CONTRIBUTION OF VASTUSHASTRA TO THERMAL COMFORT: A CASE OF SHEKHAWATI HAVELIS

A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

in

ARCHITECTURE AND PLANNING

By

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DECEMBER, 2009

INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE
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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled "Contribution Of Vastushastra To Thermal Comfort : A Case Of Shekhawati Havelis", in the partial fulfilment of the requirement for the award of the Degree of Doctor of Philosophy and submitted in the Department of Architecture and Planning, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during a period from January 2005 to December 2009 under the supervision of Prof. Rita Ahuja, Indian Institute of Technology Roorkee, Roorkee (India).

The matter presented in the thesis has not been submitted by me for the award of any degree of this or any other Institute/ University

(Avlokita Agrawal)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: 24.12.2009

(Rita Ahuja)

Supervisor

The Ph.D. Viva-Voice examination of **Ms. Avlokita Agrawal**, Research Scholar, has been held on 29.10.2010

Signature of Supervisor

Signature of External Examiner

Dedicated to my parents who encouraged me, supported me and held the confidence in me.

ABSTRACT

In earliest times, heat and cold discomfort were the normal conditions for most people, when individuals relied upon clothing to maintain thermal equilibrium. Recent trends, however, depend upon the production of artificial interior climates. Achievement of indoor thermal comfort is considered to be one of the finest achievements of modern civilization. However creating a comfortable environment at a low price was possible during the late nineteenth and early twentieth centuries. However, with the energy crisis of the 1970's and today's fluctuating energy costs, this process became quite expensive, which led to the researches about providing a comfortable environment, saving energy and money.

In the wake of energy crisis, there is a clear need to further develop the traditional systems based on natural resources. Before inventing or proposing new mechanical solutions, traditional solutions in vernacular architecture should be evaluated, and then adopted or modified and developed to make them compatible with modern requirements. This process should be based on modern developments in the physical and human sciences, including the fields of materials technology, physics, aerodynamics, thermodynamics, meteorology, and physiology.

Before the advent of modern mechanical means for obtaining thermal comfort, people in the hot arid and warm humid zones were forced to devise ways to cool their houses with only natural sources of energy and physical phenomena. Generally, these solutions have been found to be much more energy efficient than modern means.

Since it is most difficult to achieve thermal comfort in Hot-dry climates (because of unavailability of water and very high solar radiation resulting in high daytime temperatures), the challenge of designing comfortable buildings is also greatest. Yet the traditional buildings provide thermally comfortable environment without the use of

mechanical means. In Hot-dry region of India, traditional buildings (rural and urban both) are the finest examples of energy efficient architecture. Most of these traditional buildings were designed based upon the principles of Vaastushastra. Thus hot-dry region of India was selected for studying the effect of Vaastushastra on thermal comfort.

Vaastushastras are books containing prescriptions regarding design and planning of buildings, settlements and furniture. They are derived from Sthapatya Veda which is an upaveda dealing with all the 64 fine arts of which architecture is one. The knowledge in Sthapatya Veda was understood by scholars from all regions of country. It was then rewritten in the form Vaastushastras which also took into account the local conditions (Social conditions, resource availability, physiological conditions etc.). Therefore even though the contents in all Vaastushastras procured from different parts of the country are similar but there are minor variations. Within the scope of current research, Vaastushastra poplar in western region of India was identified. It was identified as Rajvallabhmandanam which was created by Sthapati Sutradhar Mandan who was the chief architect of Maharaja Mokal of Mewar in Rajasthan. Its contents are similar to other Vaastushastras available in different parts of country.

For analyzing the effect of Vaastushastra on thermal comfort, such traditional buildings were required which have not changed from their original design. Rajasthan has many such places where buildings are intact in their original form. However since Vaastushastra finds its applicability more in residential buildings and majority of buildings fall under this category; residential buildings were to be identified. Shekhawati region in Rajasthan is world famous for its frescos on the walls of residential buildings called Havelis. The streets here are lined with painted walls which give an effect of an open air art gallery. Beyond the painted facades, these Havelis are thermally comfortable inward looking residences which housed a multitude of functions inside.

Shekhawati Havelis were constructed by the rich Marwaris as a mark of their success in business. The lavish Havelis competed with the forts owned by rajput rulers in their extravagance. Marwaris were patrons of local art and these Havelis reflect that. All the Havelis essentially have courtyard in the centre of the house; rest of the spaces surrounded courtyard. courtyard not only served as the common space for celebrating occasions and day to day activities but it also regulated the climate as it brought all five elements of nature into the building. The Havelis have traditional construction made up of hand pressed bricks and lime mortar. The walls are exceptionally thick and lime mortar is used for laying of bricks, plastering, flooring and finishing. The typical features of traditional architecture such as chajja and jharokha are present in these Havelis. All these features help in maintaining thermally comfortable environment inside. It was sure that all these features help in achieving thermal comfort but whether prescriptions laid in vaastushastra help in achieving thermal comfort was to be established. 25 Shekhawati Havelis were documented and analysed within the scope of this research.

To achieve this task of analyzing effect of Vaastu on thermal comfort in Shekhawati Havelis, both these parameters had to be quantified. Quantifying thermal comfort is easy as there are many quantities which could be used to represent thermal comfort. But quantifying Vaastu application was difficult as Vaastu is a qualitative subject. Therefore a quantity called Vaastu score was formulated. The prescriptions in Rajvallabhmandam which could be manifested in physical form were identified. A weightage was assigned to each prescription depending upon its importance as per Vaastu. Final score obtained as a total of scores obtained against each prescription was called Vaastu score. For quantifying thermal comfort, a new quantity called PUHos was devised. It was the 'percentage of uncomfortable hours inside against outside in summers'. This reflected the percentage of uncomfortable hours which were converted to comfortable with the help of building. But percentage of uncomfortable hours in summers only was considered because summer is the more problematic period in Shekhawati. For most part of the year it remains hot and the prime objective of buildings is to maintain a cooler environment inside. Therefore all passive techniques employed in Shekhawati Havelis lead towards cooling except heavy thermal mass. This reduces the heat gain in winters also thereby reducing comfort in winters. Also since it is possible to enhance thermal comfort by increasing clothing while it is not possible in summers, summer becomes more challenging in hot-dry regions.

For calculating PUHos, all the case studies were simulated using Energy Plus and Design Builder Software. The output was obtained for all the habitable zones in each Haveli. Hourly data was obtained for Dry Bulb Temperature (DBT), Relative Humidity (RH) and Air velocity (v) for all habitable zones. Since thermal comfort is not dependant of any one of these quantities in isolation, thermal comfort index was used which took into account the effect of all these quantities. There are many comfort indices which have been developed. However most suited for the Indian subjects is Tropical Summer Index (TSI). From the hourly readings of DBT, RH and v, TSI was calculated as per the formula. The comfort range of TSI is between 25-30 TSI and the extended comfort range is 19-34 TSI. Extended comfort range was considered for calculation of PUHos.

Once Vaastu score and PUHos were calculated for all the cases, regression analysis was carried out to establish the relation. The analysis revealed significant findings. It reported that PUHos is significantly affected by Vaastu score. Higher Vaastu score implied lesser PUHos which means enhanced thermal comfort. Relationship was also established between Vaastu score and percentage of uncomfortable hours in winter and for whole year but significant relationship was not established. Shekhawati Havelis were also analysed for quantifying the effect of passive design parameters on thermal comfort. It was found that number of storeys affect the PUHos most significantly while other factors such as Width to height ratio of courtyard, width of courtyard as percentage of width of building etc. did not affect PUHos that significantly. However the nature of relationship was established which was exactly as per theoretical understanding.

Individual prescriptions of Vaastushastra were also analysed to quantify the effect on PUHos. It was established that Vaastu prescriptions relating to Courtyard, Building elements, Orientation, Landscape, Construction and Spatial Planning affect thermal comfort significantly in Shekhawati Havelis. However it should be noted that the results are specific to Shekhawati Havelis and Vaastu prescriptions laid in Rajvallabhmandanam.

It was also established that most of the passive design parameters prescribed for Hot-dry climate are followed in Vaastushastra also. This proves that Vaastu has a scientific rationale behind it which might be a result of prevalent socio-economic conditions. Although the language of Vaastu texts is religious, it has a scientific basis.

Hence it can be concluded that- Vaastushastra contributes significantly towards achieving thermal comfort in Shekhawati Havelis in summers. In other words, Shekhawati Havelis following more Vaastu prescriptions remain more comfortable. So Vaastu prescriptions should be applied in modern residential buildings also to achieve similar results but the change in context makes it difficult. However with a little innovation, some of the Vaastu prescriptions can be easily applied in residential buildings in hot-dry climate. Efforts will also be needed at policy making level to implement reasonable Vaastu prescriptions. It is difficult but still possible in modern context. Thus Vaastushastra should not be discarded as a mythological and religious text. It may however be modified to suit the present context while keeping the essence intact.

ACKNOWLEDGEMENTS

A few words written on this piece of paper are not enough to express my gratitude for all those who supported me throughout this time. Yet everything has to be physically manifested to be understood in this world (as my thesis also goes) and these words are just an expression of those feelings.

'Almighty', I am nothing but a small reflection of you. I am the ignorant *Atma*, you lead me, you show me the path, you make these circumstances, you make me work but the world around me which is also created by you is ignorant too; so I get the credit for what you are doing. Thank you for blessing me.

First of all I express my sincere gratitude to my supervisor **Prof. Rita Ahuja.** Her valuable suggestions and guidance improved the quality of this work. Her supportive attitude made me feel comfortable whenever I was in soup and I kept moving forward.

I would also like to thank **Prof. R. K. Jain** for his continuous advice, motivation and support during the course of my research at the Department of Architecture and Planning.It was simply impossible for me to reach this stage without his help which very often extended beyond the boundaries of work.

I thank **Prof. S Y Kulkarni,** Head of Department of Architecture and Planning for providing the necessary support from the department. I also thank all the teachers in the department specially **Prof. P S Chani** who helped me to establish important contacts in the field of Building Simulation and Energy Efficiency. Not only work, but his understanding attitude helped me to recover in unfavorable times. I thank all the staff of Department of Architecture and Planning who supported this work in all possible ways they could. They never imposed any problems and the work moved on smoothly.

Lot of people from various organizations helped me through the course of this work. Prof. Rajan Rawal-CEPT Ahmedabad, Mr. Bipin Shah, Mr. Karan Tibrawalla and Mr. Pawan Tibrawalla- my current employers at Green Build Energy Pvt. Ltd., New

Delhi, Sh. Basant Kumar Goenka- Dundlod, Mr. and Mrs Jangid (Vivek's parents)- Nawalgarh, Sh. Kapil Goenka- Laxmangarh, Sh. Sanjay Sharma- Dundlod, Ar. Sanjay prakash-New Delhi, Ms. Sanyogita Manu- CEPT Ahmedabad, Mr. Prakash Paul- Fairwood Consultants New Delhi, Mr. Ramashish Ji- research scholar, Department of Statistics, Delhi University, North Campus, Mr. Mahabir Bhandari- Design Builder USA, Ms. Robin and Mr. Christian-Lawrence Berkeley National Laboratory, California, Sh. I C Sharma-Roorkee, Mr. R D Singh -CBRI Roorkee; All helped me in various ways which eventually resulted in this report.

My friends were always ready to extend their warm cooperation. I am thankful to Shilpa, Ratnesh, Naveen, Priyanka, Sujata, Stuti, Sanghmitra, Anjali, Lata, Kushagra, Vivek, Rajeev, Ajay, Matinder, Pooja, Hironmay, Anurag, Abhinay, Ashish and an endless list of friends whose names I might not be recalling but they helped me out in all possible ways.

Last but not the least, my family who supported me throughout. First of all, my Husband who managed my absence without any complaints and stood beside me at all times. He was my ultimate resort whenever I was trapped and always held my hand. Thanks for being the most dependable person in my life. I thank my parents who provided me the constant encouragement to complete research and my parents-in-law who accommodated my absence at home without ever complaining.

And Savyasachi, my two months old son, I stole his share of time to give the final shape to this work. His smiles relieved me of all tensions and relaxed me; motivating me to work more. Thank you for cooperating.

(Avlokita Agrawal)

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Abbreviations and Notations

ECBC	- Energy Conservation Building Code
U-Value	- Air-to-air transmittance
R-Value	- Resistance
Vaastushastra	- Traditional Indian treatises on the subject of architecture
OPEC	- Oil Producing Countries
GDP	- Gross Domestic Product
MW	- Mega Watt
MT	- Metric Tonnes
USDOE	- United States Department Of Energy
ISHRAE	- Indian Society of Heating, Refrigeration and Air-conditioning Engineers
DB	- Design Builder
EP	- Energy Plus
CFD	- Computational Fluid Dynamics
PUHos	- Percentage of Uncomfortable Hours Inside Against Outside in Summers
DBT	- Dry Bulb Temperature
RH	- Relative Humidity
ASHRAE	- American Society of Heating, Refrigeration and Air-conditioning Engineers
ET	- Effective Temperature
CET	- Corrected Effective Temperature
TSI	- Tropical Summer Index
Tw	- Wet Bulb Temperature
Tg	- Globe Temperature
V	- Air Velocity

HVAC	- Heating, Ventilation and Air-conditioning
.dxf	- File format for drawing files (Drawing Exchange Format)
Zone	- An enclosed space in a whole building simulation model which has same boundary conditions of activity, schedule, construction, lighting, HVAC and occupancy
SPSS17	- Software for statistical analysis

Hindi Words

Sthapati	- Traditional Architect
Havelis	- Courtyard type residential unit
Bhoomi	- Earth
Prasada	- Building
Yana	- Vehicle
Sayana	- Bed
Vedas	- Ancient treatises containing knowledge on all spheres of life
Vedic Dharma	- Religion Mentioned in Vedas
Upavedas	- Supplementary Vedas
Vedangas	- Limbs of Vedas
Upangas	- Supplementary Parts of Vedas
Sthapatya Veda	- Upaveda dealing with 64 Fine Arts
Shilpas	- Fine Arts
Purana	- North Indian Religious Texts Devoted to worship of Lord Vishnu
Dravidian	- South Indian
Aryan/Nagara	- North Indian
Brihat Samhita	- Aryan Vaastushastra
Kasyapa Shilpa	- Dravidian Vaastushastra
Agama s	- South Indian Religious Texts Devoted to worship of Lord Shiva
Vishvakarma	- Mythological Character of Chief Designer who was entrusted with the responsibility of creating earth
Mandala	- Grid
Mandapam	- Main Hall of Temple
Gopuram	- Entrance Gateway

Rajput	- A Descendant of King
Rajasthan	- A Western State of India
Shlokas	- Verses
Vaastupurusha	- Mythological Character who's spirit is believed to be residing in every building/construction
Sutradhar Mandan	- A Historical Sthapati
Mewar	- South wester region of Rajasthan
Kumbha Rana	- A Famous King of Mewar
Todarmall	- A Courtier of Emperor Akbar
King Bhoj Dev	- Famous King of Central India
Chaturvarg Chintamani	- An Aryan Vaastushastra
Angula	- Basic measurement Unit
Uttama	- Best
Madhyama	- Better
Adhama	- Good
Brahman	- Explanation of Vedas
Vaastu Padas	- Grids Planned as per Vaastu
Hasta	- Hand/Cubit Dimension
Chajja	-Projection on Roof
Jalis	- Perforated Screen
Rajas	- Kings
Rao Shekha	- King ho Founded Shekhawati
Jhunjhunu	- A North Eastern District in Rajasthan
Sikar	- A North Eastern District in Rajasthan
Churu	- A North Eastern District in Rajasthan

Mughals	- Muslim Rulers of India who Invaded India from North West
Sarais	- Rest Houses for travellers
Baolis	- Step Wells
Shekhawat	- Descendants of Rao Shekha
Baghis	- Rebels
Marwaris	- A Business Community
Thikana	- A Small State
Muslim Nawabs	- Muslim Kings
Jharokhas	- Balconies covered with jalis
Surkhi	- Brick Powder
Urad Dal	- A type of Cereal
Chattris	- Cenotaphs

Scientific Names of Indian Trees Mentioned in Rajvallabhmandanam

Champa	- Michelia Champaca
Kapittha	- Acacia Catechu
Bel	- Aigle Marmelosa
Shami	– Khejri- prosopis cineraria
Ashoka	- Saraca Indica
Sheesham	- Dalbergia Sissoo
Nagkesar	- Mesua Ferrea
Deodar	- Cedrus Deodara
Arjuna	- Terminalia Arjuna
Chameli	- Jasminum Grandiflorum
Maousri	- Mimusops Elengi
Chandan	- Santalum Album
Ketaki	- Pandanus Odoratissimus
Bargad	- Ficus Bengalensis
Peepal	- Ficus Religiosa
Goolar	- Ficus Mimosifolia

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Energy crisis of 70's generated a great deal of interest worldwide for energy conservation in buildings. Several agencies were set to rediscover the use of renewable sources of power that is Sun, Wind, Water and Biomass, in buildings and inventions and innovations took place at a global level. Substantial successful research took place in India too but it remained confined to laboratories, research publications and theory. And Indian architect still continues the usual practice with the change being visible only marginally. [1]

Today, the relevance of the idea of energy conservation is well established in India but the question remains- why have we failed to implement the idea of energy conservation into practice. The answer is that the rules of energy conserving buildings are not well established in India. An effort in the form of ECBC (Energy Conservation Building Code) has been drafted but it primarily focuses on air conditioned buildings. The main concern in the ECBC is to reduce the load on air conditioning plant. However if we look at the actual conditions of buildings in India, we find that bulk of the buildings fall under residential category, majority of which are non-air conditioned buildings. Such buildings on a smaller scale would most likely overlook the prescriptions in ECBC. Moreover ECBC draws suggestion based upon US energy code. The U-values and R-values which have been prescribed for India are practically difficult to achieve because

[1] Vinod Gupta, Energy conservation: Indian myths and realities, A+D, May-June 1992, pp 19-24

the code doesn't take into consideration the materials and techniques which are used in Indian construction industry for achieving energy efficiency.

If one looks at the traditional vernacular buildings in any region of India, excellent examples of thermally comfortable buildings are found. The art of traditional building developed and improvised over thousand years. The rules of designing and building in each region were coded into books and were followed religiously. These served the purpose of achieving sustainable construction and built environment. The solutions offered by traditional architecture present better, reliable and sustainable solutions to the problems of cooling and heating the buildings without consuming energy. All regions of India present excellent examples of optimum utilization of resources for achieving thermally comfortable environment inside without consuming conventional means of energy.

On analyzing the climatic regions of India, it is observed that most of the regions are warm except the extreme North and North-Eastern part and implementing energy conservation in buildings in cold climate is not as difficult as it is for warm climates. All the natural elements i.e. sun, wind and water can be used to heat the space through passive means. However in hot climates, only wind and water can be used to take away the heat of the building while heat from sun can only be rejected from reaching the interiors; and wind is hot and water is generally scarce in hot climates therefore heat rejection becomes challenging. Thus the task of creating thermally comfortable buildings in hot climates is much difficult than for cold climates[2]. Despite the magnitude of problem, traditional buildings in hot-dry regions of country have tackled the problem of

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[2] F. Ali-Toudert and Helmut Mayer, Numerical Study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot-dry climate, Building and Environment, 41 (2006), pp 94-108

space cooling quite effectively. Almost all these buildings were designed based upon the principles of *Vastushastra* (the ancient traditional knowledge system of building and construction in India). *Vastushastra* or popularly known as *Vaastu* had become a forgotten practice but it has redeemed its place in the society and is in good demand these days. However general public and users are not well informed about the actual practices and prescriptions of *Vaastu*. This gives way to improper implementation of this traditional wisdom. As a qualified architect in modern system of education and practice, it is a duty to bring clarity upon this topic. Hence a research into the topic of scientific and logical reasoning of *Vaastu* is a relevant issue of discussion.

This research plan has been prepared with an aim to study the traditional residential buildings designed as per *Vaastu* guidelines in order to quantify the reduction in energy consumption for achieving thermal comfort. This will include recommendations regarding judicious use of *Vaastu* in modern context, which will help the architects to justify incorporation of *Vaastu* practices.

1.2 RELEVANCE OF RESEARCH

In modern context, the need for sustainable and energy conserving architecture is much more than the context in which these vernacular buildings were created. Demand to supply ratio is much higher and there is an acute shortage of natural resources which is increasing exponentially. Hence there is a need of studying the traditional architectural styles prevalent in different climatic zones of the country and draw significant conclusions which shall provide an insight into the applicable practices which can be successfully and appropriately used in the modern context.

1.2.1 Energy Scenario in India

The world at large and India is moving towards a severe Energy Crisis which can be defined as a shortfall in the energy resources. The crisis often has effect on the rest of economy. Due to shortage in energy resources, cost of all products rise because of high manufacturing costs. The historic origin of energy crisis can be traced back to 1973 when OPEC (Oil Producing Countries) refused to sell the oil at the price which was fixed by America. The crisis became severe after 1979 Iranian revolution and 1990 Gulf War.

Besides decreasing availability of energy resources, demand for energy is increasing worldwide. In the wake of increasing industrialization and use of intensive energy gadgets, the energy demand in India is anticipated to rise sharply. India represents a rapidly growing economy. It is, in fact, currently rated as the second fastest in the world[3] (Fig. 1.2.1). Gross Domestic Product (GDP) represents the extent of economic growth of a nation and for India it has grown with an unprecedented rate in the last few years. Figures suggest that India's real GDP grew by 8.7 percent during 2005 and then reached an impressive 9.1 percent during April-September 2006[4].

