 20th centuries. In the Maibud area, already well established by the mid-nineteenth century no new villages were built after 1850 when Abbott completed an inventory of settlements in the area (Abbott, 1853, FO.251/42/9059, pp.71-77). It may be suggested that there was a certain degree of stability in the population of the Ardakan / Maibud area, a stability reflecting the antiquity of settlements in the area and reflected in the unchanging use of the uni-directional low badgir which was used in the 15th century in the area.

An investigation of the development of Yazd may illustrate at what point the histories of the two adjacent population and market centres diverged.

4.5 THE HISTORY OF THE EVOLUTION OF YAZD CITY IN RELATION TO THE USE OF BADGIR TYPES IN THE CITY.

4.5.1 Method of historical investigation

The dating of the badgirs of Yazd, although disparate texts from architectural historians, historians and geographers were used, is largely taken from accounts of early travellers who visited the city, writing in, or translated into, English or French.

Several short histories of Yazd are also drawn on (Curzon,1892,pp238-244; Lockhart, 1939, pp.106-111; Bonine, 1980, pp.12-25;) and the works of architectural historians (eg.O'Kane,1976,pp.79-92).

4.5.2 Early history of the city of Yazd to the 15th century

The city of Yazd is of great antiquity (Curzon, 1892,p.238-239). However there is little historical record or archaeological evidence of its early history. By the 10th century it was an important trading centre, when Ebn Haukal, the Arab geographer, wrote of the district of Yazd that it was the most considerable division of the Koureh of Istakhr, the province of Isfahan, and was served by main roads from Isfahan, Kerman, and across the desert to Khorasan. Its early name was Kattah and it was one of the three places in the province with a mosque, the others being Meibed and Mahein (modern Maibud and Nain). The city of Kattah (Yazd) was well built and fortified and had two iron gates, bab izad and bab al-masjid, the latter being near the mosque in an extensive suburb. A small stream flowed out of the castle hill and it was an extremely fertile area. There was a lead mine in the vicinity and a flourishing silk industry. Yazd was built of sun dried mud bricks and each house had a cistern fed by channels that brought water from the hills (Curzon, 1892, pp238-242).

When the Muslim Arabs invaded Persia in the 7th century A.D. they inflicted widespread persecution on the Zoroastrian faith, the main religion of Iran then, and the

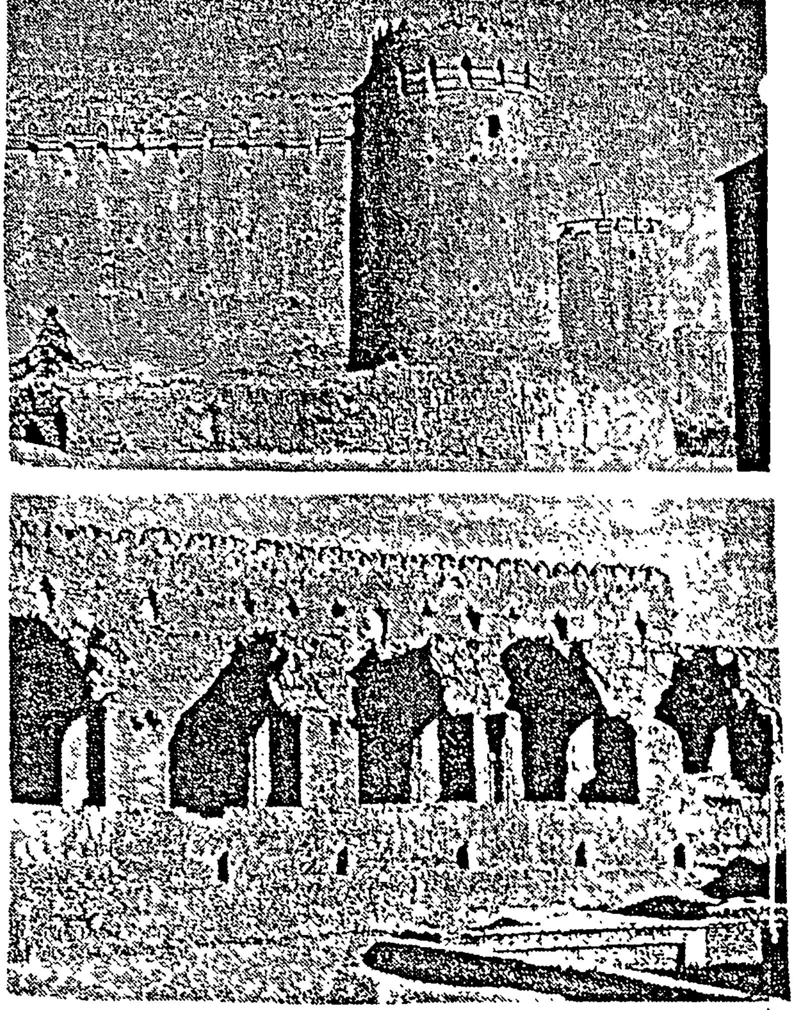


Figure 4.4. Two views of the 14th century mud walls of Yazd. (Afshar, 1969-70, vol.2, plate 158)

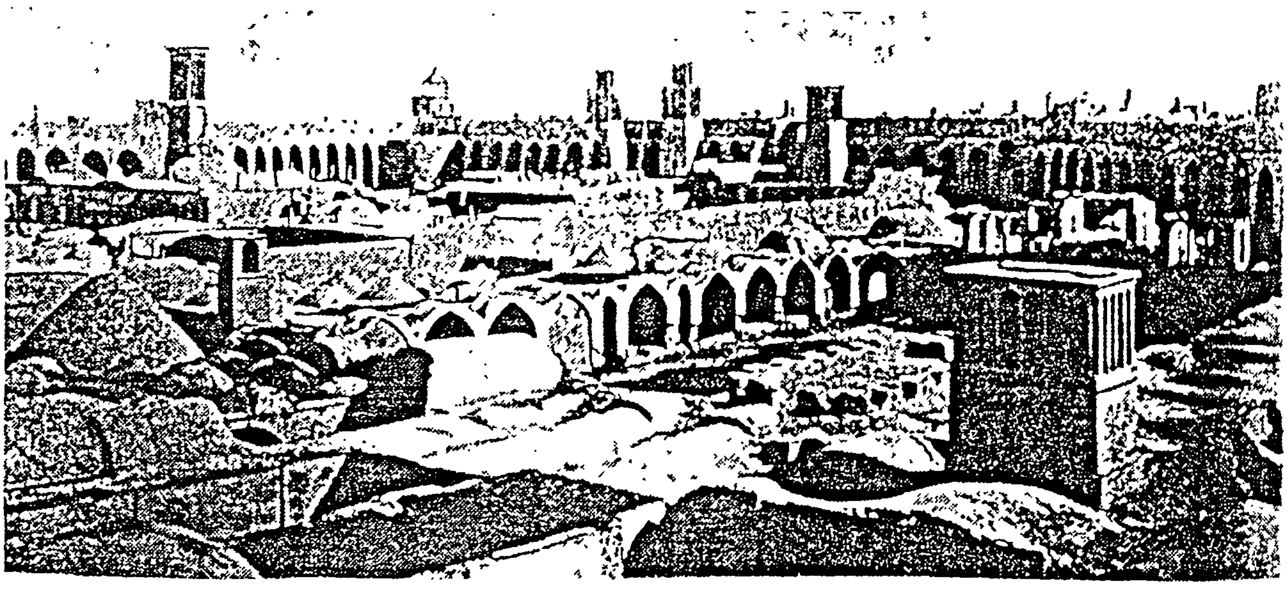


Figure 4.5. View of the walls of Yazd from within the old city. (Napier, 1905, p.215)

fire altars of Media and Hyrcania were extinguished and acolytes of the religion escaped to the more secure, isolated areas of Yazd and Kerman (see Boyce,1975 and 1979). Both these cities are still centres of Zoroastrian populations in Iran.

From the 11th to the 13th centuries Yazd was the capital of an independent Atabeg dynasty and it was during this rule that Marco Polo passed through the city in 1272. He wrote of it:

> Yasdi is also properly in Persia; it is a good and noble city, and has a great amount of trade. They weave there quantities of a certain silk tissue known as YASDI, which merchants carry into many quarters to dispose of.
>
> When you leave this city to travel further, you ride for seven days over great plains finding harbour to receive you at three places only. There are many fine woods (producing dates) upon the way ..... at the end of those seven marches you come to a fine kingdom which is called Kerman. (Yule, book I, p.88)

Polo describes the windcatchers of Hormos in some detail (see 1.6) but does not mention them in Yazd. This lack of reference to badgirs occurs again and again in traveller's accounts before the mid-nineteenth century.

4.5.3 Yazd in the 15th century to the late 18th century

In 1474 the Venetian Josefa Barbaro described Yazd as follows:

> From thense, following on or. waie we came to Jex, a towne of artificers, as makers of sylkes, fustians, chamlettes and other like. This towne is walled, of v miles in circuite, Wth. very great suburbs,..(figure 4.4)

He described the trade in silks between China, India, Russia Turkey and Syria and described the caravanserais in the city which he called then Fondacos: (Barbaro, 1873, p.73)

However it is known that there were badgirs on the houses of Yazd in the fifteenth century, and the evidence of extant early examples suggests that 15th century badgirs were fewer in number than later, and were of the Khargird model, that is low and facing in one direction generally, and therefore less obtrusive than those in Bushire, Bandar Abbas, Lar and Hormuz (1.6).

However by the seventeenth century travellers still did not mention the badgirs of the city. Tavernier, who wrote with interest about the wind chimneys of Lar and Ormus (see 1.6 and Tavernier, book V, page 254) (figures 1.20 -1.23), described Yezd' in some detail, having spent three days there, in 1678:

> 1678 - It is a great Town (YEZD) in the middle of the Sands, that extend themselves for two Leagues around it:.... Between the Town and the Sands there is a little good soil, which produces excellent Fruits, ... There are three Inns i'th' City, and several BAZARS or Market-places cover'd and vaulted, which are full of Merchants and Workmens Ware-houses. (Tavernier, Book I, p.44)

Tavernier does not mention any wind chimneys at all in Yazd. One may therefore surmise that they were still not as visible as when described by later travellers.

Yazd was beseiged in 1724 by the Afghan leader, Mahmood, who took Isfahan and Shiraz but was twice thwarted by the Yazdis. The city was briefly described at that time by a Jesuit priest, Kruisinski:

> 1722-24 - About ten Days Journey from Ispahan, in Rout to Candahar, there is a pretty strong City, called Jest, or Yesd,.. (Kruisinski,1728, vol.II,p.144).

This 'pretty strong' city must have been built largely within its walls, or at least those inhabitants outside the

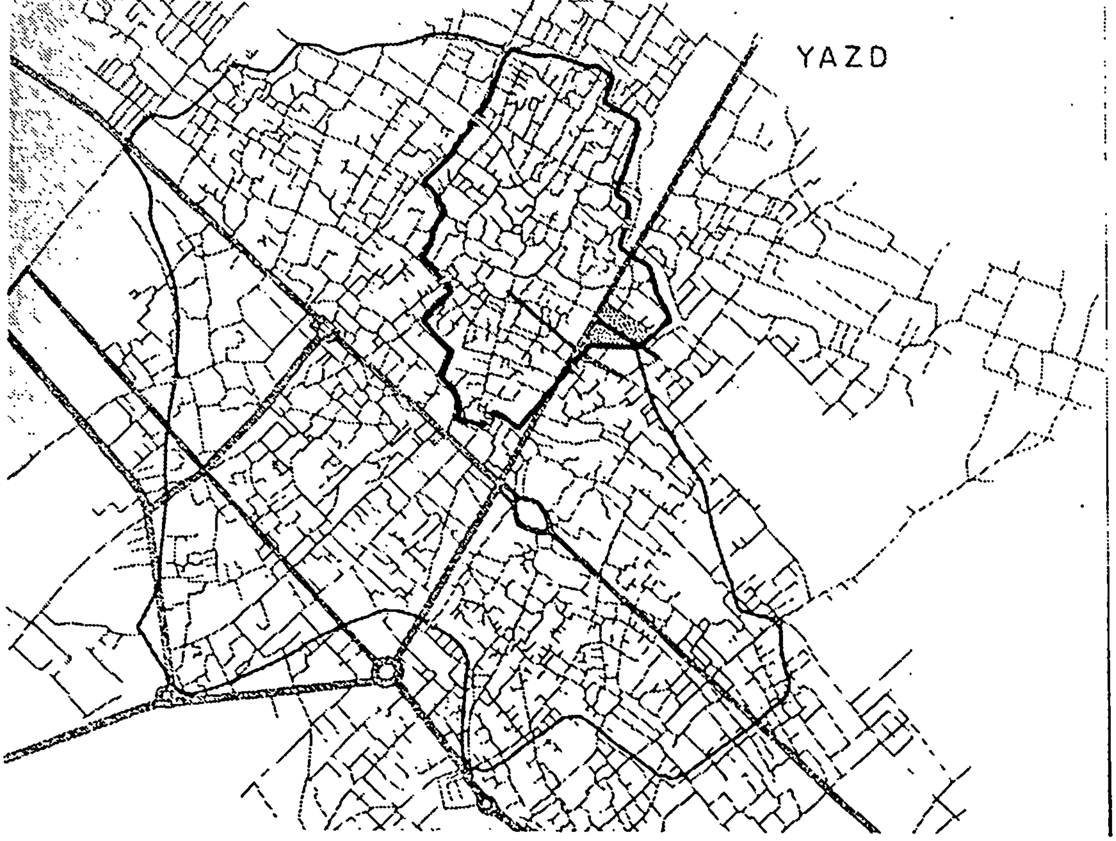


Figure 4.6. Plan of the city of Yazd showing the location the 12th and 14th century wall and the later outer wall built in the 1820s (Bonine, 1978, p.211).

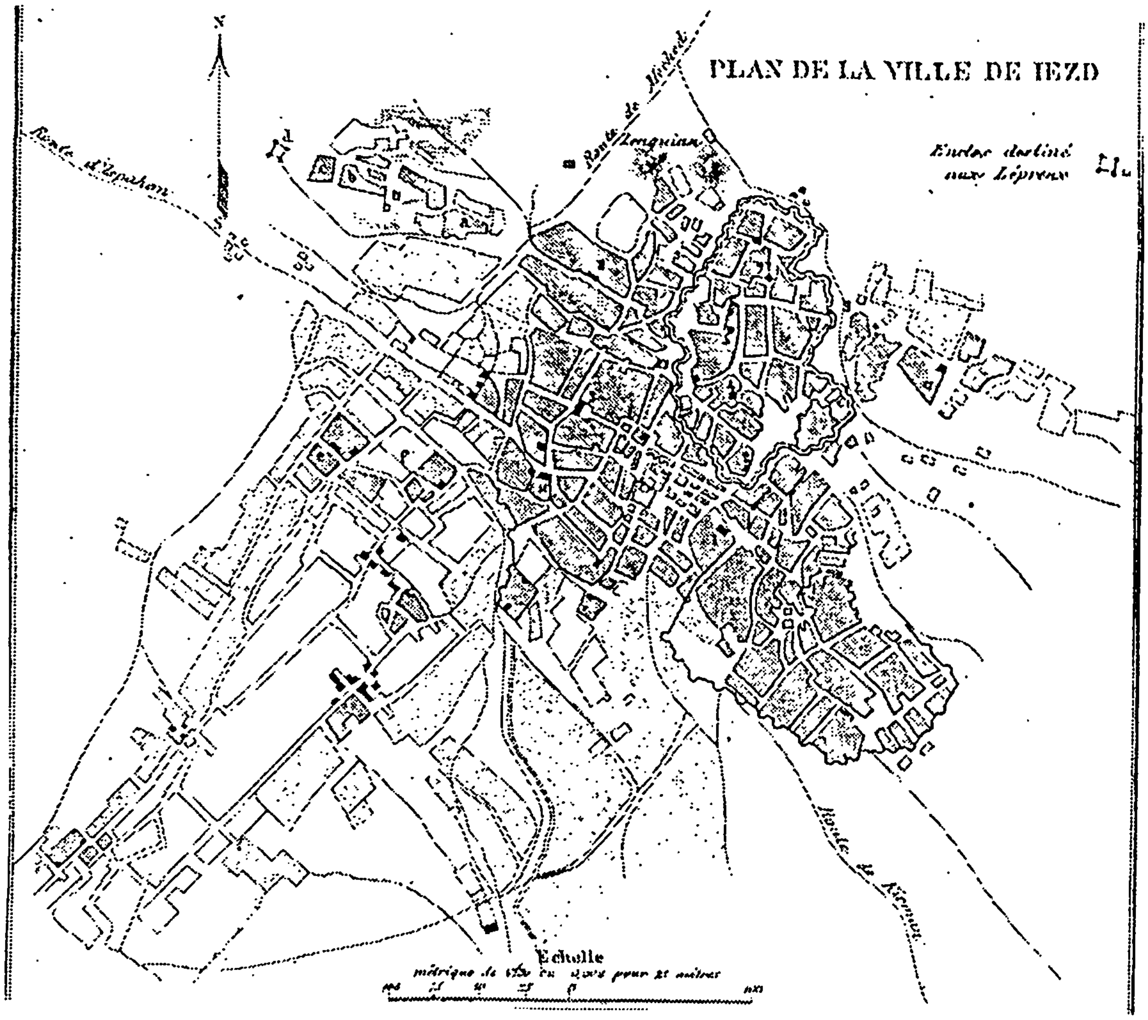


Figure 4.7. Map of Yazd in the 1850s. (Khanikoff, 1873)

walls would have sought refuge within the encircling walls that had been built by Mohammad Muzaffar in 1346-7 and still stood intact to withstand the ferocity of the Afghan attack (figure 4.6). Mahmood apparently had allied with some Guerbers (Zoroastrians) who were to have opened the doors of the city to him but were discovered before they could betray the city. During the turbulent 18th century few Europeans visited Yazd.

4.5.4 Yazd in the nineteenth century

At the beginning of the nineteenth century an influx of visitors provided a more complete record of the city:

> Yezd is a very large and populous city, situated on the edge of a sandy desert, contiguous to a range of mountains running east and west.
>
> The city has a mean appearance, and has once had a wall, part of which still remains. (Pottinger, appendix, p.421 and 422).

In the 1820s a new city wall to the south of the old city was constructed by Valli Mirza.(Bonine,1980,p.15)

> 1831 - The city of Yexd is situated near the foot of the range of mountains which bound the plain to the westward, and it is about 5 miles in circumference. The town, though walled, was easily taken by Hassan Ali Mirza; but he was unable to gain possession of the ark (citadel), in which 'Abdu-l Riza Khan held out until he was relieved by 'Abbas Mirza. The latter is surrounded by a strong wall and deep trench, and contains a palace built by Mohammed Wali Mirza, together with several other public buildings, and the residences of a number of the chief men of the district.
>
> The bazars in the outer town are spacious, but were at this time almost entirely abandoned, having been plundered by Hassan 'Ali Mirza's Troops.....
>
> The country having been for sometime the scene of civil war, famine, as a natural consequence, had ensued; and provisions of all kinds were so exceedingly dear that

> the poorer classes were unable to purchase them, and numbers died of absolute starvation.' (Gibbons, 1841, p. 139)

Now we come to one of the most telling accounts of the mid-nineteenth century. The first is that of Abbott who visited Yazd in 1849-1850, and completed a detailed foreign office report on the city. The report is written in two different hands. The second is perhaps that of Lord Clarendon who may have accompanied him as suggested by Khanikoff (1861, p.64).

> The city is enclosed by a ditch and double wall with numerous detached towers around it, all in tolerable repair and its circumference is about 2 1/2 miles - the area within being crowded with houses and gardens. At the Eastern side within the walls stands the Narenj Kaleh or Citadel, an irregular square of about 400 paces in diameter, possessing a ditch, double wall and towers, but it is now only occupied by a few ruinous Barracks for soldiers. The city is surrounded by the habitations and gardens forming the town, which is the most populous division of the place and , I should suppose, must be 5 miles in circumference. A low wall was drawn around it during the rebellion of Abdool Rezah Khan, in Futteh Ali Shah's reign, which is partly in ruin.(In the hand of the first author - Abbott?, 1853, FO.251/42/9059, pp.33-34)
>
> The town (Yazd) is much like other places in Persia; but it does not possess extensive garden or field cultivaton beyond the walls; and it is situated in the midst of a sandy desert. The bazars are generally mean; though that is necessary in the way of provisions etc. - is found there in abundance; (The hand of the second author - Lord Clarendon?, 1853, FO.251/42/9059, part II, p.30)

The second detailed account was published in 1866 by a Russian traveller, Khanikoff (figure 4.7). He too gives a detailed description of the city in the middle of the nineteenth century without mentioning the badgirs:

> The part of the city that offers actually the most interest to travellers is, without doubt, the rich vaulted bazaar, around which are grouped the numerous material manufacturers, dyers and makers of sugered sweets, establishments which form the base of the commercial wealth and importance of Yazd. (Khanikoff, 1866, p.202)

Khanikoff provides a map of the city on which there is no indication of the presence of badgirs in the city (figure 4.7).

No mention of the towers is made by Goldsmid, or his companion Major Smith, writing in 1867 (pp. 274-285).

> The greater part of the town is built outside the city wall, and the Governor lives in a separate fortified enclosure of his own. As in almost every town in Persia ruins are super-abundant. The inhabitants account for this, first by the Afghan invasion nearly 150 years ago,and more recently by the rebellion of one of its governors... (Goldsmid,1867, p.277)

There appears to be a turning point in the history of the badgir in Yazd. General Goldsmid, writing 10 years after his first visit in 1867, tells of three important events that had occurred in the decade of the 1860s. There was a great famine, a new bazaar was built, and badgirs appear as a dominant feature of the skyscape of Yazd.

> The famine which has been desolating Persia for nearly two years was nearly over.
>
> Towards the end of 1870 I marched down the road to Bushire from Shiraz... At every halting place crowds of famished half-naked men and boys (the women and children were nearly all dead) thronged around our camp, too weak to beg...
>
> Yazd, Isfahan, and Khurasan were the greatest suffered .... The population of Isfahan, Yazd and Mash-had were diminished by a third at least....
>
> The city is large and comparatively populous: but it has few buildings save one mosque worthy of notice; and it is chocked with ruins within and around. The new bazar looked handsome enough of its kind; but the older bazars are very dark, ruined and dirty; and we saw in them small signs of life or active trade.' (Goldsmid, 1876, pp 170-175)

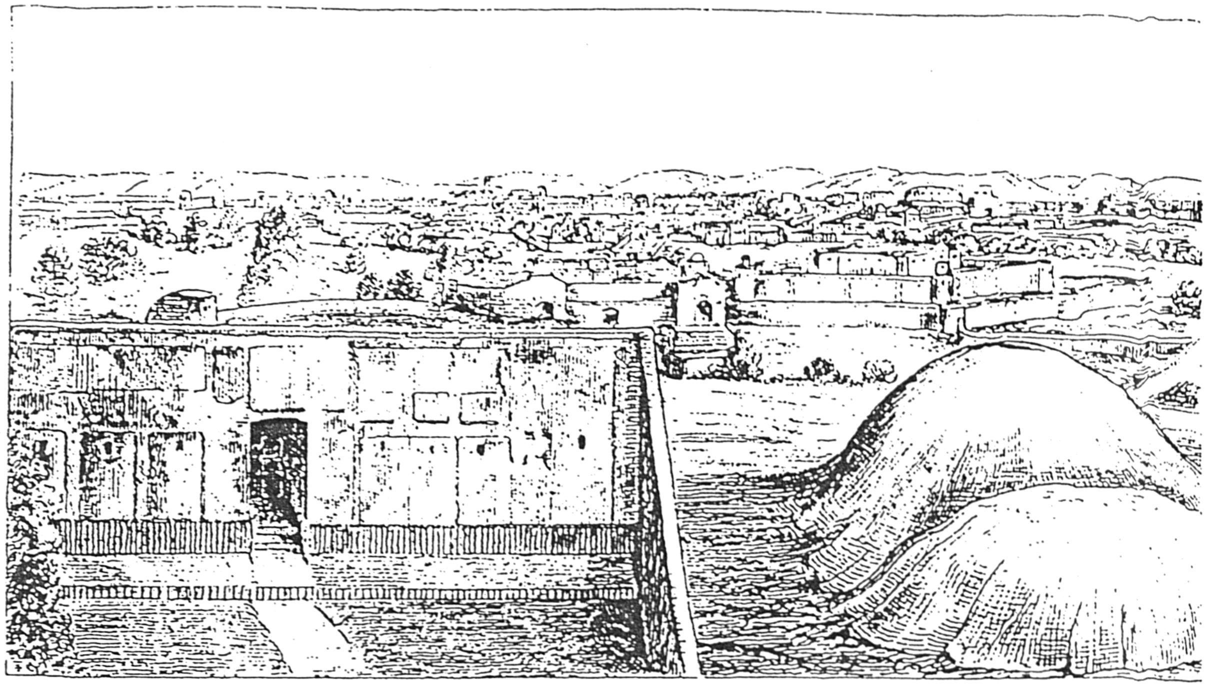
> At this point the minarets and badgirs of Yazd were visible. (From Gird-firamuz a village some six miles from Yazd) (Goldsmid, 1976, p 172)

An astounding fact is the lateness of this earliest eye witness account of the windcatchers of the city. The first recorded one by an English traveller, Goldsmid, on his visit in 1871 (the account of which was published in 1876), after which time almost every traveller mentions them and they become one of the first things to be mentioned on any approach the city.

It was suggested that this lack of recorded sightings of badgirs prior to 1871 is the result of their absence in in Yazd. But it has already been shown that a number were built in the region by the 15th century. However their forms made them less noticable. They were probably at least lower than the post-1865-1870 models. It appears that some badgirs built after this date made an immediate impact visually probably due to the unusual height.

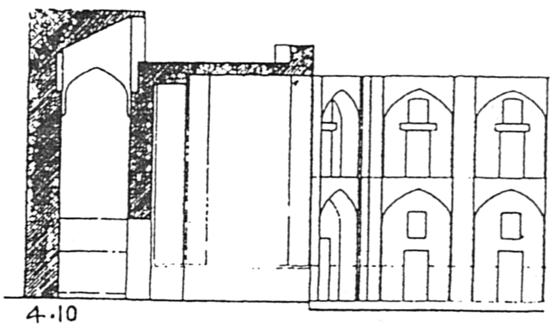
> 1879 - There are many fine gardens in the valley, (near Taft, 5 miles outside Yazd) among which may be mentioned the Bagh-y-Sad, where there is a well built house with a high "bad-geer" in it, and which many of the other houses also have.
>
> The view of Yuzd from any direction is extremely uninteresting, and presents nothing but a sea of house-tops, of a dead earth colour, only varied, but not relieved by numerous "badgeers".
>
> One of the most noticeable features of this place is the large number of "badgeers" (Literally an airy house. They are, as mentioned before, apartments built on the tops of houses, and open on all sides so as to catch every breath of air) "sardabs" (a subterranean room), and "zer zamins" (an apartment similar to sardab) which are met with, and which go to show that the climate is much warmer than in other parts of Persia above the passes.' (MacGreggor, 1879, pp.74-76)(figure 4.8)

> 1882 - Perhaps the abambars are the chief glory of Yazd. Their domed roofs are really noble, and the wind-towers which surround them testify to the care taken to keep the water cool.(Stack, 1882,p.266)



1. YUZO, FROM THE BAGH-Y-DOWLUT. [To face page 71.

Figure 4.8. Sketch of Yazd from the Bagh-e Dowlatabad by Magreggor (1879, p.71). Note the city walls in the distance and the ice-houses in the foreground to the right of the picture.



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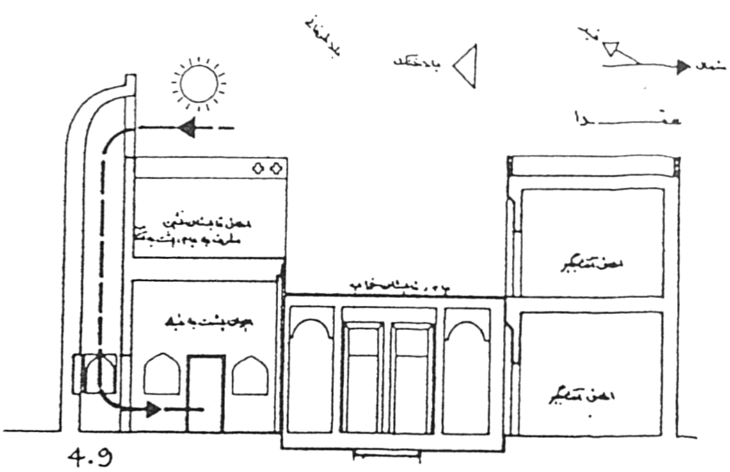

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Figure 4.9. House in Aqda, measured in the 1970s and published by Tavassoli in 1975 (p.20),

Figure 4.10. Section through the 15th century badgir on the school at Khargird in Khorasan (O'Kane, 1976, pl.4)

1882 - The very large and important city of Yezd lay in the far distance, stretching right across the horizon. Its lofty minarets seemed innumerable (many must have been badgirs - S.R.), and it was many years since we had seen a city nearly so large and important. (Floyer, 1882,p.351)

1888 - As we approached it (Yazd from Shiras via Taft), I was much puzzled by the nature and function of the numerous tall chimney-like structures, the like of which I had not hitherto seen. Knowing that Yezd gloried in the title "Daru'l-Ibadat" (the Abode of Devotion"), I was for a moment disposed to regard them as a new variety of minaret; but I soon learned that they were really BAD-GIRS or wind-chimneys, designed to collect and convey into the interiors of the better class of houses such breaths of fresh breeze as might be stirring in the upper regions of the air which lay so hot and heavy over the sun-parched plain. (Browne, 1888,p.396)

1890 - A curious feature here is the great number of wind towers; these are high square erections, rather top-heavy, and resembling an old fashioned kitchen clock with the face knocked out, through which the wind pours down into the lower rooms of the houses, and keeps them cool during the summer months, when the heat is so great that many people live altogether in subterranean apartments. Others who can afford to leave their business retire to their summer houses on the Shir Kuh and there pass the summer. (Vaughan,1890,p.585)

1892 - The new arrival (in Yazd) finds something imposing in the great extent of buildings, in the fortified ENCEINTE of the citadel rising from the interior of the town, in the numerous wind-towers, and in the minars and the front of the Musjid-i Jami, or Great Mosque. (Curzon, 1892,p.240)

1905 - Also there are, sticking out from the town, a lot of high square air shafts, looking like short factory chimneys... (Napier,1905,p.7)

...Also there is the inevitable bad-gir, or square air-shaft, running down to the back of the large portico, or TALAR, and furnished at the top with long slits on all four sides to catch any air that may be moving. (Napier,1905, p.14)

4.5.5 <u>The rise of the 'high' badgirs of Yazd</u>

It may be concluded from traveller's descriptions that the first big badgirs were built in the Gulf ports and recorded by Marco Polo at Hormos in the 13th century. Later in the

17th century they are widely reported along the Gulf coast in Lar, Bushir (Gombroon) and Hormuz, and in Shiraz (1.6).

The high' badgirs of Yazd not mentioned by European travellers until 1871 when Goldsmid visited the city, describes also the new bazaar in the city. This was not due to the absence of badgirs in the area prior to that date. So what brought about the change? More detail of the city history may provide an expla nation.

In the first half of the nineteenth century the city of Yazd was torn by civil war and famine. Mohammad Valli Mirza, son of Feth Ali Shah and Governor of Yazd in the 1820s, was recalled to Tehran by his father and in his absence his Vizier, Mirza Abdul Rezak took possession of the city and raised an army. On his return the Shahzadeh (son of the Shah) brought an army and seiged the city. During a long defense, during which the city was almost destroyed, Abdul Rezak was was forced to flee..(Goldsmid, 1867,p.277; Abbott, 1853, pp.2-3). This prompted Mohammad Valli Mirza to build a new wall around the south of the city. However the bazaars in the outer city were in ruins in 1831 when visited by Gibbon:

> The bazaars in the outer town are spacious, but were at this time almost entirely abandoned , having been plundered by Hassan Ali Mirza's troops....(Gibbon, 1841, p139)

The civil war and famine had reputedly reduced the population of Yazd from 100,000 at the beginning of the century to 40,000 in the decade of 1860-70 (Curzon, 1892,p.240). Then a new prosperity led to the building of the new bazaar (Goldsmid,1876,p.175) on which the high badgirs first appeared.

The reason for the new prosperity in the city was opium. In the Abbott. report to the foreign office of 1853 the following was written:

> The Opium is of a quality much esteemed in Persia; and though its production is at present limited by demand, I believe that it might be obtained within a moderate period to almost any amount for which a market could be found (Abbott, FO. 251/42/959, 1853, p.24)
>
> The amount of it obtained yearly varies considerably, and seems to depend on a very uncertain demand; it may have been in 1849 - about 1,300 mens shaheh (equal to 17,001lbs) which was stated to be less than usual; and a great deal more might be produced in a short time on order. Occasionally an active demand occurs for it for Meshed and Afghanistan (probably for China through Bokhara and other parts) for which market it is said to be well suited.
>
> In 1849 - the price was toms.(tomans) 10 per men (= 91s/- for 13lbs) for such as had undergone the thorough process of kneading and purifying, and toms.xx (illegible)(= 65s/- to 67s/6d) for such as had not.
>
> The Guebers are the principal cultivators of the poppy, which is raised in about 21 villages around. (Abbott, 1853, FO. 251/42/9059, pp.110-111)

A number of later authors mention the opium trade and the best description of it is by Stack in 1882.

> The grand staple of Yazd is opium. All the fields around the city, while I was there, were white with poppy, and the time for gathering the opium had just begun.... The crop seemed a magnificent one; I had not seen such tall strong poppy in India, with such full heads. One must also remark the growth of trade during *late years. The first hint I had of this* was in Qazran, *where the cultivation of poppy has* lately been introduced, and is revenue-free. The Zarand district has recently begun to raise opium on loans advanced by Yazd merchants; thus in Sar Asiab and Chatrut we were told that Gabrs from Yazd had come last year for this purpose, while in the neighbouring village of Gurcha the people had not yet learned poppy cultivation. Kuhbanan seemed wholly given over to poppy. The opium trade of Persia dates from the Chinese war. In the security afforded by the British occupation of Hong-Kong, Persian opium began

to find its way to China. The prohibitive duties in the Indian ports were a great obstacle, and for a long time more opium went to Constantinople than to Hong-Kong. The the route via Ceylon was struck out by certain merchants of Yazd, and now in these latter days opium is shipped direct for China from Bandar-Abbas by steamers of the Peihi Company. Last years export was 6000 peicul or boxes; this years export (1881) is expected to reach 8000 boxes. In 1871 the export was 4000 boxes. Thus the trade has doubled in ten years, and perhaps is increasing now faster than ever before. Reduced to English figures, the weight of 6000 boxes would be equivalent to 360 tons, and of 8000 boxes to 480 tons. These figures do not look formidable, especially when we remember that the Indian trade is ten times as great. Still if the shah could bring himself to spend some of his hoarded money on improving communications with the sea, it seems quite possible that the rivalry of Persian opium might be sensibly felt in India. The Persian price is somewhat lower than the Indian....

Next to opium, silk is a notable product of the Yazd district, but the industry has much declined of late. There were 1800 silk-houses here a few years ago, there are scarce 150 now; (Stack, 1882,pp.263-265)

Opium replaced silk as the principal product of Yazd after the Anglo-Chinese wars of the 1850s, which opened China to international trade (Curzon, 1892,p.242) and led to a boom in the economy of Yazd which in turn almost certainly led to the building of the new bazaars and houses on which high badgirs were built. Neither Khanikoff writing in 1866 (p.202) nor Goldsmid in 1867 (pp.274-285) mention opium as a main crop, a role they attribute only to silk. By 1876 4000 chests a year were being exported via India, despite the heavy duty on it (Goldsmid,1876,p.175) and by 1888 the increase in export since 1849 has exceeded fiftyfold.

The new economic upsurge in the trade life of Yazd, due to an 'opium boom' was concomitant with a new trend in badgir height. The increased badgir height may also indicate a a new badgir type in Yazd in the late 19th century. The Subsequent expansion of the city and villages of Yazd followed. Chapter 6 deals with the relationship between date and tower type in the city of Yazd and chapter 8 investigates the forms and distribution of the highest towers in the city (8.6).

4.6 CONCLUSIONS ON THE INFLUENCE OF HISTORICAL FACTORS ON THE DISTRIBUTION OF BADGIRS IN THE YAZD BASIN.

While influences on the design of badgir types originating from local market centres, or from patrons from outside the area (4.2.3 and 4.3.2) appears not to be of any real importance in the exposed settlements in the northern desert areas, such historical factors may have played a key role in the distribution of badgir types in the Yazd basin.

Climate is obviously important in the choice of badgir type, in the Yazd basin this may be particularly true in the more exposed locations on the fringes of well-treed population conglomerates, bordering open desert where climate dictated badgir form and orientation (3.5.7).

However the distinctive pattern of uni-directional towers in the centre of the basin, associated with the population centres of Maibud and Ardakan, may also be related to the traditional use of uni-directional towers in this area, dating back to at least the 15th century, and the independence of the traditional building industry of the Ardakan/Maibud area from the influence of the city of Yazd.

There is evidence of a market in Ardakan (and to a lesser extent Maibud) serving the north-west of the Yazd province which extented traditionally to Aqda. The hinterland of this market centre co-incides closely to the limits of the uni-directional badgir towers in the Yazd basin. This similarity suggests that the building industry of this market centre generated a badgir type copied in the villages of its hinterland, a type which appears to have changed little since at least the 15th century. This continuity of use of a single badgir type in the Ardakan/Maibud region, despite a revolution in badgir design, centred on the high badgir, that appears to have occurred in the adjacent area of Yazd in the late 19th century suggests a high degree of independence in the traditional buildings industried of the two adjacent areas of the Yazd basin [figures 4.9 and 4.10].

The lack of expansion in the central settlements of Ardakan and Maibud after the latter quarter of the 19th century may suggest a stagnation in the development of these towns, reflected in the stagnation in the evolution of badgir design in the central oasis. In short it may indicate a conservative traditional building industry in these towns.

In contrast the new prosperity of the city of Yazd in the latter part of the 19th century seems to relate to the building of high badgirs in the city, and suggests that the badgirs in the city were changing where those of Ardakan/Maibud were not. Chapters 6-8 deals with the evolution of badgir types, their forms and distribution in the city of Yazd. These findings emphasise the strength and durability of the local building industries and traditions in the area.

CHAPTER 5

INTRODUCTION TO PART II AND III - RESEARCH DESIGN AND METHODOLOGY

7.1 QUESTIONS RAISED FROM THE GENERAL AND REGIONAL REVIEW

A review of literature on the subject of windcatchers in the Middle East in chapter 1 highlighted the need for an in depth regional study of windcatchers in order to determine the reasons for the use of different types of windcatchers in different areas, and to provided more detailed data on their function.

Chapters 2 - 4 dealt with the possible climatic and historical influences on the distribution of rural badgir types in the region of Yazd, and in so doing raised further questions which it will be attempted to answer in Parts II and III of this thesis based on field work in the city of Yazd.

At this point in the thesis the question of whether the mutitude of badgirs on the skyline of Yazd occured as a result of historical factors or for climatic reasons is still unanswered.

That the relationship between nurture and nature in the evolution of the bagdir is complex can be seen from the results of the village badgir survey where results in adjacent districts were very different, with climate predominating as an influence on badgir type and design in the exposed desert villages while historical factors, it is argued, over-rode these climatic considerations in the more sheltered Yazd basin. These findings are dependent on two assumptions:

1) that in the desert areas the climate may be unsuitable, probably too hot, for badgirs in some villages (3.6)

2) that in Yazd badgir design evolved from an earlier low uni-directional form to a high' badgirs frequently noted by travellers in the late 19th century (4.6)

Part II of the thesis deals with the question of the influence of historical factors on the evolution of the badgir in Yazd; and in Part III the significance of the summer climate of Yazd on the function and widespread use of the domestic badgir in Yazd and the implications of the findings for the definition of suitable' climates for windcatchers in other areas are investigated.

Parts II and III of the thesis are based on two periods of field work in Yazd. During the first, in 1976, a survey of the badgirs of the centre of Yazd city was completed. In the second field trip during 1977, the measurement of climate in and around the houses and badgirs of Yazd and the measured drawings of the urban houses were completed.

5.2 STRUCTURE OF PARTS II AND III

In part II the investigation of the history of the evolution of the badgir in the context of the house (chapter 6), the diversity of badgir types and sizes in the city (chapter 7), and the attempts to date badgir types and sizes in relation to their location in the city (chapter 8), provides an understanding of the extent to which historical factors may have contributed to the range of badgir types, their proliferation, and importance in the city of Yazd.

In part III, in chapter 9, the measurements of climate in the houses and badgirs of Yazd are presented as an indication of the general temperature range experienced in summer in the houses of Yazd.

In chapter 10 the climate of the house is then considered in terms of the spaces occupied during the day and behavioral strategies employed in ameliorating the summer climate, and the impact of the badgir on the occupied climates of the houses.

The general temperature ranges outlined in chapter 9 and 10 are then considered in terms of western comfort standards and in respect to the physiological responses of the body to high temperatures (chapter 11). In so doing it is hoped to arrive at some limits by which a climate can be judged to be suitable or unsuitable for the use of the badgir. In so doing it may be possible to understand if, or why, the climate of the city of Yazd is particularly suited to the use of the badgir while in more exposed areas of the Yazd region the climate appears to be unsuitable for the use any, or a particular form of badgir.

The conclusions on the relative importance of historical and climatic factors on the proliferation of badgirs in the Yazd region are outlined in chapter 12, followed by a consideration of the implications of the findings in relation to would-be users of windcatchers in the modern buildings of the Middle East.

An outline of the methodologies employed in Parts II and III of this thesis follow.

5.3 AN EXPLA NATION OF PART II - THE SURVEY OF HOUSES AND BADGIRS IN YAZD

Secondary sources outlined in chapter 6 indicate that the largest badgirs in Yazd may have been built in the late 19th century as a result of fashion and economic prosperity. This hypothesis can be investigated in two ways which provide the best possibility for dating the badgirs of Yazd: The first is to date the houses of the city and to see if there is any relationship between house date, house type and badgir type. This may show that houses prior to the late 19th century had large high badgirs; in which can the initial hypothesis must be re-examined. The dates and development of the domestic architecture of Yazd investigated in chapter 8.

The second method of dating the badgirs was by locating and surveying all the badgirs in the city centre and then to date the suburbs or neighbourhoods of the city in which they were built. Thus by building up a picture of the development and expansion of the city into different areas it was hoped to be able to relate this expansion to the occurrence of different badgir types associated with suburbs of different dates, and by so doing date badgir types.

Thus in this historical investigation of badgir types by date two different methodological approaches were used, firstly the investigation of house and badgir type by date using surveyed houses and secondary sources, and secondly by plotting badgir types and location in the city through survey and dating them by location using secondary sources.

5.3.1 The survey of houses in Yazd

Eight houses in the city of Yazd were selected and surveyed. Their dates range from the 18th century ruined house, D, (see 9.2) to the two courtyard house, G, built in the 1950s. These were chosen to provide a content of developing house types against which the evolution of the badgir could be seen. The choice of houses measured was primarily on date and size but an overiding factor was the accessibility of properties for survey.

Other available published house plans from Yazd (from Tavassoli, 1975; Afshar, 1969; Bonine, 1979) have been included in parts II and III to illustrate house types and the historical sequence of houses in the city.

It should be noted that the whole consideration of the evolution of the domestic architecture of Yazd has been severly hampered by the almost total lack of comparative studies of traditional domestic architecture in Iran. The findings on the evolution of house types in Yazd represent the first published attempt to classify chronologically house types in any region of Iran.

5.3.2 Problems with dating houses in Yazd

Mud brick houses are often very difficult to date by details, and few written records of house dates are kept in Yazd; therefore as recounted in chapter 8 much care has been taken to attempt to arrange the house types chronologically, in order to date the phases of the development of the domestic badgirs of the city.

Decoration is an obvious dating tool, but in Yazd so many of the everyday decorative details date back to at least the 15th century that only exceptionally is decoration useful. Vaults and domes have generally changed little since the Middle Ages (Godard, 1949). The introduction of the metal 'I' beam in the 1910s-20s is an obvious turning point, providing a very general dating tool, but most buildings with jack-vaulted roofs are either shops or offices.

A standard method of architectural historians is to use comparison with other similar buildings to establish the date of a structure. Here again problems exist. The paucity of published studies is one. No other detailed study of the regional vernacular architecture of Iran has been published in English. There are a few publications in which there are single illustrations of houses, whether line drawings or photographs; the majority were written in the last century, when travellers (Morier, 1816; Ouseley, 1819; Dubeux, 1843). Only one available book has been written specifically on the houses of the central Persian Plateau and that is a far-sighted book by Mahmood Tavassoli on the Architecture of the arid region' (1975). This provides one or two illustrations of settlements from the regions of Khorasan, Tabas, Kerman, Yazd to Kashan. It is an important book because it documents for the first time the tremendous regional variations in house design, but it does not attempt to date individual houses. There are a number of articles and books on aspects of Persian urban architecture, especially 'The Bazaar in Isphahan' (eg.Oliver, 1983) but these are offer little assistance in dating houses in Yazd.

Scholars who deal with 'Islamic Architecture' generally produce studies on a particular building or the monumental or religious buildings of a particular period (O'Kane, 1986) These are invaluable to the present study as they give an historical contextural 'style'. Of the few studies relating specifically to the Yazd area, the main historical thesis is on the 13th (Holod, 1972), although Siroux (1938 and 1944) and Godard (1939 and 1949) both published a number of studies on buildings in the area. An exceptional work is the 'Survey of Persian Art' (1938-1939) edited by Arthur Upham Pope, and first published in 1938. However the sections on domestic architecture are very general and the one paragraph relating to Yazd is based on speculative interpretation rather than on research and the relevant illustrations are wrongly dated (Pope 1938, pp.1224-1225). Other dates of domestic and some religious buildings in the publications have also been treated with caution (Pope, 1938, p.1218 35).

Two excellent studies of the area have been done by geographers. The first is a study of Yazd by Michael Bonine (1980) and the second a study of Kerman by Paul Ward English (1976), a city on which Philip Beckett has also written (1966). These have provided excellent background material but the central subject of these studies is not directly relevant to the present thesis.

The book that has proved most useful in the dating of the Yazdi houses is Tarikh-e Yazd, by Iraj Afshar (1969). This two volume work documents thoroughly many of the buildings of the area and his descriptions are clear and well researched. However, where houses are supplied with inscriptions, no distinction is made by the author between the inscription date and the original date of construction of the house, and therefore these texts provide interesting historical insights and some important dates but not conclusive evidence of construction dates. The nature of the dates must be clearly established as they often refer to dates of rebuilding rather than of original construction and some illustrations are clearly wrongly labeled (Afshar, 1969, vol.2, plate 32 - see figure 8.9).

The method eventually used by the author to attribute a date to a house was one of trial and error. Beginning with careful comparison between houses, groups of buildings were loosely dated to period. Then secondary references were referred to, such as those outlined above, and with the aid of inscriptions a general historical framework for the houses of Yazd was established. For dating of the 19th and

20th century houses one material, glass, emerged as the clearest dating tool. Glass was undoubtably the most expressive element in the courtyard facades, not only by its presence and absence, but also by where it was used, what type of glass, how it was used and its dimensions in situ. Post 1800 houses generally have double doors and windows facing onto at least three sides of the courtyard. Coloured and opaque glass was used in the 19th century and the early 20th century. Flat glass subsequently became widely available and opaque and coloured glass ceased to be used almost completely. In the 20th century, every 10 - 20 years a new and larger pane size was introduced and became the standard of the day. By using cross comparisons and local knowledge it has been possible to date the 20th century examples by the size of the glass panes in the windows of French doors. This has in turn led to the dating of other elevational features such as recessed window niche types. The use of glass as a dating tool has also facilitated the attribution of different courtyards of the same house to different dates.

In arranging the houses by date it has been possible to loosely outline the development of the badgir from the 18th century to the present day.

5.3.3 The survey of windcatchers in the city of Yazd

Having established a tentative historical frame work for the evolution of the domestic badgir in the houses of Yazd, confirmation of the findings on the development of badgir types in the city was sought from an investigation into the type, form and distribution of badgir types in the centre of the city described in chapter 7. This chapter is based on a survey of badgirs in the centre of the city of Yazd carried out by the author in April, July and August of 1976 in which 713 badgirs were recorded, listing listing up to thirteen attributes for each badgir including:

1) Location
2) Type
3) External cross-sectional dimensions
4) Height from the parapet wall to the top of the tower
5) Height from the parapet wall to the base of the vent
6) Position of the <u>badgir</u> in the building
7) Orientation of vents
8) Approximated age of the structure
9) Condition of the structure
10) Eave detail
11) Vent detail
12) Detail at the base of the vent section
13) Plan type.

The order of listing of attributes was arrived at through convenience for recording.

In the literature, while many authors, particularly architects, display an interest in Iranian badgirs there are very few contemporary published measured drawings of badgirs (Tavassoli, 1975; Beazley and Harverson, 1982) while other authors invent the dimensions of their diagrams (Bahadori, 1977 and 1978) and that other authors who deal fully with the vernacular architecture of Iran (Siroux, 1944) do not mention badgirs or include measured drawings (Wulff, 1966). This dearth of measured drawing has led to considerable confusion as to what an Iranian windcatcher looks like as exemplified by Bourgeoise's misleading description (1980, p.75) of windcatchers on the Iranian Plateau:

> Wind towers - tall to reduce the admission of dust - are topped by slender openings up to thirty-five feet high.

The survey was designed to provide a body of quantative material on the type and form of windcatchers in one city.

In chapter 7 the findings of this survey are outlined and patterns established for the various attributes. In this way generic groups of plan, vent and other details are recorded, as are the sizes of towers and orientation. The first quantative record of windcatchers in one city thus resulted. In it, not only can the overall characteristics of the badgirs be appreciated, such as the general direction in which they face, and their common forms, but also the idiosyncracy of each individual tower has been recorded.

In chapter 8 this data is applied to the question of the date of badgir types in the city with a view to finding out whether the majority of high towers in the city can be dated to the late 19th century and in turn to answer the question of the extent to which fashion, carried forward by prosperity, can be said to be responsible for the status of Yazd as the city of windcatchers.

5.3.4 Dating of suburbs

From secondary sources, and primarily those of travellers in the 19th century to Yazd (Pottinger, 1816; Khanikoff, 1861 & 1873; Goldsmid, 1867 & 1876; MacGreggor, 1879; Stewart, 1881; Floyer, 1882; Stack, 1882; Vaughan, 1890; Curzon, 1892; Napier, 1905), and the work of modern architectural historians (Afshar, 1969) and geographers (Bonine, 1980) it has been possible to loosely date suburbs in the centre of Yazd, generally included within city walls of known date, which in turn gives some indication possible date of badgirs in various suburbs.

The location of the eight dated houses within the suburbs substantiated this wider evidence but the techniques of dating by suburbs have a number of pitfalls: one is the common practice of building later infill housing within the fabric of the old city on the sites of earlier houses; the second is the location of the quarters of minority populations, such as those of the Jews and the Zoroastrians, outside the original city limits. Within the latter quarters there are houses of varying antiquity and the whole quarter may be engulfed later by expansion of building of radically different date. An interesting example of the early building of an outlying suburb is the Tehran quarter beyond the east gate of the Bagh-e Dowlatabad, built in the last two decades of the 18th century. The present suburbs of Yazd have only approached and surrounded this much earlier district in the 1960s.

The conclusions of chapter 8 show that indeed there was a fashion for high towers in the areas of the city developed in the late 19th century, a period at which individual master builders contributed to the new flowering of the 'classic' Yazdi badgirs. However it is shown in chapters 8-10 that badgirs were built in considerable numbers, of all types, in all parts of the city, and at all dates. Thus it is necessary to re-evaluate the question of the importance of climate in the widespread use of badgirs in the city and area of Yazd. This widespread use, while influenced at different periods by fashion, must be dependent on the suitability of the local terrain to the use of badgirs and in particular to the suitability of the local climate.

5.4 AN EXPLANATION OF PART III: THE CLIMATE IN AND AROUND THE BADGIRS AND HOUSES OF YAZD

The need for recording the climate around badgirs is clear. The aim of the thesis is to understand in what way and why Yazd is important as the centre for windcatchers in the Middle East. In order to do so the question of historical factors versus geographical factors as the determinants of the proliferation of windcatchers in the area of Yazd has been raised. To provide concrete answers to this question, statements such as suitable climate, and 'suitable winds' must be clarified and quantified.

The domestic architecture of the Middle East is enormously varied and the study of climate within the houses of the area involved a labyrinth of complexity. Variables abound such as geographical location, micro-climate, traditional house form, building materials, building elements, and considerations of how to assess 'comfort' in the context of climate.

Studies often deal with one aspect only of the morass of variables. For instance much work has been done on the performance of roofs (Koenigsberger and Lynn, 1965; Mukhtar, 1978; Givoni, 1962; Ahmad, 1974; Colonial Building Notes, nos.15 & 16, 1952), of windows and ventilation (Givoni, 1962; Givoni, 1965; Richards,et.al, 1960, Van Straaten, 1967; Koenigsberger, et.al, 1959; Webb, 1960), and of materials (Van Straaten, 1964; U.N., 1971; Oakley, 1961; Olgay, 1963; Lippsmeier, 1980; Givoni, 1981; etc). These are three of a wide range of design variables selected and researched individually and such reports are generally based on field or laboratory experiments.

A second type of research on the domestic architecture of hot climates has been based on the building of a research house, built of the traditional materials in the local manner. This has been done for instance in Sudan (Kuba, 1970), in India (Raychauduri, 1964) and Saudi Arabia in Dammam (Bajwa et. al., 1987). In the two former studies single mud-brick rooms were built and used as a basis for experiments. Interestingly Raychauduri found that the in-situ recordings taken in the experimental building diverged considerably from the predictions of responses of climate calculated prior to the in-situ temperature recordings.

A third area of interest to researchers is the performance of the courtyard within the house. To date no substantial work on the climatic performance of the courtyard has been published although subjective claims to its function in the house proliferate in print (Dunham, 1960. McHarg, 1969; Noor, 1986; U.N.,1971 etc.). On the other hand a number of theoretical mathmatical studies have been done on the potential performance of the courtyard in relation to the impact on solar radiation incidence of form and orientation of the house (Numan, 1977; Mohsen, 1978.).

Between these two extremes of approach to understanding the performance of the courtyard house, one based on subjective experience and the other on mathamatics, there are very few studies which have actually recorded the temperatures experienced in the courtyard houses of the Middle East which have been shown by Fethy and Roaf (1986) in Baghdad to have been very high, in the upper 40s centigrade during the day in mid-summer. Studies based on fieldwork in the Middle East such as Al Douri's doctorate (1985) provide valuable data by which 'theoretical' models of courtyard climate can be evaluated.

A fourth possible approach to the study of climate in traditional houses in the Middle East is to use an already formulated methodological analysis for the data as a yard stick by which to compare and contrast the data with established climatic criteria and the performance of houses in different areas. Research during this century has produced a wide range of heat stress indices such as the Equivalent Temperature Index (Bedford, 1936); Effective Temperature (Houghten and Yagloglou, 1923 & 1924; Yagloglou and Miller, 1925); the Corrected Effective Temperature (Vernon and Warner, 1932; Bedford, 1946; Smith, 1955); The Wet-bulb Globe Temperature Index (Yaglou and Minard, 1957); the Wet-bulb - dry-bulb Index (Lind et. al., 1957 & Lind, 1963); and the Predicted 4 hour Sweat Rate (McArdle et. al., 1947). Of such indices the Effective Temperature remains the best way of comparing and describing conditions at mild levels of heat stress and in the comfort zone (Fox, 1978, p.63) and is the most widely used by architects in tropical design, and is recommended by the School of Tropical Architecture, London, best exemplified by the work on the subject by Koenigsberger et. al (1973).

Since the mid-sixties an increasingly popular methodological tool for the analysis of climate has been Victor Olgay's 'Bio-climatic evaluation method for architectural application to architecture' (Olgay, 1963), on which has been based at least one British doctoral thesis (Abdin, 1982) and which is used widely in published works on climate and architecture (Talib, 1984; Labs, 1978, Watson and Labs, 1983). When more data on regional badgir performance is available a suitable subject for further research may well be a bio-climatic comparison of badgir climates in different regions of the Middle East. However chapters 2 and 3 of this thesis emphasise that data on the micro-climate of badgir locations should be used for such a study rather than general climatic data, as in the Yazd district the climate and performance of badgirs is very different in adjacent areas.

A system of methodically categorising climates and associated reccommended design strategies for architects was devised by Carl Mahony (U.N.1971) and publicized by Koenigsberger et.al. in 1973. Both these publications were widely read and followed. However the subjectivity of the recommended design strategies was never emphasised, and has apparently never been questioned despite the inclusion of reccommendations to use, for instance, compact courtyard planning in Baghdad, Iraq, which has one of the harshest climates of any large city in the Middle East. The evolution of a comprehensive set of design recommendations for the use of windcatchers in different areas of the Middle East may be also a useful subject for further work but is beyond the scope of this present research.

5.4.2 Methodology adopted for the measurement of climate and badgirs in Yazd

As a single researcher with limited time and finances (see below) it was decided initially to provide a set of readings giving a general indication of the parameters of summer performance of the towers, in terms of the temperatures, humidities and windspeeds generally experienced in and around badgirs and summer rooms of the houses of the area.

Secondly it was decided to record the use of space in the house over 24 hours of the day to determine the climate of occupied spaces as well as the climate of the badgir rooms only.

Thirdly, after comparing the very high recorded temperatures in Yazd to western studies of comfort and finding no way of understanding the first using the second, it was decided to look at the recorded temperature ranges in the light of the physiological responses of the body to high temperatures, in order to establish upper levels of temperature which would be acceptable to the local population of Yazd in summer. In so doing it was hoped to establish the limits of climate in which the badgir would, or would not, be useful to and used by the local populations.

5.4.2 The readings taken

A programme of readings was undertaken by the author in a number of houses with badgirs, of which sketch plans, sections, and elevations were made. 24 hour readings were made in the rooms of three houses only, providing a sample selected for reasons of security and accessibility, which of necessity over-rode considerations of representativeness.

Readings were taken only in badgir houses with fair sized wind-towers and not in those with simpler domestic ventilators. Larger towers were considered of more interest for this study as they might give more idea of the potential of the badgir to provide air-conditioning' as well as ventilation in the houses of the area.

5.4.3 Limitations of the technical study

While a number of general readings were taken, this study makes no claim to being a full 'scientific study' of the insitu operation of the badgirs of Yazd. Although the readings may be indicative of a general range of climates within the houses and badgirs of Yazd, the prolonged, labour and cost intensive study necessary to provide sufficient averages and means of temperatures for exact repeatability of findings was far beyond the scope of this study, carried out within a number of very stringent limitations including:

1) Resources and time. The total cost of the equipment, travel and living expenses for this fieldwork was covered by a modest award for the work by the Royal Institute of British Architects, and a small stipend from the Ancient Monuments Department of Iran. The equipment included:

- wet and dry bulb whirling hygrometer
- globe thermometer
- thermo-anemometer
- compass
- camera

An aneroid barometer was decided to be unnecessary as it was a bulky and expensive piece of equipment, and opinion held that the pressure gradients within the towers would be virtually unrecordable.

The main priority in the planned collection of climatic data was the taking of wet and dry bulb temperatures, globe temperatures, and windspeeds: purchases were directed to that end.

Time was also limited to an intensive two months during July and August 1977, when optimal climatic conditions for the use of the badgir occured, during which the recordings of the houses of the city of Yazd, and the corresponding climatic readings in these houses were made.

3) Political and social restrictions. Whilst it was possible at this time to enter houses for short periods as a guest, to make measured sketches and spot readings, it proved a very different matter to take readings in a house over a full 24 hour period because of the need for security

and niceties of social convention in the city. 24 hour readings were taken in three houses only: the house of Mr. Mashrouteh, the author's host in Yazd; the house rented by the author for two months in the Zoroastrian quarter; and the Hareem of the Bagh-e Dowlatabad, owned by the Ancient Monuments Department of Iran, and the office used by the author where a twenty-four hour guard was in residence.

4) Man power and equipment. More readings could have been taken a) with an assistant and/or b) with suitable electronic equipment that did not require constant monitoring.

5) Due to a seven year period of residence in Iraq, during which time the author was largely engaged in archaeological excavations as assistant to Dr. Michael Roaf, a gap exists between the taking of the recordings and the final writing up of the thesis. During this time the technical, particularly the computer based, equipment available for climatic field studies has advanced enormously and the method in which these present readings were taken already appears outdated. For instance the use of the whirling thermometers and the large globe thermometer, both extremely time consuming for simple readings, have been replaced by equipment that takes virtually instantaneous recordings and need be monitored only once in twenty-four hours.

6) The political situation. Since 1978 no British field researchers have been able to work in Iran. This has precluded the repeating or continuation of readings in Yazd.

5.4.4 Limitations of the readings taken include:

1) As one person was recording and noting the readings in a sequence of up to twelve spaces in the house over 24 hours the readings were not simultaneous, but sequential in the different rooms, or spaces. For taking windspeeds in the different shafts of a badgir this is an obvious drawback. Had more complex and expensive electronic equipment been available simultaneous readings would have been possible to record.

2) Due to physical limitations of the recorder, such as fatigue and fear, some readings were ommitted, such as the taking of globe temperatures at night time.

3) Some very rudimentary techniques were used, such as the establishment of air-flow direction by using a smoking match or cigarette, a technique suggested by Dr. Wills of the National Physical Laboratory, Teddington. This method coupled with the use of the direction-sensitive hot wire of the thermo-anemometer proved adequate in the circumstances.

4) Due to the equipment used and the methods with which readings were taken figures provided for temperature cannot be generally claimed to have more than 0.2c accuracy, and occasionally less. Similar margins of error should be allowed for other readings.

However the fact that one person was taking the measurements to a degree ensured some consistency in the readings, as no doubt it would also in the errors in the readings. Care was taken for instance that:

A) The whiring hygrometer readings were taken at head height, approximately 2 feet from the head.

B) Temperatures were taken in the centre of spaces except where otherwise specified.

C) Globe temperatures were taken in the shade unless otherwise specified.

D) Readings were taken in different houses on different days, with different external climates. Comparison of results between houses is therefore only possible in very general terms. The limited scope and number of readings is an obvious drawback of the study and conclusions drawn from these results are necessarily speculative.

5.4.5 Justifications for including the technical study

Given the limitations of the technical study the question of the value of including the readings in this thesis is valid. However for four reasons it is thought worthwhile to include them, because the readings are:

1) Unique to date: They are valuable in that they provide the only existing climatic study of windcatchers done to date in the Middle East. Had the Dammam University project, in Saudi Arabia, with a special monitored windcatcher built into the test building on the campus been in a closely comparable climate, the reasons for publishing the climatic study below would have been questionable, and the author may possibly have ommitted Part III of this present thesis. However the Yazd climate is hot and dry, not hot and humid, as is that in Dammam, and so this study may provide very

different, and useful comparative material.

2) Unrepeatable at present: Due to the present political situation there is little likelihood of a study of the climate in the badgirs of Yazd being attempted in a more scientific fashion in the foreseeable future.

3) Answering, however basically, some important questions: Within the limitations outlined above the readings taken in 1976 give a clear indication of the nature of the limits of performance of the windtowers in the city and provide a basis for comparison with other regions in the area. In short they go some way to providing some of the answers to the questions for which they were designed.

4) Important in providing some data by which current theories of windcatcher performance may be judged: The study was designed to answer specific questions that had not been answered in literature published previous to 1976. That a gap has occurred between the date of the readings and the submission of the thesis has emphasised not only that no insitu study on the function of the windcatchers in the Middle East has been attempted in the interim period but that there are no studies known to the author planned for the future on the windcatchers of the hot dry of the area. In the mean time the discrepancies of claims about the performance of the windtowers are becoming more exaggerated in the literature and the stereotypes more entrenched.

CHAPTER 6

THE EVOLUTION OF HOUSES OF THE CITY OF YAZD IN RELATION TO THE DEVELOPMENT OF THE BADGIR WITHIN THEM

6.1 INTRODUCTION

From the investigation of the history of Yazd it appears that a revolution in badgir design may have occurred in the city in the late 19th century. This highlights the need to review the evolution of the badgir types in the city to assess whether changes in basic badgir types did occur over time, and the significance of the developments of the late 19th century.

One way of answering these questions is to examine the badgirs of houses of known date. By so doing it may be possible to assess whether indeed badgirs changed with date and if they did how, and why, they changed.

The chapter begins with a brief description of the urban environment of Yazd and the general organisation of the urban houses of Yazd: then follows the description of ten houses, arranged chronologically, chosen to illustrate the develop ment of the urban houses of Yazd: From this an outline of the evolution of the house types, summer rooms, and badgirs is suggested, providing examples of the different badgir types used at different periods. Fuller descriptions of the houses are included in this chapter, because due to the lack of any other published descriptions of the houses of the area which could be drawn on to provide the basic data on which the conclusions of the chapter could be based.

6.2 THE URBAN ENVIRONMENT OF YAZD

6.2.1 <u>The street system of the city</u>

The old city of Yazd is divided into quarters, each of which contains its own small shops, public baths, water cisterns, and mosques or open air prayer halls. Each quarter is defined and served by a network of alley-ways which are generally narrow, being between 1m to 3m wide and flanked by the walls of houses that rise up to 5m or 6m above them.

Michael Bonine in his study of the street patterns of Iranian towns (Bonine, 1979) points out that the alleys in Yazd are unusually straight and can run for up to one km in one direction. These linear alleys are generally aligned NW/SE and NE/SW, forming an irregular grid pattern rather than the maze' described by many writers.

Bonine suggested that two important determinants in this street alignment were the orientation of the houses towards the north-west, for climatic reasons, and the original pattern of underground, and surface qanat channels incorporated into the settlement as it expanded (Bonine, 1979, pp.213-223).

The orientation of both the uni-directional badgirs and the street pattern of Ardakan in the same direction, ie. to the north, from which the prevailing wind comes, and the orientation of the badgirs and street patterns of Yazd to the north-west from whence the prevailing wind comes, lends some support to the Bonine's first suggestion.

6.2.2 The qanat system

The houses of Yazd may be seen to be connected by a second system of routeways, below ground in the system of subterranean qanat channels.

The extent of the underground system of waterways is indicated by the fact that almost every large house in the old city was supplied with water from a qanat. Larger houses have stairways down to the water while other houses have well shafts tapping the channels from which water was extracted by winch and bucket. Many houses have both. Households with no access to a qanat collected drinking water from the district water cistern, which was *filled* directly from a qanat (Beazley and Harverson, 1982, pp.39-45).

6.2.3 Informal routes between houses

A third informal system of movement through the city exists in the form of numerous connections between the different adjacent houses of members of extended families. These connections may take the form of doors in walls, passages above and below street level or routes over parapet walls at roof level. This multiplicity of routes between houses is of use in allowing women to move in privacy between houses and also for defensive purposes.

6.2.4 House plots

The alleys of Yazd enclose the high mud-walled house plots that make up the bulk of the city. The sizes of house plots vary enormously as do the sizes and also the number of courtyards within a house. A small house may be built on a plot 10m x 10m, while the largest houses including six or seven courtyards may be as large as 50m by 100m.

Plots of land are seldom rectangular and in order to orientate properly the main features of the house on an unsuitable plot, with summer room on the south and winter room on the north of the court, many of the rooms around the courtyard are irregularly shaped and sized. Such a house in Yazd is termed kaj-e kula, ill-fitting (see for instance the plan of Mashrouteh's house in appendix K).

The limits of the houses set within the grid of alleyways is obscured by high continuous mud-plastered walls. The presence of a door may be the only indication that one house has finished and another begun.

6.3 GENERAL INTRODUCTION TO THE HOUSES OF YAZD

Whereas the village houses display a wide variety of forms and types, the houses of the city of Yazd are almost exclusively courtyard houses. The main exceptions are the houses of the poor and garden pavilions. The houses of Yazd are fundamentally similar, composed of the same main elements, and yet they display an enormous variety in size, structure and organisation. Complexity of plan form is not necessarily related to size.

There may be up to 10 different courtyards in one house:

ANDARUNI	- main family court	BIRUNI	- guest court
RIKDA	- Zoroastrian court	MUJTAMEL	- annex court
ESTABLE	- stable court	HYAT	- kitchen court
NARENJESTAN	- orangerie	GODAL BAGCHE	- sunken garden
PA-E AU	- large sunken garden or lower court		

Figure 6.1. Sketch of a typical Yazdi house showing the types of room commonly found in Yazd. A) biruni, guest courtyard B) nimiyeh wall, a blank wall on the east of the courtyard C) talar of the andaruni, the main family courtyard D) badgir E) Living room on the east or west wall of the courtyard F) ditto G) store room H) stable J) basement room with qanat K) basement living room L) kitchen M) hoz khaneh or pool room.

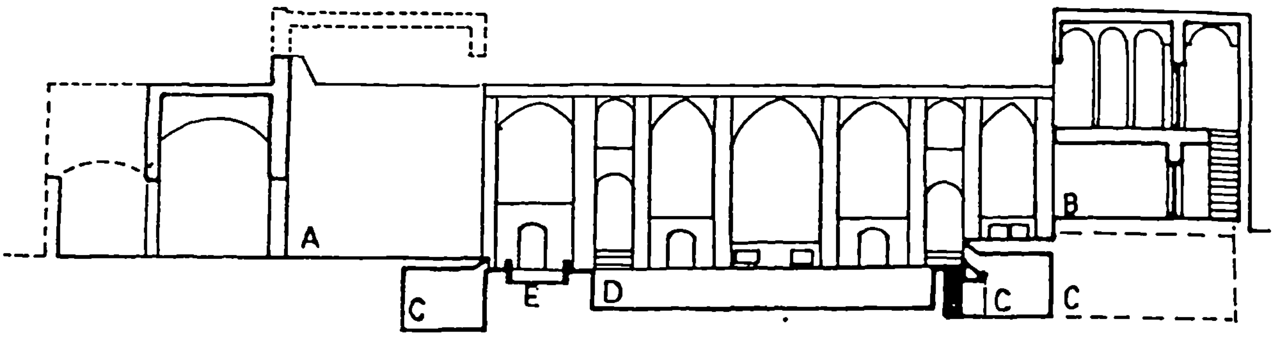


Figure 6.2. Reconstructed sectional elevation of the house of Immam Hussein, dating from the 15th century. A) winter portico B)Summer portico C) basement rooms D) sunken garden E) pool.

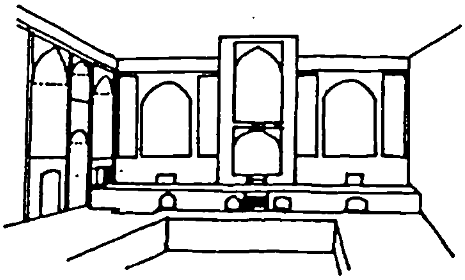


Figure 6.3. Reconstructed south elevation of the Immam Hussein house showing elevated central portico.

Generally, however, houses have only one courtyard, the andaruni, or two, the andaruni and the biruni.

Figure 6.1 shows the typical types of rooms and spaces found in a Yazdi house.

Two types of compound houses with more than one courtyard served by a single entrance are found in Yazd. The first type, known as darvazeh or gate' house, occurs where several houses share a common small entrance alley which has a gate separating it from a main street. This gate is closed at night for security, and such houses occur largely in the Zoroastrian quarters of the city and its surrounding villages (see Boyce,1971, p.138).

The second type is known as a khaneh darbandeh, or closed door house. This term refers to a house with a number of family courtyards served by one common main door to the street.

In such houses the courtyards are considered to be on one large house plot, while in the darvazeh houses one gate links a number of separate house plots.

The main summer living rooms of houses on the ground floor are the aivan and the talar. Both are rooms with three walls and open side facing the courtyard. The difference between them is that the aivan in a high deep space, longer than it is broad, similar to the central aivan of a traditional mosque, while the talar is generally broader than it is deep, lower in overall proportion of width to height. The aivan was commonly roofed with a pointed vault while the talar was covered with a barrel vault (see appendix A). The talar in Yazd emerged only in the 19th century (see appendix A) by the end of which the practice of closing off the wall to the courtyard with a row of glazed French doors had become common.

6.4 CASE STUDIES OF HOUSES IN YAZD

The ten houses below are arranged chronologically. Each house is described with reference to the following parts of the house only: 1.Summer rooms 2.Basement rooms and 3.Badgirs.

6.41 15th century house of Immam Hussein

This house is situated Makhzan quarter of the city near the Bazar-e No (new bazaar). When the Ancient Monuments Department of Iran (Afshar, 1969, vol.1) began its restoration of this house in 1975, it was a virtual ruin. It had been damaged during the centuries and the extant facades were the result of many rebuildings. Sufficient of the original building remains to be able to extrapolate a simple facade pattern for the courtyard of the original building. The courtyard with its deep sunken central garden is dominated by the two great aivans at centre of the north and south facades (figures 6.2 and 6.3).

The elevation of the summer rooms to the south consists of a tall narrow two storey aivan, flanked by a pair of lower wider aivans. In front of these three rooms is a dias, raised 30cms above the court, called also aivan' in the local modern Yazdi dialect. This terrace also links

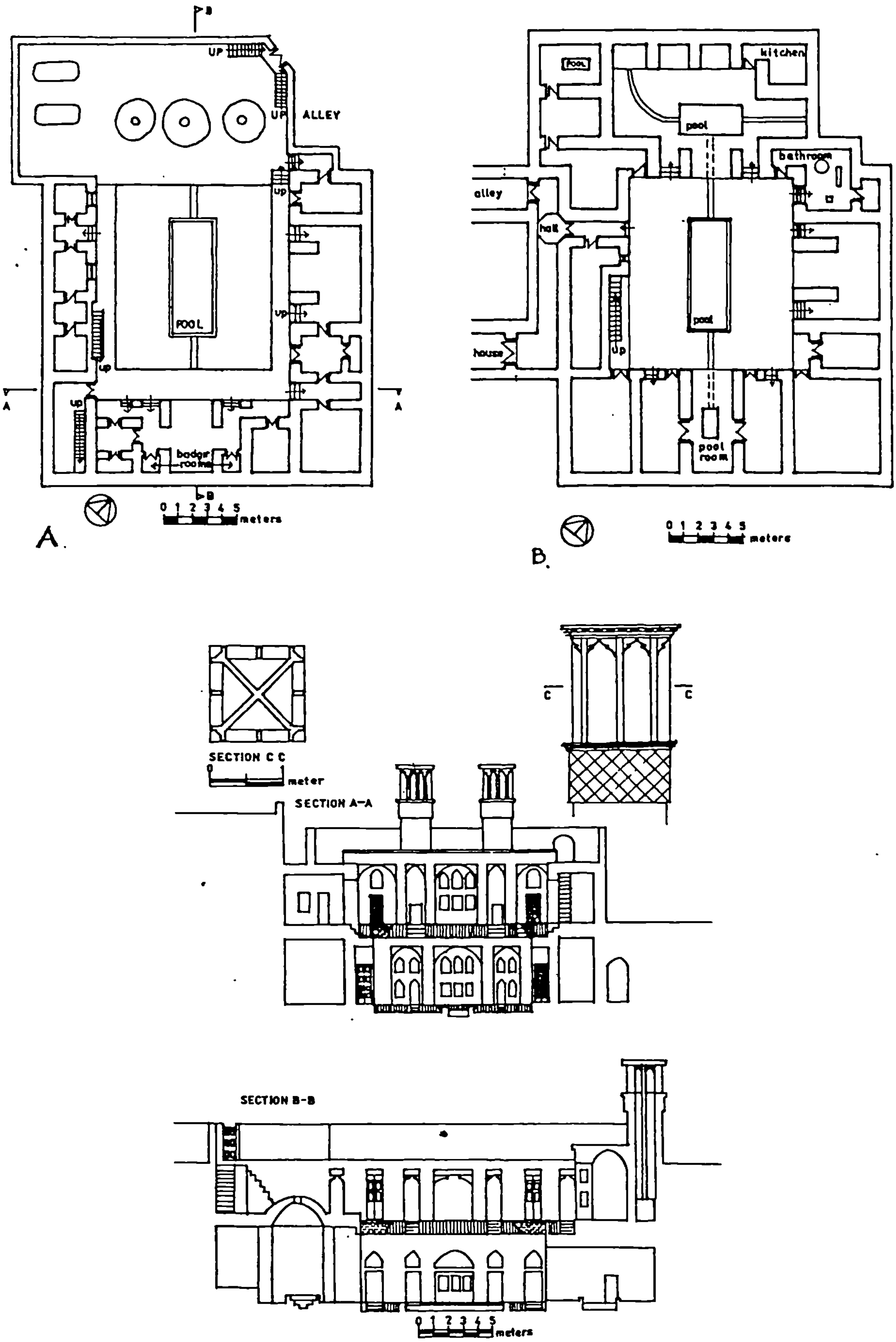


Figure 6.4. Plans and section of the ruined house (house D).

these three aivans to the two aivans at the south end of the lateral facades of the court.