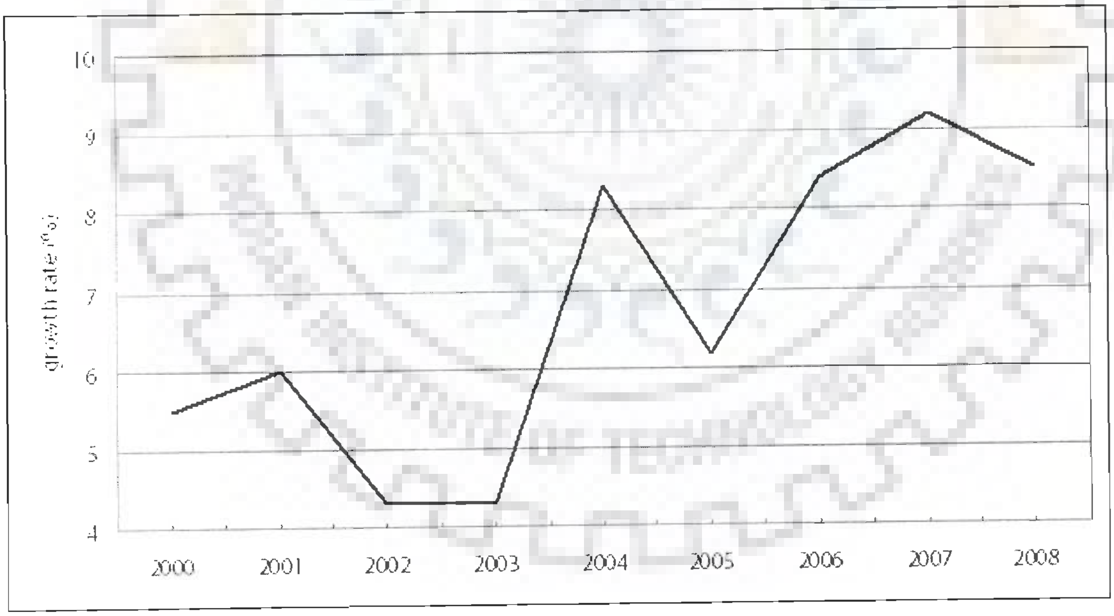

Figure.1.2.1 Graph showing India's real GDP growth 2000-08
(Source: CIA World Factbook)

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[3] *GDP of India, 13 Sep. 2008. http://www.tradechakra.com/indian-economy/gdp.html.*

[4] *India Energy Data, Statistics and Analysis - Oil, Gas, Electricity, Coal, Country Analysis Briefs, Jan. 2007, Energy Information Administration, 13 Sep. 2008, http://www.eia.doe.gov/cabs/India/Background.html*

But along with this accelerating economy there comes a rapidly increasing need for energy because this economic growth rate cannot be sustained without having enough energy to support it. Hence, India's rate of energy consumption is projected to increase in order to support the increasing growth. Already, the total energy production within the country cannot meet the energy demands. Even though both are growing, the gap between the two is increasing every successive year (Fig. 1.2.2). The present power scenario of the country shows a total energy shortage of roughly 7% of the total demand and the peak shortage of about 12% of the peak demand[5]. The peak shortage normally occurs at a time when the residential and commercial sector consumes the maximum power. It is anticipated that an additional requirement of 100,000 MW of electricity by 2012, 148 MT coal by 2020 and 313 MMSCMD Gas by 2012 will be required. It is also estimated that the present coal reserves will last for another 40 years only and gas reserves will last for another 20 years.[6]

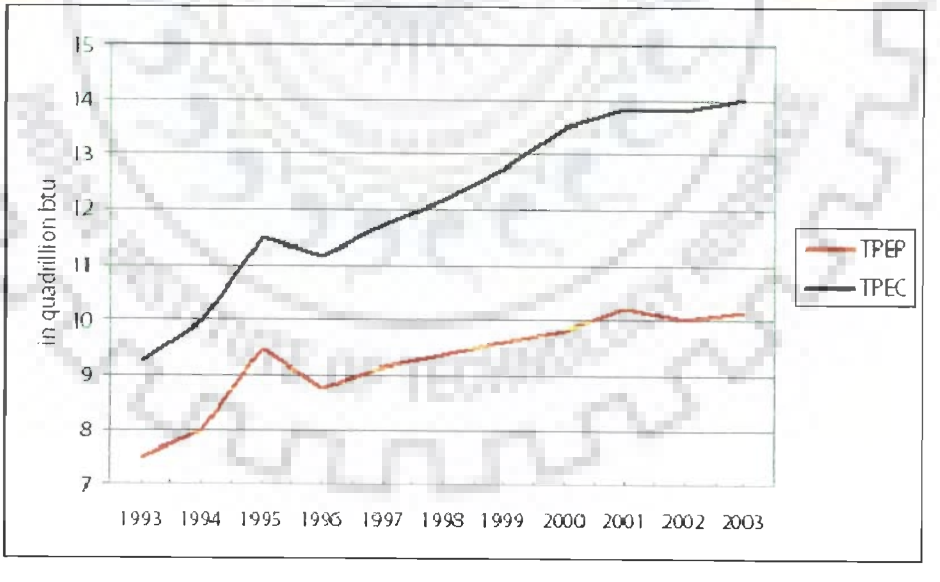

Figure 1.2.2 Graph showing Total Primary Energy Production (TPEP) and Consumption (TPEC) *(Source: DOE/EIA)*

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[5] *Ref: Speech by Shri P M Sayeed, Hon'ble Minister of Power's article on the occasion of Energy Conservation Day, on 14th December 2005*

[6] *Ref: www.ergconsultancy.com*

The figures also show that even though “India currently ranks as the world’s eleventh greatest energy producer, accounting for about 2.4% of the world’s total annual energy production”, it is also “the world’s sixth greatest energy consumer, accounting for about 3.3% of the world’s total annual energy consumption. Despite its large annual energy production, India is a net energy importer.”[7]

It is obvious that India is growing and consuming vast amounts of energy to do so. But in the face of issues like climate change, environmental pollution, resource depletion, etc., India is in a difficult position of experiencing accelerating economic growth and not having the choice to go the same way about development as the developed countries. More and more people are becoming aware of the fact that the country has to chart-out a very different development plan which is both environmentally responsible and offers exponential potential for growth as well.

1.2.2 Buildings and Energy Use

Building sector is increasingly assuming a critical position in the context of energy use. A lot of energy is used in building construction, services, and materials (production and transport). Since it is obvious that this activity is not going to decrease in momentum at any point of time – in fact trends suggest the contrary, and a developing country’s infrastructure would always require construction of buildings – it is important to optimize energy use within buildings by all means and at all levels possible, leading to energy efficiency and, consequently, to conservation, more so in view of the wasteful building practices rampant all over the country.

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[7] An Energy Summary of India: Overall Production and Consumption, Carbon Sequestration Leadership Forum, 13
Sep. 2008, http://www.cslforum.org/india.html

It is evident from statistics that around 60%, of the total energy consumption in India is consumed by residences (Fig 1.2.3) of which approximately 45% is used for heating, ventilation and air-conditioning (Fig 1.2.4). This implies that major portion of energy goes into creation of thermal comfort inside residential buildings.

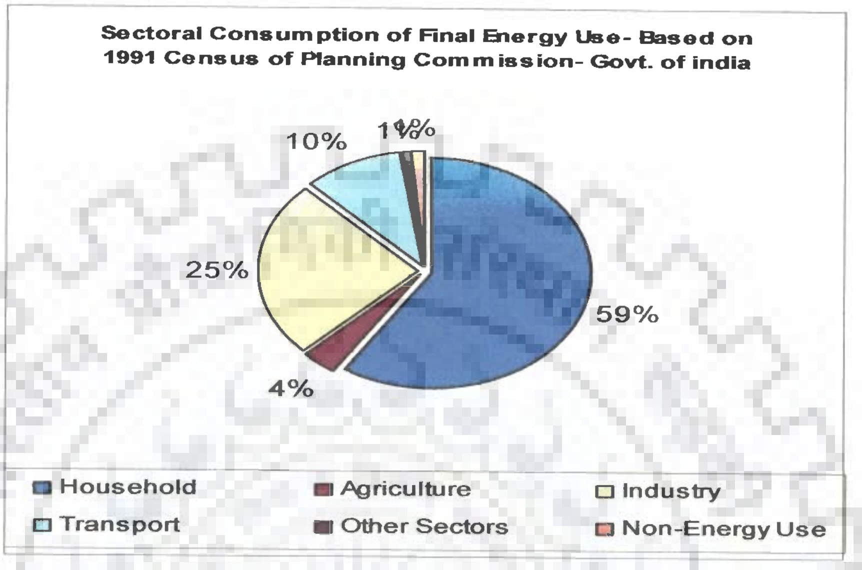

Figure 1.2.3- Sectoral Consumption of Final Energy Use

Source - www.rrcap.unep.org, (Planning Commission (1991) Sectoral Energy Demand in India, New Delhi : Govt. of India)

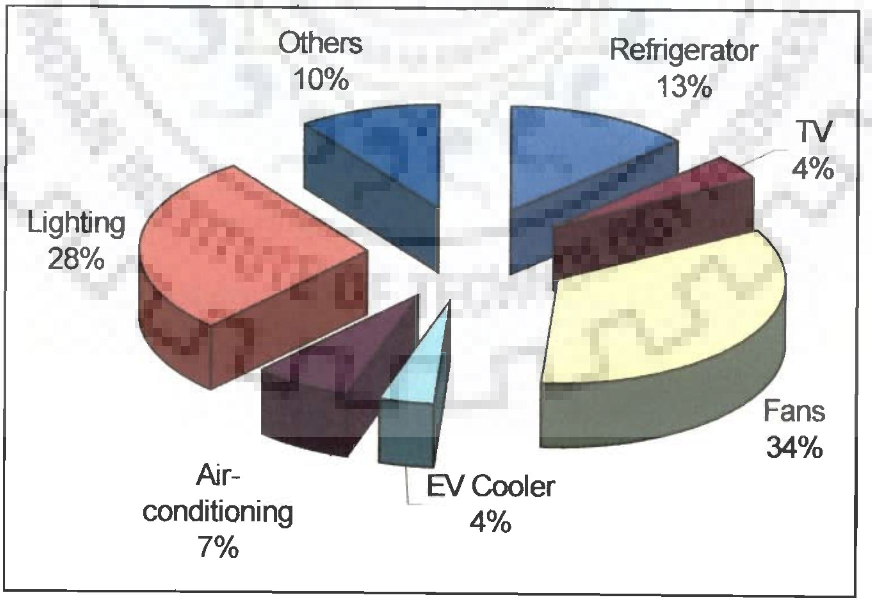

Figure 1.2.4- Activity wise consumption of Final Energy in Households,

Source: Ref.- Inderjeet Singh and Axel Michaelowa, Indian Urban Building Sector:CDM Potential through Energy Efficiency in Electricity Consumption, HWWA Discussion paper, www.hwwa.de

The over all energy consumption in India has come down from 3.5% to 1% of GDP since the starting of planning year. In the developed countries, this figure stands from 0.35% to 0.5% of their GDP. It implies that there is enough scope of energy saving through implementation of energy efficiency methods. It has been estimated that a single unit of energy saved at the end use point is equal to 2.3 unit of energy produced. Cost of generation of power and addition in power generation capacity are quite high. If energy efficiency methods are properly implemented, about 25000 Megawatt equivalent capacity of power can be created through promotion of energy efficiency measures.[8]

The present day buildings that are designed and used, symbolize un-restrained consumption of energy, be it a five star hotel, commercial establishment, Government building or a residence complex. Thus there is need to design and develop the new buildings on sound concepts of sustainable and efficient use of energy and also apply suitable retrofit options to existing buildings that could substantially improve the energy efficiency.

While energy conservation implies reducing the amount of energy required to achieve the same results or output, energy efficiency implies enhancing the output quantity and quality by using the same amount of energy. Energy conservation in buildings is similar to solar passive architecture. Energy efficiency incorporates not only solar passive architecture/ energy conservation but also the active techniques of reducing dependency on conventional sources of power and enhancing the efficiency of mechanical means (used for building construction, achieving thermal comfort etc.). However energy efficiency in buildings usually refers to energy conservation measures.

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[8] Ref. www.ergconsultancy.com

mechanical means (used for building construction, achieving thermal comfort etc.). However energy efficiency in buildings usually refers to energy conservation measures.

1.2.3 Traditional Buildings and Energy Efficiency

Traditional buildings and settlements all over the world symbolize sustainability and optimum use of resources[9]. Optimum utilization of resources and sustainability is most highlighted in the residences of common man because of limitation of finances and resources. In India, sustainability was not just a theory as it is understood today but it was a way of life. Since architecture of any period is a reflection of the society, traditional architecture of Indian subcontinent reflects sustainability which was deeply rooted in the society.

In India, the principles of design and techniques of construction of buildings were coded in books known as *Vastushastra.* The prescriptions were prepared by learned saints' long time back and were coded in the form of *Vastushastra*s in simple language for the layman. It could be called as bye-laws of those times. *Vastushastra*s not only took into account the spatial and structural requirements but also considered the socio-economic effect on the buildings. Thus the buildings designed by keeping *Vaastu* into consideration fulfilled all requirements. The *Vaastu* prescriptions were associated with religion and futuristic aftermaths therefore people followed them as an essential part of adhering to the religion.

Now whether the traditional knowledge was improvised and then coded into *Vaastu* or *Vaastu* was improvised and then the buildings were created which we see as examples of traditional construction today or both were improvised in parallel - in all cases, the

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[9] I A Touman and F Al-Ajmi, Tradition, climate: As neglected concepts in architecture, Building and Environment, 40 (2005), pp. 1076-1084

outcome is the same. The techniques of design and construction as well as the *Vaastu* texts were renovated from time to time taking into account the advancements. The materials used were locally available, thus the construction techniques varied with region. This implied lesser embodied energy and greater energy conservation.

Vaastu prescriptions also responded appropriately to the climatic requirements of the region. Buildings in hot-dry climates were prescribed to be constructed differently than in cold climates. This resulted in climate responsive buildings which remained comfortable throughout the year.

1.3 STATE OF ART

Many qualified architects are practicing *Vastushastra* in their buildings and design. But from the survey (conducted with architects in Delhi and Jaipur- Appendix 1.1 and1.2) it is evident that the architects are not well versed with the content of *Vaastu*. 99% of them do not even know the prevalent *Vaastu* texts and also that different regions in India have different *Vaastu* texts applicable in specific region. But presently the practice of *Vaastu* and a handful of knowledge are mandatory to fetch business and clients. Therefore architects are practicing *Vaastu*. Most of the *Vaastu* practitioners are traditionally qualified priests who themselves are not very well versed with the original texts. This state of art has created mixed responses in the society. Because of unexplained concepts and practices in *Vaastu*, a section of architects and people claim this knowledge to be false and religious in nature. However a large section of society comprising of layman believe in *Vaastu* and want it to be implemented in their buildings. Therefore a large section of architects practice *Vastushastra* despite skepticism of *Vaastu* because of the demand.

In such circumstances, it becomes important to clearly know the scientific rationale behind *Vaastu*. Thus a research in establishing a relationship between *Vaastu* principles and scientific knowledge is appropriate and desired. No such study from scientific perspective has been conducted so far.

1.4 HYPOTHESES

The following Hypotheses have been framed after thoroughly analyzing State of art and gap in research -

- Buildings designed as per *Vaastu* design principles are more energy efficient.
- Energy consumption for maintaining comfortable interiors was much less in traditional buildings thus resulting in energy efficiency in buildings.
- Traditional buildings are more comfortable even in absence of mechanical means of comfort.
- *Vaastu* plays a significant role in making traditional buildings thermally comfortable.

1.5 OBJECTIVES

The chief concern of this research is to establish if the concepts and prescriptions of *Vaastu* contribute positively towards achieving thermal comfort. A set of objectives have been formed to achieve this task which are as following-

- To understand *Vaastu* prescriptions pertaining to climate and passive designing and their effectiveness in bringing thermal comfort inside residential building.
- To study the thermal behavior of residential buildings designed as per *Vaastu*.
- To analyze the feasibility of application of *Vaastu* in the modern context.
- To suggest measures (based upon *Vaastu*) for reduction in energy consumption for creating thermally comfortable residences at building design and policy level.

1.6 SCOPE

The scope of research has been limited to evaluating the effectiveness of *Vaastu* prescriptions in bringing thermal comfort inside the residential buildings in hot-dry region of India. Residential buildings constitute a large proportion of buildings in India and *Vaastu* is largely applicable to residential buildings. Hence scope of research has been defined as follows-

- The study concentrates upon *Vaastu* text most popularly followed and conveniently available in the western region of India.
- The area of study is limited to the *Shekhawat*i region of western India.
- Only the residential *Haveli*s of *Shekhawat*i have been studied for *Vaastu* and thermal comfort significance.
- The thermal performance of buildings has been calculated using Energy Plus with Design Builder user interface.

1.7 LIMITATIONS

The guidelines of *Vaastu*, which refer to any astrological, religious or philosophical context have not been compared with the modern architectural theories of passive design (which are based upon more scientific and logical studies)

- The *Shekhawat*i region comprises of 24 small towns which have ingenious frescos painted *Haveli*s. Of these, very few are surviving in good conditions and are still in use. Most of them have witnessed changes in design and construction to suit the changing functional and social requirements. Only those *Haveli*s which have retained the original design have been documented.
- Due to limitation of time, weather data from secondary sources (USDOE and ISHRAE) has been used.

- Validation of the results obtained through simulation has not been done physically.
- Since there are many software available for building performance evaluation, the software for simulation and analyses purpose has been chosen based upon the comparative report of simulation tools available in the market by US Department of Energy (USDOE).

1.8 METHODOLOGY

The methodology has been prepared without any prejudice. It is aimed at finding out a relation between *Vastushastra* and thermal comfort. It aims at creating a relation between scientific knowledge and *Vaastu* prescriptions. The conceptual methodology has been shown in Fig. 1.8.1 and it is planned to be supported by relevant literature survey, field surveys on site, analysis of case studies from point of view of application of *Vaastu*, analysis of *Vaastu* from scientific perspective, simulation of the short listed case studies for their thermal performance using relevant simulation software, mapping of *Vaastu* principles on passive parameter framework etc. The detail of work to be done under each subhead of conceptual methodology has been elaborated in Fig. 1.8.2.

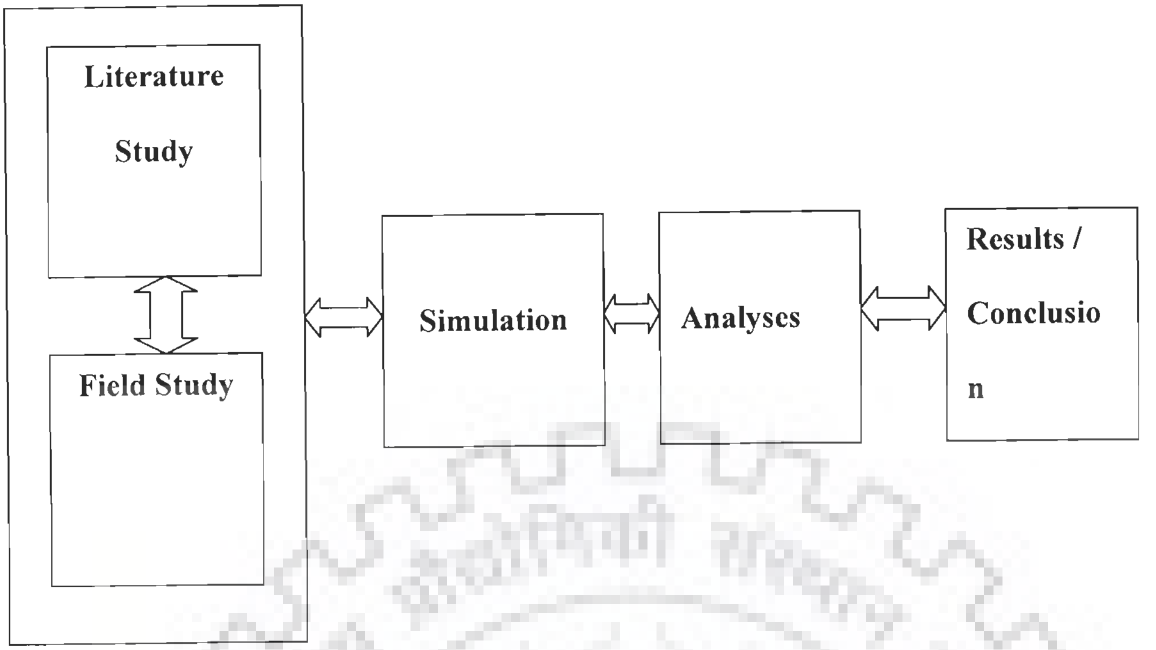

Figure 1.8.1 Conceptual Methodology

The literature study includes

i. Study of *Vaastu* texts prevalent in western region of country and applicable to residential buildings.
ii. Identification of one *Vaastu* text for reference.
iii. Identification of *Vaastu* prescriptions which can be physically manifested.
iv. Understanding passive design parameters which affect the built environment and thermal comfort inside the building. Selecting passive design features for Hot-dry climates which have been applied in Case studies.
v. Physiological study of region under observation.
vi. Procurement of weather data files for the region, relevant simulation software, and material properties (U-values etc.)

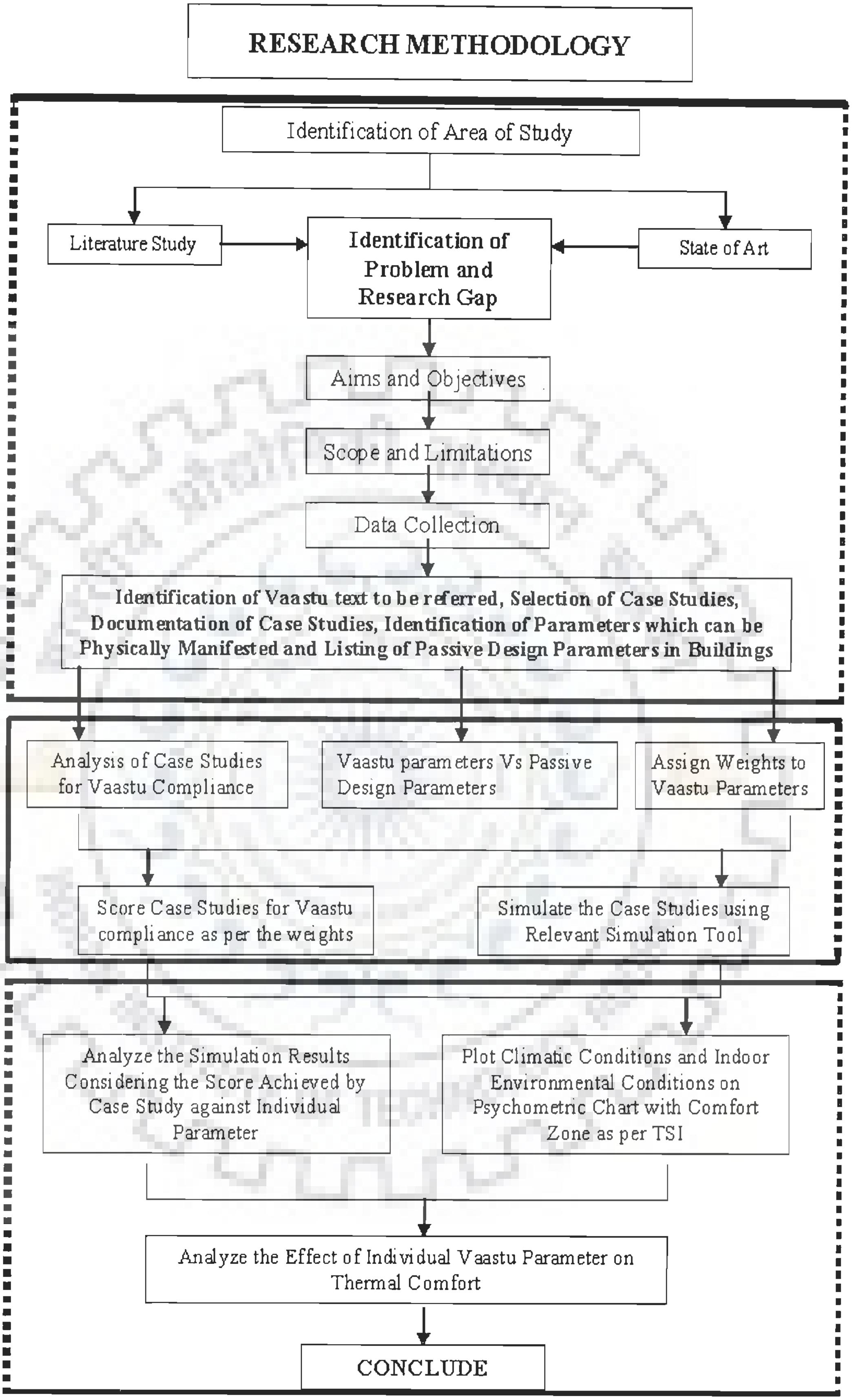

Figure 1.8.2 Detailed Methodology

The outcome of literature study was selection of a *Vaastu* text which would be suitable for the region under study and identification of passive design parameters which affect the thermal comfort.

The field study included survey of the region under study, identification and documentation of case studies, mapping of passive design parameters and *Vaastu* principles on case studies and detailed information of the case study(like materials of construction, procedure of construction, age, ownership etc.)

The case studies were then simulated using Design Builder (DB) and Energy Plus (EP). The weather data files used were procured from secondary data sources. The results were obtained in the form of internal temperatures graphs and humidity charts. The results thus obtained from simulation were analyzed in comparison with the data procured through literature study and field study.

1.9 DATA COLLECTION AND SOFTWARE USED

Data required for research purpose comprises of following-

1. Weather Data for the region under study that is *Shekhawat*i in the North East of *Rajasthan*.
2. Detailed drawings and information of the *Haveli*s.

Weather data was procured from secondary sources (USDOE and ISHRAE). Detailed drawings were prepared after primary survey of the region. Information was collected in the form of photographs, drawings and survey sheets. Since the buildings are very old and there is not living account of their making and construction details, information given by local masons and persons has been relied upon.

Once the data was procured, case studies were simulated for their thermal performance. For the simulation purpose, latest version of EP was used with DB as the user interface. This particular software has been used because of the following reasons-

- As per the yearly report published by USDOE, in the year 2005 **"Contrasting the capabilities of building energy performance simulation programs"**, comparing capabilities of 20 major building simulation programs, Energy Plus has been identified as the most comprehensive and versatile program able to perform maximum tasks .
- Weather data files are available for Indian cities which can be easily mapped into the software.
- Thermal modelling of courtyard type building is also possible (without CFD)
- Thermal modeling of massive buildings using materials with high U-value is possible with EP.
- It takes lesser time to model and simulate a complicated building as compared to other softwares.
- The three dimensional model of building can be made in DB unlike other thermal modeling softwares where building model data is fed in terms of co-ordinates.

1.10 ANALYTICAL PROCEDURE, SELECTION CRITERIA OF CASE STUDIES

The present study is scientific and numerical in nature. But because of *Vaastu* being religious and philosophical in nature, at some places normative style of research has also been used. To understand the relation between *Vaastu* and thermal comfort, one of the climatic zones (Hot-Dry) of India has been selected. Within this climatic zone, *Shekhawat*i region has been identified for study. The residential *Haveli*s of *Shekhawat*i are world famous for their wall paintings which have stood for centuries. The region itself is mentioned as an open air art gallery with walls of all residences being painted. Apart from the aesthetic and artistic component to these residences, the craft of space articulation is also highly developed. These *Haveli*s not only provide a treat to the eyes through their magnificent wall paintings, but also provide a comfortable environment inside without the use of any mechanical means or imported technique/material of construction. These small wonders have been created right out of the locally available resources and are scattered all over the region. Out of these around twenty five case studies situated at different places in the region have been selected. These case studies are typical courtyard type *Haveli*s. These stand in one of the extremely harsh climates of the world yet they provide comfortable environment inside without the use of external means of comfort. The buildings have been designed and constructed to suit the context. The design is as per the text of *Vaastu* which was prevalent in those times. The intention here is to explore the quantitative effect of prescriptions of *Vaastu* on thermal comfort inside these buildings. The research work can be divided into two parts-

First part is normative and descriptive in nature. Here the *Vaastu* text and climatology principles are studies and compared for similarities. Once similarity is established through descriptive method, the case studies are selected and simulated using computer programmes which becomes the second part. Thus second part includes scientific numerical analysis done through simulations to access the real conditions of thermal comfort and environment. The results are then interpreted from calculations and numerical results.

1.10.1 Selection criteria of case studies

Most of the frescos painted *Haveli*s in *Shekhawati* are in dilapidated condition. Majority of them are abandoned as their owners have moved to bigger cities for better opportunities of business and work. All of these *Haveli*s cannot be studied for research purpose here and only 25 *Haveli*s have been documented based on following criteria-

- *Haveli*s constructed after 1800 AD have been considered for selection.
- Buildings existing in the original condition without renovation are preferred.

- Occupied buildings where users are living are preferred.
- Buildings of varied sizes are documented. However similarity in system of design and construction is maintained.

While selecting the case studies, it was found that courtyard type planning is common in all residential buildings. All buildings have at least one central courtyard. The number and size of courtyards increases with size of *Haveli*. There are planning differences between large and small *Haveli*s. Small *Haveli*s were used by subordinates of the business men and other rich and elite in the society. *Haveli*s of all sizes have been documented to check the application and effect of *Vaastu* in all cases.

Another harmony between the case studies was that the name of designer is not known for any of the case studies. All buildings have same building materials and similar construction techniques. The architectural features such as entrance gateway, brackets, columns etc are also same in all *Haveli*s. Even the spaces are similar except for their sizes and number which was proportionate to the size of *Haveli*.

1.11 RELEVANCE OF RESEARCH TOPIC

Today *Vaastu* (which was the practice a few centuries back) has regained consciousness. It is being practiced by academically qualified architects as well as the traditionally trained *Sthapati*s and *Vaastushastris*. Its market is well established and in fact growing exponentially. However, there is a missing link between scientific rationale and *Vaastu* practices. This work presents an attempt to understand *Vaastu* practices through a scientific and logical methodology.

Vaastu is completely theoretical and (if the language is to be seen,) religious in nature. Studying such a text for its scientific basis was a challenging task. *Vaastu* covers a variety of subjects ranging from geometry, soil investigation, structure etc. to sociology, economics and anthropology. Establishing relationship between all these domains in a rational way was difficult. Thus to limit our scope of work, thermal comfort was identified. The reason being- the main aim of a residence is to provide thermal comfort and protection from the extremities of climate. It is also one of the most quantifiable subjects. Also since the world is facing energy crisis, thermal comfort creation inside the residences without consuming large amounts of energy is a prime concern. Thus keeping in mind all above stated reasons, it was decided to work upon the **"Contribution of Vastushastra to Thermal Comfort: Case of Shekhawati Havelis".**

1.12 ORGANIZATION OF RESEARCH REPORT

Chapter One forms a prelude to this report. Relevance of current research for analyzing effect of *Vaastu* principles on energy performance of buildings is discussed followed by formulation of Hypotheses. After discussing the state of art of *Vaastu* application in the field of architecture and its energy implications, objectives, scope and limitations have been defined. For achieving the stated objectives, procedure and requirements of Data collection, analytical procedure and selection criteria of case studies has been discussed.

Chapter two presents the literature collected which strengthens the understanding of *Vastushastra*, Thermal Comfort, Energy Efficiency and Passive Designing. Literature related to these topics was collected and summary has been compiled. It was understood that many *Vaastu* texts are available and there was a need to identify one *Vaastu* text for analysis. The text has been identified as *Rajvallabhmandanam* and its contents have been discussed at length and prescriptions (which can be physically manifested have been identified). Passive design features which should be incorporated in building in Hot-dry climates have also been identified.

Chapter three presents the compiled data collected for *Shekhawat*i *Havel*is. Origin, location, physiography, climate, socio-economic, political and religious conditions of *Shekhawat*i region is discussed. Data regarding origin, design and architecture of

*Shekhawat*i *Haveli*s is compiled to present a clear understanding of the *Haveli*s. Lastly the details of all 25 documented *Shekhawat*i *Haveli*s have been presented.

Chapter four discusses the methodology formulated to prove/disprove the hypotheses. Firstly *Shekhawat*i *Haveli*s have been analysed for application of *Vaastu* prescriptions and then passive design features. Passive design features are then compared with *Vaastu* prescriptions to establish scientific rationale of *Vaastu* prescriptions. Based upon evolved methodology, two quantities namely *Vaastu* Score and Percentage of uncomfortable hours inside the building against outside in summers (PUHos) have finalized. *Vaastu* score is then calculated for all the *Shekhawat*i *Haveli*s under study. PUHos has been explained in the end.

Chapter five continues the previous chapter and explains the methodology to calculate PUHos. Firstly all available software programs used for whole building simulation are studied and compared after which Energy Plus has been finalized to be used for simulation. Computerised model is then prepared for each case study and simulation is carried out. Output consists of hourly DBT and Relative humidity. PUHos for each case study is then calculated from the hourly data obtained.

Chapter Six covers the analyses carried out with the values obtained for *Vaastu* score and PUHos in chapter four and five respectively. Data is analysed to establish relation between –

- *Vaastu* score and PUHos,
- *Vaastu* score and percentage of uncomfortable hours inside against outside in winter *and*
- *Vaastu* score and percentage of total uncomfortable hours inside against outside.

Effect of individual *Vaastu* prescription and passive design parameters on PUHos is then analysed. Effect of orientation on PUHos of closed and semi-covered spaces and hourly temperature profile for habitable spaces in *Haveli*s is also analysed.

Chapter Seven presents the conclusions and recommendations drawn based upon the analysis carried out in chapter six. It is proved that *Vaastu* prescriptions help in bringing thermal comfort inside buildings in Hot-dry climate and hypotheses is proved with certain exceptions. Scope for further research has been suggested in the end.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

Before starting with research, a clear understanding of subject is essential. The three subjects which needed to be covered here are- *Vastushastra*, Thermal comfort and *Shekhawat*i *Havel*is. *Vastushastra* and Thermal comfort required a theoretical understanding while *Shekhawat*i *Havel*is had to be visited personally. Hence the information related to *Vastushastra* and Thermal Comfort has been collected and compiled in this chapter while data related to *Shekhawat*i *Havel*is has been compiled in Chapter three.

2.2 VASTUSHASTRA

Literally, *Vaastu* is defined as a dwelling in Sanskrit, "anywhere where immortals or mortals live" and Shastra is a treatise. Thus *Vastushastra* means the treatise on dwelling or science of architecture. There are two words associated with this science - *Vastu* and *Vaastu*. *Vastu* means pure, subtle energy and *Vaastu* means embodied material energy. The material forms of pure energy such as buildings, temples, idols, etc. are called *Vaastu*. Today, *Vaastu* is commonly used to denote buildings[10]. *Vastushastra*s start with the definition of *Vaastu* followed by specifications which show that the topic of architecture is very wide and is divided into four categories: *Bhoomi*, the Earth/site (considered as original dwelling), *Prasada*, the buildings, *Yana*, the vehicles (modes of

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[10] Harmonizing Humanity and Nature Through Vastu Shastra, The Ancient Indian Science of Time and Space, An interview in *YogaLife* with Dr. V. Ganapati *Sthapati*, www.vastu-design.com. Dr. V. Ganapathy *Sthapati* is a traditional architect, builder and sculptor of international repute. He comes from the *Sthapati* clan, a family of hereditary designers and builders, many of whom have built famous monuments.

transport) and *Sayana,* the furniture[11]. Last three are derived from the first i.e. Earth which is "*Vastu*" or the purest form. "*Vaastu*" pertains to the physical, psychological and spiritual order of the built environment, in consonance with the cosmic energies.

Abiding by the principles of *Vastushastra*s, environments can be designed to be built in harmony with the physical and the metaphysical forces/ energies of the cosmos- gravitational, electromagnetic, supernatural etc. Both modern architecture and *Vastushastra* aim at achieving health, happiness and well being of occupants. It is possible through bodily comfort which eventually results in mental peace leading to happiness and well being. The only difference is in the approach and inspirations. While modern architecture aims at functional effectiveness of the structure, *Vaastu* aims at establishing relationship of building and occupants with higher order of cosmos which is believed to result in harmonious environment. Therefore even for *Vastushastra*, the primary aim was to achieve comfort through architecture which would lead to spirituality and connection with divine. As per Maslow hierarchy also, the ultimate objectives of spirituality and divination cannot be fulfilled unless the basic needs of food, clothing and housing are not met with.

2.2.1 Origin

Like all other ancient Indian knowledge, *Vastushastra*, the ancient Indian treatises of architecture, evolved from *Vedas*. Vedic wisdom contained in *Vedas* is considered to be synonymous with divine knowledge of the cosmic mind obtained by sages in deep states of meditation. *Vedas* cover all aspects of life and topics beyond life also. Vedic philosophy is the origin of many eastern religions. Vedic *Dharma* in totality is not only a

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[11] Based upon the study of various *Vastushastra*s including Mansara, Mayamata, *Vaastu Rajvallabhmandanam* etc.

religion but it is a way of life- a sustainable way of life which is reflected in contents of *Vastushastra* also.

Vedas are divided and brought into the written form making it easier for people to understand. There are four *Vedas* which are further supplemented by *Upavedas*, *Upangas* and *Vedangas*. *Sthapatya Veda* is an *Upaveda* which explains the subject of *Shilpa*. There are 64 *Shilpas* or fine arts of which *Vaastu* is one. *Vaastu* is a *Shilpa* dealing with the science and art of architecture in detail. Besides *Vedas* and *Upavedas*, the subject of *Vaastu* has also been discussed in many other texts such as *Skanda PuRana, Agni PuRana, Garuda PuRana, Vishnu PuRana, Brihatsamhita, Kasyapa Shilpa, Agama Sastra* and *Viswakarma Vastushastra* and many more. The guidelines and principles explained in these scriptures were adapted and rewritten in the form of treatises called *Vastushastras*.

Vastushastras developed during the period of 6000 BC and 3000 BC[12] (Ferguson, Havell and Cunningham) and were handed over by ancient architects through word of mouth or hand-written monographs. They were created and revised in different regions and periods; so they experience a lot of regional impact and distinction of style exists due to each document's place of origin.

2.2.2 *Vastushastra* - prevalent texts

There are two sets of *Vastushastras*- Dravidian and Aryan/Nagara. *Mayamata* and *Mansara* are considered Dravidian because they are from South India whereas *Viswaskarama Vaastu Shastra and Aparajitpruchcha* are considered Aryan due to their North Indian origin. The fundamentals of all these texts remain the same as they are derived from the same set of parent texts which is *Sthapatya Veda*. The minor variations

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[12] **James Fergusson:** History Of Indian And Eastern Architecture,

occur due to local adaptation, availability of resources, social and physical requirements. Due to invasions and cultural dilution, very few *Nagara* style *Vastushastra*s are available presently. However many Dravidian texts are available and are still popular in use (Appendix 2). The break in continuity of practice of *Vastushastra*s lead to dilapidation of these texts. Many of these have been restored by Sanskrit scholars based upon the procured copies which were often having minor changes as these were rewritten at different times.

Of all the available *Vastushastra*s today, Mansara is the most comprehensive work. It is a Tamil text and a *Shilpas*hastra as it discusses the sculpture part at length. It devotes some chapters for town/ village and house planning but mainly discusses different features of temples.

It starts with the system of measurement, soil examination and determination of direction, which is common to all constructions. Then different types of *Mandala* plans are described with their suitability to different purposes. It then prescribes the dimension and characteristics of villages, towns and forts after which the dimensions of different storied buildings is discussed. The usage of these buildings is not mentioned; only their characteristic as per the height and number of storeys has been discussed. Now different parts of the buildings are discussed with their classification based upon measurements. The different parts consist of- foundation, pedestal, base, pillar, entablature etc. A complete chapter has been devoted to wood joinery which suggests that considerable amount of construction used to take place in wood at that time. Then it mentions the characteristics of single storied, double storied up to twelve storied buildings. The courtyards in the site are then discussed. Each part of the building is then elaborated with their classification- *Mandapam, Gopuram*, attendant deities' shrines etc. The thirty sixth chapter explains about dimensions of dwellings. The location and measurement of doors has been dealt in successive chapters. Next chapter talks about the royal palaces, courts and kings. Next part of Mansara describes the dimensions and construction of furniture, cars and statues. This makes a total of thirty chapters of which almost half is devoted to sculptural arts.

Though the residential buildings have not been attended to properly in Mansara as it is mainly a temple architecture text, but the holistic arrangement and coverage of topics is appreciable.

Mansara is a south Indian text and follows Dravidian culture. But the region of study for this research is confined to *Shekhawat*i which is in North India and it is most unlikely that the buildings of *Shekhawat*i region would have followed Mansara. Moreover, the study is limited to residential dwellings of common man while Mansara discusses the architectural guidelines for temples, cities, palaces of kings and his court men. Therefore one of the Nagara style *Vaastu* text dealing with architectural guidelines for common residence had to be identified and studied thoroughly to find the practical applicability in the same context.

2.2.3 North Indian *Vastushastra*s

Unlike a number of Dravidian *Vaastu* texts available in South India, very few are available in north India. It was because of continuous war and attacks from invaders. The invaders not only destroyed the architectural monuments such as temples and other public buildings but also damaged the literature, libraries, manuscripts and other literary documents which were representative of Hindu culture. Therefore very few of *Nagara* style *Vaastu* texts have survived. Most of these texts were preserved by strong and influential royals.

Since, *Rajput* kings in *Rajasthan* continued their strong hold, the architectural heritage in *Rajasthan* continued to survive along with the *Vaastu* texts which prescribed the guidelines. Moreover since the area of research was limited to residential dwellings in hot-dry region of India, it was easier to procure texts which were prevalent in *Rajasthan* and *Shekhawati*.

Some of the texts which were studied are-

- *Brihat Samhita*
- *Vaastusaukhyam*
- *Samrangana Sutradhara*
- *Vaasturajvallabh Mandanam Or Rajvallabh Mandanam*

Presently available texts were compiled by respective authors after studying all available copies of the same text. These copies of above mentioned texts were collected from different sources and were created at different times. And every time the text was reproduced, certain changes were incorporated depending upon the author, place and time.

Two more *Vaastu* texts were studied which contain '*Shlokas*' compiled from different *Vaastu* texts available. The *Shlokas* are compiled as per the topic discussed in different texts. The compilations which were studied are-

- Vaastusaarsangrah
- Vaasturatnakara

The original texts referred in these two texts are-

1. *Shulbasutra*
2. *Brihatsamhita*
3. *Laghujataka*
4. *Vishwakarprakasha*
5. *Siddhantashiromani*
6. *Siddhantatatvaviveka*
7. *Jyotirvidabharan*
8. *Jyotirnibandha*
9. *Rajmartanda*
10. *Narpati Jayacharya*
11. *Vaastu Rajvallabh Mandanam*
12. *Ratnamala*

13. *Muhurtamartanda*

14. *Muhurtamganpati*

15. *Muhurtachintamani*

16. *Peeyushdhara*

17. *Vaastupradeep*

18. *Parishishtadeepak*

19. *Dikmimansa*

20. *Pindaprabhakar*

21. *Falitnavratna sangruha*

22. *Janmapatra Deepak*

23. *Rekhaganit*

24. *Vaasturatnavali*

25. *Vaastuvidya*

It is an exhaustive list of texts which have been referred for these two compilations. But the source, author and region of application of these texts is not known for most of these texts. Knowledge about origin and region of practice of a text makes it easier to find the relevant architectural examples where the practical application of guidelines of these texts may be seen. Four such individual texts which have been studied are as follows-

2.2.3.1 Brihat Samhita-

Brihat samhita like other *samhitas* deals with a variety of topics ranging from cookery, *ayurveda* to *Vastushastra*. It discusses *Vaastu* in one chapter very briefly. Here only residential *Vaastu* has been discussed.

It starts with the mention of mythological story of *Vastupurusha*. Then it elaborately mentions the dimensions of houses for different levels of officials, kings and other common men. It tells about the following components and their dimensions through only one *shloka* each (i.e. in brief)-

- Verandah
- Room size
- Height of buildings and respective storeys
- Thickness of walls (varying with material)

- Main door dimensions
- Dimensions and placement of other doors
- Measurement of stile and bastions of doors
- Different types of pillars
- Various parts of pillar
- Different types of house plans depending upon the constructed portion around the courts
- Various *Mandala* plans
- Positioning of deities in *Mandala* plans
- Surrounding buildings around house
- Foundation
- Examination of soil
- Trees around house

In between these topics the topics of astrological importance are also discussed. Here we find that the arrangement of topics is entirely different from what is generally followed in *Vaastu* texts. Even though its brief, it presents a comprehensive picture of *Vaastu* applied to residential dwellings. Since *Samhitas* were further referred and elaborated in the form of *Vastushastra*s, it is difficult to find a specific region of application.

2.2.3.2 Vaasturajvallabh Mandanam Or Rajvallabh Mandanam-

This *Vaastu* text clearly mentions the name of the author- '*Sutradhar Mandan*'. He was a learned scholar who belonged to *Chittor* state and worked for the king during the reign of *Kumbha Rana* (1433-1467 AD). He authored several other books on *Vastushastra* and related topics. This text is the *'Nagara'* style *Vastushastra* for residential *Vaastu*.

It also draws heavily from the field of astrology. Leaving apart this aspect, it discusses all topics related to the residential *Vaastu* such as-

- Examination of soil
- Orientation
- Foundation
- Trees on site
- Main entrance
- System of measurement
- Dimensions of houses
- Different *Mandala* plans with presiding deities
- Forts and town planning
- Streets, gates, roads, wells, water bodies
- Royal palace
- Residences of other officials and common men
- Different types of houses

It is a popular text of western region for residential *Vaastu* and one of the most comprehensive ones but unlike *Mansara*, it does not discuss ornamental details. However planning aspects of residential architecture have been dealt in detail.

2.2.3.3 Vaastusaukhyam

Vaastusaukhayam was authored by King *Todarmall* who was a Hindu courtier of Emperor *Akbar*. According to some scholars, *Todarmall* did not create these texts but he seized these during a war in the form of manuscripts, which he published under his name. But there is no proof of this theory. Vaastusaukhayam is one of the seven volumes dealing with other mathematical and astrological data.

Vaastusaukhayam is a popular text in central region of India and deals with residences only. Its topic contents are same as *Rajvallabhmandanam*. It doesn't present a comprehensive picture of *Vaastu* as *Rajvallabhmandanam* does but briefly discusses almost all the topics related to residences. It also lacks the ornamental detail.