Basements are numerous in the house, situated under all four sides of the court. These appeared to be very poorly lit, with small grills beneath the raised floors of the aivans, and their entrances were cramped and difficult to negotiate, suggesting that they may have been used for storage rather than as afternoon living rooms.

No badgir appears to have been built in this house, although Mohendiz Pirnian claims that there is a badgir on a Timurid house, the Fagighi house, in Yazd.

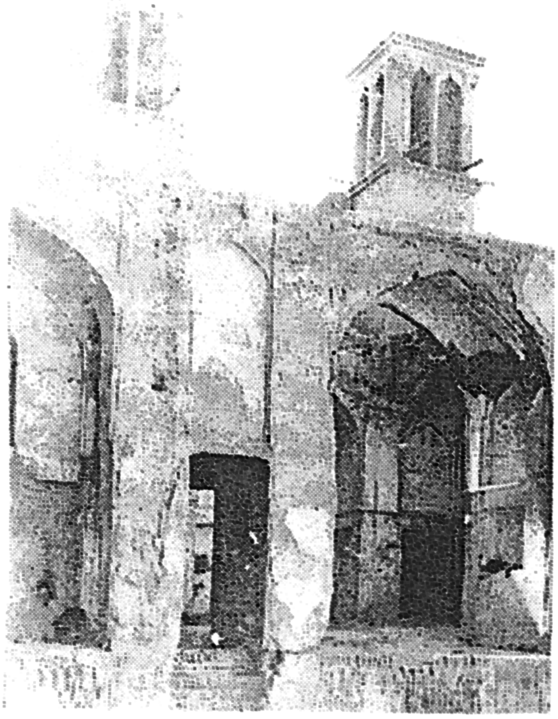
This house demonstrates a style of architecture dominated by the open aivan. Aivans were built all around the court except for two small winter rooms to the east and west of the north facade, which were separated from the court by wooden doors. The aivan house type was most likely built in the region after the Sassanian and Parthian periods (see appendix A).

6.5 18th CENTURY HOUSES IN YAZD

6.5.1 Ruined house near Pahlavi street - House D

This house, built in the mid-eighteenth century, represents the last stage of the 'aivan' house in the city as later houses had extensive glass doors on several facades (figures 6.3 and 6.4).

The house is the first of a pair of darvazeh houses reached by a small alley with a door on to the main alley. The alley has a hashti, or octagonal dome above the entrance



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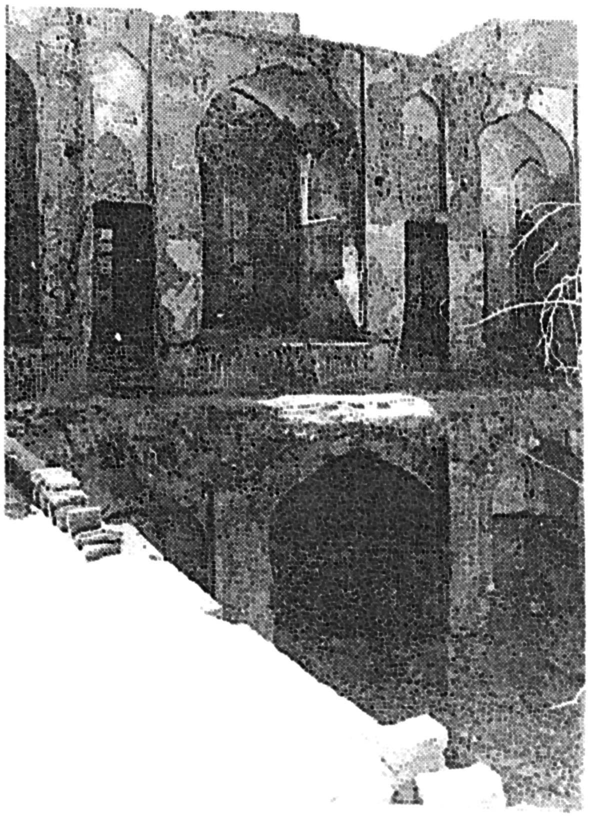

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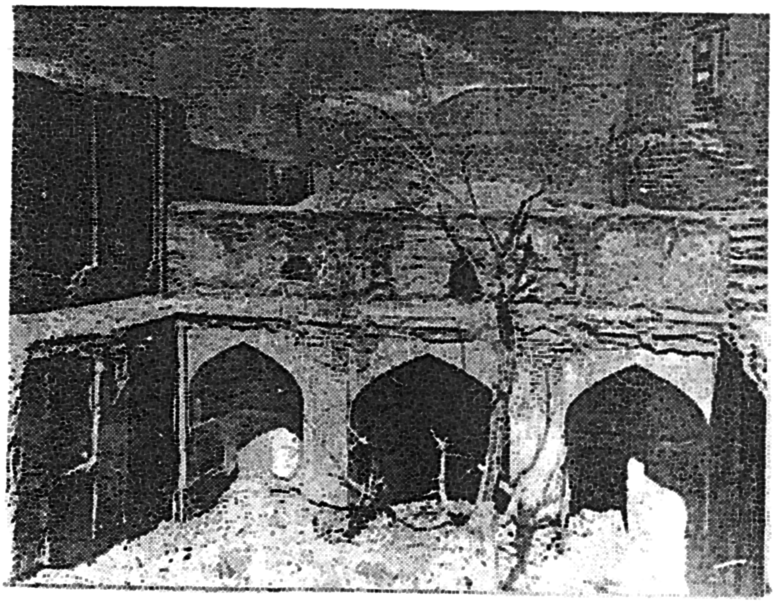


C.

Figure 6.5. Photographs of the ruined house A) the south-east facade B) the two storey south-east facade C) the north-west facade.

hall to the first house and continued to the door of the second house (which was occupied).

The double height courtyard descends well below the street, to the level of the qanat, a common feature of the older houses of Yazd (Floyer, 1879, p.354)

There is a complex network of water channels in the lower court that serve the courtyard pool, the pool room, the kitchen and the bathroom.

The main summer rooms are built on the south east wall of the courtyard and consist of a first floor aivan served by a pair of badgirs and at ground floor level a pool room. Both of these open vaulted spaces are flanked by small living rooms. The paired timber doors of the upper court have two leaves, each consisting of an upper opaque glass lattice panel and a lower timber panel.

Access to the aivan is via a pair of stairs to the courtyard which are divided from the main space of the aivan by a short truncated wall. In the other two corners of the cruciform aivan are the badgir rooms.

There are no basements in this house.

The fine pair of wind towers on either side of the rear of the aivan, descend through its vault and become ceiling height square rooms, with a door facing forwards into the main space of the aivan.

Some conclusions may be drawn from the ruined house: the elevations of the facades are a development of the earlier aivan style, using the rhythm of three vaults, the central

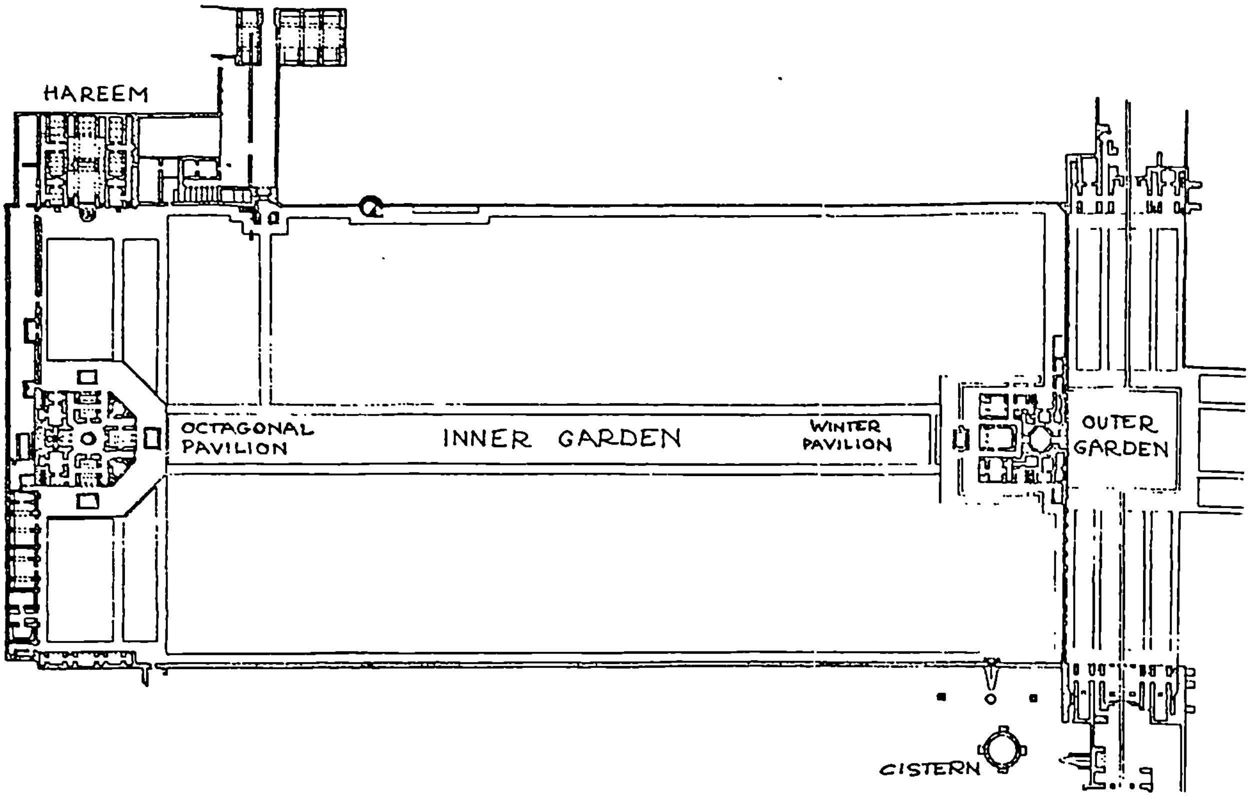


Figure 6.6. Plan of the garden of Bagh-e Dowlatabad drawn by the Ancient Monuments Department of Iran. (Afshar, 1969, vol.1)

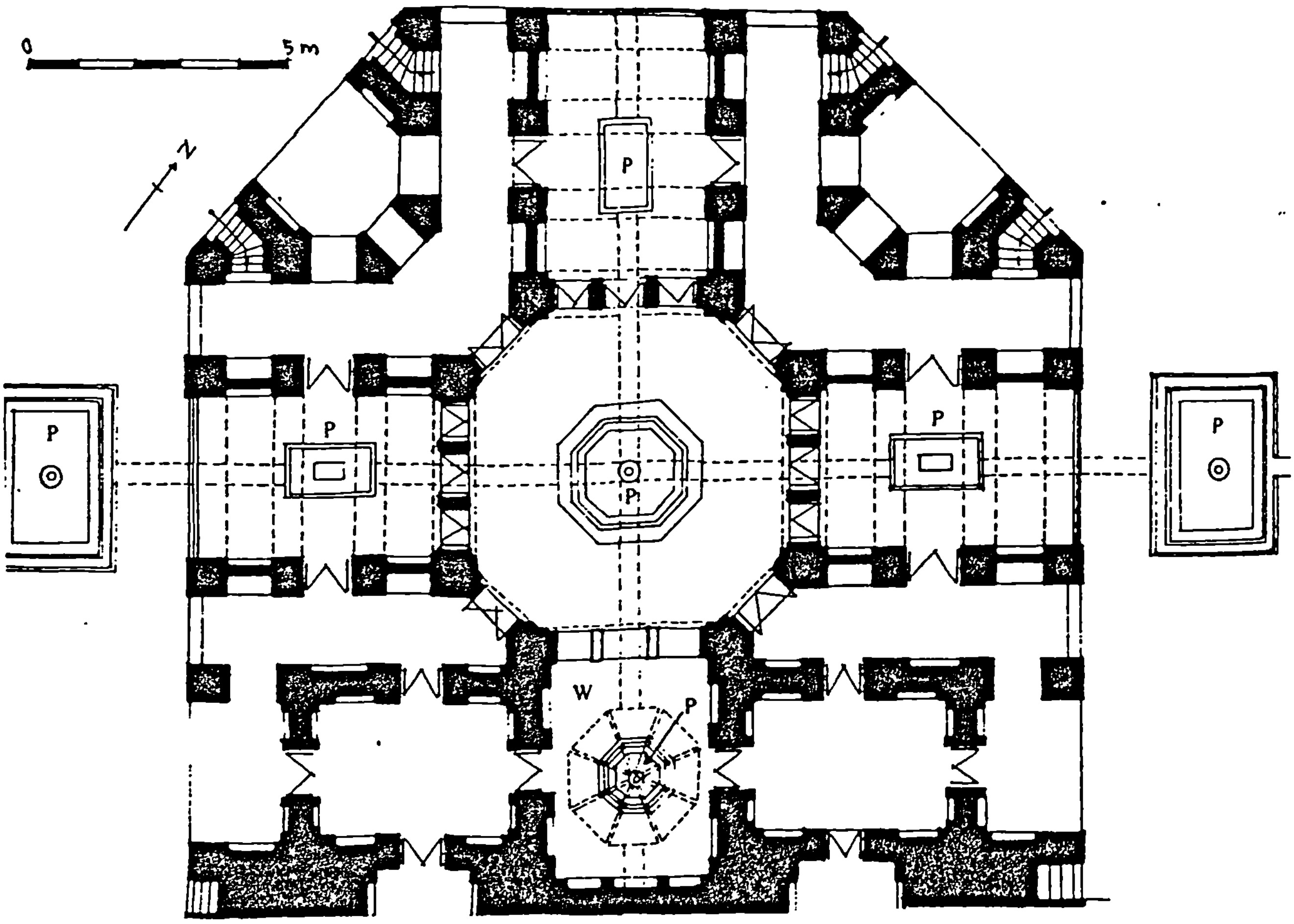


Figure 6.7. Plan of the octagonal pavilion at the Bagh-e Dowlatabad. (Ancient Monuments Department of Iran)

one being dominant, separated here by narrow corridors.

The roof-line of the facades is now virtually level. Gone is the elegant raised central aivan of the Timurid house and the impression in the facade is one of equality and solidity in which each part supports the other, in a technically unimpeachable fashion but in one that has none of the innovative and poetic elevation of the high central aivans of the Immam Hussein house.

In this building we can seen the early use of glass and timber doors around the courtyard facade, here with thick opaque glass.

The similarity of the lateral paired location of these towers and the paired badgirs of the Timurid mosques of Kuchuk and Bafru'iyya should be noted. It is conceivable that this location represents a continuation of an earlier tradition of locating badgirs over the side naves of mosques where worshippers knelt to pray.

6.5.2 The Bagh-e Dowlatabad - House E

Mohammad Taqi Khan, who governed Yazd from 1747 until 1798, was responsible for a period of building unparalleled since the end of the Timurid era. The most important house he built was the garden complex to the west of the city where he and his court lived during the last 16 years of his reign (Afshar, 1969, pp.529-534) (figure 6.6).

Built in 1782 (1,160 A.H.) the garden had two main walled domains. One was a south garden in which his wives and children lived, in the Hareem, and in which were also located

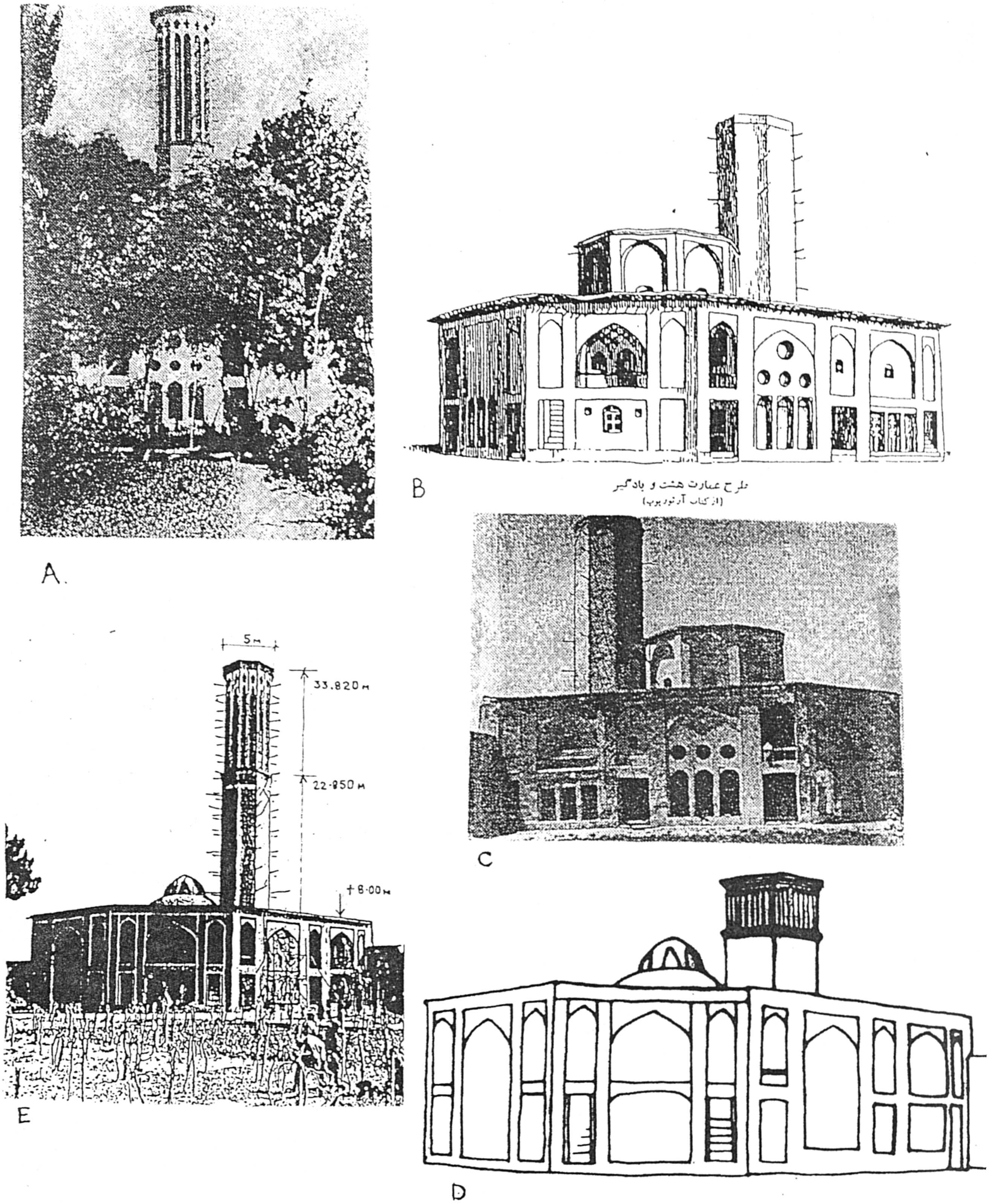


Figure 6.8. A) Turn of the century photograph of the Qajar badgir on the octagonal pavilion at the Bagh-e Dowlatabad (Afshar, 1960, vol.2) B) sketch by Pope of the ruined badgir on the ocatgonal pavilion at the Bagh-e Dowlatabad. The original tall badgir was probably built in the 1890s and ruined by the late 1920s showing that the structure at vent level proved unstable (Afshar, 1969, vol.1) C) Photograph of the pavilion with ruined badgir (Afshar, 1969, vol. 2) D) Reconstruction by the author of the original badgir on the octagonal pavilion at the Bagh-e Dowlatabad reflecting that on the Hareem and similar to that on the house of Nowab Rasoui in which the five rooms of the octagonal pavilion are replicated. E) Photograph of the octagonal pavilion at the Bagh-e Dowlatabad restored in 1975-1976 by Mohediz Talaie of the Ancient Monuments Department of Iran.

his two main personal abodes. These were the octagonal pavilion (the Khan's summer pavilion with badgir), and his winter pavilion.

In the northern walled garden, the enclosure for official guests and business, there are three other pavilions, built to house his guests, his court and those whose business was with the Khan. As well as these principal residences were the servants' quarters, kitchens, stables (including a camel stable), and supporting buildings such as a water cistern fed by the qanat of the garden, a store house, and an ice house.

A residential quarter outside the garden walls housed numerous of his acolytes, apparently from Tehran, as the quarter is called the Tehran quarter.

The two buildings of interest to this study are the octagonal pavilion and the Hareem.

The octagonal pavilion (figure 6.7) has at its centre an octagonal domed room with a pool, with three aivans and the badgir room leading off its four longer sides. The three aivans are separated from the central room by curtain walls of coloured glass. In the eastern and western aivans are pools, a feature absent from the north facing aivan.

A high degree of passive climatic control, in terms of temperature and wind speed, could be achieved by opening and shutting doors and curtains, and in the choice of seating position.

There are no basements in this pavilion.

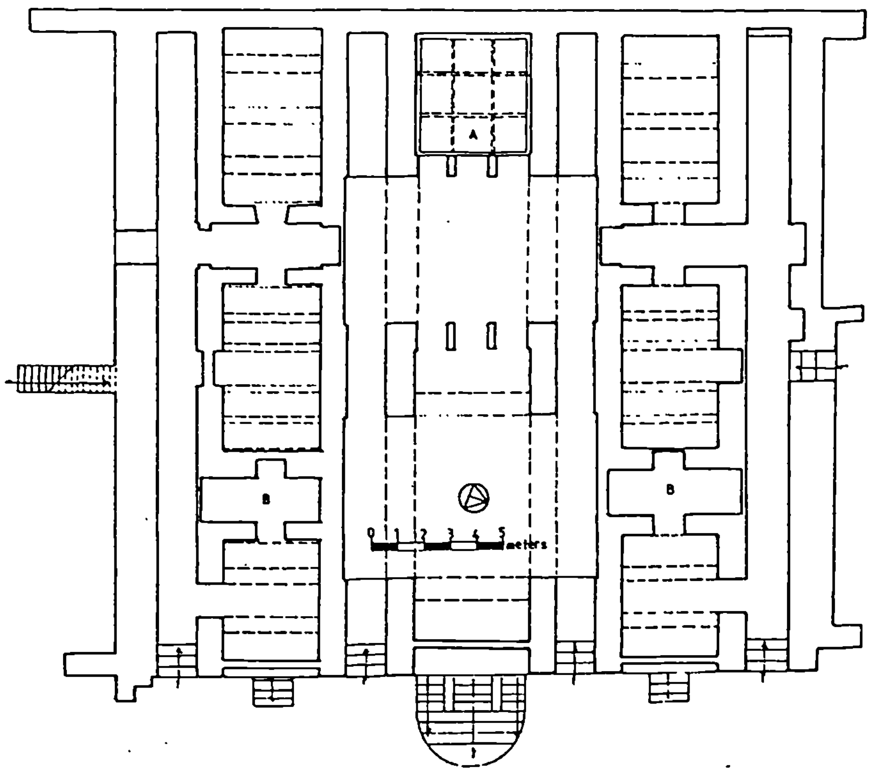


Figure 6.9. First floor plan of the Hareem (house E) at the Bagh-e Dowlatabad. (*Ancient Monuments Department of Iran*).

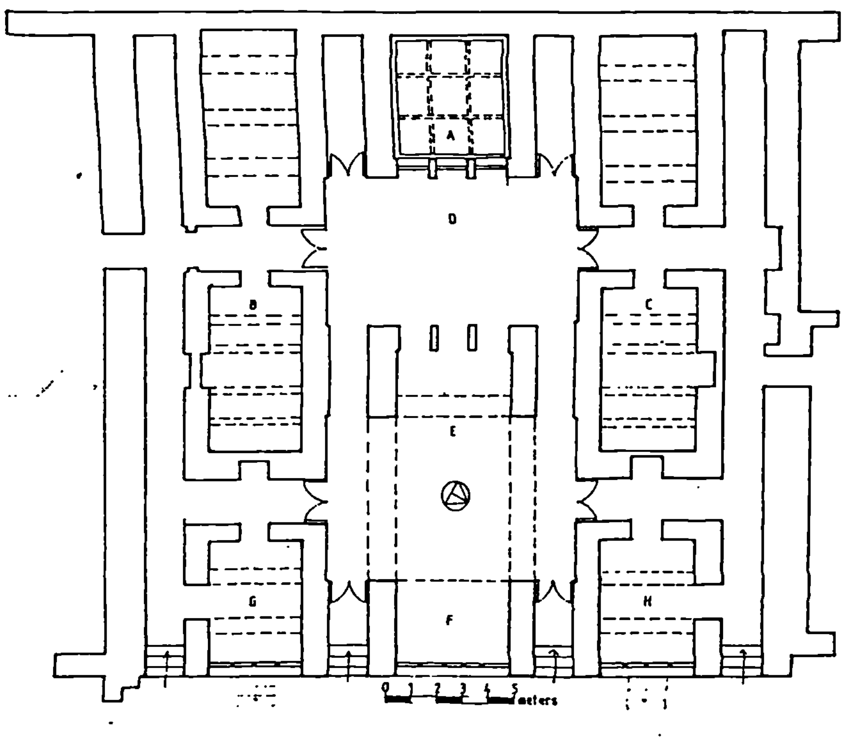


Figure 6.10. Ground floor plan of the Hareem (Ancient Monuments Department of Iran).

The present badgir, built on the southern wall of the octagonal pavilion, is the highest in the world, an octagonal structure 33.8m high with vents 10m high at its head (figure 6.8). This badgir is most probably not original. The rectangular recessed badgir room is similar in proportions to that of the Hareem and the original badgir, in the octagonal pavilion, was most likely to be large and low like that of the Hareem (figure 6.8D). Confirmation of this comes from two sources. Perhaps the best is from the house of Nowab Rasoui, described below. He was the son of Mohammad Taqi Khan, and the main summer rooms of his house were almost identical to those of his fathers' pavilion. In the Nowab Rasoui house the badgir is very similar to that of the Hareem. The second piece of evidence is the account of a British traveller who stayed at the Bagh later in the nineteenth century. In 1879 MacGreggor described the garden where he stayed as The Bagh-y-Dowlat is a fine but dilapidated house' (MacGreggor, 1879, p.71). No mention of the massive badgir at the Bagh, although he does describe the others in the city. Over the rectangular badgir room the octagonal tower has been added, probably during the reconstruction of the garden at the end of the nineteenth century. The circular Qajar bat and ball details (figure 6.8B) suggest a date of about 1880-1890. Unfortunately the structure was flimsy and the upper vent section was already ruined forty years later when Pope sketched the pavilion in 1930 (Figure 6.8B).

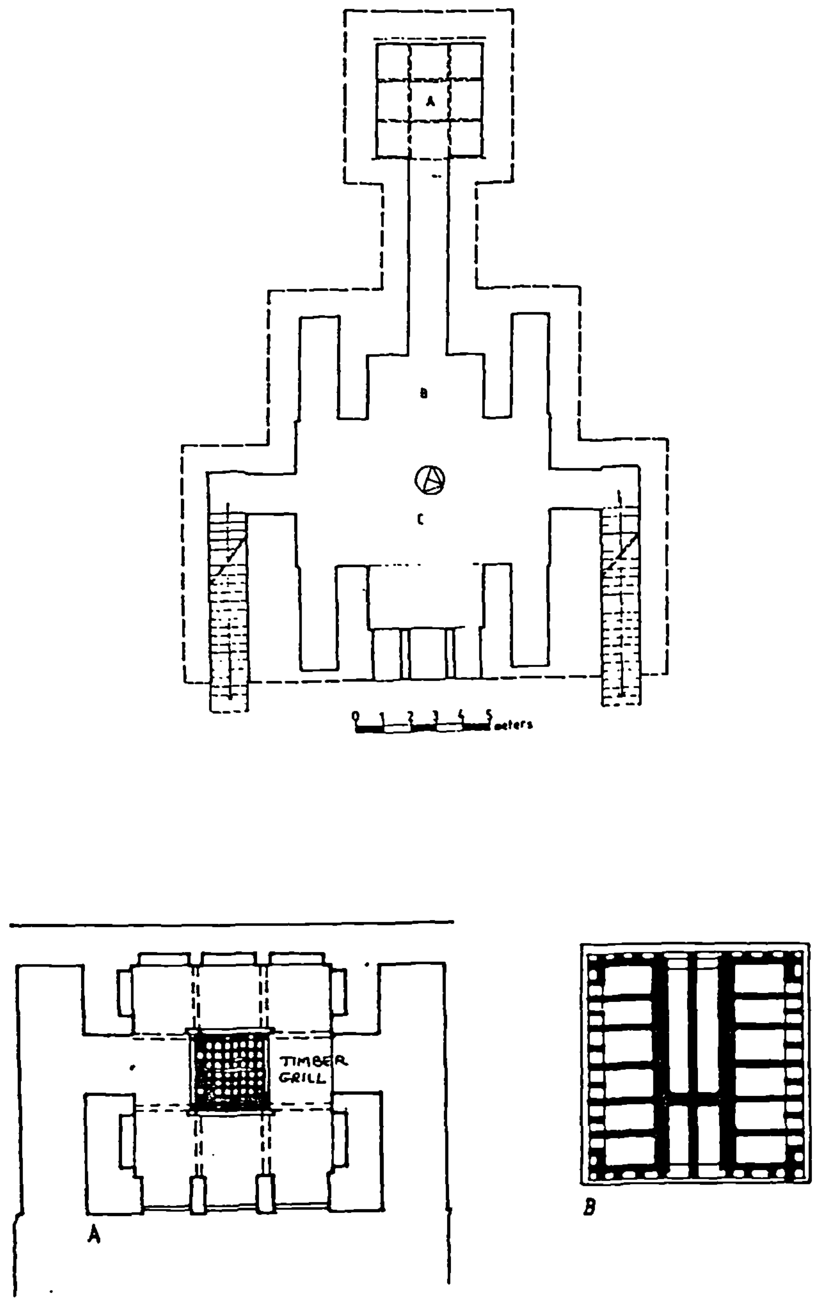
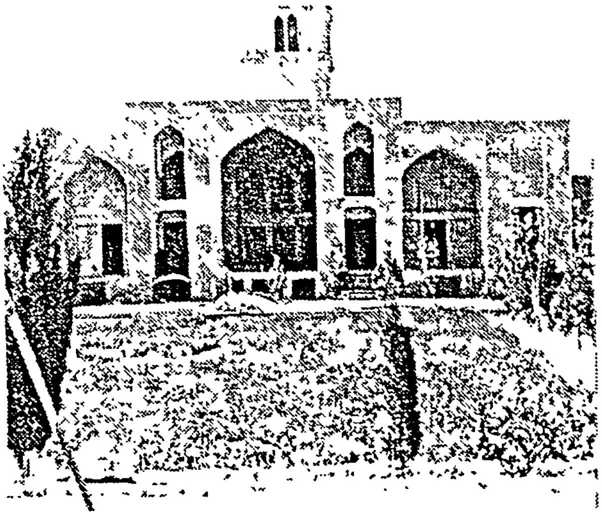


Figure 6.11. Basement plan of the Hareem with plans of the bagdirs at A) ground floor and B) vent level (Ancient Monuments Department of Iran).



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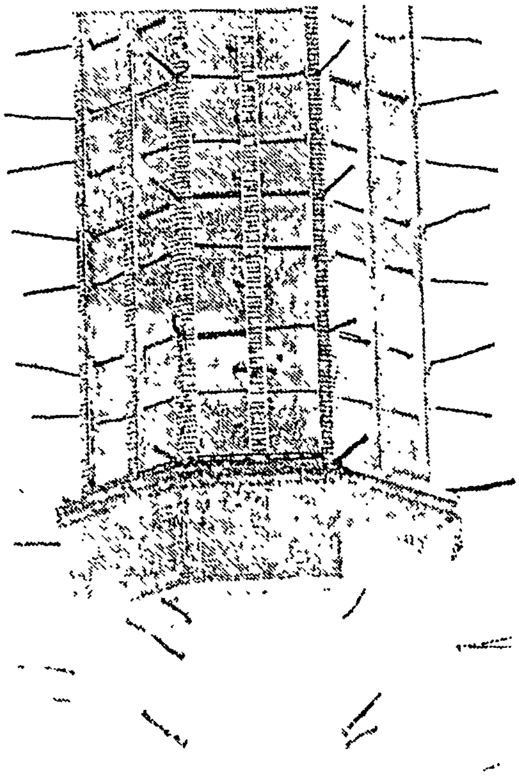

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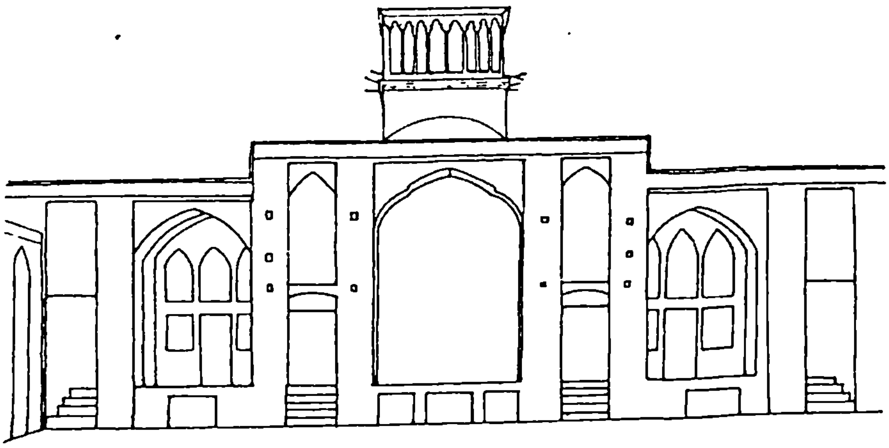


C

Figure 6.12. Photograph of A) the east elevation of the Hareem and B) the base of the vent section of the badgir on the octagonal pavillion showing the scaffolding poles; and C)drawing of the east facade of the Hareem at the Bagh-e Dowlatabad.

The ruined pavilion was stripped of its Qajar over-coat in 1975 when reconstruction of the garden began under the auspices of the Ancient Monuments Department of Iran. The badgir was rebuilt to its present height and work was nearly completed in 1978 (figure 6.8E).

The Hareem has a very deep high central aivan with flanking rooms and high two storey corridors (figures 6.9-6.12).

The large and comfortable living room in the basement has a moderate and uniform climate. The uneven roof surface of the Hareem suggests that its occupants did not sleep on the roof, but probably in the cool basement.

The main badgir at the Hareem is a large, but not high, structure serving the ground floor central aivan and the basement, through a grill in the floor of the ground floor badgir room. An exciting discovery was made in 1977 by Mohendiz Talaie, the architect responsible for the restoration of the Bagh-e Dowlatabad. This was the plastered over shafts of two further badgirs on the Hareem above the corridors flanking the main aivan. These badgirs have subsequently been rebuilt.

This garden contains the finest building complex of the late 18th century in Yazd and was subsequently much copied. Many features included in these buildings were used in later buildings, notably the use of large areas of coloured glass, the five room summer complex of the octagonal pavilion and the large low badgirs. An important factor in considering

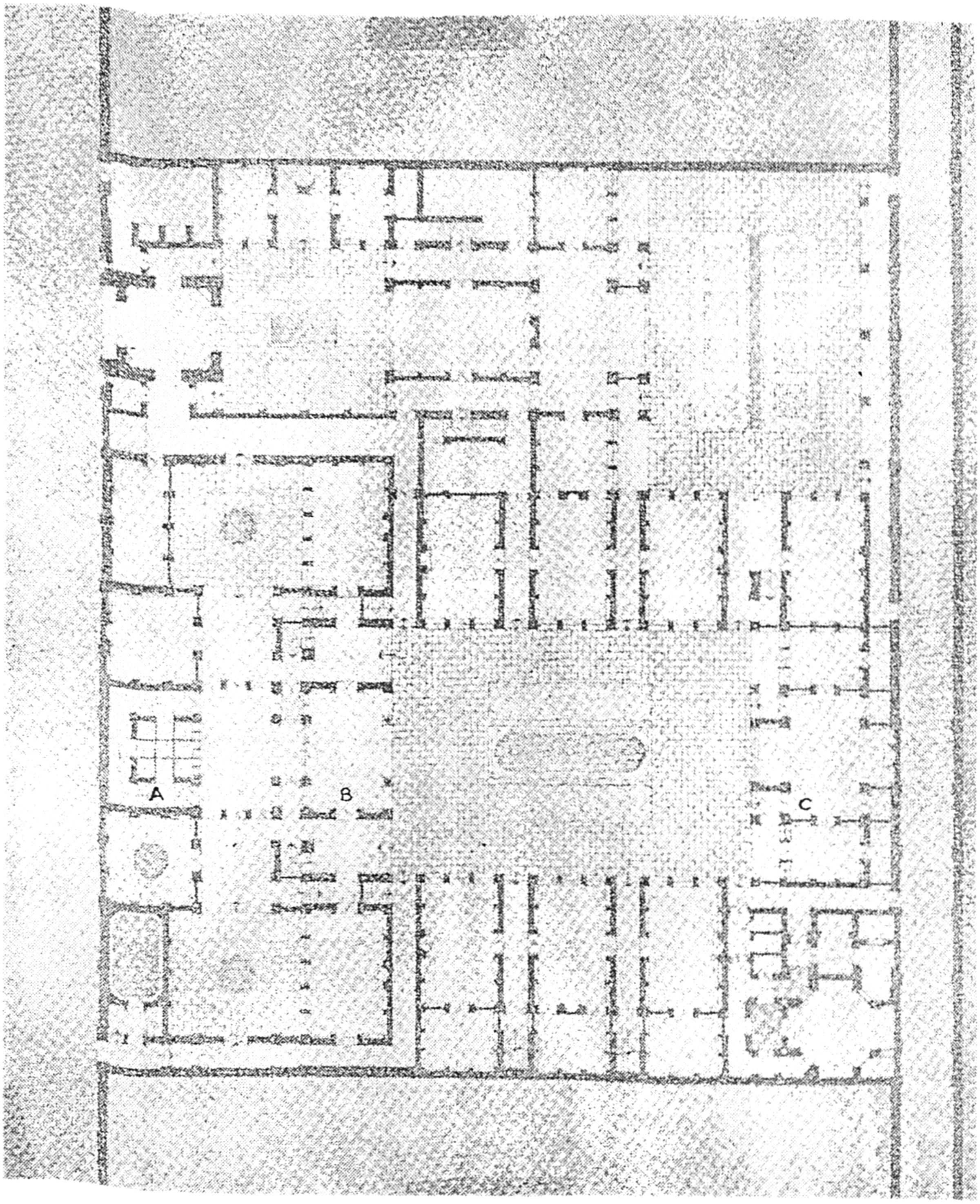


Figure 6.13. Plan of the house of Nowab Rasoui drawn by Mohendiz Pirnian.(reproduced in by Afshar 1969, vol.1)

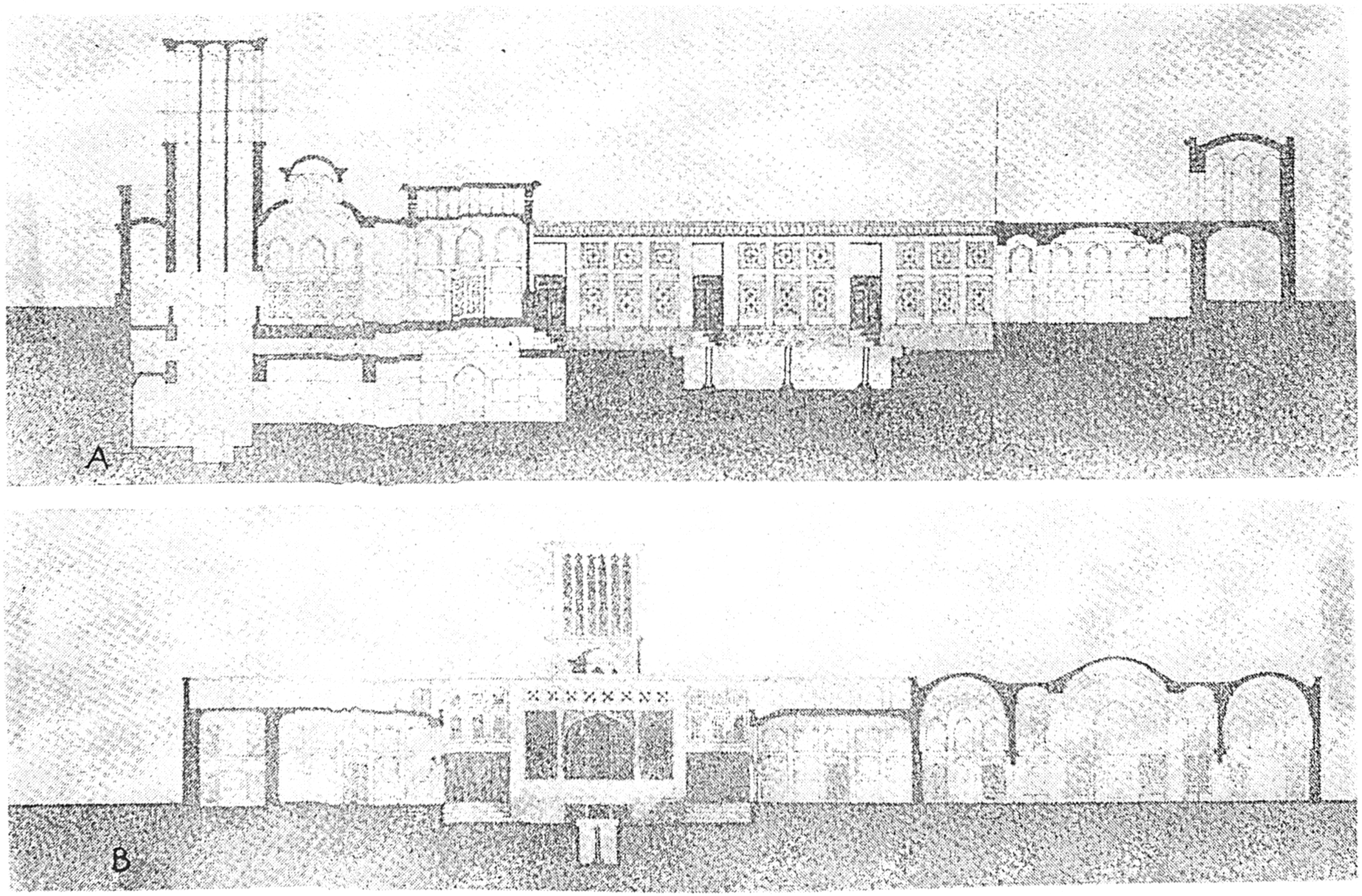


Figure 6.14. Sections through the house of Nowab Rasoui.
(Afshar, 1969-70, vol.1)

the reasons for the changes in architecture this building complex embodies is the origin of the architect who possibly come from outside Yazd.

6.6 EARLY 19TH CENTURY HOUSE

6.6.1 Nowab Rasoui house

This house was built by a member of one of the original families of tribal Khans of Yazd. His name was Zein Alabadi Khan Fars, the son of Mohammad Taqi Khan, who built the Bagh-e Dowlatabad. This house, first described by Iraj Afshar in his two volume work Memories of Yazd' (Afshar, 1969, vol.1, pp.526-527), was probably built in the first two decades of the 19th century. It is situated between the Khatib alley and the al-Shafi gate. It was recorded and restored by Mohendiz Pirnian of the Ancient Monuments Department of Iran, and was in a ruinous state when work by the Department of Ancient Monuments commenced on it. In size it resembles a small palace as do many houses of the merchant princes of Yazd (figures 6.13 and 6.14).

The main five room summer complex at the south end of the andaruni courtyard consists of a series of spaces closely resembling those of the octagonal pavilion at the Bagh-e Dowlatabad. There are the north, east, and west aivans, surrounding the central domed hall at the back of which is the badgir room. Air from the badgir can be diverted directly through the three aivans by shutting appropriate doors. The air from the tower also descends into the basement directly or via a channel in the roof. All the

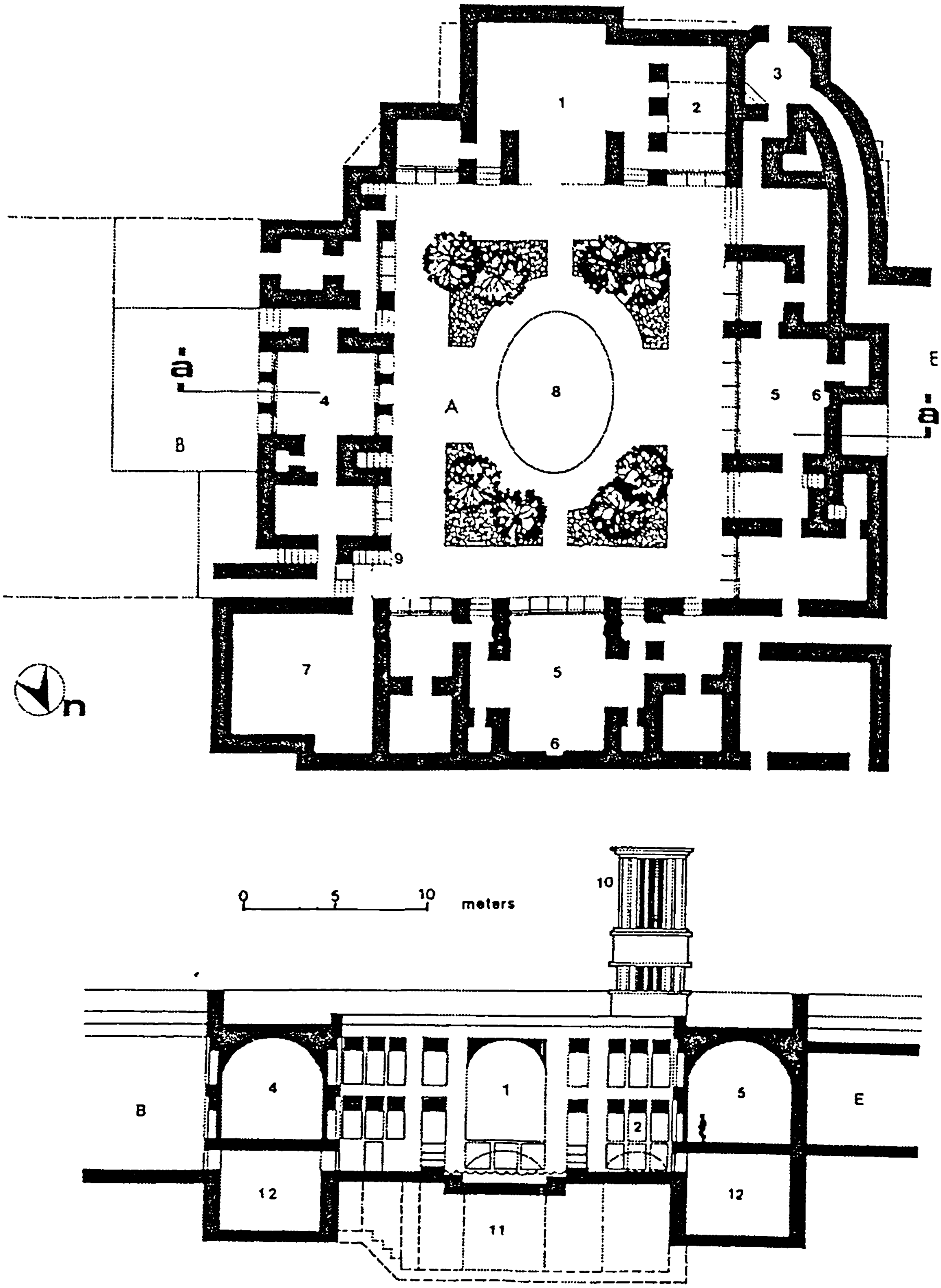


Figure 6.15. Plan and section of the Gazorgah house, Yazd. (Bonine, 1980b, p.207-209)(See P.T.O. and p.136).

main winter living rooms, which are indicated by the presence of fireplaces, are glazed, except the winter aivan in the south west courtyard which is a traditional long narrow aivan open to the courtyard.

The summer basement living room is spacious and approximately the height of that at the Hareem of the Bagh-e Dowlatabad.

The badgir is similar in plan dimensions, but with higher vents than the Hareem at the Bagh-e Dowlatabad. The massive cross sectional area would provide the large volume of air needed to make any impact in the large ground floor and basement living rooms. (See also the Gazorgah house of the early 19th c in figure 6.15).

6.7 EARLY 20th CENTURY HOUSES

6.7.1 Zoroastrian house - c.1900 - House C

This house is of particular interest because of its mixture of Islamic and Zoroastrian architecture (figures 6.16 - 6.19).

The house was probably built just after the turn of the century and may well have been the house described below:

> Bad-girs were still forbidden to the Parsis while we were in Yazd, but in 1900 one of the bigger Parsi merchants gave a large present to the Governor and to the chief Mujatahid (Mohammedan priest) to be allowed to build one. Upper rooms were also forbidden. (Napier, 1905,p.40)

The house was restored by the the Ancient Monuments Department of Iran between 1975 and 1978.

The courtyards of the house include: andaruni, biruni, second family courtyard, with a fourth courtyard being the

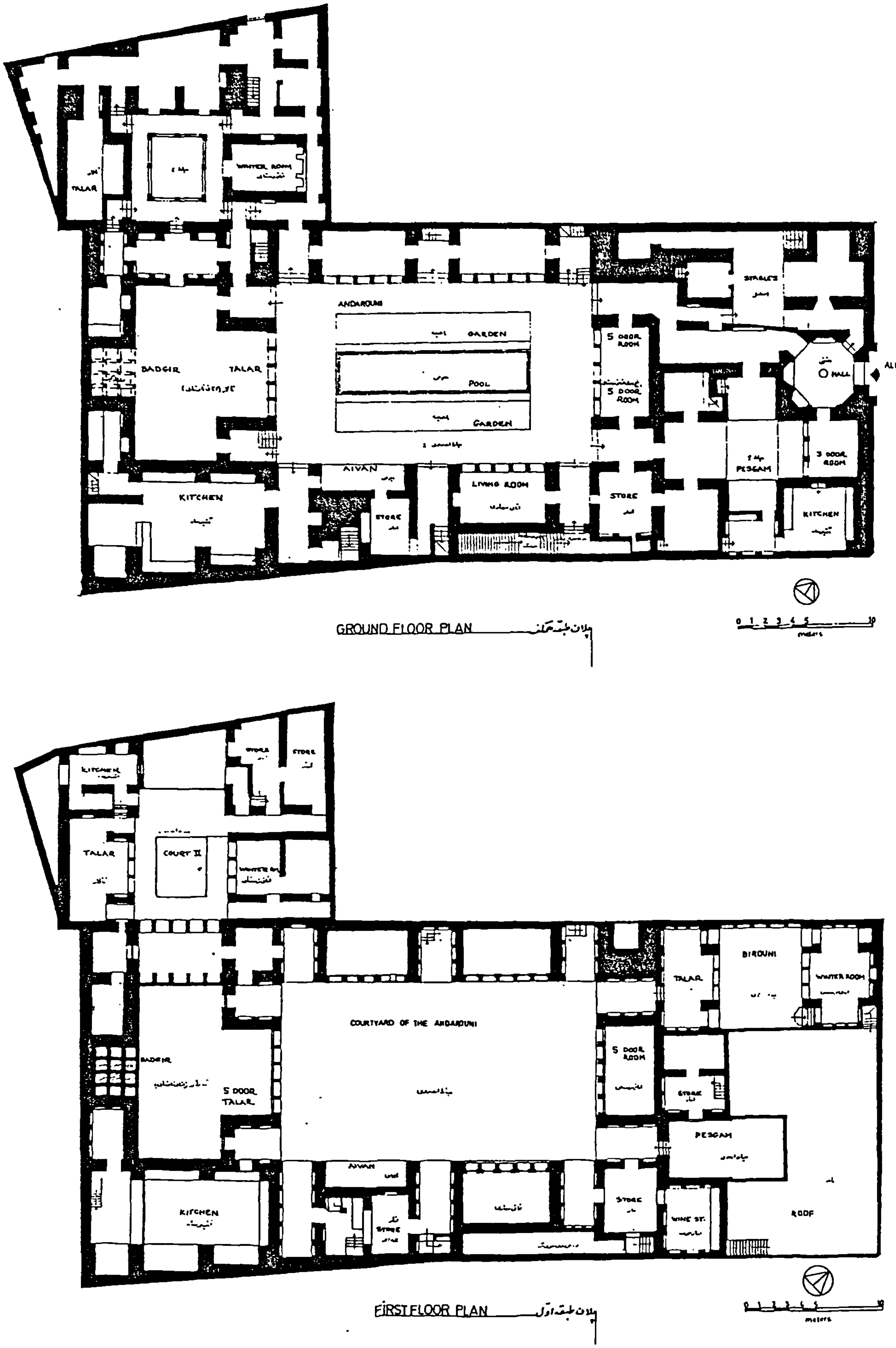


Figure 6.16. A) Ground floor and B) first floor plans of the Zoroastrian house (house C). (Ancient Monuments Department of Iran)

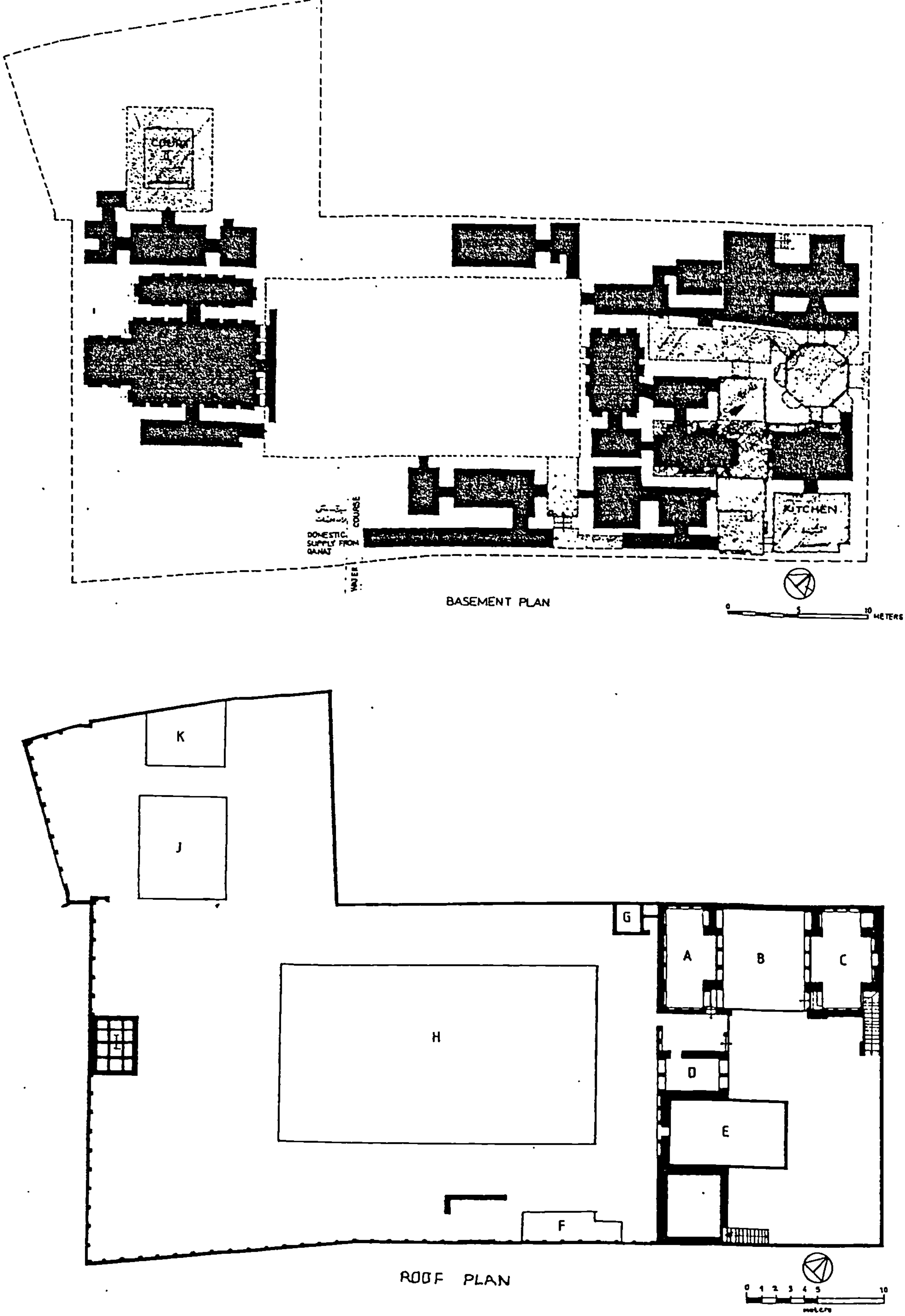


Figure 6.17. A) Basement and B)roof plans of the Zoroastrian house. The roof plan shows A) talar of the biruni B)biruni courtyard C)winter room of the biruni D) bala khaneh E) the Zoroastrian courtyard F) lightwell above the stairs down to the qanat. (Ancient Monuments Department of Iran)

Rikda, or the Zoroastrian court (see 3.3.5.5).

The elegance of the courtyard is emphasised by the concentration on two story elements, doors, windows, corridors and niches on the facades. These elements, though usually rather rectangular in form in the 1870s (see the Gazorgah house in Bonine, 1980, pp.207-213) achieved almost perpendicular' (Gothic) proportions by the turn of the century which gave the houses, according to Napier, an ecclesiastical' appearance (Napier, 1905, p.20).

A new feature in this house is the narrow, raised vaulted platform, or wide bench, on the east wall of the andaruni. This area known as an 'aivan' can be seen as a direct development of the deeper aivans on the east wall of the earlier houses. The translation of this aivan into a seating platform takes advantage of the position on the west-facing wall to maximise the impact of the winter sun, both with direct and reflected heat, to create an ideal zemestan neshast, a winter seating area. It may also be used on summer mornings, before about 10am. to take advantage of the cool early morning climate before the courtyard becomes too hot to sit in .

The second family courtyard, where part of the extended family lived, was built about 20 years later than the rest of the house, and has the lower, rounded arches, and clear glass characteristic of the 1920s houses.

The summer rooms of the andaruni are the basement living room and the talar, a seven door room. Napier described a typical talar at the turn of the century thus:

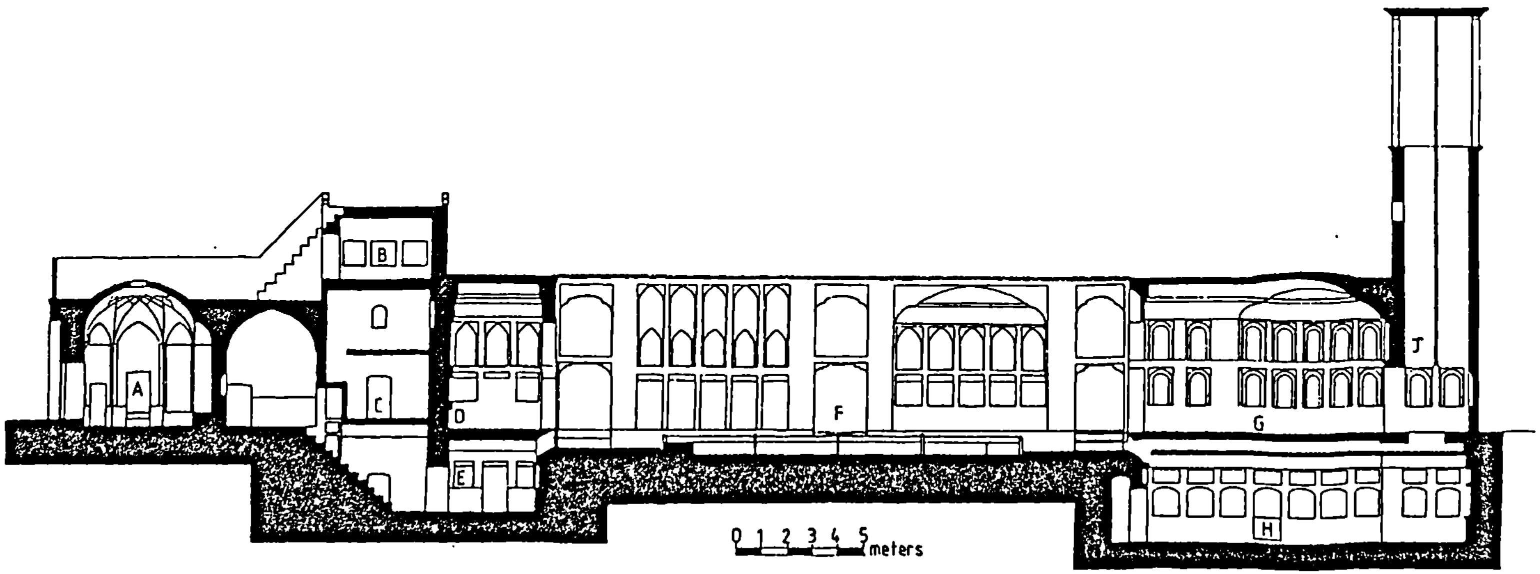


Figure 6.18. Section through the Zoroastrian house, showing A) octagonal entrance hall B) bala khaneh C) store D) winter room E) basement living room F) andaruni court and pool G) talar H) summer basement living room J) badgir. (Ancient Monuments Department of Iran)

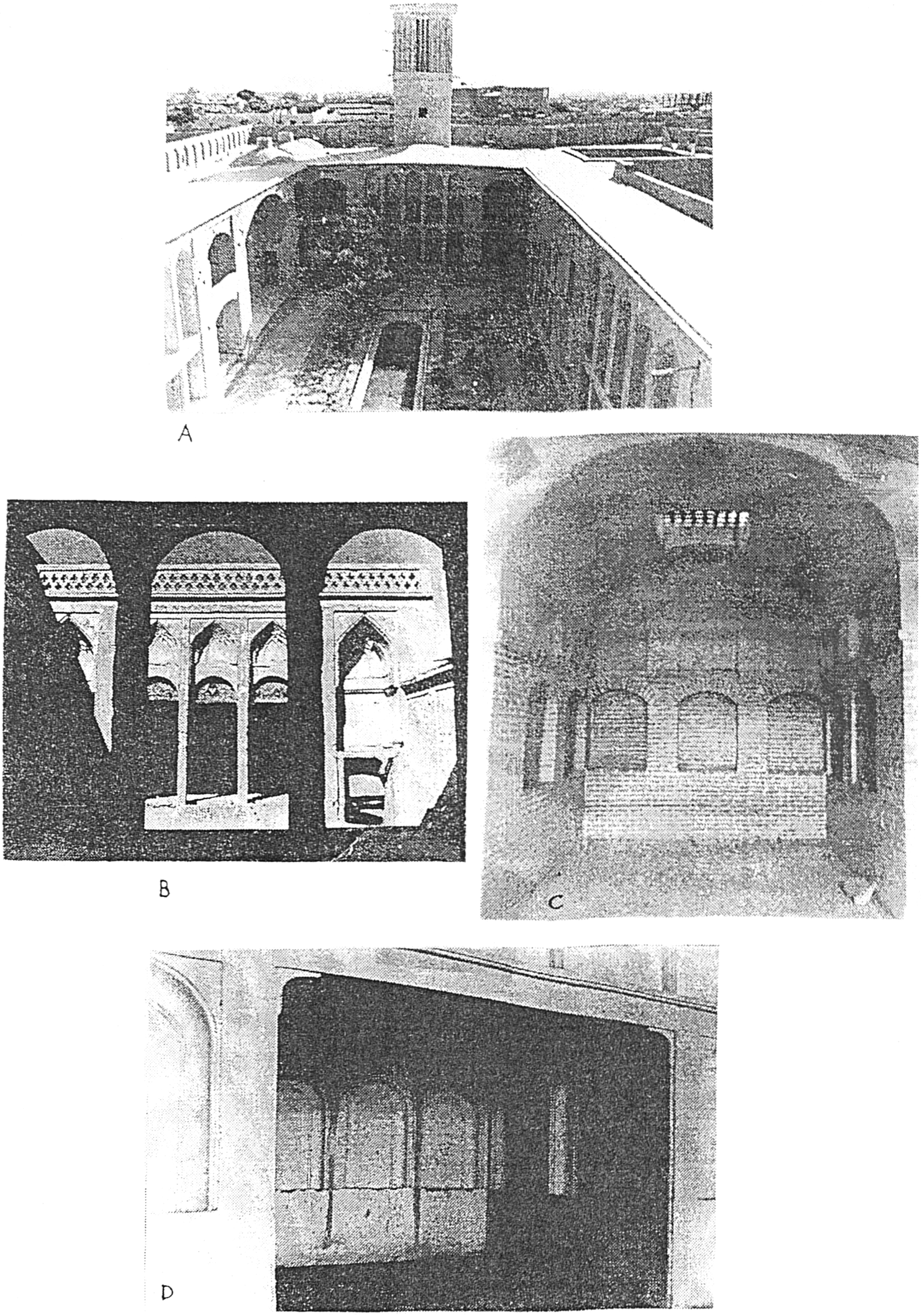


Figure 6.19. Photographs of the Zoroastrian house: A) the summer rooms of the andaruni B) The north-east facade of the biruni C) the badgir recess at the rear of the summer basement room D) the badgir recess at the rear of the talar of the andaruni.

> Also there is the inevitable bad-gir, or square air-shaft, running down to the back of the big summer portico, or talar, and furnished at the top with long slits on all four sides to catch any air that may be moving. This talar is the principal room on the summer side, which faces north. It is often built in the form of a cross with very stumpy arms, or rather of an oblong with the corners so taken off as to render it slightly cruciform. The long side of the oblong, faces the court-yard, and has no wall at all, but there is a curtain of tent cloth that moves up and down on pulleys. To the right and left of this sun-blind are short walled off passages, which are used as entrances. Corresponding to the projecting front part between the passages there is at the back a recess under the <u>bad-gir</u>, completing the cruciform design. The roof is arched into a high dome. The whole talar is raised three feet above the level of the garden, so as to give room for a two-foot upright grating, which is the window of the cellar room underneath. For five months in the year these are the only habitable rooms in a Persian house; and they are both furnished as living rooms. (Napier, 1905, pp. 14-15)

In the Zoroastrian house the canvas curtain is replaced by a curtain wall of coloured glass, consisting of seven French doors with seven fanlights. The doors can be opened to create a semi-open space facing the courtyard.

There are extensive basements under all sides of this house, many more than is common, and it is interesting to note that in 1900 Napier wrote:

> Up to about 1860 Parsis could not engage in trade. They used to hide things in their cellar rooms, and sell them secretly. (Napier, 1905, p.40)

The badgir of the Zoroastrian house has assumed a typical position for 20th century houses. Set in a recess at the centre of the back wall of the cruciform talar, the height of the badgir vents is greater than the length of the longest side of the tower. The badgir shaft itself is divided into six equal compartments separated by timber, brick and plaster partitions. A grill directly under the

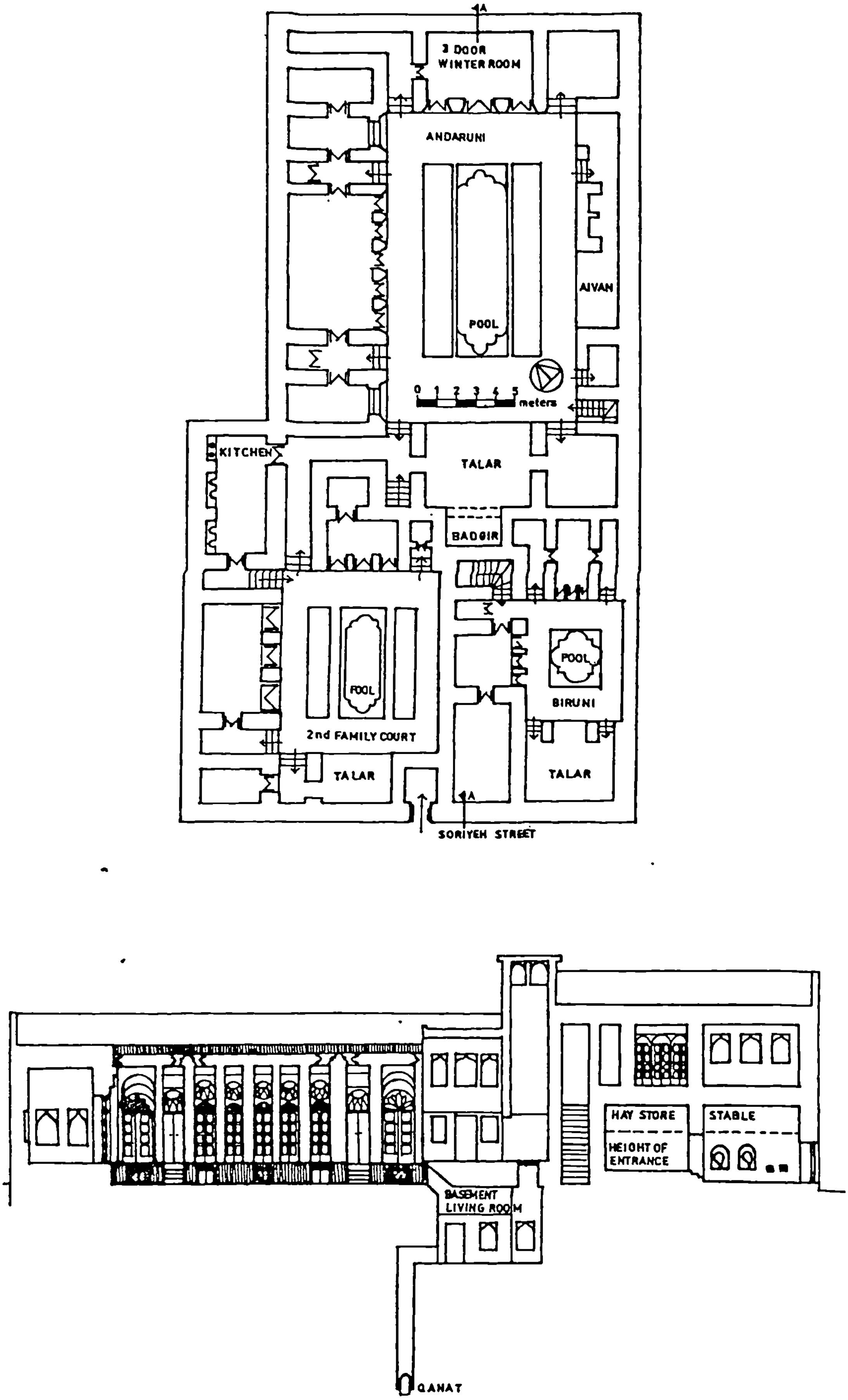


Figure 6.20. Plan and section of the house with a two-directional badgir (house A).

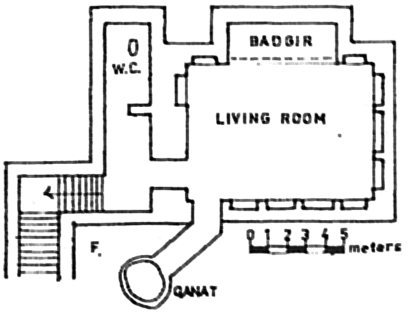
badgir directs air from the badgir down into the recess of the room below in the basement living area. This basement has an adjacent smaller basement for members of the family to retire in privacy. Grill windows link the basement with the courtyard.

6.7.2 <u>House with a two directional badgir - House A</u>

Situated Soriyeh street, to the south of Amir Chaq Maq, this house dates from two periods (figures 6.20 - 6.21).

The original small courtyard to the south-west is elegantly detailed in a a style that suggests a date similar to that of the Zoroastrian house, at the turn of the century. It has a small open vaulted talar with two storey niches around its internal walls. The decorative external niches are topped with pointed arches and the winter room has three glazed french doors. When the new portions of the house were built this courtyard reverted to a second family court.

The two other courtyards, the large andaruni and the small first floor biruni above the entrance passage and stables, were built in about 1935 judging from the glass panes used. Both these latter courtyards have talars and winter rooms and rooms to the west of the court. Neither has rooms on the eastern wall of the court. On the north east wall of the andaruni there are two winter seating platforms 'aivans', similar to that in the Zoroastrian house. The biruni has a nimiyeh wall, that is a blank wall to the east of the court.



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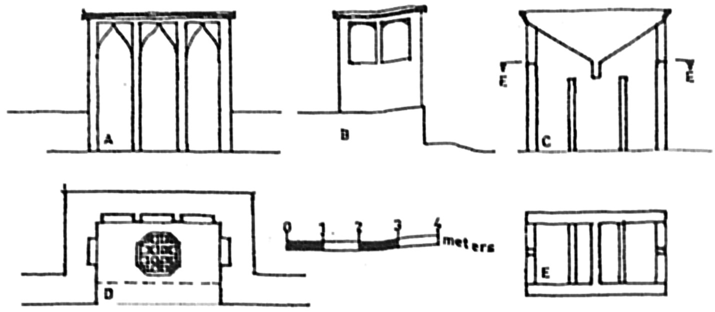

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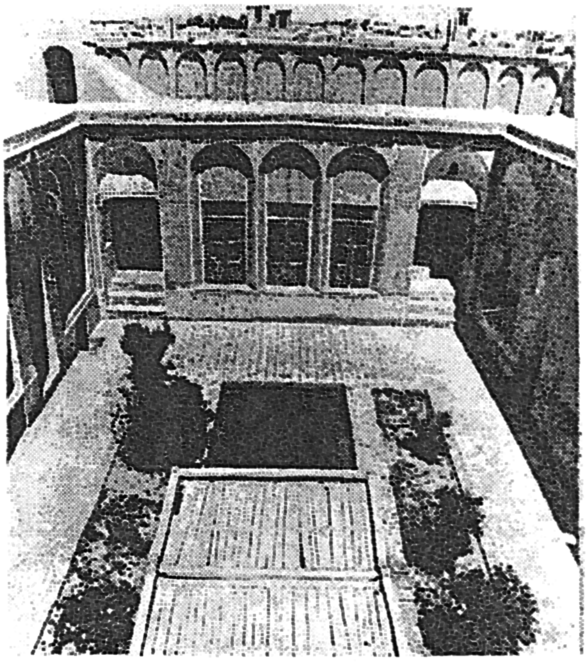

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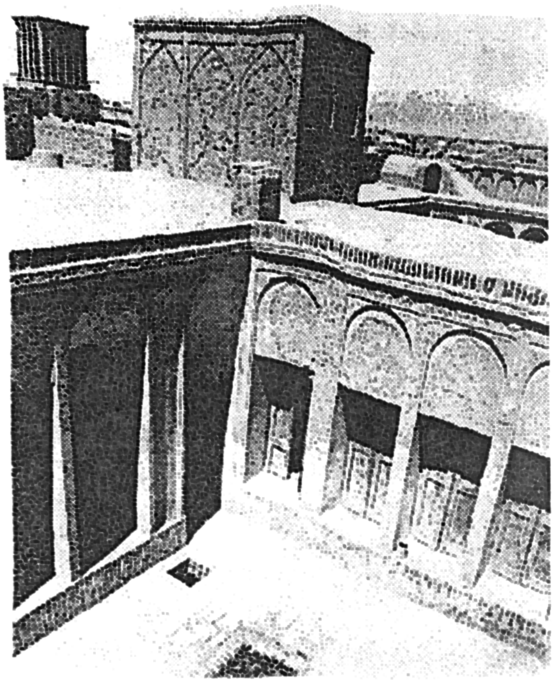

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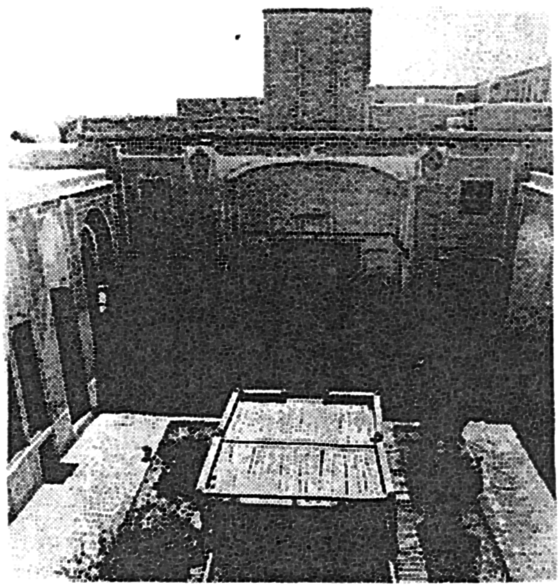

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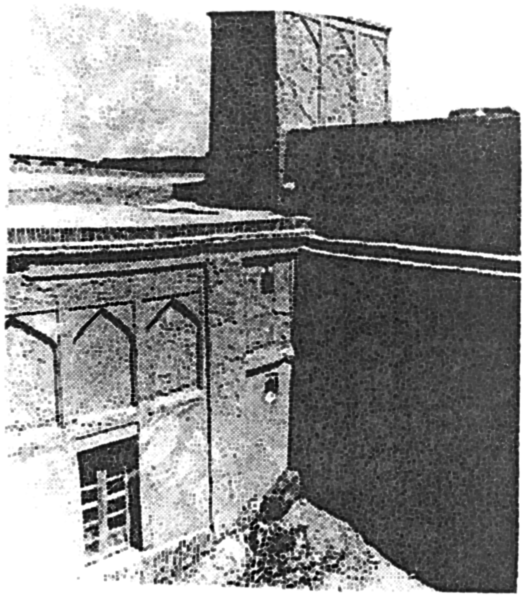


F

Figure 6.21. badgir house photographs

A) plan of the basement of the two-directional
B) plans and elevations of the badgir and
C) the winter room of the andaruni
D) south-west facoing winter rooms of the biruni
E) talar of the andaruni with badgir
F) south-west facade of the second family court.