2.2.3.4 Samrangana Sutradhara-

This text was created by King *Bhoj Dev* around 11th century. It deals with the subject of residential architecture in a holistic manner; starting from the mythological understanding of evolution of universe to the detailed planning of a residence. Its subject content covers all topics related to the residence design as in other *Vaastu* texts. It discusses some additional topics such as following-

- Evolution of universe
- Classification of countries/settlements based upon the surroundings or location
- Qualities of architect
- Qualities and characteristics of kings
- Preparation of mortar for construction- *this particular topic is very unique to the text and is not found in any other text.*

While this text also lacks the ornamental detail, it is one of the most comprehensive of the western Indian texts available. Also, the discussion of topics has been done in great detail.

Of the above discussed texts, *Rajvallabhmandanam* presents the most comprehensive study of residential *Vaastu*. The author and region of application of this text is clearly known from the contents of the text itself. Since the region of study for this research is *Shekhawat*i in *Rajasthan*, and the text was created by its author in *Mewar* region of *Rajasthan*, it is most likely that the text found its applicability in *Shekhawat*i region too. The texts prevalent in one region have similar origins and reference texts and therefore the contents are also the same. Hence it is most logical to study and analyze the contents of *Rajvallabhmandanam* for studying *Vaastu* prescriptions, their application and effect on residential buildings in *Shekhawati* region within the scope of this research.

2.2.4 *Rajvallabhmandanam*

Rajvallabhmandanam was created by *Sthapati Sutradhar Mandan* around 1434 AD. The text is based upon an earlier *Vaastu* text, Aparajitprichchha, which was prevalent in Gujarat province. It is stated in the main text of *Rajvallabhmandanam* that most of its contents are derived from *Aparajitpruchchha*. *Sthapati Sutradhar Mandan* originally hailed from Gujarat province and migrated to *Mewar* early in his childhood when *Maharaja Mokal* of *Mewar* invited his father, who was also a *Sthapati* (traditionally qualified architect). *Sutradhar Mandan* learnt *Sthapatya* i.e. architecture from his father. *Sthapati Mandan* was a learned scholar and created many other texts related to *Vaastu*. [13]

Rajvallabhmandanam deals with creation of houses for kings and common man both. In fact no other *Vaastu* text (studied and discussed so far) presents guidelines for construction of residential dwellings as elaborately as *Rajvallabhmandanam* does. This text is considered to be the last creation of its author. Hence it reflects the effect of all previously created and studied texts. This text is influenced by *Matsyapuran, Aparajitpruchcha, Chaturvarg Chintamani* and *Mayamata*. Influence of *Aparajitpruchcha* can be clearly seen on the content and organization of this text.

The text is organized in 14 chapters which contain subjects ranging from architecture, astrology, religious practices etc. Many of the guidelines stated in the text give astrological details. As stated earlier, only the guidelines which can be manifested in

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[13] Shailja Pandey, *Rajvallabhmandanam*, Chaukhamba Subharti Prakashan

physical form have been considered. All the chapter wise contents which could be manifested in physical form are discussed as follows-

2.2.4.1 Mishraklakshanam

Starting from worship of God, it states the need to have a house. Then the method of testing soil has been mentioned along with the preferred orientation of slope of land. After this, the directions are ascertained and the method to find out north is mentioned. Then the foundation stone is to be laid in clockwise direction starting from south-east. The foundation should be dug up to first layer of water and stone. The walls of foundation and superstructure should be heavier at base and should go on decreasing in thickness with height. The plaster on walls should be even. The joints of walls should be proper. Then the trees to be planted around the house are mentioned. Milk bearing, thorny, trees bearing yellow flowers and fruit bearing trees are not prescribed near the house (within the boundary). Shrubs of *Champa*, Rose and trees of banana, pomegranate and creeper of grapes are said to be good near the house. Huge trees of *Kapittha* in north, *Bargad* in east, *Goolar* in south and *Peepal* in west are preferred. However none of the trees should be planted inside the house but they should be planted in open area surrounding the house. System of measurement is then discussed. Main unit of measurement is a *Hast* or hand and smallest unit is *Angula*. *Angula* is of three types (*Uttama*, *Madhyama* and *Adhama*) and each one is used for measurement of different objects. *Uttama Angula* is used for measurement of settlements, *Madhyama Angula* is used for measuring temples, palaces and idols of Gods and *Adhama Angula* is used for measuring residences, beds, carts etc. Once *Angula* is established, a measuring scale is constructed using prescribed woods. Further other units are derived as follows-

12 Angulas = *1 Tal /Balisht /Vitasti*

2 Vitasti (24 Angulas)	=	*1 Hasta*
1 ¾ Hasta(42 Angulas)	=	*1 Kishku*
4 Hasta (96 Angulas)	=	*1 Chap*
2000 danda	=	*1 Kos*
2 Kos	=	*1 gavyuti*
2 gavyuti	=	*1 Yojan*
100 yojan	=	*1 Koti*

The system of measurement varies slightly in different texts of *Vaastu* (Appendix 3). While the basic unit of measurement remains the same i.e. *Angula*, derivation of other units differs slightly. System of measurement in *Rajvallabhmandanam* is more similar to *Samrangana Sutradhar* than *Mansara* and *Mayamata*. However, the detail of *Angula* and other units is not given in *Rajvallabhmandanam* as is clearly stated in *Satapatha Brahman* and *Taittriya Brahman.*

2.2.4.2 Vaastulakshanam

This chapter details out the religious significance, procedure of conducting religious ceremonies while starting construction of building and association of different types of *Vaastu padas* with respective Gods of Hindu mythology. However none of the guidelines are related to design, construction and planning of residences. Therefore no guideline has been analyzed in this research.

2.2.4.3 Ayadilakshanam

This chapter lists the calculation and details regarding *Aya* (income), *Vyaya* (expenditure), *Nakshatra* (Zodiac), *Tara* (Star), Day and Date. All these parameters are calculated based upon the length and width of building. It is prescribed that the income should always be greater than expenditure, only then the house and its occupants can flourish. Income is calculated by dividing the area by 8. The remainders starting from 1 to 8 gives eight different types of income (all have different names and represent the eight cardinal directions starting from east). The area is to be calculated using '*hand*' as a measuring unit. However this exercise is not fruitful to establish the desired ratio of length to width. It is because a remainder of 1 can be achieved through many combinations of length and width while the area remains the same. Therefore this chapter also doesn't yield any useful information regarding design, construction and planning of residences. However an already constructed or chosen proportion of length and width can be checked for compliance with the rules mentioned in this chapter.

2.2.4.4 Nagarprakaryantravapikooptadagkundlakshanam-

Details regarding design, construction, planning, types and faults of towns, ponds, structures for water collection, shelter for travelers and forts are mentioned in this chapter. Since the scope of this research is limited to residential buildings, none of the guidelines are analyzed within the scope of this research.

2.2.4.5 Rajgrihaniveshadilakshanam-

This chapter lists the guidelines regarding size, design and planning of residences (for different classes starting from kings to common man) and different elements of a residence. Most of the guidelines prescribed in this chapter have effect on design and construction of residential buildings and can be physically manifested. Width of residences start from 4 'hands' (1 hand being almost equivalent to 2 feet) and goes up to 108 'hands'. Residences having width up to 18 hands can have only single storey. An additional storey can be added with an increase of 10 hands in width. Minimum height of residences is 5 hands and maximum is 13 hands. Wall thickness is specified according to the specific residence and should be constructed accordingly. Width of walls varies from 14 '*Angula*' to 30 '*Angula*'. Bricks were also specified to be of three sizes of 14, 15 and 16 *Angula* in length. An apron is mandatory all around the house with a minimum width of 1 hand. A platform should be constructed above the apron having a height of minimum 3 hands. Height of doors is determined from the length of the residence. Height of door is equal to 70/ 60/ 50 *Angula* added to the length of the residence measured in hand but taken in *Angula*. Width of door is proportionally calculated by adding 1/16th of height of door to half the height of the door. Plinth should increase with increase in size of the building. Where entrance gateways are provided, their height should be proportional to the width of the building. Larger buildings should have higher entrance gateways being 14 *hands* high. Entrance gateway should be maximum 7 *hand*s wide. Wood used for construction in residence should not be obtained from dried, burnt, thorny or such trees which have any other kind of defect. Trees which should be used for construction include Teak, *Arjuna, Sheesham, Chandan*, *Deodar* and trees having red colored wood. Entrance door is most preferred on east. Door on upper floors should be smaller in size than the doors on lower floors. Doors should be proportional to the size of the building. Ventilators should be placed in north. There should not be any common wall or column between two residences. Square shaped columns are more preferred in residences. *Chajja* should project equally from all sides. It should have a minimum width equal to 1/5th of the height of the residence. Stairs are preferable in east and south direction. Each stair should have the door on upper floor. Size of the door on upper floor should be lesser than the door on lower floor. Stone should be used for construction of temples, public buildings and palaces. Its use is prohibited in residences. However stone can be used for the construction of external walls, foundation and column base. Verandahs must be provided in the house in all directions. Rooms should be arranged inside the house in following manner-

E- Bath

Main entrance

Entry

E- Store for Edibles at the back of kitchen

SE- Music Room

Kitchen

S- Dining

S- Bedroom (towards interior courtyard)

SW- Toilets

Study

Store of valuables

W- Family room/ Entertainment Room

NW- Store

N- Store of valuables

NE- Prayer

A variety of design of residences is obtained depending upon the number of rooms around the central courtyard. Starting from one room up to 10 rooms, a number of variations are possible depending upon the location of verandah. The above suggested arrangement of spaces is prescribed for all variations depending upon the location of the room.

2.2.4.6 EkshalDwishalGrihaLakshanam-

Different types of residences having one room, two rooms, three rooms and four rooms are described here. Variation in design is obtained through placement of room(s) in different orientations. However it is not relevant to this study.

2.2.4.7 Shayan SinhasanaGavakshSabhashtakaVedika Deepstambh pramanlakshanam –

As discussed earlier, design of furniture and other articles of use in a residence (*Shilpashastra*) was an integral part of *Vastushastra*. All *Vaastu* texts have some chapters describing the design and construction of articles such as beds, chairs, throne for kings, etc. design of such articles is not within the scope of research. Hence the prescriptions of this chapter are not analysed here.

2.2.4.8 Rajgrihadilakshanam-

This chapter describes the dimensions of residences and palaces for king, his sons, courtiers etc. The details are related only to the size of plots for constructing buildings, gardens, stable for horses and entrance gateways. The prescriptions are out of the scope of this research.

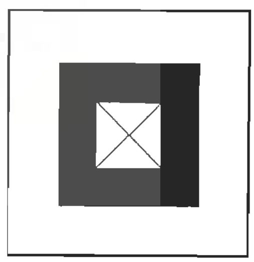
2.2.4.9 Chapter ten to thirteen-

The last four chapters deal with astrology, mathematics and calculations pertaining to determination of auspicious and inauspicious conditions for construction of residence and other articles. However as stated earlier, the scope of research is limited to the *Vaastu* prescriptions which can be physically manifested and hence these chapters hold no significance for the current research.

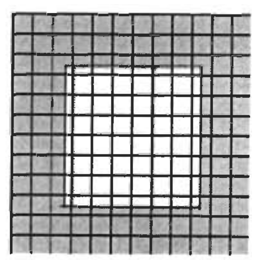
2.2.5 *Vaastu* Prescriptions

As defined in the scope of research, *Vaastu* prescriptions which can be manifested physically have to be identified and analysed for establishing the effect on thermal comfort. Such prescriptions have been identified as follows –

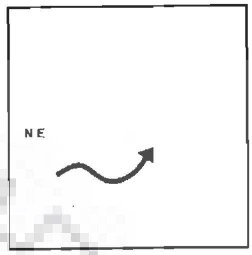
- Courtyard should be present in the centre of all residences. It should be left open to sky and there should not be any construction in courtyard.



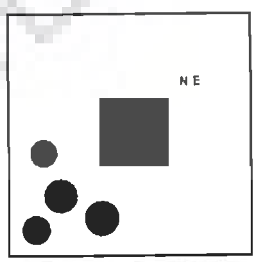
- Rooms should be constructed all around the courtyard. If the width of building is divided in 24 parts, 14 parts should be left in the centre as courtyard. (Approx 55% of width)



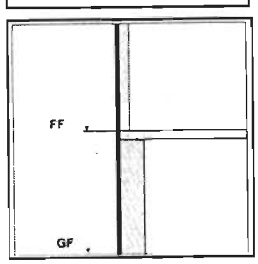
- Site should be sloping towards East, North-East or North. Although *Shekhawati* region is flat and slope of site does not hold much significance, it has been analysed because the plinth of inner courtyard is higher than outer courtyard which is higher than street. Thus a slope is created which affects the air movement. Moreover, *Shekhawati* region receives wind from NE quarter for most part of the year. Hence this prescription will come into effect.



- Site should be facing North, East, West and South in the order of preference. Orientation has been prescribed for different castes in the hierarchal order of caste system. This prescription has also not been analysed because it has been assumed that if a site orientation is allowed for a particular caste, it is allowed for construction.
- Milk bearing, thorny and fruit bearing trees should not be planted around the building.
- Trees bearing yellow colored flowers should not be planted around the building. *Champa, Rose, Banana, Chameli, Grapes,* Pomegranate, *Bel, Shami, Moulsri, Nagkesar, Ashoka and Ketaki* are preferred to be planted around building.
- Trees should not be planted inside the building.
- Huge trees of *Kapittha,* Bargad, Fig *and Peepal* are preferred to be planted around the building.

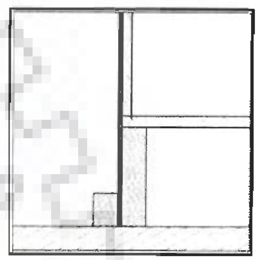


- Walls should be thicker at base and should go on decreasing with height. Plaster on walls should be even and brick should not be broken at joints. Though it is difficult to find out the

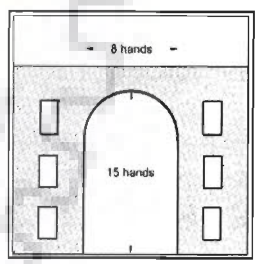


condition of bricks at joints, other two prescriptions can be analysed.

- Thickness of wall should be proportional to the width of the building. It should be equal to 1/16th part of width of building. Width of walls varies from 14 '*Angula*' to 30 '*Angula*'.
- Three sizes of bricks are prescribed- 16 x10x31/2 *Angulas*, 15x9x3 *Angulas* and 14x7x21/2 *Angulas*. Brick should be selected according to wall thickness. This prescription has not been analysed as size of brick inside the walls could not be verified.
- Apron should be constructed all around the building. Width of apron should vary from 1 *hand* to 3 *hands* (2 ft to 6 ft). A platform should be constructed above the apron having a minimum height of 3 *hands* and maximum of 6 *hands*.

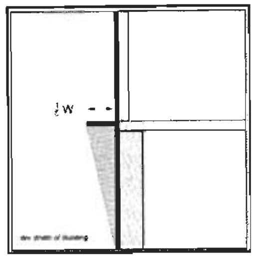


- Height of plinth should increase with increase in size of the building.
- Height of entrance gateway should vary from 11 *hands* to 15 *hands*. Width of entrance gateway should vary from 6 to 8 *hands*. However not all *Haveli*s have the entrance gateway and it is not mandatory also to provide it. Hence this prescription has not been analysed.

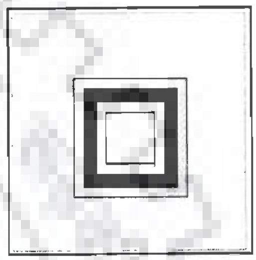


- Entrance door is most preferred on east.
- Door on upper floors should be smaller in size than the doors on lower floors.
- Height of door is equal to the 70/ 60/ 50 *Angula* added to the length of the residence measured in hand but taken in *Angula*. Width of door is proportionally calculated by adding 1/16th of height of door to half the height of the door. Doors should be proportional to the size of the building.
- Ventilators should be placed in north.

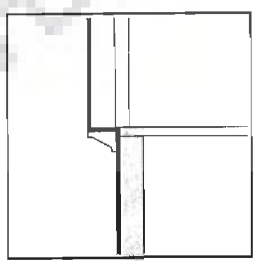
- There should not be any common wall or column between two residences.
- Square shaped columns are more preferred in residences.



- *Chajja* should project equally from all sides. It should have a minimum width equal to 1/5th of the height of the residence.
- Stairs are preferable in east and south direction. Each stair should have the door on upper floor. This prescription has not been analysed because all *Haveli*s had symmetrical plan and had two stairs in opposite directions.
- Verandahs must be provided in the house in all directions.



- Stone should be used for construction of temples, public buildings and palaces. Its use is prohibited in residences. However stone can be used for the construction of external walls, foundation and column base.
- Building should not receive shadow of any other building in afternoon. However since sun is at very low altitude in evening and it is impossible to avoid shadow from other buildings and structures, the prescription has been analysed for any shadow falling over building up to 3 pm.
- Height of upper floors should be less than lower floors.
- Entrance door should be the largest door in a building.



- *Jharokhas* must be present in buildings in all directions.
- Rooms should be arranged inside the house as described in 2.2.4.5.

- Mortar should be strong enough to bind bricks together.
- Guest room and external rooms should be decorated with paintings while habitable rooms should be simple and without much ornamentation.

Once the prescriptions are identified, *Shekhawat*i *Havel*is are analysed for application of above stated prescriptions in following chapters.

2.3 THERMAL COMFORT

Comfort can be described as 'a feeling of contentment, a sense of coziness or a state of physical and mental well-being'[14]. Comfort is a highly flexible and diverse terminology the meaning of which depends on the social context in which it is defined. This is a contested field, for there are different views about what kind of conditions are healthy for body and mind, and whether perceptions of environment and buildings relate to the human comfort.[15] Meaning of comfort has changed dramatically over the last century with considerable implications for indoor environment management and energy demand, and hence it had become necessary to quantify the comfort conditions.

Human comfort can be broadly categorized in two parts namely Physical comfort and Psychological comfort. Psychological comfort is mainly understood as visual comfort and it is also dependant upon the mental state of the individual. However the study here is concentrated upon the physical comfort which is synonymous to thermal comfort. A series of tests was conducted by a scientist Fanger in Denmark in 1970 on a large number of people. The aim of the tests was to quantify the sensation of thermal comfort. The

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[14] Heather Chapells and Elezabeth Shove, Comfort: A Review of Philosophies and Paradigms, March 2004

[15] *ibid*

findings of the test were unique and were considered as a major achievement in the field of psychrometry and thermal comfort-

- There is no significant difference in comfort perceptions due to geographical location or season (including tropical regions).
- There is no significant difference due to age (e.g. because older people have lower metabolic rate counteracted by lower perspiration rates);
- There is no significant difference due to sex, body build and ethnic origin.

From this it was concluded that thermal comfort conditions can be universally defined. However a change in perception can still be there which may arise due to individual's response to the environment around him. This was called adaptive comfort[16]. Thus thermal comfort has been defined as-

- As per ASHRAE standard 55 2004 and ISO 7330, Human Thermal Comfort is defined as the state of mind which expresses satisfaction with the surrounding environment.
- It can also be defined as the absence of thermal discomfort. Conditions in which 80% to 90% people feel comfortable can also be defined as thermal comfort. [17]
- As per SP-41, 'Handbook on Functional Requirements of Buildings other than Industrial Buildings', thermal comfort is a condition at which human body is able to maintain a constant internal temperature. It implies a set of conditions at which thermal balance of the body is maintained and the heat loss from the body is equal to the heat gained by the body.

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[16] Fanger, P. O. 1970. *Thermal Comfort.* Copenhagen: Danish Technical Press

[17] Givoni, B. 1976. *Man, Climate and Architecture.* 2nd ed. London: Applied Science Publishers Ltd.

2.3.1 Parameters Affecting Thermal Comfort [18,19,20]

Once it was established that thermal comfort can be universally defined and attempts were made to find the parameters that affect it. Several tests were carried out at different places. Various parameters were considered as variables and their effect on human thermal comfort was studied. It was concluded that thermal comfort depends on following variables:

i. Temperature- (Usually taken as ambient air temperature or dry bulb temperature of the environment). It is the main determinant of thermal comfort. It is measured in Kelvin or Degree Celcius.

ii. Radiant Temperature- In case the body is exposed to direct radiation, the temperature of the radiation is taken as radiant temperature. It is measured by using a globe thermometer. Thus it is also termed as globe temperature. It is measured in Kelvin or Degree Celcius.

iii. Air Velocity- The same reading of temperatures can produce different comfort effect depending upon the velocity of the air present in the environment. Higher air velocity implies faster evaporation rate from the body and hence reduced skin temperatures. Thus it produces cooling effect. It is expressed in *m/s*

iv. Humidity- The vapour present in the air affects the rate of evaporation of sweat from the skin. However, low humidity allows faster evaporation and thus more cooling effect. However very low humidity results in discomfort due to excessive dryness of skin; and very high humidity causes discomfort due to increased precipitation. Humidity is expressed in grams of moisture per unit volume of air. A more useful term is Relative

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[18] Givoni, B. 1976. *Man, Climate and Architecture.* 2nd ed. London: Applied Science Publishers Ltd.

[19] Fanger, P. O. 1970. *Thermal Comfort.* Copenhagen: Danish Technical Press

[20] O'Callaghan, P. W. 1978. *Building for Energy Conservation.* Oxford: Pergamon Press

Humidity. It gives ratio of amount of moisture present in the air to the amount of moisture which can be present in the saturated air at that temperature. It is measured as a percentage.

v. Metabolic Rate- Thermal balance of body is affected by the metabolic rate which depends on the activity of the body. Greater is the metabolic rate of body, higher is the rate of heat production. Hence a feeling of warmth under the same conditions will prevail. It is expressed in *Met*.

vi. Clothing- Clothing affects the rate of evaporation and heat dissipation from the body. Thicker clothes allow lesser heat exchange while light clothes allow greater exchange of heat between body and environment. It is expressed in *Clo*.

These parameters of human comfort vary from culture to culture and there is evident variation between individuals as a function of one's physical condition, activity or lack of it, and psychological expectations[21]. The acceptable comfort range also varies for the same individuals throughout the year, so that one might speak of distinct summer and winter limits within the comfort zone. But there are obvious limits to the range of temperature, humidity and ventilation within which human comfort can be maintained and beyond which some psychological stress occurs.