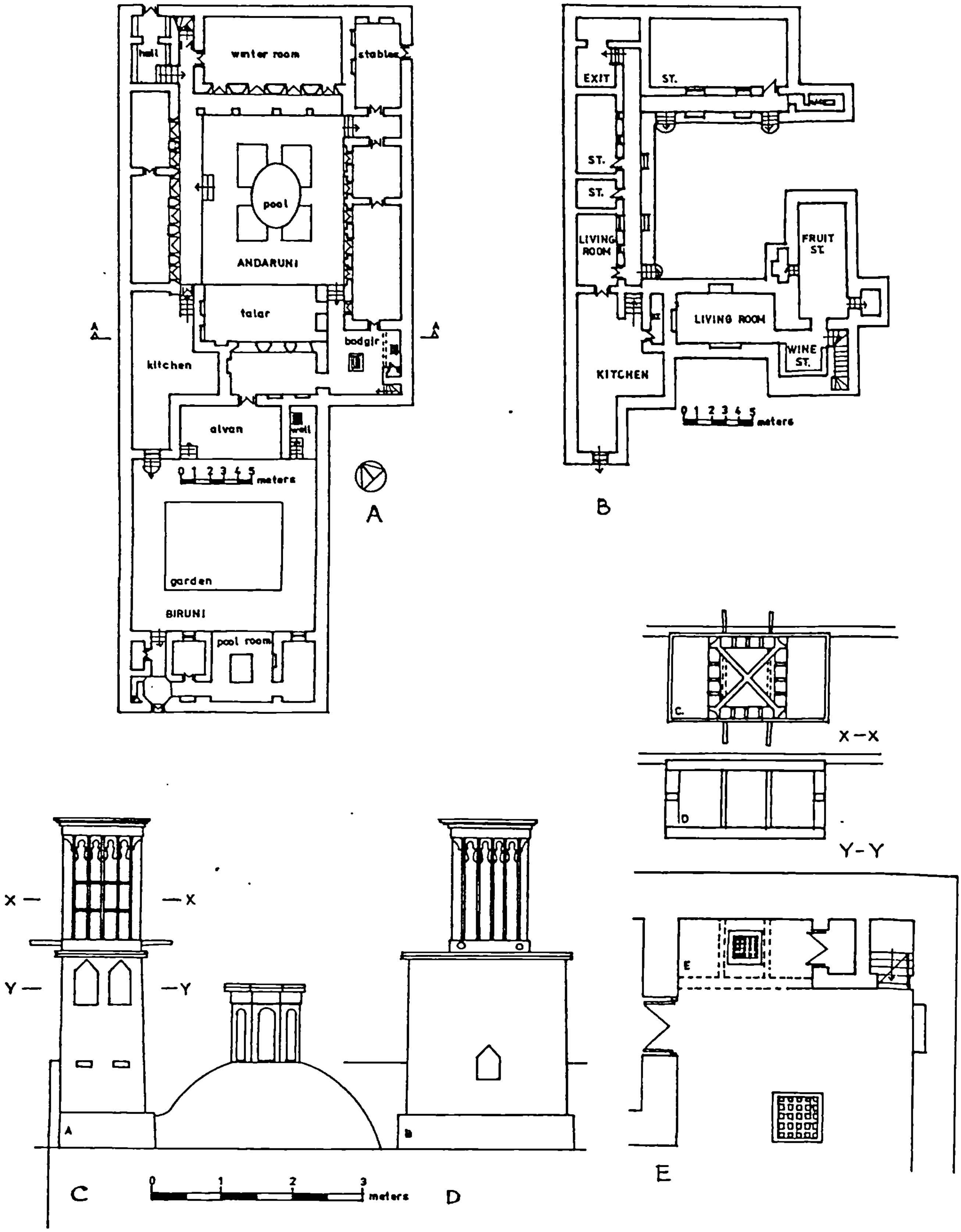


Figure 6.22. Two-storey badgir house (house B): A) Ground floor plan B) basement plan C) north-east elevation of the badgir D) north-west elevation of the badgir E) plans of the badgir at vent and ground floor level.

The large andaruni with its imposing central pool and talar with badgir has rounded niche recesses and crisp elaborate gypsum details on the piers and pediments of its internal facades.

Full basements are limited to the areas beneath the talar and eastern wing of the andaruni, but extensive half basements beneath the two smaller courtyards house the kitchen, stores, stable, and subterranean entrance passage from the street.

The summer basement living room has a badgir recess on the back wall and a single side entrance. It also has a second low door in the north wall of the room leading to the well shaft of an underground qanat channel.

The solid two directional badgir is ponderous for the period, and surprisingly has pointed arches adorning its long walls. These suggest that it dates from the earlier period of the house, which would imply *that the newer* andaruni may have been rebuilt rather than a new courtyard.

6.8 LARGE TRADITIONAL HOUSES OF THE MIDDLE OF THE 20th CENTURY

6.8.1 Two-storey badgir house - c. 1930-1940. House B

This house, situated just off Soriyeh street, spans three alleys, with the main entrance to the andaruni in the north-west corner, and to the biruni in the south-west corner. A third entrance from a small side alley leads to a stable from which there is access from the courtyard (figures 6.22 - 6.23).

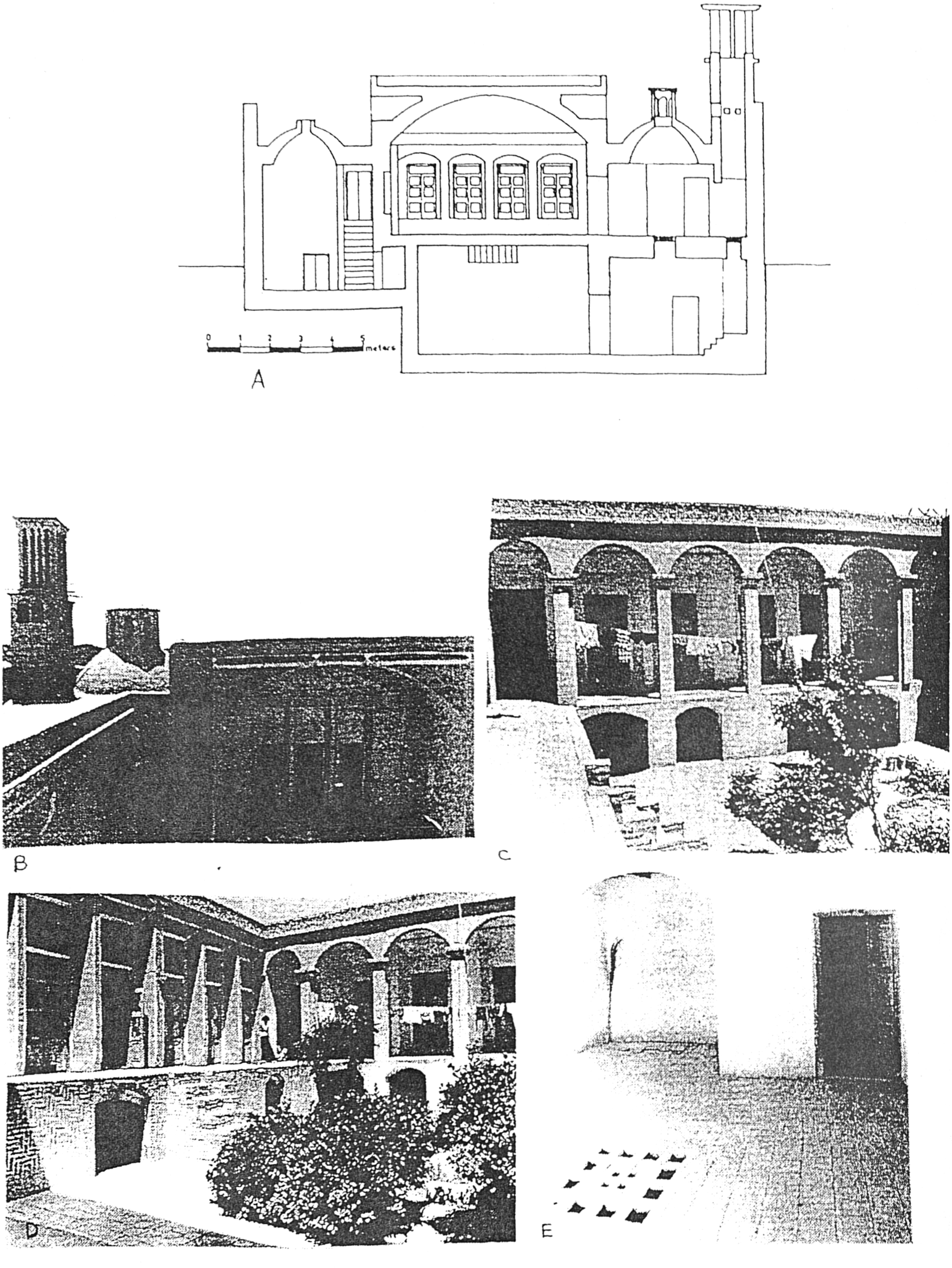


Figure 6.23. Two-storey badgir house: A) section through the summer rooms of the andaruni looking north-east and photographs of the B) talar of the andaruni C) north-east facade of the andruni D) north-west facade of the andaruni and E) ground floor badgir room with badgir recess and stairs to basement.

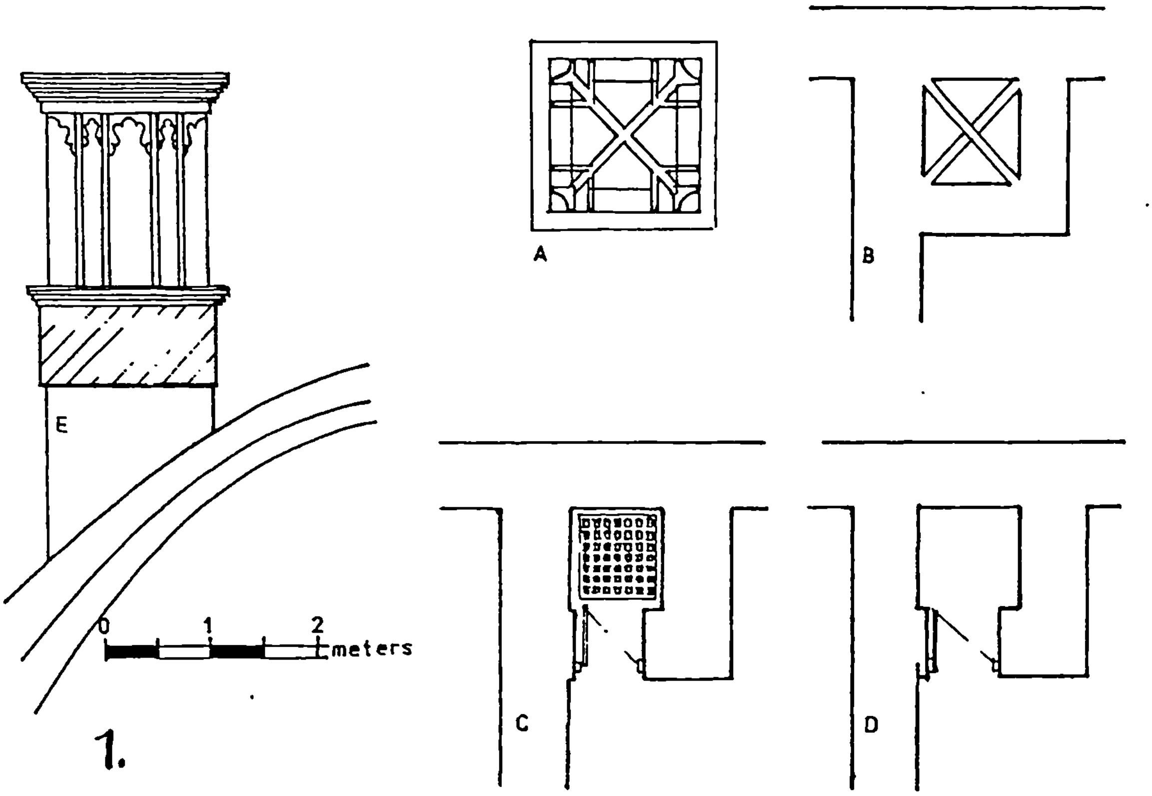
The biruni has a simple combination of winter aivan and summer pool room around a courtyard with one of the few large trees in central Yazd.

One the north-west wall of the andaruni is a half basement which has above it a colonnaded walkway on the north, covering an arched corridor with windowed rooms behind it. Above the half basement to the west of the court is an open terrace, an evening aivan.

The introduction of the colonnaded verandah is a new and popular feature in post 1930s houses in Yazd. This expansion of the architectural vocabulary of the city may have resulted from the influences of a movement of colonial architecture' as practiced by the building division of the British Government's India office, working in India in the 19th century and for instance in Iraq after 1916.

The summer rooms of the main andaruni consist of a talar, lateral badgir room, basement living room and a central hall between the winter aivan of the biruni and the main talar of the andaruni. The talar is a rectangular space open to the court, of a distinctively 20th century form, covered with a high round vault and is nearly twice as wide as it is deep. This provides an exposed, breezy location in a space that completely dominates all the other volumes of the courtyard facade.

The basements of the house include full basements beneath the main talar and to its north-east, and the half-basements on the west and north walls of the andaruni, in the south of



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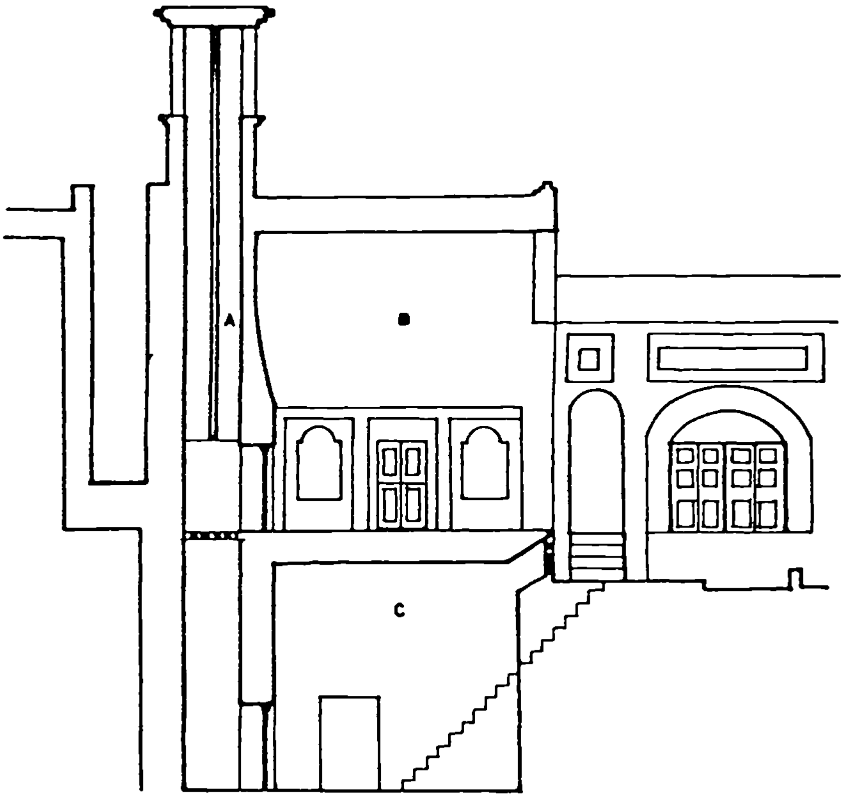


2.

Figure 6.25. Darbandeh house: 1) the badgirs A) plan at vent level B) plan at the base of the tower shaft above ground floor door C) plan at ground floor door level D) plan at basement door level and E) north-east elevation of the tower. 2) Section through the summer rooms of the house showing the A) badgir shaft and doors to B) talar and C) basement living room.

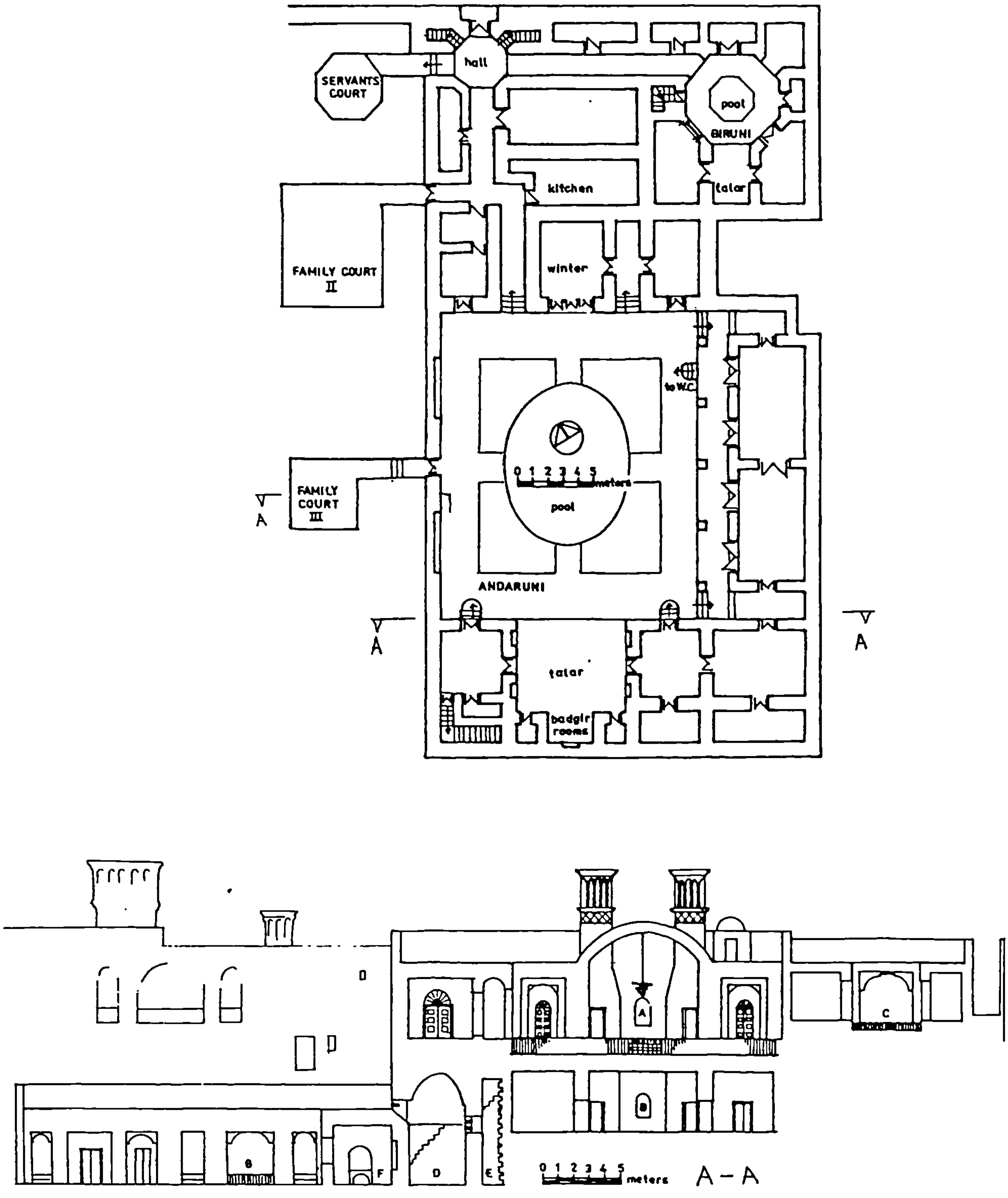


Figure 6.24. Darbandeh house (house H): A) ground floor plan of the main courtyards B) composite section to show relationship of the ground floor courtyards to the sunken store rooms and orchard garden, showing a) talar of andaruni b) basement living room c) talar of family courtyard d) large basement store room e) pigeon house f) kitchen and g) garden talar.

which is the kitchen.

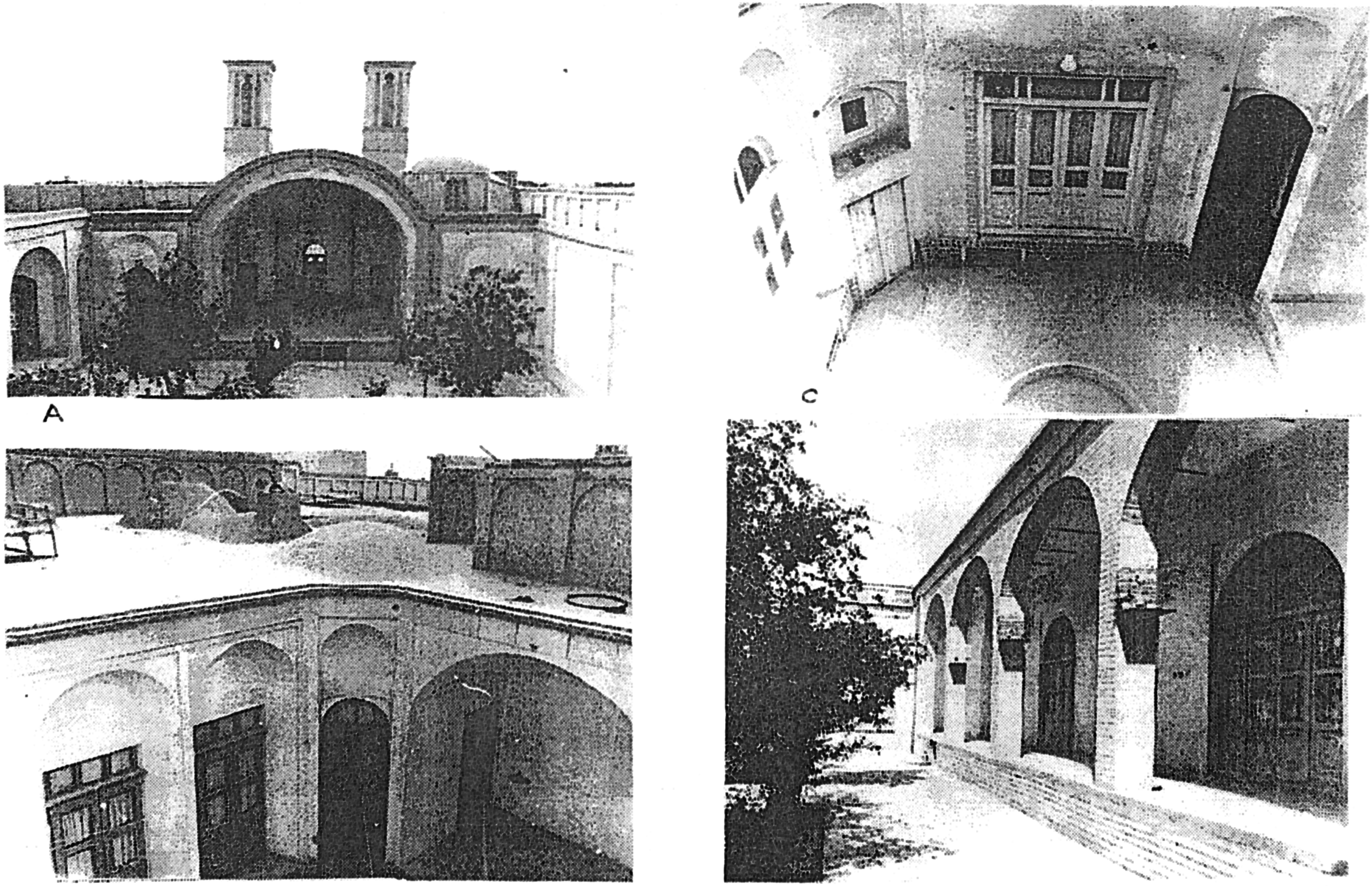
The badgir is unusual. It is two-storey and situated in a lateral badgir room. On both counts it resembles the Gazorgah in the quarter to the south-east of Amir Chaq Maq Square (figure 6.15), a house which has a lateral badgir room, and double height badgir. The Gazorgah house was built in the early 19th century and has a large rectangular lower badgir similar to those at the Bagh-e Dowlatabad, and Nowab Rasoui house. The upper tower was probably built in the last quarter of the 19th century. The lateral badgir room in the Gazorgah house would have been used as an airy living room when the temperature of the external air was suitable.

6.8.2 Darbandeh house - c. 1945. House H

This large house has five courtyards and an orchard yard, all entered through one main door and octagonal entrance hall. Two of the subsiduary family courtyards have secondary access doors from a side alley, as does the sunken garden. The organisation of the rooms around each court is straight-forward with the summer rooms to the south of the courtyard (figures 6.24 -6.26).

The west wall of the andaruni is a nimiyeh, or blank wall, and the rooms on the east wall of the andaruni are protected from the summer sun by a brick colonnaded verandah.

The talar of the andaruni dominates the spaces of the house and is a high, round vaulted, rectangular space with



A B C D

Figure 6.26. Darbandeh house: photographs of the talars of the A) andaruni B) biruni C) servant's courtyard and D) the south-eastern collonaded verandah of the andaruni.

the two south corners occupied by a pair of small badgir rooms.

The basement areas of the house include two interesting features. The mivehdun, fruit store, is 5m. high and has on its west wall a narrow corridor as high as the room with pigeon roosts on the west wall. The east wall of the corridor is perforated at intervals, with high level windows for access for the pigeons and a ground level door for cleaning access.

The bistan, the garden at basement and qanat level, with citrus trees, has servant's quarters on its west wall and on the south wall has stables and a talar with two flanking corridors; a delightful place for the contemplation of nature and the coming and going of doves. This court is 10m. below present ground level, at the pa-e-au, or the foot of the water', the qanat water level.

The paired badgirs have walled shafts that open into the talar and basement by doors facing the courtyard. In a volume of the size of the talar, unless the wind is very strong, the impact of these badgirs would be little felt. In the talar, their function appears almost vestigial. However they provide effective ventilation in the basement.

6.9 THE MODERN HALL HOUSES OF YAZD

6.9.1 Susan Khanum's house, 1978

This house has an L-shaped living room, two bedrooms, a kitchen and a bathroom arranged around a central roofed hall. It is constructed of baked brick plastered only

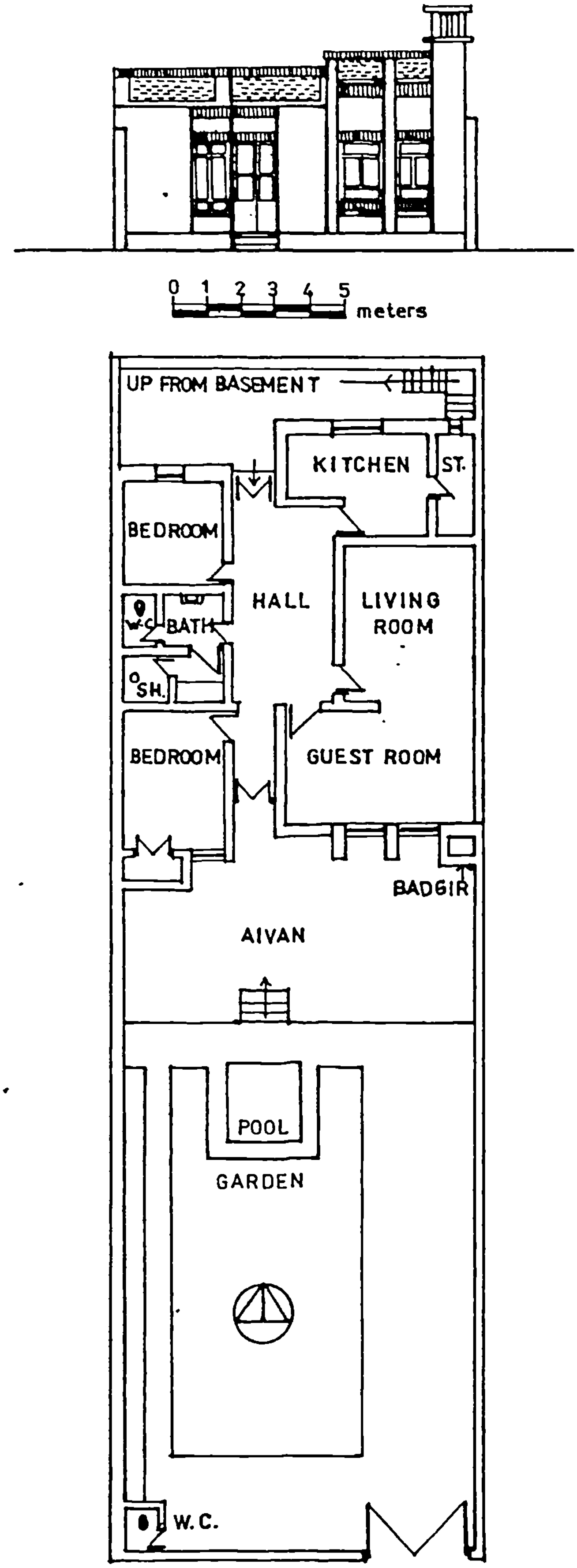


Figure 6.27. Plan and south elevation of Susan's house, built in 1978.

internally, with white gypsum plaster (figure 6.27).

The central hall is protected from the sun, and well ventilated by a cross draught from the two external doors to the north and south of the room. This is the main family living room of the house.

The facade of this house has a stepped plan to reduce the intake of solar radiation into the house on summer afternoons.

The house is cooled by (see page 198) swamp-coolers on the roof, but as in many other Middle Eastern cities, Yazd is prone to power failures in the middle of summer afternoons when maximum demand from coolers overloads the electricity supply system. When this occurs the hall is the coolest room in the house: rooms facing south with windows allowing the entry of direct solar radiation are impossible to occupy.

An interesting feature of this and many of the new houses of Yazd is the open seating terrace, called 'aivan', in front of the house. Much time is spent here, out of doors, on summer mornings and evenings. It has exactly the same function as traditional aivan in the Mashrouteh and the Immam Hussein houses.

The large basement beneath the living areas is well ventilated, having a badgir, but was, in 1978, used solely for storage.

Such badgirs are a concession by local builders to traditional houses of the area. Its diminutive size serves

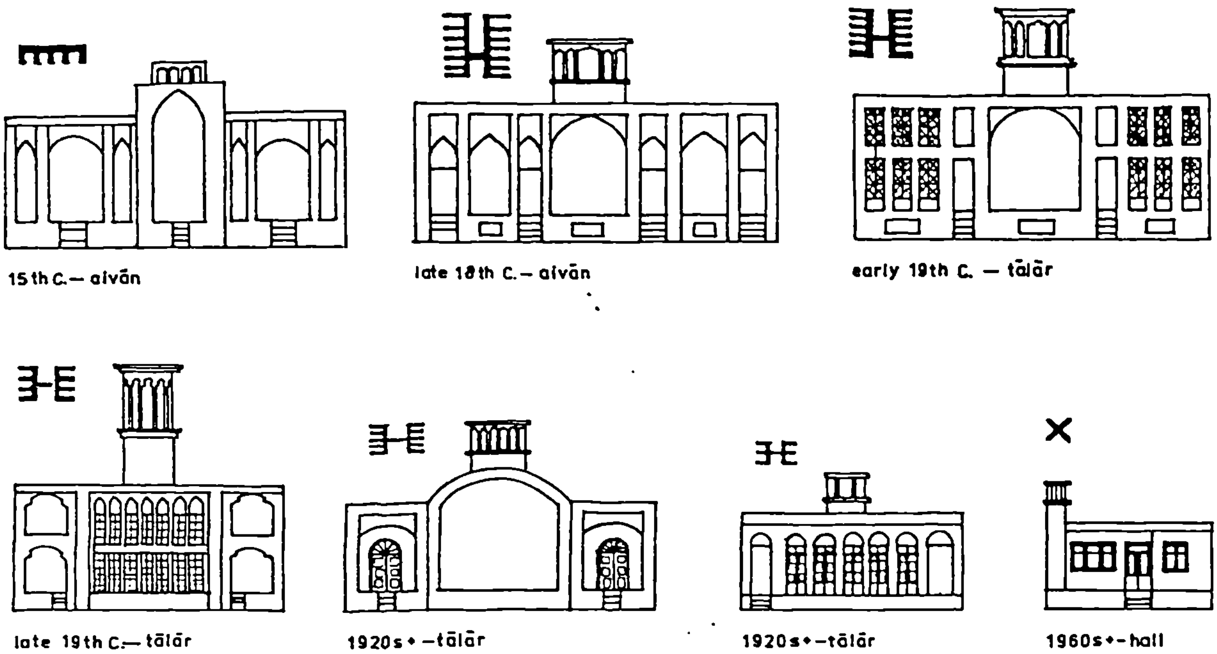


Figure 6.28. Theoretical reconstruction of the evolution of the houses of Yazd, by the author.

15th century house: aivan house with elevated central portico and low uni-directional badgir.

Late 18th century: aivan house with level roof-line and arches of squat proportions. Low square badgir with height of vents less than longest side of tower.

Early 19th century: Talar house with level roof-line and barrel vaulted talar. Coloured glass windows used in many of the courtyard doors and the badgir still square but height of vent section up to one and a half times the length of the longest side of the tower.

Late 19th century: talar house, eclesiastical' in appearance with level roof-line and lateral elements incorporated in single arch. Coloured glass doors widely used and badgir vent height up to and exceeding double the length of the longer side of the tower.

1920s - 1940s: Talar house with raised barrel-vaulted talar. Lateral rooms with clear glass in double doors and rounded fan-lights. Rectangular with height of vents equal to or less than length of longest side of tower.

1920s to 1940s. 3 - 5 door room house. The talar is virtually replaced by a summer room of modest proportions beneath level roof-line. If found badgirs are low rectangular structures. Glass is clear in large rectangular panes and this is best described as the panke' or ceiling fan house.

1960 +: Hall house with air-conditioning. Badgirs rarely found and used to ventilate basements.

well enough for its sole purpose in the house, to ventilate the basement.

The modern houses of Yazd are predominantly of the hall' type, as they are throughout Iran. These houses represent a complete stylistic break from the traditional courtyard house, with the central living area now covered.

Climatically successful traditional architectural elements continue to be used in the modern houses of the area, such as the unroofed aivan and the badgir, albeit in a reduced capacity.

The rapid change of the central family unit from the large extended family to a small nuclear family has perhaps dictated the smaller sizes of these houses and in turn is necessitated by it. While social units are changing in the new houses the cultural standards and taboos of the society are perpetuated. This is witnessed by the high walls that surround the gardens, maintaining strict visual privacy within the confines of the house.

6.11 Historical house types of Yazd

From the late eighteenth century until the present day, it appears that three main houses types have been built consecutively: (figure 6.28)

The aivan houses - built until the 18th century
The talar houses - built in 19th and 20th centuries
The hall houses - built post 1960

Conclusions that can be drawn on the house and badgir types of the 18th, 19th, and early 20th century house described in this chapter include:

The development of the aivan house into the talar house is shown in differences between the ruined house and that of Nowab Rasoui. This latter house is very different from the ruined house built three quarters of a century earlier, but bears a remarkable resemblance, on several counts, to both the octagonal pavilion, a transitional building, with a similarly arranged complex of summer rooms, and the Hareem, with similarly proportioned basement and badgir.

The plan of the Nowab Rasoui is very much in the Yazd tradition, but the elevations are completely different from those we have seen in the examples of earlier architecture of the aivan houses. In the latter houses the courtyard facades were dominated by the aivan vaults, creating a sense of deep open space, whereas here the courtyard is enclosed in walls of brilliantly coloured glass in sash windows, with the summer talar being the only deep space opening on to the courtyard.

A fundamental change has occured in the main summer living room. The aivan has become a talar (see appendix A) There are three possible sources for this revolutionary change.

1) Baghdad, where in the 18th century talars were built with paired pillars and complex capitals, and with mezzanine rooms flanking the main talar (called Kabishkhan in Badghdad), and ursi windows, small-paned coloured glass sash windows, around the courtyard: all features found in the courtyard of Nowab Rasoui house (see Reuther, 1910; Warren and Fethy, 1982). Yazd had trade connections with this city.

The title Nowab may be derived from the Arabic na'ib (plural nuwab) meaning representative or agent etc.

2) India. The title Nowab is also an Indian one, and Yazdis traded freely with the Indian sub-continent, via Bandar Abbas and Bandar Lingeh. The timber arched screen between the columns of the talar may well have an Indian flavour.

3) The Zand court at Shiraz. This house is obviously influenced by the houses and pavilions of the ruler Karim Khan Zand (1740-1779) who had his capital in Shiraz. In one of his garden houses, the Bagh-e Dilgusha, the north facade incorporates a two columned modified Safavid talar (appendix A) creating a portico/aivan facing the garden (Lockhard, 19), enclosed mezzanine rooms, and large sash windows. This may well have been a strong influence for the Yazdi talar, and the interchange of architects and builders between the cities seems likely.

Changes also occurred in the nature of the talar house between the beginning and the end of the 19th century, including:

1) The talar developed from a deep space into the shallow wide talar, with a transverse barrel-vault, characteristic of the end of the century. Such later talars could either be open or glassed in with three to seven pairs of French doors.

2) Badgirs, which in the houses described were large, low structures at the turn of the 19th century, developed in the latter half of the century into taller and smaller tower.

The Zoroastrian house has a tower over three times as high as the longer side of the tower. In the Hareem at the Bagh-e Dolatabad the vents of the badgir are lower than the length of the longest side of the tower. In the Nowab Rasoui house the vent area of each side is almost square.

3) The square, squat proportions of the early nineteenth century houses developed into the elevated pointed features of the houses of the last quarter of the century. The elegance of the high badgir of the latter half of the 19th century is reflected in the delicacy of the high proportions of the internal and external elevations of the buildings at the same period.

4) A new feature in the architecture of the late 19th century is a semi-open aivan or Zemistan neshast to the east of the andaruni. This forms a narrow seating bench facing the afternoon sun, for use in the early morning in summer and in cool weather in winter.

5) Non-coloured glass was still opaque at the end of the 19th century. Coloured glass was widely used in courtyard elevations at this time but in a cruder fashion than half a century before:

> Some of the older windows contain exceedingly fine work, but even when it is well done it is not very durable, and nowdays they can only do very rough work. Some of the work that is forty or fifty years old is marvellous, but could not be done at the present time for love nor money.(Napier, 1905, p. 19)

6) Four-directional badgirs were probably the commonest in the homes of the wealthy in the 19th and 20th centuries. However two-directional badgirs were also built.

By the middle of the 20th century the house had undergone a second revolution and many were characterised by the following elements:

1) Double timber doors with the upper half glazed and the lower half of timber panels, above which are three glass window lights over each pair of doors.

2) Colonnaded verandah on the north, east or west side of the court on some houses of the period.

3) Brickwork on the columns, piers, and the facade is exposed, in the Mohendizi', the engineer's, or the measured, style.

4) Badgirs, generally reduced in dimensions, built with an almost vestigial function in the large volume of the open summer talars but undiminished function in providing ventilation in the basement.

5) High, vaulted, open, rectangular talars.

In the twentieth century with faster transport and communications, influences from many directions were flowing into Yazd. However one important influence on building style in the city must have come from the erection of the new Zoroastrian Fire temple, built in 1935, in an updated version of the similar colonnaded fire temple built in Tehran in 1920 in a neo-classical style, with Indian money and perhaps Indian designers (Goddard, 1938, p.17). Other sources of influence were the neo-colonial buildings of Baghdad and India.

The pace of change rapidly increased in the twentieth century, for by the third quarter yet another house type, the hall house, had replaced this mid-century style. In the hall house the talar ceased to be built.

In the earlier centuries changes in the style of domestic architecture had occurred over hundreds, rather than tens of years.

6.12 BADGIR TYPES, SUMMER ROOMS AND HOUSE TYPES

The houses described above have shown that at different periods, and in different house types, badgirs and summer rooms have evolved hand in hand. Figure 6.28 shows the relationship between these developments.

The ceiling fan, and subsequent mechanical cooling systems have apparently rendered ground floor design elements such as the badgir, the canvas awning and the talar itself, obsolete in the modern buildings of Yazd.

6.13 GENERAL CONCLUSIONS ON THE EVOLUTION OF HOUSES AND <u>BADGIRS</u> IN YAZD

1) The domestic architecture of Yazd is not a static entity and house and badgir types appear to have evolved continuously and concommitantly.

2) The evolution of the domestic architecture appears to be influenced by two groups of factors:

A) External: i) Design influences from abroad, ie. India, Iraq
ii) Imported architects (i.e. from Zand court)
iii) Availability of imported materials (i.e. glass)
iv) Periods of isolation from above

B) Internal i) The process of local design <u>evolution</u> with its own internal momentum, i.e. development of talar design

ii) Local design innovation, such as the introduction of the Zemestan Neshast, the narrow winter seating platform on the eastern side of courtyards in the late 19th century.

iii) Design continuity, such as the use of the aivan, the external seating terrace from the earliest to the latest houses in the city.

iv) Inter-action between the evolution of the individual elements of the houses, witnessed by the changing badgir form in response to the changing aivan/talar form.

3) It appears that in the houses of Yazd, each built by an individual owner in the same local framework of service industries, there is a strong relationship between house and badgir type and date. The style of the houses is reflected in the style of the badgirs and the size of the badgir is related to the volume of the summer room, although until the introduction of the mechanical cooling devices in the city it appears that the badgir towers all served similar functions. These functions will be investigated in chapters 9 to 11.

That the basic blue-prints for badgirs may change over time suggests that, in a city like Yazd in which the expansion of buildings into the outer suburbs can be loosely dated, different types of badgir will predominate in areas of the city of different dates.

The evidence from this chapter suggests that the four-directional badgir has been used in the houses of Yazd since at least the 18th century and in the late 18th and early 19th century the towers were much larger than in the early

20th century houses. They were however lower. Further investigation of the distribution of badgir types in the city is necessary to determine whether badgirs can be proved to have increased in height after 1870 and whether four-directional towers were rare in the earlier quarters of the city or common at all periods. These questions will be addressed in chapter 7and 8.

CHAPTER 7

THE CONSTRUCTION AND COMPONENTS OF THE BADGIRS OF THE CITY OF YAZD

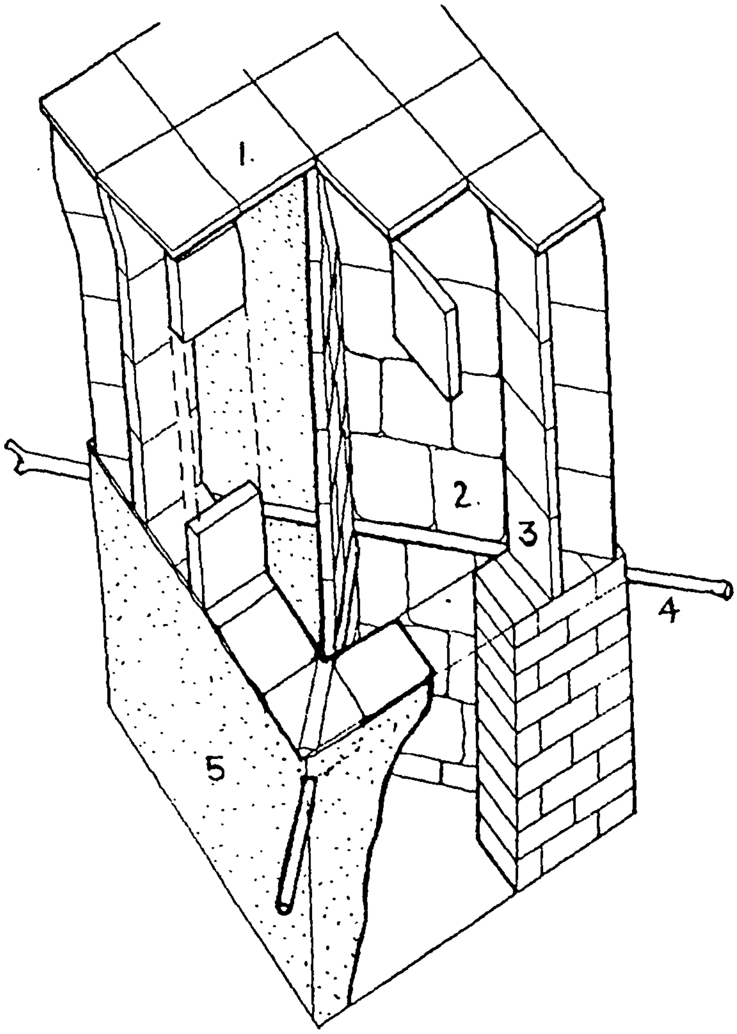
7.1 INTRODUCTION

This chapter outlines the construction and forms of the badgirs of the city of Yazd. It is divided into two parts: the first is a description of how a badgir is built and its component parts; the second describes the attributes of the individual badgirs of central Yazd, of which 713 were surveyed in 1977.

References are few in this chapter as it is largely based on field work by the author. Many of the local Yazdi names for badgir elements were collected, but due to the unique local dialect and the specialised nature of the vocabulary few Persian words are used in this thesis. It has been impossible to verify them as few occur in the dictionary of the Yazdi dialect (Safiryan, 1975) and Persians, even specialists in architectural history, are not familiar with the builders' terms used in Yazd. It is hoped to be able to publish the Yazdi terminology for badgir details at a later date, after further work in the field.

7.2 THE CONSTRUCTION OF BADGIR TOWERS

Badgir is a word used to describe many different types of ventilator, some of which are barely visible above the roof line. The following descriptions deal solely with the larger brick badgir tower.



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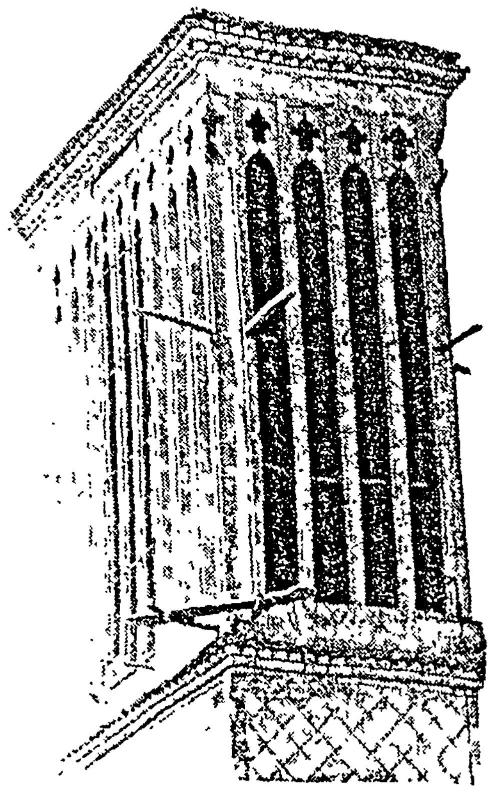


7·2

Figure 7.1. Axonometric to show the construction of a badgir. 1) roof of baked paviers 2) mud-brick internal partitions supported on diagonal timbers 3) brick-on-edge vent partitions 4) timbers protruding from the structure to form scaffolding supports 5) mud-brick walls plastered with coarse straw plaster externally and internally.

Figure 7.2. Photograph of a high badgir showing the eave, vent and sill details.

These towers are built either of mud-brick, or of baked brick, a material that was particularly popular after the turn of this century.

Mud-plaster with fine or coarse straw chopped into it was commonly used over most surfaces in the Yazdi house, including the internal and external walls of the badgir. In baked brick houses internal walls and external decorative features were executed in white limestone plaster (gatch).

In many towers the eave and sill details, the roof and internal vertical partitions, may be of farshi tiles (baked square paviers) while the rest of the tower is constructed of mud-brick covered with mud plaster.

The above-roof tower can be divided into seven parts, described below from the base upwards (figure 7.1).

7.2.1 The brick tower

Called locally the pa-e badgir (foot of the badgir) or sotun (column of the tower), the baked or mud brick tower is usually covered with mud plaster or occasionally with fine white gypsum plaster. Badgirs built of baked brick have no external plaster.

Timber beams, or rather branches, are built into the tower to support partition walls at various heights, to tie the structure together, and to provide a ladder and scaffolding for use during subsequent maintenance of the badgir. These poles also increase the shear resistance of the tower on which, in the higher examples, the stability of the tower largely depends [figure 7.2].

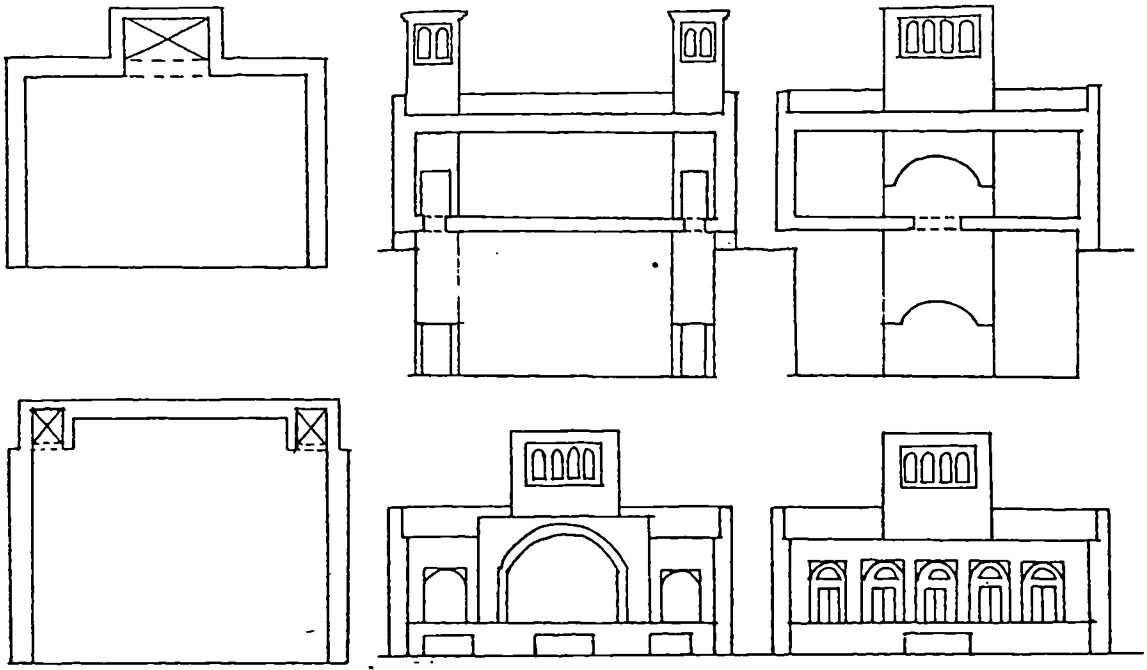


Figure 7.3. Most typical location of badgir in the house is the central position in either an open talar or summer room with French doors. Less common are the paired towers with shafts enclosed and opening on to rooms through doors in the ground floor and basement.

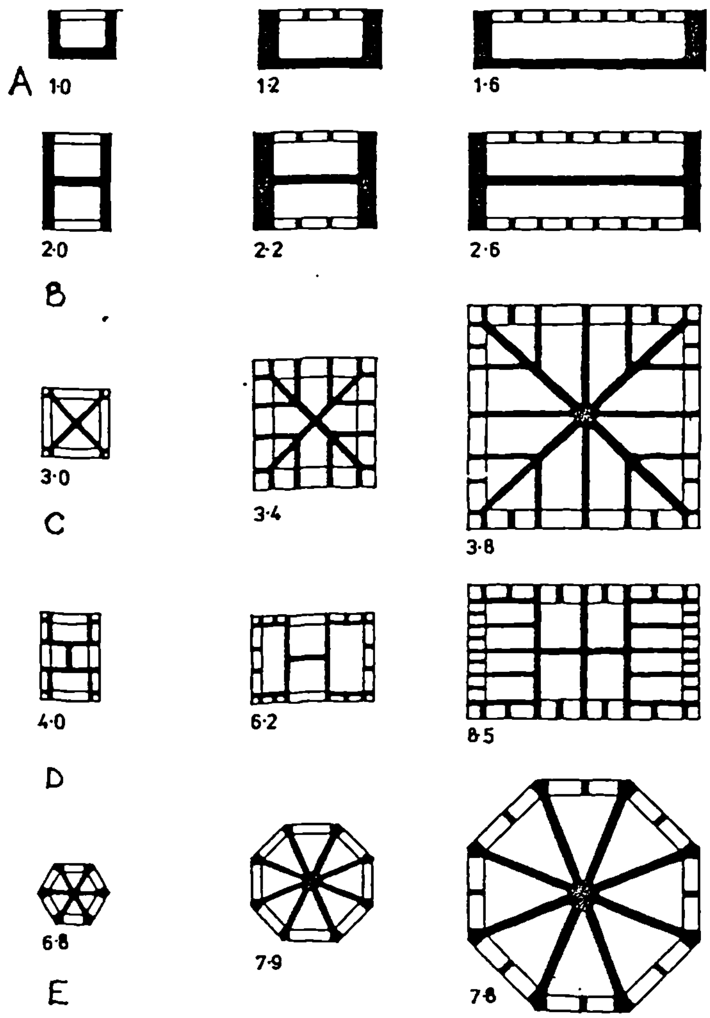


Figure 7.4. Key of plan types recorded in the survey:
A) uni-directional B) two-directional C) four-directional with diagonal partitions D) four-directional with H'-shaped partitions and E) octagonal and hexagonal towers (see also figures B.4 and 5)

7.2.2 The shaft of the tower

The internal shaft of the tower is divided by partitions made of farshi (square brick tiles) or bricks on edge, plastered with rough straw plaster. The partitions are supported on a timber frame. The wood used is often mulberry, which is said to be resistant to termites.

The internal partitions are, where possible, carried down to between 1.5m to 2.5m above the floor level of the badgir recess or room at the rear of the summer living room. Local builders maintain that the low thresholds are more effective. In badgirs associated with water cisterns, builders recommend that the internal partitions of the tower descend to approximately 1m. below the sill of the vent (Hajji Reza Baghoush, a local builder). Where paired corner badgirs are separated from the talar by a door, the internal partitions may continue down to just above door level (figure 7.3). In some towers, notably on those of water cisterns (figure 3.8), the internal shaft is narrowed just before the outlet into the cistern, a device which is designed to increase the air speed through the outlet by reducing the cross-sectional area of the shaft.

7.2.3 Decorative band or diagonal carpet'

Just below the vent section of the badgir there is often a band of decoration formed by a field of applied baked brick paving tiles in a diagonal pattern. Occasionally the paviers are applied perpendicularly to the tower.

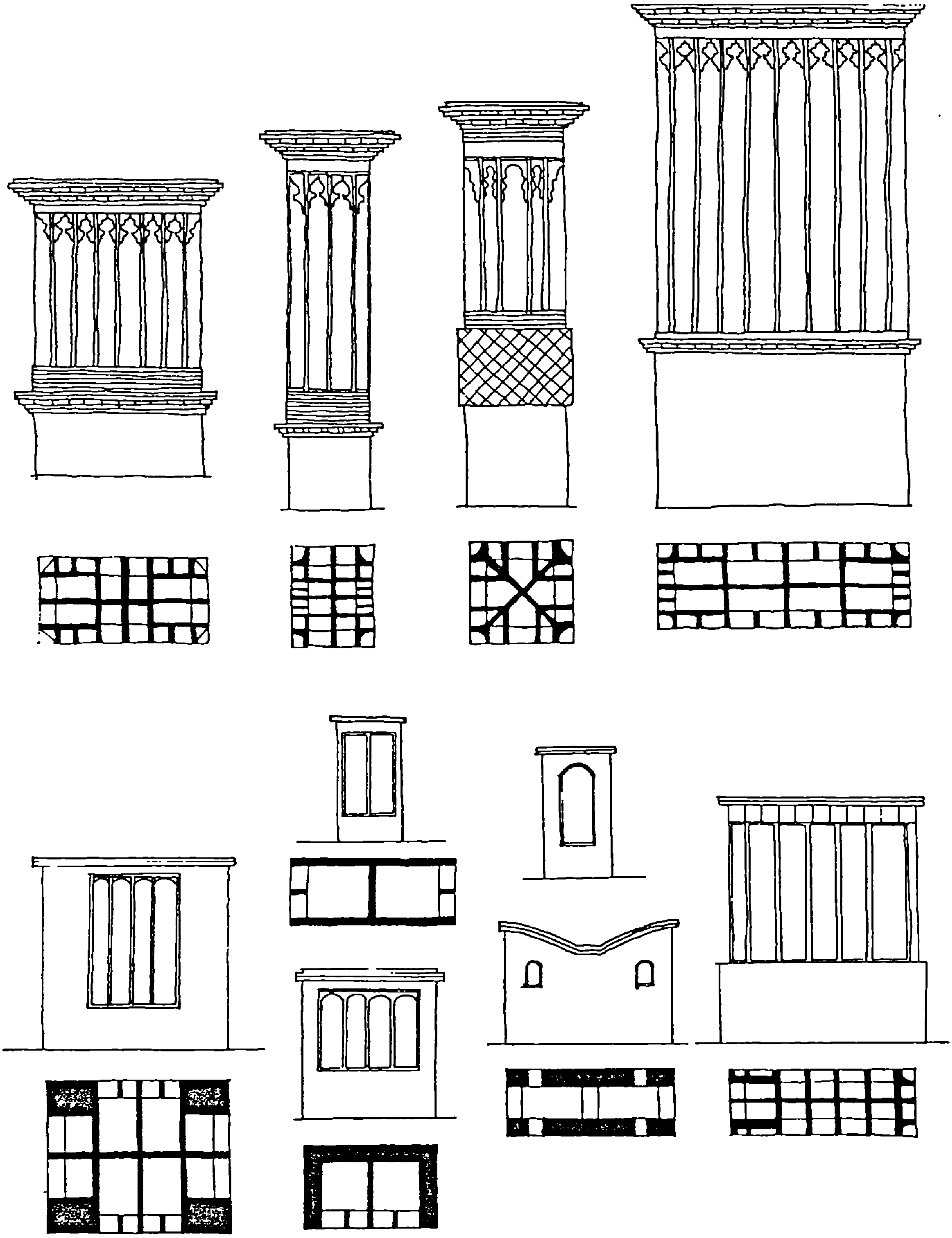


Figure 7.5. Plans and elevations of simple and more elaborate towers illustrating that complexity of plan does not relate necessarily to the size of the tower or the elegance of its elevation.

The *farsh* or carpet pattern is usually 60-80 cms high. This detail, using baked tiles, also presents a more resistant surface to the wind and rain than mud-brick or mud plaster.

7.2.4 Sill detail

At the head of the brick tower is a drip course formed of one to eight courses of corbelled baked bricks, baked bricks on edge, or tiles [figure 7.5 and 7.6].

Mud-brick is a vulnerable material and a wide drip course provides protection from the rain to the top of the tower. The cantilevered sill also effectively divides and directs the air travelling into the vents from that flowing down and around the tower, so minimising turbulence at the base of the vents. In some towers there are several courses of bricks between the sill detail and the base of the vent proper.

7.2.5 The vents

These are formed by vertical partitions built of mud-bricks or baked bricks or tiles on end, and can be either the depth of the external wall, around 20-25 cms, or continue to the centre of the tower, forming a separate shaft behind the vent.

It is common practice to have wide shafts which face in one direction, separated into two or three separate shafts, with two to four vent entrances for each sub-shaft (figure 7.4).

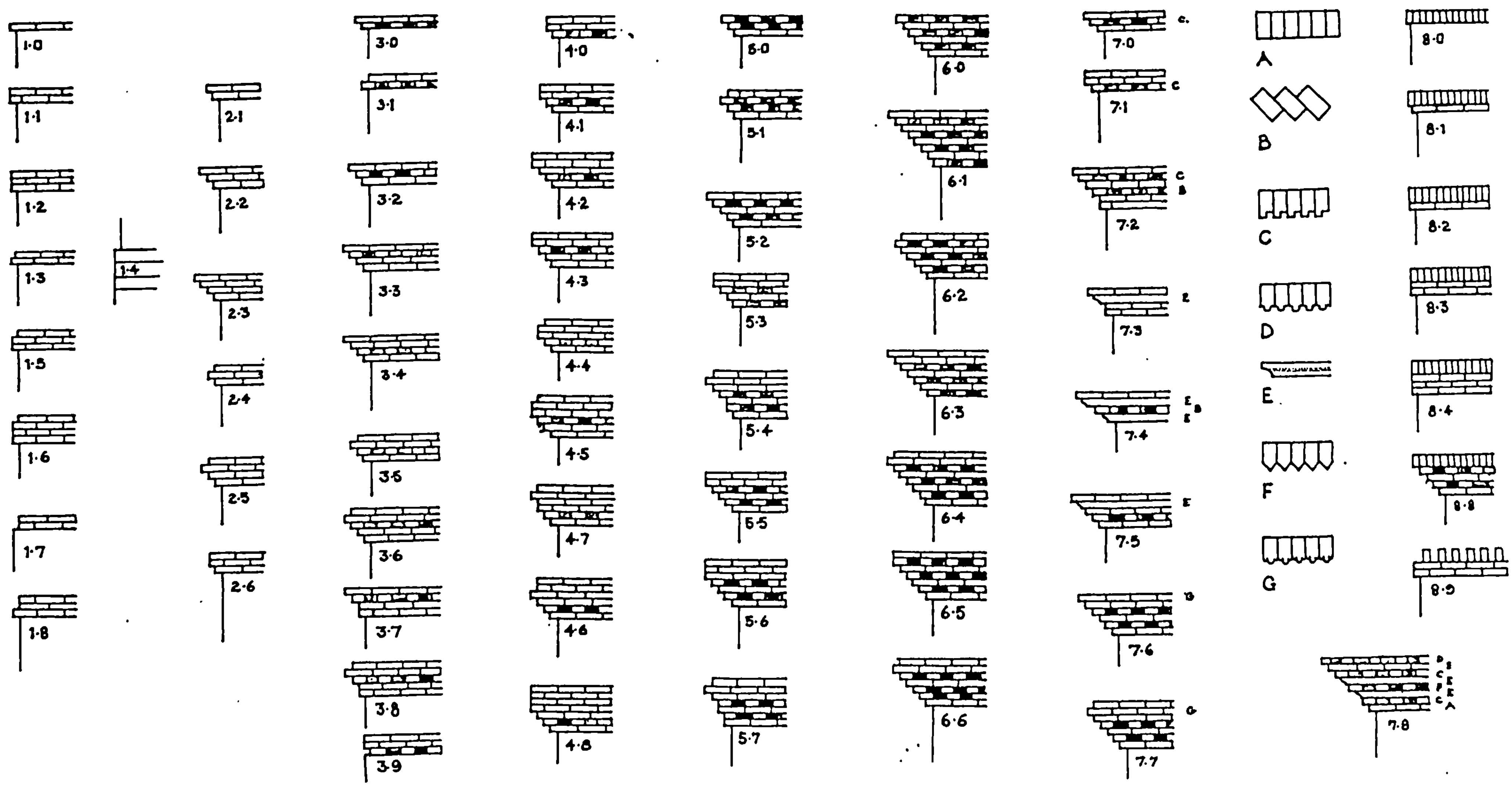


Figure 7.6. Key to the eave and sill details recorded in the survey of 1976 (see also figure B.3).

Vents facing towards the wind are said to have an ear' (goosheh) to that wind. So a wind-tower that faces in four directions is said to have four ears to the wind.

At the corners of the towers vents are often merely blank decorative niches backing on to the walls of the vent shaft behind. These niches have the same form as the open vents, with similar details at their heads. They are called by several names locally, including false one', decorative one', or closed one' (figure 7.2).

7.2.6 Vent head detail

There is a wide variety of vent head details (figure 7.7). Most of them are of recognisable types, each named, although a number of cruder examples defy such categorisation.

The details are carved from plaster and their designs are often constructed by using a pin and string and a system of known centres. The most elaborate are cut by using a stencil.

7.2.7 The eaves details and roof

The eaves of wind towers are, like the sills below the vents, generally cantilevered out in one to eight courses of plain and decorated farshi tiles. This detail provides a drip course, protecting the upper half of the vents from damage during heavy rain. The cantilevered eave effectively divides the air descending into the vents and flowing over the top of the tower, so reducing turbulence around the head of the vent.

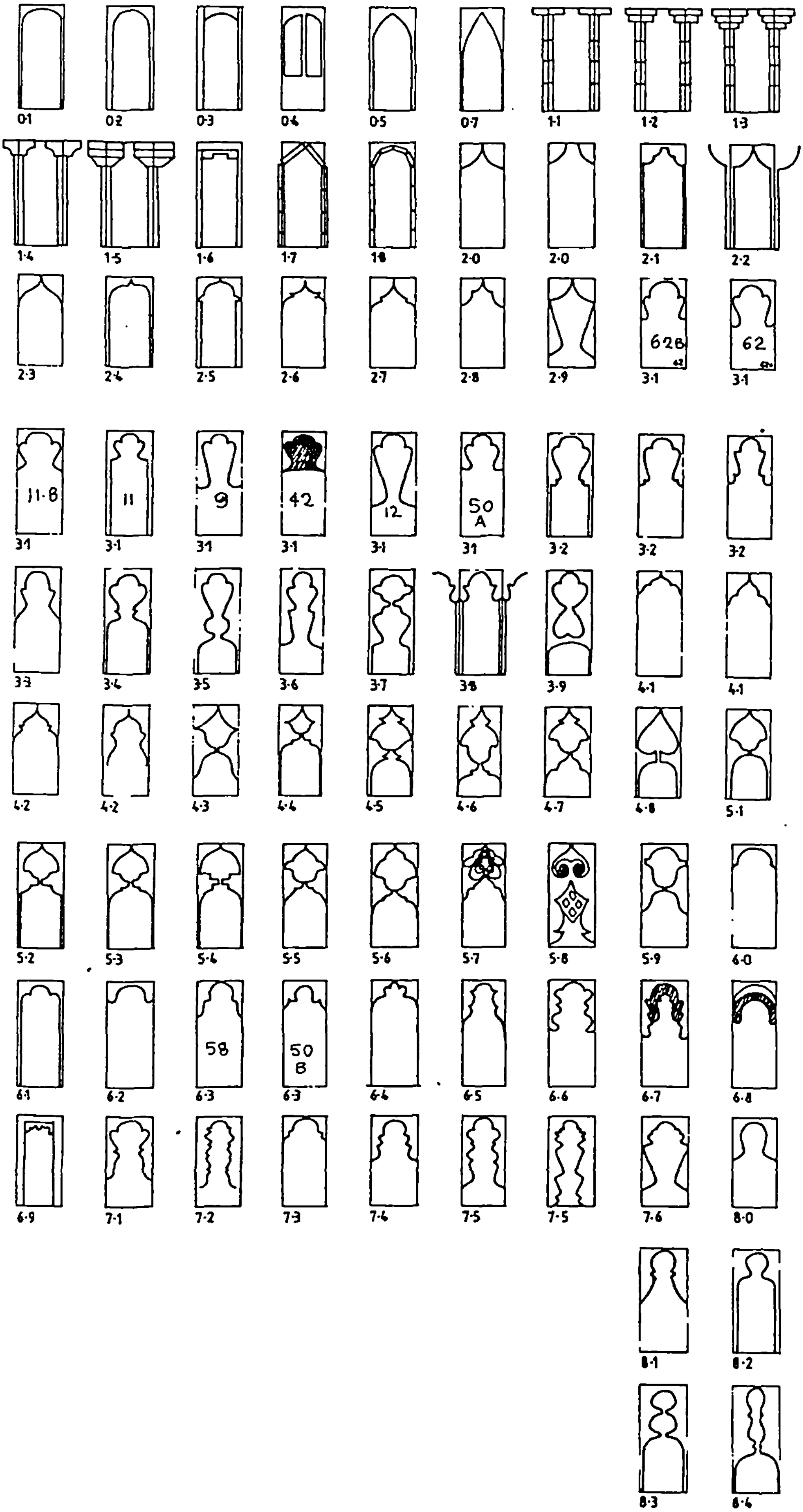


Figure 7.7. Key to the vent head details recorded in the survey of 1976 (see also figure B.2).

The roof of the shafts may be sharply angled down towards the centre of the tower to smooth the path of the air down the shaft. However one local builder maintained that this was unnecessary as the wind would find its way down anyway' (Hajji Ali Akbar, local builder).

7.3 RESULTS OF THE SURVEY OF THE BADGIRS IN YAZD

In 1976 713 badgirs in central Yazd were surveyed and the analysis of the attributes recorded are outlined below.

Where a badgir could not be reached to be measured approximated dimensions were calculated using the standard measurement of the Yazdi mud-brick, which is 20 x 20 x 10 cms. During the survey a key for each attribute was built up and new details were added to it as they were recorded. At the conclusion of the survey the key was then reorganised into generic groups of details and plan types. For example, while the plan types fell into six clear groups, the vent head details originally numbered no less than 82, and were subsequently re-classified into eight main groups.

An unfortunate accident occurred en route from Persia to England in 1976 and half the survey sheets were stolen. Three attributes contained on each survey sheet were on record elsewhere. These were badgir type, height and condition. Figures 8.5 - 8.7 show these complete distributions in central Yazd. All badgirs were given a number and for tower 389 to tower 713 complete records are available.

In this chapter all discussions of badgir type, condition and height are based on the full sample of 713 badgirs, while those of other attributes are based on the 389 - 713 sample. On individual towers a particular attribute, or group of attributes, may have been obscured or absent so each category below in based on as large a sample as is available.

7.3.1 Buildings with badgirs in the city

The majority of badgirs in the city (86%) were built on houses. 44 badgirs (13.4%) were built on water cisterns. Only two badgirs were recorded on mosques in the survey area.

7.3.2 Location of domestic badgirs in the house

Two thirds of all domestic badgirs were built on the south wall of the house.

north wall of house	-	23	(8.1%)
south wall of house	-	192	(67.8%)
east wall of house	-	21	(7.4%)
west wall of house	-	30	(10.6%)
south-west wall "	-	7	(2.5%)
south-east wall "	-	9	(3.2%)
north-east wall "	-	1	(.3%)

The location of a badgir on the west or east wall of a house may be an indication of the presence of a lateral badgir room, adjacent to the main summer room. As compass readings were not taken on every tower, these figures should be taken to indicate that the majority of badgirs were built on the south, south-south east and south-south west walls of houses.

7.3.3 Orientation of domestic badgirs

In the city of Yazd the eight main orientations are recognised by the following names, which indicate either the direction from which winds come, or the names of cities that occur in the direction from which the winds come:

shomali	- north wind	Isfahani	- north west wind
jenubi	- south wind	Kermani	- south east wind
gharbi	- east wind	Mashadi	- north east wind
sharki	- west wind	Qibla(Mecca)	- south west wind

The best orientation for a badgir is locally said to be towards the Isfahani wind, to the north-west. Climatalogical data shows that the strong prevailing wind comes from this direction.

Badgirs are often described by the number of directions in which they face; for instance they are described locally as yek tarafi (one directional) or doh tarafi (two directional) towers. Six and eight sided towers are described as having zelli (sides), not direction.

A badgir with an angled roof facing in one direction is known as a Kermani, and four-directional towers are called Yazdi, and also east west towers.

The badgirs are also called after the direction in which they face, for example a north south' tower.

Over two thirds of the badgirs in Yazd face north-west and south-east with their largest vents.

TOWARDS: NW/SE	- 180	- 69.5%	SWW/WWE	- 1	- .38%
NE/SW	- 70	- 27 %	NW	- 2	- .77%
SE	- 7	- 2.7%	N	- 1	- .38%
6-8 directions	- 61	- 23.5%			

7.3.4 Plan forms of badgir towers

In the survey of windtowers a simple key was devised and used which covered all the badgir types recorded. Five basic types of badgirs emerged, although the original key included no less than 63 different plan types. The five main types are as follows: (figure 7.4)

A) One directional towers

These towers generally face north-west or north, except for water cisterns on which badgirs face in different directions. Several are placed equi-distantly around the tank, facing away from it.

In Yazd uni-directional towers have from one to seven vent openings arrayed long the open side of the tower. These towers are called Kermani if they have a sloping roof and one or two vents only. Otherwise uni-directional towers are commonly described by the direction in which they face, such as shomali, or north facing.

There are only 22 examples of uni-directional windcatchers in Yazd and they are mostly on water cisterns or on simple houses.

B) Two directional towers

The head of the two-directional badgir is constructed of three solid walls, two lateral walls, and a central brick partition separating the two vents and supported on a timber frame.

In simple examples there is only one vent opening on each side of the partition wall, while the most elaborate example recorded had 15 vents on either side. There are 127 two-directional examples, all occurring on houses, often called by direction, such as shomal-e jenub, or north/ south towers.

C) Towers with diagonal partitions

The 'left right' towers have shafts divided by diagonal partitions running from corner to corner. The maximum number of vents recorded on each side of this form of wind-tower is six. This is the second most popular plan form, with 113 examples among the 713 towers.

Hajji Ali Akbar, a Yazdi builder, claimed that there was no working difference between the square towers with diagonal partitions or perpendicular partitions, or rectangular towers, if the tower had the same cross-sectional area for vents in the same directions. He maintained that the choice of the shape of the tower was a result of how large the summer room was and of the personal choice of the house owner or builder. The square towers required more depth of site on which to build than the rectangular towers. Thus the older towers, built when land was more readily available, were square.

D) Yazdi or 'east west' towers

The Yazdi or 'east west' towers have four vertical shafts separated by a central H-shaped partition. These are called Yazdi locally because they are so common in Yazd. The shortest side usually has the largest number of open vents, while the longer side has more 'false' vents. This makes sense aerodynamically as the minimum surface area and maximum vent area are presented to the wind, so reducing the pressure incurred by the structure and the negative pressure in the form of the leeward vortex, both of which are potentially destabilizing to the structure (Sachs, 1978, p.230).

On the short wall of the tower are one to nine open vents while the long sides have three to eleven vents, of which approximately two thirds are false' vents, being blank recessed niches.

Just over half the badgirs in Yazd are of this form. The most popular form of this type has two open vents on the short side and two blanks, two open vents and a further two blanks on the longer sides. The most complex of this type has nine open vents on two sides and three blank, three open, three blank on the other two sides. Its plan dimensions are surprisingly small; it is only 120 x 120 cms square.

E) Shish or hasht Zelli, six or eight sided towers

There are 20 multi-directional examples in the survey of the 713 badgirs. Six sided badgirs and eight sided badgirs are most common on water cisterns.

Ostad Ali Akbar, a local builder, maintained that six or eight sided towers are less efficient than the four square towers as they 'encouraged the wind to go around the tower and not down it'.

F) Unique plan types

21 of the 713 towers are of unusual design.

Seven of these towers are one or four-directional with with massive walls. One has a plan form resembling a swastika. One belongs to a pair of badgirs on a water cistern, of which the other tower has diagonal partitions. This tower has no internal partitions at all and was presumably designed to draw air up from the cistern, in the Venturian fashion, while the opposite tower channeled air down into it. There are a similar pair of towers on a cistern in Mohammadiyeh near Nain.

Of the remainder, five examples belong to a separate sub-group, those facing in three directions, with vents on the short side.

F) Stumps of badgirs

In the survey of 713, 19 stumps of badgirs were recorded. The head of the badgir is structurally more fragile and likely to collapse than the column of the tower and often decayed first and was removed, although the relatively solid column of the tower was not removed.

G) Double badgirs

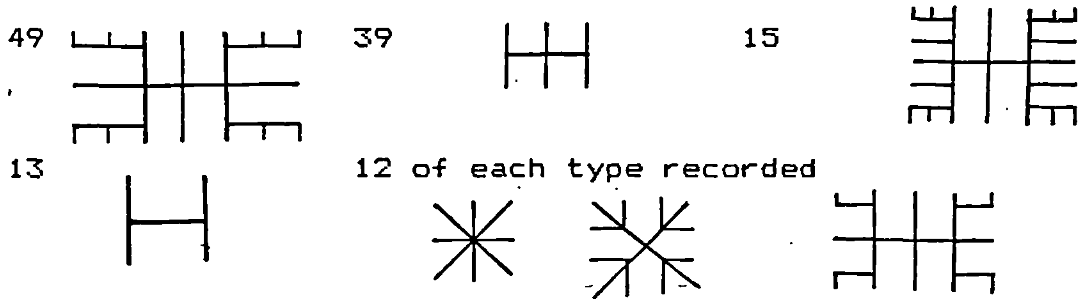
These are built one on top of the other: there are only three in central Yazd.

7.3.6 Conclusions on badgir tower types

The most common plan of badgir at vent level is the 'Yazdi' badgir with H-shaped central partitions. One fifth of all towers recorded in Yazd were of this type with six vents on the long side and either two or four vents on the short side.

The second most common plan type was the two-directional badgir with one or two vents, and one sixth of the sample were of this type. This is illustrate by the following chart showing the most popular plan types from the sample of 324 towers, with the number of each recorded.

MOST POPULAR PLAN TYPES AT VENT LEVEL



There were less than 6 examples of each of the other plan forms in the smaller remaining sample.

7.3.7 Plan dimensions

There is an enormous range of sizes in the recorded external cross-sectional areas, at vent level, of the badgirs. The smallest measured a mere 40cms x 80cms, while the largest tower was 5m x 5m.

49 towers of the 324 sample were square. The majority of these 49 were on water cisterns. Hajji Baghoush, a local builder, claimed that the ideal tower dimensionn for a cistern are 120cms x 120 cms for a diagonal tower and 180cms by 180 cms if there are six vents on each side.

The second most common ratio of side lengths is 1:2 of which there were 38.

CHART TO SHOW PREFERRED RATIOS OF SIDES

RATIO	NO	RATIO	NO
width 1:1 length	49	width 2:3 length	15
1:2	38	4:5	14
5:6	29	3:5	13
2:5	22	1:3	10
4:11	16		

7.3.8 Heights of towers

HEIGHT OF BADGIRS ABOVE PARAPET WALLS

CATEGORY	HEIGHT	DESCRIPTION	NUMBERS
1	0-120cms	barely noticeable	141
2	121-229	low visual intrusion	255
3	300-499	medium level intrusion	157
4	500-999	recognisable landmark	103
5	1000cms +	exceptional badgir	7

The majority of windtowers are less than 3m high. The area of Yazd where the windtowers are noticeably lower is shown on figure 8.7 and represents a trend in the reduction in height of badgirs after the 1940s. Over 90% of the towers in the suburb of about this date are less than 3m high and over half are lower than 120cms.

Two important 'positive' factors vary with the height of the tower. The first is a rapid increase in windspeed with increased height in the first 30m above the settlement or ground (or roof) level (Geiger, 1965, p.76). The second is that temperatures decrease with height above the ground surface. In desert conditions this decrease can be extreme and a remarkable 27c drop in temperature in the first 50mm. above a sandy desert was recorded in Arabia by Griffiths in 1966 (Oke, 1978,p.67) and while the drop in temperature above a mud roof would be much less it would be significant;

However a third factor is negatively affected by height. This is the structural stability of the tower. With increasing height the potential for structural failure of the tower increases, particularly in the head of the tower, which is weakened by the numerous vents. The ruin of a number of towers indicates that structural failure occurs.

7.3.9 Height of vents

Over a third of the towers have vents that are less than 150 cms high, with the majority of vents being 100cms to 120cms high. 47 are over 180 cms high, 35 over 200cms, and 27 are 300 cms or higher.

The actual structure of the vent section is relatively flimsy, given the strong winds, and the highest towers need to be well constructed to withstand them, and are therefore expensive. The partitions of the vent section of the tower are often the first part of the badgir to deteriorate.

Sachs has calculated that a masonary chimney 76cms x 38cms and 305cms high would blow over in winds of 16.6m/sec, in the absence of all shear resistance (Sachs,1978,pp.230-231).

7.3.10 Roof to vent height of the column of the tower

Tower heights were measured from the top of the parapet wall of the building to the sill of the vents of the badgirs, as the base of the shaft directly above the roof was seldom visible.

44% of the towers of the 426 sample have a decorative band of brickwork below the vents, generally less than 100cms high. The commoness of this detail indicates that this band may well have a structural function.

44% are between 101 and 300 cms above the roof and only 11% of the sample were above 301cms high, showing that the majority of badgir towers are of medium to low height.

7.3.11 Eave and sill details of badgir towers

Figure 7.6 shows the range of ornamental brick and tile details on the eaves and sills of badgirs.

The most common decorative course is the diagonal pattern where the bricks or tiles are angled at 45 degrees to the tower, creating a serrated pattern that is highlighted in the strong sunlight.

Over half the towers built have elaborate head and sill details for the vents, the acme of which is a detail with no less than 8 cantilevered courses (Fig.7.6), a feat of some structural ingenuity for the Yazdi builder.

7.3.12 Vent head details

In all, a total of 86 different vent details were recorded. Many were unique, including the simplest and the finest with carved plaster details at the head (see figure 7.7).

The emphasis in vent detail type is on simplicity, with the only two of the 'classic' Yazdi details common on the higher towers (see 8.6) being commonly used.

7.3.13 Condition of the badgirs of Yazd

Although an attempt was made to approximate individually the age of each badgir recorded, this eventually proved impossible, due to the importance of maintenance to their appearance. An extremely old badgir could look as new if recently restored.

It was however possible to record the condition of the badgirs in the city. For the survey the following categories were used:

EXCELLENT - as new
GOOD - in good repair
FAIR - not well maintained but no obvious structural damage
POOR - obvious structural damage
RUINED - ruined

Results of the survey on the condition of badgirs in the city showed the following results:

EXCELLENT	- 12	1.8%
GOOD	- 103	15.3%
FAIR	- 223	33.1%
POOR	- 203	30.2%
RUINED	- 132	19.6%

This table demonstrates that about a half of the badgirs were in poor to ruined condition. A third were in fair condition, and a sixth were in good to excellent condition.

The area in which most ruined badgirs occurred co-incides with that part of the city which was developed by the turn of the century. The areas with fewest ruined badgirs are the newest suburbs shown on the plan (figure 8.6).

7.4 CONCLUSIONS FROM THE SURVEY OF BADGIRS IN YAZD

The survey of the badgirs of Yazd city has shown that the description of badgirs as high towers sticking up from the city' (Napier, 1905, p.8) is a misleading one. The survey has shown that over 60% of all windcatchers are less than 3m high above roof level and only 15% rise above 5m high. This latter group, described in the survey as towers forming recognisable landmarks, numbers about 110, which would be sufficient to give an impression of a sea of high towers. However the majority of towers form low visual intrusions on the skyscape of the city.

The most common type badgir in the city is a modest structure; around 150cms high, and typically 120cms x 100cms to 200cms x 100cms in cross sectional area. It has a 50% chance of facing in two or four directions and is in fair condition. It is on the south wall of the house and faces to the north-west. It has a simple square or round vent head detail. This type is still being built today on the new traditional' houses of the suburbs of the lower income groups.

The high badgirs of the city have some characteristics common to, and some distinct from, their smaller cousins: These towers are similarly located on the southern walls of houses but face in at least four directions, and very occasionally in six or eight, and were built exclusively on large houses or public buildings indicating that the high badgir probably was a recognised status symbol or wealth and importance to the Yazdi.

These high badgirs often reached over 5m in height and are characterised by the elaborate details vent details. Plan forms become equally elaborate, with six to ten vents on the sides of the towers being common.

In relation to the findings of chapter 4 it is noticable that in Yazd city only 22 badgirs, 3% of the towers, are uni-directional. The significance of this low number of uni-directional towers can only be seen in relation to the location of the towers. Are they are situated in the older parts of the city or on modern buildings and on what buildings are they built? If they are all built on water cistern, in the modern sector the implications are very different to those arising if they are all built on houses in the oldest part of the city. These questions are considered in chapter 8.

Figure 8.1. Plan showing the lines of the early walls of the city of Yazd published first by Afshar in 1969. (Tavassoli, 1975, p.25)

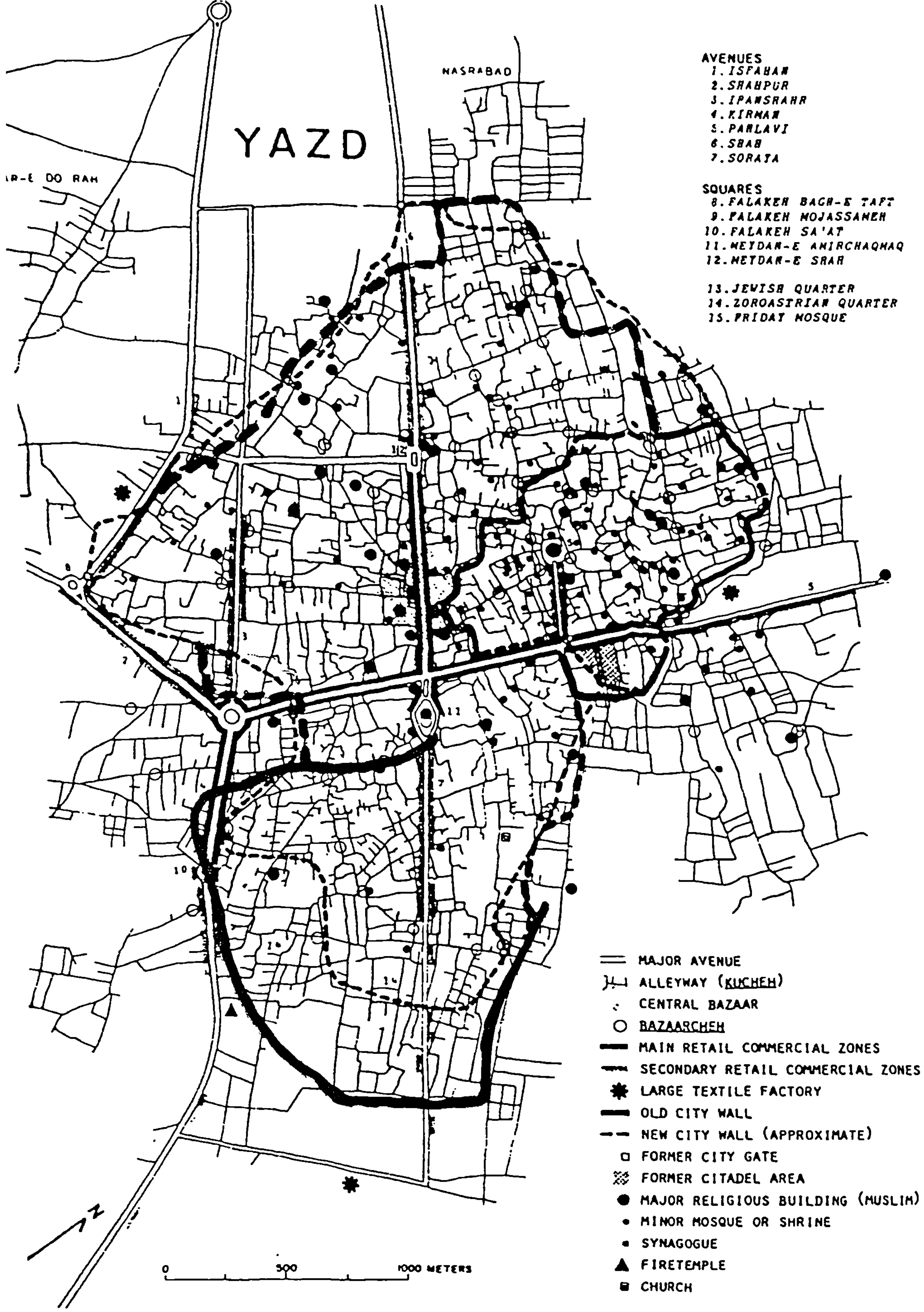


Figure 8.2. Plan of the city of Yazd showing the lines of the 14th century and the 19th century city walls (Bonine, 1980, fig. 17). The red lines show new limits indicated by the Khanikoff plan of 1855 (see figure 4.7), complete lines show wall extant at that date and dotted line indicates limits of the built-up city.

CHAPTER 8

AN INVESTIGATION INTO THE DISTRIBUTION OF BADGIRS WITHIN THE CITY OF YAZD, AND THEIR DESIGNERS

8.1 INTRODUCTION

Several questions raised so far in the thesis can be answered by the investigation of the distribution of badgir types in the city of Yazd. The first is location of the uni-directional towers in the city. If they are located in the oldest quarter this would suggest that they represent an earlier type. The second question is whether the highest towers are typically located in the area of the city built after the middle of the 19th century. If so this would confirm, as implied by the accounts of travellers in the 19th century (4.5.4), that there was a revolution in badgir design after 1870 when the high towers for which the city is famous were built. If so what can be learnt of the processes by which this revolution came about?

The first step in understanding the distribution of the towers of the city is to date the suburbs in which they are located.

8.2 DATES OF THE SUBURBS OF CENTRAL YAZD

In 1969 Afshar published a plan of the city of Yazd showing the dates of the city walls (figure 8.1). In 1980 Bonine published a plan showing the early walls and the approximate limit of the early 19th century walls (figure 8.2).

However for the purposes of this study the city of Yazd

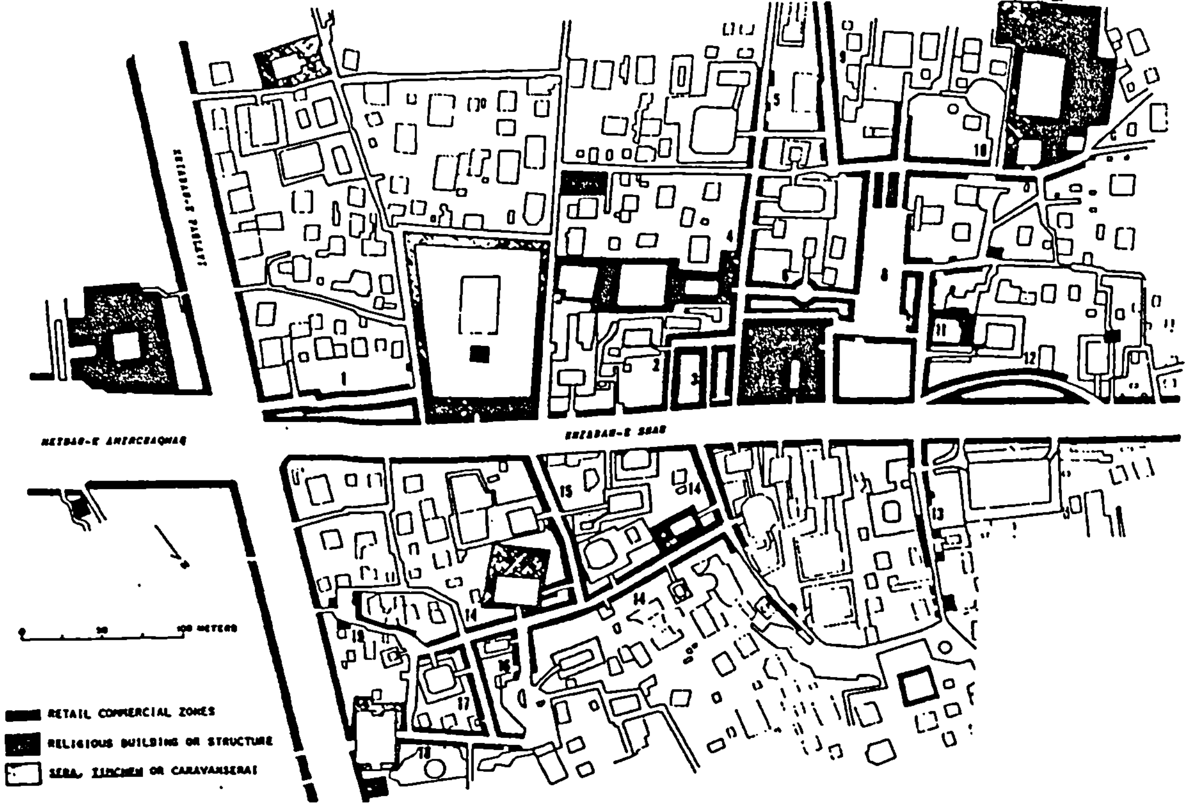


Figure 8.4. Plan of the bazaar area to the south of the old city wall (Bonine, 1980, figure 17). Names of the bazaars are as follows: 1) Mohammad Ali Khan 2) Ja'far Khan 3) Alaqabandi 4) Panjeh Ali 5) - 6) clothsellers 7) Chitsazi 8) Meydan-e Khan 9) blacksmiths 10) Hazarat-e Abbasi 11) coppersmiths 12) Timcheh-e Hajji Ali Khan 13) Tajeh 14) cloth sellers 15) goldsmiths 16) Darvezeh Mehriz 17) Afshar

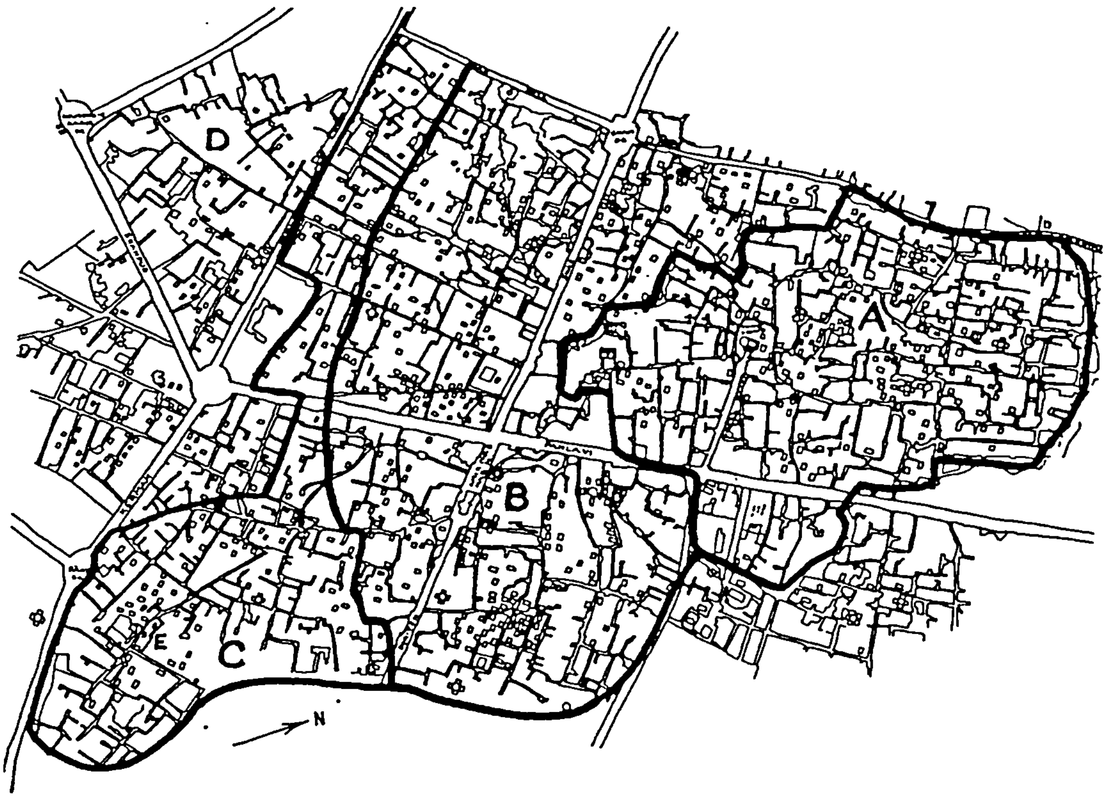


Figure 8.3. Plan of the centre of Yazd showing the areas of different dates identified for the purpose of this study, with the location of badgir towers recorded.

may be divided into four roughly datable areas relating to the survey map in figure 8.3:

A) The area which lies within the original walls of the old city, rebuilt in 1346-7 (Bonine,1980,p.13). This is the oldest part of the city although within these walls houses have continually been replaced.

B) The area of bazaars and houses immediately to the west and south of this wall where the a bazaar was first built in the late 14th century (Bonine, 1980,p.95), probably effectively destroyed in the Afgan invasion in the 1720s, rebuilt under the rule of Tagi Khan in the late 18th century (Bonine, 1980, p.95), again damaged during the civil war of the 1820s (Gibbon,1841,p.139 and Abbott, FO. 251/42/9059, 1850,pp.33 and 34), and finally rebuilt from the 1860s onwards. Some houses in the area date from the turn of 19th century while others are later.

C) The area which lies to the south and west of area B within the walls built during the rebellion of Abdul Reza Khan (ibid, 1851, p.33 and 34) in the 1820s. The majority of the buildings in the the outer area of the new walls were built after 1850.

D) Area D covers the new suburbs to the west of Kirman street and Shishomeh Bahman street built largely after 1940.

8.3 DENSITY AND DISTRIBUTION OF BADGIRS IN THE CITY

The distribution map of the badgirs of central Yazd (figure 8.5) shows an irregular pattern of distribution. In the walled city (area A) there is a concentration of badgirs in

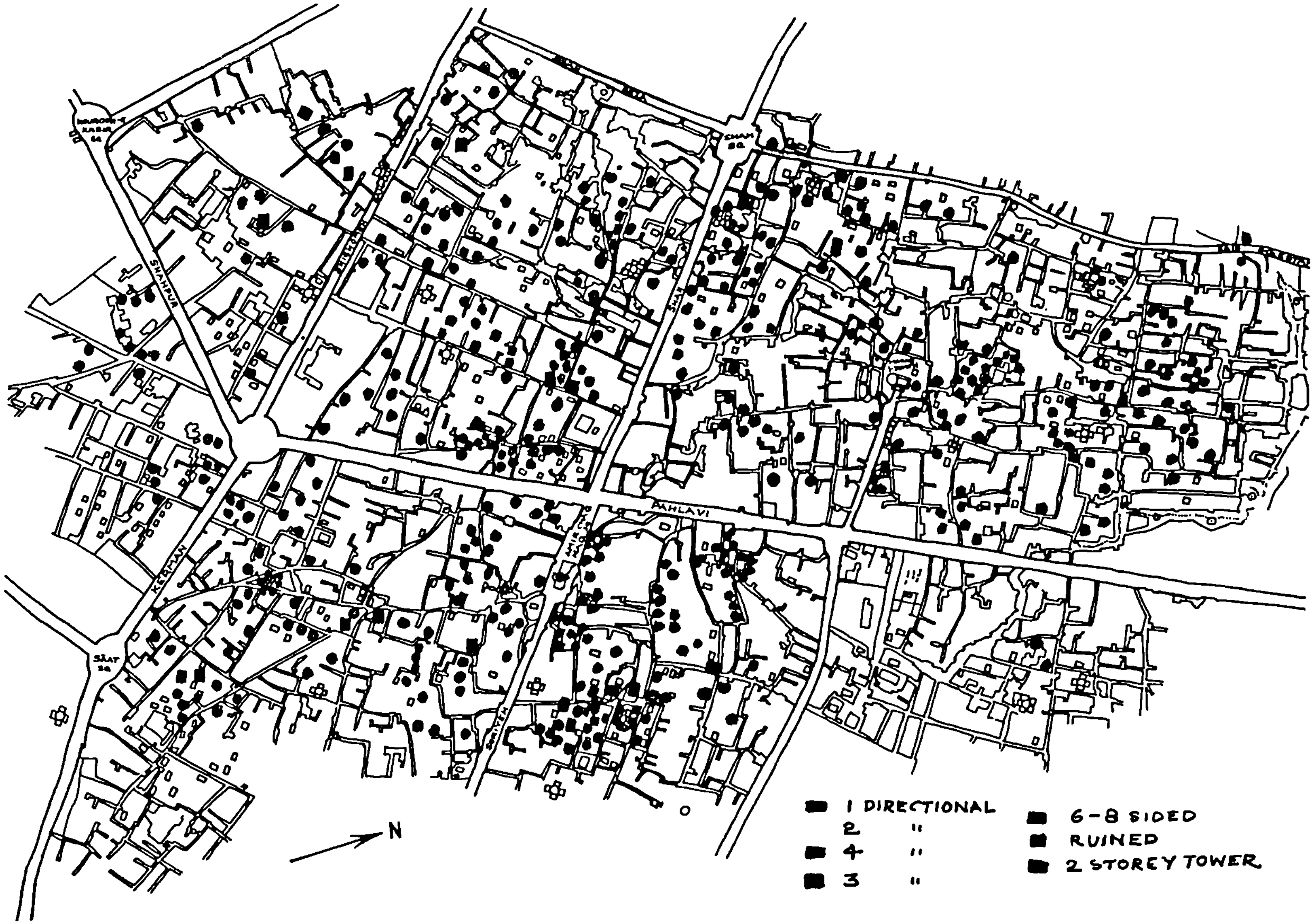


Figure 8.5. Plan of Yazd showing the distribution of tower types recorded in the survey of 1976.

the areas to the north of the Masjid-e Jumeh. However the greatest density of badgirs occurs in area B, peaking in two areas to the north-east and south-west of Amir Chaq Maq square. A second concentration of towers is found in the southern Zoroastrian suburb of area C. Here, with the prohibition on building badgirs on Zoroastrian homes before 1900 (Napier, 1905, p.40) one can assume that the majority of these towers were built after this date.

8.4 DISTRIBUTION OF BADGIR TYPES IN THE CITY

There are equal numbers of two and four-directional towers in Yazd as a whole. One directional towers are less common and scattered throughout the city. Octagonal and hexagonal towers are rare and apart from three groups on water cisterns only two exist (in the 389-713 sample) and these are in area B (figure 8.5).

Other patterns in distribution include:

1) There are more than two and a half times as many four-directional domestic badgirs in area A and area B than in the other areas.

2) Badgirs above 5m high all have four-directional towers.

3) In area D the majority of domestic badgirs are two-directional. Only in the suburbs built later than 1940 do two-directional towers predominate.

4) Of the 18 water cisterns surveyed, 13 have two-directional towers, three have four-directional towers, two have hexagonal towers and one has Kermani (one-directional) towers. Of the cisterns in central Yazd, two have two

8.6

Figure 8.6. Plan of Yazd showing the distribution of towers in various conditions recorded in the survey of 1976.

towers, one has three, twelve have four, two have five, and one cistern has six towers. Thus cisterns most commonly have four two-directional towers.

5) Uni-directional badgirs appear to be scattered through all quarters of the city, with a possible concentration of towers to the south of the old city wall around Amir Chaq Maq square, an area which was largely built in the 19th century. There is no concentration of uni-directional towers in the old city.

8.5 DISTRIBUTION OF BAGDIRS BY CONDITION

Many of the badgirs in areas A, B and C either are in poor or ruinous condition (figure 8.6). In only two areas of the city are the towers generally in fair, good or excellent condition. These are in the suburbs to the north-east of the Naranj Qaleh (citadel) and those in area D. Both of these areas largely of newer suburbs, and with newer one and two-directional towers.

8.6 VENT TYPES AND BADGIR HEIGHTS

The data collected in the survey of Yazdi badgirs was put on a Database II file, and by sorting by height (figure 8.7), vent (figure 8.8), and plan (figure 8.5) type in that order (above figure), and then locating the vent types on the survey plan, it is possible to draw some conclusions on the 'high' badgirs of Yazd. The data thus sorted was from the 389-713 sample.

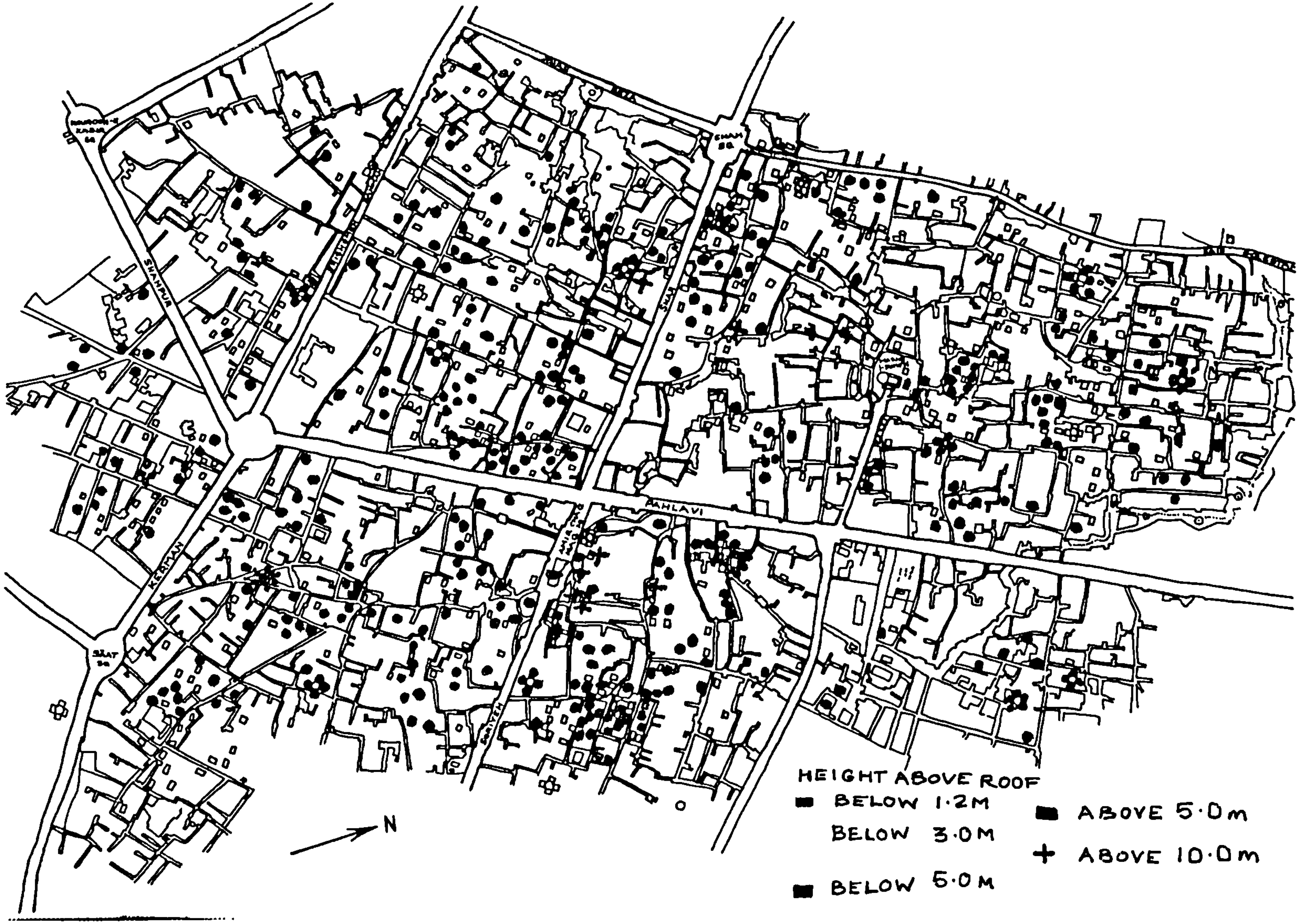


Figure 8.7. Plan of Yazd showing the distribution of towers of different heights recorded in the survey of 1976.

RELATIONSHIP OF VENT DETAILS TO TOWER HEIGHT AND PLAN

No.	Egs.	1	2	3	4	5	Plan Frequencies
0.1	39	19	13	5			2.1x8,1.9x6,2.0x4,3.0x4, 5.4x2,1.1x2,1.0x2.
0.2	24	10	11	2	1		1.9x4,5.4x3,2.1x3.
0.3	11	3	4	1	3		5.4x4,2.1x2.
0.6	8	1	7				2.1x5,2.2x2.
0.7	44	22	18	4			2.0x7,5.4x7,3.2x6,1.9x6, 2.1x5.
1.2	9	2	7				5.2x2,2.1x2.
1.3	4		3	1			
1.5	2	1	1				
1.7	2	1	1				
2.0	11		2	6	3		5.4x4.
2.3	27	7	11	6	3		5.4x11,3.2x3,5.2x2,5.5x2.
2.6	3		2	1			5.4x2.
3.1	25	6	6	5	6	1	6.6x3,7.5x2,7.2x2,5.4x2, 5.7x2,5.2x2,2.2x2,3.4x2.
3.2	4	1		3			3.4x2.
3.6	2	1		1			
5.5	13		2	7	4		7.4x3,7.2x2.
5.6		1	1				
6.1	4	2	2				
6.3	2		1	1			
7.5	2				1	1	
8.0	2			2			5.4x2.

The vent details that occur on more than one tower are listed by the vent number (No.) and followed by the total number of examples (Egs.) found in the survey sheets; then the incidences of the detail in towers 1) below 100cms high, 2)between 1-200cms, 3)between 2-300 cms and 4)between 500-1000cms high and 5) above 1000 high. Then the frequencies of plan types with more than one example for each vent detail are given with the plan number first and the number of examples of each after the times sign (x).

There appears to be a very strong relationship between badgir vent detail, plan form, and height. For instance in area D is a group of lower badgirs of two types: the first are usually below 3m in height and have vent detail 0.6 and occur to the south of the area; the second are below 120cms and have vent detail 0.7. These are all in the A,B,C condition group and were probably built since 1940 and

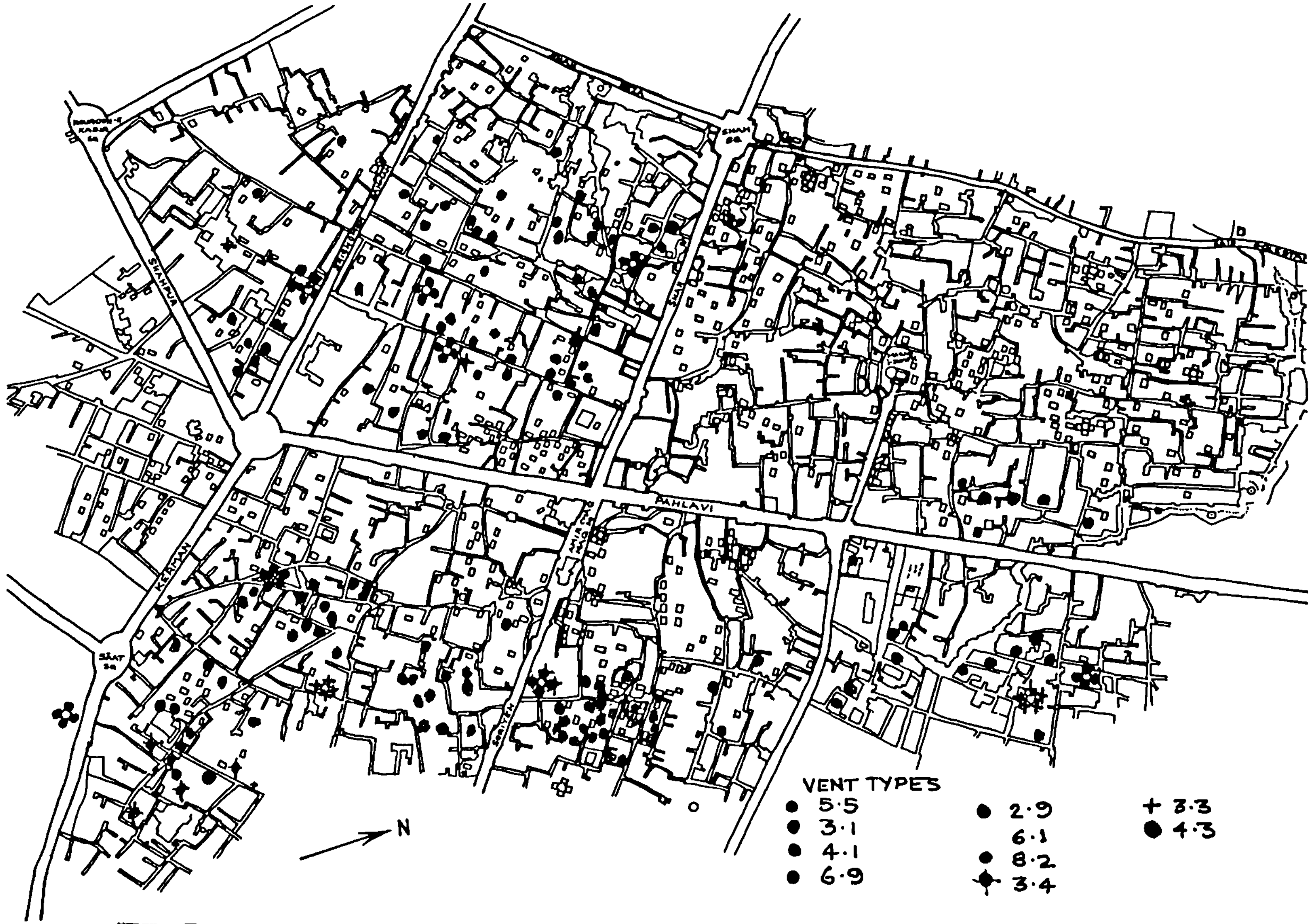


Figure 8.8. Plan of Yazd showing the distribution of the vent types recorded in the sample numbered 389 - 713 in the survey of 1976.

probably by builders following common blue-prints.

The higher badgir towers generally have one of the following four following vent types:

1) <u>The round arch</u> (vent details 0.2 or 0.3). Perhaps the oldest is the simplest and a large number of towers, particularly in the heart of the old city, around the Masjid-e Jumeh, have the plain round arched vent head.

What probably began as a structural detail became a common decorative, that is non-structural, detail at the vent head.

2) <u>TRIPLE ARCH VENT HEAD</u> (vent details 2.0 or 2.3). Another popular and simple vent detail is the triple arch detail 2.0 and 2.3, where the plaster detail at the vent head is developed by using a string and a pin to shape the quarter circles in plaster to form the structure of the detail.

The two details above occur mainly in towers under 3m high, but are also found in the higher towers, especially ones that appear to be older.

The piece de resistance' of the vent details on high towers are the following two ‘classic', ie. first class, examples:

3) <u>CLOVER LEAF</u> (author's description) (vent detail 3.1), with 14 examples above three meters in height.

4) <u>FLOWER VASE</u> (vernacular name) (vent detail 5.5), with 13 examples above 3m in height.

Towers with these two details occur mainly in area B, with a few examples in area A. Unfortunately here the data on the vent types in the bazaar areas around Amir Chaq Maq is missing.

On the high badgirs in the heart of the bazaars of Maidan-e Khan and Hazarat-e Abbasi (figures and 8.11), in area B, there are none of the 5.5 and 3.1 details that dominate the residential areas directly to the south and east of area B (figure 8.9). The 3.1 and 5.5 details extended southwards into the suburbs of area C (figure 8.10).

The distribution of the high badgirs and the classic' flower vase and clover leaf vents details, concentrated in the southern two thirds of area B, appears to support the theory that the high badgirs of Yazd were constructed at one period of expansion of the city, probably when the outer town was rebuilt in the latter half of the 19th century.

8.6 BADGIR PATRONS

A long tradition of excellence in building exists in Yazd. Many factors have combined to create the unique mud-brick based architecture of the area; climate, physical isolation, limited building resources, economic prosperity in this silk producing market centre, foreign influences and skilled master builders.

Fine architecture is fostered in periods of political stability and economic prosperity such as occurred in Yazd in the last quarter of the 18th century, under the rule of Mohammad Tagi khan, and during the last four decades of the 19th century, particularly under the governorship of

Mohammad Khan Valli during the 1860 and 1870s (Bonine, 1980, p.15). During these two lulls in the political turmoil of the two centuries the greatest advances in badgir design occurred. The late 18th century saw the emergence of the great low squarish towers, as found at Bagh-e Dowlatabad, the Nowab Rasoui house, and the Gazorgeh house, with their similarly planned badgir rooms beneath. The 1860s and 1870s saw the rise of the high badgirs for which Yazd is most famous today.

8.9 BADGIR BUILDERS

It is possible by looking closely at the vent details of the high towers to recognise the hand of an individual builder on the towers of Yazd. For example one signature that is easy to recognise is that of the bad builder. There are a number of unique and rather amusing details that a respectable builder today considers inferior work. For example one builder who was shown the range of vent details surveyed, pointed out 7.5 as being a poor one.

There are a number of examples of these very individual towers, and pairs of towers, surely constructed by a single designer, must include 6.1, 7.6 and 8.0. Can one extrapolate from this and suggest that, as one builder was responsible for the least skillful details on badgirs, so perhaps the finest details on the towers, the flower vase and clover leaf towers, were also were also the work of one or two master builders?

From the 'classic' towers it can be suggested that the majority of the details 3.1 and 5.5 were built by two

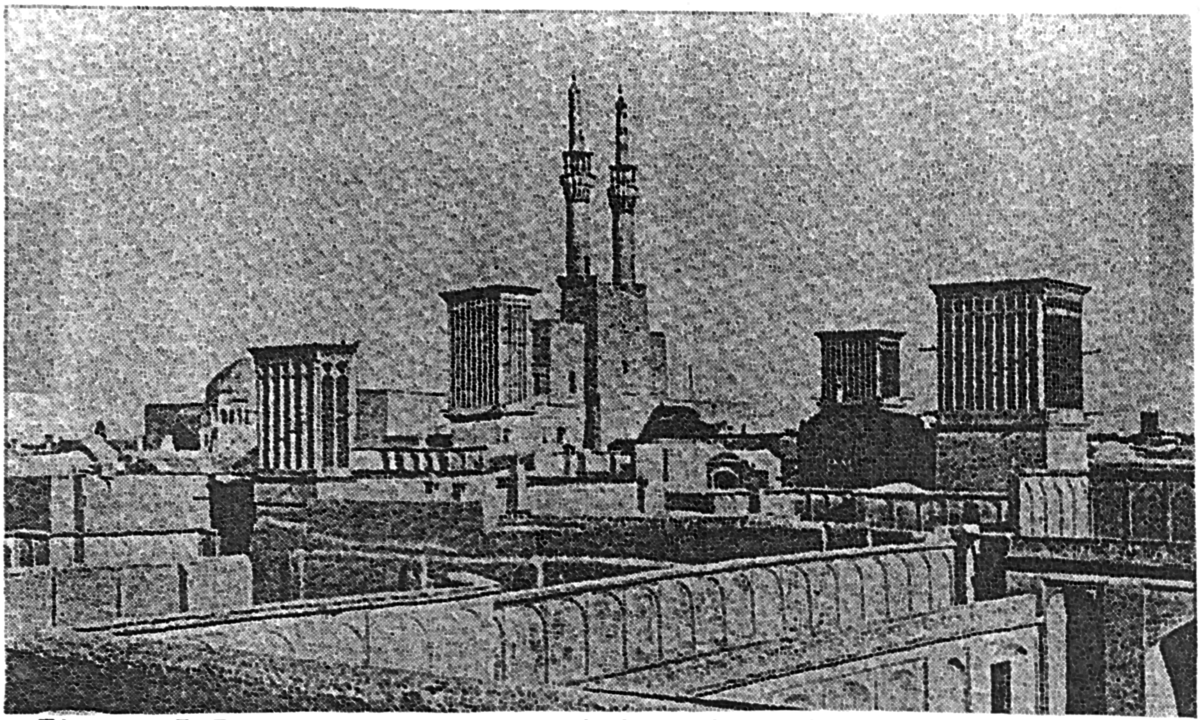


Figure 8.9. Windcatchers rising above the buildings to the south-west of the 14th century walls of Yazd. (Afshar, 1969-70, vol. 2, plate 32). A mistake has been made in the printing and labelling of this photo - it was printed back to front and is of a view looking west past Amir Chaqmaq mosque, not of the Friday Mosque, as labelled)

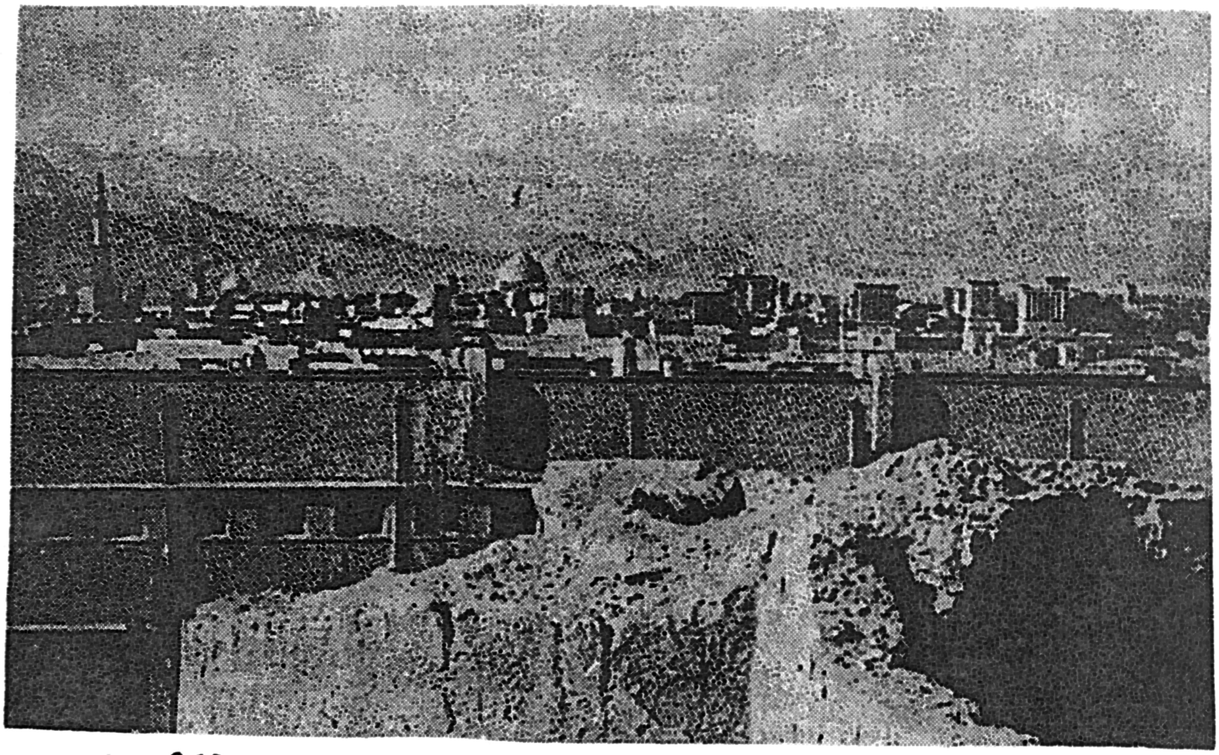


Figure 8·10 Photograph taken from the walls of the citadel in Yazd showing the high badgirs to the south-west of the old city with the Masjid-i Mir Chaqmaq to the left of the picture. (Afshar, 1969-70, vol.2, plate 158/8) different master builders.

Detail 5.5 has a core group of vents which were listed as detail 24 in the original survey (see figure 7.7), and appear so similar in style and excellence of execution that they could well all be built by the same architect. These include the badgirs listed by the following numbers from the survey:

389	391	400	410	414	420	568	604	498
650	660	463	467	392	537	539	543	697

The probable master builder worked mainly in the area to the south-east of Amir Chaq Maq Square; it is suggested that he built houses and badgirs between 1870 and 1900 and he also built the vent detail 5.6. 4.3-4.7 and 5.1-5.4 were later and imitative, perhaps from pupils of the same master's school (see figure 7.7).

A better illustration is that of the 3.1 school. The master is the producer of the vent details originally numbered 11, 9 and 12 (see figure 7.7) in which the proportions of the three headed central form and the hanging goosheh or dandoneh (the ears or teeth), formed of carved plaster, are uniform and skillfully executed. It appears that the following details were imitative - 13,14, 42, 62B, 62, 50, 52 (figure 7.7). Of the details with two teeth', the originals may well be 55 and 10 with 53, 56, 15 and 65 executed by followers. This would mean that the master of the clover leaf detail built the following towers from the survey:

394	404	405	409	411	412	415	419	421	554
644	646	647	648	489	532	442	546	446	479
483	486								

The locations of towers with these two types of vent, the 5.5 and the 3.1, overlap considerably, implying that they were built during the same period of expansion of the city.

It may be suggested that these two vent types were in fact built by the same builder; however this may be disputed on two grounds. The first is practical. The towers are numerous and it would be extremely difficult for one traditional builder to erect such a large number of houses. The second is stylistic grounds. The elegance of the flower vase, and the clarity and beauty of its execution, bears little resemblance to the finely but simply constructed details of the towers with clover leaf vents, which also are most commonly built with a tower plan, 7.4, which never occurs with the flower vase vents. Thus it appears that two master builders working side by side, at the same time, may have chosen to use different plan forms, perhaps as a form of personal signature for their design.

An interesting feature of the distribution of the high badgirs in the area to the west of area A can be seen in development of the Maidan-e Khan and Hazarat-e Abbasi bazaars.

In these two bazaars there were at least three master builders at work, but there is not a single incidence of the 3.1 or 5.5 vents seen elsewhere in area B. In turn, none of the vent types found here on the eight towers over five meters high are found on any of the other high towers of the district to the south. The vent details of the high towers of these two bazaars are not simpler than those of the 5.5 and 3.1 towers, but are more crudely executed.

VENT DETAILS OF THE TOWERS BUILT BY THREE OSTADS IN THE MAIDAN-E KHAN AND HAZARAT-E ABBASI BAZAARS

BUILDER C	perhaps built vent details	7.4 & 7.6, 3.4 & 3.6
D	perhaps built	6.1 & 8.0
E	perhaps built	5.8 & 4.2

It may well be possible that these were the first prototypes of the high' badgirs produced later, since this was the first part of the ruined bazaar in this area to be rebuilt in the middle of the 19th century.

It may also be possible that what one is looking at is a pattern of block development within the city, in which one area of land was owned by X who brought in builders 3.1 and 5.5 to build on it, while the adjacent area was owned by Y, who brought in three other builders, who were all less skilful.

Further survey work may clarify this point, but at present the first explanation, on stylistic grounds, seems more likely.

8.10 CONCLUSIONS ON THE DISTRIBUTION AND BUILDERS OF <u>BADGIRS</u> IN THE CITY OF YAZD

The survey of badgirs in Yazd has shown a wide range of types and sizes of towers built in the city. Practical reasons for building different tower types have been given,

Figure 8·11 Moharram procession in Yazd, in which followers of the Muslim faith carry the great wooden Nakhl covered with cloths and mirrors (Napier, 1905).

such as the amount of space available at the back of a summer room (7.3.4.C).

The investigation of the distribution of badgir towers in the city of Yazd has confirmed that different badgir types were used in the different areas of the city at different dates.

The phenomenon of the high badgir in Yazd, for instance, probably occurred during the rebuilding of the city in area B, much of which was done in the last quarter of the 19th century. The elaborate, four-directional *Yazdi badgir*, above 5m in height, probably reached its apogee between 1870-1900 and had degenerated into a smaller lower two-directional form by the second quarter of the 20th century.

Evidence has been presented that suggests that the design and building skills of individual master builders had a significant influence in the floruit of the badgirs of Yazd and evidence for the hypothesis of two designers working side by side in the late 19th century can be found in the distinctive plan and vent types each used in the high towers they built. Evidence that highlights the importance of individual choice in the design of badgirs.

From the data presented in the last three chapters it is apparent that changes occurred in badgir design with time and contiguously. Factors that have been shown to have stimulated such changes include the historical developments in the house and the associated evolution of the badgir, economic conditions, practical considerations and the choice of individual designers or house owners.

8.11 IMPLICATIONS OF THE CITY SURVEY ON THE FINDINGS ON THE DISTRIBUTION OF RURAL BADGIRS IN THE YAZD PROVINCE

In two ways do the badgirs of Yazd appear to differ from those of the neighbouring Ardakan/Maibud region. Firstly it appears that four-directional towers have been built in Yazd since at least the 18th century, with only 3% of the cities towers being uni-directional, while in Ardakan/Maibud the majority of towers are uni-directional. Secondly the badgirs of Yazd appear to have been undergoing a continual process of evolution in response to changing house form, since the 15th century, while in Ardakan/Maibud the badgir type used on houses appears to have changed little since the 15th century.

It appears that in the two adjacent areas the two competing market centres for the building industry are completely independent of each other in terms of goods and services provided and the traditional badgir type propagated. This finding emphasises the strength of the processes that perpetuate such a building tradition, and the importance of market centre in the diffusion of design types in a region.

CHAPTER 9

THE FUNCTIONS OF THE BADGIRS OF YAZD

9.1 INTRODUCTION

In chapters 2 and 3 of the thesis investigations into the possible climatic reasons for the distribution of windcatchers in the Middle East and in the region of Yazd led to the conclusions that there were temperature thresholds associated with the concept of suitable' and unsuitable' climates for windcatchers. From the survey of rural badgirs it was seen that the distribution of badgir types in settlements was to a large extent influenced by the local micro-climate and that in the Yazd basin considerations of suitable micro-climate were less important than those of historical influences. From this finding it was concluded that the climate in the region of Yazd was approaching the upper limits of suitability for the use of badgirs.

In the following three chapters this premise is examined from the point of view of the function of the badgirs in the houses of Yazd (chapter 9), the summer climate experienced in the occupied spaces of houses in Yazd (chapter 10) and the significance of the general climatic ranges, discussed in terms of the temperature thresholds that may be latent in the design and use of badgirs in the Yazd region.

9.2 HOUSES WHERE CLIMATES WERE RECORDED

The following outline of the way in which the badgirs in Yazd function is based on the results of a series of readings taken in the summer of 1977 in the following eight houses in Yazd:

House A - Two directional badgir house (see 6.7.2)

House B - Two storey badgir house (6.8.1)

House C - Four-directional badgir in the Zoroastrian house (6.7.1)

House D - Paired badgirs in the ruined house (6.5.2)

House E - Four-directional badgir in the Hareem at the Bagh-e Dowlatabad (6.5.2)

House F - Mashrouteh house without badgir (Appendix K)

House G - House in Koudakestan Rashid without badgir (see Appendix K)

House H - Darbandeh house with paired badgirs (6.8.2)

9.2.1 <u>Readings and buildings</u>

The choice of houses and badgirs measured was largely based on the accessibility of the properties for measurement (see 5.4.2).

Two different types of reading are included in this chapter. The first are readings taken over a period of one hour or several hours in houses A, B, C, D and H.

The second are three sets of measurements taken over 24 hours in houses E, F, and G, in 12, 11, and 9 rooms in each house respectively.

The readings taken include measurements of wet and dry-bulb temperature, globe temperature and air velocities.

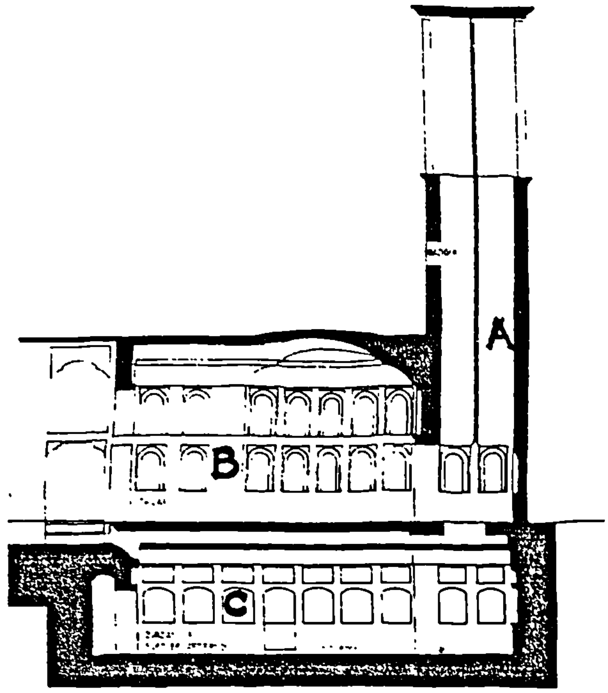


Figure 9.1. Section through the badgir and summer rooms of house C, showing A) the badgir shaft B) the ground floor summer talar and C) the basement summer room.

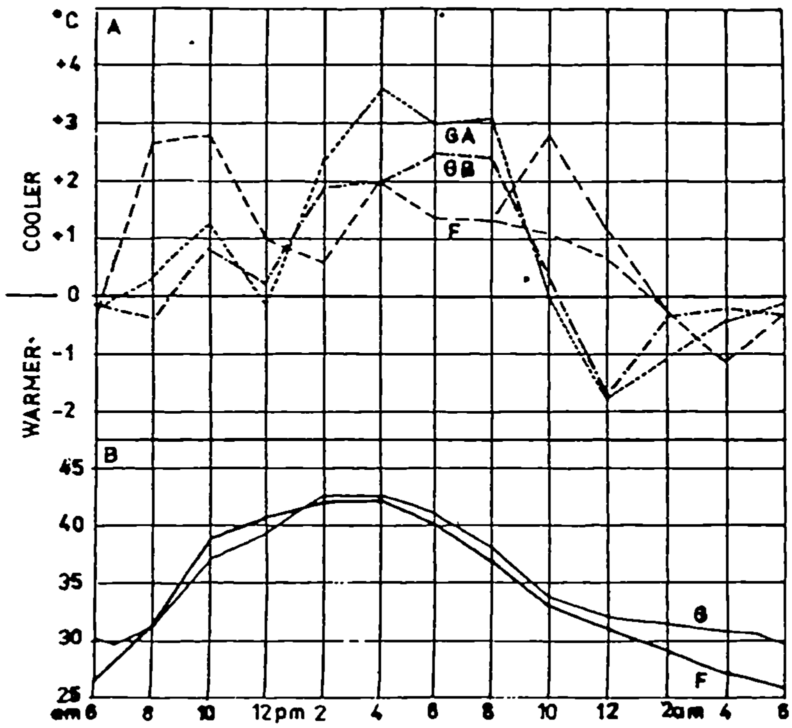


Figure 9.2. Graph showing A) the dry-bulb temperatures of three courtyards subtracted from those of the roof at the same time of day, over 24 hours. This indicates the times at which the courtyard temperature is warmer or cooler than roof temperature. F = the larger (10m x 14m) of the three courtyards, that in house F (see figure K.1 and 2) GB = the andaruni courtyard of house G (8.7m x 7m) GA = the biruni courtyard of house G, the smallest court (8m x 7.3m) (see figures K.3). B) graph of the dry-bulb roof temperatures in house G, and house F.

From these basic readings relative humidity, Mean Radiant temperature, and Effective temperatures, and where globe readings were available, Corrected Effective Temperature also have been calculated.

This chapter deals with the general performance of the badgir, referring to seven appendices in which more detailed measurements are included, with graphs of the 24 hour readings taken.

9.3 GENERAL DESCRIPTION OF BADGIR TOWERS AND ROOMS IN RELATION TO CLIMATE

The badgirs of the houses of Yazd may be divided into three sections for the purposes of this study: (figure 9.1):

A) the tower linking the vents to the summer room,

B) the summer room with open wall or windows to the courtyard and with a badgir recess or room,

C) the basement room with a window linking the basement to the courtyard and a badgir recess or room with a timber grill to the ground floor summer room in its roof.

When air enters the badgir vents and travels down through these three areas it is associated with three different changes in its composition (Figure 9.1):

1) It changes in temperature (and humidity) in its descent down the tower (in A)

2) It mixes with the ground floor room air (in B) causing a change in the room air temperature (and its humidity)

3) It mixes with the basement air (in C) causing a change in

the air temperature and humidity in the basement.

The nature of these three air changes and their impact on the internal summer climate in the houses of Yazd will be discussed after a short review of the roof and courtyard climates, and the prevailing winds in Yazd.

9.4 SUMMER CLIMATE IN YAZD

9.4.1 External air temperatures

Air for the badgirs is drawn from two areas, from the roof and from the courtyard.

Readings taken indicate that on the roof a regular diurnal temperature pattern exists. Maximum temperatures (in the region of 42c on clear days and 38c on cooler or overcast days - see appendix K.2 - K.3) occur around 2pm-4pm and minimum temperatures (in the region of 26c - 29c) just before sunrise (figure 9.2.B).

. The courtyard climate followed the roof climate closely in readings taken. In the large courtyard of house F, only at about 8pm in one corner, the last to lose the sun, were readings higher than roof temperatures recorded. However in the smaller courts of house G, air temperatures were higher than roof air temperature from 10pm to sunrise and during a mid- morning hot spot, between 10am to noon (see Appendix K and figure 9.2). In the smaller courtyards air temperatures were cooler than the larger court during the afternoon, when a greater percentage of the smaller courts were in shade from their own walls (figure 9.3).

Air temperatures in rooms with direct cross-ventilation

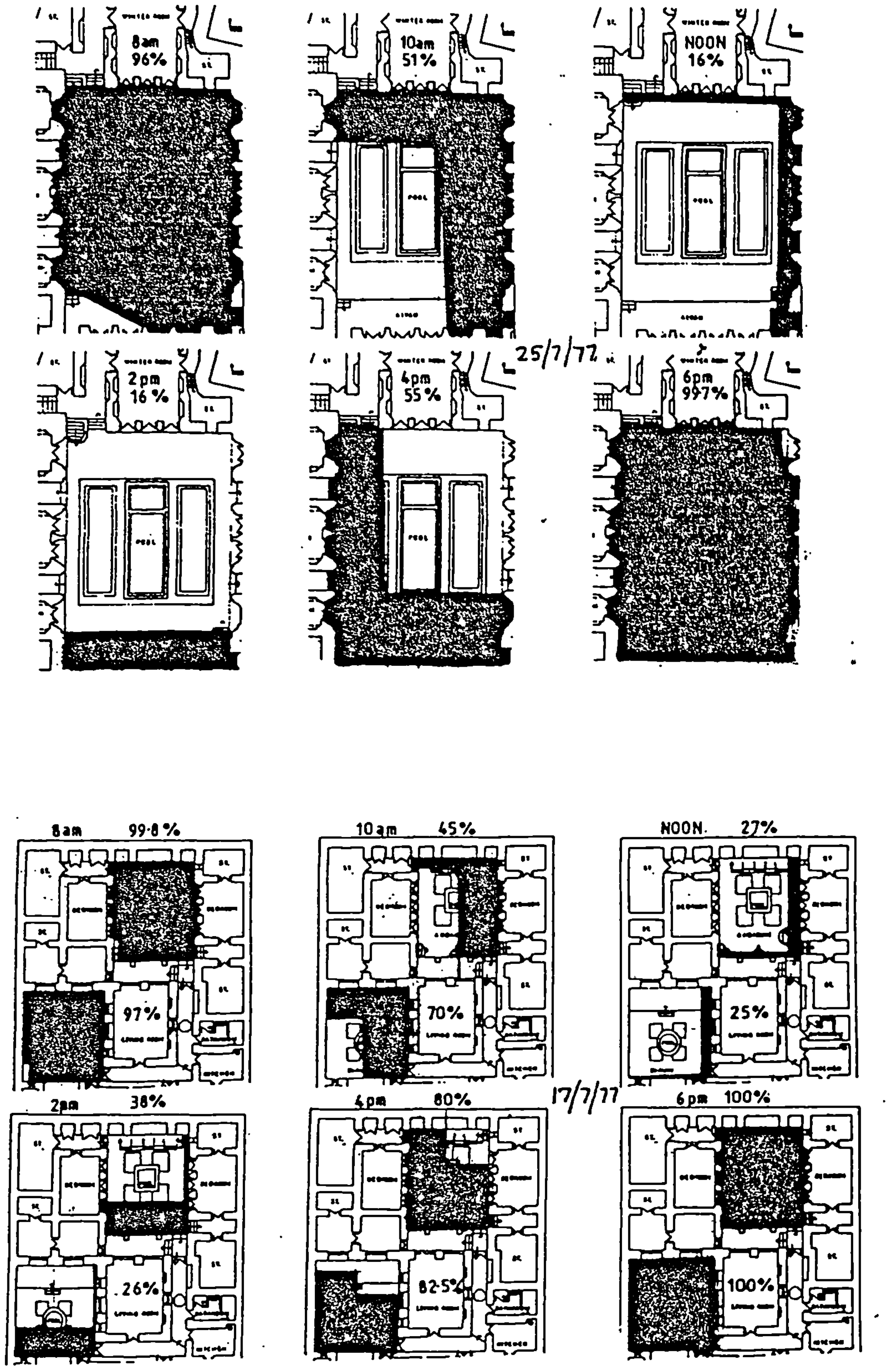


Figure 9.3. Diagram of the three courtyards of houses F and G showing the shading patterns in each between 8am and 6pm, showing the percentage of courtyard in shade, every two hours.

or badgirs are influenced both by air temperatures on the roof and to a lesser degree by those in the courtyards. Smaller courtyards may possibly encourage marginally warmer internal temperatures for much of the day.

9.4.2 Wind speeds and directions at roof level

General climatic data show that during the summer months Yazd receives a strong prevailing north-west wind ranging between 7-9 knots (2.4.4).

Readings taken of the windflow in Yazd over 19 hours (appendix C) suggest that the geographical location of the city on the fringe of the Central Desert strongly influences the diurnal pattern of flow with strong winds from the north-west in the mid-afternoon, from 5.5m/sec - 9m/sec, veering round to the north in the evening and gradually tailing off by the early morning when the wind is negligible. As soon as the land mass begins to heat up, the wind increases in velocity and veeres round again to the north-west by mid-afternoon.

Thus the characteristic pattern is of winds variable in direction and speed during much of the day, dominated by a strong north west wind in mid-afternoon, with little wind in the early morning.

The most common type of badgir in the city, Yazdi badgir, faces in four directions, presumably to pick up the variable, cooler, winds from all quarters. The most common direction for the badgirs of the city to face is north-west (7.3.3) which indicates that the very strong, and presumably hot, mid-afternoon prevailing wind is favoured for the cooling and ventilation of summer rooms.

Two characteristics of the air above roof level change with height. The air temperature decreases (7.3.8) and the air speed increases. The higher the towers, the higher the pressure available, because of the increase in average wind velocity with height, although this is offset to some extent by extra frictional loss in the tower itself. The extra friction will cancel out the extra pressure due to height and increased windspeed (Wills, 1976). In further work an interesting parameter to study would be the impact of varying tower height on the temperature and speed of air introduced into the summer room.

An important effect of the location of wind towers on the roof-scape is through the presence of other buildings or towers that may create wind-shadows on the windward side of towers. The effect of such wind-shadows was visible in readings taken on two houses with paired towers when the wind was from the direction of the axis between the two towers. In this case air moved rapidly down the windward tower and largely up the leeward tower. When two such towers are linked to common summer rooms, a strong draught is created across the rooms (appendix F), but if the towers belong to different houses a wind-shadow effect will create real problems in the performance of the leeward tower. New high rise buildings in the city obviously alter the wind flow patterns over the roofs of the city, and thus may add to the decreasing usefulnes of the badgir in the city centre of Yazd.

9.5 MECHANISMS OF AIR MOVEMENT UP AND DOWN BADGIR TOWERS

9.5.1 In moderate to strong winds

In Yazd badgirs generally face in two or four directions (7.3.6). The tower of the badgir is separated into two or more shafts, commonly four, and this subdivision of the tower allows air to move easily up and down the tower at the same time.

When vents face towards and away from the prevailing wind, air is forced, by a build up of pressure on the windward face of the tower and the existence of a lower pressure region at the base of the tower shaft, into the vents and down the tower. The air at the base of the shaft, around 2m to 2.5 above ground floor level, issues into the badgir recess from where it may travel into the room, down into the basement through a timber grill in the floor, or up the leeward shaft of the tower (see appendix D.1).

9.5.2 Air flow in the leeward tower

As air flows over the head of the badgir a negative pressure is created in the area of the leeward vents exerting a suction on the rear face of the tower (B.R.E. Digest, 1970, p.1), similar to that which has been recorded on the leeward face of chimneys (Sachs, 1978, p.230). The negative pressure draws air up the leeward shafts of towers air that either leaks up from the air issu ing from the windward tower, is entrained from the ground floor air, or

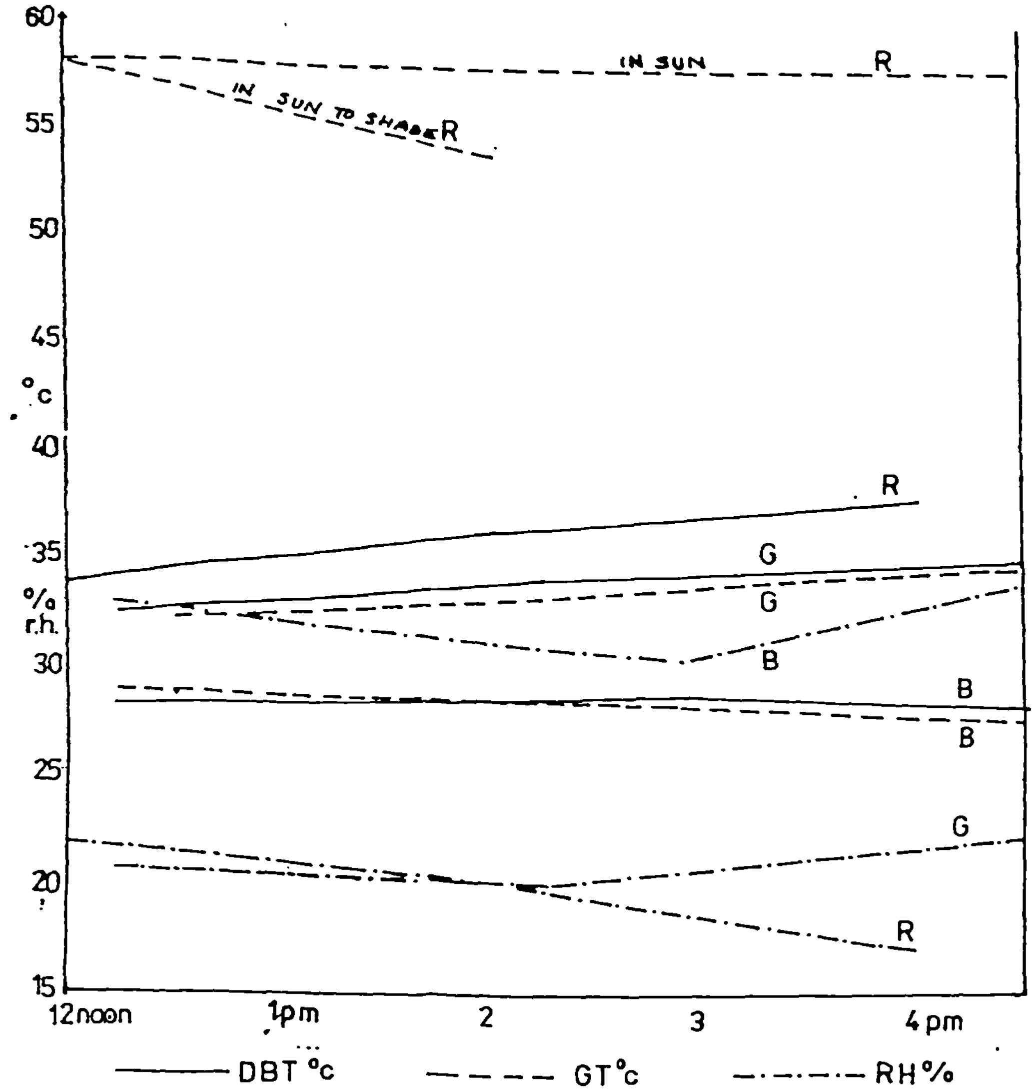


Figure 9.4. Graph showing the dry-bulb and globe temperatures and the relative humidities recorded in house C between noon and 4.30pm R) on the roof G) in the talar beneath the badgir B) in the basement beneath the talar

drawn up through the grill from the basement.

Air speeds recorded in the windward towers of downward moving air ranged typically from 0.5m/sec to 2.5m/sec, while that travelling up the leeward towers typically ranged from 0.2m/sec to 1.5m/sec. The actual design of the tower, its vents, orientation, and the room it served was seen to have a direct affect on the efficiency of individual towers in relation to internal recorded windspeeds (appendix D.2).

9.5.3 Angle of air entering the summer room

Air issuing into the ground floor room often entered at an angle to the badgir recess and was circulated around the room (appendix E) and thus mixing generally with room air.

9.5.4 Air flow up from the basement

In moderate to strong winds air travelled generally down through the grill to the basement at speeds of 0.2m/sec to 1.0m/sec; however in two particular instances the direction of the air flow was reversed and air flowed up through the grill from the basement into the ground floor room. This was in mid-afternoon in house C, with a north-westerly wind, when air movement up the leeward shafts of the tower was assisted by a stack effect created by the heating up of the south wall of the tower (appendix E.1). Also in house E air currents into and out of the basement were seen to be constantly reversing over 24 hours, probably due to changes in wind direction, and the direct introduction of air into the large windows in the basement forcing air to move up

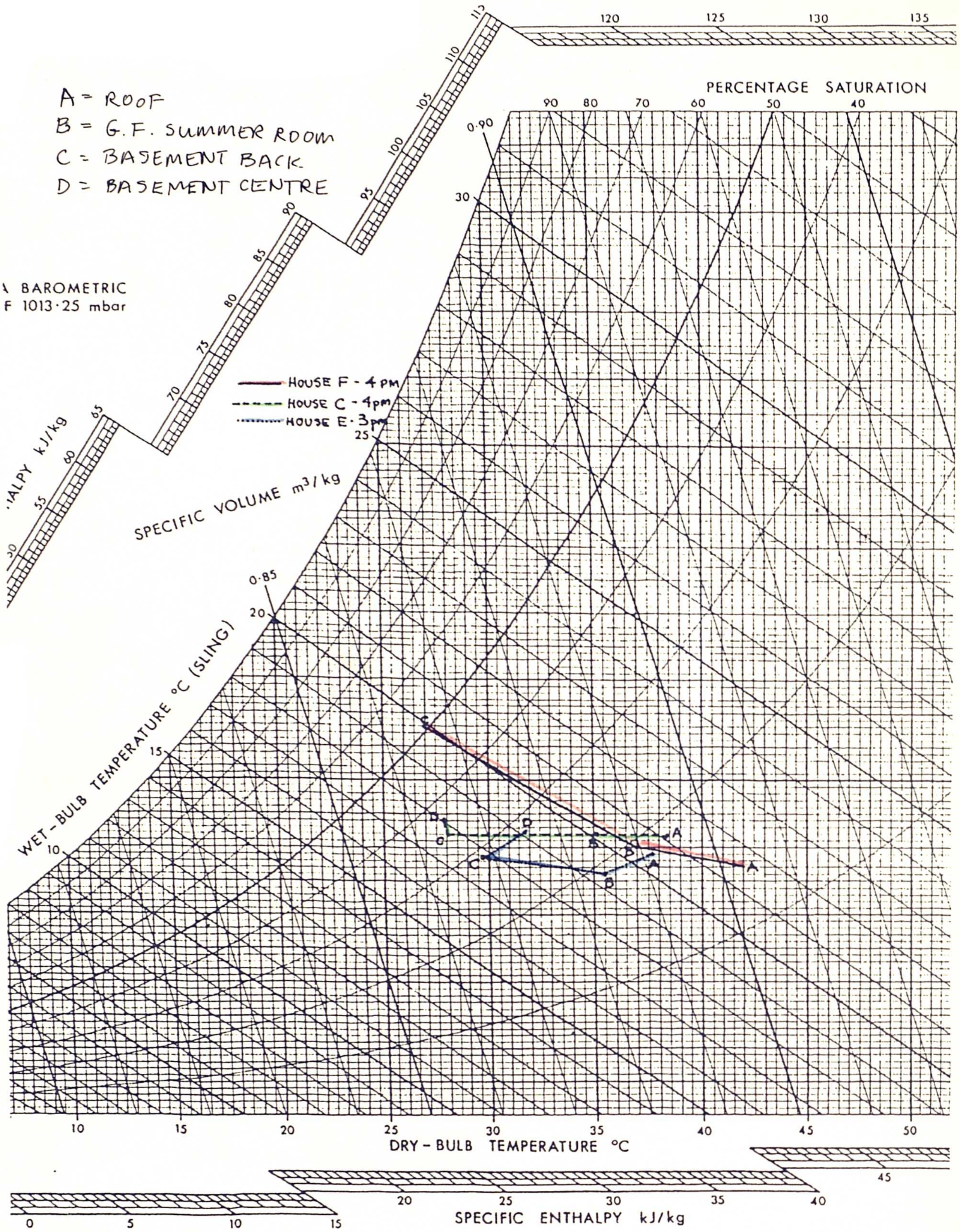


Figure 9.5. Psychrometric chart showing the changes in the water content of the air in its descent between the roof and the ground floor in C = house C at 4pm. No change in water content in air in the shaft of the badgir (A). E = house E at 3pm shows a decrease in the water content of the air as it moves down the tower to the ground floor. F = house F showing the far higher water content of the air in ground floor and basement rooms without a badgir.

from the basement through the grill (appendix E.2).

9.6 TEMPERATURE AND HUMIDITY CHANGES DOWN THE TOWER

9.6.1 During the day

Air moving down the tower is cooled during the day. Readings taken in Yazd indicate that the extent to which the air is cooled varies with the time of day. At mid-day the recorded temperature change in air moving down the tower was in the region of 1.25c to 1.75c, while at 2pm this figure had risen to over 2c and by 4pm it rose by up to up to 3.2c (Appendix G.1 and 2).