2.3.2 Thermal Comfort Indices[22]

The parameters described above affect the thermal comfort in different magnitudes. During the past 80 years, scientists have carried out many experiments to

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[21] Z Wang, A field study of thermal comfort in residential buildings in Harbin, Building and Environment, 41 (2006), pp 1034-1039

[22] Koenigsberger, Ingersoll, Mayhew and Szokolay, Manual of Tropical Housing and Building,1973, Orient Longman Ltd.

devise a single scale which can be called as the comfort scale or the scale of warmth or index of comfort. The most important ones are listed below-

i. Effective Temperature (ET) - This was the first scale developed by Houghton and Youglay in 1923 at ASHRAE. It was defined as the temperature of a still, saturated atmosphere which would in absence of radiation, produce the same effect as the atmosphere in question. The modified version of ET included the effect of temperature, humidity and air movement.

ii. Corrected Effective Temperature(CET)- It included the effect of radiation also in the ET. This is one of the most widely accepted thermal comfort Index.

iii. Equivalent Warmth – It was developed by Bedford in England. It included the effect of air temperature, humidity, mean radiant temperature, clothing and activity of subjects under study. It defines the comfort zone up to 35° C with low RH and 30° C with high humidities. It underestimates the effect of air movement at high humidities.

iv. Operative Temperature- It is similar to Scale of Equivalent Warmth. During the experiment to find operative temperature, only cool conditions were studied. It was developed by Winslow in the USA.

v. Equatorial Comfort Index- It is very similar to ET and takes into account the effect of air temperature, humidity and air movement on the acclimatized subjects. It was developed by CG Webb in Singapore during 1960's.

vi. The Bioclimatic Chart (Figure 2.3.3.1) - It was developed by V Olgyay. He said that there is no point in arriving at a single figure combining the effect of all the variables as the parameters are controllable by different means. He constructed the bioclimatic chart and showed the comfort zone as defined by the temperature and relative humidity. But subsequently it is shown by additional lines which represent air movement, radiation intensity and moisture addition. He argues that with the help of these factors, comfort zone limits can be stretched.

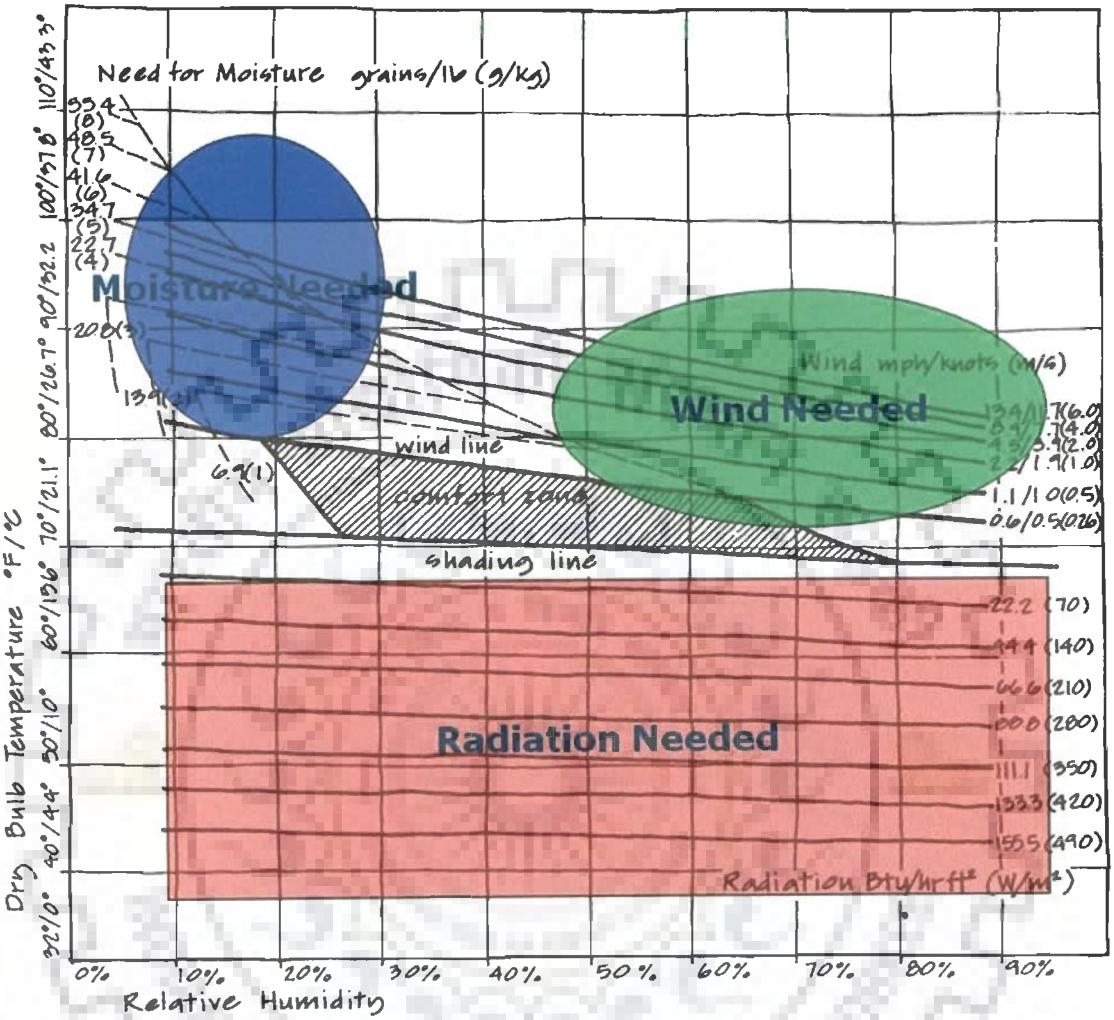

Figure 2.3.3.1 Bioclimatic Chart (*Source: www.aa.uidaho.edu)*

vii. Tropical Summer Index(TSI)- this was developed my M R Sharma in 1977 at CBRI Roorkee. It combined the effect of air temperature, radiation, air movement and humidity. The subjects studied were all Indians. This Index is most suited for the tropical climates like India. It is also recommended for use in SP-41 'Handbook on Functional Requirements of Buildings other than Industrial Buildings'.

2.3.3 Tropical Summer Index[23]

From the above sections it is clear that comfort can be defined in many ways. No one definition and scale can be considered as perfect. However it would be difficult to proceed with multiple definitions and boundary conditions of thermal comfort for this study. Since the Tropical Summer Index (TSI) is considered most appropriate for Indian subjects and conditions; it has been chosen to define the thermal comfort conditions.

"The TSI is defined as the temperature of calm air, at 50 percent relative humidity which imparts the same thermal sensation as the given environment. The 50 percent level of relative humidity is chosen for this index as it is a reasonable intermediate value for the prevailing humidity conditions."[24]

Mathematically, TSI ("C) is expressed as

$$TSI = 0.308T_w + 0.745T_g - 2.06\sqrt{V + 0.841}$$ [Ref. 23,24]

T_w = Wet Bulb temperature in ° C

Tg = Globe Temperature in ° C

V = Air Velocity in m/s

For indoors, Globe temperature can be replaced with Dry-Bulb temperature. It is because Globe temperature takes into account Dry-Bulb temperature as well as effect of direct radiation also. Thus in the absence of radiation, globe temperature is almost the same as DBT. The environment was found comfortable between 25 to 30 TSI. It was

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[23] MR Sharma and Sharafat Ali, Tropical Summer Index-A Study of Thermal Comfort of Indian Subjects, Building and Environment, Vol. 21, No. 1, pp 11-24, 1986

[24] Handbook on Functional Requirements of Buildings other than Industrial Buildings, Bureau of Indian Standards

tolerable up to 34 and down to 19. Lesser than 19, it was considered as too cold and beyond 34 it was considered as too hot. The TSI decreases further with increase in air velocity. (Table 2.3.4.1)

Table 2.3.4.1 Decrease in TSI with Increase in Air Velocity

Air Velocity m/s	Decrease in TSI in ° C
0.5	1.4
1.0	2.0
1.5	2.5
2.0	2.8
2.5	3.2

2.4 PASSIVE DESIGN PARAMETERS

With the continuous increase in population and industrialization, the need for energy is increasing simultaneously. But with the limited sources of energy, which are depleting day by day, energy conservation becomes the most important issue. As is evident through statistical data, buildings consume considerable amount of energy and energy conservation in buildings would help in achieving substantial energy savings.

Systems which are used to provide comfortable environment inside the buildings without consuming energy are called passive systems of designing. These systems consume energy only during their construction/implementation which is called embodied energy. Once complete, they function throughout their life without consuming extra energy. Passive design features use the natural energies such as sun and wind to achieve comfort condition thus saving appreciable amount required in building heating and cooling.

Passive designing which can also be called climate responsive designing helps to maintain comfort inside the buildings. Landscaping, built-form, envelope, materials and other features bring the environment conditions in buildings within the comfort range.

Almost all aspects of design of building and built environment are affected by climate and in turn affect the conditions inside the building. Passive design parameters vary for different climates. Passive design parameters for hot-dry climate have been arranged in the sequence of macro level to micro level detail. The theoretical understanding of each parameter has been presented along.[25,26]

- <u>Landform and landform orientation</u> - The topography of a site could be flat, sloping or undulating. If the land is flat, similar conditions would prevail all over the site. The orientation has little meaning in that case. The building placement is not governed by the climatic features in that case. In Hot-dry climates, buildings would be preferable on orthern slopes so that radiation is cut off. However measures to bring in day light have to be incorporated. (Figure 2.4.4.1).

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[25] A Krishnan, N Baker, S Yannas and S V Szokolay, Climate responsive Architecture, Tata-McGrawhill publishing company ltd., pp. 22-58

[26] Koenigsberger, Ingersoll, Mayhew and Szokolay, Manual of Tropical Housing and Building,1973, Orient Longman Ltd., pp 201-229

Figure 2.4.4.1.1 Buildings on northern slope receive minimum radiation *(Source: A Krishnan et al)*

- Vegetation pattern – Trees and plants affect the climate around the building by shading, creating pressure differences and also by humidifying the air.

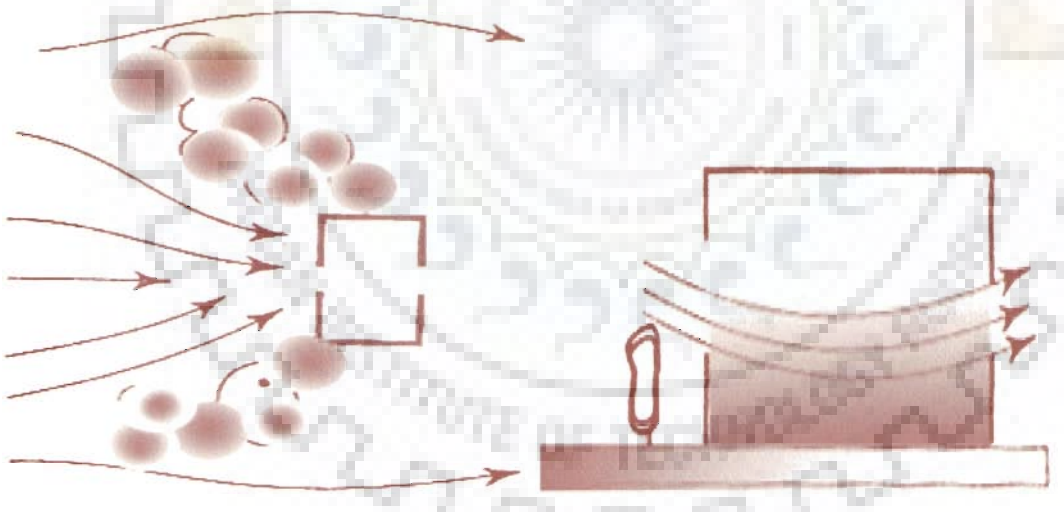

Figure 2.4.4.1.2 Vegetation helps in directing the wind and shading the building *(Source: A Krishnan et al)*

The placement of trees and hedges can cause minor pressure differences. Trees can be effectively used to cut off the low east and west sun. Hot breezes can also be cut off by planting thick foliage trees and hedges. (Figure 2.4.4.1.2 & 2.4.4.1.3) Plantation of deciduous trees is more useful in hot-dry climates as they shed their foliage in winters and allow sun to penetrate inside the building; while at the same time providing shade during summers.

Figure 2.4.4.1.3 Vegetation helps in creating minor differences in pressure *(Source: A Krishnan et al)*

- <u>Water Bodies</u>- Water absorbs large amount of radiation and remains cooler during day and comparatively warmer during night. As a result, building around water bodies remain cooler during day and receive heat during night from the water body. (Figure 2.4.4.1.4) Water also allows for evaporative cooling. If water body is placed in the path of incoming air, it will also affect the humidity of air. It is preferable to have provisions for evaporative cooling on the roof surface during evenings in summers. A roof top water body is also preferable in summers.

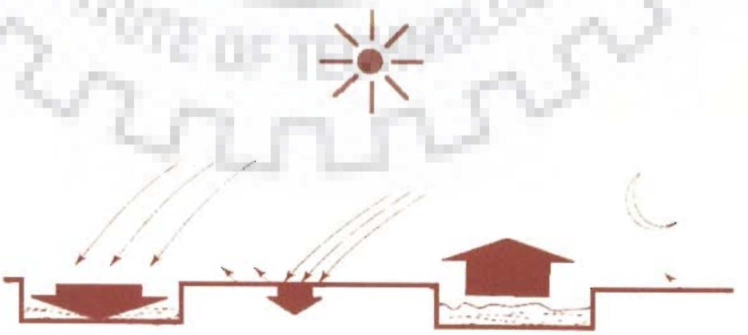

Figure 2.4.4.1.4 Water bodies absorb large amount of radiation during day and reradiate during night *(Source: A Krishnan et al)*

- Street Widths and Orientation- Street width and orientation determine the amount of radiation which is received by the building façade. The orientation of street also helps in enhancing natural ventilation depending upon the direction of prevailing wind. The open spaces can be effectively planned in conjunction with streets to reduce or increase the speed of wind as desired (Fig 2.4.4.1.5). In hot-dry climates, narrow streets are preferred as they help in shading. Small street width to building height ratio ensures minimal heat gain. In particular, streets running north-south should be narrow. This would enable mutual shading from morning and evening sun. East-west streets should be avoided as it is difficult to cut off the low sun.

Figure 2.4.4.1.5 Narrow North-South Street helps in cutting off the Sun
(Source: A Krishnan et al)

- Open Spaces and Built Form- Open spaces have to be planned in conjunction with built form and streets. They affect the radiation received by the built mass and also the wind flow patterns. The size of open space and the built mass surrounding it govern the shading pattern. Compact planning with little open spaces in preferred in Hot-Dry climates. This helps in minimizing heat gain at the same time, minimizing heat loss. Thus it should be seen that open spaces are optimally sized to allow night time cooling and minimal heating during the day. (2.4.4.1.6)

The surface of such open spaces should preferably be kept soft and green so that radiation is not reflected to the buildings. It can also be planted with deciduous trees to allow shading on buildings and ground. Open spaces also affect the day-lighting levels inside the building.

Figure 2.4.4.1.6 Optimum open spaces permit night time re-radiative cooling, Soft ground cover reduces the ground reflected component *(Source: A Krishnan et al)*

- Ground Character- The properties of ground affect the absorption, reflection and re-radiation. In Hot-dry climates, the ground should be left green and soft to minimize heat gain and reflection of radiation onto the surrounding buildings. Where hard paving is unavoidable such as on streets and roads, light coloured rough paving should be used. This would make the surface less absorptive as well as less reflective. (2.4.4.1.7 & 2.4.4.1.8)

Figure 2.4.4.1.7 Soft cover reflects less amount of heat *(Source: A Krishnan et al)*

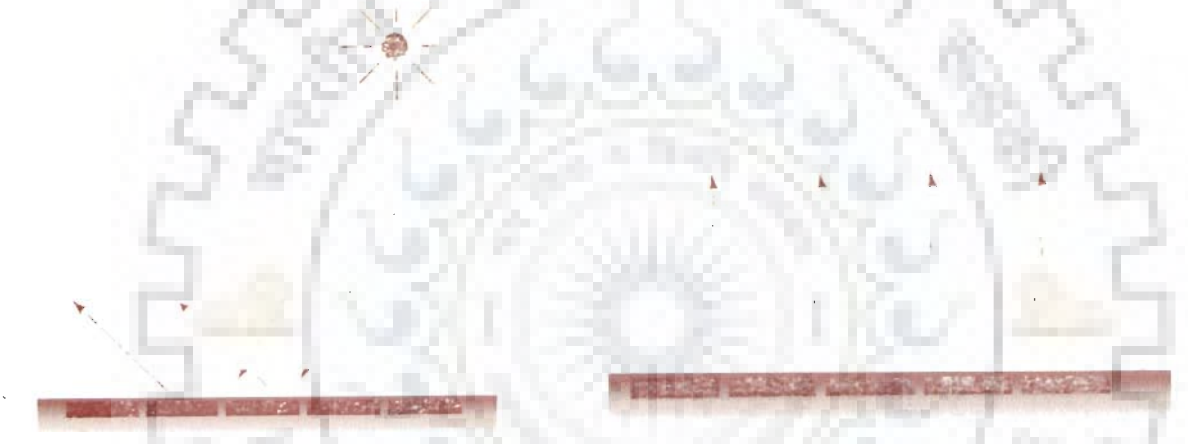

Figure 2.4.4.1.8 Hard paving absorbs more heat during day and re-radiates it during night *(Source: A Krishnan et al)*

- Plan Form- The plan form determines the perimeter to surface area ratio of the building. It is an important indicator of heat loss and heat gain. The plan form also determines the air flow through the building. In hot-dry climates, Perimeter to Area ratio should be minimized. This implies closed forms such as square, rect*Angula*r and circular. Open forms are not preferred as natural ventilation is not a compelling proposition. (Figure 2.4.4.1.9)

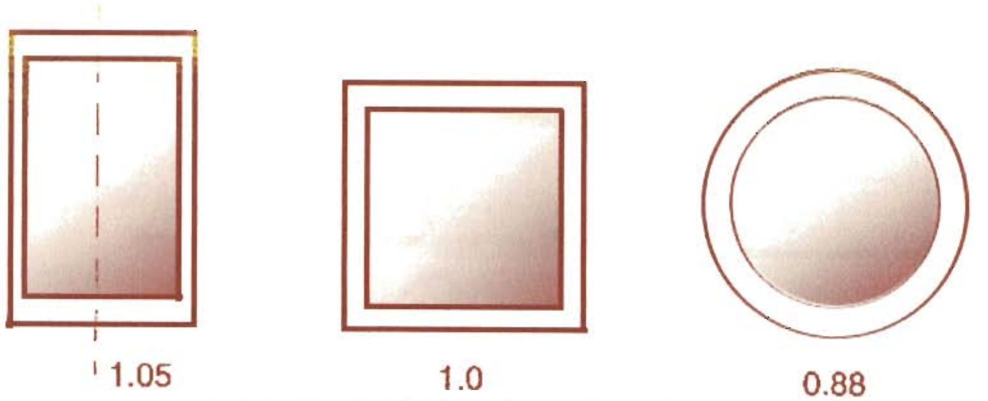

Figure 2.4.4.1.9 Closed forms with lesser perimeter to area ratio should be preferred

(Source: A Krishnan et al)

- Plan Elements- Besides the incorporation of vegetation, water bodies, air movement and radiative heat gain and heat loss at site planning level, all these factors can be integrated in building design also. Water bodies are an effective means of evaporative cooling. It can also be used as thermal mass when used with glazing. Vegetation can be integrated with building to absorb radiation and therefore effect cooling. Screens (*Jalis*) can be integrated with openings in design to increase the speed and reduce the temperature of incoming wind. It is desirable to integrate vegetation and water bodies. Terrace gardens and planters on windows are preferable as they absorb heat and increase moisture levels. Optimum size of courtyards which remain shaded most of the time during day are beneficial as they store cool air during night and facilitate night time re-radiative cooling. Wind tunnels and wind towers which bring air into the building after cooling it helps in cooling the indoors. However, care should be taken against rodents and insects making shelters inside these tunnels and towers. Earth berms and basements are also preferred as earth acts as an insulating material. (Figure 2.4.4.1.10)

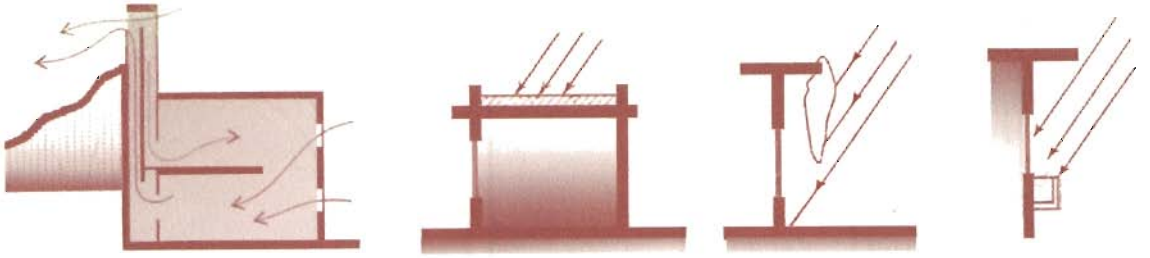

Figure 2.4.4.1.10 Wind tunnels draw cool air, Planters help in cutting off the radiation, Roof top water body helps in evaporative cooling *(Source: A Krishnan et al)*

- <u>Building Orientation</u>- The building orientation determines the amount of radiation received by the building. The orientation with respect to wind patterns affects the natural ventilation. Since North direction receives minimum radiation in northern hemisphere, in Hot-dry climates, north is the most preferred building orientation with longer axis running east-west. [27]
- <u>Surface Area to Volume Ratio</u>- It has a direct effect on radiation received by the building. Thus it is a direct measure of heat gain and heat loss. Taller buildings with lesser area on ground is preferred in hot-dry climates. This will ensure small surface to volume ratio. (fig. 2.4.4.1.11)

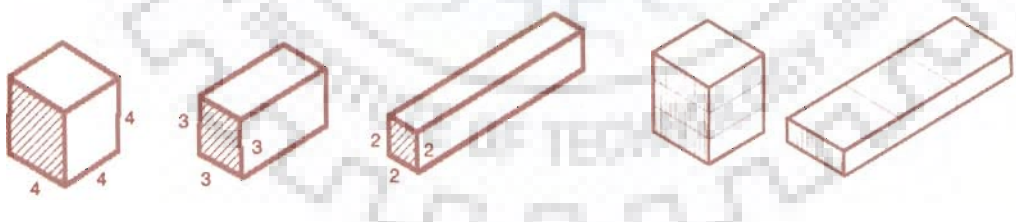

Figure 2.4.4.1.11 Blocks having same volume but different surface area

(Source: A Krishnan et al)

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[27] A S Muhaisen, Shading simulation of the courtyar form in different climatic regions, Building and Environment, 41 (2006), pp. 1731-1741

- Roof Form- Roof is an important part of the building as it receives maximum radiation.. It also helps in heat loss through re-radiation during night. It can also be used as an effective means of day lighting. The slope and overhangs in roof affect the air movement also. Overhangs help in cutting off the radiation received by the vertical surfaces and openings. To minimize natural ventilation, flat roofs are preferred in hot-dry climates. But since flat roofs receive more radiation, vaulted or domical roofs would be advisable. The roofs should be projected to provide shading on the walls. Sloping roofs should be avoided as they provide more area for exposure and enhance natural ventilation.
- Fenestration Pattern, Orientation, Configuration and Controls- It involves the area, shape, location, relative positioning and orientation with respect to prevailing wind direction of the openings. This would affect the air movement, day lighting and glare indoors (Fig 2.4.4.1.12). In Hot-dry climates, windows should be appropriately shaded. They should be small in size as neither ventilation nor day light is much desired. In case window sizes are increased for night time cooling, they should be properly shaded. Openings should be provided with thick insulating shutters to minimize the heat transfer during day. For better ventilation, windows should be staggered rather than being in a straight line. Partitions and obstruction should not be placed directly in front of the opening. High openings are preferable in hot dry climates as they allow hot air to escape faster. Windows are not much preferred on east and west walls as they allow low sun to enter inside the building. If windows are properly shaded, they can be fitted with jails to enhance the air speed. However, in case of improper shading, this will have an adverse effect because the sir needs to be cooled first. Glazing should be avoided.