Such hourly differences are possibly due to the increasing difference between the external air temperature and the temperature of the walls of the tower which are slower in heating up than is the external air. The graph showing the recorded air and globe temperatures in house C suggest that air travelling down the tower was tending revert to the temperature of the walls of the tower (figure 9.4). This explains the recorded hourly differences in temperature from the top to the bottom of the shaft during the afternoon.

Maximum difference between the globe temperature at the base of the tower and that of the external air temperature occur at around 4pm and are in the region of 3c to 3.5c. These figures may be compared with those given for the temperature differences recorded down the tower of the malqaf at Gurna which was 3.9c (Oakley, 1962, p.126).

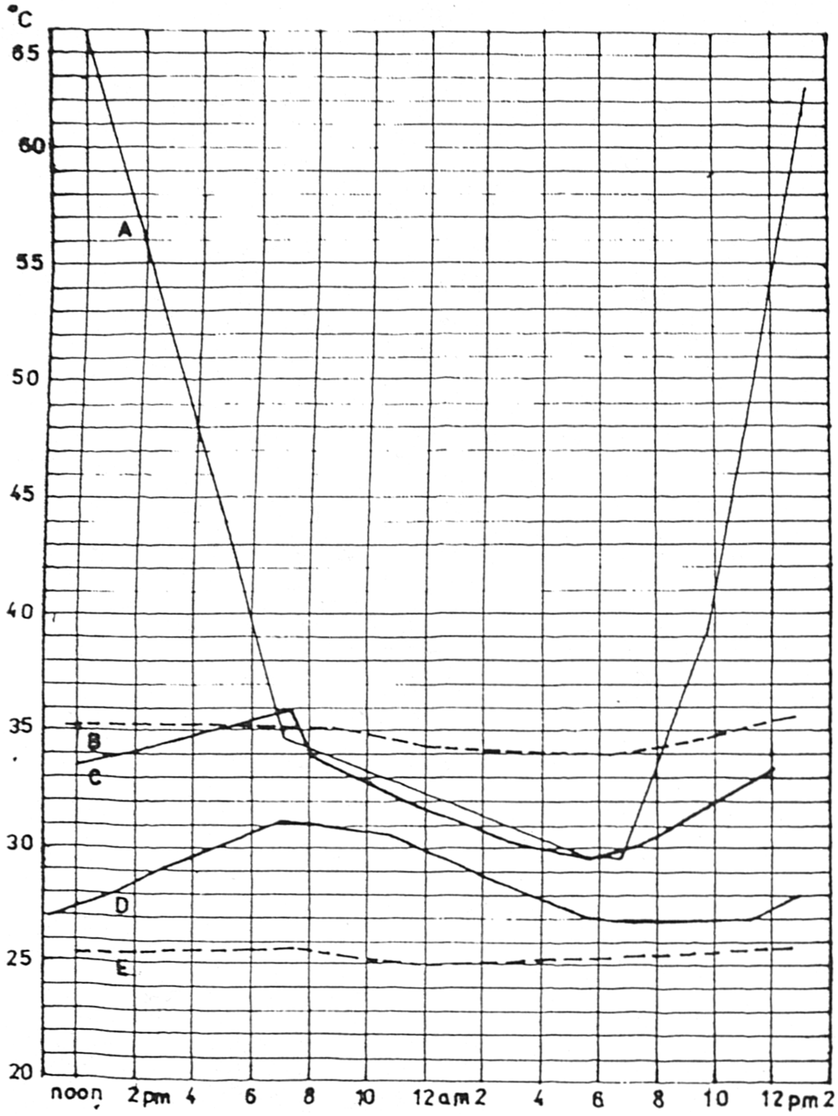


Figure 9.6. Graph showing the globe temperatures A) on the roof of house G without badgir B) in the summer room of house G C) beneath the ground floor badgir in house E D) in the basement badgir room of house E and E) in the non-badgir basement of house G.

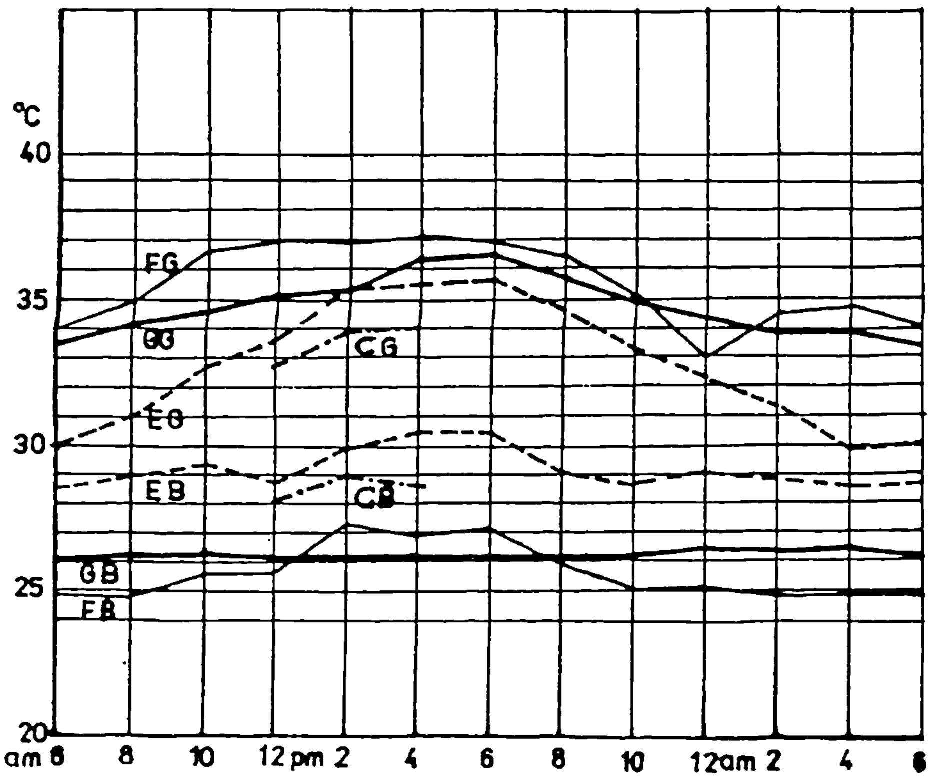


Figure 9.7. Graph showing the dry-bulb temperatures in houses C, E, F, and G, in the -G ground floor rooms and -B basements.

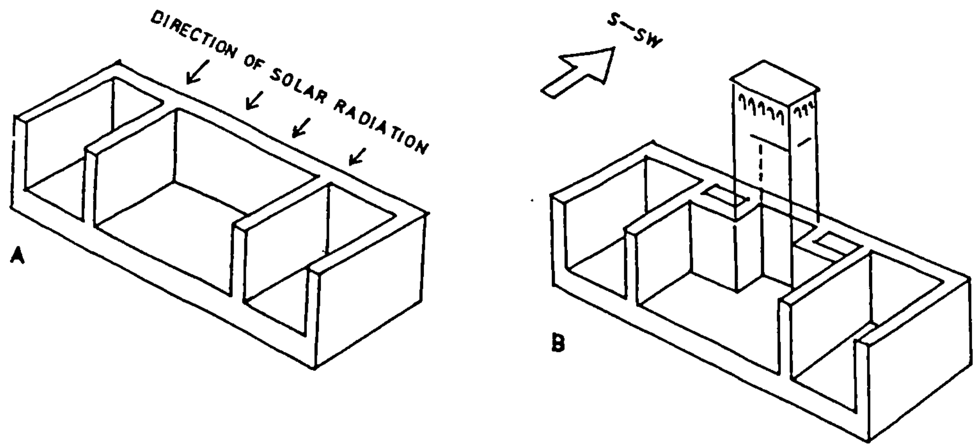


Figure 9.9. Sketch to illustrate the importance of the structure of the badgir walls in insulating the rear south facing wall of the summer room. A) unprotected rear wall of non-badgir house and B) shows the rubble filled battress walls that reduce the penetration of heat from the outer face of the wall.

9.6.2 Stable water content of air

Readings taken in Yazd indicated that the water content of the air either remained constant during the descent of the air down the tower or water was lost to the internal surface of the tower during its descent to the ground floor (figure 9.5) (Appendix G.1).

Air introduced into the ground floor summer room by the badgir appeared neither to add nor detract significant amounts of water from room air with which it mixed.

9.6.3 During the night and in the morning

As soon as the sun sets the external temperature falls rapidly and after 8pm - 10pm the external air temperature was lower than the Mean Radiant Temperature at the base of the tower (Appendix H), which was similar to the temperature of the surfaces of the room. Thus air moving down the tower at this time is drawing heat from the structure, both from the internal walls of the badgir and the badgir room (figure 9.6. and 9·7).

By 8am the air temperature in the badgir room had fallen to 29.8c while the Mean Radiant Temperature of the badgir room was 31.7c, indicating that heat was still being drawn from the walls. By 2pm the air temperature in the badgir room was 35.5c while its Mean Radiant Temperature was lower, at 33.8c, showing that heat was being gained by the walls from the moving badgir air (see appendix H). The cooling of the structure of the tower by night air appears to occur typically between 8pm and 8am, for around 12 hours a day.

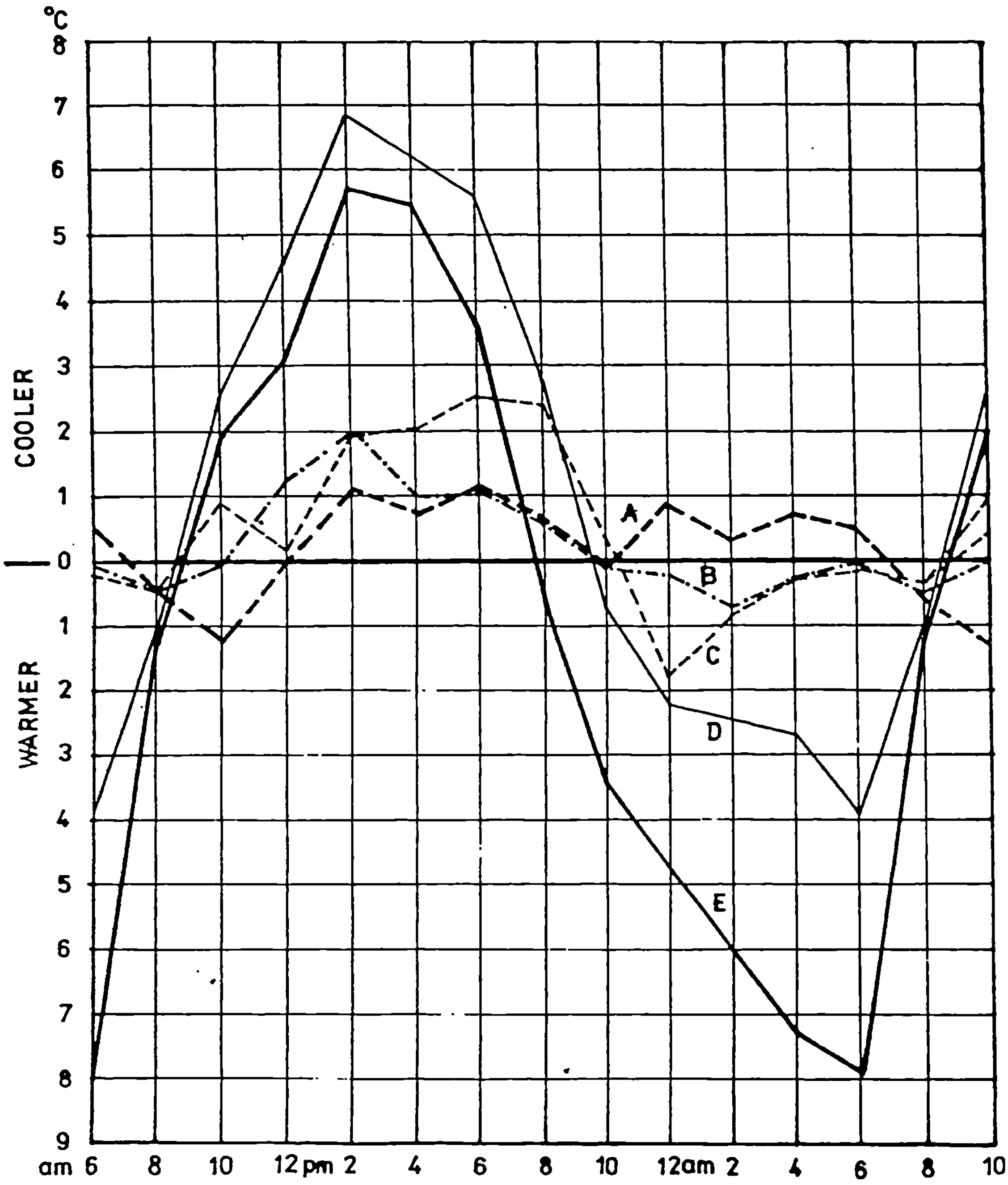


Figure 9.8. Graph showing the relative performance of ground floor rooms over 24 hours. In this figure room temperature is subtracted from roof temperature at the time. In so doing the extent to which rooms are cooler or warmer than the roof. A) house E, south front aivan

B) house E, ground floor beneath badgir

C) house G, talar

D) house G, east facing room in andaruni

E) house F, summer room

9.7 INFLUENCE OF THE BADGIR ON THE GROUND FLOOR SUMMER ROOM CLIMATE

9.7.1 Stable temperatures in unventilated non-badgir rooms

In houses F and G, which do not have badgirs, both displayed a similar and even climate with internal air temperatures around 36.5c to 37c during the day, peaking at 6pm. At night, temperatures ranged between and 33.5c to 34.5c with lowest temperatures recorded just before sunrise (Appendix K.4). Here was a maximum diurnal range in temperature of around 3.5c.

9.7.2 Diurnal range in temperature in badgir rooms

In a summer room with a badgir the temperature pattern is radically different from that of an unventilated room (figure 9.8.D and E). Badgir rooms have a climate more similar to that recorded in a talar (9.8.A) and open aivan (figure 9.8.C). The diurnal range in temperatures is double that of an unventilated room, i.e. about 7c. The pattern of heating of the room air follows that of the external air, with maximum internal air temperatures in the summer room being recorded at 4pm (see appendix G.2). The maximum internal air temperatures recorded in rooms with and without badgirs were similar but the big difference occurred in the minimum air temperatures of the rooms in the early morning. The unventilated, non-badgir summer rooms in house F (33.9c) and house G (33.4c) were both over 4c warmer than rooms ventilated by the badgir (29.3c in house E) (see figures 9.8 and K.10, 11 and 12).

9.7.3 Night cooling by badgir ventilation

At night, ventilation of the summer rooms removed, by badgir, substantial amounts of heat from the walls, floor and ceiling of the summer room that accumulated during the day, heat that was not lost from the unventilated rooms (see appendices H.2 and G.2).

9.7.4 Day-time cooling by cross ventilation

During the day the cross-draught issuing from the base of the badgir, reduced in temperature by 1c - 4c during its descent down the tower (see appendix G.1), did not result in excessive heating of the ground floor room, that is it did not bring the room air temperature in house E significantly above the air temperatures of the unventilated rooms in houses F and G (Figure 9.7) in which there was no breeze (Appendix K.4).

9.7.5 Cooling power of a cross draught

The possible cooling power of the air moving through the room was not investigated but Givoni has shown that this may be an important factor when assessing the effectiveness of cross ventilation.

> The different arrangements of the windows, while producing only slight changes in air and wall temperatures, brought about marked changes in air motion and in the cooling power of the environment. Intensified air motion resulted in a certain increase in indoor temperature during the daytime. However within the range of air temperatures in question, intensified air motion also results in more intensive cooling, which seems to outweigh the effect of the temperature increase.
>
> The reduction in cooling time suggests that improved ventilation of rooms (windward or cross ventilation as against leeward ventilation) results in an appreciable

> increase in the cooling power of the environment. Since a one-minute reduction in cooling time is approximately equivalent to a decrease of 2.3c in still air temperature, it follows that changing from leeward to windward or cross ventilation is equivalent to a reduction of 3.5c and 7c, respectively, in still air temperature during the afternoon and evening. (Givoni, 1962, p.IV)

The importance of the cooling power of air in relation to the efficiency of badgirs would be an interesting one for further work.

9.7.6 <u>Evening hot spot in badgir rooms</u>

A hot spot occurred in the badgir ground floor room in house E about 6pm (figure 9.6), when the globe temperature rose above that recorded in the summer room of house G.

9.7.7 <u>Badgir air warmer than room air</u>

Readings taken indicate that between 10am and 6pm air introduced into the ground floor room by a badgir was warmer than room air by a maximum of 1c - 4c at 4pm (appendix G.1).

9.7.8 <u>Badgir as a form of solar insulation for summer rooms</u>

The effectiveness of the badgir in cooling the summer rooms was dependent to a degree on the design of the summer rooms themselves. In some apparently similar rooms very different temperatures were recorded indicating that some rooms were warmer' than others (figure 9.7). The same was seen for courtyards in 9.4.1. One important influence on temperature in the houses measured appeared to be whether the rear wall of the ground floor summer room was exposed to direct sun or not (Appendix K.4). This suggests that an additional function of badgirs built on the exposed rear south walls of summer rooms was as an air and masonary insulating device (figure 9.9).

The central recess of the badgir on the south walls of the ground floor summer rooms was constructed with two very thick rubble-filled flanking buttresses, in the houses of mud-brick construction, which provided considerable protection against the penetration of heat. Air moving through the central recess reduced the heat gain into the room from this south wall, through heat loss by convection. This was observed but not measured.

9.7.9 Badgir as an unseen window

An important function of the badgir is that it excludes direct solar radiation from the room while providing effective cross-ventilation between itself and the courtyard. Rooms receiving direct solar radiation were hotter than those into which sunlight never entered (Appendix K.4.3).

9.8 THE EFFECT OF THE BADGIR ON BASEMENT CLIMATE

9.81 Stable climate of basements without badgirs

The climates in basements without badgirs are remarkably constant. In house G with a 3.5m deep non-bagdir basement the diurnal range in temperature was only between 26.1c to 26.5c with relative humidities of 36.5% -48% (appendix G.3).

In the deeper basement at house F which was 6m below ground level temperatures were recorded between 24.8c and 27c with a relative humidity of 45% - 55% (rising on other occasions to 76%). This basement was occupied during the afternoon and had some cross ventilation through one door and a grill window (Appendix K.5).

9.8.2 Less stable climate of basements with badgirs

The impact of introducing badgir air into the basement in considerable. Despite the relatively small size of the timber grill in house E, the air passing through it from the badgir was sufficient, when mixed with the basement air, to raise the basement air and Mean Radiant Temperature over 24 hours to well above those that were recorded in non-badgir basements (appendix H.2).

The recorded air temperatures in the basement of house E ranged from 28.3c at 6am to 30.5c at 6pm (figure G.2 - graphs9, 10 and 12). Internal air temperatures peaked in basements with badgirs in late afternoon and early evening.

9.8.3 Badgirs heat basement air

Over 24 hours the temperatures of the surfaces of the basements with badgirs were heated by the passage of warmer air through them. The recorded globe temperatures in the basement of house G, which did not have a badgir, remained fairly constant at about 25.5c (Figure 9.6). In the basement of house E with a badgir globe temperatures fell in the early morning to 27c but rose rapidly after about 11am to about 31c between 6pm and 8pm (appendix H.1).

9.8.4 Badgirs dry basement air

The bagdir removes moisture from the basement. The air descending into the basement of House E during the afternoon, with a relative humidity in the region of 20% - 25%, mixed with the basement air which had a higher water content and humidity with the following consequences (figure 9.5): after mixing with the basement air the badgir removed water from the air in the basement, in its passage out of the space, so lowering the overall relative humidity of the basement air. Thus in basements with badgir, relative humidities in the range of 26% - 38% over 24 hours were recorded, considerably lower than those in non-badgir basements (see appendix K.5).

9.8.5 Air changes per hour in basements with badgir

The improved ventilation provided in the basement by the badgir is an important factor during the afternoon occupation of the space (10.5.4.2).

For instance there are up to 15 occupants of the basement in the Mashrouteh house from noon to 5pm, eating their main meal of the day, sleeping and sitting, and so the build up of heat and smells in the basement requires ventilation to improve its habitability. In house F, with a floor area of 44 square meters and a depth of 6m, and a window 1.8m x 1m high, even with the recorded air speed of 0.1-0.2m/sec, the air changes were considerably less than those in all basements with air introduced through a grill beneath the badgir in the afternoon, where speeds of 0.3m/sec to

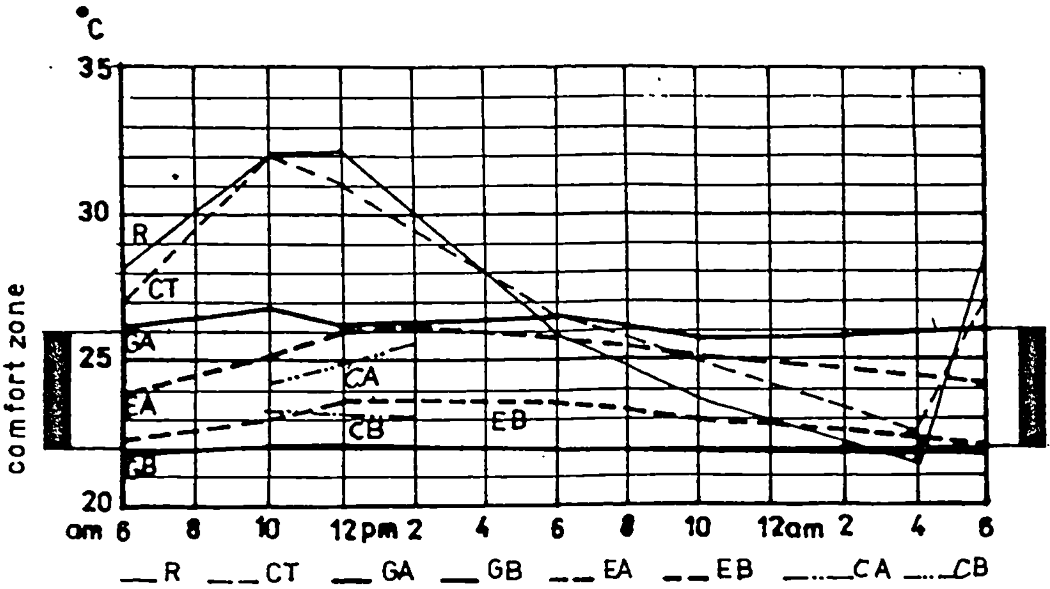


Figure 9.10. Graph showng the Corrected Effective Temperature in house E with badgir, and house G without badgir. Upper limit for comfort is 26c and lower limit is 22c (see 9.9).
R) roof of house G
CT) courtyard A of house G
G-) house G E-) house E C-) house C
-A) ground floor room -B) basement

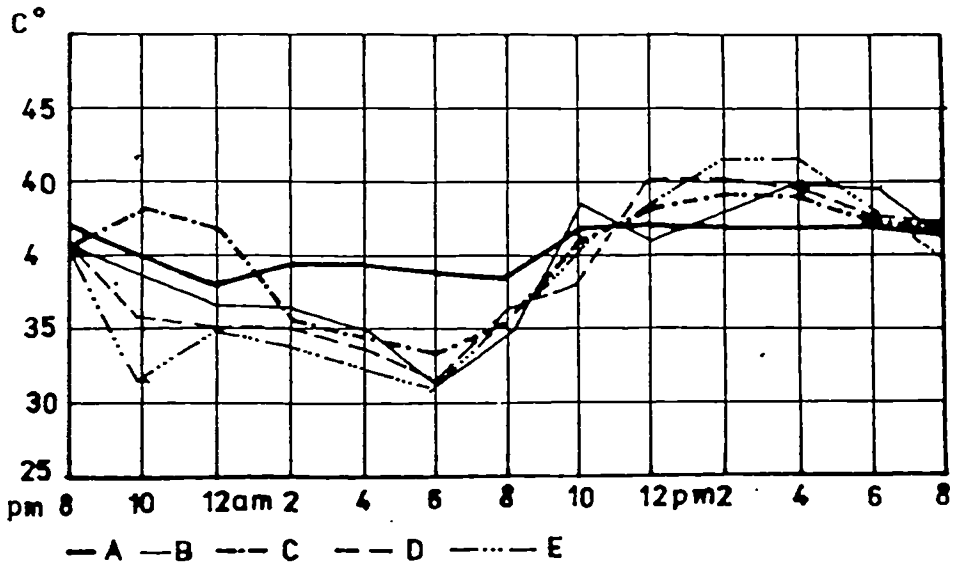


Figure 9.11. Dry-bulb air temperatures in house F.
A = unventilated summer room. B = ventilated S.E. room
C = ventilated S.W. passage D = S.W.courtyard
F = S.E. courtyard (heavily watered at 9pm).

1.5m/sec were recorded. through the grill beneath the badgir.

9.8.6 Qanats in the basement

Qanats are occasionally used to decrease the temperature in basements with bagdirs. In house A the temperatures recorded near the entrance to a qanat tunnel were 6.3c lower than those in the badgir recess on the other side of the room, and had a relative humidity reading 15% higher (Appendix C). The advisability of having such low temperatures and high humidities in the basement would seem to be questioned by the rarity of the use of qanats in association with basements (appendix G.3).

9.9 THE EFFECTIVE TEMPERATURE (E.T.) AND CORRECTED EFFECTIVE TEMPERATURE (C.E.T) OF NON-BADGIR ROOMS

9.9.1 Importance of badgir in modifying climate according to C.E.T and E.T. limits of comfort

Comparison of the Corrected Effective Temperature readings for the basement and ground floor summer room of house E with a badgir and those of house G without indicate the effectiveness of the badgir in modifying the internal climate of houses in Yazd (Figure 9.10).

The readings for house E fall within the upper and lower comfort limits of 22c and 27c (Koenigsberger, et. al, 1973, p.57)., whilst those for house G skirt very close to them. For Yazd an upper limit for C.E.T. comfort of 26c has been chosen as the climate is hot/ dry rather than hot/humid as are those for which an upper limit of 27c are applicable, according to Koenigsberger et. al.

Edholm (1978, p.53) gave 25.4c E.T. as the upper limit for comfort in Iran. If this is so, only in the early morning would the unventilated summer room of house G have been comfortable on the day when measured. At 8am, 2pm, and 8pm the Effective Temperatures for this room were 25.2c, 26.9c, 26.9c, and 25.7c respectively.

A lower level of 22c C.E.T. has been adopted. An unventilated basement appears to be very close to the lower limit of comfort by general Corrected Effective temperature standards while a basement with badgir falls well within the comfort zone.

9.9.2 Physiological E.T. limits

Various studies have shown that Effective Temperatures of 27c are nearing critical levels for European subjects. Johansson claims that high temperatures impair the performance of mental, perceptual and psycho-motor tasks for subjects stripped to the waist and a critical zone exists between 27c - 30c E.T. and optimum performance was achieved at 24c - 27c E.T. (Johansson, 1975, p1). It appears that Effective Temperatures during the day in unventilated ground floor summer rooms are nearing Johansson's critical levels.

9.9.3 The suitability of the Yazd climate for badgirs

The Corrected Effective Temperatures shown in figure 9.10 suggest that the internal house climates in Yazd are close to the limits of acceptability in terms of comfort and the body's ability to respond to high and low temperatures. This might indicate that in a climate that was slightly colder or hotter than that of Yazd Corrected Effective Temperatures associated with the use of the badgir may fall above or below the acceptable comfort limits, and that the badgir in Yazd is operating within critical temperature thresholds, supporting the premise that the climate of Yazd is particularly suited to the use of bagdirs.

9.10 THE EFFECT OF CROSS VENTILATION WITHOUT BADGIR ON THE TEMPERATURE OF GROUND FLOOR SUMMER ROOMS

Rooms with direct cross-ventilation have a noticeable more extreme internal climate than unventilated rooms or rooms with badgir.

In house F two spaces were recorded with cross ventilation. The first was the small room in the north east corner of the court with open French doors to the court and an open pair of doors on the south east wall. The second was the entrance passage in the south west corner of the court with open doors at both ends.

Figure 9.11 shows that between 6am and 8pm areas with through drafts were cooler than roof temperature but still 'hot' with temperatures over 39c between 2pm - 6pm. This is 2.5c cooler than the roof and 3c warmer than the closed room.

However at night the increased ventilation in these rooms made them up to 5c cooler than the closed rooms, while still up to 2.5c warmer than the roof temperature.

The climate within the rooms with direct cross-ventilation corresponded closely to the external air temperature, becoming cooler at night and warmer in the day.

This emphasises that ground floor summer rooms ventilated by a badgir have a temperature buffer against the external climate, consisting of the reduction of, or increase in temperature in air coming down the badgir tower during the day and night of 1c - 4c. This temperature buffer protects the ground floor summer rooms from being exposed directly to the extremes of courtyard and roof climate, unlike the rooms with direct cross-ventilation.

9.11 THE IMPACT OF FANS AND SWAMP COOLERS ON THE INTERNAL CLIMATES OF ROOMS WITHOUT BADGIRS

The following figures are given as a brief record of the difference in performance of two mechanical cooling methods. The ceiling fan has been used in Yazd since the 1930, when electricity was brought to the city. The swamp coolers consists of an electric fan which draws external air into the room across water-soaked straw panels, thus introducing cooled air with a considerable water content. These have been used widely since the 1970s, but suffer from the disadvantage that in Yazd, as in many other cities of the Middle East, in mid-afternoon in summer, when the maximum load is placed on the electricity supply system, frequent power failures occur in the city.

9.11.1 Ceiling fans

Readings taken in house G showed that a ceiling fan, on for over two hours, lowered the temperature in the east-facing room by only 1c, with a corresponding increase in the relative humidity of the air of 1% - 2%. The main impact was to increases the air speed in the room considerably.

9.11.2 Swamp coolers

In contrast, a swamp cooler when on for only 5 minutes in the summer living room reduced the temperature by 3c and increased the R.H. by 15%. When it was left on for half an hour in the summer room of house G, the R.H. rose 11% and the temperature dropped a further 2c. Over a longer period the recorded relative humidity in the room rose to 70%, with an overall drop of 10c in air temperature.

These figures compare well with those published by Lippsmeier (1980, p.165) who found that when the relative humidity of the ambient air was lower, the cooling effect of the swamp cooler was greater. At 35c with a relative humidity of 40% a swamp cooler caused a reduction of 5c, but when the relative humidity was 10%, a reduction of 11c occured.

9.11.3 Swamp coolers considered unhealthy due to the high humidity levels they produce

Swamp coolers are understandably popular and are generally used in rooms with closed doors and windows to maximise their impact on room climate. The very high levels of humidity they produce are often remarked upon by the older generation of Yazdis who are very wary of high humidity which they claim to be harmful to the health, causing colds and rheumatism. In Yazd it is very common to hear comments on the rutabat, the humidity of a room. However such coolers are widely used in all types of houses and are increasingly popular with the Yazdi.

9.12 CONCLUSIONS ON THE OVERALL ROLE OF THE BADGIR IN THE HOUSES OF YAZD IN SUMMER

The readings taken in Yazd are insufficiently detailed to provide more than a general indication of the complex role of the badgir in creating summer comfort in the houses of Yazd. However the readings do indicate that their primary function is to moderate the climate in the summer rooms of the houses.

9.12.1 When air is moving down the tower into the ground floor rooms and into the basement

In the ground floor summer rooms:

1) The badgir reduced the temperature of air descending down the tower by 1c - 4c during the day (9.7.7), as suggested by many previous authors (1.7.1).

2) Air circulated by the badgir through the summer room reduced the temperature of the surfaces of the badgir room by up to 6.5c at night.

3) The badgir provided a strong cross draught in the ground floor summers room at temperatures modified as above.

4) Modified badgir air circulating through the ground floor summer rooms and mixing with room air effectively reduced the temperatures of the surface of the room to below those surface temperatures recorded in non-bagdir rooms over 24 hours. Only between 2pm to 8pm did air and surface temperatures in the badgir rooms approach, and or exceed, those in the non-badgir room.

5) The ground floor rooms with badgir produced an internal climate that was comfortable during the morning and in mid-late evening, while the non-ventilated rooms had a climate that was unoccupiable during the day and early evening.

<u>In the basements:</u>

1) The badgir increased the temperature of the air and surfaces of the basements over 24 hours of the day.

2) The badgir removed moisture from the basements, so reducing the relative humidity of the room over 24 hours of the day.

3) The badgir improved the ventilation of the space (see 10.5.4.2).

4) The badgir, by warming and drying the basements, was seen to bring them well within the range of Corrected Effective comfort limits, whereas the non-badgir basement of house G was almost too cold for comfort to people accustomed to the climate of Yazd, over 24 hours.

5) The recorded relative humidities of 76% in the basement of house F show that damp is a problem in some basements, a problem alleviated by the use of a badgir (see 10.5.4.3).

9.12.2 When air is moving up from the basement

In readings taken in house E air was seen regularly to move up from the basement into the ground floor summer room through the grill. Suggested reasons for this included the occurance of a stack effect in the tower in mid-late afternoon, change in wind direction and speed so that air is moving directly into the courtyard windows of the basement and is then forced under pressure to move up through the grill, and a cross-draught in paired windtowers under certain wind directions, forcing air up the leeward shaft.

Air moving up from the basements through the grills is cooler and has a higher moisture content than that in the ground floor rooms and cools the area and air into which it moves by evaporation and convection.

9.12.3 Comparison of the badgir with other forms of cooling

Passive:

1) Direct cross-ventilation of rooms appeared less satisfactory than ventilation by badgir. It produced greater extremes of internal room climate than the rooms with cross- ventilation produced by a badgir; such rooms are protected from such extremes, particularly of afternoon peak temperatures by the temperature buffer effect of the towers, which reduce the temperature of incoming air by 2c - 4c in mid-afternoon..

2) Unventilated ground floorrooms proved unoccupiable at times during the day.

Mechanical:

3) Swamp coolers increase the relative humidity while decreasing the temperature and increasing air movement in rooms. The badgir cools the air and surfaces of rooms without creating unhealthily high levels of moisture in the air.

4) Ceiling fans make little change in temperature or water content of the air but increase the air movement. The badgir cools incoming air during its descent down the tower and removes moisture from damp basements.

5) The dissadvantage of the badgir is, as with the ceiling fan, that from 10am to noon it does not produce low enough temperatures in ground floor summer rooms for modern comfort requirements, whereas the swamp cooler does.

9.13 THE PERFORMANCE OF THE BADGIR IN INDIVIDUAL HOUSES

It was found that some badgirs are more efficient than others, due to design, orientation, and associated house design. It was also found that some courtyards, noticably smaller courts, were warmer than others over 24 hours, noticeable smaller courts, and some rooms performed less well than others in reducing internal day time temperatures. A reason suggested for the latter was an exposed south facing wall in a summer room.

The performance of the badgir must be seen in the total context of the climatic performance of the house and the efficiency of the total system was seen to be influenced by the design of the individual elements that made it up.

It was impossible in this thesis to deal with the whole range of variety in room types, badgir types, and courtyard types. However the existance of such variables should be recognised, and the limitations of the data presented kept in mind when the above conclusions are studied.

9.13 FURTHER ASPECTS OF THE BADGIR TO BE INVESTIGATED

Two important aspects of the performance and use of badgirs in Yazd have been only lightly touched on in this chapter and will be dealt with in the following chapters:

Chapter 10. The diurnal use of the house and badgir in summer in Yazdi houses.

Chapter 11. The implications of the temperatures and windspeeds recorded in Yazd in terms of comfort and the physiology of human responses to high temperatures.

Figure 10.1. 'Yezdi Types' (Napier, 1905). From left to right they are 1) The qanat maker 2) The Zoroastrian peasant farmer 3) A porter 4) A man from Luristan. These tall men came to Yazd with the caravans 5) A Jew 6) An oil-seller who carries oil in gourds 6) A darvish, a religious mendicant 7) An Arab. These were occasionally seen in Yazd, like the Lur, but did not belong to the city.

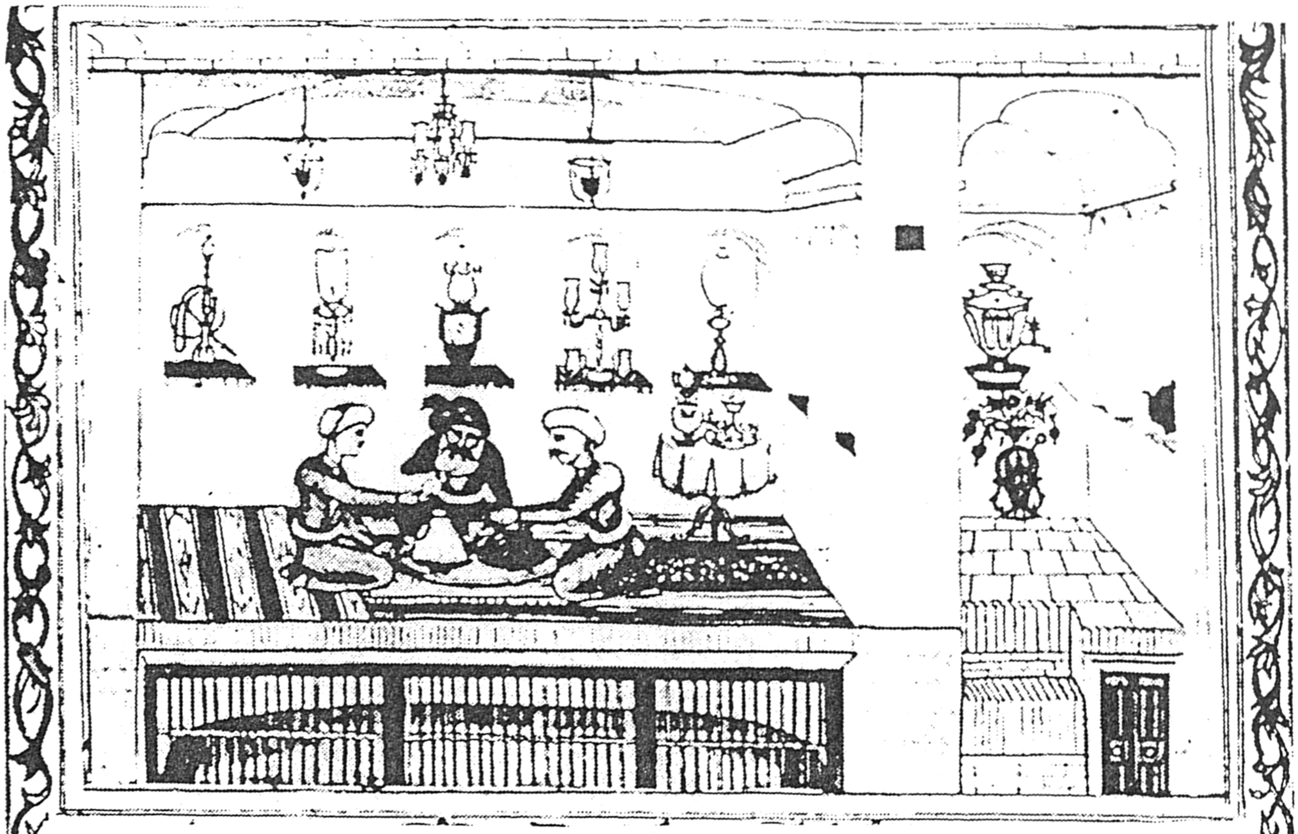


Figure 10.2. Sweet eating in a talar' (Napier, 1905). The three men are sitting in the ordinary Persian way round a tray of sweets. They eat them as we do cakes but in rather larger quantities. This talar is a small one. The larger ones are generally cruciform in shape. It has no badgir (air-shaft) or front curtain.' Note the grill to the basement beneath the talar and the steps to the basement on the right of the picture.

CHAPTER 10

SUMMER LIFESTYLE, HOUSE USE AND CLIMATE IN YAZD

10.1 INTRODUCTION

In contrast to the Western approach to comfort and design in which the individual chooses the climate for a room, the Yazdi in a traditional house selects a room for its climate.

Such choice and movement around a house during a day constitutes a behavioural adjustment that has been an essential adaptation by the traditional populations of such hot desert regions, enabling them to inhabit a seemingly hostile environment with some degree of comfort. The consequence of this daily movement around the house is that by recording climate in one or two spaces one does not cover the diurnal range in climate experienced by the occupants of houses. In Yazd it has been necessary to follow the occupants around the house, climatically, in order to record and in turn understand the nature of the 'occupied' diurnal summer climate in the houses of Yazd.

If one recorded only the diurnal climate in the ground floor summer room with a badgir, then the climate described would appear unacceptable at various times of day; but when judged against the regular changes in living areas around the house over 24 hours the real importance and sophistocation of the badgir as a device for ameliorating the internal summer climate of the occupied spaces in the Yazdi house can be appreciated.

In this chapter the lifestyle of the Yazdis, and their use of space in the typical house is described in relation to the climate of the occupied spaces.

The chapter is divided into two parts:

1) The use of space in the house.

2) Average climates of the used spaces in houses with and without badgirs.

10.2 THE LIFESTYLE OF THE YAZDI AND THEIR SUMMER USE OF SPACE IN THE HOUSE

The Yazdi is by habit a sedentary nomad.

From the findings of the field work in Yazd it appears that the Yazdi does not migrate to cooler summer quarters like a true nomad, but he also migrates around the house and even around a room at different times day in the various seasons, to take advantage of different climatic conditions in each place.

10.2.1 <u>The Yazdi long migration</u>

At the begining of summer, those Yazdis who could afford to, packed up their households and sent the women, children and servants, to the summer quarters (<u>sard sir</u> or cold land or <u>yeilaq</u>). Here they owned or rented a house in one of the high villages above Taft, on the flanks of Shir Kuh mountain. In these well-watered villages such as Deh Bala, with their abundance of fruit trees and pleasant cottages, they stayed until the end of the summer (Napier, 1905, pp31-33).

The men of the house remained with a skeleton staff in the Yazd home, and visited their families occasionally during the course of the summer months.

Today many women and children are still sent to spend the summer in the sard sir but the husbands may now visit every weekend, because of the improved roads and car transport.

This summer migration, which once kept the bulk of the household away from home for up to four months of the year (Napier, 1905, pp.31-33), has recently changed slightly in nature, as the richer families of Yazd had, in the twenty years before 1978, replaced the Shir Kuh villages by modern bungalows on the Caspian Sea, in the north of Iran, or by holiday flats in Europe.

The habit of this summer migration suggests that in summer the city of Yazd was considered uncomfortably warm, and worth escaping from. One might guess that, with the introduction of modern air-conditioning systems into the homes of the rich, the need to move away from the city in summer has been removed. This is true up to a point but the total environment of the city is still extremely hot during the summer and air-conditioners moderate only the internal climate. The wealthiest families still migrated away from Yazd during the summer before 1978, when the city was last visited by the author.

10.2.2 Intra-mural migration - the short alternative

For those who remain in Yazd the long migration is replaced by a short migration, around the house. A typical outline is shown in the chart below.

TIME SPACE AND ACTIVITY IN THE MASHROUTEH HOUSE IN JULY

Time	space	Men	Women	Food
6am	roof	waking & rising	waking and rising	
7am	S.E.ct.	sitting,eating	sitting,eating	BF.
7.30		to work	still sitting	
9.30	house		housework,cooking	
11	S.E.ct. kitchen		sitting cooking	
12pm- 12.30	kitchen Basement		cooking sitting	
2pm	Basement	return from work eating	eating	L.
3pm	Basement	sleeping	sleeping	
5pm	Basement	waking,sitting	waking,sitting	tea
6pm	S.W.Ct. aivan	sitting	sitting	fruit
7.30	Court	guests,sitting, some men back to work till 10pm	sitting	tea
9pm	Kitchen		cooking	
10pm- 11pm	Court	eating	eating	S.
12am- 1am	Roof	retire (children to bed earlier)	retire	C.W.

BF.= Breakfast of tea,bread, butter, jam, cheese.
L. = Lunch, stew and rice taken with cold water.
S. = Supper is either bread and cheese or stew and rice.
C.W. - Cold water taken to roof in thermos kept beside bed.
During the evening fruit, sherbet and sweets consumed.

From the chart above it can be seen that the family is in continual motion around the house, both vertically and horizontally, in search of an optimum climatic environment.

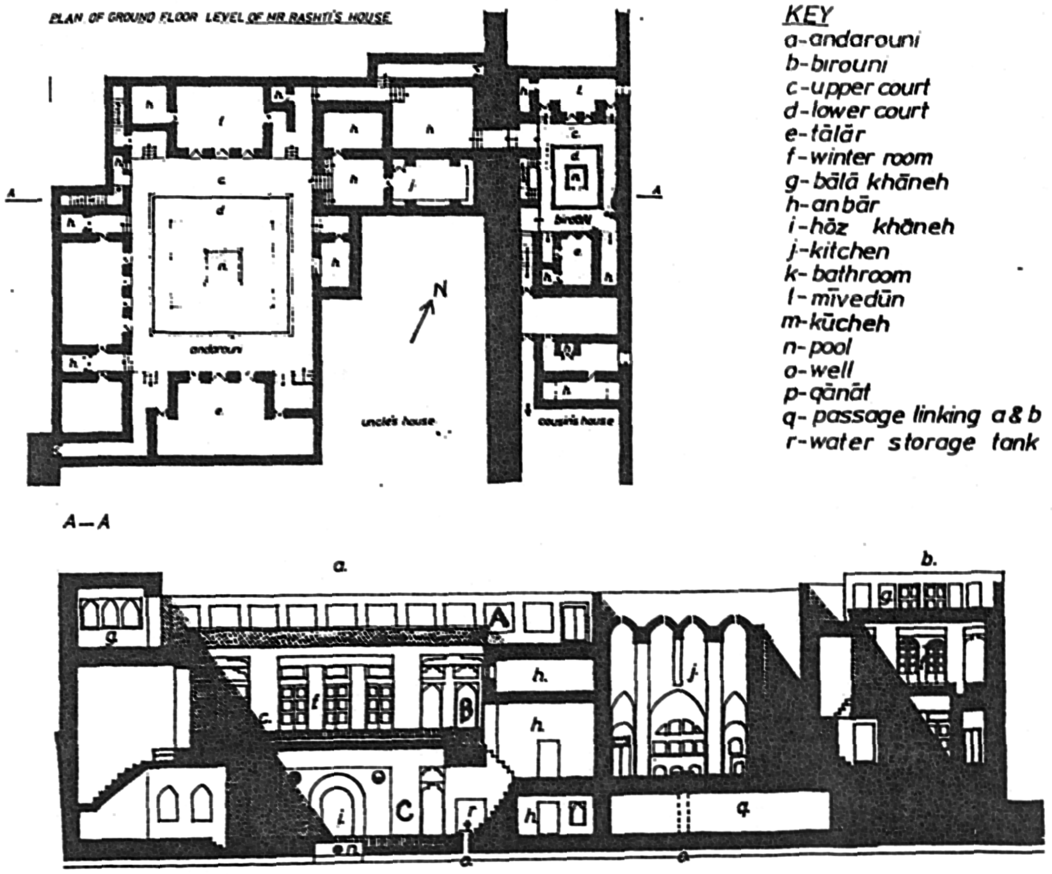


Figure 10.3. Plan and section of house R, owned by Mr. Rashdi. Temperature readings were taken at points:
A – on the roof, B – in the upper courtyard
C – in the lower courtyard.

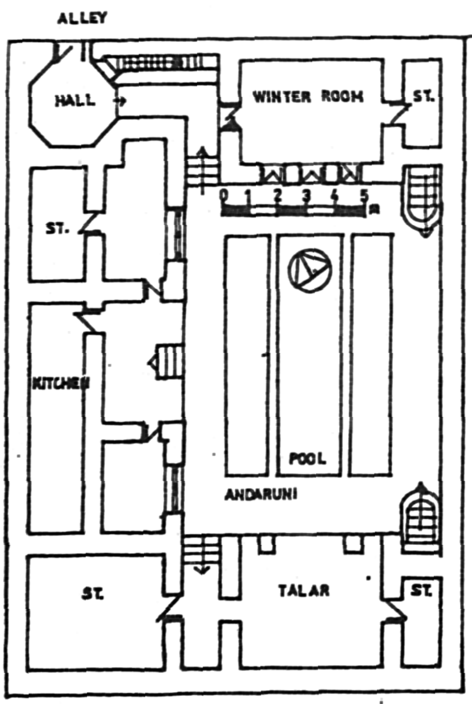


Figure 10.4. Plan of Javad's house.

IMPACT OF HORIZONTAL MIGRATION ON CLIMATE EXPERIENCED

HOUSE	TIME	SPACE	TEMP. C	RH.%
House F	2pm	GF winter room	36.9	20.1
		GF summer room	36.9	22.2
House G	2pm	GF winter room	38.1	19.8
		GF open talar	40.1	17
		GF winter room	35.3	23
House F	4pm	GF winter room	38.2	18.8
		GF summer room	37	22

IMPACT OF VERTICAL MIGRATION ON CLIMATE EXPERIENCED

House F	2pm	roof	42.5	16.8
		basement	27.3	52
House E	2pm	roof	37.4	19.8
		GF under badgir	35.4	21.5
		Basement	29.9	30
House R	11am	roof	36	19.8
		1st floor court	35.8	20
		lower court	31.8	22.5

House R = Rashdi house illustrated in figure 10.3.

The above table demonstrates that considerable differences in climate can be experienced by horizontal, and even more by vertical, migration through the house. These differences are influenced by the nature of the room, its orientation, exposure to direct and indirect radiation, ventilation and the time of day.

By migrating horizontally, that is on one level, in rooms around the courtyard of the house, a change in dry bulb temperature of 4.8c can be achieved by moving from an open talar to a closed north facing room at 2pm.

By migrating vertically, in the open air, from the roof to the lowest of two courtyards on a summer morning, a decrease of 4.2c is achieved , but a move from the open roof to the closed basement without badgir, is attended by a drop in experienced temperature of over 15c, with an increase in relative humidity of 35%.

Two important variables which have an impact on what is considered acceptable temperature at various times of day are activity and clothing. These are dealt with below, before a detailed outline of the daily migration.

10.3 ACTIVITY

Different activities generate very different levels of sensible heat output from the body. Since standing or moving produce 65-130 Watts per meter square, sitting 50-60 W/m2 and resting around 40 W/m2 (Humphreys, 1976, p.178), the organisation and timing of the daily activities obviously plays a part in the comfort of the occupants of houses in very hot climates.

Household work is done in the early morning or evening so that maximum levels of heat generated by the body co-incide with cooler air temperatures. The hottest time of the day is when activity levels are lowest.

Eating also generates heat output, and the two largest meals of the day, one eaten at 2pm and one at 10pm, are followed by the two periods of sleep, from 3pm-5pm, and from 12 mid-night to 5.30 am, respectively.

10.4 CLOTHING

While the European takes clothes off in the heat, the Yazdi remains fully clothed all day and night, changing clothes only once a week, during a visit to the public bath (figure 10.2).

Clothes greatly reduce thermal stress in desert climates as indicated by the following figures. Thermal stress in the desert sun is 3.4 times that in the tropical sun for the nude man, but for the clothed person the figure for the desert sun drops to 2.4 times that of the tropical sun (Adolph, 1947, p.318).

Traditionally Yazdi men dressed in a loose cotton shirt, camis, and baggy trousers, shalvar, with nothing on underneath. Women wore a loose dress, pirhan, with trousers, shalvar beneath. Loose fitting shoes or the traditional rope shoes or giveh were worn (see Wulff, 1966). Women in traditional clothing now generally wear brassieres. Underpants are not worn beneath the shalvar. These clothes probably represent 1 clo. unit (standard measurement of clothing), are of light material, and cover most of the body, leaving only hands and head exposed.

When women walk in the streets they wear the chadur, a veil, that covers them from head to foot, leaving only the eyes exposed. The women of Yazd, renowned for their beauty, 'For certainly the Women of Yezd are the handsomest Women in all Persia', (Tavernier, 1687, book I, page 44), are very conscientious in their concealment, and when people who are not from the close family are in the house they also wear a chadur in the house. Voluminous clothing loosely worn provides an excellent micro-climate beneath ' (Ingram and Mount, 1975, p.161). Such clothes are ideal for the climate:

> In preparation for a journey under desert conditions, perhaps the most important measure that a man can take is to dress in clothes that reduce the radiant heat load, and so reduce the quantity of heat that must be lost by evaporation. In comparison with the unclothed state, light clothes with long trousers and long sleeved shirt reduce radiation heat load by half and water loss by two thirds. (Ingram and Mount, 1975, p.150)

> Clothing in arid climates provides shelter from direct, reflected and re-radiated radiation and the often voluminous clothing, as it billows, catches and circulates air around the body from which heat is lost. (Clark and Edholm, 1985)

Within the environment of the house radiant heat levels are high in the courtyard and covering clothes are necessary even in the house.

10.5 FUNCTIONS OF THE BADGIR ALONG THE MIGRATION PATH IN MID-SUMMER

10.5.1 <u>At night</u>

1) Cross ventilation of the rooms of the house by the badgir at night have the effect of cooling down the walls, floor and ceiling of the summer room and heating up those of the basement.

2) Ground floor rooms are not slept in at night. But basements in some instances are, and the warming up and de-humidifcation of the basement by the badgir creates a basement climate that may be comfortable to sleep in during extremely hot periods of the summer.

3) Basements without badgir, such as in the House F, where temperatures of 20c with 76.25 % RH were recorded at 9pm, are unpleasant for sleeping, being too cold and dank.

An example of a basement with badgir occupied through the summer at night was recorded at the Bagh-e Khan. Here (Figures 3.21, 3.22 and 12.1) the elderly owner, creator of the pommad-e Valli', had a bed placed just below the outlet of the efficient badgir (see 12.6.2). The owner had improved the operation of the badgir by installing a fan in the horizontal shaft of the badgir. The basement itself is high, with enormous openings, ensuring that by being well ventilated it would never be damp' at night.

One example of a house without badgir, where the basement was occupied at night, was noted in Yazd (figure 10.4). Javad's family, an educated one, in which the two daughters are school teachers, have four metal beds in the basement where they sleep in summer. Although there are no climatic measurements for this house it was recorded by the author that the basement is a high, whitewashed room with a large grill onto the garden, and feels relatively warm and well ventilated basement.

No example of a family sleeping in a ground floor living room was recorded but there are, over a number of courtyard pools, large wooden beds, <u>takhta</u>, which are apparently slept on in summer (figure 6.21).

Readings show that after about 8pm in the evening the temperature in the courtyard falls to below 36c and after midnight on the roof temperatures fall below 32c.

10.5.2 Sleep

The family sleeps on thin mattresses, covered with quilted eiderdowns, because although the night time roof temperature never fell below 26c during the recordings, this temperature is considered to be cold, due largely to the heat loss by radiation to the clear sky above. This happens because on the roof at night the globe temperature falls to below the dry-bulb temperature by 2-3c but from midnight to sun-rise the total drop in globe temperature is only 1c and dry-bulb temperature 2c showing a slight, but steady, reduction in temperature as heat is re-radiated to the sky at night.

Studies in the hot dry region of Australia show that even with enhanced ventilation the degree of disturbance to sleep rose sharply above 26.8c (MacPherson, 1962, p.456). Humphreys claimed, with little empirical evidence, that 27c could be suggested as a maximum temperature for undisturbed sleep (Humpheries, 1976, p.178). Mackworth found that at temperatures of 30.8c subjects slept much more restlessly than at 26.1c (Angus, 1968, p.33). These estimates suggest that the late hour of retiring may be determined by the temperature thresholds that produce comfortable sleep. They also point to the fact that ground floor conditions within the house would be less comfortable for sleeping in, without a badgir.

10.5.3 The morning

The occupants of the house rise at 5.30-7.30am and descend to the ground floor, where they eat breakfast either in the courtyard or in the front of the talar. Closed summer rooms are too hot to occupy at this time of day.

Generally only the females of the house are at home during the morning: they are engaged in domestic chores, in the courtyard and the rooms around it, particularly in the kitchen.

Typical dry (DBT) and wet-bulb temperatures (WBT) readings taken and calculations of relative humidity (%RH), globe temperature (GT), and Corrected Effective (CET) and Effective Temperature (ET) for these spaces at 10am are as follows:

PLACE	DBT	WBT	GT	%RH	ET	CET
HOUSES WITH BADGIR						
House E talar	33.5	19.2	33.5	25	25	25
House D summer room	32.5	17.4	33.2	24.3	24.3	24.8
VENTILATED SPACES						
House F courtyard	33.5	21		33.4	26	
House C talar-11.am	33	19.5	35.6	27.8	25.3	26.2
House G courtyard	36	19	59.25	18.5	26.1	31
UNVENTILATED SPACES						
House F summer room	36.5	20.2	36.5	22	27	27
House G summer room	36.5	19.2	36.5	18.1	26.3	26.3

These figures show over 2c difference between the rooms with and without badgirs, and as the upper temperature is approaching Mackworth's critical zone' of Effective Temperature (28.3c - 30.8c) above which the accuracy of the performance of mental tasks declined (Angus, 1968, p.32), the difference is significant.

A summer room with closed doors provides the least comfortable conditions for use in the mornings, and the occupants of house F, and of many other houses in Yazd, sit in the shaded part of the open courtyard in the morning. This area is subjected at that time to far higher levels of solar radiation incidence than the room, as is evidenced by the difference between the Effective Temperature and Corrected Effective Temperature for the courtyard at house G at 10am; Corrected Effective temperature takes into account the radiant heat whereas Effective Temperature does not. Apparently the advantages of the fresh breeze outside more than compensates for the extra radiant heat imput to the individual.

The talars or five-door rooms with badgirs are cooler than those without, for reasons indicated in 9.7.2.

10.5.4 <u>Afternoon use of badgirs</u>

Observation and experience suggest that ground floor rooms are considered too hot for occupation in the afternoon in Yazd. The majority of the population of Yazd appears to retreat into deep basements between about 12 noon and 5.30pm. Up to 15 - 20 people of an extended family may commonly be present to eat lunch and enjoy the afternoon siesta in one basement room. During this time public offices close for the day, and the bazaar is closed until the evening opening between 7pm until 10pm.

10.5.4.1 <u>Basement temperatures</u>.

Recorded temperatures in the basements during the afternoon range from 24-32 dc with relative humidities of 30-60% (see 9.8). This represents a wide range of climates, which in warmer ventilated basements fall within the Corrected Effective Temperature comfort range but in basements without badgirs are considered close to being too cold for occupation (9.9.1).

10.5.4.2 Ventilation of basements.

Van Straaten (1967, p.228) lists the uses of ventilation to include not only thermal comfort by removal of heat, body cooling and structural cooling, but also for health, for oxygen, prevention of high levels of bacteria, removal of hazardous gases, vapours and dust, and removal of body and other odours. Recommended levels of air changes per hour vary considerably. Lippsmeier claims 5 - 8 air changes per hour for living rooms and bedrooms and 10-12 air changes per hour for bathrooms are necessary (Lippsmeier, 1980,p.169). British Standards claim 2 air changes per hour are sufficient for bathrooms (British Standards, 1950 C.P.13, ch.1(c)).

> Although they are prepared for U.K. conditions they are applicable to those warm climates where buildings are shut up during the day such as in Iraq, Egypt and other hot, dry regions but where fresh air must still be provided to occupied rooms. (Oakley, 1961, p.120)

Discrepancies between recommended standards mentioned above emphasise the need for more work to be done to establish acceptable standards for ventilation for use by the indigenous population of Middle East, as well as for its visitors.

However it appeared that basements without badgir had lower levels of air changes per hour than those with badgir

(9.8.5) and thus are less good in terms of ventilation, particularly when occupied by numbers of people during the afternoon.

10.5.4.3 Moisture content of basement air.

Basements with badgirs do not feel dank and humid to occupants as do those without badgirs in which, by 5pm - 5.30pm, one begins to shiver and feel the moisture in the air. This reflects measurable physical conditions. In the Mashrouteh basement at this time the relative humidity was as high as 62%. High humidity also has an adverse effect on the health of occupants of the basement, and complaints such as rheumatism and chest ailments may be linked to such high humidities (Yodfat, 1979).

10.5.4.4 Reduction in climatic stress

By moderating the basement climate to make it warmer and less humid, in addition to making it more acceptable in itself, the impact of moving from its environment to up tp the courtyard is reduced. This may well increase the comfort' of those using the house.

10.5.5 Evening

Ground floor summer rooms are not used in early evening when a courtyard location is preferred.

After the afternoon siesta the occupants of the typical Yazdi house emerge into the courtyard. The men of the family many may have shops in the bazaar to which they return for the evening business, from 6 pm onwards, after a cup of tea.

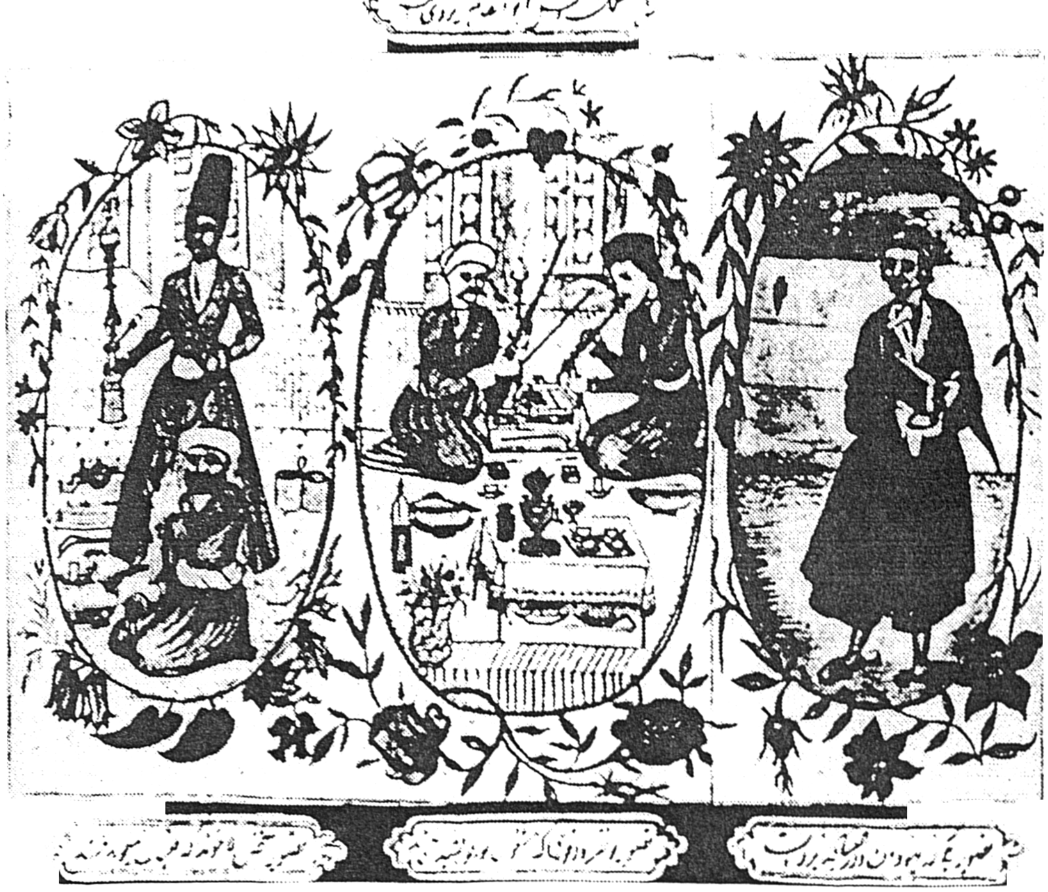


Figure 10.5. Scenes in Yazdi life' (Napier, 1905).
The centre of these three pictures represents two men smoking opium. Behind them is a qalian, or hookah, for tobacco; in front is a sherbet bowl, and also a small tea-table with sweets underneath.'

The picture on the left represents two men; one holding a rosary, and the other a hookah.'

The single figure on the right is a Jew, with his book for divining. The Persians use the jews as diviners a good deal.'

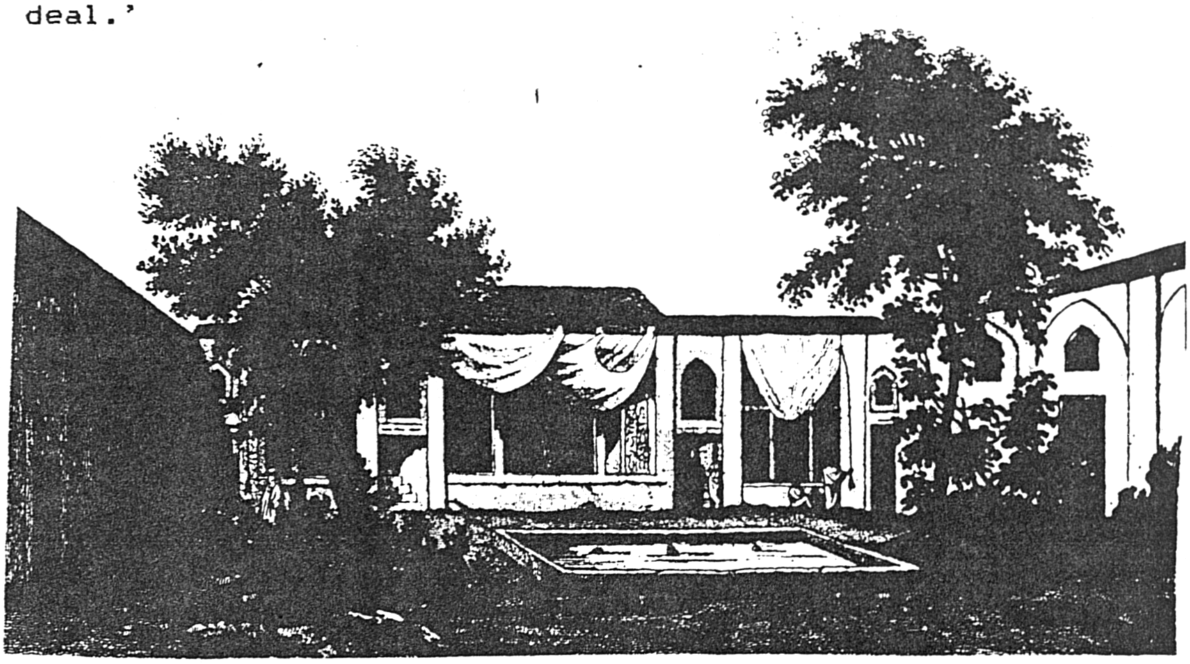


Figure 10.6. House in Tehran with talar above which are suspended the canvas awnings that were lowered during the heat of the day. Note that this house appears to have no basement rooms below the summer quarters (Dubeux, 1841).

Business in the market only gets going after about 6 pm and continues to 9-10 pm in the long summer evenings.

For those who work in government offices, which close at 2pm, and for the house-bound members of family, the evening's activities begin as they establish themselves in the next living area on the path of their diurnal migration.

In many houses carpets are placed in the front of the talar or on an open aivan, where maximum advantage of the evening breezes can be taken, and where the watering of the courtyard floor will have the greatest impact on the climate of those seated. Here the movement of the family to the front of the talar served by a badgir, rather than the centre or back of it which may be used in the mornings, should be noted (figure 10.5 and 10.6). Not only do the Yazdis migrate around the house but also around individual rooms as well.

Traditionally canvass awnings were lowered down over the courtyard side of the talar to lower the heat gain during the afternoon from solar radiation received from the court, thus making them cooler when the canvass was raised in the early evening (figure 10. 6).

The remarkable fact is that people emerge from the basement, from temperatures of 25c-26c in house F for instance, to sit in a courtyard where the temperature may be as high as 38c.

It feels, as one walks out into the courtyard from the basement, as if the heat slaps one in the face, and stings the skin for some time afterwards, until one has adjusted to the courtyard climate.

Expectations of discomfort at this time reduce or modify the feeling of discomfort. An important factor in this period of discomfort is that it is short in duration and is a part of the regular daily routine, a known quantity and part of a safe pattern of climate. A characteristic of heat stress is that the individual does not know that he is suffering from it (Gamberale et al., 1977, p.323) and no doubt this may prove a problem for an unacclimatised foreigner in the area who does not have the tried and tested safety net of routine. The courtyard of house F is indeed considered hot' at this time, and to make it comfortably warm', every evening as the family emerged from the basement the courtyard floor was heavily watered, so reducing the temperature on the aivan where the family sat in the evening by 1c - 2c. This reduction may take the temperature from 38.5c to 37.5c-36.5c. which is perfectly comfortable to sit in, even for an acclimatised foreigner such as the author, who lived in this house.

At this time of day the air temperature on the roof was in the region of 40c. The air flowing through the summer rooms served by badgirs had increased the temperature of the walls, floors and ceilings of these rooms to above 35c (see appendix H.2) and air flowing through the rooms from the badgirs is probably at a similar temperature.

Any enclosed space subjects the occupant to a re-radiated heat from the walls, which together with the high air temperatures of the late afternoon and evening combine in house F to keep the internal temperature of the summer room above 36c until after 8pm.

An evening sitting area in, or near, the courtyard is chosen by the occupants due to the rapid loss of radiant heat to the sky that occurs in late afternoon (figure 9.2), courtyard A) and to the presence of a stiff breeze externally in the early evening. At 10.30pm at house E a dry-bulb temperature and a globe temperature of 33.2c was recorded with a good south west prevailing wind of 1-1.2m/sec, which would provide an air velocity of at least 0.5m/sec issuing from the badgir. Thus it would seem that later in the evening the climate in the vicinity of the badgir is comfortable.

One further factor that should be taken into account when considering why people move up from a well-ventilated basement to a hotter courtyard is that traditionally these houses were lit with candles and oil lamps. Basements or deep aivans become very dark in early evening, while the courtyard is light until around 10pm. Thus the desire for good lighting may have tempted people out into the open, choosing a slightly warmer well-lit environment to the cooler dark one of a well-ventilated basement with badgir.

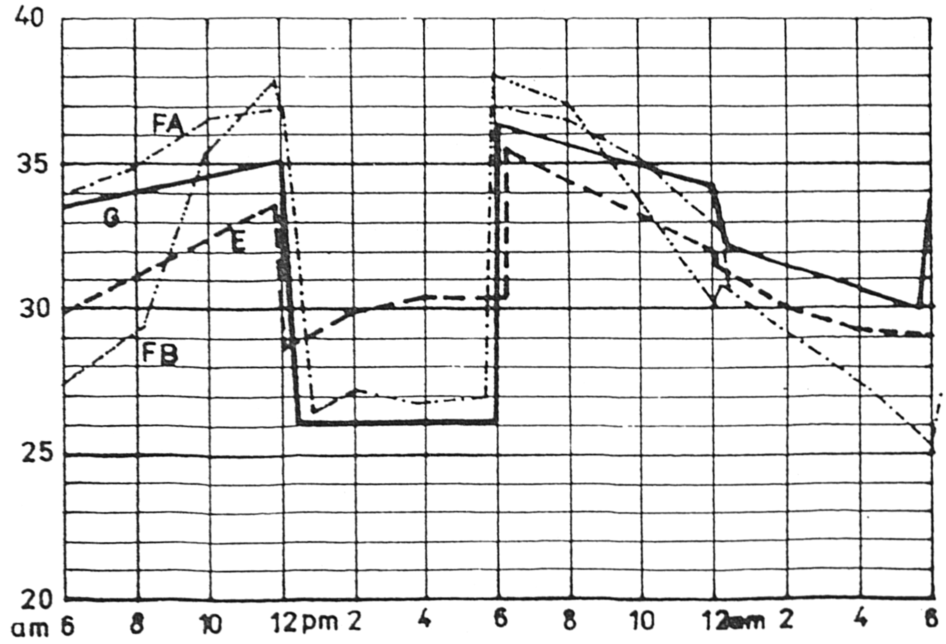


Figure 10.7. Graph showing the air temperature of occupied spaces over 24 hours in house E with badgir, and houses F and G without badgirs. FA) in house F using the courtyard, basement and roof FB) house F using the summer room, basement and roof G) house G using the summer room, basement and roof and E) using the large aivan, basement and roof.

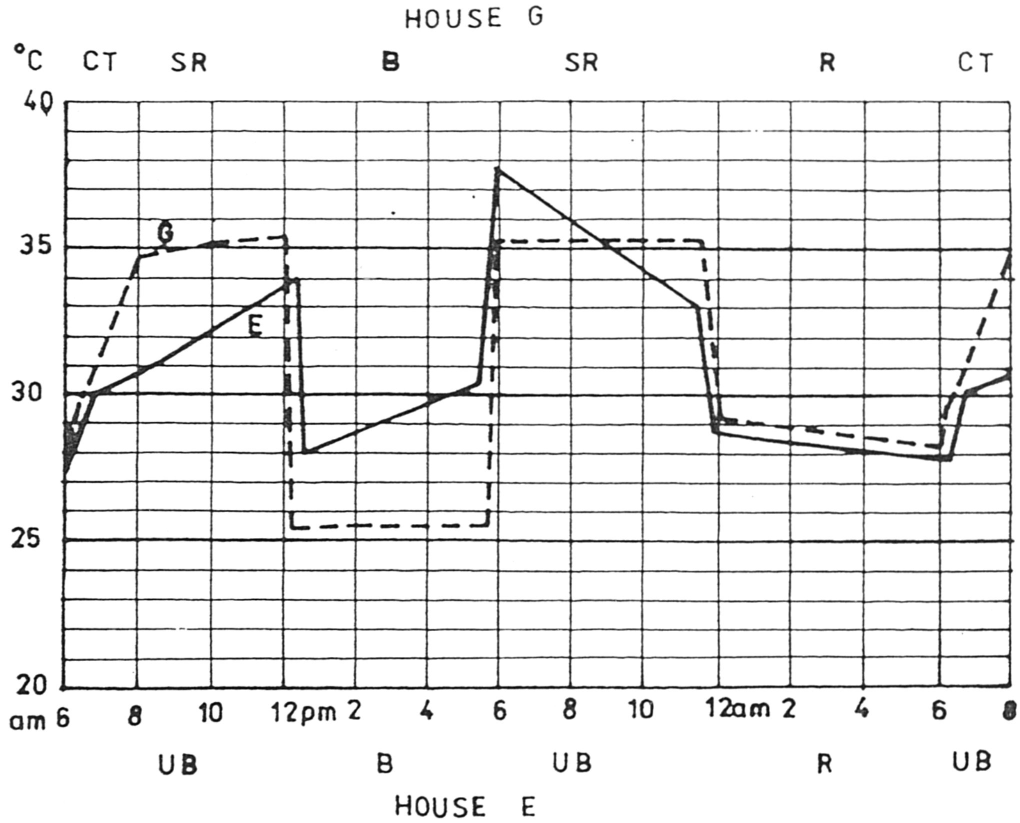


Figure 10.8. Graph showing the globe temperatures in occupied spaces in house E with badgir, and house G without badgir. CT) courtyard SR) summer room R) roof B)basement UB) ground floor under badgir.

10.6 CONCLUSIONS

10.6.1 The necessity for migration

The climate of Yazd in summer is extremely hot with diurnal ranges of up to 16c recorded. Comfort in the house, without the aid of mechanical cooling, is only possible to achieve, in summer, by moving around the house to take advantage of the most suitable of the diverse climates in the house at any particular time of day.

In Yazd this involves the use of the roof at night, the use of the ground floor in morning and evening and the use of the basement during the hottest time of the day, between noon and 6pm when maximum levels of direct solar radiation co-incide with the highest ambient external temperatures.

10.6.2 Air temperatures of occupied spaces.

Figure 10.7 shows the dry-bulb temperatures of the spaces occupied along the diurnal migration path. It emphasises the modifying effect of the badgir on the internal climate of the house; the result of the heating of the basement and cooling of the ground floor room reduces by over a half the temperature difference experienced by occupants moving between ground floor rooms and the basement.

10.6.3 Globe temperatures of occupied spaces.

Figure 10.8 compares the globe temperatures of occupied spaces in houses with and without badgirs and emphasises the considerable effect of the badgir in lowering the ground floor temperature in the morning and late evening when occupied, and in raising the basement globe temperatures in the afternoon when occupied.

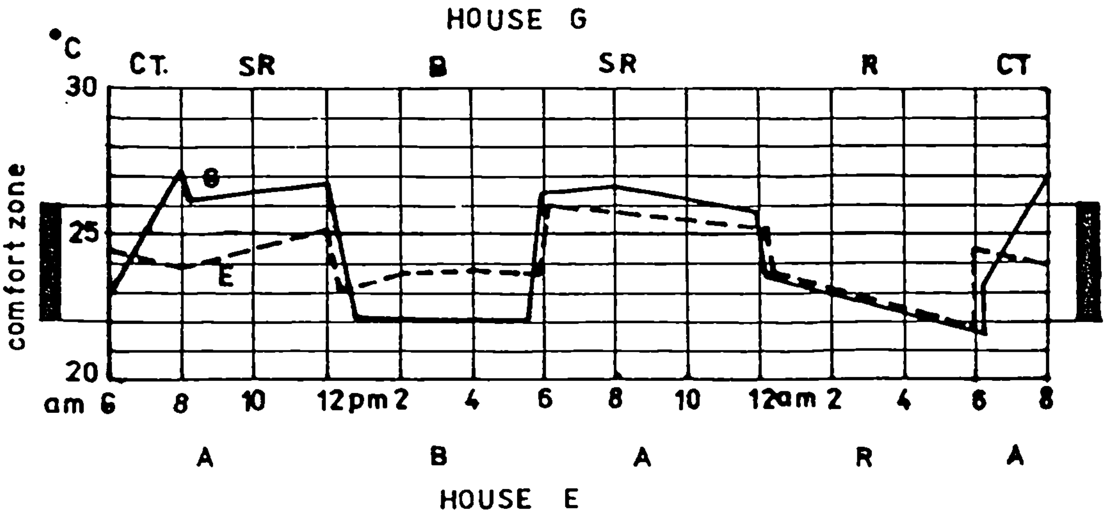


Figure 10.9. Graph showing the Corrected Effective Temperatures of occupied spaces in house E with badgir, and in house G without badgir. CT) courtyard B) basement R) roof A) aivan.

10.6.4 Corrected Effective Temperatures of occupied spaces. Figure 10.9 shows the Corrected Effective Temperatures for the climates of the occupied spaces only. It should be repeated that given the differences in house forms, sizes and their climate on days measured, no firm statement about the complete effect of the badgir can be made on this data. However it appears that the function of the badgir in terms of its impact on the climate of occupied spaces is to reduce the maximum, and increase the minimum C.E.T. experienced in these spaces.

This modification of the climates brings them quite noticeably towards the centre of the Corrected Effective Temperature limits of comfort. In contrast the Corrected Effective Temperatures of the houses without badgirs the limits of comfort, being too cold during the day in the basement and too hot during the morning and evening on the ground floor (see 11.1).

The roof readings show that thick eiderdowns are necessary for sleepers where the Corrected Effective Temperatures in the early morning falls below the comfort zone.

CHAPTER 11

COMFORT, PHYSIOLOGY AND THE BADGIR

11.1 INTRODUCTION

Having established a general range of climates in spaces in the Yazdi house and outlined the perceived functions of the badgir in Yazd (chapter 9); and investigated the climate of occupied spaces around the house (chapter 10); two questions that require further examination arise. These concern firstly the nature of the upper and lower temperature limits that exist for the successful use of the badgir in Yazd; and secondly the role of air movement in the modification of the internal climate of the house in relation to the temperatures experienced in it.

Further examination of these questions may lead to the elucidation of levels of temperature and windspeed found acceptable in the Yazd region, and inherant to its use of badgirs. Further they may provide guide lines for temperature and windspeed limits that indicate whether badgirs as used in Yazd may be suitable to other regions of the Middle East.

In an attempt to interpret the climatic thresholds around which the badgirs in Yazd are designed, this chapter investigates the findings of chapter 9 and 10 in relation firstly to Western research on comfort standards used in architecture with reference to the importance of air movement in comfort, and secondly to the physiological response of the body to high and low temperatures. In the third part of the chapter the findings of the first two parts are channelled into formulating tentative climatic thresholds against which the successful use of the badgir may be judged, both in the city and region of Yazd and in the wider area of the Middle East.

11.2 COMFORT

Having successfully used the index of Corrected Effective Temperature to demonstrate how the badgir modifies the climate in houses and brings it generally to within comfort limits prescribed by the Corrected Effective Temperature standard (see 10.6.4 and 9.9.1), further investigation of the concept of comfort' in relation to the climates recorded may help in establishing the climatic limits of performance of the badgirs in Yazd.

Many studies by Western academics have attempted to define comfortable indoor climates. Published results of laboratory studies have included numerous variables to explain the wide range in comfortable' climates chosen by different individuals taking part in such studies:

Factors outside the scope of this study

Age (Humpheries,1976,p.177; Fanger 73,p.134)
Sex (Fanger,1973,p.137)
Height (Edholm,1978,p.20)
Size/shape (Folinsbee, 1978,p.523)
Fitness (Adolph, 1947,p.31)
Circadian rythm - diurnal variation in core heat of body (Fanger, 1973,p.137; Edholm, 1978,p.7)
Individual variability of basal metabolism (Auliciems, 1969, p562; Wyndham, 1976,p.192)
Personality (Auliciems, 1975,p.pp.43-97)
Emotional stimuli (Ingram et al.,1975,p.58)
Adaptation (Fanger,1973,p.134)
Ethnicity (Auliciems,1984,p.32;Edholm,1978,p.19;Wyndham, 1976,p.192; Woolard,1981,p.94 - Figure14.1)

Acclimatization (Edholm, 1985,p.147; Fox, 198x,p.67-76; Ingram and Mount,1975,p.147))
Preconceived expectations of comfort (Auliciems,1984,p.31)

Factors pertinent to, and covered by this study

Time of day & Time of year (Auliciems,1981,p.117 & 1984,p32)
External weather conditions (Auliciems 69p.563; Baranowska and Gabryl, 1981, pp123-)
Clothing (Humphreys,1973,pp.192-202 & 1976,p177; Ingram and Mount, 1975,pp.150-162)
States of Nutrition (Auliciems, 1969,p.562)

The range and importance of the variables at play in the determination of comfort' have led Auliciems to state

> The expression thermal comfort in particular has become hackneyed to such an extent that it can no longer be used to identify specific levels of signal integration. Perhaps it should be retained only as a general functional term to describe all perameters and processes, being on a par with thermal perception.(1981p. 119)

The above statement is borne out by the climatic results of the last two chapters. Despite the depth of, and the wide range of variables, explored by existing publications on comfort the figures produced by them (except for the general Corrected Effective Temperature standards) bear little relation to the high temperatures occupied and enjoyed in the traditional houses of Yazd.

11.2.1 Studies of comfort in hot dry climates

Nicol in his publication of Humphreys' study of comfort in Iraq and India wrote:

> In their survey of office workers in England, Humphreys and Nicol (1970) found a mean air velocity of about 0.15 m/sec. Fanger's (1970) prediction shows a comfort optimum of 26.5 dc.( )fig x) at this air velocity, assuming a metabolic rate of 58 W/m 2(50 kcal/m2h) and a clothing insulation of 0.5 clo (approximately that for Indian and Iraqi subjects). For

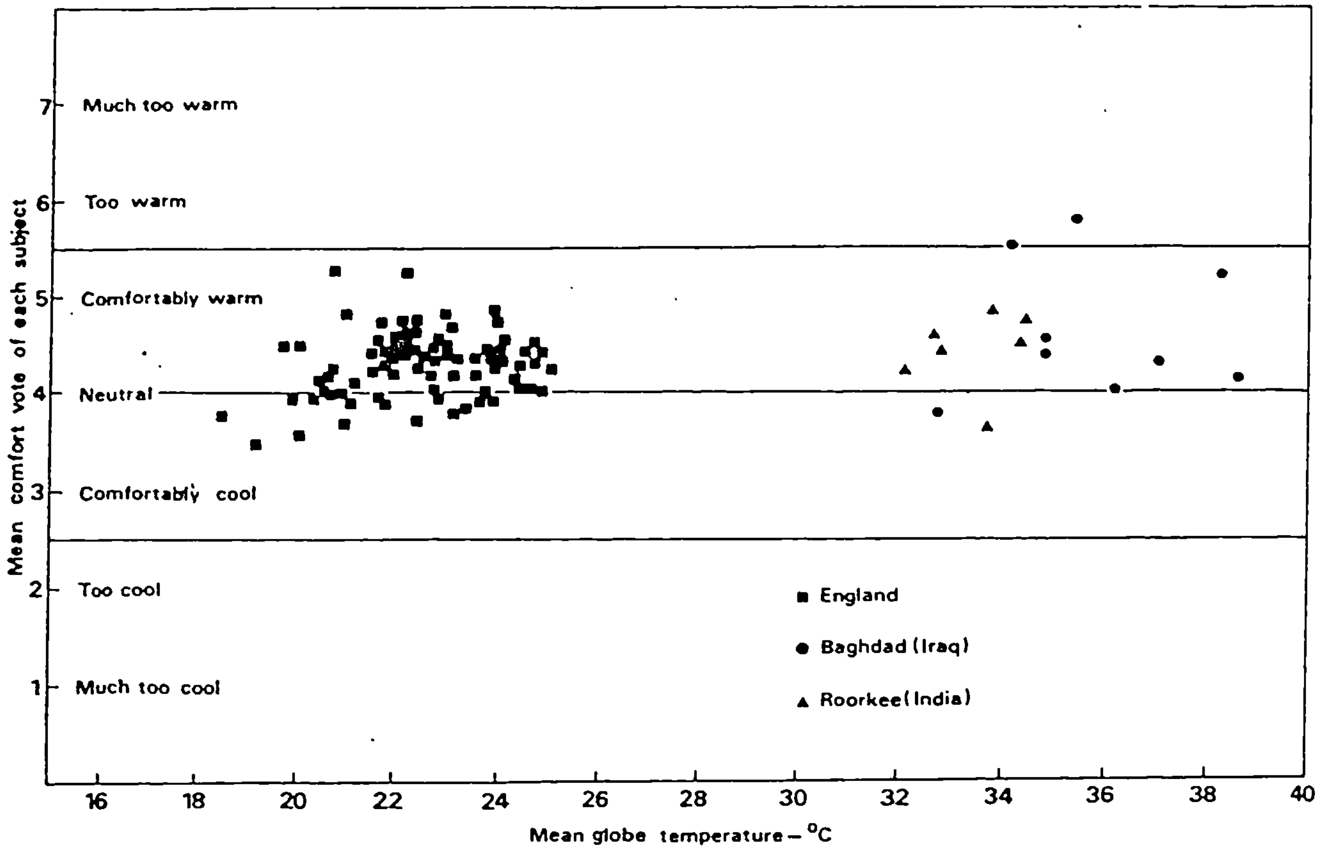
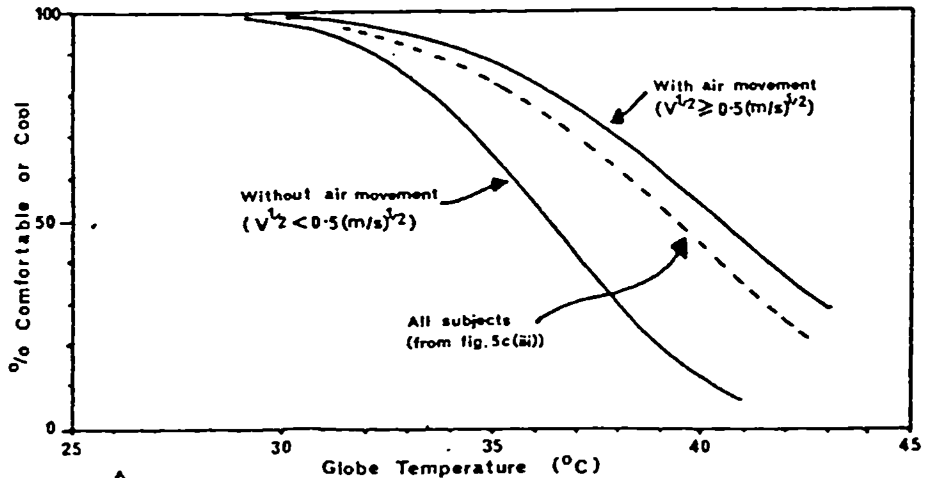
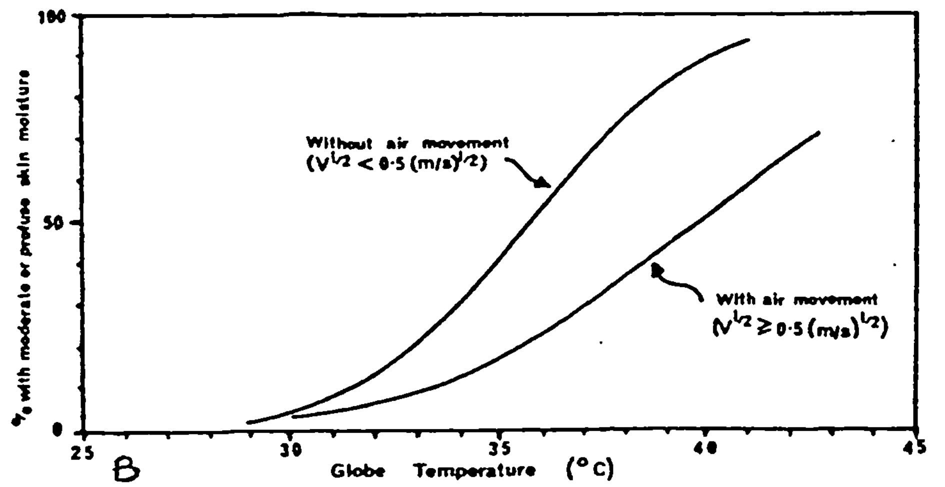


Figure 11.1. Graph by Nicol showing the mean comfort vote of individuals against the mean globe temperature in England, Iraq and India. This emphasises the discrepancies between Western and Eastern limits of comfort (Nicol, 1975, p.7).



Probability of being comfortable or cool against temperature: the effect of air movement.



Probability of moderate or profuse skin moisture against temperature: the effect of air movement.

Figure 11.2. Two graphs from Nicol, 1975, p.7. showing, for Baghdad and Roorkee, the relationship between temperature, comfort, skin moisture and air movement.

the higher mean air velocity (1.0 m/s) of the present results, Fanger predicts an optimum of 28.4 dc. Fanger's method further predicts that 70 % of the population would be uncomfortable at 32 dc. Other theoretical models (Humpheries, 1970; McIntyre, 1973) would also estimate an optimum temperature in the region of 28 dc. These results show that acclimatized subjects can be comfortable at temperatures considered unacceptable in models developed for temperate regions. (Nicol, 1975, p.10)

Many other authors have tried to define comfortable conditions in warm climates.

Lippsmeier (1980, p.58) claimed:

> The result of many such experiments (no references given) is that the temperature range for comfort in the vicinity of the equator lies mainly between 22.5 and 29.5c at relative humidities of 20% - 50%.

Van Straaten in his work in South Africa (1964, p.156) found that:

> The upper thresholds of definite discomfort are taken to be 31c for warm arid conditions. The upper threshold of the comfort range in summer conditions is taken to be 27.8c for warm arid conditions ... with likely optimum values for summer comfort of 26.1c.

Nicol, in publishing Humphreys data from Baghdad (Iraq) and Rookgee (India), provided rare and important data for comparison in this study. This paper concluded by proffering a suggested mean comfort temperature of 32c. Nicol correlated the Baghdad findings with a number of comfort and stress indices (Fig11.1) and found that:

> In the conditions of the present study, none of the indices tested appeared to be significantly better than globe or air temperature in accounting for thermal sensation. Nor did the mean thermal sensation of an individual over a period of time seem to depend very much on the mean temperature over that same period (Nicol, 1975, p.10)

Woolard found in the South Pacific (1981,p.97) that:

> The air temperature is a reasonable thermal index by which the thermal neutrality of the Solomon Islanders, engaging in light activity indoors, may be measured.

The large differences between the temperatures included in this study and those prescribed by Fanger, Van Straaten and Lippsmeier above, suggest that criteria different from a Western idea of comfort', should be sought in order to understand the climatic limits within which the badgir operates.

However first other factors will be investigated in this chapter. They include air movement, its effect on the temperatures in the building and its psychological and physiological impact on the occupants of the Yazdi houses, and the physiological limits of the body's response mechanisms to high temperature.

11.2.2 The effect of air movement on comfort

In Yazd the wind speeds of air issuing from the shaft of badgirs varied from a recorded maximum of 7m/sec beneath the badgir at the octagonal pavilion of the Bagh-e Dowlatabad to less than 0.1m/sec in basements of house G and House F.

A common range of wind speed readings in the area beneath the badgir ground floor areas was 0.3 to 1.5 m/sec. Over the grill to the basements from the ground floor, recordings of downward moving air were typically in the region of 0.3 - 1 m/sec.

The effect of air movement on thermal comfort has been reported by a number of workers. Dunham et. al (1946) and

MacPherson (1960) in extensive climatic experiments found that environments with air movements less than 0.25 m/s were whole heartedly disliked by lightly clad subjects. (Nicol,1975,p10)

In hot climates air movement over the skin increases feelings of comfort. Humphreys' studies in Baghdad, in which temperatures comparable to those in Yazd were recorded, demonstrate this effectively. In these studies it was shown that:

> Air movement reduced discomfort from heat at temperatures above 31 dc; below this temperature there were few votes indicating heat discomfort. At temperatures above 40 dc discomfort from heat was experienced whatever the air velocity.(Nicol, 1975,p.6)

Figure 11.2 shows two charts from Nicols' article in which the close correlation between the decrease in the percent of people showing moderate or profuse skin moisture and the probability of feeling comfortable or cool; both of these are plotted against increasing temperature and indicate that by reducing the amount of moisture on the skin, at temperatures above 31c, and particularly over 37c when heat loss from the body is dependent on evaporative cooling, a person is likely to feel more comfortable. An effective reduction of skin moisture is achieved in air movement of 0.5m/sec. It follows that air movement enhances comfort in temperatures between 31c and 40c.

0.5m/sec is a wind speed that would commonly be reached or surpassed in the ground floor in the vicinity of an effective badgir.

The Nicol study found that:

> The English workers are comfortable or comfortably warm at globe temperatures of 20-25c; the results presented above show that provided that the air movement exceeded 0.25 m/sec, sedentary acclimatised subjects had little discomfort from warmth at temperatures below 32c and that thermal discomfort did not exceed 20% until the temperature rose above 36c, and 50% until the globe temperature rose above 40c. These differences are large; they may be attributed to acclimatization and to habituation, to differences in clothing and probably to behavioral effects (Nicol, 1975, p.10).

Figure 11.1 (Nicol, 1975, p.7) shows that the acclimatised inhabitants of Baghdad and Roorkee were comfortable in temperatures of over 38c.

> Man has a remarkable ability to control the micro-environment surrounding the body. Edholm in studies in the Negev found that in dry bulb temperatures of 35-38c and wet bulb temperatures between 27-30c in average wind speeds of 1 meter per second men would work for profit from 6am to 6pm. He observed that the men would work for 3 minutes and then pause for 30 seconds and do 3 more minutes work and so on. When measured it was found that their body temperature did not rise and their heart rate did not exceed 100 beats per minute. (Clark and Edholm, 1985, pp.188-189)

The high air temperatures (from 35c to 38c) common in occupied spaces in the Yazdi houses are approaching the physiological limits of the body's thermo-regulatory processes, as were those in the Negev. A further investigation of the body's ability to respond to high temperatures may give some insight into the limits of operation of the badgir, where comfort studies have failed to provide such significant insights.

11.3 PHYSIOLOGICAL RESPONSES OF THE BODY TO HIGH TEMPERATURES

The processes in the body that enable heat loss to occur at high temperatures include convection, radiation, conduction and evaporation. These processes are discussed below.

11.3.1 Convection

Convection, as a means of loss of body heat depends on the difference between the skin and air temperature, and the rate of air movement. As well as being effective in enabling heat loss from the body, it prevents heat gain to the body, acting differently with different windspeeds at different temperature ranges, due to the nature of the metabolic processes involved in heat transfer through convection.

11.3.2 Temperature limits for convection

A) Bottom temperature limit for convective heat loss (28c)

At the lower end of the temperature scale man's metabolic rate increases below 28c (Edholm, 1985,p.134) and at temperatures below 27c the body needs to produce heat to maintain the the heat balance (Edholm, 1978,p.26). A critical temperature of 28c has been proposed for vaso-dilation by Ingram and Mount (1975, p.151).

B) Moderate convective heat loss (28c - 34c) (Edholm, 1985, p.135).

C) Maximum efficiency for convective heat loss (33c - 37c)

The core temperature of the body is 37c - 37.5c. In normal conditions there is a moderately steep temperature gradient between the skin at 33c-34c. and a core temperature of 37c reached at a depth of about 2 cms (Edholm, 1978,p.6).

When the ambient air temperature reaches skin temperature the process of increased vaso-dilation occurs, with the thick muscular wall of the arterioles relaxing to alter the diameter of the tube. In this fashion heat loss by convection and radiation, on which depends the surface temperature of the skin, can be varied over a wide range of rates from nil to five to sixfold.

This increase in efficiency occurs with vaso-dilation, which comes into effect in temperatures between 33c - 37c when maximum flow is reached.

D) Upper limit of convective heat loss (37c). Beyond this temperature the body gains heat through convection.

11.3.3 Suitable windspeeds for effective convective heat loss for the different temperature ranges

A) At temperatures below 28c: minimal air speeds are adequate to Conservation of body heat becomes increasingly important with lower temperatures, therefore heat loss through convection should be minimised below an air temperature of 28c.

B) Low windspeeds. At the lower end of air movement, in air velocities not higher than 0.09m/sec - 0.1m/sec, convection is virtually independent of air velocity in the surroundings and is practically solely dependent on the air movement produced by the temperature difference between the body and the air (Nielsen & Pedersen, 1952, p.293).

C) <u>High wind speeds</u>. In high winds, above 4 m/sec to 5m/sec, little additional change in the efficiency of the process occurs at higher windspeeds. (Stanier, Mount & Bligh, 1984,p.29)

Givoni found that at air speeds with a velocity greater than 1.5m/sec caused annoyance to subjects (Givoni, 1976, p.312).

D) <u>Windspeeds for effective convection.</u> Temperatures for efficient convection are between 33c - 37c in windspeeds of about 0.5 - 3m to 4m/sec (Edholm, 1978, p.55).

Edholm recommended that in terms of physiology, the most effective wind speed in hot dry and hot humid climates is 0.5 m/sec (Edholm, 1978,p.4). Although he suggests that this speed is best produced by slowly revolving fans with long blades, it is also similar to the mean of the range of windspeeds issuing from the badgirs of Yazd, at ground floor level.

E) <u>Windspeeds for high temperatures.</u> Above 37c, that is when air temperature is greater than body temperature, a moderate amount of air movement, up to 0.5 m/sec, increases thermal comfort by increasing evaporation of sweat, but at high air speeds the body will start to gain heat from hot moving air by convection, which will more than balance the increased heat loss.

11.3.4 Optimal windspeeds and temperatures for convective heat loss from the body

The following general ranges of optimal windspeeds and temperatures for convective heat loss from the body may be suggested:

temperature		optimal wind speed
Below 28c	-	less than 0.2m/sec
28c - 33c	-	0.5m/sec
33c - 37c	-	0.5m/sec - 3m/sec
above 37c	-	less than 0.5m/sec

11.3.5 Convection and badgirs

It is remarkable how closely the climatic readings taken in the badgir houses of Yazd mirror these requirements for convective heat loss from the body. In the morning, when temperatures are between 31c to 34c, the light morning winds provide typically 0.5m/sec - 1.0m/sec. In the hot afternoon and evening when temperatures of occupied spaces may be in the range of 33c - 37c, the higher afternoon and evening winds provide ground floor air speeds of about 1.0m/sec to 3.0m/sec. In the basements the design of the badgir inlets ensures adequate ventilation without excessive heat gain to basement air or occupants.

Three features of badgir performance relate its role in convective heat loss to the needs of the occupants of summer rooms. The badgir enables:

1) maintenance of ground floor Mean Radiant Temperatures, surface, and air temperatures between 33c - 37c.

2) maintenance of basement Mean Radiant Temperatures and air temperatures above 28c during the afternoon.

3) provision of air moving at between 0.5 - 3.0m/sec adjacent to the badgir in the ground floor rooms.

11.3.6 Radiation

As no direct solar radiation enters the summer rooms via the badgir, the importance of radiation in the performance of the badgir is indirect, being dependent on the altering of surface temperatures by convection.

The Mean Radiant Temperatures of the various surfaces around the human body determine the extremes of the net heat loss or gain from the body.

Thermal radiation is not affected directly by air movement, and is influenced by air temperature only to the extent that this air movement influences the surrounding surface temperatures through convection.

Here the importance of the efficient cross draught from the badgir becomes apparent for it is this which reduces or increases the Mean Radiant Temperature of the surfaces of the room during the day and night. This causes the surfaces of the ground floor rooms to have a lower Mean Radiant Temperature than the equivalent rooms without badgir, as the following chart shows. Only from 4pm to about 8pm are the surfaces of the badgir rooms warmer than the rooms without badgir.

The temperature of the walls of the basements with badgir are consistently higher than those without, remaining above 28c for about 20 hours a day, including that period at which it is occupied.

11.3.7 Evaporation

This process involves the evaporation of water from the surface, passing through the skin in insensible perspiration', from sweat glands in the skin.

Evaporation plays a vital role in regulating the body temperature in desert conditions. The amount of sweat produced is physiologically regulated and very large amounts can be produced for short periods. 1 1/2 litres per hour water loss from the body through evaporation is common in desert conditions and a body may lose up to 10 - 15 litres in a day (Ingram and Mount, 1975,p.60). However clothing modifies water loss levels (see 10.4). The quantity of sweat needed to be evaporated per hour for a constant body temperature to be maintained by a man under desert conditions at 40c amounts to 1.5% of his body weight (Ingram and Mount, 1975, p.148).

11.3.7.1 Temperature limits for evaporative cooling of the body

Evaporation is effective in cooling the body at temperatures above 31c and vital in temperatures above 37c.

Above 37c, convection and radiation cause the body to gain heat, and evaporation alone causes the body to lose heat by decreasing the skin temperature heat gain to the body. If evaporation cannot reduce skin temperature sufficiently a resulting rise in core temperature occurs, and eventually collapse and heat stroke will result.

11.3.7.2 Air movement and evaporative cooling

Figure 11.2 shows the effect of air movement on the probability of moderate or profuse skin moisture against temperature for a climate in Baghdad comparable to that in Yazd (after Nicol,1973). It emphasises that not only does increased windspeed reduce skin temperatures through evaporation, but it also enhances feelings of comfort by reducing skin moisture at temperatures between 31c - 40c range.

11.3.7.3 Peak times for evaporative cooling in the day

A) Ground floor rooms

At two times of the day evaporative cooling of the body is important for the comfort of the Yazdi in the ground floor rooms: in late morning, and during the evening when temperatures are within the 31c - 40c range.

On initial exposure to heat there is a variable delay of 5 - 40 minutes before sweating occurs, so when it does fast cooling is necessary (Ingram and Mount, 1975,p.58). This may explain why, when emerging from the basement into the courtyard in the early evening it is common practice to water the court to reduce thermal stress before either convective or evaporative cooling of the body is efficiently functioning.

B) Basements

In the basements of Yazd low temperatures during the heat of the day preclude the need for evaporative heat loss from the body; however in basements with badgirs increased air

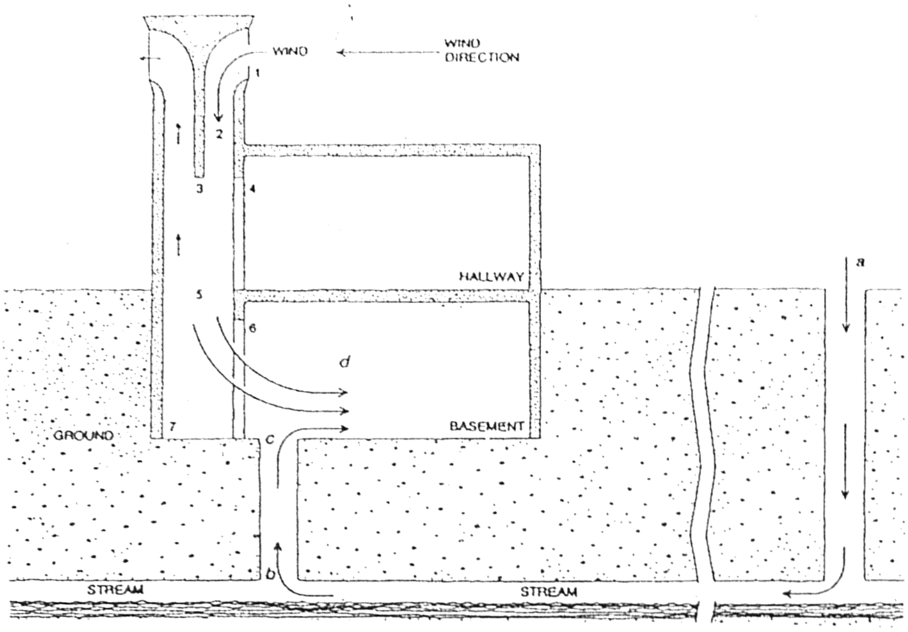


Figure 11.3. Bahadori's questionable section through a Yazdi house with badgir and basement tunnel to qanat (Bahadori, 1978, p.146). This diagram is probbly based on a verbal description given to Bahadori in 1976 of house A in Yazd (see 6.7.2). Note the lack of windows in the ground floor and basement rooms.

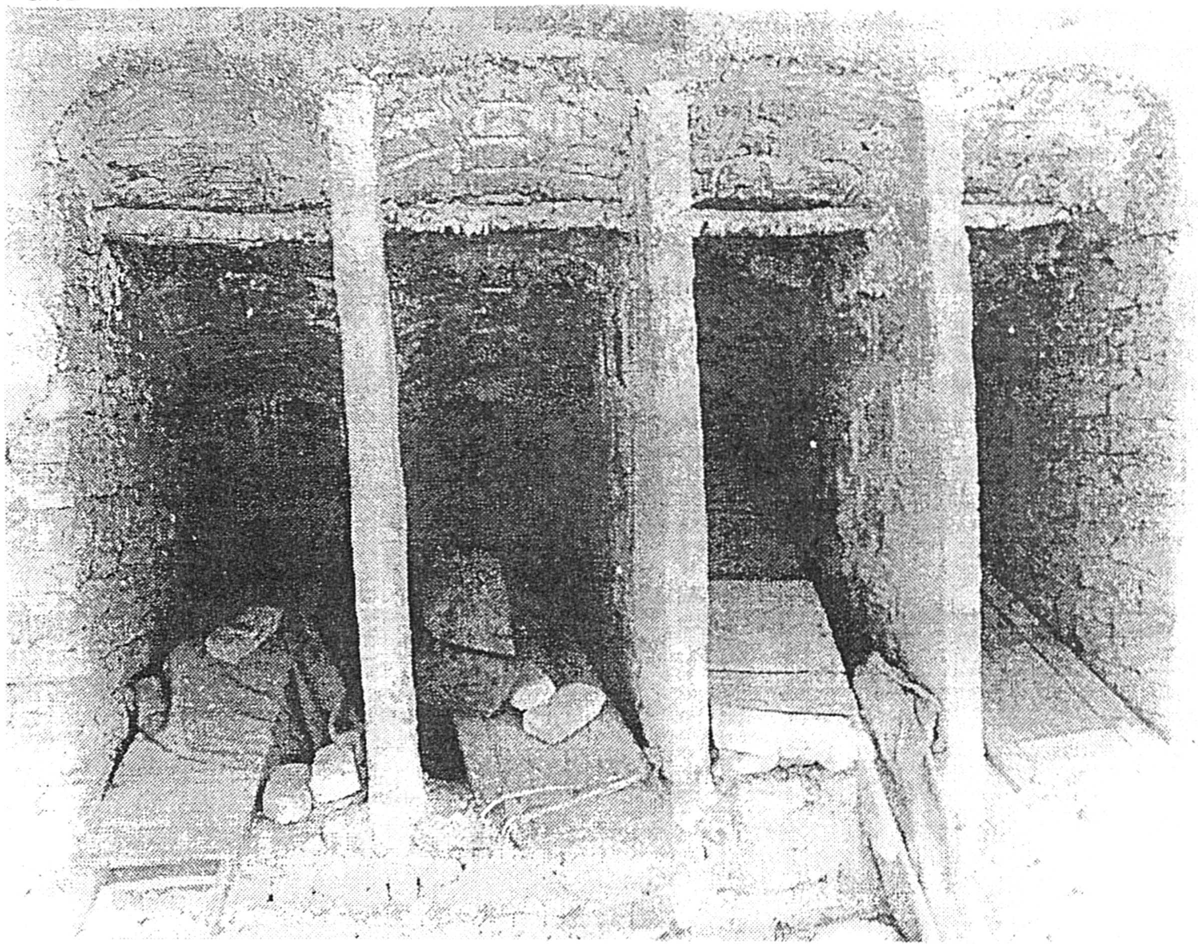


Figure 11.4. Vents of a badgir in Chupanan showing the vent openings closed off with boards, cloths, and stones.

movement is needed to stimulate convective and evaporative heat loss in the higher mid-afternoon air temperatures of up to 32c.

11.3.7.4 Evaporative cooling in hot humid climates

When skins are moist, whether from perspiration or otherwise, the cooling effect of moderate air velocities is greater and increases as the temperature rises (Webb, 1960, p.297). Sweating has been found to begin to play a major part in thermal relief at wet-bulb temperatures above 26.8c (Webb, 1960,p.301).

However very high humidities reduce heat loss by evaporation (Edholm, 1978, p.22). In hot humid climates, such as those of the Gulf, high air speeds are required to remove moisture from the skin, unlike Yazd which has a hot dry climate.

11.3.7.5 Pools and pots in basements

The high humidity levels in the basements of Yazd and Baghdad (Fethy and Roaf, 1984, p.46) make the use of open pools (Bahadori, 1978, p.147) or suspended pots in the badgir shafts (see 1.7.1) appear unnecessary and unlikely. Neither have they been observed to be used in the basements of traditional houses in Yazd, Iran or Iraq by the author who has lived on and off in traditional houses of the two countries for 10 years (figure 11.3).

The influence of Fathy's malqaf in the School in Gourna (Oakley, 1961, p126-127; et.al. in 1.7.1) has no doubt stimulated the proliferation of published drawings of pots and pools. In Yazd, however, two houses have been described with tunnels linking the basement to underground water channels (see 8.7.2, and 10.5.1.3) - Bahadori, 1978, pp.147 and 149 copied these with some inaccuracies - figure 11.3).

In ground floor rooms in Yazd only one room, in the octagonal pavilion at the Bagh-e Dowlatabad, was seen with a pool which undoubtedly cooled the incoming air considerably.

11.3.8 Conduction

In Yazd heat conduction is of importance when people are reclining to sleep at night, after 10 pm, when the air temperature on the roof is below 32c and the family retires, and in the basement from 1 to 5pm during the siesta period. This represents 12 hours of the day when conduction provides useful cooling or warming.

In the West conduction is less effective as a source of heat loss from the body as furniture is usually raised from the floor; in Yazd people usually sit or recline on a material palette beneath them directly laid on the floor, to moderate the heat loss or gain to or from the floor.

The maintenance of surface temperatures at between 27c - 34c, the upper limit of skin temperature, has obvious advantages in minimising heat loss or gain to the body through conduction. This is achieved in the morning in the ground floor summer rooms.

11.4 CONCLUSIONS ON COMFORT AND THE PHYSIOLOGICAL IMPLICATIONS OF BADGIR PERFORMANCE IN YAZD

The findings below relate only to the climate as experienced and perceived by the indigenous Yazdi population, accustomed to living in the traditional houses of the region. They have little relationship to the climate as experienced by unacclimatized persons, either living in, or visiting the area.

A) The migration of the Yazdi around the house appears to be motivated by a desire to avoid unsuitable climates rather than a desire to occupy comfortable ones.

Comfort in the Western sense appears to play little part in the judgements about climate and lifestyle of the Yazdi.

Unsuitable' climates in the houses of Yazd correspond to limits imposed by the thermo-regulatory processes of the body - in this case, the body's ability to cope with high temperatures.

B) These physiological air and surface temperature limits in relation to optimal minimum and maximum air speeds may be suggested to fall into five groups:

1) Below 28c with less than 0.2m/sec

2) 27c - 31c with 0.1 - 0.5m/sec

3) 31c - 34c with around 0.5m/sec - 1.0m/sec

4) 34c - 37c with 0.5 - 3.0m/sec air movement.

5) 37c - 40c with 0.5m/sec

C) In modifying the internal climate of the summer rooms in Yazd the badgir appears to produce air speeds, and surface and air temperatures that are more effective in providing optimal conditions for physiological heat loss from the body during the day than than those which occur in the summer rooms of houses without badgirs.

D) The badgir houses appear to be operating at the very limits of suitable' climate. In areas with an average maximum monthly temperature of, for instance, 2c higher than that of Yazd, these physiological temperature thresholds would be exceeded.

In climates where average maximum monthly temperatures were 2c lower, the buffer effect of the badgir on the internal ground floor climate might be unnecessary to produce suitable temperatures in the room; however the function of the badgir as a ventilator may still useful.

11.5 IMPLICATIONS OF THE PHYSIOLOGICAL FINDINGS ON THE DISTRIBUTION OF RURAL BADGIRS IN THE YAZD AREA

As the indoor temperatures in Yazd are close to the limits of the physiological responses of the human body to high temperatures, a difference of 1c-2c in internal air temperature of houses may under certain conditions be critical.

The preference, in the villages of the Yazd region, for winds that have been conditioned by passage over hills or vegetation in the province of Yazd suggests that careful choice of orientation of village badgirs may bring temperatures below such critical temperature thresholds.

It is inevitable that in the exposed villages, where there are few basements, the internal house temperature rises above 37c, and in this case the only mechanism for heat loss from the body is evaporation. Controlled air flow through the summer room from the badgir provides some relief from discomfort through this mechanism.

It is noticeable that near the open vents of the village badgirs there are usually boards for the rapid closing off of the shaft; these are seldom obvious around the badgirs of Yazd city. In high winds and high temperatures, in village houses with only one living room, the vents must be closed rapidly to reduce the introduction of excessively hot air (figure 11.4).

Further work could be done on the afternoon temperatures in village houses at the height of summer to see to what extent they exceed the 37c temperature threshold, and to confirm that the notion of suitable winds includes those between 37c-40c in mid-afternoon. Such a study may tell us more about the human limits of the response to high temperatures and to traditional limits of habitation in hot climates.

11.6 PHYSIOLOGICAL IMPLICATIONS FOR BADGIR DISTRIBUTION IN IRAN AND THE MIDDLE EAST

11.6.1 Discussion of the implications in the Middle East

The physiological temperature limits provide a key for the assessment of the suitability of badgirs for the different regions of the Middle East, at various times of year.

In Yazd the mean maximum temperature in July is 39.5c (see 2.6). Given that the average temperature reduction down the badgir tower from external air temperature to internal air temperature of an average of 2c - 3c for the hottest times of day (see 9.6.1), the resulting internal Mean Radiant temperature and air temperature in ground floor badgir rooms in late afternoon is around 37c. This is near the maximum for a physiologically unstressful, indoor ground floor climate, with air speeds of 0.5 - 1.5 m/sec, such as those provided by the bagdir.

Kerman, with its higher location and far fewer towers, often ferocious north westerly winds (2.5), and mean maximum temperatures of 35.8c (see 2.6); this suggests that while cooling of the ground floor rooms may, in mid-afternoon, be necessary, the strength of the local winds may prove too strong for comfort if badgirs are added.

In Giza, just outside Cairo, mean maximum temperatures are 35.8 for July (see 2.6). This seems a very suitable temperature for the introduction of breezes through the ground floor summer rooms and explains why the larger windcatcher, the malqaf in this case; is suitable.

At Kashan, where the mean maximum temperature in July is 40.9c, then even a 3c reduction in the mean indoor temperature with cross ventilation from a badgir would produce a temperature of about 38c. This would provide a stressful indoor climate over several hours, where heat gain by convection and radiation in the ground floor rooms (and to their occupants), would be inevitable with wind speeds of up to 1.5 m/sec. Selective ventilation of rooms by closing badgirs off during the day and opening them up in the evening, night and morning would be a preferable strategy. However in the basements of Kashan, a limited amount of ventilation would be an advantage by creating a less cold and humid environment. This prediction of suitable use for the badgir in Kashan is significant in relation to the drawings by Tavassolli (1975,p.71) of a house in the Kashan area with an interesting badgir, serving only the basement {fig 11.5}.

As for Baghdad, again one can understand why badgirs in the ground floor rooms are not used; they would introduce air at about 40c-41c into ground floor rooms during the day. However the use of small badgirs in the basements provides ventilation for the numerous occupants of the extended family who traditionally spent the afternoon below ground (Fethy and Roaf,1986, p.49).

In the settlements of the Gulf region where temperatures are extremely high, as are relative humidities (see 2.6), the large badgir has been used since at least the 13th century (see 1.6). The harshness of the Gulf climate cannot be over-estimated; but even with the large badgir, and wall and parapet ventilators introducing air through the rooms at temperatures which must exceed 37c for much of the day, if air velocities can be maintained at around 0.5m/sec, excessive heat loss through convection can be avoided while the essential heat loss through evaporation can take place at an acceptable rate. In the Gulf region there is no

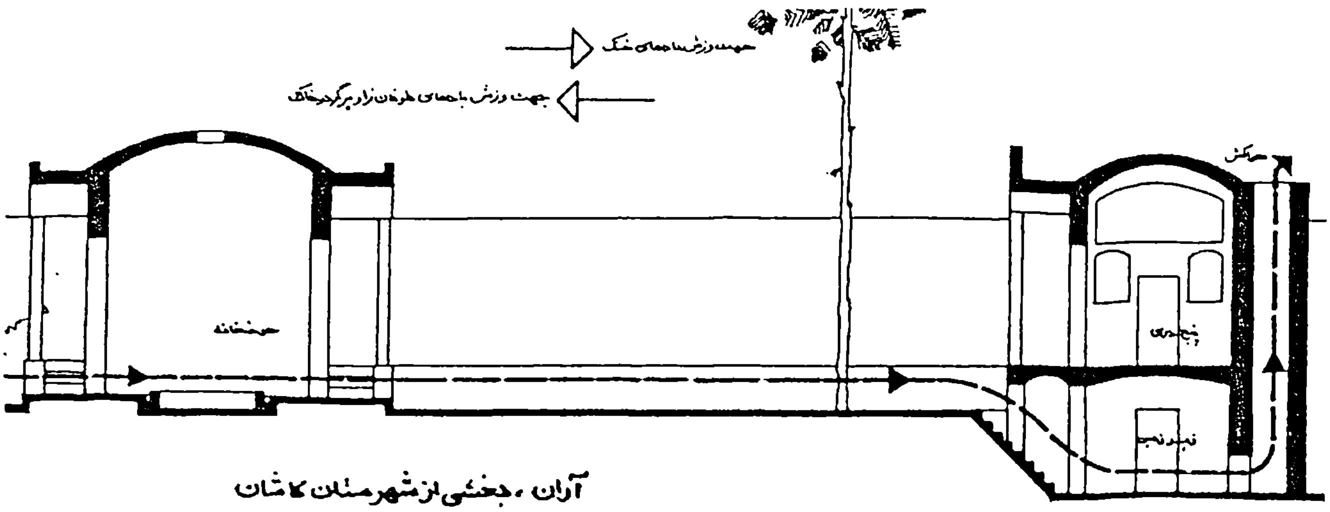


Figure 11.5. Section through a house in Kashan showing the unusual badgir serving the basement only (Tavassoli, 1975, p.71)

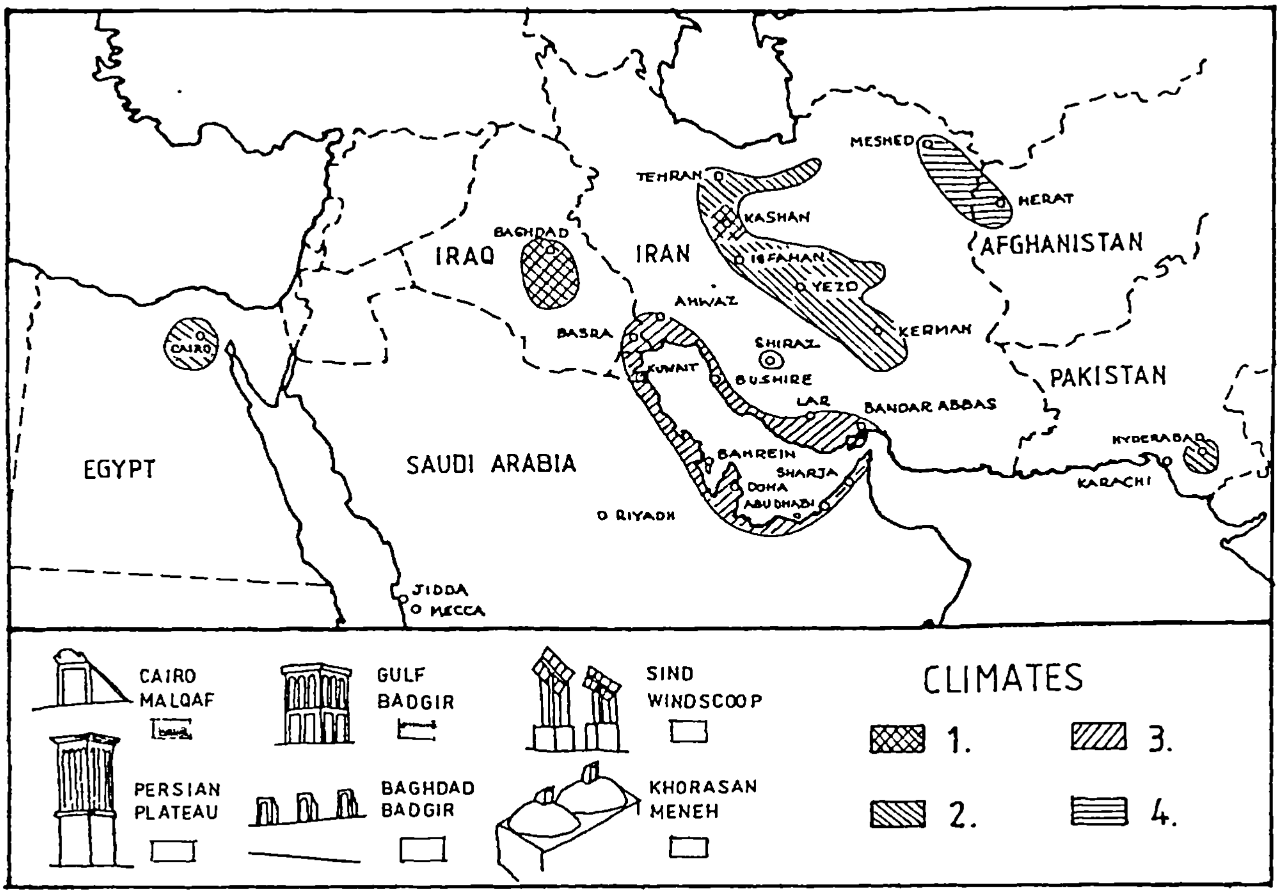


Figure 11.6. Map of the Middle East showing the relationship between the distribution of windcatcher types and of climate types (see 11.6.2).

passive design alternative for body cooling other than to stimulate air movement in dwellings, and the windcatcher is an effective mechanism for doing this.

Even if 1c or 2c tolerance is allowed each side of these figures, they do indicate that general temperature and windspeed thresholds for the successful use of windcatchers in the Middle East exist.

11.6.2 Suggested temperature thresholds for the use of the various windcatcher types in the Middle East

Very general climate thresholds for the use of various badgir types might be categorised speculatively as follows:

CLIMATE 1: VERY HOT; DRY

-Av.Max. daily July temp - above 40c.
mean R.H. - below 30%
-Badgirs mainly in basement

CLIMATE 2: HOT; DRY
-Av.max. daily July temp - between 40c - 35c
mean R.H. - below 30%.
-Large badgirs to ground floor and badgirs in basement

CLIMATE 3: HOT; HUMID
-Av.max.daily July temp - above 33c.skin temp.
mean R.H. - above 30%

-Large badgirs, wall and parapet ventilators, few basements.

CLIMATE 4: MODERATELY HOT; DRY
-Av, max.daily July temp - below 35c.
mean R.H. - below 30-35%

-small ventilators

The difference between the effective minimum temperatures for hot dry and hot humid regions results from discomfort being experienced at lower temperatures with high humidity.

Such generalized limits are applied to areas where suitable prevailing winds exist.

This classification, based on average maximum daily temperatures and relative humidities, appears to predict differences in the desirable type and use of windcatchers in the different regions, and the application of these three climatic categories to the initial chart in 2.6 that such limits may well be valid (figure 11.6).

CHART TO SHOW THE CHARACTERISTICS OF JULY CLIMATES OF CITIES IN AREAS WHERE WINDCATCHERS ARE FOUND; ORGANIZED INTO THE FOUR CLIMATE TYPES DESCRIBED ABOVE

		TEMPERATURES				
PLACE:	BADGIRS	AV.MAX.	ABS.MAX.	MEAN	LOCTN	%R.H.
CLIMATE 1.						
WINDCATCHERS MAINLY TO BASEMENTS						
Kashan	few	40.9	47.8	33.1	U.I.P.	30
Baghdad	many,small	43.9	50	35.5	Interior	23
CLIMATE 2.						
LARGE WINDCATCHERS TO GROUND FLOOR + BASEMENTS						
Yazd	many,big	39.5	50	35.5	U.I.P.	15
Hyderabad	many				I.C.P.	
Cairo	big	35.8	45.5	35.5	Interior	30
CLIMATE 3.						
LARGE WINDCATCHERS TO GROUND FLOOR						
Ahwaz	big	45.8	54	36.2	I.C.P.	34
Basra	modest	39.8		33.8	C.P.	49
Bahrain	big				Gulf	
CLIMATE 4.						
FEW / SMALL WINDCATCHERS						
Mashad	small				U.I.P.	
Kerman	few	35.8	41.1	27	U.I.P.	20

LOCTN= location: U.I.P.= upland interior plateau
I.C.P.=inland on coastal plain
C.P.=coastal plain

It would appear that the badgir types do fit loosely into such categories and this in turn has implications for:

1) Transference of badgir types between climatic regions. Al-Wakil transfered a large ground floor Eqyptian style windcatcher to Jeddah (see 1.10), ie. from climate 2, hot/dry, to climate 3 hot/humid - to a region where badgirs are not found on traditional houses. This house may provide an excellent testing ground in which the implications of transfering badgir types between regions could be recorded and assessed.

2) Application of this study to the study of traditional houses in the area. If badgir forms are so different in these climatic regions, and so climate-specific, so too may be the use, for instance, of the courtyard, in traditional houses in different climatic regions. There are no studies on the difference between the form and use of the courtyard in very hot/dry climates compared with their use in hot/dry climates in the region. The badgir findings suggest that such an investigation might be fruitful and valuable in understanding the climatic performance, and design rationale of the traditional architecture of the hot regions of the Middle East.

CHAPTER 12

CONCLUSIONS

12.1 INTRODUCTION

The aim of this thesis was to provide a detailed case study of the windcatchers of one area of the Middle East. Yazd and its hinterland was selected as the study area because of the abundance of windcatchers in the Yazd region, and in particular in the city of Yazd. It was suggested at the end of chapter 1 that such a case study might, in analysing the reasons for the use, incidence, distribution of types, and proliferation of windcatchers in the Yazd area, help to provide clues to the reasons for their distribution in the wider region of the Middle East.

In the Yazd region a wide variety of badgir types and sizes were recorded. In the villages simple mud-brick one or four-directional towers predominated (3.4) while in the city badgirs ranged from simple uni-directional towers to huge ornate structures up to 32m high (chapter 6 and 7).

The range of badgir types in this one region led to an investigation, central to the thesis, of the reasons for the for the use and distribution of different towers types in different settlements of the area and different suburbs of the city. The extent to which climatic and historical factors influenced badgir design in the region was investigated.

The findings proved complex, suggesting that design determinants varied considerably between three different areas: the exposed desert area to the north of the region (3.4); the more sheltered locations of the Yazd basin (3.4); and in the city of Yazd itself (4.6).

In part III an investigation into the function of the badgirs in the city of Yazd indicated the existence of temperature thresholds in the internal climate of the Yazdi house of which the badgirs of Yazd operate near the critical upper limits. These findings provided insight into the reasons for the imbalances that occurred in the distribution rural badgirs in exposed, as opposed to sheltered, locations, and in turn indicated climatic limits that may explain the distribution of different windcatcher types in the wider area of the Middle East (11.6.2).

This chapter firstly draws together the knowledge about factors influencing the distribution of badgirs in the Yazd region. These include climatic, historical, stylistic and practical considerations. Secondly, the functions of the badgirs in Yazd are assessed and conclusions drawn. The implications for the distribution of badgirs in the Middle East are then considered. Thirdly, the existence of a single stereotype of windcatcher performance in the Middle East is questioned and shown to be wrong.

Finally, the implications of the findings of the research are assessed and the potential for the use of windcatchers on modern buildings in the Middle East is discussed. Recommendations are made for use in future designs.

12.2. FACTORS INFLUENCING THE DISTRIBUTION OF BADGIRS IN THE YAZD REGION

Climate was seen to have more influence on the determination of badgir incidence and type in the exposed desert areas than in the sheltered settlements, including the city of Yazd, in the heart of the Yazd basin in the following ways:

12.2.1 Influence of climate on the distribution of rural badgirs in the Yazd region

1) Badgir incidence in the exposed northern settlements.

In isolated exposed locations close to fringe of the desert in the north of the region, the presence and use of badgirs was dependant almost entirely on the micro-climate and micro-location of the settlement (3.6). In villages protected from the full force of the prevailing desert wind by hills or gardens, which in effect received a conditioned' wind, badgirs were commonly used, while in completely exposed villages badgirs were rare due to the high temperatures of air that a badgir would introduce into the house during the day (11.5).

2) Badgir incidence in the Yazd basin. In the more sheltered oases settlements of the Yazd basin, the modification of wind temperatures and speeds by passage over hills, or extensive gardens, settlements and orchards in turn modifies the micro-climate of settlements. This brings the temperature of air introduced by badgirs into the houses below the critical temperature thresholds (11.5), thresholds beneath which badgirs enhance loss of body heat

rather than cause heat gain to resting individuals in the afternoon, as they would at higher temperatures.

3) Badgir incidence in the city of Yazd. From the investigation of the functions of badgirs in the city of Yazd (chapter 9), it was shown that summer temperatures in the houses are high, and when reviewed in relation to comfort standards and the physiological responses of the human body to high temperatures (chapter 11) it was concluded that while the badgirs of Yazd operate efficiently in the city, they are operating at the upper margins of acceptable temperature (11.4.D)).

The use of the houses of the city of Yazd involved a long period in the afternoon when the basement was occupied to avoid the worst of the afternoon heat (see 10.5.4). In the villages, where incomes were lower, the houses were generally built without basements (see 3.3.5.2).

12.2.2 The influence of climate on badgir type

1) Rural badgirs in the northern desert area. In the exposed settlements to the north of the region the distribution of tower types appears to be dependant on the existence of local conditioned' winds. Where there is a conditioned wind from four directions then the tower may face in four directions; if the conditioned wind is from one direction only then the towers of the settlement face in one direction only (see 3.6). Hot winds blowing directly from the desert floor are avoided.

2) Rural badgirs in the Yazd basin. In the peripheral villages on the exposed desert fringe of the Yazd basin oases, villages have towers facing away from the desert and opening only towards the oasis, while within the heart of the well-treed conglomeration, towers may face in several directions and still receive conditioned wind (3.5.7 and 3.6.2).

12.2.3 Historical factors influencing the use of different tower types in adjacent villages or suburbs of the Yazd basin

In the Yazd basin most settlements have a climate that suitable for use in towers facing in several directions. However in the Ardakan/Maibud area towers face in one direction only while in Yazd and its hinterland villages they face commonly in four directions (3.4).

In the city of Yazd many different forms of badgir are built side by side (chapter 7).

It appeared that historical, rather than climatic, factors may have been important in determining the choice of badgir tower in the Yazd basin and investigation of the historical factors involved led to the following conclusions:

1) Market factors. In the adjacent areas are served by the separate market centres of Ardakan/Maibud and Yazd, the badgir types most commonly built in the hinterlands two separate market centres were shown to be different (see 4.6).

It was suggested that the reason for the use of uni-directional towers around the Ardakan / Maibud market centre compared with the four-directional towers common in the villages around Yazd was that the two markets and their hinterlands appear to have been independant of each other for building services, finance, expertise and badgir design traditions. No factors other than the independant markets and building tradition of the two areas were seen to have caused the continuing use of the earlier uni-directional towers in the Ardakan/Maibud area (4.6), while in the Yazd area villages adopted the widespread use of four-directional tower, built in the city of Yazd from the 18th century onwards (7.8).

2) Religious influences on badgir distribution. The investigation of the house types of the province in relation to badgir distribution showed that while in general house type did not determine the badgir type used, the traditional houses of the Zoroastrians did not have badgirs before the turn of this century because they were forbidden to build them (3.3.5.5). Thus the existence of different religious populations living in a different quarter of the town, or in separate villages may have been reflected in the nineteenth century absence of badgirs on their houses. However today this earlier dearth of badgirs on Zoroastrian houses has been obscured by the permitting of building of badgirs by Zoroastrians in the 20th century. In Zoroastrian houses built before 1900 one would not expect to find a

contemporary badgir, although this was found not to be a significant factor in the overall distribution patterns of badgirs in the Yazd basin or the city of Yazd.

12.2.4 Historical influences on the distribution of urban badgirs in Yazd

In the city of Yazd badgir types changed radically over time and it was possible to trace their evolution in relation to changing house types in the city (6.8).

It was found that badgirs of discrete types were consequently found in adjacent suburbs of different date in the city of Yazd (8.10 and 8.11). For instance the sea of high towers rising above the centre of the city, for which the city is famous, were largely built in the last quarter of the 19th century (see 8.6 and 8.10). The rapid expansion of the city during this period, enhanced by a new prosperity attributable to the boom in the opium market, may largely be responsible for the most conspicious of the badgirs of Yazd (4.5.3).

12.2.5. Stylistic and practical considerations

A number of stylistic and practical reasons for the use of different tower types on the buildings within one suburb of the city of Yazd were identified including:

1) Different tower types were used on different building types: for instance two-directional towers were customary on water cistern towers (8.4.4) in a suburbs with four-directional domestic towers.

2) The choice of the house owner was influential. One owner might prefer a single central badgir while a neighbour chose pair of badgirs in the summer rooms (7.3.4.C). Part of the explaination for this may have been the economic status of the house owner, reflected in the choice of badgir type. The richer the house owner, the more likely that his house would have a large and elaborate tower type, while the houses of the poor were more likely to have badgirs in the form of a simple ventilator (7.4). Large and small houses, reflecting different financial status, often found beside one another in the same neighbourhood.

3) The style of an individual builder might have determined badgir type. In chapter 8 (8.9) three different builders, all producing high elaborate towers in the late 19th century were identified; but each builder characteristically used different tower plan types and his work was characterised by unique details on the towers.

4) Practical considerations might have affected the form of badgir used in a particular space. The square tower with diagonal partitions or the rectangular Yazdi' tower with rectangular shafts might have resulted from practical considerations such as the amount of space available at the rear of the room for the building of the badgir (7.3.4.C).

12.3 FUNCTION OF THE BADGIRS IN YAZD

The investigation into the function of the badgirs in the city of Yazd was included in the thesis to provide a basic record of the summer performance of the domestic badgirs of the area and to identify the general climatic limits within which they operate. The study of their function led to the establishment of theoretical limits of performance for the rural badgirs of the region and of windcatchers in the wider area of the Middle East.

Five main functions of the badgirs in Yazd were recorded of which three appear to be dependant on the existence of suitable air temperatures. Those not dependant on temperature will be considered first:

12.3.1 Functions of the badgir not dependant on temperature:

1) Basement ventilation. The badgir opening into a basement is important for ventilation, particularly for the removal of body, food and smoke odours, and the introduction of oxygen, in a space where 15 people or more may eat and sleep in the afternoon (10.5.4.2).

2) Increasing the healthiness of basements. The reduction of relative humidities, which rise as high as 70% in unventilated basements, by the use of the badgir has implications for the health of the afternoon occupants of the basement. A basement with badgir is said by the Yazdi to reduce respiratory ailments, the incidence of colds, flu and rheumatism and arthritis (10.5.4.3).

12.3.2 Functions of the badgir dependant on temperature

1) Warming the basement. The badgir introduces air into the basement which mixes with the basement air, causing an increase in the air temperature and the Mean Radiant

Temperatures, and a decrease in the relative humidity of the space. This heating up of the basement prevents the space from becoming too cold for Yazdi comfort in the afternoon (10.5.4.1) and can enable the basement, if well ventilated, to be used as a sleeping area at night (10.5.1.3). The increase in basement temperature also reduces the temperature difference between internal and external climate. When moving between the courtyard and the basement climate at noon and in early evening, the occupants experience less contrast in temperature, and therefore less thermal stress (10.5.5).

2) <u>Provision of a breeze in summer rooms</u>. During the day badgirs provide summer rooms with a cross draught with speeds averaging typically between 0.3 - 1.5 m/sec. This increases heat loss from the body by convection and evaporation. The reduction in temperature of air moving down the badgir shaft of an average 1c-4c between the roof and the ground floor room is important (9.7.4), generally bringing the air temperature to below 37c, ie. body temperature, during most of the day. The exception to this occurs in late afternoon on very hot days when, in the area directly below the badgir shaft, globe and air temperatures may rise above 37c until about 8pm (9.7.6). Therefore in early evening a seating position near the open courtyard is usually taken up (10.5.5).

3) <u>Reduction of the average temperatures of surfaces of summer rooms</u>. Air flow through the ground floor summer

rooms at night and during the morning draws heat from the surfaces of the ground floor rooms, mainly by convection, so lowering the Mean Radiant Temperature of the surfaces of the rooms (9.6.3), and decreasing temperatures experienced by occupants of the rooms during the day, through the processes of radiation and conduction, and to a lesser degree indirectly by convection (11.3.6).

12.4 DISTRIBUTION OF BADGIRS IN THE MIDDLE EAST

It was concluded from the findings on the existence of temperature thresholds in the Yazdi badgirs that temperature and humidity dictate to a large extent the suitability of an area not only for the use of windcatchers, but for the type of windcatcher (11.6.2). For instance in very hot dry climates the windcatcher is suitable for use only as a small basement ventilator; in hot dry climates it may be larger cooling basements and also ground floor living rooms; and in hot humid areas large windcatchers traditionally provide strong air movements, essential in areas of high humidity to effect heat loss from the body, largely through the removal of sweat from the skin. It would appear that the existing distribution pattern of windcatcher types (2.6) in the Middle East supports this rationale for distribution.

12.5 A SINGLE STEREOTYPE OF WINDCATCHER PERFORMANCE IN THE MIDDLE EAST?

1) Badgir variety. Windcatchers in the province and the city of Yazd display a remarkable variety of forms and sizes (3.4 and chapter 7). There is not one single type or size of badgir that can be said to be predominant in the province or city, although certain forms of classic' Yazdi badgir predominate the skyline of the city visually due to their height and elegance (8.6). This variety in Yazd reflects the enormous variety in the windcatchers in different areas of the Middle East and negates the concept of a single sterotype to be found throughout the Middle East. This stereotype has been reinforced by the repeated use of the badgir diagram by many authors (1.7.1).

2) Badgir function. The function of the badgir is generally briefly described by many authors who rightly claim that air is cooled in its descent down the larger windtowers of Yazd (1.7.1), as it undoubtably is, for instance, in mid-afternoon.

However this air on entry into the ground floor summer rooms in the mid to late afternoon may, despite having been cooled in its descent down the tower, be warmer than, and mix with, room air (9.7.7). The effect of daytime ventilation of summer ground floor rooms by badgir is to heat the rooms, which rise in air and surface temperature to about 6c - 7c above minimum night time temperatures (9.7.2). This explains why Yazdi leave the ground floor summer living rooms in the afternoon, during which period they occupy the basement.

In basements the introduction of badgir air serves to <u>heat</u> the room for up to 24 hours in the day by at least 3c to 5c (9.8.3) but this has a desirable effect by ensuring that the basement is not <u>cold</u> when occupied during the afternoon (10.6.4).

3) <u>Windcatchers and water</u>. Contrary to popular opinion (1.7.1), it is very rare to find pools of water associated with badgirs in Yazd. They are virtually never found in basements (11.3.7.5), although in several houses the water channels of qanats are linked to the basements served by badgirs, directly or indirectly (3.3.5.4 and 6.7.2). Neither in Yazd, nor in Baghdad, have porous pots containing water specifically for the evaporative cooling of the basement in association with badgirs (as opposed to holding drinking water) ever been recorded by the author.

12.6 IMPLICATIONS OF THE STUDY FOR THE POTENTIAL FOR THE USE OF WINDCATCHERS ON MODERN BUILDINGS IN THE MIDDLE EAST.

The following discussion of the consequences of the findings of this thesis, in relation to their potential application in modern design are purely speculative and draw briefly on the additional consideration of rationalisation of windcatcher design in order to illustrate this potential.

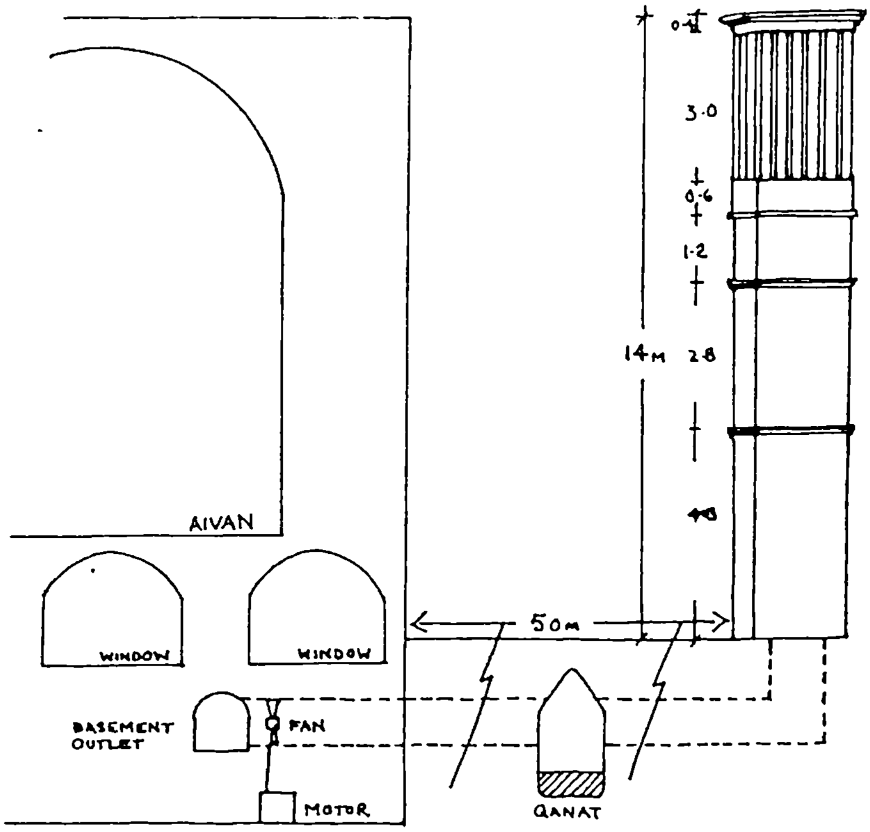


Figure 12.1. Diagramatic sectional-elevation showing the badgir at , the Bagh-e Khan and the tunnel linking it to a qanat channel, and the basement of the garden pavilion. Air flow into the basement from the badgir is enhanced by a motor-driven fan installed into the badgir tunnel by the owner in 1976.

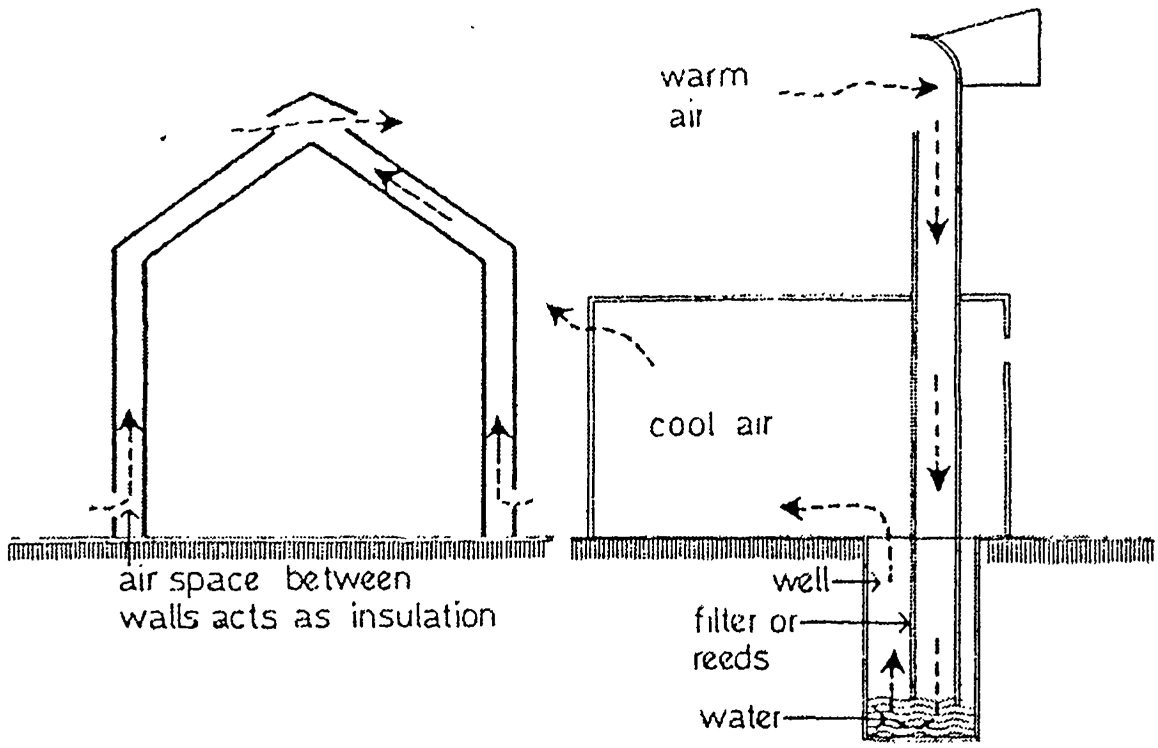


fig. 12.2. System of passive cooling suggested by Kukreja (1978,p.123) using a movable vent with vane, and a shaft which passed air, drawn by exhaust fan, through water before supplying the rooms of the house with conditioned air.

12.6.1 Rationalisation of the badgir design

The traditional badgir in Yazd does not provide a ground floor climate in mid-summer that conforms to modern Western, or even Middle Eastern, standards of comfort (9.12.3.5).

Tappuni and Rassam claim a clear failure of the system', ie. cooling by the addition of badgirs, shown in the non-use of badgirs in the modern houses of Baghdad (Tappuni and Rassam, 1981, p.2). The same might be claimed of the badgirs of Yazd.

A number of owners and architects have attempted to improve the function of the windcatcher by rationalising its design. These rationalisations could be placed in two catagories: those that attempt to turn the windcatcher into a mechanical air-conditioning device (1.7.1) and those that see the function of the windcatcher as that of a 'clever' window.

12.6.2 The windcatcher as an air-conditioning device

The most efficient modified badgir seen by the author is that at the Bagh-e Khan, Yazd (3.3.5.4 and 10.5.1) (figure 12.1), where the tower, 50m distant from the house, has an underground channel ducting air from the tower to the basement, passing the air over an underground water or qanat channel. Into the mouth of the shaft in the basement the owner fitted a fan in order to control the speed of the air passing into the basement. The badgir was so efficient that the owner of the house slept next to its outlet in the afternoon and at night. Saini has proposed a comparable

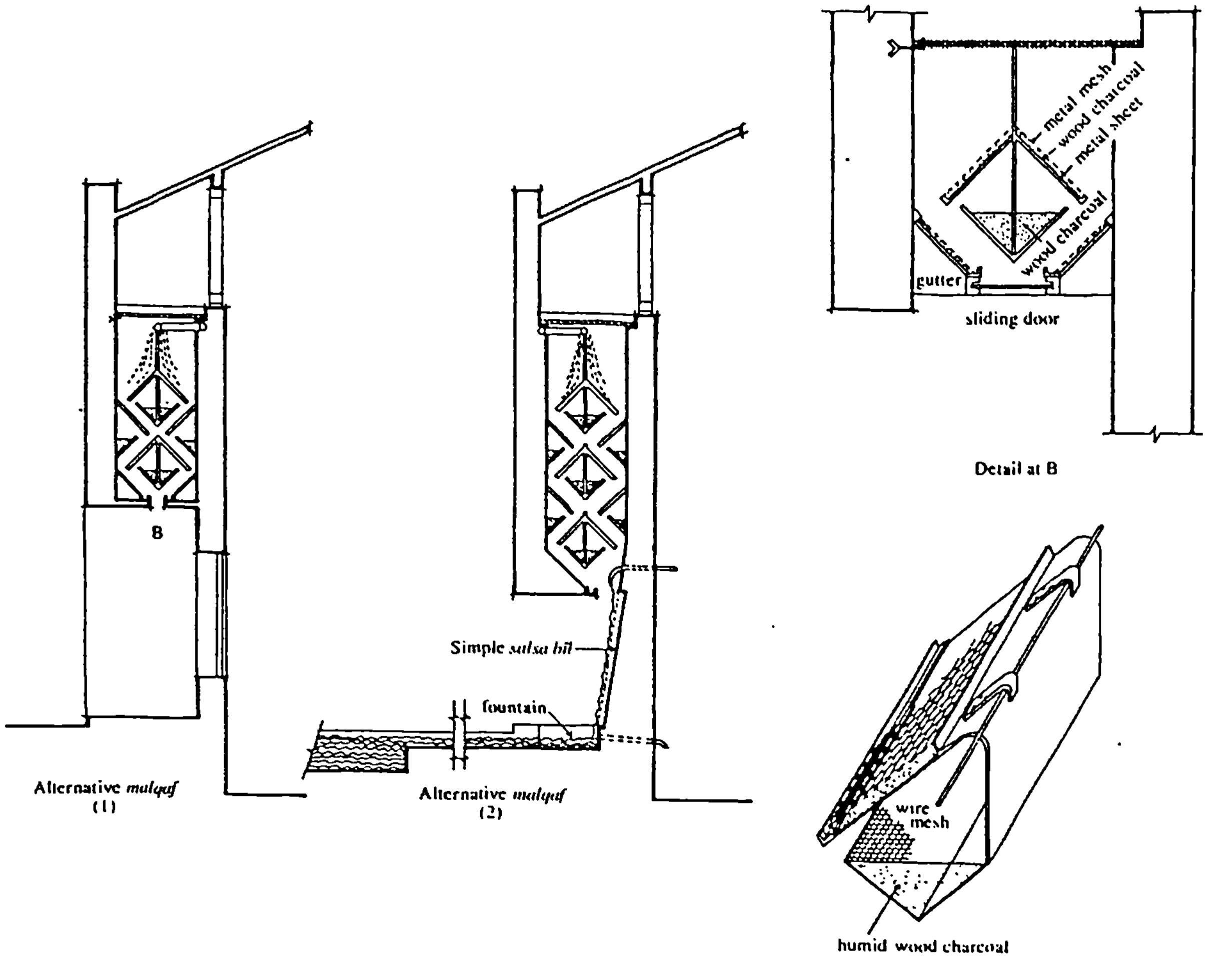


Figure 12.3. Two systems for cooling room air by ensuring that air entering the room from the malqaf is cooled and humidified by mixing with, and passing over water (Fathy, 1986, fig.156).