Instead of glass, opaque insulating materials such as wood should be preferred for shutters.

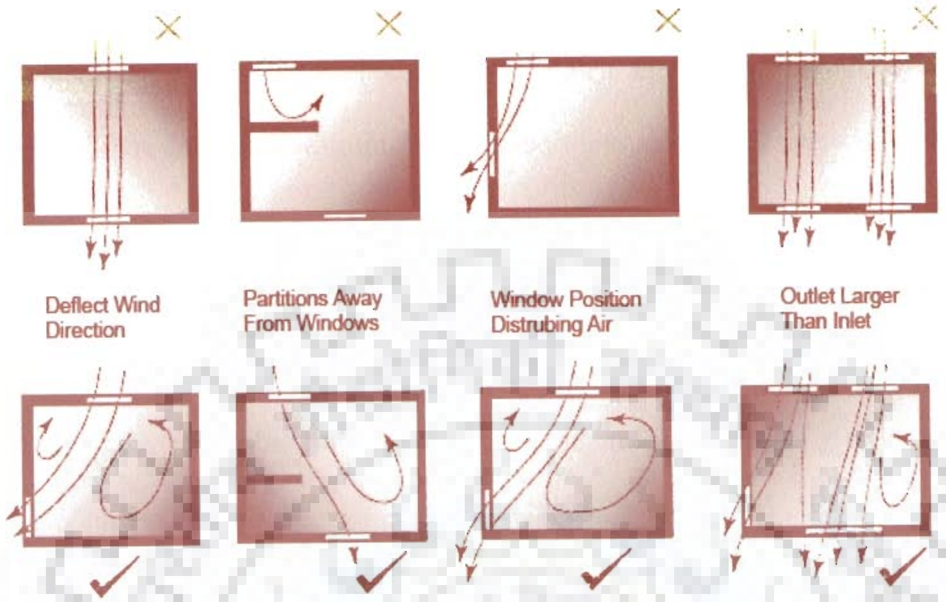

Figure 2.4.4.1.12 Window size and location affect the air movement inside

(Source: A Krishnan et al)

- Walls and Roofs- The materials for walls and roofs are one of the most important factors in determining heat gain and heat loss to the building. Materials with high thermal capacity absorb large amounts of heat and reradiate them during night. For roof in warm climates, reflective materials can help in reflecting the incident radiation falling on the roof. Dark colours can help in absorbing large amounts of radiation. In Hot-dry climates, walls and roofs should be constructed with materials having high heat capacity.

Figure 2.4.4.1.13 Thick walls and cavity walls help in storing heat and create time lag *(Source: A Krishnan et al)*

This will allow greater time lag and reduced temperatures inside the building. The U-values of wall and roof materials should be as low as possible. The finished outer most surface should be reflective and light in colour. Roof should preferable be finished white. Air cavities in walls enhance the thermal performance. (2.4.4.1.13)

xiv. External Colours and Textures- Similar to the ground character, the colour and texture of external surface determine the amount of radiation absorbed by the building. Light and smooth surfaces reflect the radiation falling on them while dark and rough surfaces absorb large amount of heat. In Hot-dry climates, the external surfaces should be smooth and light in colour to reflect as much heat as possible. However, this would imply increased glare on the streets. Thus external surfaces should be properly shaded.

2.5 ENERGY EFFICIENCY IN BUILDINGS

Energy conservation implies reducing the amount of energy required to achieve the same results or output. Energy efficiency implies enhancing the output quantity and quality by using the same amount of energy. Energy conservation in buildings is similar to solar passive architecture. While energy efficiency incorporates not only solar passive architecture/ energy conservation, it also implements the active techniques of reducing the dependency on conventional sources of power, enhancing the efficiency of mechanical means used for building construction, creating thermal comfort or any other work. However energy efficiency in buildings usually refers to energy conservation measures.

2.5.1Definition-

Energy efficiency refers to systems designed to use less energy for the same or higher performance than regular systems. Energy-efficient buildings are designed to use less energy than traditional buildings. Saving energy through efficiency also saves money on utility bills and protects the environment by reducing fossil fuel consumption and emissions.

2.5.2 Need-

As discussed earlier, buildings are a major consumer of energy all over the world. Most of this energy in buildings is consumed for heating-ventilation and lighting. With increasing economic standards and enhanced living standards, energy consumption in buildings is increasing day by day. More and more houses are being air-conditioned. This is increasing the rate at which fossil fuels are depleting. The main objective of energy efficient buildings is the reduction of energy consumption in the buildings. This in turn helps in reducing the energy produced at source. All over the world, major component of energy is still being generated using fossil fuels. It causes environmental pollution thereby increasing the problems such as global warming, Ozone layer depletion and many others. Thus in the wake of increasing environmental pollution and depleting conventional sources, it becomes essential to reduce the energy consumption in buildings and completely eliminate the dependency on fossil fuels.

Energy efficiency is the most important part of sustainable architecture. Sustainable buildings are known by many names- Green buildings, Zero Energy buildings etc. The main concern of such construction is to minimize the impact of building on the environment and increase the efficiency with which building uses resources (energy, water, materials). The results of extensive use of natural resources are being seen in the form of global climatic change. Glaciers which fed evergreen rivers are melting at an ever high rate.

2.6 INFERENCES FROM LITERATURE SURVEY

Literature related to *Vastushastra*, Thermal Comfort, Passive design features and Energy efficiency in buildings has been collected and studied in this chapter.

Vastushastra is an ancient Indian art of designing buildings. A number of *Vastushastra*s were used in earlier times, however very few of them (especially of *Nagara* style) still exist. Of the available texts, four have been studied in detail and only one has been finalized for the purpose of this study. The text is called *Rajvallabhmandanam* (RVM) which was popular in western India. Major contents of RVM relate to astrological and religious prescriptions which fall out of the score of present study. Therefore only the prescriptions which can be physically manifested have been identified. A total of 47 such prescriptions have been identified which will be analyzed in *Shekhawat*i *Haveli*s in later chapters.

Thermal comfort and conditions of thermal comfort have been defined. The index for analyzing thermal comfort has been selected as Tropical Summer Index (TSI) which was developed taking Indian subjects. The data which will be obtained after whole building simulation of case studies will be processed to obtain hourly TSI. analysis of comfort achieved in a space will be determined based upon the TSI calculations.

It is evident that many *Vaastu* prescriptions can be physically manifested. The prescriptions affect certain building elements which eventually have effect on thermal comfort. However it would be analysed in later chapters of this report whether identified *Vaastu* prescriptions have some effect on thermal comfort or not. Data collected from *Shekhawat*i would be analysed to establish relationship between *Vaastu* prescriptions and Thermal Comfort.

Since *Vaastu* prescriptions deal with practically applicable guidelines for designing comfortable buildings, it is anticipated that these would also be in line with passive design parameters. Hence passive design parameters for hot-dry climate have been studied. Besides analyzing relationship between *Vaastu* and Thermal comfort, *Vaastu* prescriptions will also be compared with passive design features.

The basic need for studying all of the above material is in light of increasing need for energy conservation in buildings. In the wake of ever increasing energy needs and decreasing resources of energy, it is important to find solutions to minimize the dependence on conventional sources of energy. Since buildings are major consumers of energy, it is essential to reduce energy consumption in buildings. The aim of this research is to find solutions to reduce energy consumption in buildings for achieving thermal comfort through traditional design methodology and this literature would help in achieving this aim.

Chapter 3

DATA COLLECTION: SHEKHAWATI

3.1 LOCATION

Nestled in the dusty and semi-desert part of *Rajasthan* (a western state of India, which is called to be the abode of the sons of kings, the *Rajas or Rajputs*) Fig. 3.1.1 is a group of towns that constitute the colourful region of *Shekhawat*i. Here the streets are lined with '*Haveli*s' painted in nature of an open-air art gallery. *Shekhawat*i meaning the land of Shekha's clan derive its name from *Rao Shekha* (1422 AD – 1488 AD, a king).

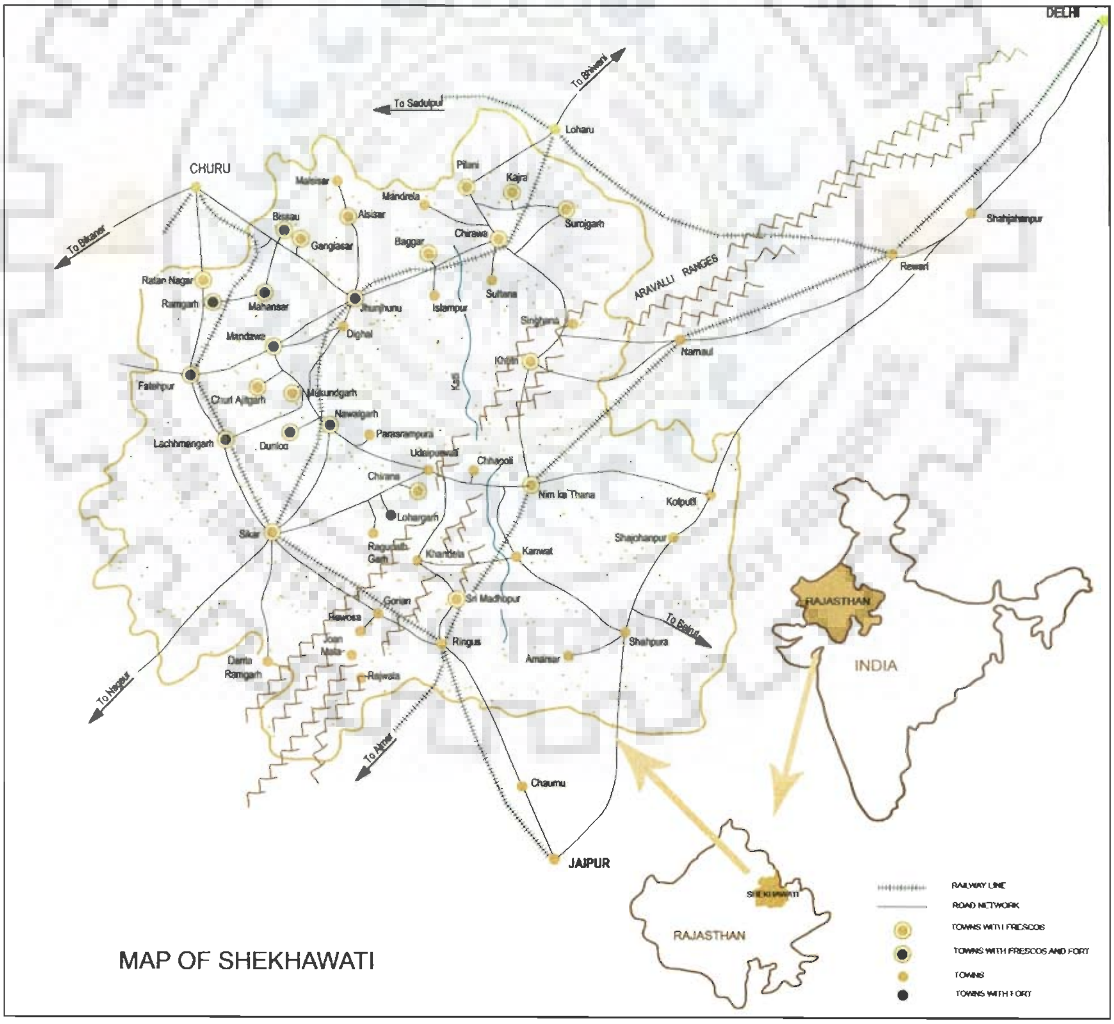

Figure 3.1.1 Map of *Shekhawat*i

Shekhawati sits as a region north of Jaipur on 270° 20' to 280°34'N Latitude and 740°41' to 760°6' E Longitude. The regions under *Jhunjhunu*, *Sikar* and *Churu* formulate the extant of *Shekhawati* is a semi desert with sparse trees.

3.2 PHYSIOGRAPHY

3.2.1 Landform

Shekhawati region is primarily plain. The undulations are not significant except in towns like *Mandawa* and *Mahensar* where small stretches of rocky hills are present.

3.2.2 Soil Type

The soil is a well graded mixture of fine and coarse grained sandy soil. The bearing capacity of soil here is 300 Kg/ cm^2. The upper layer of soil extends up to 12-15 m below earth. The hard rock layer is found at a depth of 30- 35 m. The soil here absorbs water because of being sandy in nature thus surface gets dried up very fast. In case of water run off, natural drainage patterns are formed on the basis of topography. The soil is fertile enough to support one season of harvest in fields.

3.2.3 Ground Water Table

Shekhawati has potable ground water level at 200 ft. This makes agriculture and irrigation difficult. It also affects the vegetation cover which is sparse in this region.

3.3 CLIMATE

3.3.1 Temperature

Maximum temperature in summers rises up to 45°C while night temperatures fall to 20°C. Winter days are temperate around 8°C while night temperatures reduce to just above freezing. This region has a typical hot-dry climate with high day and low night temperatures.

3.3.2 Rainfall-

It remains dry for most part of the year having only scanty rainfall. Annual rainfall is 600mm falling largely in the months of July- October.

3.3.3 Humidity

Apart from monsoon season, Relative Humidity is terribly low varying between 10-55 percent, categorizing the climate as Hot Dry.

3.3.4 Wind

Throughout the year dominant wind comes from NE quadrant and SW winds are experienced late in the monsoon. The wind temperature is hot in summers while very cold in winters. The only times when winds are preferred inside the building are summer nights and monsoon days.

3.3.5 Solar radiation

The solar radiation is intense around 700-800 Kcal/Sqm with sky being clear almost throughout the year.

3.3.6 Sandstorms

Dust storms and sandstorms are very common both during day and night.

3.4 SOCIETY

3.4.1 Social System

It was a complicated society with various factors being influential. Most important was sex discrimination. There was no visible interaction between men and women even within the family and females were supposed to remain veiled all the time. Their roles were clearly defined and demarcated. Men performed outside activities while women took care of household. This demanded segregation of spaces which resulted in multiple court *Havelis*.

It was always a joint family system where at times even three to four generations of a family lived together within the same household. The hierarchy and supremacy was clearly defined. The eldest male of the house was the head of family and looked after finances and business. The head's wife or mother was the female head and looked after household matters. A new house was constructed only if a feud occurred in family over business matters or usually when the shortage of space within the house was felt because of increasing family. The families stayed together because they usually shared the business/land. The extended family also included servants and their families who were associated for generations. Therefore *Haveli*s usually had areas for servant quarters.

3.4.2 Religion

Until the invasion of *Mughals*, Hinduism was the dominant religion in this region. Hinduism was not limited to a few rituals but it was a way of life. All elements of nature found their place in the religion and were worshipped as gods such as trees, water, fire, wind, sun, animals; everything was treated with respect and care. This enhanced the sustainable living. Donations and community service were a part of religion which encouraged the rich to construct places of public use such as temples, wells, rest houses called *Sarais* for travelers, step wells or *Baolis* etc. Society was God fearing and religion dominated every aspect of life. Religious stories found their place in the paintings on walls becoming a part of day to day living.

Most of the rituals revolved around fire. Rituals starting from birth to marriage and death, all were performed around fire. Since public places were not used for such ceremonies, there was a need for open space within the house where these rituals could be performed. Courtyard served this purpose.

3.4.3 Political Scenario

Shekhawati was never consolidated into a single kingdom, but remained a loosely held confederation of feudal principalities, for the most held by community of *Rajputs* known as the *Shekhawats*. The *Shekhawats* were considered *Baghis* (rebels) and were not allowed to build inside the city walls of Jaipur. When the new city of Jaipur was commissioned in the 18th century, the *Shekhawat* chieftains in the Jaipur court were offered land outside the walled city to build their town houses. From the turn of the century until 1822, vast amount of trade was diverted through *Shekhawati* and more merchants were attracted into the region. These merchants and their descendants financed the majority of *Havelis* and the murals.

During the 18th century, the *Rajputs*, the ruling community, founded the main towns of *Shekhawati*. They constructed forts and palaces where they had some rooms painted. They were the first patrons of the wall painting tradition in this area. *Marwaris* prospered until the beginning of the 19th century because of the caravan routes that crossed the area to reach the ports of Gujarat. Between 1830 and 1930, they erected buildings in their homeland, *Shekhawati*, as evidence of their success. As the ultimate symbol of their opulence, the *Mawaris* commissioned artists to paint those buildings.

Shekhawati remained as an important *thikana* under the Jaipur State, which was over the time controlled by Muslim *Nawabs*, *Rajput* Rulers and the British till India's Independence. A mutually advantageous relationship existed between various rulers and the *Marwaris*. The security offered by the rulers to the *Marwaris* saved them from the trouble of maintaining their own armies. In return, *Marwaris* financed the rulers to maintain that security. Due to unstable political situation, a sense of insecurity prevailed which is reflected in the built environment.

3.5 HAVELIS

The word '*Haveli*', in Persian, means 'a surrounded or an enclosed space'. Its origin could be traced to the word '*haowala*', which means 'partition' in old Arabic and it also is related to the term '*hawaleh*' meaning 'all round' or 'round about'. *Haveli*s were mansions, the original function of which were to wall in the domestic life of the family apart from providing the residence and had developed into the smallest survival unit in the civic structure.

3.5.1 Origin

The *Haveli*s in *Shekhawati* (Fig 3.5.1.1) were mansions built by the *Rajput* estate owners or *Rajputs*. Later with the change from agrarian to trade and commerce, the patronage of constructing these mansions moved from hands of the ruling *Rajputs* to the affluent trading merchants or *Marwaris*.

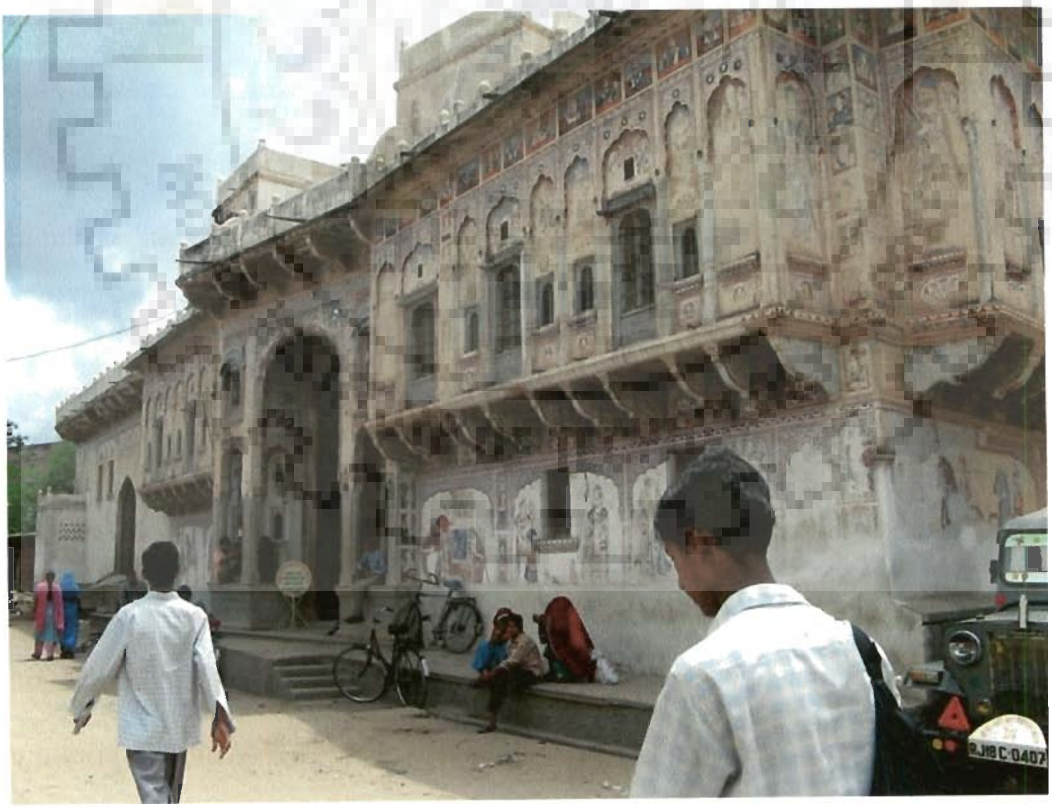

Figure 3.5.1.1 A *Haveli* in *Nawalgarh*, *Shekhawati*

The great era of the *Shekhawati Havelis* was the mid and the late 19th century. The *Havelis* were the symbol of the status of the *Marwaris* and a home for their extended family, providing security and comfort in a style. Secluded from the outside world, the *Haveli* set its own pace of life. Built by the rich merchants of the region, *Havelis* displayed a unique architectural style that evolved around the courtyards to ensure safety and privacy of the women folk and protection from the heat of the long and harsh summers. These *Havelis* were large and normally could accommodate several families who lived together as an economic, civic and socio-unit, sharing many common amenities.

3.5.2 Design

Havelis were usually designed by Hindu *Sthapatis* or architects. They were responsible for the spatial planning and almost everything. They were the master craftsman, painter and artist. They decided upon the details of paintings, design of brackets etc., supervised the construction and at times worked themselves too.

The methodology of design was unique. Design was never prepared on paper or any other medium which could be preserved. It was a spontaneous decision depending upon the size of plot. They first measured the plot and then located the centre of inner courtyard which was the most important point to be identified. Rest everything followed the courtyard. In case of irregular plots also, the courtyard was fixed as square or rectangle and the built form was accommodated in the residual space between plot and courtyard. The dimensions and spaces were all related to each other. It was a typical design with semi open and covered spaces around the courtyard. There was little intervention from the owner. All the elements of design and their proportions were fixed; only the scale varied depending upon the space available for use. This resulted in similar design pattern with variation brought through paintings and ornamentation.

3.6 ARCHITECTURAL ELEMENTS AND ORNAMENTATION IN HAVELIS

All the *Haveli*s in *Shekhawati* region (built between mid and late 19th century) have same elements of architecture and ornamentation. The uniqueness in each *Haveli* is achieved through combination of these elements. Elements are designed to provide comfortable space throughout the year and at all times of the day. Some elements were used only to fill the residual space or to make maximum use of the space which would otherwise remain unused.

*Haveli*s have a strong sense of symmetry and centrality. It was believed that a mirrored space nullifies all the negative energy associated with a certain layout. Hence we find that all *Havelis* in *Shekhawati* are mirrored along the central axis.

3.6.1 Architectural Elements

Chowk – Courtyard was called *Chowk* and was the most important part of house. All activities revolved around the *chowk*. It was used from morning to evening except in afternoons when it would receive direct sunlight. Activities of bathing, washing, preparation for cooking, chit-chatting etc, all took place in *chowk*.

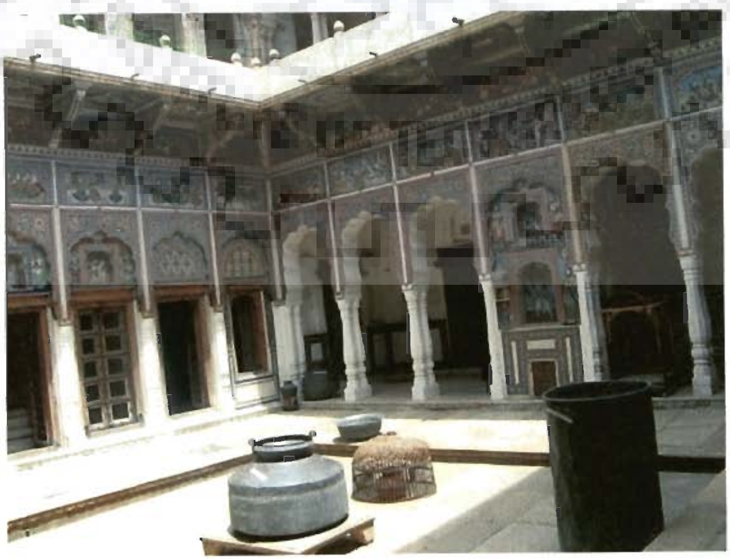

Figure 3.6.1.1 Inner *Chowk*

Inner *chowk* was the main area for women while outer *chowk* was used by men for commercial and business related activities. (Fig 3.6.1.1 and 3.6.1.2) *Chowk* came alive during occasions such as festivals, birth celebrations and marriages. The third *chowk* also remained active throughout the day with servants and attendants moving in and out for work. *Chowk* was the space which brought in the five elements of nature- sun, water, wind, sky and earth, into the building which is an important part of Hindu mythology. The *chowk* never had any construction below it in the form of basement. It was believed that the connectivity with the ground should not be broken and all five elements of nature must be present in the centre.

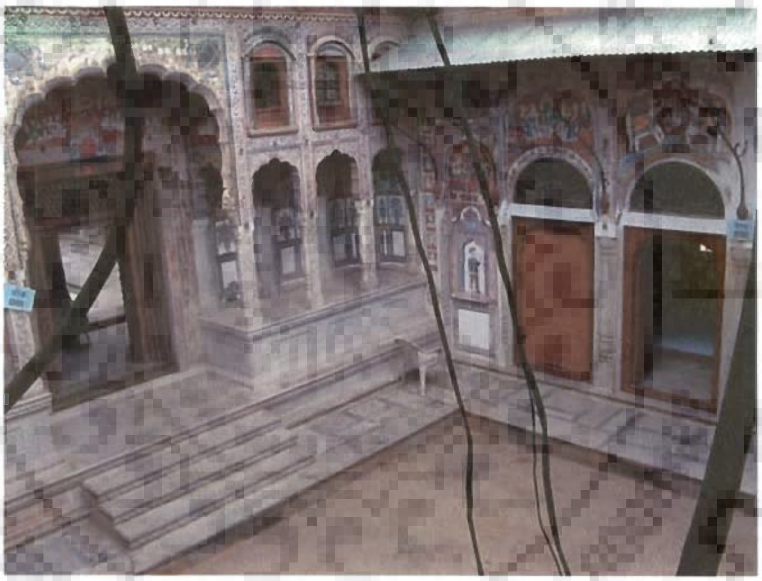

Figure 3.6.1.2 Outer *chowk*

Inner *chowk* was usually kept soft without any paving. It had a *tulsi* plant overlooking the entrance and there was no other vegetation. All the water from bathing, washing of utensils etc was absorbed by soft ground on inner *chowk*. It helped in maintaining cooler air. Outer *chowk* was however hard paved and remained hotter. This resulted in upward movement of hot air. This created a forced draft of cool air from inner court to outer court.

Chowk was surrounded by arches all around. Usually the number of arches on two sides was equal and odd numbered e.g. three, five, seven, nine and eleven. At times unequal number of arches on other side was also found but essentially odd numbered. Covered space around the *chowk* was arranged in bays which increased in number with increase in size of courtyard. There were maximum three bays in *Havelis*. Most common was a seven by seven arched *chowk* with two bays on all sides.

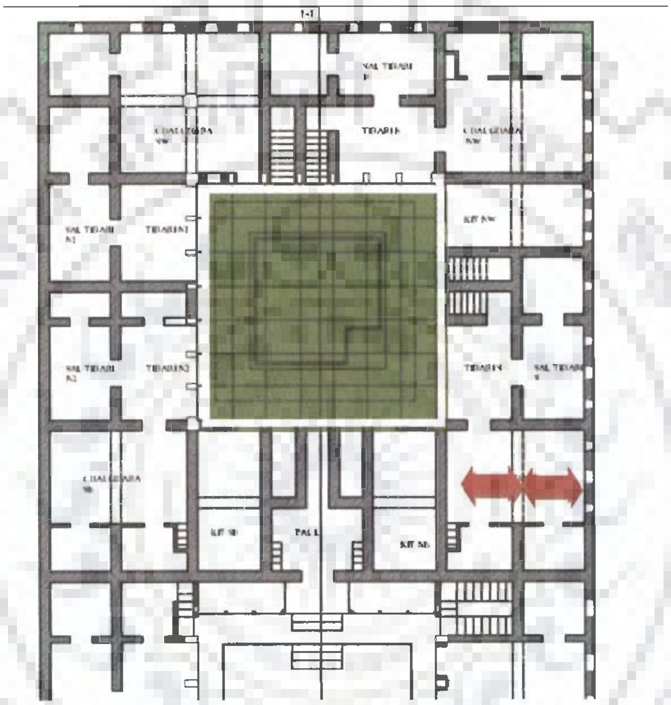

Figure 3.6.1.3 Green showing *chowk* having seven arches, red arrows showing bays of construction

Pauli – *Pauli* was the transition space between any two courtyards or outside and inside. It had a deferred entry for privacy. It had a small window in front of the main door on outside which was used by women to remain connected to outside activities without being visible. *Pauli* signified the sanctity and privacy of the space to be entered and was treated with much reverence. It usually had viewing galleries at mezzanine level which were used during occasions. (Fig. 3.6.1.4)

Figure 3.6.1.4 Pauli from Outer to Inner Chowk

Baithak – The semi-covered and covered areas in outer *chowk* were used for formal interaction by men. *Baithak* was the most elaborately painted and biggest room in a *Haveli*. It was used to receive guests. It had viewing gallery all around it which was used my women at times of important functions, performances or ceremonies. (Fig. 3.6.1.5)

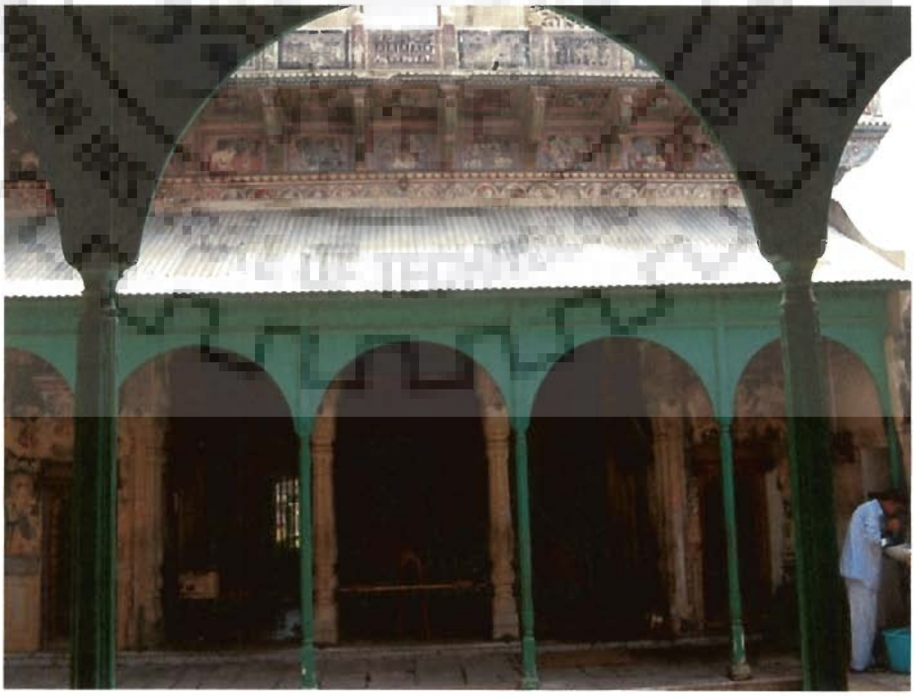

Figure 3.6.1.5 Baithak in outer Chowk (Tin Shed is a later addition)

Figure 3.6.1.6 Deodhi in one of the *Haveli*s (Note the orange paint in the centre, it signifies that family worships Lord Hanuman)

Deodhi- The arch over elaborate gate between outer to inner *chowk* or between street to outer *chowk* before *pauli* was called *deodhi*. It derives its name from *Dev Paudhi* or meaning Space for Gods. The projected arch over the gate was used to display the family God/Goddess and also to mark the recent incident in the family such as a marriage, a birth or a death. Each had a symbol which was put on deodhi so that visitors to the house are aware of the circumstances. Also since it was an interactive society, *deodhi* was used as a means of communicating the state through which family is going. (Fig. 3.6.1.6)

Gokha – A small covered platform with arches on both sides of Deodhi was called *gokha*. It was used by men folk as a seating on the street to communicate with each other across the street and with people walking down the street. The space above *gokha* was accessible from inside and was used by women folk to watch processions on the road. (Fig. 3.6.1.7)

Taj – the elaborate doorway consisting of *deodhi, gokha* and small rooms on both sides of gate, called *bagli*, used by gate keepers collectively were called *Taj*. It was the largest and most elaborate doorway in the house. It had special significance during marriages. The height of *Taj* depicted the status of the family. (Fig. 3.6.1.7)

Figure 3.6.1.7 Elaborate Taj in a *Haveli* (Note the fan shaped object (encircled) in deodhi. It signified marriage of a girl in the house)

Tibari- It was a semi-covered space with three arches opening towards courtyard. It was the most used semi-covered space. It was used when ambient air temperatures were within tolerable range but courtyard received direct sun for most of the day to day activities. It was the least private space in the inner chowk and was used for miscellaneous activities throughout the day such as eating, resting etc. *Tibari* was the transitional space for entering the enclosed spaces which were more private thus maintaining the hierarchy of spaces and privacy. (Fig. 3.6.1.8)

Figure 3.6.1.8 Tibari

Figure 3.6.1.9 Rasoghada

Rasoghada- Rasoghada was the name for kitchen. In Indian culture, all festivals are associated with some God in the form of a natural element, a specific season, foods suiting the season depending upon the climate as well as availability of food during that season and clothing. Especially *Marwari* culture is famous for its love for exotic food. Thus *rasoghada* played an important role. The tibari next to *rasoghada* usually served as dining area. As a result of symmetric plan, there were at least two kitchens in the *Haveli*. But only one kitchen was used for cooking. The other was used for storing utensils and uncooked food materials. (Fig. 3.6.1.9)

Parinda- Small space next to *rasoghada* was used for keeping water and was called *parinda*. It had a *Jali* door which allowed increased ventilation. Since water was kept in earthen pots, air flow was necessary to keep the water cool. Hence *parinda* always had a jail door either made up of wood or iron. Because of symmetrical planning, there were at least two *parinda* in the inner court (there were more in outer court too). One was used for storing water for kitchen and members of the house, other was for bathing. In case there were more, depending upon design, one was demarcated for servants also. The drain from parinda was directed to courtyard which was soft. (Fig. 3.6.1.10)

Figure 3.6.1.10 Parinda

Sal- The inner private rooms accessible through *tibari* were called as *Sal*. *Sal* was uaually used by women and it was the most private area. (Fig. 3.6.1.11)

Figure 3.6.1.11 Sal with almira in the center

Kothri- The stores inside the Sals were called *kothri*. *Kothri* was a small room with double floor which increased storage area. It was used to store valuables. The thick walls in *kothri* had hidden storage units called *athedi* which were not easily visible from outside but ran deep in the wall. Almost all *Sals* had *kothris*. (Fig. 3.6.1.12)

Figure 3.6.1.12 Kothri inside the Sal (Shown in Fig 3.6.1.11)

Chaughara- The corner *sals* which were bigger in size and included four bays together were called *chaughara*. *Chaughara* was used as family room. It had double floored areas around it which were used for sleeping and storage. In case there was no wall or column inside the room, then the roof was a flattened dome with ornamentation in white lime. Paintings were not used for inside rooms and these were always finished smooth with lime with a lining at dado level. (Fig. 3.6.1.13)

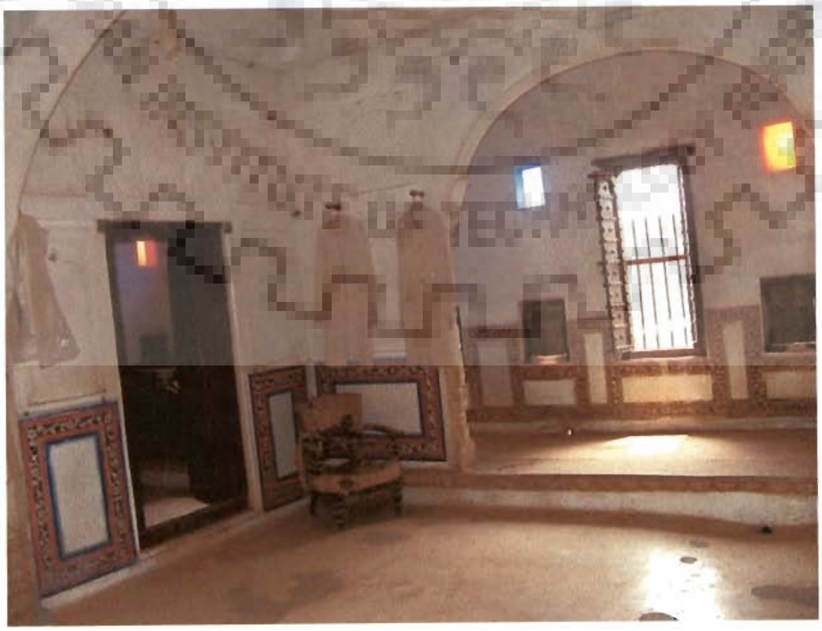

Figure 3.6.1.13 Chaughara (Note the Kothri and extended area of *Jharokha* beyond arch)

Paidigalo- The stairs called *paidigalo* were provided for accessibility to the roof or *chat*. The terrace of stairs was called *dakli*. It was a special terrace and was reserved for the newly wed couple of the house as the rooms never had a demarcated user.

Kamra – Rooms opening directly into the *chowk* were called *kamra*. It was used as family room and had lesser privacy than *sal*.

3.6.2 Ornamentation Elements

Many of architectural and structural members were designed to ornament the building. Most of these had geometrical and floral designs. Following is the list of such members-

Jharokhas- Space inside *Jharokhas* was integrated in the room. These were constructed in brick and lime over the projected roof slab which was made up of stone. They had large sized windows fitted with thick wooden shutters. The walls of *Jharokhas* were painted from outside. (Fig. 3.6.2.1)

Figure 3.6.2.1 *Jharokhas* projecting out on wall, help in shading the wall

(Note size of windows on *Jharokhas* which is larger than other windows on wall)

Brackets- brackets were used to support the roof projections, *Chajjas* and *Jharokhas*. They were made up of stone and had a typical design as shown in figure. (Fig. 3.6.2.2)

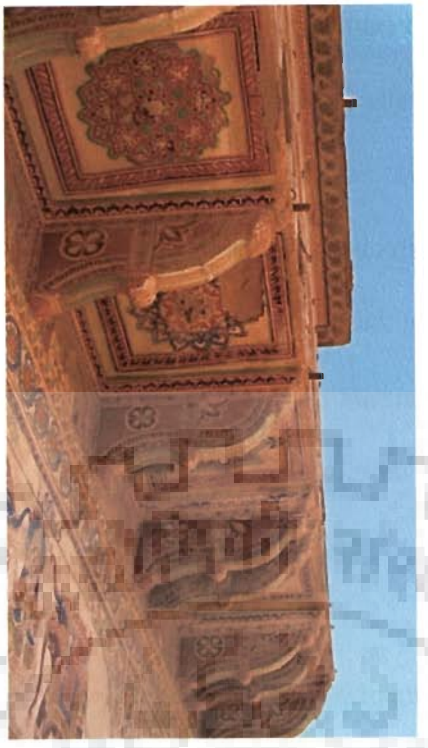

Figure 3.6.2.2 Typical Bracket

Column- columns were used only to create arches in *tibaris* and had a typical design. The painting over the column varied but the design remained same. (Fig. 3.6.2.3)

Figure 3.6.2.3 Typical column and arch assembly

Arches- Arches varied in shape and size depending upon the space available. The number of curves increased with increasing size of arch. It was usually painted. (Fig. 3.6.2.3)

3.6.3 Paintings on walls and ceilings

In contrast to plain and drab country side the people in desert filled their lives with colours. *Shekhawat*i gains its recognition today as a region with its painted *Haveli*s in rich artistic tradition. The stone available in *Shekhawat*i cannot be carved intricately as seen in other parts of *Rajasthan*. That is why the rich merchants got their *Haveli*s painted, which not only made their *Haveli*s a visual treat but also set the entire *Shekhawat*i apart. These paintings adorned the huge exterior facades of the *Haveli*s to the smallest elements like brackets, small niches in the walls, arches and ceilings. The interiors had more intricate work with combination of glass work and extensive use of colours.(Appendix 4)

3.6.4 Material and Technique of Construction

These *Haveli*s were erected in an era when steel and glass were not easily available in India and were not popular. Similar to traditional constructions all over the world, the system of construction here is load bearing. Bricks, stone and lime mortar were mainly used to construct the buildings. All these materials are not good in tension. Thus arches were used to cover the spans so that the material always remains in compression. However during earthquake, such structures are most liable to fail.

Walls

Walls were made up of burnt bricks set in lime mortar. The bricks were hand pressed and properly burnt. The strength of brick is not known but during a visit to *Shekhawat*i, it was observed that the masons and laborers found it difficult to break these bricks to use them as bats or for filling while the presently available bricks were brittle to be broken easily. The lime mortar was prepared using locally available lime obtained from the quarries. It was mixed with many other materials like brick powder (*surkhi*), crushed sea shells, powder obtained by crushing locally available stone and some organic material (like jaggery, *Urad Dal* etc.). The bricks were laid in popular bonds like English and Flemish bonds. Fig 3.6.4.1 and Fig 3.6.4.2. The mortar was very thick, up to 2 inches, unlike the thickness of mortar in modern construction. This provided immense strength to the masonry. Fig 3.6.4.3. The thickness of the walls varied from 4 feet at the plinth level, 1 foot- 2 feet at the ground level and 1 foot-6 inches at first floor level. The plaster was done in 3-4 layers. The base layer was of the same mortar which was used for main structure. The second layer was a fine paste of lime, sea shells and marble stone which was passed through muslin cloth. On this layer of plaster, the sketch of the drawing was made with pencil/charcoal. The final layer was done using fine sea shell and marble powder (called *pana*) filled in a muslin cloth. It was applied as the finest layer over the second layer in a dry form only. The final painting was done above it. The finest layer gave a shine to the plaster which was comparable to the polished marble. Fig 3.6.4.4. Even today, in the interiors of the *Havelis*, the lime marble has remained as shining as ever and much whiter than marble of the same age.

Figure 3.6.4.1- Bond in Brick Masonry

Figure 3.6.4.2 Thickness of Mortar in Masonry

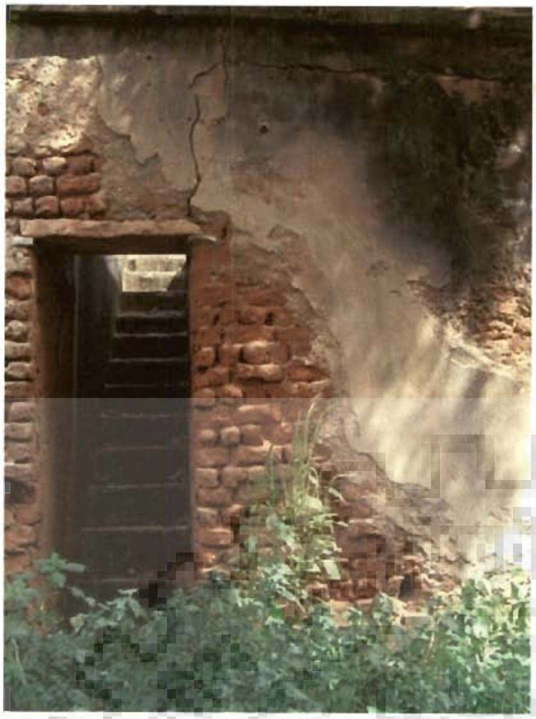

Figure 3.6.4.3 Bonding in Brick Masonry

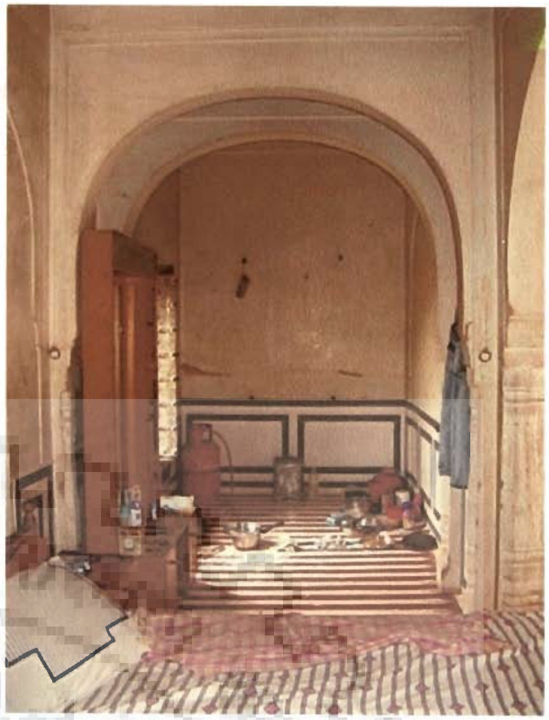

Figure 3.6.4.4 Lime Plaster on Walls

Roof/Floor

The floor was made up of brick and lime mortar. The floor on the ground was first filled and compacted with earth. Over it a layer of stones was compacted, which was then covered with 2-3 layers of brick. The top was finished in the same manner as the walls. The roof or the floor at first floor level was supported on a flattened dome made of bricks and lime mortar. The top was flattened and finished with lime mortar same as the ground floor and walls. Fig. 3.6.4.5. On the terrace, roof was constructed in the same manner. The top was finished with water proof materials such as brick tiles which were again plastered with lime mortar having more stone powder and more in thickness. Fig 3.6.4.6.