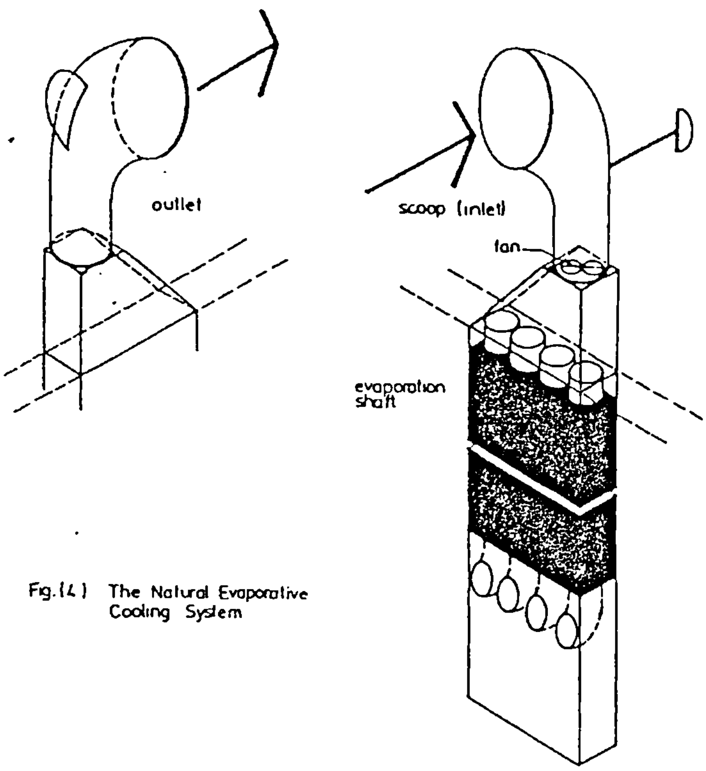


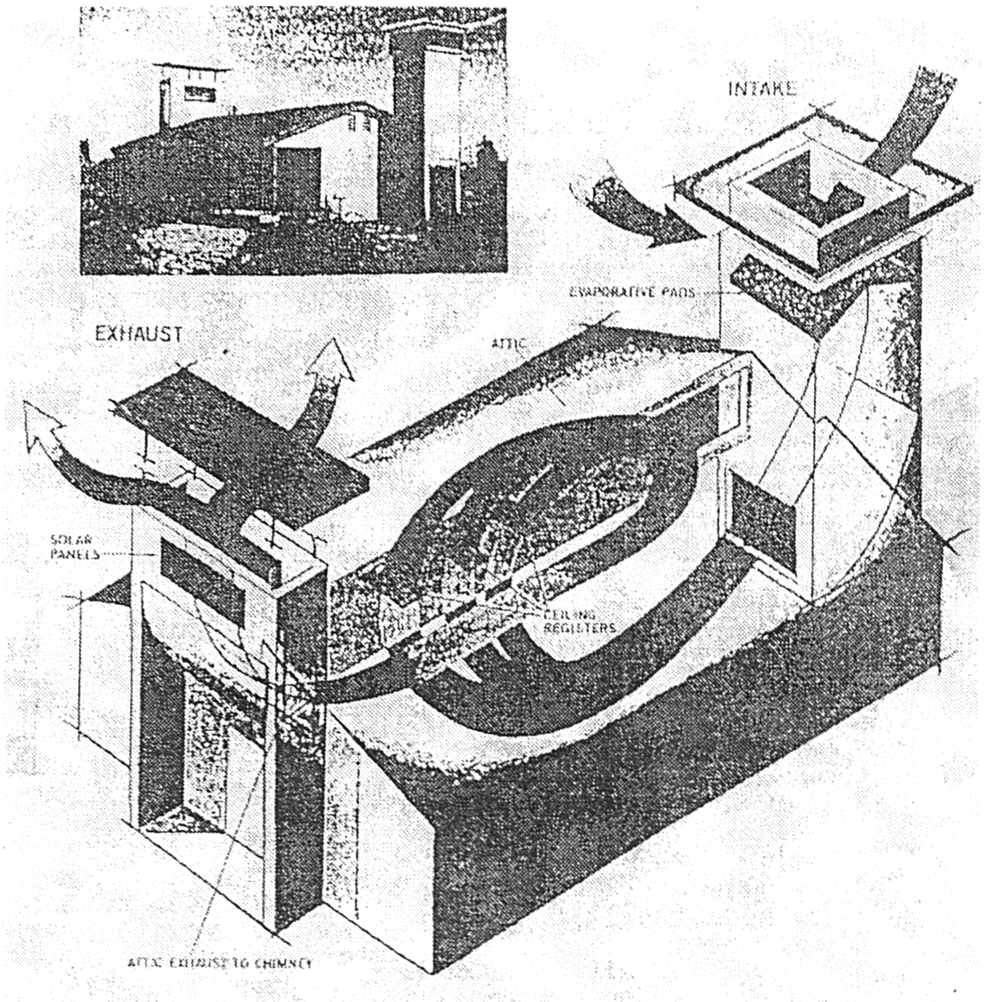
Figure 12.4. Tappini and Rassam's suggested system for Baghdad: a windcatcher with movable vent with wind-vane, an inlet fan to drive the air down moistened shafts into the rooms (Tappuni and Rassam, 1981, figure 4).

system using an underground water tank (Kukreja,1978,p.123) (figure 12.2). But such designs would only be advisably where, inter alia, excessive humidity would not be created by such schemes.

Other published rationalisations of windcatchers involve a higher level of mechanical equipment (Fathy,1986,pp.) (figure 12.3); and Tappuni and Rassam, 1981,pp.6-10) (figure 12.4).

Work is at present being carried out by Dr. Cunningham, at the Environmental Research Laboratory, University of Arizona, into the use of a windcatcher, combined with a solar chimney, to cool the interior of houses in the hot dry climates of the area (Australian, 2/5/86) (figure 12.5). This system involves pads at the top of the wind-tower, moistened by a submersible pump. This rationalisation thus requires a system of pipes and pumps.

The main reservation which the present author has about more complex mechanical and/or structural modifications of the traditional windcatcher system, which usually involve the addition of water to the moving air, is that if the solution involves mechanical equipment, or structural elements that are too complex, or the difficult to reach for maintenance, it would fail for purely practical reasons of non-upkeep of the system. This should be taken into account in projects in the Middle East where the designer has no means of specifying or controlling the maintenance practices of the building, and mechanical skills may be scarce.



The experimental house shows the system to cool houses in low humidity areas being tested at the University of Arizona

Figure 12.5. Dr. Cunningham's experimental wind-tower house in Arizona (The Australian, 2/5/86).

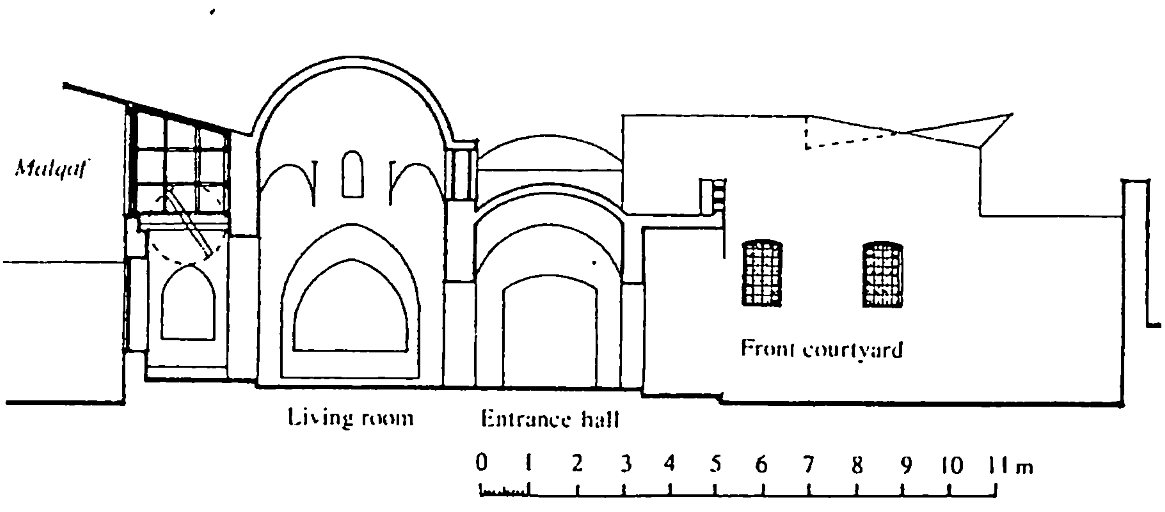


Figure 12.6. Hassan Fathy's revolving trap-door for closing off the malqaf of the Fu'ad Riyad house (Fathy. 1986, fig.62). One problem that may arise in this design is the deposition of dust and debris on opening the trap-door after a windstorm.

12.6.2 The windcatcher as a clever' window

Traditionally a degree of short-term climatic discomfort in the houses in Yazd was expected from high winds, temperatures or dust levels in the air. In modern homes such inconveniences, likely to result from an open badgir, are not acceptable.

One solution would be the development of an easily and tightly closable windcatcher vent. However the height of the vent opening, which creates not only a physical distance, but also a psychological distance between the room occupier and the vent opening presents a difficulty. Where a room occupant would immediately open or close doors or windows to a room, a windcatcher vent might be left open because it was not seen to need shutting, or could not be reached.

The use of a mechanical or electrical device to open and shut the vent opening easily, combined perhaps with a visual link between the occupied room and the vent itself, might encourage the use of the windcatcher as a high level window (figure 12.6). The advantages would be enormous. The windcatcher could be opened at night in summer and closed during the day in suitable climates. Such a system might be particularly effective in bedrooms where the noise of mechanical systems of cooling is often intrusive for those trying to sleep, and the night air is cool and refreshing even in mid-summer. Such a windcatcher could be regularly used in months when the average maximum temperature is between 31c - 35c.

In cool months, for instance, April and May, and September and October the windcatcher could be opened during the day and closed at night.

The badgir would provide a useful basement ventilator in most climates, but in regions where the July average maximum temperature exceeds 40c, openings into the basement from the badgir shaft should be limited in size to prevent excessive heat gain to the occupants and surfaces of the room in summer.

There are many possibilities for the use of a correctly oriented windcatcher as a window providing a high level of air movement, higher than that which would be achieved through a comparable window opening at floor level, and also restricting the entry of direct solar radiation. Flexibility and ease of use would be the key to the successful use of the windcatcher as a window.

In mid-summer however the windcatcher would be insufficient to cool the living rooms in the afternoon in climates 1, 2, and 3 (11.6.2) and mechanical cooling would be required at the hottest periods of the day and year. Such a system of combined passive and mechanical cooling would theoretically lead to individuals being accustomed to generally higher ambient internal temperatures than conventional electrical air-conditioning provides and in turn likely to place less demand on urban power supplies, even at peak times. The desire to acclimatise' buildings would still provide an important buffer, in the form of the passive cooling apparatis in the house between the occupants and the external temperature, and create a more realistic approach to temperature in a desert climate. There would be less heat stress due to sudden expose to much higher temperatures such as occur when the inevitable power failures occur at the hottest time of day and year.

12.6.3 The specification of badgirs in modern houses

A badgir designed in hot dry regions might well prove a useful addition to the passive cooling systems of a house, if fitted with secure and easily opened or shut doors to the vent, and if the following conditions are observed:

A) In hot, dry climates, the necessary climatic perameters are (ie. the climatic factors over which a designer has no control):

1) an assumed comfortable' temperature range of 27c - 32c, tolerable for even the acclimatised Westerner (32c suggested as an optimum temperature where least discomfort was experienced in Baghdad by Nicol, 1975,p.2).

2) a mean monthly relative humidity below 30%.

3) an assumed mean afternoon reduction in temperature down the tower of 3c.

B) If the above conditions prevail, the designer should follow the design guide lines below:

1) A tower of solid mason ry construction is recommended.

2) Ensure a well-investigated and suitable micro-climate around the building.

3) Moderately sized towers are advised. The experience of the Yazdi towers suggests no less than a 1.2m x 1.2m cross-sectional area. They should be higher than 1.0m to 1.5m above the roof, to vent base, and vents should be above 60cms high, with at least two internal divisions, and facing in at least two directions, one towards the best available wind in terms of temperature and humidity.

4) The wind catchment area of the tower should not be directly in the wind shadow of another structure.

5) Where possible filter incoming wind. The best method of filtering dust and sand out of the air and cooling and humidifying air of the prevailing wind is to ensure that the air travels over gardens before it arrives at the tower.

6) A suitable mesh should be provided to exclude the entry of birds into the tower. In Yazd, chicken wire is often used over the vents.

7) The structure of the badgir may provide useful insulation against excessive heat gain from a wall facing directly to the direction of the sun. In the northern hemisphere this would be an exposed south facing wall.

12.7 IN CONCLUSION

This study has included a wide range of aspects of the history and performance of windcatchers in Yazd and the Middle East. It highlights the many gaps in our knowledge of the traditional windtowers of the region and the pressing need for more field and laboratory studies on the subject, to assist contemporary architects designing for such climates, and also to provide historical records of the fast dwindling traditional architecture of the Middle East.

Unfortunately the urban badgirs, like many traditional structures, are already being replaced by machines. Having been regarded as obsolete, they are fast disappearing before their effectiveness has been properly assessed, or their suitability to a given life-style and pattern of daily living fully understood.

APPENDIX A

THE HISTORY OF THE AIVĀN, AND THE TĀLĀR IN YAZD

A.1 The tālār and aivān are both vaulted reception rooms with an open wall facing on to the courtyard. However similar in form they appear they are very different in origin. The aivan has probably been used in houses in the Yazd area since Sassanian times, and the tālār was introduced first into Yazd in the late 18th century from Safavid Isfahan, via the Zand buildings of Shiraz.

A.2 The early history of the aivān, iwān, or eyvān, has been well covered by Downey (1985, pp.111-129), Keall (1974, pp.123-130), and Reuther, 1930, pp.411 -435) . Many early examples of the aivan in the Near East were functionally important spaces, being either audience halls for kings or gods: such were the magnificent aivān at Ctesiphon, the Sassanian capital in Iraq, or the triple aivan before the temple of Shamash, the sun god, at Hatra built by Arab vassels of the Parthians in the first century A.D.

By Parthian times however the classic two and four aivān courtyard plan forms had become common in larger houses, as excavated at Ashur, and in palaces, including those excavated in Ashur and Nippur.

By the Sassanian period (300 - 600A.D.) the four aivān house was already built in a form that was still used in 18th century Yazd. An excellent example of such a Sassanian house was excavated in eastern Iraq, in the Jebel Hamrin, by Fawzi Rashid and Awad Kissar at the site of Abu Shiafa.

Four aivān courtyard houses were typical in the Samarran houses of the 8th and 9th centuries in central Iraq, and have subsequently been built throughout the Middle East.

Four aivān mosques were widely built in Iran from the 12th century (Keall, 1974, p.123) while three earlier mosques in the Yazd region, as at Fahraj (Matheson, 1979, p.177), Nain, Masjid-i Jumeh and Masjid-i sar-i Kucheh (Matheson, 1979, p.175) have vaulted aivāns.

The aivan appears to be associated with status, and the function of reception.

The aivān was widely used in the houses of Yazd, probably from the Sassanian period to the late 18th century.

A.2 The tālār

The origin of the Yazdi tālār is much more humble than that of the aivān, being originally a raised timber or mud platform. By the 17th its function had become intermingled with that of the royal aivān, and it developed into the audience hall or reception room used in the houses of Yazd in the 19th and 20th centuries.

The word tālār has no apparent root in Pre-Islamic literature; it is not found in early Islamic literature, nor was it mentioned in the Shah-Nāma of Firdausi (c. 1010).

A root form is still used today in the Tajiki Persian of Eastern Afghanistan in the form of tāla, adjective meaning:

1) Made flat, levelled.
2) Spread on a surface, such as mud onto a flat construction.

In the Panjshér Valley tāla shud' means it was spread', therefore may have the meaning of flat', or perhaps even a flat place.

An early literary record of its use exists in the writings of Sūzanī (Šhamsud-din Muhammad) of Samarkand, a poet of the Khwarazm-Shahī Court. He was known best for his satirical and indecent poems:

> I had to impose on him sufferings and pains.
> and so to carry him up to the tālār. (top of the roof?)

Thus in the Sūzanī poem (he died in 1172, 569 A.H.) Tālār here means flat top of the roof.

In the Borhān-e Qateʿ, by Mohammed Hossein ibn-i Khalaf Tabrizi, then resident in India, a Persian to Persian dictionary written in (1062 A.H.), 1652 A.D. in Hyderabad Deccan, India, and edited in Tehran by the later scholar Muhammed Mo'īn; he defined Tālār as:

> A takht, or wooden surface raised above the ground, or a khāna, house built on 4 columns, or more generally made from wooden boards.

A note of Muhammed Mo'īn adds that talar also is used in the Gurani, Kurdish dialect and in the Guilaki dialect of Gilan (information taken from the 1963, Tehran edition, vol 1, p.462). Of the buildings of the Safavid court several famous 17th century talars still exist, notably the Ali Kapu and Chihil sotūn pavilions in Isfahan.

In the 19th century the meaning of tālār changed as we would expect from the use of the word in Yazd at the end of the 19th century. For instance Napier describes the Yazdi tālār as a big summer portico with a cruciform plan (Malcolm, 1905, pp.14-15).

In the Farhang-e Anand-Raj, by Muhammad ——— -- Padshah, compiled in India in 1881(1289 A.H.), and edited in Tehran in 1957 by Muhammad Dabir Seyagi, the following description is given of talar:

> A Takht or a house built on four pillars on which people go up by a ladder which is removed at night. Found generally in Tabaristan . Also called napar. Now in Iraq talar means a vast building with columns.

In a Turkish and English Lexicon written in Constantinople in 1890 tālār is described as a word coming from the Persian meaning: 1) A flat form on posts.
2) A hall.

It is this second meaning that sheds some light on the emergence of the Yazdi tālār as a summer living room. In the later Persian English dictionary written by F. Steingass in 1892 tālār is defined as:

1) A bed chamber or saloon built in wood and supported by four columns.
2) Tālār-i Salam, a reception room.
3) Tālār-i Supa, a supper room.

The conclusions are several:

1) That talar is a Persian word, and its original meaning was, and still is in Tajiki Persian, flat or flattened.

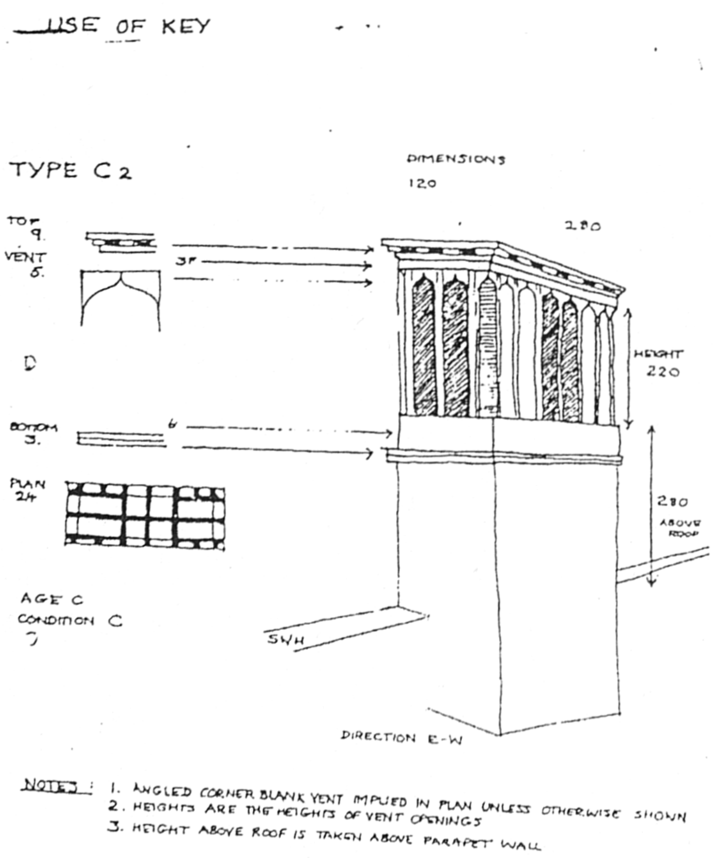
2) Already in the 12th century it was used for a timber room with a flat roof.

3) In the Safavid period the tālār reached its apogee as a timber columned reception room, in the Chihil Sotūn, and the Ali Kapu pavilions.

4) In the 18th century the Tālār was adopted in a modified form in the summer reception halls of western Iran and Iraq, notibly by the Zand rulers in such buildings as the Dil-

Gūsha Pavilion (Lockhardt, 1970, p.39). The tālār was then imported into Yazd where the summer reception halls became commonly called tālār in the 19th century. By the end of the 19th century the term was widely used in Shiraz, Yazd, Tehran and in Turkish to mean a reception saloon.

5) In Yazd in the 20th century it is commonly used to describe the large vaulted summer reception room on the south of the courtyard, which is generally open to the courtyard but in some cases is glassed in with a series of French doors. It is intersting to note that the early tālār at the Nowāb Rasoui house is constructed with timber columns in the Baghdad tradition, imitating the gracious timber columned halls of the Safavid court, but the fashion for wooden columns soon disappeared. The pragmatic Yazdi is uncomfortable building in anything but brick because of a shortage of large timbers in the area and subsequently their cost.



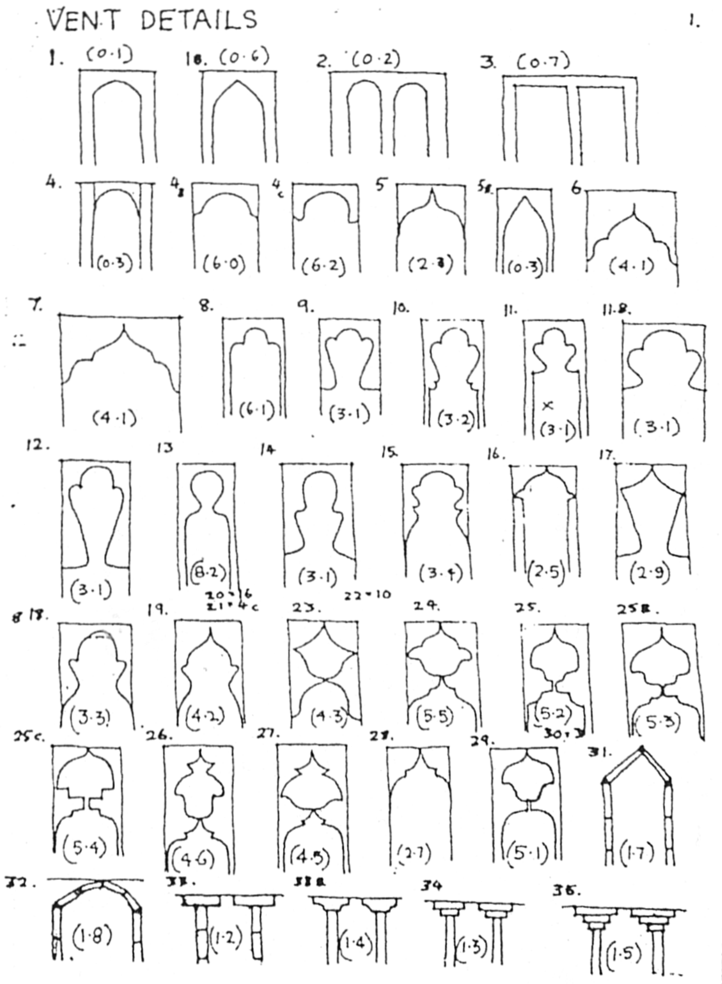


Figure B.1. Cover of the original key used for the survey of badgirs in Yazd in 1976, with page one of the vent details recorded.

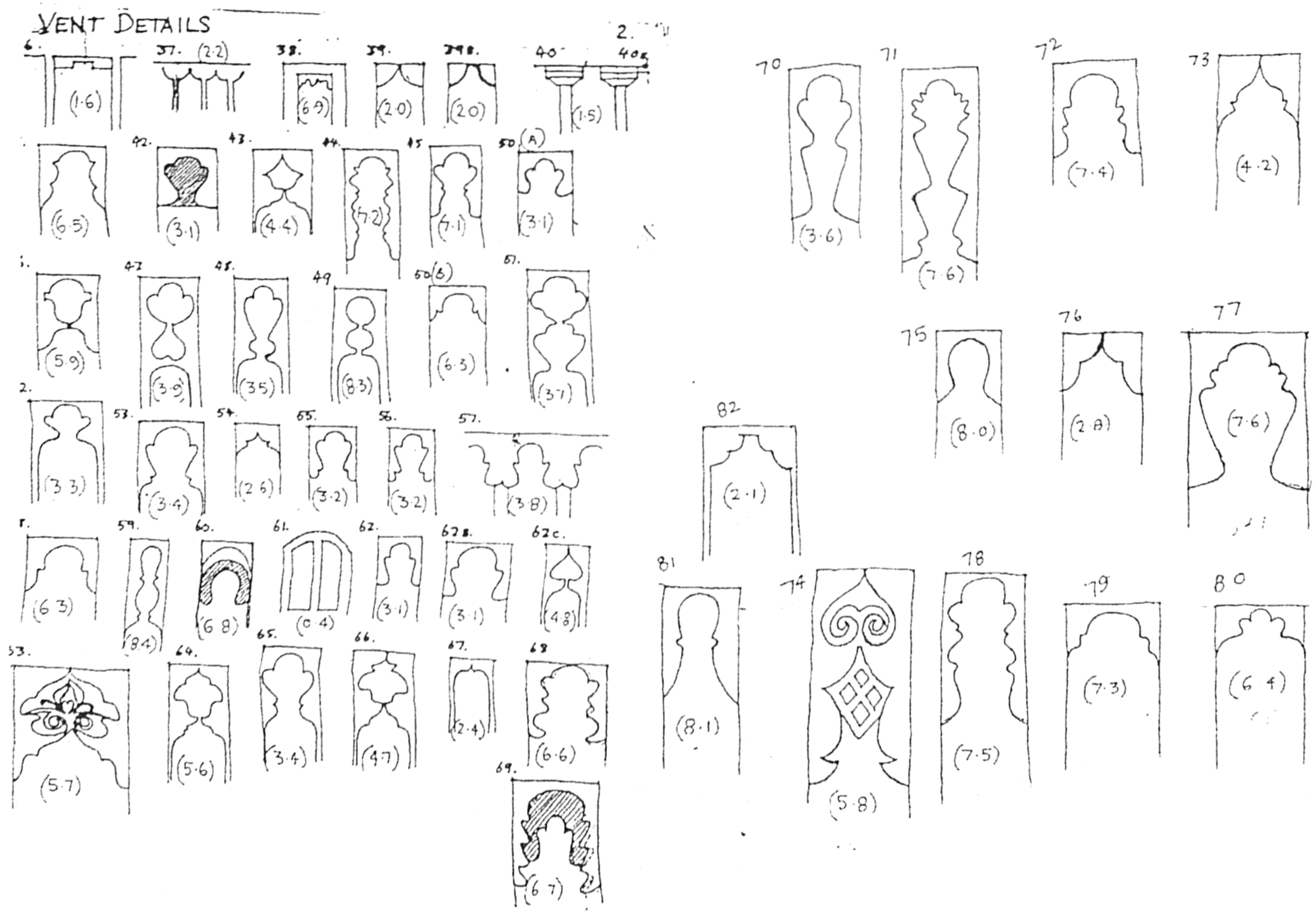


Figure B.2. Vent details from the 1976 survey key.

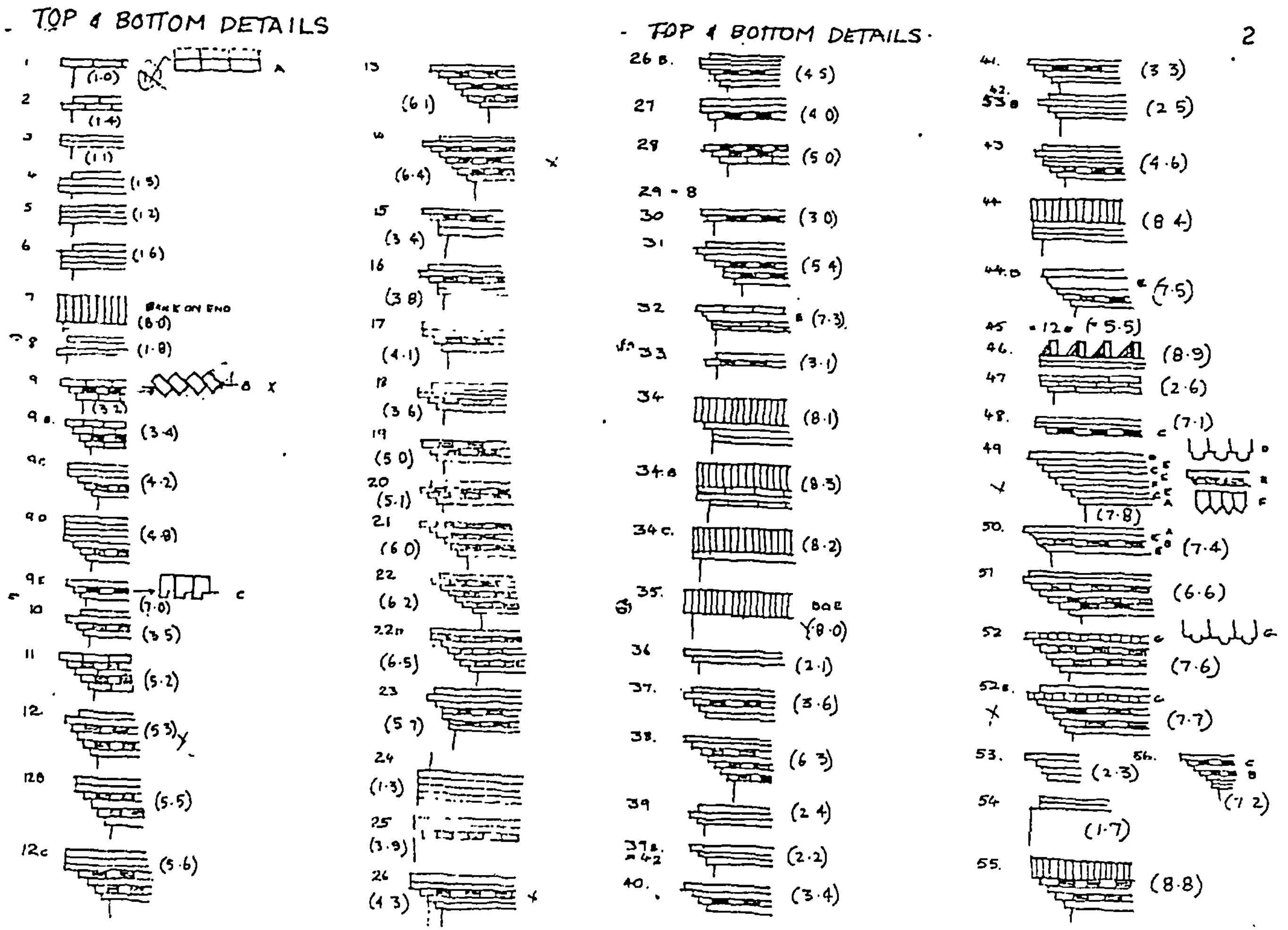


Figure B.3. Base and sill details from the 1976 survey key.

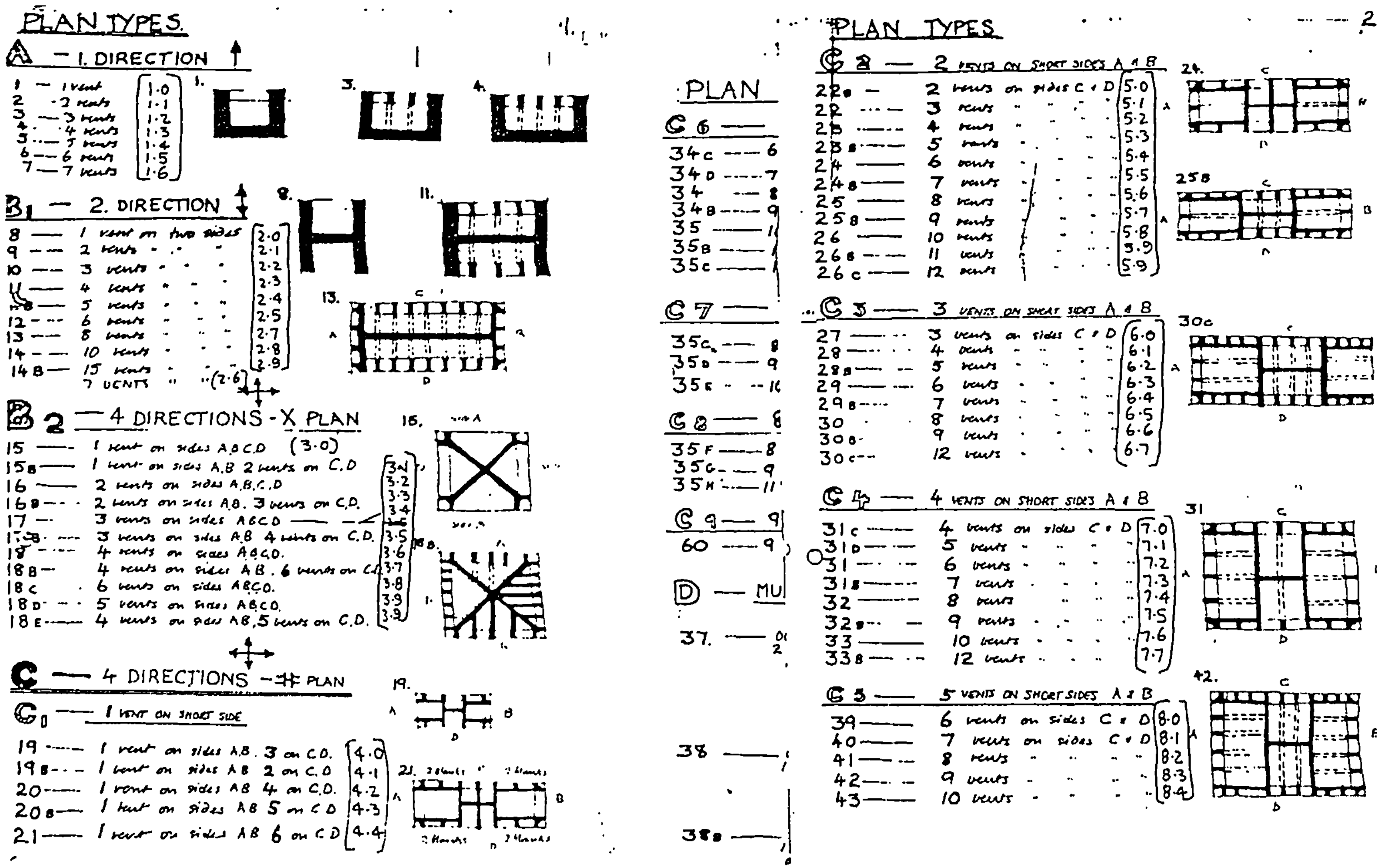


Figure B.4. List of plan types from the 1976 survey key.

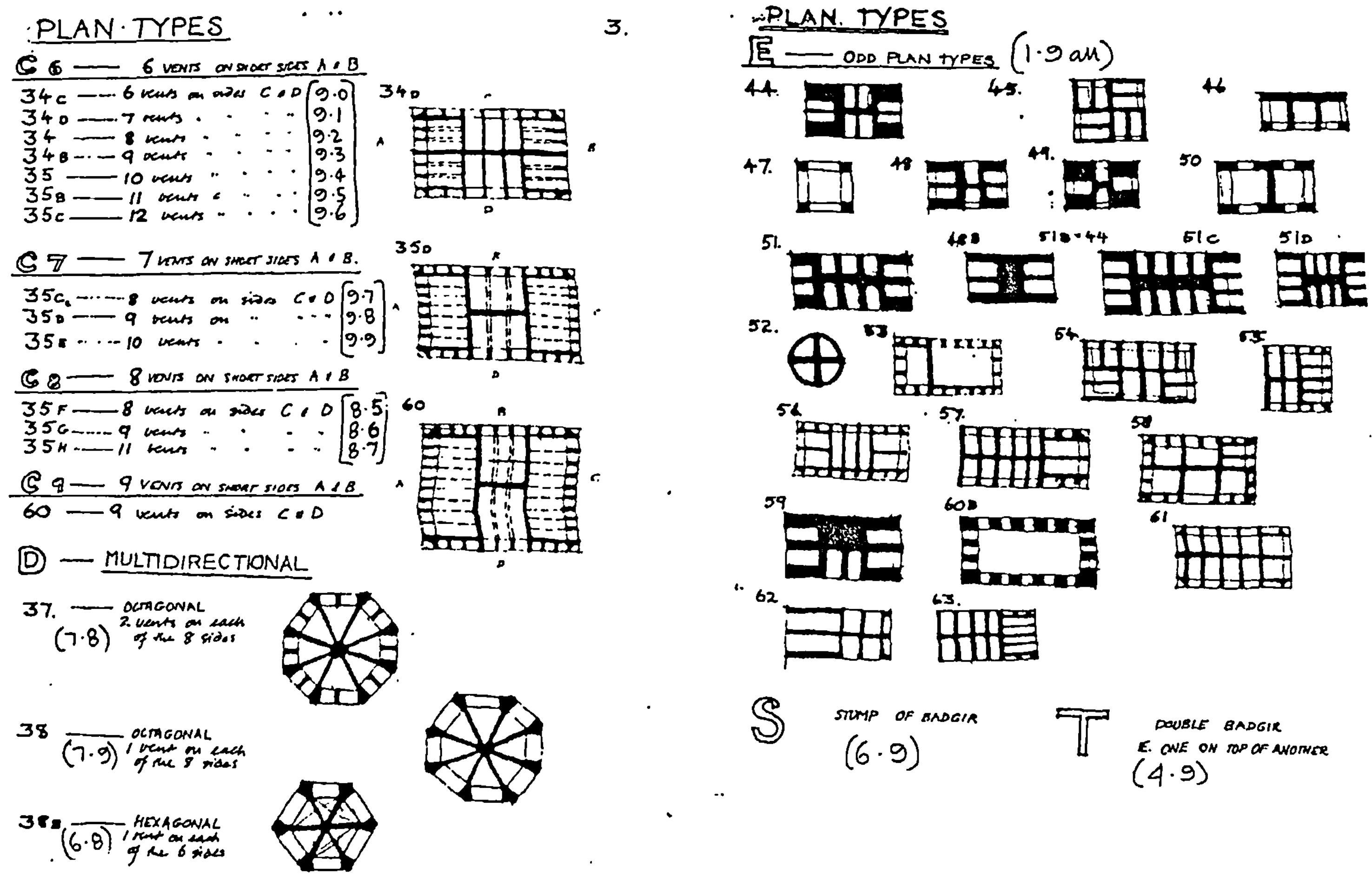


Figure B.5. Further list of plan types from the 1976 survey.

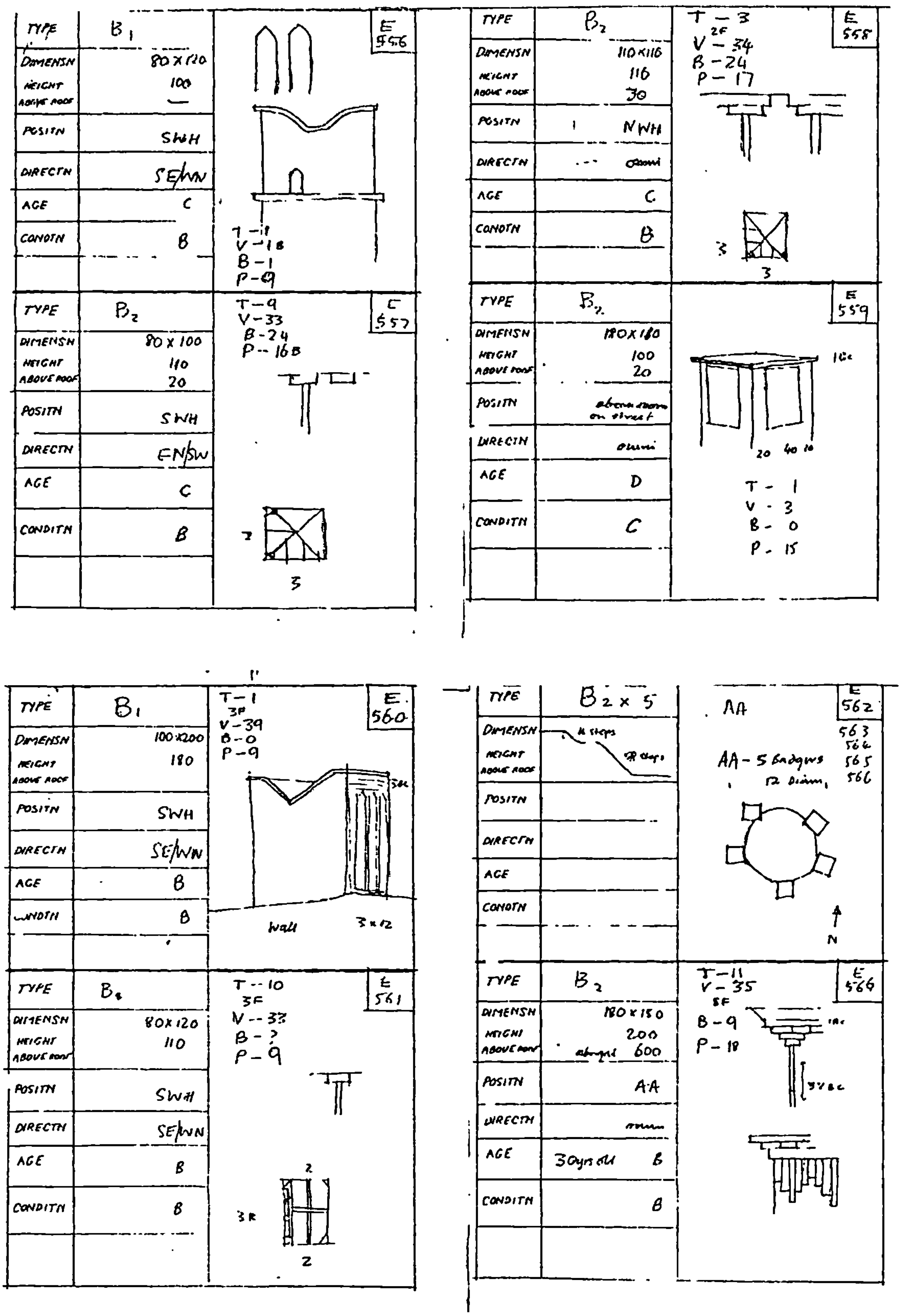


Figure B.6. Examples of the badgir survey sheets used in the 1976 survey in Yazd showing how 11 separate towers were recorded.

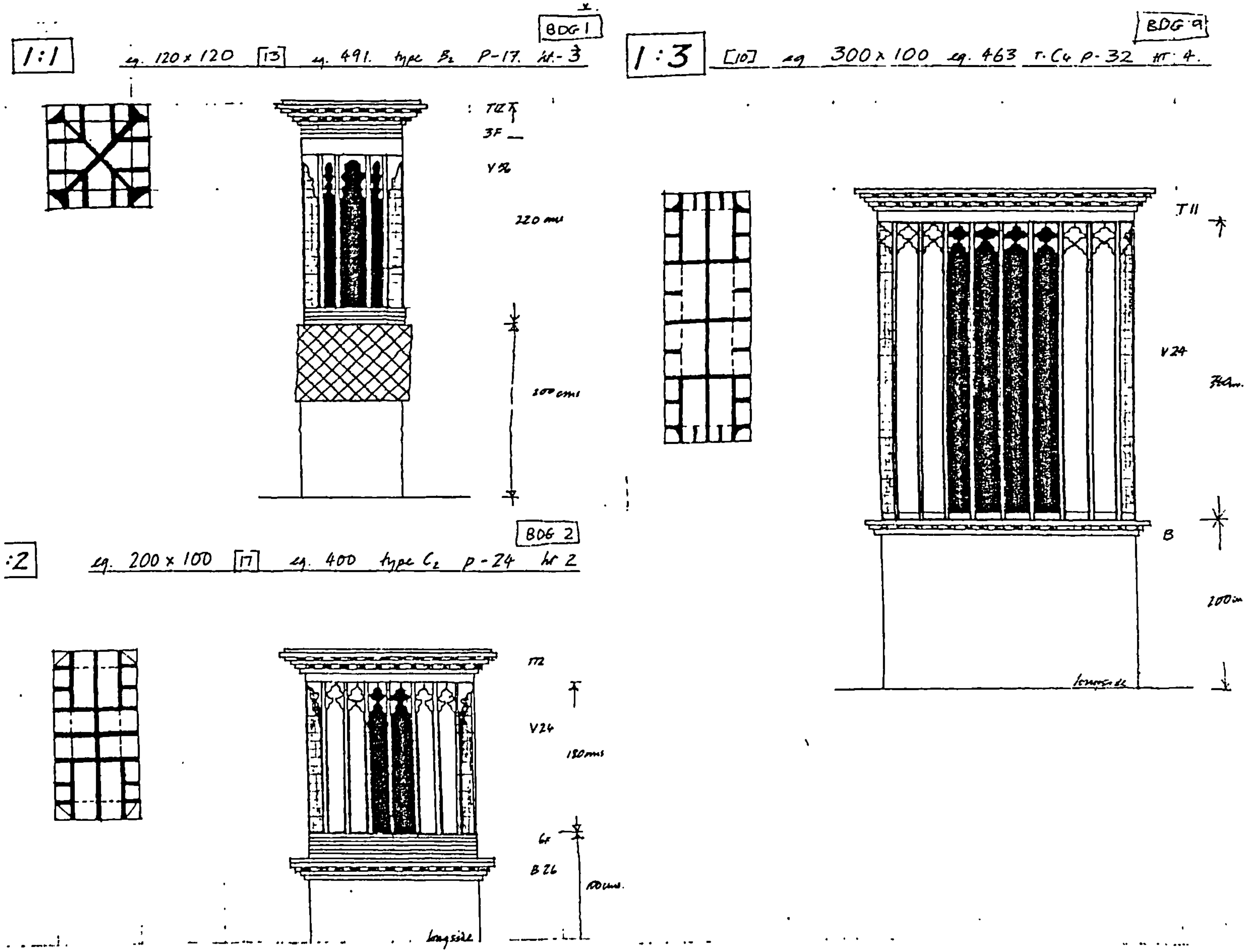


Figure B.7. Examples of towers reconstructed from the original survey data.

00001	389	c4	300	120	300	3	s	nw	c	5.4	5.5	4.3	7.4	180	b
00002	390	b1	500	200	150	2	s	nw	e	1.2	0.1	0.0	2.5	0	b
00003	391	e2	180	100	300	4	s	nw	d	6.4	5.5	5.2	1.9	320	b
00004	392	c4	220	80	300	3	s	nw	0	5.3	5.5	0.0	7.4	0	b
00005	393	c2	100	60	100	2	w	n	c	3.5	6.1	1.3	5.4	30	b
00006	394	c6	400	120	120	2	se	nw	c	3.5	3.1	3.2	9.7	150	b
00007	395	e	260	120	260	3	n	ne	e	6.0	1.4	3.2	1.9	200	b
00008	396	c4	220	100	300	4	s	nw	e	3.2	5.6	4.5	7.5	280	b
00009	397	c2	200	100	320	4	s	nw	e	5.4	4.5	5.5	5.4	280	b
00010	398	e	500	300	340	3	n	nw	d	1.0	0.7	1.0	1.9	0	b
00011	399	c2	300	100	120	1	n	nw	d	1.1	2.3	0.0	5.4	0	b
00012	400	c2	200	100	180	2	s	nw	d	5.3	5.5	4.3	5.4	100	b
00013	401	c2	200	80	180	2	n	nw	d	3.5	0.7	1.3	5.4	0	b
00014	402	s	400	200	400	3	n	ne	e	0.0	0.0	5.2	0.0	0	b
00015	403	ooo	0	0	0	0	oo	oo	o	0.0	0.0	0.0	0.0	0	b
00016	404	c6o	300	280	300	4	s	ne	e	5.2	3.1	5.5	9.4	260	e
00017	405	c2	280	80	300	4	s	nw	e	3.5	3.1	4.3	5.2	280	e
00018	406	c6	300	220	200	4	s	nw	c	6.2	2.3	3.2	9.3	300	e
00019	407	c4	120	110	320	4	s		c	6.2	3.1	9.0	7.2	180	e
00020	408	c2	320	120	220	3	s	ne	e	6.4	3.2	2.2	6.4	100	e
00021	409	c3	200	110	120	2	s	nw	c	5.3	5.1	1.1	6.6	30	e
00022	410	c2	180	80	200	3	s	nw	d	5.3	5.5	5.2	5.4	100	e
00023	411	Tc6	300	200	400	4		ne	d	5.3	3.1	5.2	9.1	300	e
00024	411	Te	700	300	200	1		ne	d	1.1	3.1	0.0	1.9	0	e
00025	412	Tc3	320	200	400	4	s	nw	c	6.1	3.1	0.0	6.0	100	e
00026	412	Tb2	900	620	100	1	s	nw	c	5.2	3.1	0.0	2.2	100	e
00027	413	b1	300	100	100	2	s	nw	b	1.1	0.7	0.0	2.1	100	e
00028	414	c4	180	120	320	3		ne	c	6.0	1.3	0.0	7.2	100	e
00029	415	b18	80	60	120	2	s	ne	d	3.5	3.1	3.0	2.2	100	e
00030	416	b18	200	100	120	1	s	nw	c	1.1	0.7	0.0	2.0	0	e
00031	417	c28	220	80	120	2	s	nw	c	3.2	2.3	1.1	5.7	100	e
00032	418	b1	180	80	160	1	s	nw	b	1.0	1.7	0.0	2.0	0	e
00033	419	c2	220	110	300	3	s	nw	c	3.5	3.1	0.0	5.7	0	e
00034	420	d	80	60	160	3	n	nw	e	6.4	5.5	4.3	6.1	160	e
00035	421	c6	300	220	320	4	s	nw	c	5.3	3.1	4.3	9.3	260	e
00036	422	c2	220	80	180	3	s	nw	e	3.5	2.3	1.1	5.4	120	e
00037	423	c2	260	60	160	2		ns	e	3.5	2.3	1.1	5.4	100	e
00038	424	c2	200	80	160	2	s	nw	d	3.5	2.3	1.1	5.4	100	e
00039	425	a	120	100	100	2	w	ne	d	1.1	1.7	0.0	1.2	100	e
00040	426	e	400	160	80	2	s	nw	c	0.0	0.1	0.0	1.9	60	e
00041	427	b1	110	80	80	1	s	nw	b	1.0	0.1	1.0	2.1	0	e
00042	428	c2	220	80	120	2	s	nw	c	3.5	2.3	1.1	5.4	100	e
00043	428	c2	220	80	120	2	s	nw	c	0.0	5.0	3.0	0.0	100	e
00044	429	c2	220	80	220	3	s	nw	c	3.5	0.7	1.1	5.4	100	e
00045	430	e	320	100	100	2	s	nw	d	1.1	0.1	0.0	1.9	100	e
00046	431	s	300	180	160	3	n	nw	e	1.4	0.0	1.4	0.0	200	e
00047	432	b1	200	100	80	1	s	nw	d	1.0	0.1	0.0	2.1	0	e
00048	432	b1	200	100	80	1	s	nw	d	1.0	0.1	0.0	2.1	0	e
00049	434	b1	160	110	110	0	s	nw	e	1.0	0.1	0.0	2.1	0	e
00050	435	b1	160	110	110	3	s	nw	e	1.0	0.1	0.0	2.1	200	e

00051	436	b2	160	160	180	3	aa	oo	d	5.3	0.1	1.0	3.0	200	e
00052	437	b2	160	160	180	3	aa	oo	d	5.3	0.1	1.0	3.0	200	e
00053	438	b2	160	160	180	3	aa	oo	d	5.3	0.1	1.0	3.0	200	e
00054	439	b2	160	160	180	3	aa	oo	d	5.3	0.1	1.0	3.0	200	e
00055	440	b1	100	80	90	1	s	nw	b	1.1	0.7	0.0	2.0	0	e
00056	441	e	220	100	100	1	s	nw	d	1.1	0.1	0.0	1.9	0	e
00057	442	c3	220	100	110	1	s	nw	c	3.5	3.1	1.1	6.4	0	e
00058	443	c3	220	100	120	2	n	ne	b	5.2	1.3	1.3	6.7	30	e
00059	444	c4	200	100	120	1	s	nw	a	3.2	3.1	1.4	7.5	0	e
00060	445	b1	200	80	100	2	s	nw	c	1.0	0.4	0.0	2.1	100	e
00061	446	c2	280	100	160	2	s	nw	d	1.8	0.1	1.0	5.4	200	b
00062	447	b2	200	80	280	2	s	nw	c	0.0	0.0	0.0	0.0	100	b
00063	448	c2	220	100	160	2	s	nw	c	1.1	0.2	0.0	5.4	0	b
00064	449	c1	160	80	180	3	s	nw	b	0.0	0.0	0.0	4.3	150	b
00065	450	c2	120	80	120	2	e	ne	b	4.0	1.5	1.1	5.2	30	b
00066	451	b1	100	60	80	1	s	nw	e	1.1	0.7	0.0	2.0	0	b
00067	452	b1	180	110	110	2	n	nw	c	1.1	0.1	0.0	2.1	60	b
00068	453	c3	280	100	100	1	s	nw	c	1.2	0.2	0.0	6.5	0	b
00069	454	c4	280	100	120	1	se	ne	c	1.2	0.2	1.1	7.5	0	b
00070	455	c1	100	80	110	2	s	nw	d	5.2	0.1	1.1	4.0	30	b
00071	456	b2	120	100	120	1	aa	oo	e	1.1	6.3	0.0	3.4	0	b
00072	457	b2	120	100	120	1	aa	oo	e	1.1	6.3	0.0	3.4	0	b
00073	458	b2	120	100	120	1	aa	oo	e	1.1	6.3	0.0	3.4	0	b
00074	459	b2	120	100	120	1	aa	oo	e	1.1	6.3	0.0	3.4	0	b
00075	460	c2	220	80	180	3	s	nw	c	5.2	0.2	1.1	5.5	100	b
00076	461	c2	220	100	120	2	w	ne	c	1.0	0.0	1.2	5.4	100	b
00077	462	b1	300	120	100	2	s	nw	b	1.2	0.0	0.0	2.3	30	b
00078	463	c4	300	100	360	4	w	ne	c	5.2	5.5	0.0	7.4	200	b
00079	464	c9	120	120	220	3	s	nw	c	5.3	8.9	3.2	1.9	100	b
00080	465	c3	200	100	180	2	w	ne	c	3.2	0.7	1.0	6.3	30	b
00081	466	c4	280	100	200	3	se	ne	e	3.2	6.3	1.0	7.3	100	b
00082	467	c6	300	100	320	4	e	ne	e	5.3	5.5	3.2	9.0	200	b
00083	468	b2	160	160	180	2	s	oo	c	3.2	3.8	0.0	3.6	0	b
00084	469	b1	120	120	120	1	ne	ns	c	1.1	0.3	0.0	2.1	0	b
00085	470	b1	120	100	110	2	aa	nw	e	1.1	0.6	0.0	2.1	100	b
00086	471	b1	120	100	110	2	aa	nw	e	1.1	0.6	0.0	2.1	100	b
00087	472	b1	120	100	110	2	aa	nw	e	1.1	0.6	0.0	2.1	100	b
00088	473	b1	120	100	110	2	aa	nw	e	1.1	0.6	0.0	2.1	100	b
00089	474	000	0	0	0	0	00	00	0	0.0	0.0	0.0	0.0	0	b
00090	475	a	220	110	110	1	w	ne	d	0.0	0.1	0.0	1.2	0	b
00091	276	c2	180	80	180	2	s	nw	c	3.2	1.2	0.0	5.2	30	b
00092	477	c2	180	80	180	2	s	nw	c	3.2	1.2	0.0	5.2	30	b
00093	478	c2	210	100	200	4	s	ww	c	3.2	0.3	1.0	5.4	300	b
00094	479	c4	300	110	300	3	s	nw	c	2.6	3.1	0.0	7.5	50	b
00095	480	e	180	80	120	2	sw	ne	c	1.1	0.2	1.1	1.9	60	b
00096	481	c4	300	120	300	3	s	nw	e	7.8	0.0	7.1	7.2	150	b
00097	482	e	50	0	60	1	e	oo	b	0.0	0.0	0.0	1.9	60	a
00098	483	c2	220	110	100	1	s	nw	c	3.5	3.1	0.0	5.1	0	a
00099	484	c2	220	120	120	2	oo	n	c	1.5	0.3	0.0	1.9	100	a
00100	485	a	200	120	200	2	s	nw	e	0.0	0.3	0.0	1.3	0	a

Figure B.8. Example print out of two pages of the Data Base II, file on which the reorganised results of the survey were stored and sorted.

APPENDIX B

DATA FROM THE SURVEY OF BADGIRS IN YAZD

This appendix shows the form of the original survey of badgirs in Yazd. Figures B.1 - B.5 show the pages of the key used in Yazd. This shows the vent types, the sill and base details, and the plan forms recorded. In the case of the vent, sill, and base details these were added to the list as they were recorded.

Figure B.6 shows the survey sheets for 11 badgir towers, and B.7 shows how individual towers can be easily reconstructed from the survey data. Where some feature of a tower is unique the sketches supply the relevant information for accurate reconstruction.

When it came to interpreting the original survey data the random numbering of attributes was reorganised to identify groups of attributes and relationships between them. In figures B.1 - B.5 the new numbers for each attribute are listed in brackets beside their original numbers. The new groupings of vent, sill and base details are shown in figure 7.6 and 7.7.

Figure B.8 shows an example printout of the Data Base II record of the reorganised data. The file contains all the available information collected in a survey of 713 badgirs in the centre of Yazd in the summer of 1976.

Numbers 0 - 389 list only three attributes of each tower (height, type and condition) which were salvaged from three maps of the towers that were not lost with the bulk of the survey records in a theft in Adana, Turkey, in the spring of 1977. Numbers 389 to 713 list all 13 attributes which were recorded and of which a copy remained in the Ancient Monuments Office in Yazd.

APPENDIX C

SUMMER WIND FLOW PATTERNS OVER YAZD

The available climatic data on the area records only monthly mean directions and velocities, which show that in the summer months the prevailing wind is from the north west. One set of readings of the di-urnal variations in wind direction and speed is available. The readings were taken by Professor Bahadori, of Pahlavi University in Shiraz, and three students, on the 12th August 1977. The chart below shows the recorded wind speeds and directions over a period of 18 hours taken 7m above the roof of the Khan's pavillion at the Bagh-e Dowlatabad.

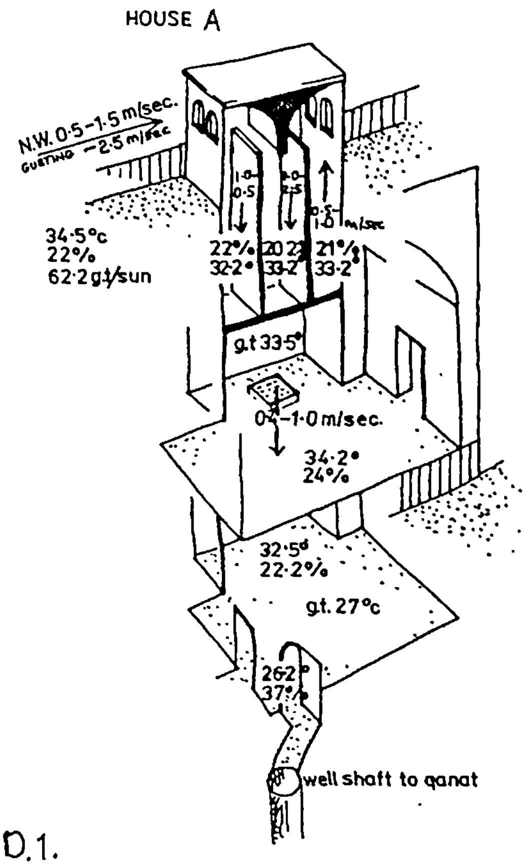
DIURNAL WIND READINGS FOR YAZD ON 12/8/77.

TIME am	WIND SPEED m/sec	DIRECTION	TIME pm	WINDSPEED m/sec	DIRECTION
6.40	0	e.n.e.	16.00	6-7	n.w.w.
7.01	0	e.n.e.	16.30	0	e.n.e.
7.30	0	e.n.e.	17.30	7-10	n.
8.00	0	e.n.e.	18.00	7	n.
8.20	0	e.n.e.	19.00	5	n.
9.00	1	w.	19.30	4.5	n.n.e.
9.30	0	w.n.w.	20.00	4	n.
10.00	1-5	w.n.w.	20.30	4	n.
10.30	1-5	w.n.w.	21.00	2.5	n.
11.00	1	w.	21.30	2	n.
11.30	0	n.w.w	22.00	1	n.e.
12.30 pm	1.5	s.w.w.	22.30	1	e.n.e.
13.00	3	w.n.w.	23	1	n.e.
13.30	0.5	s.e.	23.30	1	n.e.
14.00	7	w.	24.30	1	s.s.w.
14.30	5.5	n.w.	1.00	10	s.s.w.
15.00	7	n.w.			
15.30	9	n.w.			

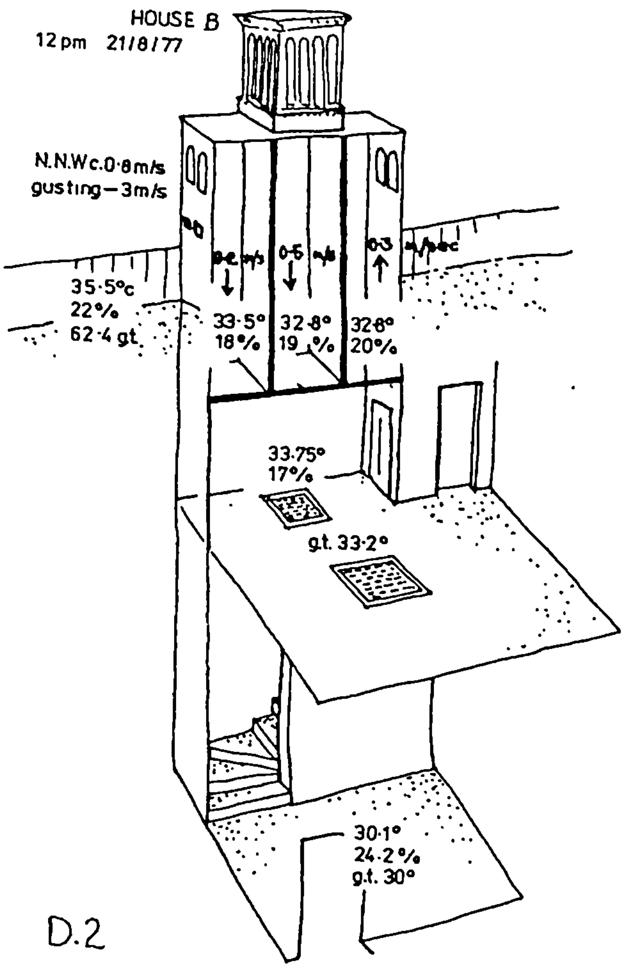
(0 m/sec must = less than 0.5m/sec)

Between 6.40am and 9.00 am the winds were very light, from the east, north-east. Between 9am and 1pm, with the rising sun, there was a period of changeable winds increasing in speed as the temperature rose. Between 2.00pm and 4.30pm there was a strong wind from the north and north-west, ranging from 5.5 to 9m/sec. After 4.30pm the wind veered round and until midnight was from the north and north-east, reaching speeds of 4.5m/sec at 5.30 pm but becoming increasingly quiescent after 10.30pm. It remained at 1m/sec until the direction changed around midnight. Windspeeds peaked at 10 m/sec from the south, south-west at 1.00am.

Figures for the early morning were not recorded.



D.1.



D.2

Figure D.1. House A, showing readings of dry-bulb temperature, relative humidity and windspeeds in and around the badgir and summer rooms.

Figure D.2. House B, showing readings of dry-bulb temperature relative humidity and windspeeds taken in and around the badgir and adjacent rooms.

APPENDIX D

AIR FLOW THROUGH TWO BADGIR TOWERS, AN EFFICIENT TOWER AND A LESS EFFICIENT TOWER

D.1 Air flow in a two-directional tower

Figure D.1 show readings taken in and around a two-directional tower in house A (see 8.7.2) on the 23rd July 1977 between 11.50am and 12.30pm .

This tower is oriented to use prevailing winds from the north to the west and also the winds from the opposite direction from the south to the east.

When the readings were taken, the wind from the north west was forced, by the build-up of pressure on the windward face of the tower, into the vents and flowed down the first two partitioned sections of the tower. In this badgir air flowed at a faster velocity within the central shaft, where the main thrust of air was forced downwards by the curved roof.

The negative pressure at the leeward face of the tower exerted suction on the rear face of the tower (BRE Digest, 1970,p.1), similar to the high local suctions on the leeward of chimneys (Sachs, 1978, p.230) and drew air up the leaward shaft of the tower; this air had partly leaked up from the base of the two leeward shafts, and was partly entrained from the room.

The internal sub-division of the tower into three separate shafts allowed the separation of air streams and thus the simultaneous movement of air up and down the tower.

When measured, the north west wind was gusting between 0.5 and 2.5m/sec, generally averaging 1.0m/sec. The air speeds in the windward shafts ranged between 0.5-2.5 m/sec and between 0.5 and 1.0m/sec in the leeward shaft.

Van Straaten found that in even the most favourable conditions of window arrangement and orientation, internal air speeds were only 30% - 40% of the free wind speed (Van Straaten, 1967, p.257).

Air was measured flowing down through the grille from the ground floor, into the basement, at speeds of 0.4-1.0m/sec. In this basement, with a floor area of 20.5m and a height of 3.5m, and an open area in the timber grill of 50cms x 50cms, had the higher reading of 1 m/sec air flow down over the grill persisted, this flow would have resulted in 12.5 air changes per hour in the basement.

D.2 A two-storey tower

Figure D.2 shows a two storey badgir on house B (see 6.8.1). The original, two-directional tower appears to have been inefficient as

a) holes have been added to the four sides, presumably to increase air catchment. It may be noted that the size of the smallest opening, the inlet or the outlet, or in this case the sum total of the inlets or of the outlets, determines the average indoor air speed at given outdoor air speeds (Givoni, 1965, p.44).

b) a higher, four-directional tower has been added on top of the original tower, seated over the central shaft of the lower tower. This placing means that there is no division of the air streams from the upper tower below the top of the lower tower.

Despite these attempts to improve the performance of the tower, the air flow recorded in the tower showed that while a 1m/sec breeze from the north north west was blowing, in the tower, with its long axis to the north, the rate of flow downwards was slow - only 0.2-0.5 m/sec down - and 0.3m/sec up. Thus this tower appears to have been less efficient than the former, because of wrong orientation and design.

A point that could explain the poor efficiency of the tower is that its ground floor outlet is in a side room with two doors into it rather than an open wall or a row of French doors such as are usually found opposite a badgir.

Givoni has shown that internal air speed is highest when the outlet is as large as the inlet and opposite it, rather than higher on a non-opposite wall (Givoni, 1965, p.44). In this house the small size of the outlets and their location may have reduced the internal wind speed.

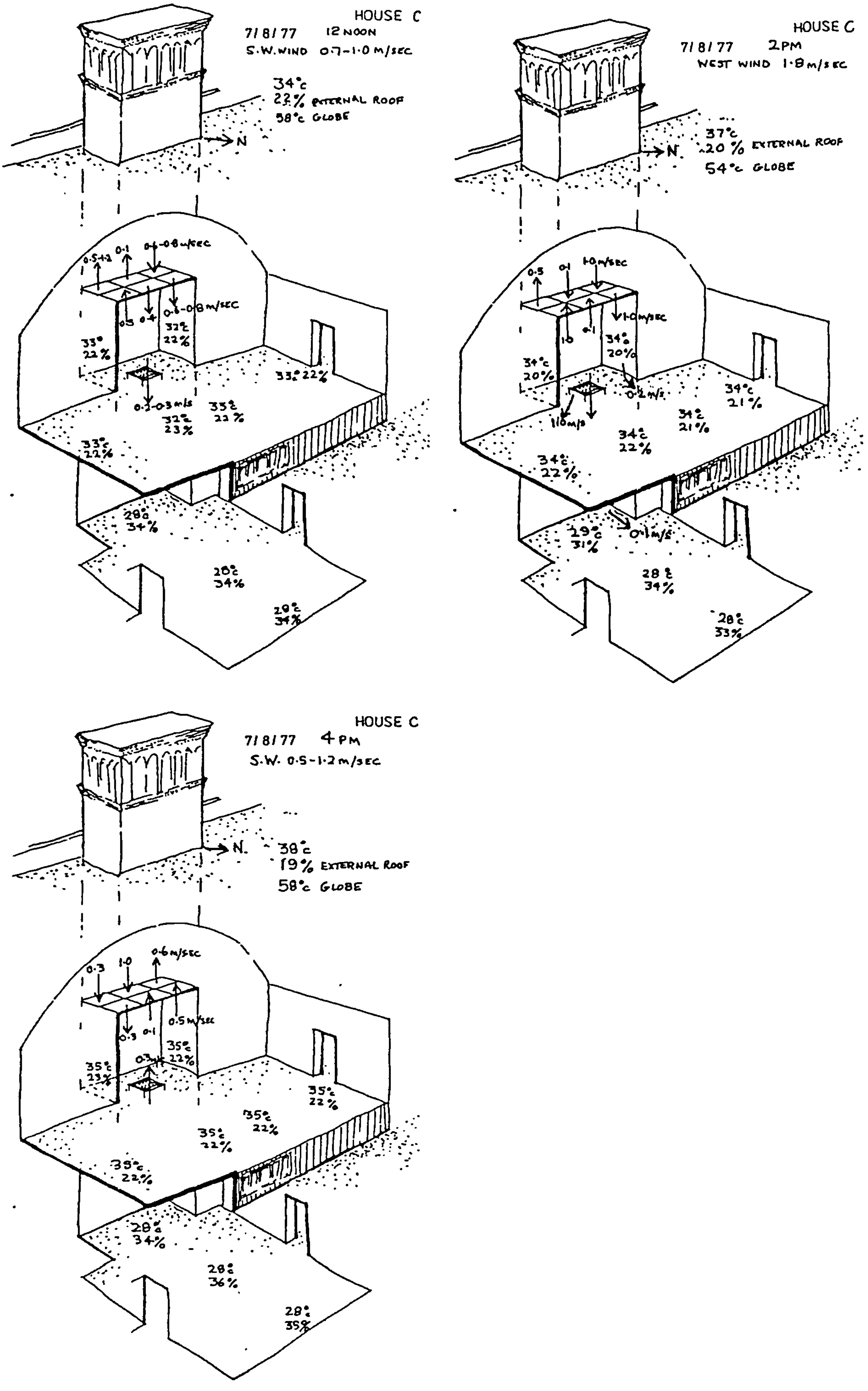


Figure E.1. House C, showing readings of dry-bulb temperatures, relative humidities and windspeeds in and around the badgir at noon, 2pm, and 4pm.

APPENDIX E

AIR FLOW OUT OF THE GROUND FLOOR BADGIR SHAFT AND INTO THE BASEMENT BELOW FOUR-DIRECTIONAL TOWERS

E.1 House C - the Zoroastrian house

Four directional towers take in wind from all directions. Figure E.1 demonstrates how the tower of house C (see 6.7.1) responded to a change in wind direction from the west at noon, to the south west in mid-afternoon, and back to the north west in late afternoon. Three of the six internal divisions of the tower shaft took air down the shaft, and three carried air up the shaft on the leeward side of the tower. The down and up shafts changed in position with the changes in wind direction. Given the same external air speeds, theoretically the highest indoor air speeds would be experienced in the centre of the room when the wind was from the north-east or south-west flowing directly into the largest vents of the tower, and straight across the room (Givoni, 1965, p.44).

As air emerged from the base of the divided shaft, 2.8m above the floor of the badgir recess at the back of the summer room, it did not, in moderate to strong winds, travel straight down to the floor and across the room but moved across the recess from the direction of the strongest downdraught and out diagonally into the room, so making the outward moving air speed strongest on the leeward side of the recess.

The downward movement of air over the timber grill into the basement forced air down through the grill, at 12.30pm and 2.30pm when the downdraught in the main tower was strong. The highest air speeds down through the grill were recorded, predictably, on the windward side of the recess at around 1.0m/sec, while the air on the leeward side of the grill, below the upward moving air in the main tower, moved downward at less than a third of this velocity. At 2.50pm air was recorded moving out of the centre of the badgir recess in the basement at 0.8m/sec.

By 4pm an interesting reversal occurred in the movement of the air across the timber grill into the basement. Air travelled down the windward shafts at 0.4-1.0 m/sec and up the leeward shafts at 0.5-0.6 m/sec. But the air now travelled up through the grill from the basement at 0.1-0.7m/sec, averaging 0.3m/sec. At 4pm with a north west wind, the heated south facing wall of the tower co-incided with the shafts containing upward moving air. Thus the air flowing up these south shafts would be heated and would rise so increasing the rate of flow from windward to leeward shafts through the tower. As a northwest wind is common in the afternoon, this may be a typical pattern of afternoon windflow through the towers. However if the wind is from the south, the direction of flow through the tower would be dependent on the temperature within the shafts and on the wind speed.

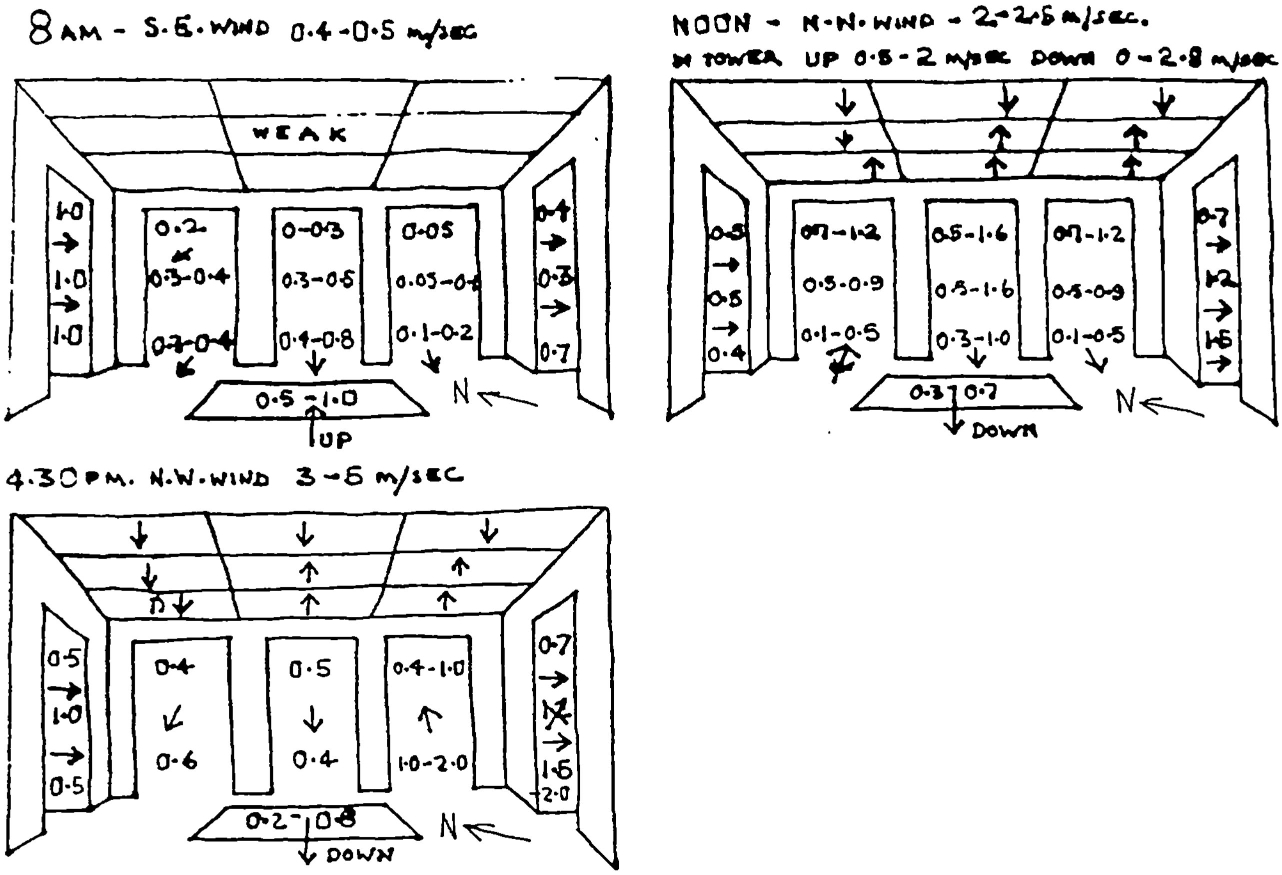


Figure E.2. House E showing windspeeds recorded in the ground floor badgir room at A) 8.30am, B) Noon, and C) 4.30pm

E.2 House E - The Hareem at Bagh-e Dowlatabad

In figure E.2, windflow readings taken in house E (see 6.5.2) show that at 8.30 am with a weak south east wind, measuring 0.4-0.5 m/sec, coming directly into the large aivan.

Air was recorded moving up through the grill from the basement at 0.5-1.0 m/sec. Air flowing into the basement from the south east, the open doors and windows, may have caused the grill to act as an outlet.

In the readings taken at 12am, with a strong west, north west wind, the strong movement of air across the badgir room divided, leaving the space by two doors, 2 and 5, with doors 3 and 4 between them introducing air, at fairly high velocities, which rose up the the leeward shafts of the tower. Thus room air was also entrained to flow up the tower. Air at this time was now passing down through the grill, into the basement at between 0.3-0.7m/sec.

At 4.30pm. when the wind had veered round to the north west, and was very strong at 3-6 m/sec, the air left the badgir room by two doors only, 4 and 5, at 0.4 - 2.0m/sec and entered by three at lower windspeeds of 0.4-1.0m/sec. Air was moving down through the grill at 0.2-0.8m/sec.

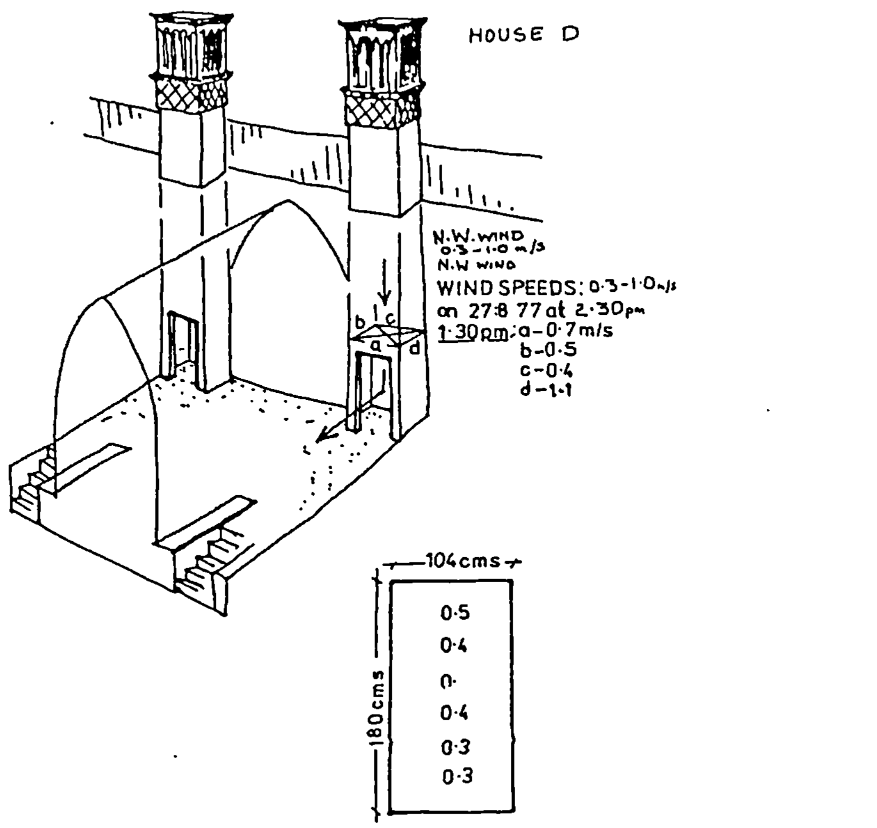


Figure F.1. House D showing windspeeds recorded at 1.30 pm in the base of the badgir shafts.

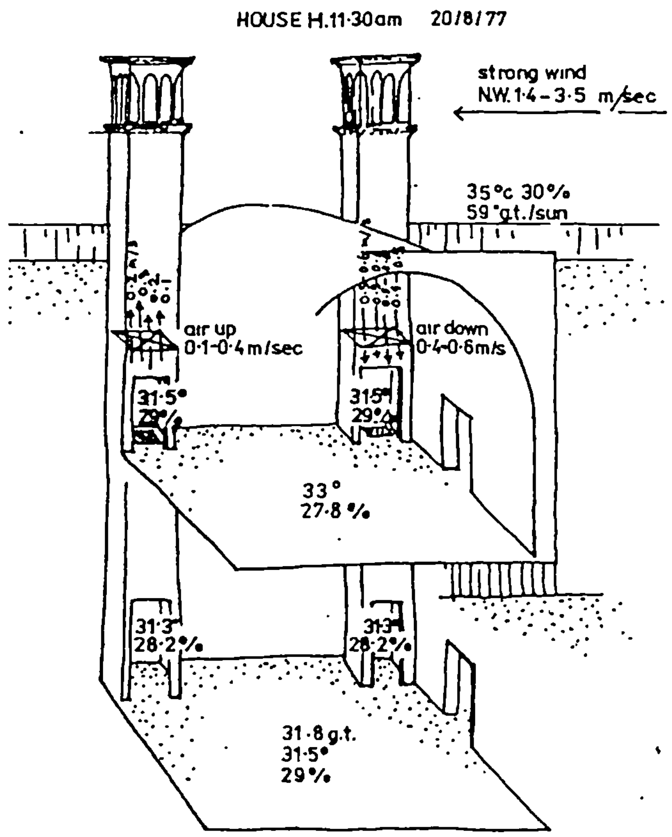


Figure F.2. House H showing the dry-bulb temperatures, relative humidities, and windspeeds recorded in and around the badgirs and summer rooms.

APPENDIX F

RECORDED WIND FLOW IN PAIRS OF TOWERS

Readings were taken in two houses with pairs of towers - at house D (see 6.5.1), and at house H (see 6.8.2).

Paired towers appeared to operate in two different ways.

1) When the wind was from the long axis of the house, from the north east and south west, and arrived at the two towers at the same moment, the towers operated as individual towers, with the windward side of the flow in the four internal shafts of the tower showing a strong down movement of air, and the leeward side with air either moving up the tower or appearing neutral (figure F.1).

2) When the wind direction was across the long axis of the house, from the north west or south east, and the prevailing wind encountered one tower directly before the second, a wind shadow effect, or wake (Sachs, 1978, p.211) caused the windward tower to have predominantly downward moving air while the leeward tower was in a field of low pressure, causing air to be drawn up the four shafts of the leeward tower (figure E.2). This created a through draught between the towers at the ground floor and basement levels.

This cross-draught appeared to be particularly effective in the basement of house H which was recorded in a strong prevailing north west wind of 1.5-3.5m/sec. In this house the similarity of climates (figure E.1) in the two towers at both ground floor and basement level indicated that this cross draught was very direct and efficient in moving and mixing the air.

APPENDIX G

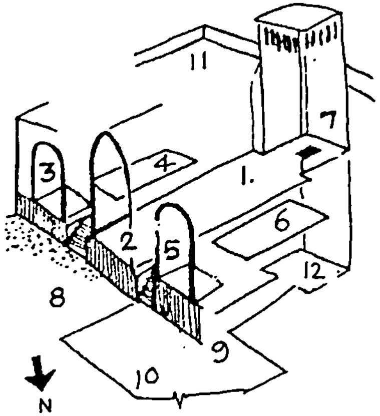
TEMPERATURE AND RELATIVE HUMIDITY READINGS TAKEN IN AND AROUND BADGIR HOUSES IN YAZD

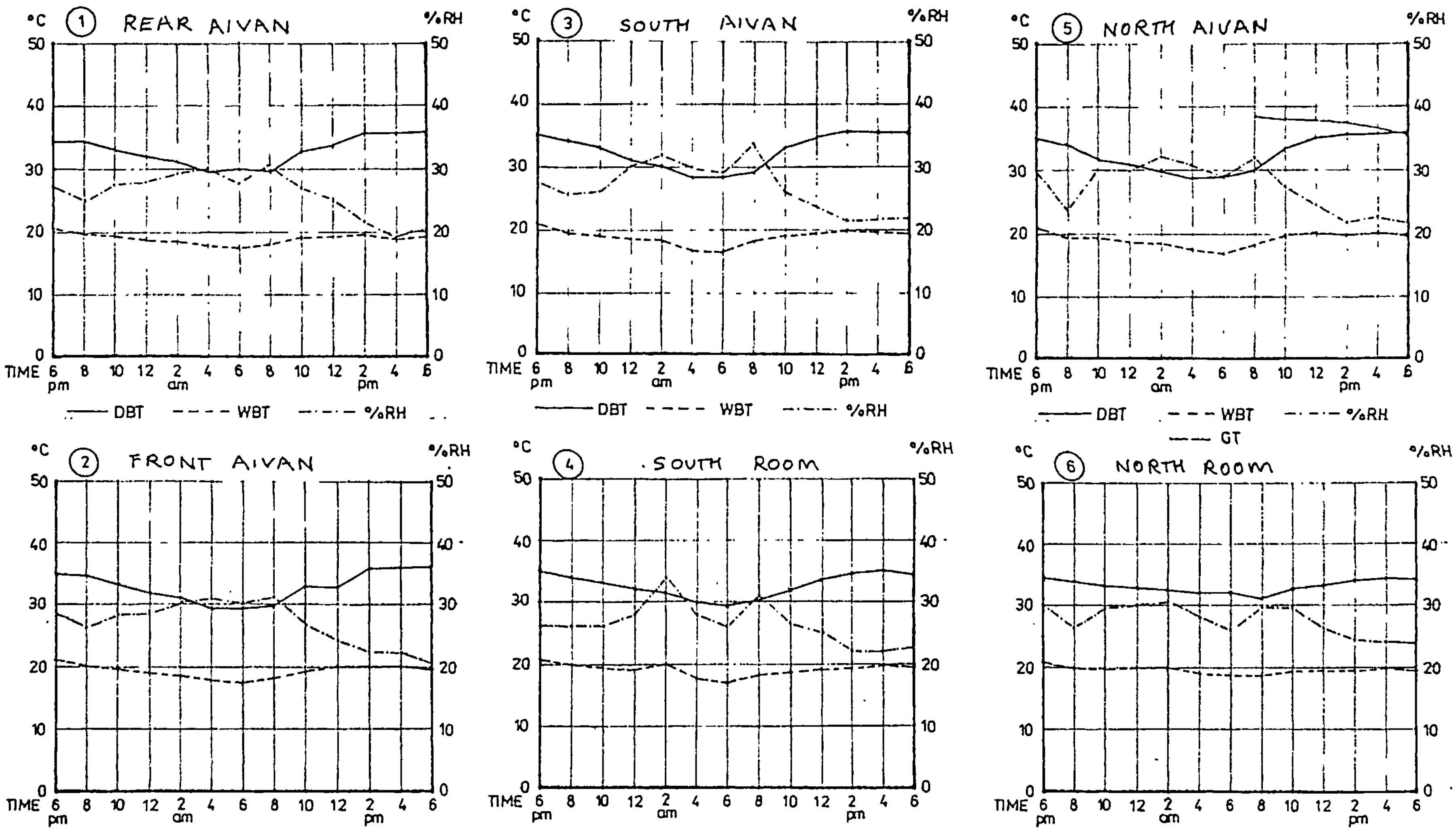
G.1 Air changes down the tower

REDUCTION IN TEMPERATURE AND RELATIVE HUMIDITY OF AIR IN THE BADGIR BETWEEN THE ROOF AND THE BASE OF THE BADGIR AT GROUND FLOOR LEVEL, AND THE DIFFERENCE IN TEMPERATURE BETWEEN THE BASE OF THE BADGIR AND THE CENTRE OF THE ROOM.

HOUSE	roof to base badgir reduction		to centre of room		
	TEMPERATURE	REL.HUMD.	ROOM	TEMP.	HUM.
AT 12 NOON					
House A NW wind, 0.5-1.5m/s	-1.25c	-1%	talar	-2c	-3%
House B NNW wind, 0.8m/sec	-1.75c	-5%	room	-0.25c	-5%
House C NW wind1.4-3m/sec	-3.5c	-1%	talar	-1.5c	+1.2%
House D SW wind 1.0m/sec	-1.5c	-1%	room	0	-0.5%
House E W wind 2-2.5m/sec	-1.25c	-.5%	aivan	+0.25c	-1%
AT 2PM.					
House D W wind 0.7-1.0m/sec	-2.3c	-0.4%	room	+0.4c	-1.5%
House E NW wind 2-4m/sec	-2.0c	-1.7%	aivan	-0.1c	0
AT 4PM					
House D NW wind 0.5-1.2m/sec	-3.9c	+3.3%	room	+0.25c	+0.4%
House E W wind 3-6m/sec	-0.9c	-1.8%	aivan	+0.5c	+1.2%

From the above table it appears that at mid-day air entering the ground floor rooms is commonly between 1-1.75c cooler than the ambient external air and is drier than the external air by 1.0% - 5% R.H. Thus air was being cooled and





Figures G.1. and G.2. House E. graphs showing wet and dry-bulb temperatures, globe temperatures where taken, and relative humidities over 24 hours in 12 different spaces:
1) rear of the aivan 2) front of the aivan 3) south aivan
4) south-west room 5) north aivan 6) north-west room

dried as it descended down the tower to the ground floor rooms. This indicates that there is a considerable loss of moisture to the interior surfaces of the shafts. One would expect the descending air as it cools and condenses to increase in relative humidity by 1-2 %.

An interesting result was the noticeably greater cooling that occurs in the small enclosed shafts of the paired badgirs in house H (figure F.1), where the air is 3.5 c cooler at the ground floor than at roof level. These readings were taken in a strong wind, and the efficient cross draught and the smaller shaft, and the wind speed, may have influenced this considerable drop in temperature. The drop was noticeable in the areas of the talar adjacent to the doors of the shaft, but had less effect on the climate in the centre of the talar where the temperature was only 2c lower than the roof temperature.

G.2 Badgirs in the ground floor summer room

Air introduced into the summer room by the badgir was generally only a few degrees centigrade cooler than the air already in the summer rooms. In the open talars, the air issuing from the badgir was up to 1.5c to 2c cooler than the air in the talar.

In mid-afternoon the higher outside temperatures meant that even with a reduction down the tower of up to nearly 4c, air entering the room is only marginally cooler than the air already in the room, ie. lower by about 0.5c. The air introduced by the badgir was then heated up again on its

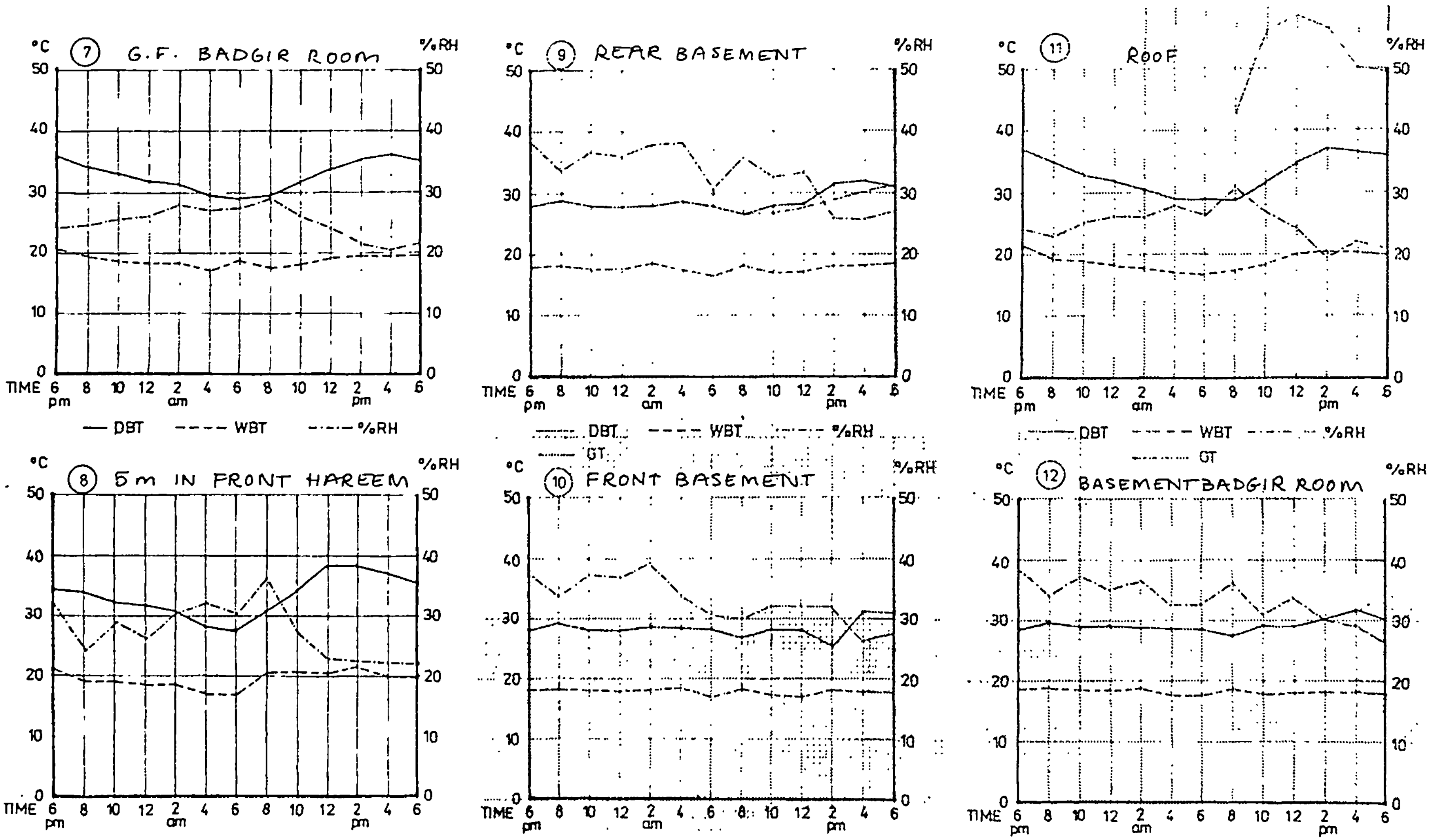


figure G.2. HOUSE E.

7) ground floor badgir room 8) 5m in front of building in garden 9) rear of the basement room 10) Front of the basement room 11) roof 12) basement badgir room.

entry into the room.

In terms of the diurnal variation of the temperatures and relative humidities associated with badgirs, the best data came from the 24 hour readings done at the Hareem, house E, on the 1st of August 1977 (Figures G.1 - G.3)

During the day the temperature on the roof and in the summer room below the badgir parallelled each other very closely. After 10pm at night the roof air became up to 2c cooler than the badgir room At 2am, the heat stored in the mud brick walls was re-radiating into the building, counteracting the tendancy of the cooler cross-draught to reduce the room temperature. At no time did the ground floor room have a higher temperature than the roof.

The north room, which had only one door into it, no cross ventilation, and was isolated from any direct solar radiation, a far more stable climate, varying by only 3.5c, from 31c to 34.5 over the 24 hours, was experienced. In the ground floor the badgir room had a diurnal temperature range of 6.8c.

G.3 <u>Badgirs in the basements.</u>

FIGURE X SHOWING THE REDUCTION IN TEMPERATURE AND RELATIVE HUMIDITY FROM THE ROOF TO THE BADGIR RECESS IN THE BASEMENT AND THE TEMPERATURE AND RELATIVE HUMIDITY DIFFERENCES BETWEEN THIS RECESS AND THE CENTRE OR FAR SIDE OF THE BASEMENT

HOUSE	Roof to basement change		change across basement	
Noon	TEMP c	RH %	TEMP c	RH %
House A	-2.0	+0.2	-6.3	+15.2
Qanat tunnel in basement				
House B	-4.4	+2.2		
2nd grill below hawa kesh				
House C	-4.2	-1.8	+0.2	+0.8
twin towers,high wind				
House D	-5.9	+13.8	-0.2	0
Double basement roof				
House E	-6.2	+11.5	-0.55	-1.3
Deep basement				
4pm				
House D	-9.75	+15.4	-0.25	+0.2
House E	-6.75	+ 7.0	+1.35	-2.5

There was a considerable difference between the basement and the roof temperature.

Four factors may have been of importance here;

1) the efficiency of the air circulation system in the basement, including design details such as a second grill below a roof ventilator, <u>hawa kesh</u>, in house B;

2) The external wind speed and temperature, as in house B where the strong wind caused a considerable rise in temperature in the basement by introducing a strong stream of warm air, a point indicated by the low humidity in this basement;

3) The size and depth of basement. In the two largest and deepest basements, at houses E and C, the lowest basement

temperatures were recorded;

4) The inclusion in the basement of a tunnel directly to a qanat stream below the basement. In house A the dramatic drop in temperature in front of the tunnel to the qanat, and increase in humidity, combined with a globe temperature in the centre of the room of 27c, emphasises that not only was cool, humid air being introduced into the basement from the qanat, but also comparatively hot, dry air was being circulated by the badgir through this basement room.

One process that was apparent in the 24 hour readings in the basement of house E was the swing in the direction of air currents. Figure G.2 shows that in conditions of a light easterly wind, air was drawn up through the grate from the basement. This reversal of current happened regularly, and the windflow over the grate changed completely over a short period. The relative humidity readings in figure G. show a regular vascillation of the humidity. At one point it resembled the reading for the roof, and at the next, the reading for the front of the basement and the garden.

The cause of this is likely to have been the reversal of the air flow through the basement. This manifests itself in fluctuations in the temperature readings for the badgir room in the basement, with lower humidities corresponding to higher temperatures.

Despite such minor changes, even with an external variation in temperature of 10c, the basement of house E changed only by 2.65c.

APPENDIX H

GLOBE TEMPERATURE READINGS

H.1 In badgir houses

The globe temperatures at ground floor level and in the basements fluctuated 5c and 4c respectively with peak temperatures at 6 - 8pm and and lowest temperatures at about 8am.

In the ground floor rooms the air temperature appears to have been warmer than the globe temperature from about 10am until 5pm - 8pm, the period at which the walls of the room would have been heated. Thus the rooms were being warmed for 7 - 10 hours a day, and cooled for between 14 to 17 hours.

In the basements, the readings taken show that the globe temperature was consistently lower than the air temperature. This suggests that rather than the cool night air reducing the basement globe temperature, the space was reverting to ground temperature, The lowest basement globe temperature was 26.9c. The air temperature fell in tandem with the globe temperatures in the basments. Thus the effect of the badgir in the basements, in terms of temperature, appears to be solely that of heating.

The Mean Radiant Temperatures has been calculated using the following formula published by Bedford. (Bedford, 1940,p.x)

$$(tg+460)^4 \times (10)^{-9} = (tg+460)^4 \times (10)^{-9} + 0.1029 \quad v(tg-ta)$$

where ts = temperature of surroundings, tg = globe temperature in degrees farenheit, ta = air temperature in degrees farenheit, v = velocity of air in feet per minute which has been taken as 101 ft/min in the ground floor (0.5m/sec), and 50.2 ft/min in the basement (0.25m/sec)

Where globe temperature was less than air temperature:

(ts+460)4 x (10)-9 = (tg=460)4 x(10)-9) - 0.1029 v(ta-tg)

Using these formulae the Mean Radiant Temperatures can be calculated for the ground floor and basement rooms beneath the badgir at various times of day: G.F. = GROUND FLOOR B = BASEMENT of the house E.

Temperatures are all given in degrees centigrade:

TIME	ROOM	AIR TEMP.	GLOBE TEMP.	MEAN RADIANT TEMP.
8am	G.F.	29.8	30.6	31.7
	B.	27.1	26.9	26.5
2pm	G.F.	35.5	34.7	33.8
	B.	31.9	29.2	27.9
8pm	G.F.	34.4	34.0	33.2
	B.	29.4	29.0	28.5

These readings were taken on a warm rather than a hot day and emphasise that in mid-afternoon warmer air is being introduced into both the ground floor rooms and the basement. This air is warmer than the Mean Radiant Temperature of the ground floor room by 0.6c and than that of the basement by 4c.

H.2 Comparison with Globe Temperatures and Mean Radiant Temperatures in houses without badgirs

Figures K.8, graphs 8 and 10, show that in the north facing summer room for approximately 15 hours of the day the globe temperature and the air temperature were similar, with the air temperature only marginally higher than the globe temperature for 6 hours of the day and cooler for 3 hours.

COMPARISON OF MEAN RADIANT TEMPERATURES IN HOUSES WITH AND WITHOUT BADGIRS. G = ground floor summer room B = Basement

Time		House E - with badgir	House G - without badgir
8am	G	31.7c	34.8c
	B	26.5c	25.5c
2pm	G	33.8c	35.3c
	B	27.9c	25.5c
8pm	G	33.2c	35c
	B	28.5c	25.2c

In the summer unventilated room in house G the similarity between the Mean Radiant Temperature and air temperature indicates that there was no significant cooling or warming of the walls, floor, or ceiling of the room throughout the 24 hours in conditions where the globe temperature of the room changed only 1c throughout the 24 hours. The globe temperature in this ground floor room in house G remained consistently between 34c and 35.5c all day and night.

In the non-badgir basement the globe temperature remained stable at 10c lower than the ground floor room, between 25c to 26 c throughout the 24 hours with the air temperature of the non-badgir basement remaining slightly higher than the globe temperature at 25.5 to 26.5c (figures K.7 and K.8).

In house E (figure 9.5), the recorded globe temperatures range between 27c and 31c in the basement, and in the ground floor rooms between 30.6 and 37c in the ground floor rooms, that is a difference of 4c and 6.4c respectively. This demonstrates the efficiency of the badgir in removing heat from the surfaces of the ground floor summer rooms during the night.

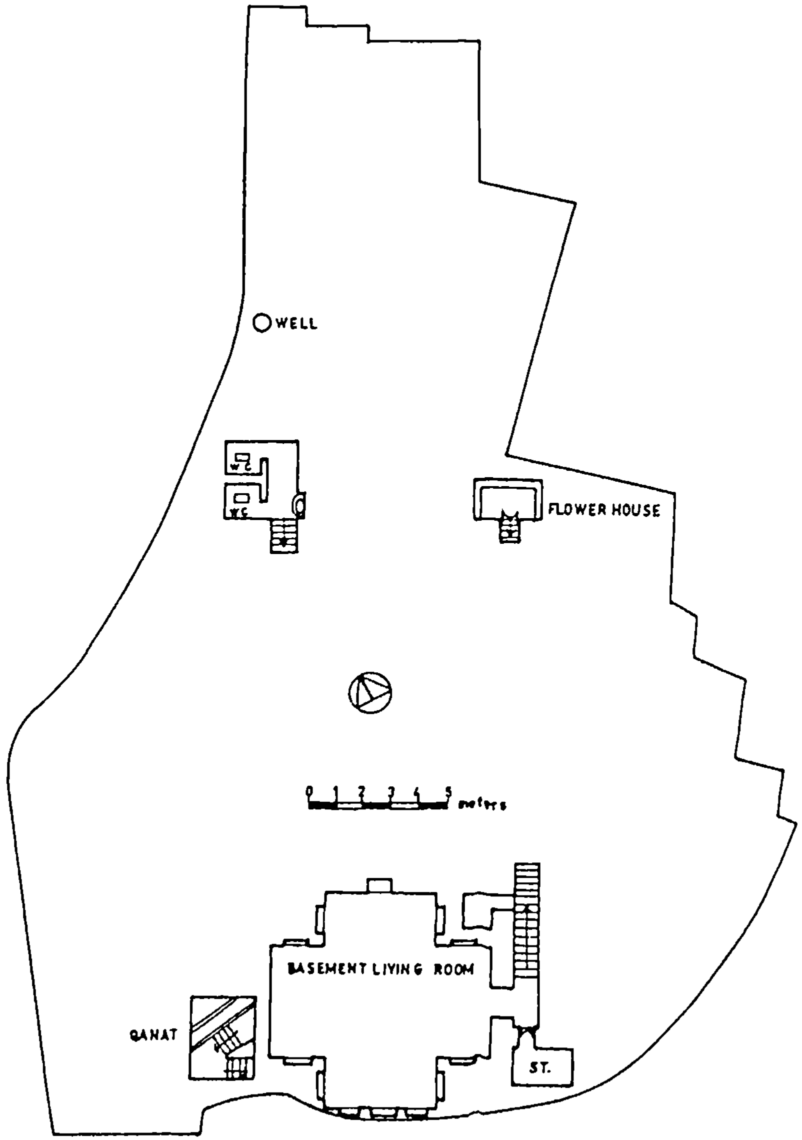


Figure K.2. Basement plan of house F.

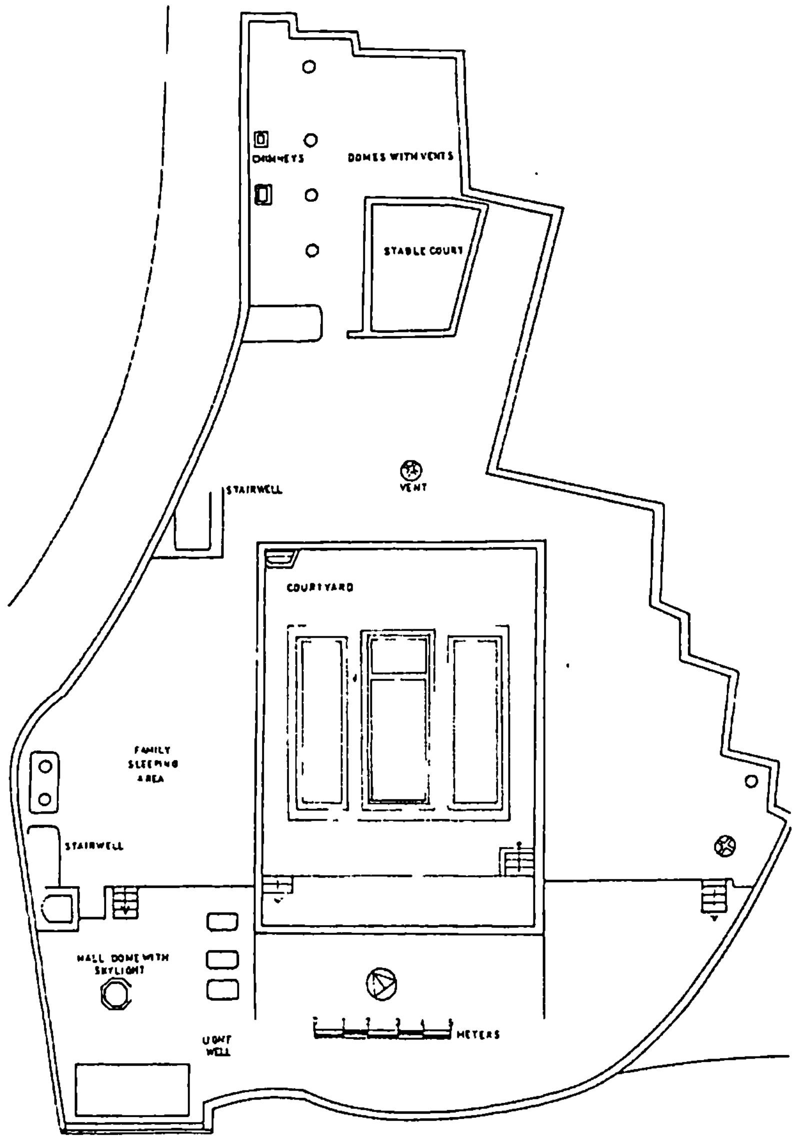


Figure K.1. Roof plan of house F

APPENDIX K

CLIMATIC PERFORMANCE OF HOUSES WITHOUT BADGIRS

K.1 Descriptions of the two houses without badgirs in which 24 hour climatic readings were taken

K.1.1 Mashrouteh house - House F

Built in around 1925 by Mr. Mashrouteh's father, a prosperous bazaar merchant, this mud brick house has one large courtyard, the andaruni, and two small associated yards, a stable and a fowlyard (figure K.1 and 2).

The house has a three-door winter room on the north wall of the court with, to its east, a small semi-sunken room known as the golkhaneh, or flower room, above which is a tiny chamber used now for storage of clothes, which may well have been a small bedchamber.

The summer quarters of the house comprise a four-door summer room, facing north, a small well-furnished guest room adjacent to it on the west wall of the court, and a deep basement, to the east of the stairs leading down to the qanat stream beneath the house. One of the most used summer living areas is the aivan, or open air terrace, in front of the four-door summer room. This aivan is used in the mornings and evenings as a sitting area, in preference to the summer room. The latter is sparsely furnished at this time of year and used primarily for storage.

The other rooms around the court are used for storage, except one in the centre of the west wall of the court in which Mr. Mashrouteh's mother lived all year round, leaving it only to go up to the roof to sleep in summer.

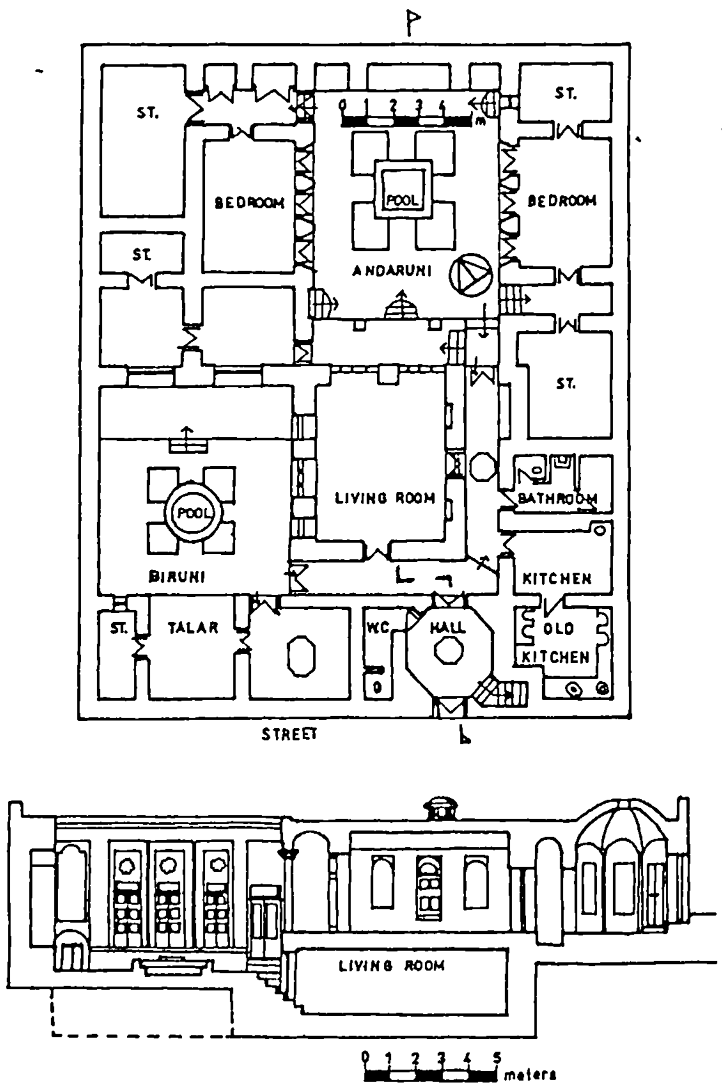


Figure K.4. Ground floor plan of house G, and north-east to south-west stepped section through the andaruni o house G.

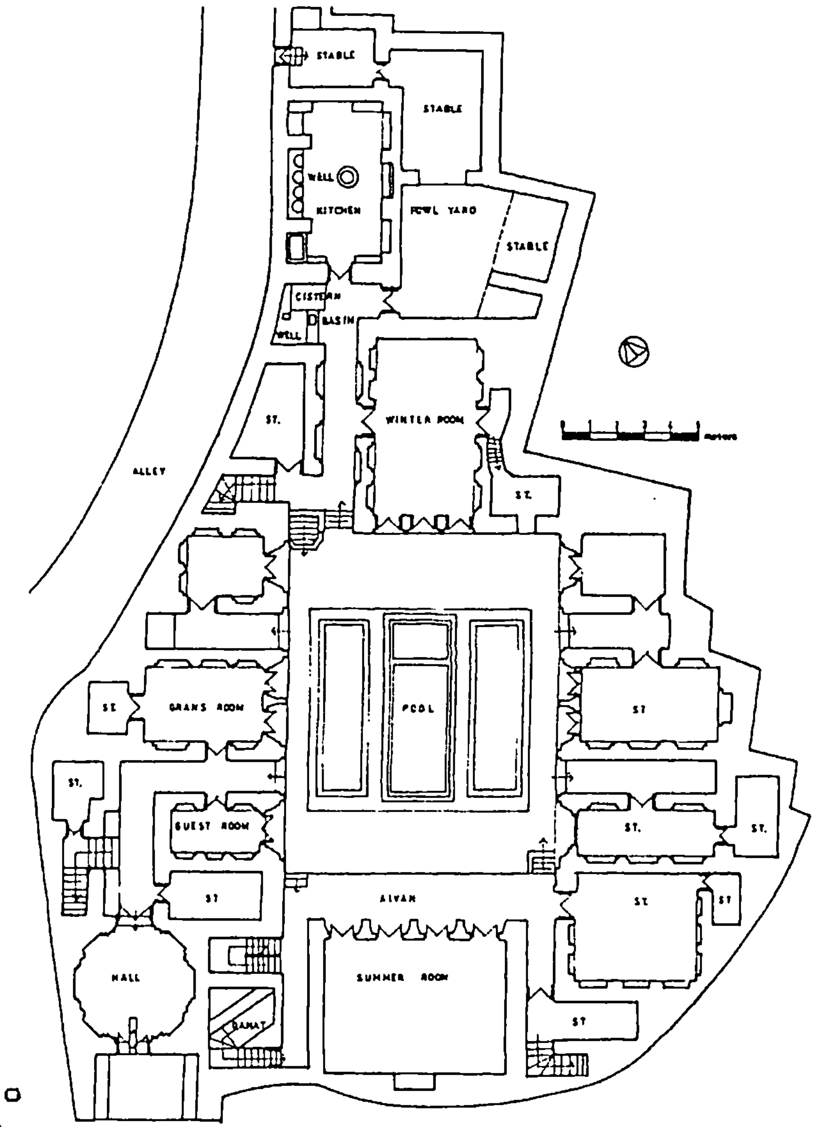


Figure K.3. Ground floor plan of house F.

K.1.2 House in Kudakestan Rashid - House G

This baked brick house built in about 1955, by a Zoroastrian family, is a good example of the modern traditional house in Yazd (figure K.4).

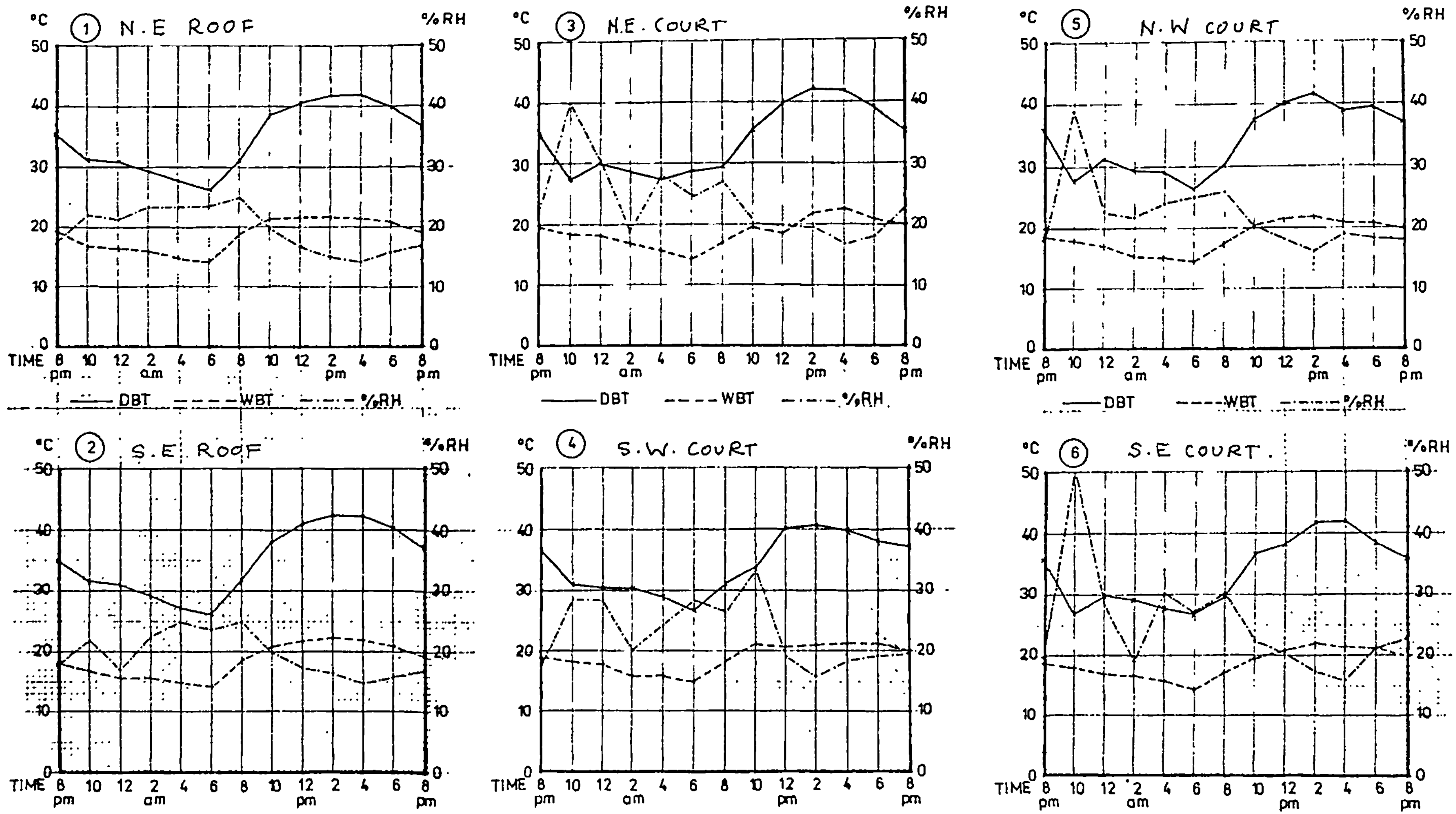
It has two courtyards, a small biruni (A) and a slightly larger andaruni (B). The andaruni has to its south a summer living room, with an arcaded terrace raised above the court, with bedrooms to the east and west of the courtyard. The main summer living room is flanked to the east by a corridor, kitchens and bathroom and to the south by a corridor and entrance hall, stairs and lavatory. These spaces serve to isolate it from direct radiation from the east and south.

The biruni has two winter rooms with paired glazed doors facing south, an open talar and an enclosed summer room to the south of the court.

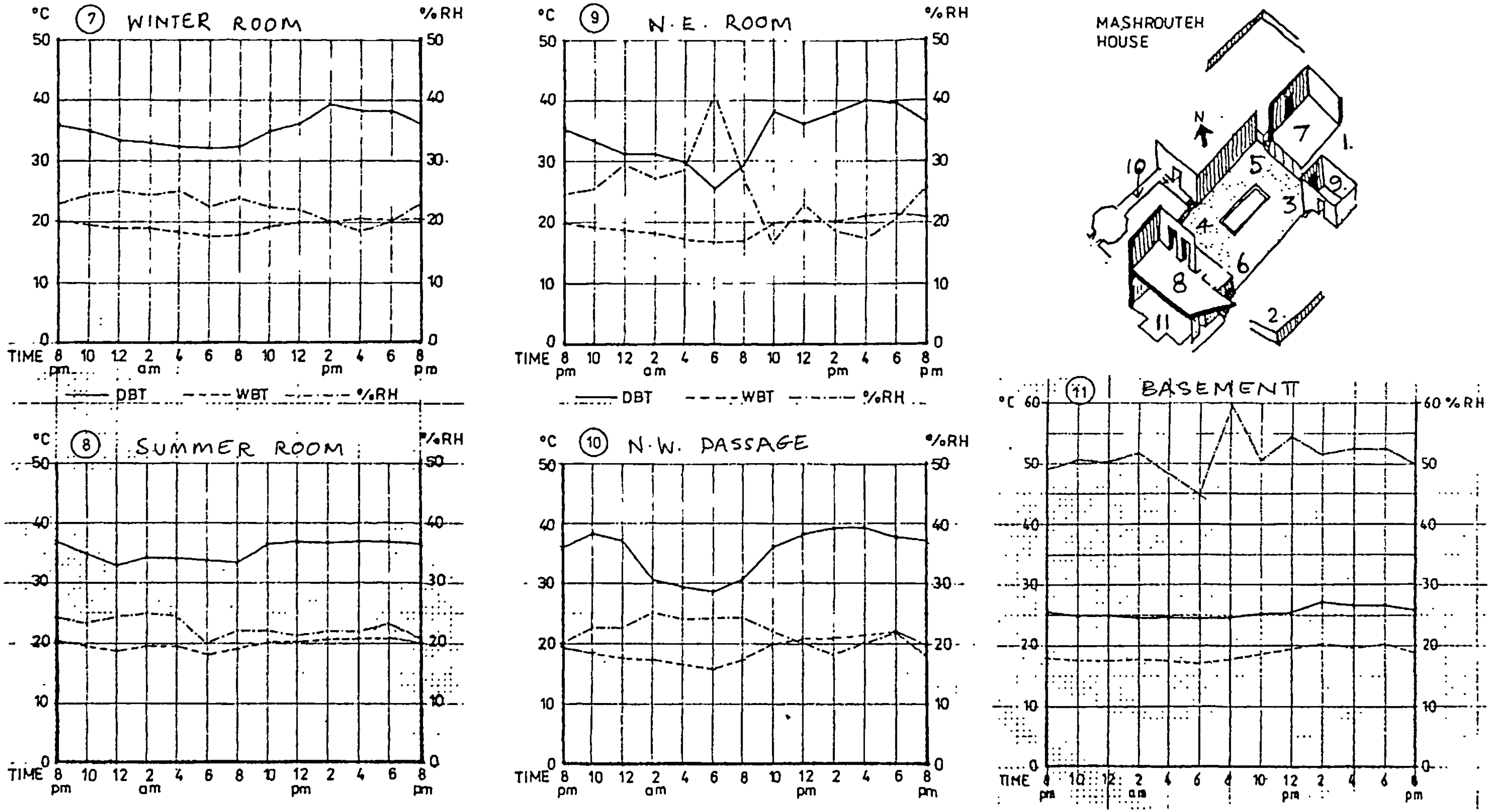
. There are basements beneath the rooms of the three wings of the andaruni and climatic measurements were taken in the basement beneath the main summer room of the house.

K.2 Roof climate

The following data on roof and courtyard climate could well have been recorded in two courtyard houses with badgirs, and in fact provides better data on the summer roof and courtyard climate than those readings taken at house E. as the maximum daytime temperature when house F and G were measured was 42c, a not unusual temperature for mid-summer in Yazd. The readings at the house E were taken on a day



Figures K.5. and K.6. House F. Graphs showing wet and dry-bulb temperatures, and relative humidities over 24 hours in: 1) north-east roof 2) south-west roof 3) north-east court 4) south-west court 5) north-west court 6) south-east court



fig·K·6· 7) winter room 8) summer room 9) south-east room 10) north-west passage 11) basement that was predominantly clear but muggy', with a maximum dry- bulb roof temperature of 37.4c. See figures K.5 - K.8 for graphs of the complete 24 hour readings of the two houses.

The roof was the hottest area of the house. Open to direct solar radiation and to the prevailing winds, the diurnal range was large. On house F, measurements taken on the 25th July show a diurnal range of 16c (figure K.5 - graphs 1 and 2). In house G, measured three weeks later, the DR was 12.8c (Figure K.8 - graph 9). Both houses had roof temperatures that went above 42c in mid- afternoon, but the house measured in August, house G, had a minimum night-time temperature of 29c while house F, measured in July, had a lower minimum of 26c. A factor influencing this difference of 3c between the two minimum readings, both taken on clear nights, may have been the increased heating up of the building mass below, or indeed the land mass in general, in the summer.

The diurnal temperature pattern on the roof was regular. Maximum temperatures were recorded at 2pm when the peak air temperatures co-incided with high, rather than maximum, levels of direct and re-radiated radiation. The temperature plateaued between 2pm and 4pm at about 42c, and then decreased steadily throughout the night until sunrise, just before which minimum temperatures were recorded.

During the daytime in house G, roof temperatures began to rise as soon as the sun touched the roof just after 6am. Between 6.30 and 8.30 am, when the fastest temperature

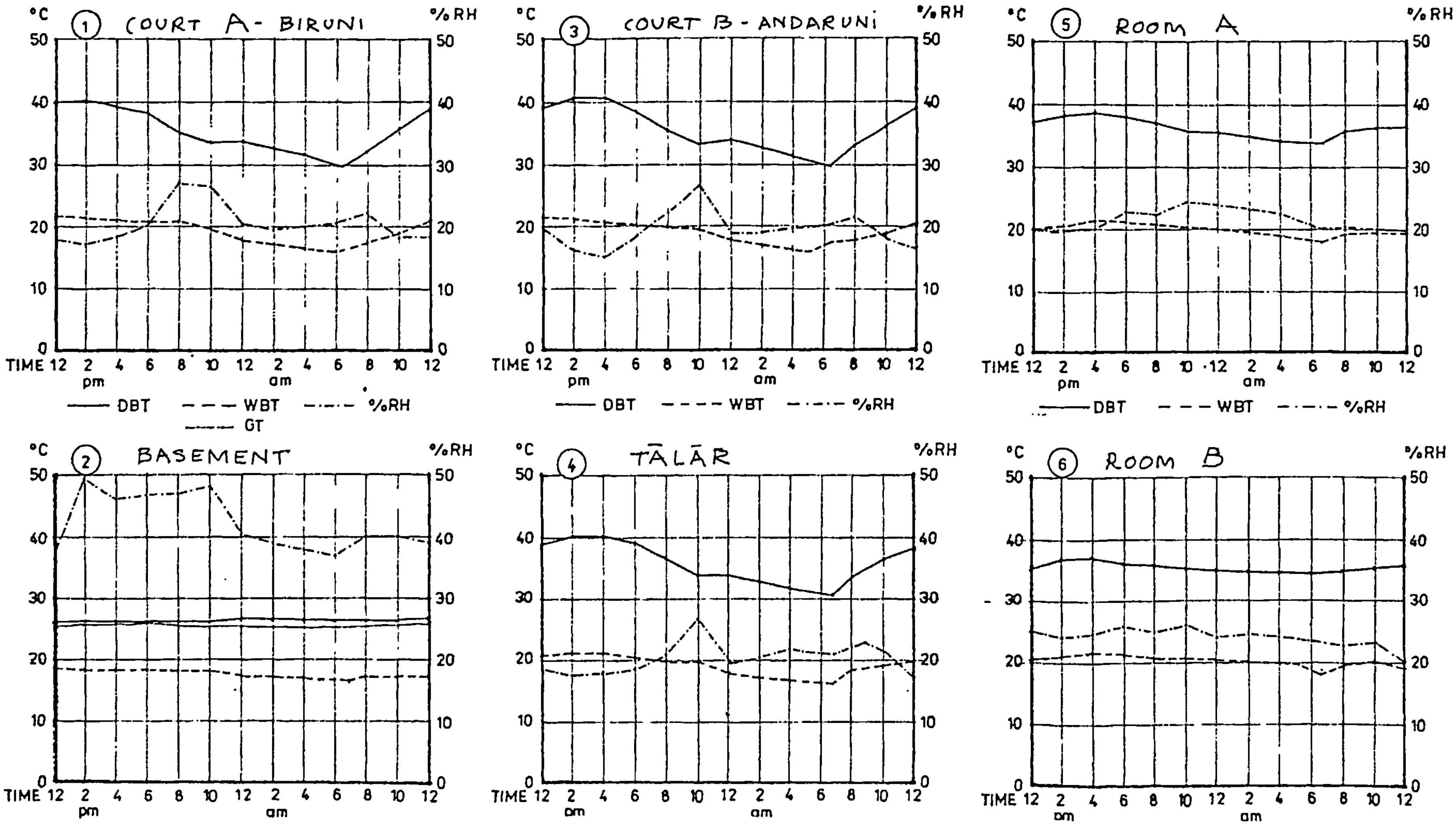


Figure K.7 and K.8. House G. Graphs showing wet and dry-bulb temperatures, globe temperatures where taken, and relative humidities over 24 hours in 1) biruni courtyard (A) 2) basement 3) andaruni courtyard (B) 4) talar 5) room A 6) room B

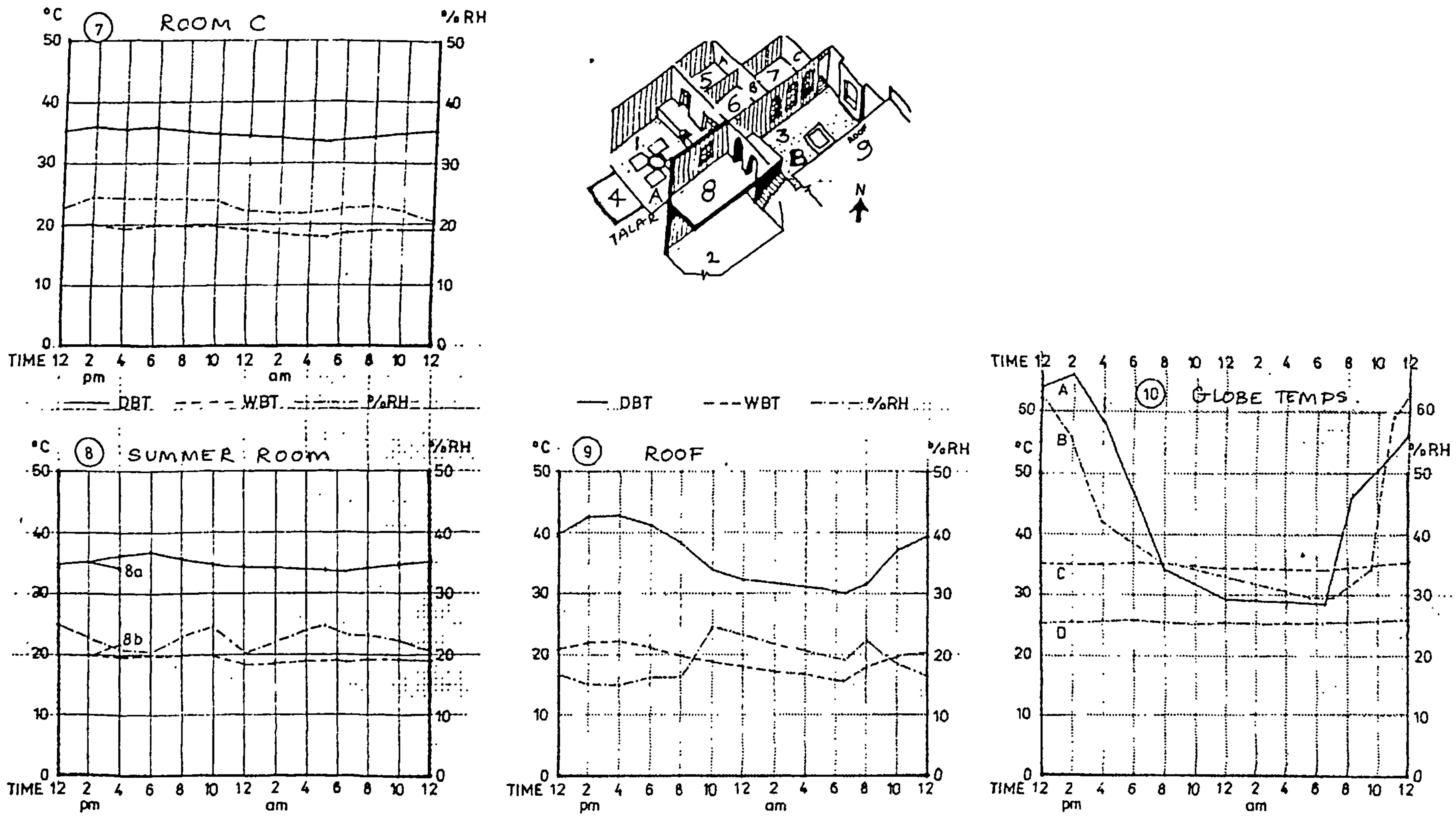


fig. K.8 7) room C 8) summer living room 9) roof

HOUSE G 10) shows the globe temperatures in a) courtyard A
b) courtyard B c) ground floor summer room of andaruni and
c) basement.

increase occured, a rise in dry-bulb temperature of 6.6c was recorded on the roof while at the same period the globe temperature had risen by around 18c (figure K.8 - graph 10).

K.3.1 Courtyard climate

Houses in Yazd are generally orientated as shown in figure K.3, with the summer rooms facing north east or north west. In both cases the vents of the badgir, usually with its long axis perpendicular to the south wall of the summer room, face towards the north-west.

A number of studies have been done on the impact of orientation on the level of solar radiation received in the court (eg. Mohsen, 1978; Numan,1978). Kuba in his work in SUDAN has shown that the house may rotate within a 40 degree arc around the north/south axis without significantly altering the level of solar radiation input into rooms facing north (Danby, 1973, p.60-61). No readings of radiation on surfaces in the houses of Yazd were taken.

Comparison of the readings in Yazd taken on the roof and in the courtyards of both houses suggest that there was only a marginal difference between roof and courtyard climates. Figures of 2c or 3c are not significant in terms of comfort when temperatures rise above 42c. However the patterns of courtyard heating display a regular behaviour and conditions can vary considerably across the court at different times of the day (figure 9.2).

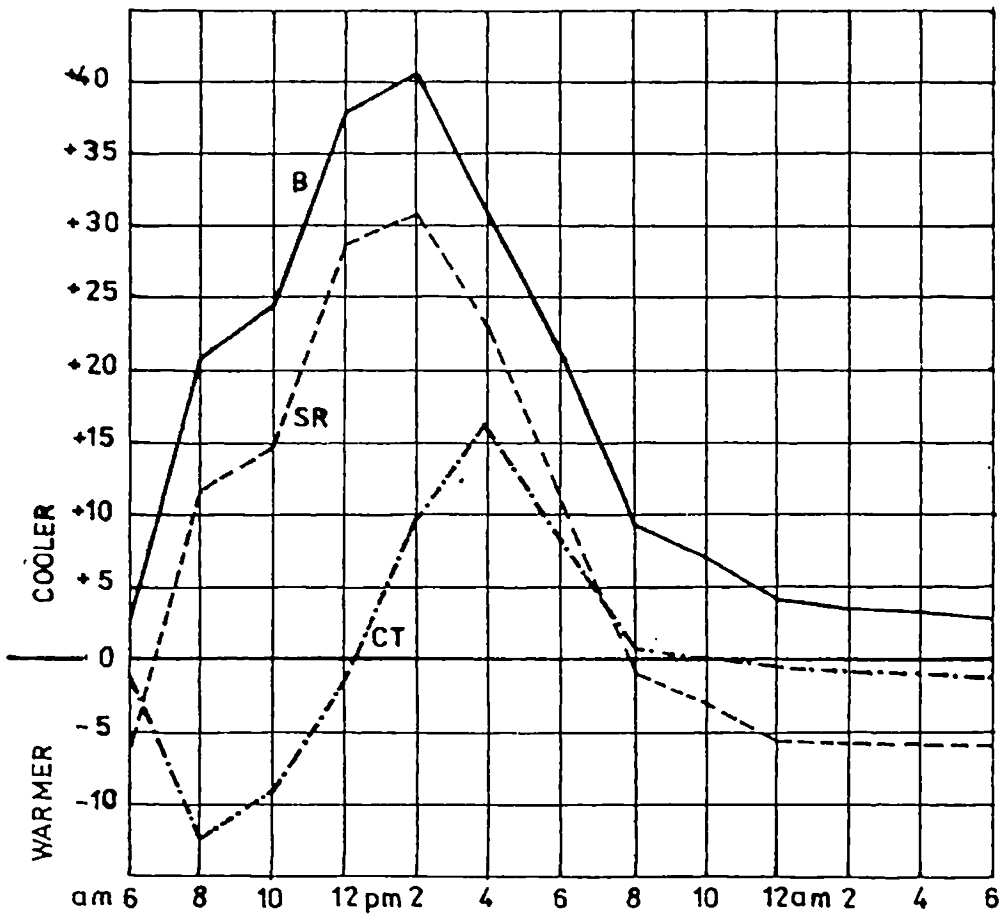


Figure K.9. Graph showing the globe temperatures in house G, subtracted from the globe temperature of the roof to show the extent to which the space is warmer or cooler than the roof. B) basement SR) summer room CT) courtyard.

K.3.2 Day-time courtyard climates

The areas of the courtyard in direct sunlight were generally 0.5c - 1c lower in temperature than on the adjacent roof and had a higher relative humidity by up to 4%. In the larger courtyard (10m x 14m) of house F, the difference between temperatures in the sun and in the shade were 1-2c, with one interesting exception. Just below the dais in the south-west court, on the aivan, is an area where the family ate breakfast, and sat until c.10.30 am (figure K.5 - graph 4). Here the temperature at 10am was almost 4c cooler, with a 12% higher relative humidity than the opposite sunny corner. This illustrates how the occupants distinguished between, and utilised, subtle temperature differences within the court.

K.3.3 Evening and night time courtyard climates

At 5-6pm in house F the family emerged to sit on the dais at the south of the court in temperatures up to 37-38 dc. As this was considered hot, the dais and south end of the court were sprayed with water so reducing the temperature by about 1c, to below the 37c which is body temperature. By 8pm the courtyard, with temperatures between 35.2 and 37.3dc, became warmer than the roof. In conditions of a fresh wind (25/7/76) the difference between court and roof temperatures was up to 4c, but in conditions of little or no wind the court and roof were the same temperature (26/7/76). Although the north east corner of the court was the hottest part of the court at 6pm, it was cooler than both western

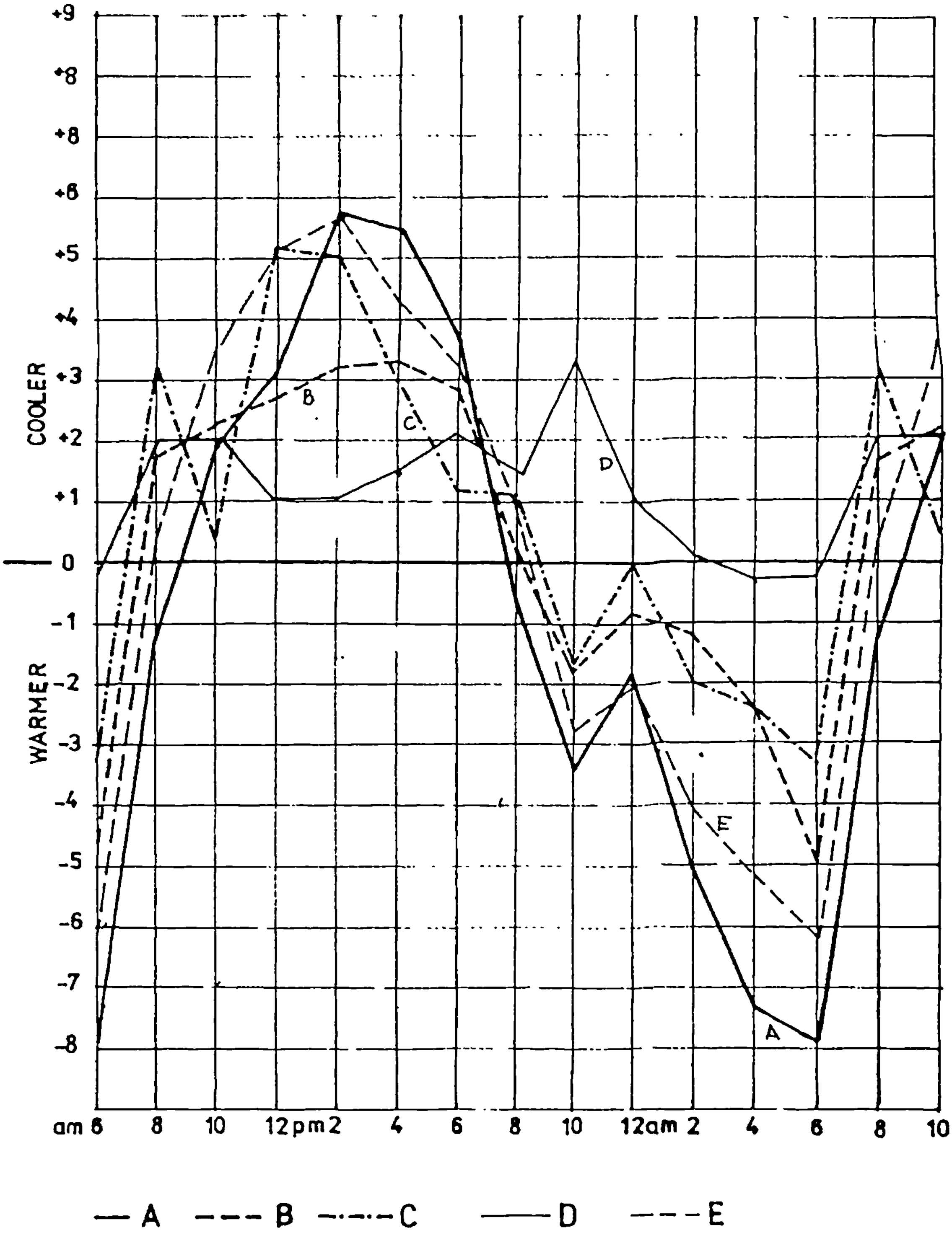


Figure K.10 Graph showing air temperatures in house F subtracted from the roof temperature to indicate to what extent a room is warmer or cooler than the roof. A) summer room B) north-west passage C) south-east room D) courtyard - watered at 8pm E) winter room.

corners by 8pm, due to a fresh north west wind.

Figure 9.2 shows that only between 1pm and 9pm are the smaller courtyards cooler than the larger courtyard.

K.4 Climate in ground floor rooms without badgirs

K.4.1 The climate in north facing summer rooms

In Yazd the main summer living room always faces north, north-east or north-west. There are two types of main summer room, the open talar or aivan and the closed summer room with three to seven glazed French doors opening onto the courtyard. Both types will be considered below (figures K.10 and K.11).

K.4.2 The open talar

In house G, court B, is a small talar open to the court with its rear wall backing on to an alley. Its small size, the heat gain through the exposed south wall, and the high re-radiation levels from the walls of the small court combine to make this an extremely hot space, in which the climate is little modified by the prevailing north-west wind, although this is caught in the barrel vault of the talar roof which is raised above general roof level.

Throughout the day and night this talar was only a maximum of 2.7c cooler than the roof temperature, and only between 10pm and 8am were temperatures lower than 36dc, ranging for the rest of the day between 40c and 36.5c. Thus for the summer months this space was hardly usable as a living area even for the acclimatised Yazdi. Local residents confirmed that this talar was little used in summer.

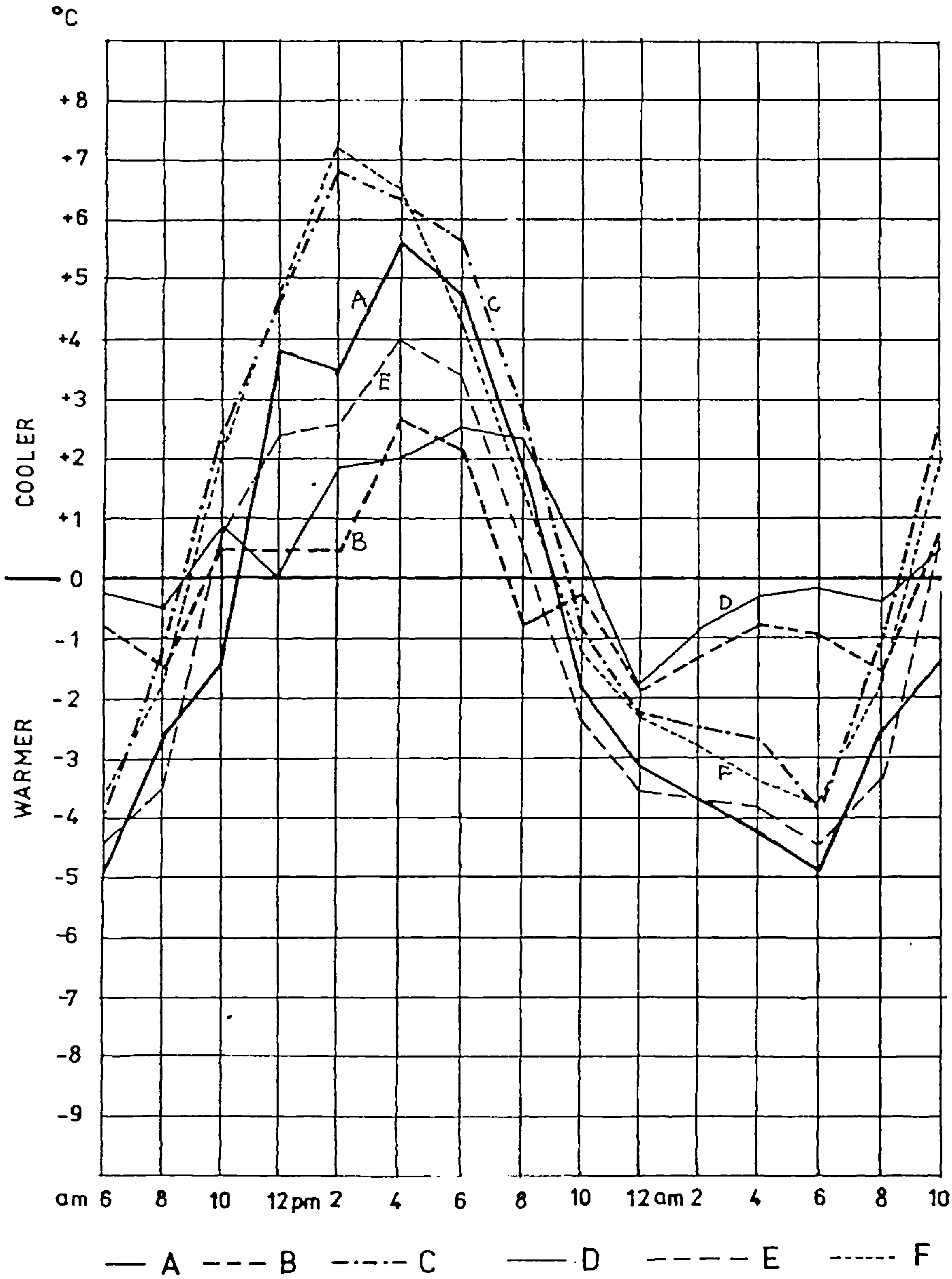


Figure K.11. Graph showing air temperatures in house G, subtracted from the roof temperature to indicate to what extent a room is warmer or cooler than the roof. A) room B B) talar C) room C D) courtyard A E) room A F) summer room of the andaruni.

The larger talars in larger courtyards would of course be less subject to re-radiation from the courtyard walls because of the larger distances between them.

K.4.3 3-7 door summer rooms

In house G the north and east facing rooms with French doors were slightly cooler than the small south facing winter rooms A and B, in court GA, which also have glazed French doors. These latter winter rooms varied up to 5c in temperature throughout the 24 hours (figure K.7 - graphs 5 and 6).

In the andaruni of house G, court GA, as in many Yazdi houses, the rear wall of the summer room is protected from direct radiation by a bank of buffer rooms, including corridor, hall, W.C., and staircase. This may well contribute to the stable climate experienced in this summer room, which varied by a maximum of 3c over the 24 hours (figure K.8 - graph 8). The pattern of heating in the ground floor room was similar to that in the basement below (figure K.9).

In house F an anomaly occured; the south facing winter room was generally cooler than the north facing summer room (figure k.6 - graphs 7 and 8). Both rooms have a row of glass French windows facing on to the court which were normally closed during the period of these readings. The winter room (facing south-east) was warmer than the summer room (facing north-west) between 2.pm and 6pm, by a maximum of 1.2c. However between 8pm and 12 noon the summer room was considerably warmer than the winter room by a maximum of

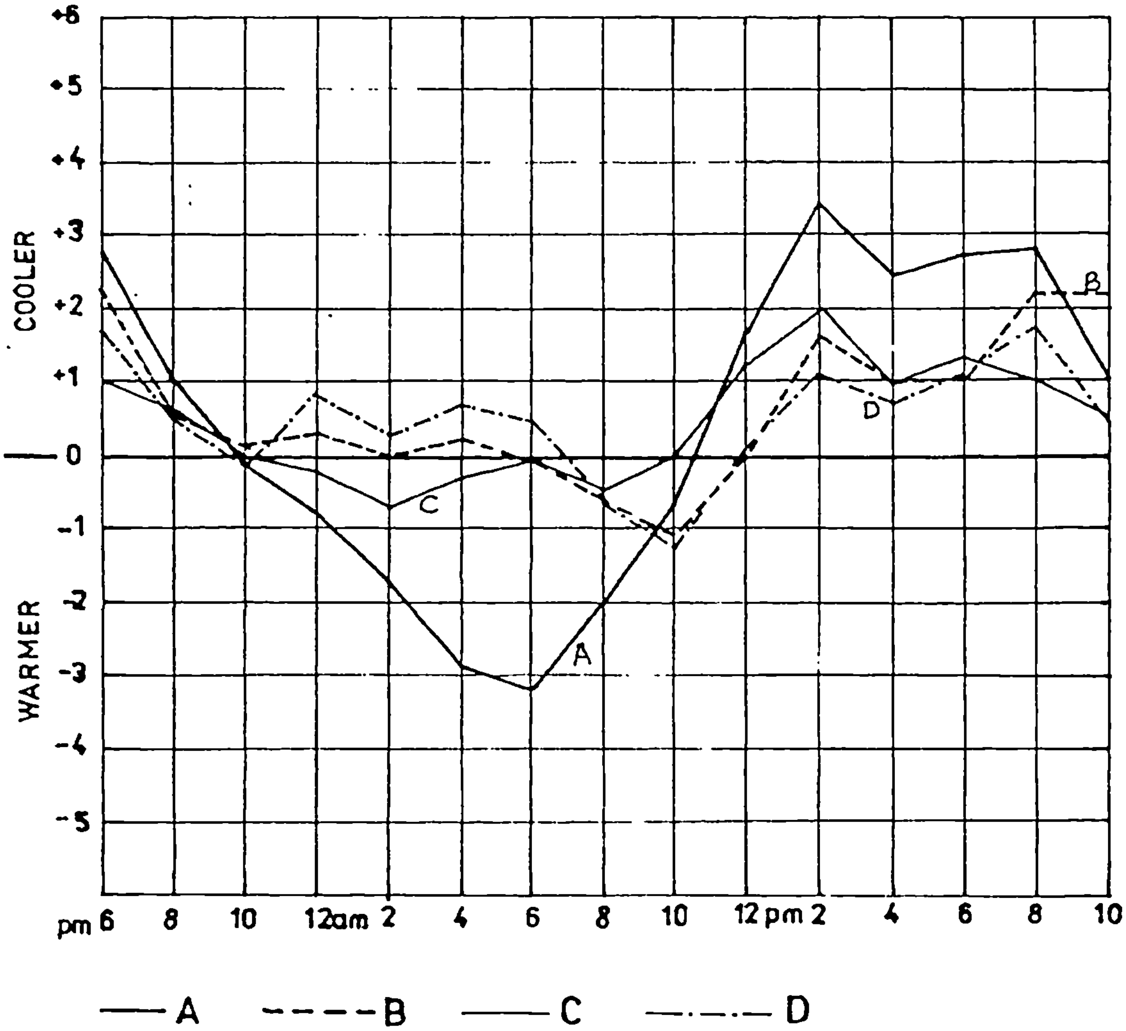


Figure K.12. Graph showing air temperatures in house E, subtracted from the roof temperature to indicate to what extent a room is warmer or cooler than the roof. A) north back room B) centre front of the ground floor aivan C) centre of ground floor badgir room D) south front aivan.

2.2c at 4am. This may be partially explained by the following points:

1) The main heat source and store in the winter room of house F are the roof and the floor directly inside the glass windows facing south east. The double doors, being recessed 70cms inside the angled intermediate buttresses and lintel, protect the winter room from a substantial amount of direct sunshine between 1 and 5pm (see figure 9.3).

2) The summer room of house F has three main heat stores, the roof, the courtyard wall, and the rear wall of the room. Direct sunlight strikes the windows of the courtyard facade only between sunrise and 11am, during the coolest period of the day in the courtyard. However the rear wall of the summer room faces directly on to a 3m wide alley which is exposed to direct sunlight all day, and thus this massive, 70cm wide mud brick wall forms a substantial heat reservoir. This heat store re-radiated steadily and continuously throughout the night and with a slight flattening out of the temperature curve in figure K.6 - graph 8, at 4am. This indicates that the heat lag across the wall is a minimum of 10-12 hours, unlike the 35cm wide, baked brick walls of house G that begin to emit substantially lower levels of heat radiation after 12 pm, indicating a far lower heat lag of about 6 hours.

K.5 Basement climates in houses without badgirs

In house F the basement floor is 6m below ground level and the basement is ventilated by an open grill window 1.2m wide x 60cms high and a single full height door in the east wall of the basement living room. The temperature remained between 25.5c and 24.8c with a relative humidity of 45-59% between 8pm and 12 noon (figure K.6 - graph 11). Between noon and 6pm, when the basement was occupied, the temperature rose from 25.5c (55%) at noon to 27c (53%) at 6pm.

This basement was recorded on a number of other days as well and the average relative humidity at 4pm was 52%, at 6pm 54%, at 8pm 55-62% and at 10pm a figure of 76.25 % was recorded one day. There appears to be an gradual increase of humidity in the basement as the evening progresses, which is predictable from the slowly decreasing temperature in early evening.

In house G the basement is only 3.5m below ground level and has a small door and two small open grill windows (figure K.7 - graph 2). The temperature here, with no through ventilation, unlike house F, fluctuated less over the 24 hour period. It was also warmer, with temperatures between 26.1c and 26.5c and relative humidities of 36.5 - 48.1% throughout the day and night.

The lack of response in the basement of house G to the mid-afternoon peak temperatures in the court and the diurnal range of only 0.4c compared with that in house F of 2.5c, may be influenced by a) the lack of cross ventilation, and b) the lack of occupants.

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