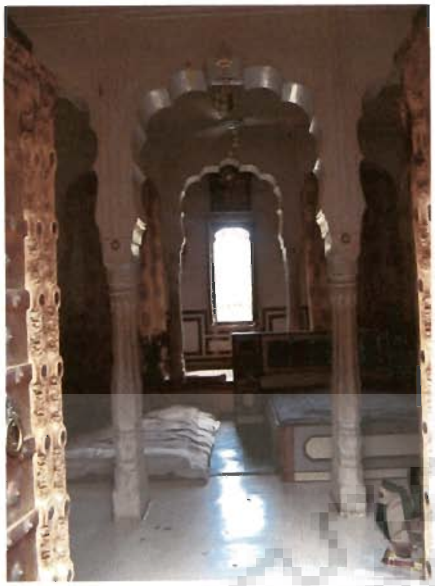

Figure 3.6.4.5 Smooth Lime Floor

Figure 3.6.4.6 Rough and strong Flooring on the Terrace

Openings

All the windows have the same sill level but the lintel level varies greatly. Fig 3.6.4.7. The opening above the openings was spanned using stone slabs or wooden beams sometimes. The window frames were always made of wood. The windows were of small size on the ground floor. Many a times, there were no windows to outside on ground floor. However, first floor had large windows opening to outside. The windows were always placed in the centre of the wall. In case of many windows, they were equally spaced to cover the wall. But openings were never near the corners.

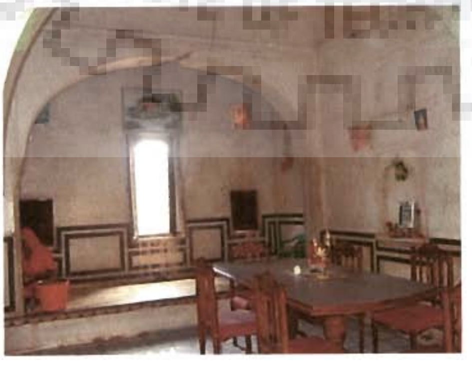

Figure 3.6.4.7 Varying Lintel Level of Openings and Arch Supporting the Roof

Projections/ Cantilevers

The whole first floor was projected around 2'6" – 3'6" out from the ground floor wall level. This was done to create shade over the walls of ground floor. The projected space was provided with large windows and was used for sleeping during night and for viewing during daytime. The projection was supported over stone brackets which were supported over the wall. (Fig 3.6.4.8) The brackets were double the width of the projection. This enabled half of the bracket to be inserted into the wall and supported firmly. Stone slabs were laid over them to form the floor. The walls of this projection were made of thin slabs of stone which only acted as screens. The load bearing walls came exactly above the ground floor walls.

Figure 3.6.4.8 Projection of Roof

3.7 TYPES OF HAVELIS

Havelis ranging from one to four courtyards were built depending upon the family structure and the socio-economic status of the *Marwaris*. One, two and three courtyard *Havelis* are most common where as four courtyard *Havelis* are rarely seen. Many of the finest examples enclose two courts, broadly differentiated into an inner courtyard for the womenfolk and an outer court for the men. The size of *Havelis* varied and was proportionate to the degree of success achieved by the family in business. A new storey would be added on a successful business deal.

Each *Haveli* had a space called *Nohra* or the space used to park vehicles and animals. In case where it was attached to the *Haveli*, it housed servant quarters, storage areas and toilets. The bigger *Havelis* having three or more courtyards had one courtyard serving as nohra which had elaborate rooms built around it.

3.7.1 One courtyard *Haveli*

With only one courtyard in the *Haveli*, it became the centre of all the activities carried out in the surrounding spaces. Thus a concept of centrality existed. The only courtyard served as the forecourt where most of the activities took place. The main activity areas of men were secluded from those of women's. The *Haveli* had only one main entrance, where one could enter the courtyard through *pauli*. Men spent most of their time in the room above the *pauli*. The spaces on the ground floor were used by women for their household work. (Fig 3.7.1).

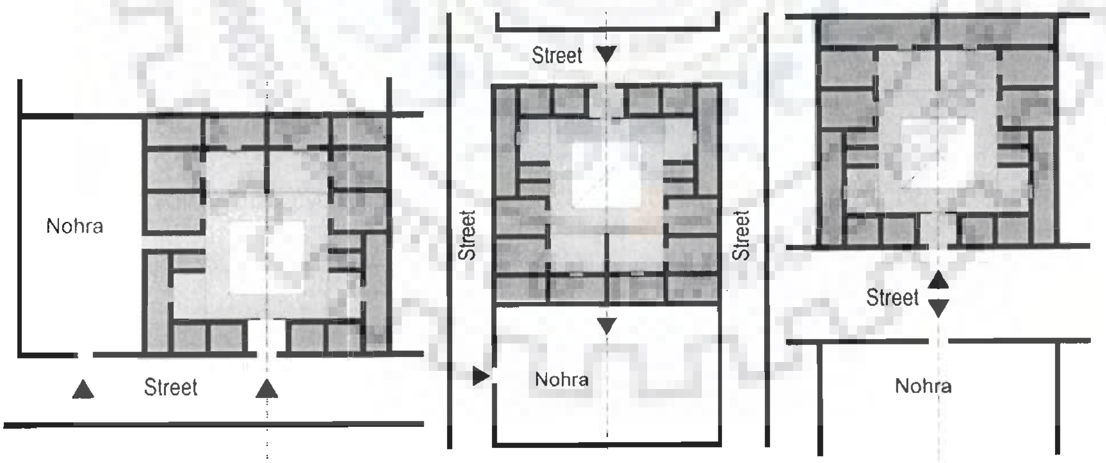

Figure 3.7.1 Single Courtyard *Haveli* with Nohra on Side, Front (Across the street) and Back

3.7.2 Two courtyard *Haveli*

The two courtyards here became the centre of activities carried out by the men and women of the family, where the outer courtyard became the forecourt where as the inner one was used only by women. Concept of privacy became an important factor in deciding the spatial organization of the *Haveli*. Forecourt was accessible to all visitors and it became the hub of all trade and commercial activities of men. All household activities took place in the inner courtyard. (Fig 3.7.2)

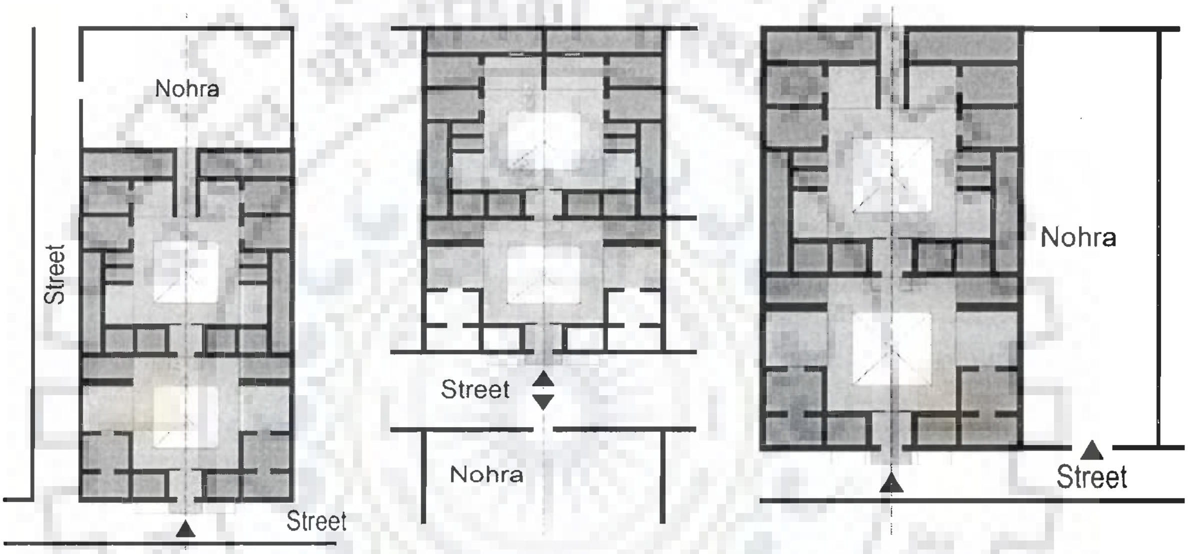

Figure 3.7.2 Double Courtyard *Haveli* with Nohra at Back, Front (Across the street) and Side

3.7.3 Three courtyard *Haveli*

The third courtyard was used by the attendants for other profane spaces and for storage. The middle court remained women's domain and the first served as the forecourt. A *pauli* existed between any two courtyards hence increasing the degree of privacy. (Fig. 3.7.3)

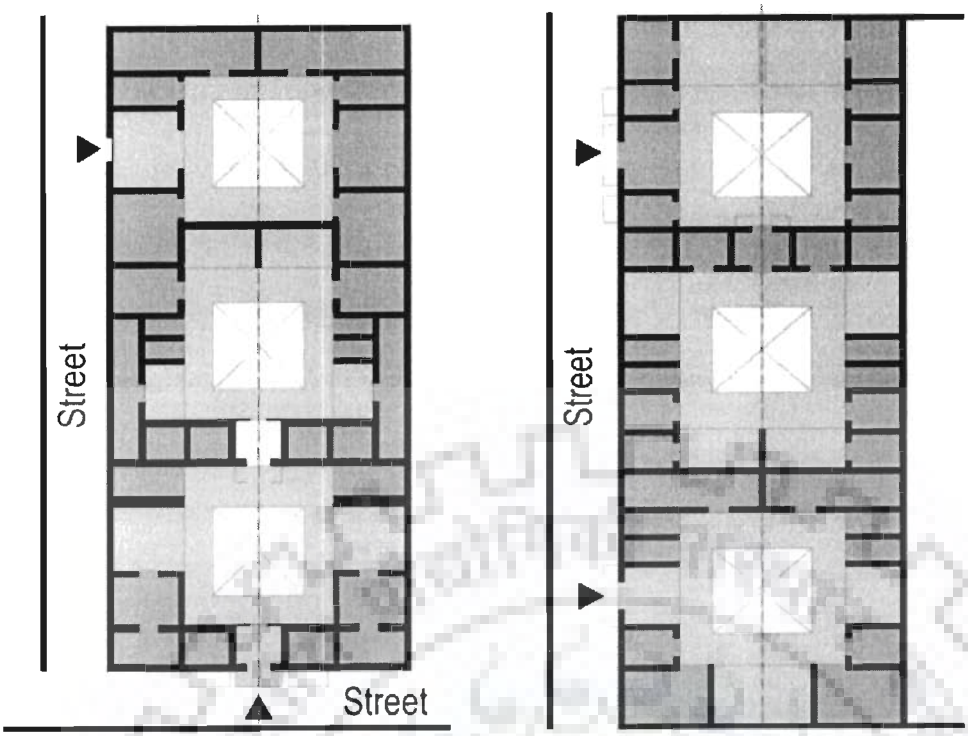

Figure 3.7.3 Three Courtyard *Haveli* with Entry from one and two streets

3.7.4 Four courtyard *Haveli*

These ones were the largest and most elaborately painted *Haveli*s in the town. They clearly reflected the economic status of the family. Most of the four courtyard *Haveli*s were actually a combination of two courtyard *Haveli*s placed next to each other. (Fig. 3.7.4)

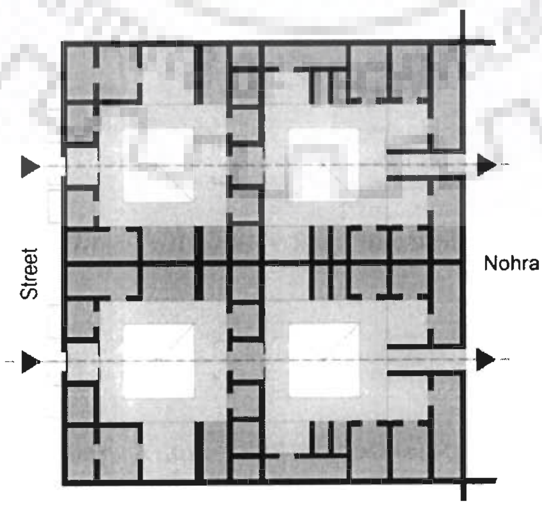

Figure 3.7.4 Four Courtyard *Haveli* with Nohra at Back

3.8 CASE STUDIES FROM *SHEKHAWATI*

During the survey of *Shekhawati* region which consists of *Haveli*s constructed during 1830 to 1930, 25 case studies were documented for study and analysis. The case studies represent almost all scales and sizes of *Haveli*s. The case studies do not have any four courtyards *Haveli*. Such *Haveli*s were few in number hence their inclusion would not have helped in generalizing the results.

3.8.1 Selection criteria of case studies

Case studies were randomly selected without any prejudice to represent all possible cases. Since physical measurement of room temperatures was not intended, condition of *Haveli* did not play any major role. **The only important criterion was the originality and similarity of design**. Most of these *Haveli*s have undergone additions and alterations depending upon modern usage. For the purpose of analysis, it was intended to document the original design so that a relationship between *Vaastu* principles, which were incorporated in design in those times, could be compared with comfort.

It was preferred to document those *Haveli*s which were occupied presently so that a direct response from user could be collected. This would have helped in comparing the results with actual comfort as experienced by the user. But most of the owners of these *Haveli*s have migrated to metro cities like Bombay, Calcutta, Ahmedabad and New Delhi for business, thus abandoning these *Haveli*s. Few *Haveli*s have front baithak areas opened to care takers and tenants, rest are completely closed. Very few *Haveli*s have the owners living in them. Thus the idea of collecting response could not be implemented and this criteria was left out. It was also observed that *Haveli*s which are being used for residence have major modifications thus changing the design considerably. Hence preference was given to unoccupied *Haveli*s.

Case studies were selected from almost all towns thereby evenly representing the whole area of study. The towns under *Shekhawat*i region have same climate. Variations were observed in the topography and soil character. The towns in the western and south-western part of *Shekhawat*i had a soil type which was more prone to uneven settlements. Therefore the *Haveli*s in these towns such as *Sikar* and *Fatehpur* had high plinths. The towns in North and North-Eastern part of *Shekhawat*i region had rocky soil. Thus the undulations on road usually required higher plinth to equalize the level within one *Haveli*.

There are a total of 47 towns in *Shekhawat*i region. Most of these towns now have size and population of a bigger village only but they used to business centre a century and a half back. Out of the 47 towns, 24 towns have elaborately painted *Haveli*s which are famous worldwide. These towns are- *Nawalgarh, Mukundgarh, Dundlod, Lachchmangarh, Fatehpur, Chudi Ajitgarh, Mandawa, Mahansar, Ratannagar, Ramgarh, Bissau, Gangiasar, Jhunjhunu, Alsisar, Baggar, Chirawa, Pilani, Surajgarh, Kajda, Sikar, Khetri, ChiRana, Nim Ka Thana and Sri Madhopur*. All the towns were surveyed and atleast one *Haveli* from each was documented. However to limit the work within this research work, 25 cases have been selected out of those. These 25 cases represent the whole region uniformly.

For many cases, the age of construction and the name of owner who constructed the *Haveli* are not known. It is because in most of the *Haveli*s, the owners are not residing and tenants hardly have any knowledge of the building's details. The design of the *Haveli*s and paintings are suggestive of the period of construction. The older *Haveli*s have limited colours used in the paintings and interiors are white. In design, they have only tibari as a semi-covered area. However in *Haveli*s constructed later, the paintings have more colours and interiors are painted in yellow occur and green colour. A continuous verandah is present all around the building towards outside and towards courtyard also.

This was incorporated in design as an influence of colonial architecture. In such *Haveli*s, even the design of column has changed to simple circular columns and typical cusped arch of traditional design has been replaced by semi-circular arch. Thus while surveying the buildings, the *Haveli*s which have traditional design and construction have been documented even when the age was not known.

3.8.2 Case studies

All the documented *Haveli*s were originally constructed and owned by Hindu owners. The documented *Haveli*s have been arranged starting under the heads of single court, double court and triple court *Haveli*s. The plans and photographs of each case study are appended in appendix 5 and 6. Following are the documented case studies-

3.8.2.1 Single court Havelis-

As discussed earlier, smaller *Haveli*s had only one courtyard. It was the basic unit. The outer courtyard was added later depending upon the increment of resources. Most of these single court *Haveli*s are modest which is reflected from their unpainted walls as compared to bigger *Haveli*s where we find almost all outside walls as painted. Most of single courtyard *Haveli*s which were surveyed had no scope for extension suggesting the limited resources at owner's disposal.

1. Chiranjilalji Dai Ma Haveli, Fatehpur

It is a single court double storied *Haveli*. It was donated to mid-wife *Chiranjilalji Dai Ma* by a rich *Marwari* as a gift for having a son. It was an elaborately painted *Haveli* but all the paintings have now faded out because of the smoke and soot from the kitchen. It is a corner building at the junction of three streets. It faces North and has streets on North and west sides. It is open from the other two sides also. On the east is the nohra space of its own and on south is open area of some other *Haveli*. It doesn't receive shadow from any other building till almost sunset because of the wide streets. Hence this

Haveli is exposed to sun from all sides. But it has no openings in east and south direction. Thick walls in these directions make it possible to block the heat transfer significantly. Because of small size of courtyard and a double storied building mass all around, the court remains shaded throughout the day thus helping in keeping the building cool. It is still occupied and is used for residential purpose only.

2. *Harsukhrai Pansari, Chirawa*

It is a single court *Haveli* facing west with half built first floor towards east. It is a simple building with typical design. It is a modest building with no painting at all. Locals inform that originally, the brackets and panels in between columns were painted. But with time all surfaces have been painted white with lime. Presently there are no paintings in the buildings. *Haveli* is open on front and back (West and East). It has *Haveli*s on both of its sides. The open area at the back is not owned by the owner. Hence the rooms inside building have fenestration openings towards courtyard only. The courtyard is wide as compared to the total width of the building. Therefore the building receives ample amount of light and fairly high radiation. The walls do not add to much heat gain because of two sides being covered by adjacent buildings and the other two having no openings. The walls in the courtyard remain shaded most of the time throughout the day as a result of the roof projections and surrounding mass on first floor. Surrounding buildings are also double storied thus adding to the shading of building. It helps in reducing the heat gain of the building.

3. *Ramgarh Haveli*

This is one of the very few *Haveli*s which are enclosed from all the three sides. Usually *Haveli*s are open on all four sides. At least, two sides are usually open. But in this case, buildings are constructed on all the three sides. Another unique thing is that courtyard is not square. It has six arches along the width and five along the length.

Usually *Shekhawat*i *Haveli*s have equal number of arches on both sides. The *Haveli* has only one side open, hence the windows are provided on the front façade and towards courtyard. The *Haveli* in single storied. Thus on one hand the heat gain through wall is greatly reduced but the heat gain from roof is increased substantially. In absence of cross ventilation, the building in not cooled during night. Without air movement, same degree of temperature also causes greater discomfort. Hence the comfort is reduced in spaces without air movement.

4. Muslim Haveli, Ratannagar

The *Haveli*s in Ratannagar have a typically high plinth. As per the typical design, rooms in plinth (referred as basement in the report because it had earth mass on one or two sides) were not used for residential purposes. The level above the basement was main activity level. Ratannagar *Haveli*s have high plinth (equal to height of one storey). The entrance to main level of house has a characteristic wide staircase in front of main door. All *Haveli*s in Ratannagar have single courtyard. Baithak was designed in the basement area on both sides of entrance staircase. High plinth was required because of frequent and strong dust storms which are prevalent in this region.

This *Haveli* was originally constructed by *Marwari* businessman whose family has settled outside Ratannagar. The *Haveli* has now been bought by a Muslim owner who runs his cloth dyeing factory from this *Haveli* which serves as his residence as well as workshop. It faces north and has two storeys above basement. It is open to environment on all four sides. It has nohra at the back and street on one side. Fourth side is open area belonging to another *Haveli*. *Jharokhas* are present on three sides. It has larger surface area exposed to sun. Similar to other *Haveli*s in *Shekhawat*i, this *Haveli* has also been designed as per *Vaastu*.

The prescriptions in *Vaastu* have been presented in a religious language, which affect the psychology of user more than the building comfort. Its practices are believed to bring prosperity and gains to the owner. Thus if some prescriptions are not followed, the idea of disastrous consequences scare the user more than the actual experience of discomfort if any.

This building has now been occupied by a Muslim owner who doesn't believe in *Vaastu* or its effects but finds this building comfortable. It implies that even when user was not psychologically influenced, he found this building comfortable. The idea of establishing relationship between comfort and *Vaastu* was thus reinforced.

5. Sahumal Khetan, Mahensar

It is a small corner *Haveli* which is open on two sides to the streets and closed on other two by adjacent buildings. Only half of the first floor is constructed on the west side. It has small openings and lesser surface area exposure. The courtyard is small and receives less amount of direct solar radiation. It is oriented towards east and is open on east and south. It is currently occupied and is being used as residence only.

6. Sidhkaranji Morarka, Mukundgarh

This *Haveli* clearly indicates the design and development process of a *Haveli* from a modest single court single storied *Haveli* to a possible elaborate *Haveli* with two or more courts and storeys. The total plot available with the owner is large and the single court and the building around it has been planned in a manner that it leaves space in front where baithak can be constructed on both sides. The remaining open area on side could be used to construct third courtyard to be used for cattle and servants. Unlike other single storied *Havelis*, it has a setback in front (to be used for extension later). It faces west and is open towards west and north. It has residential buildings on the other two sides.

3.8.2.2 Double Courtyard Havelis-

Most of the *Havel*is in *Shekhawat*i region have two courtyards. The scale of such buildings was most appropriate for a family. The two courtyards fulfilled all functions and the *Haveli* was not too big to be maintained properly. Thus we find many examples of different scale and size within the domain of double courtyard *Havel*is.

1. Babulalji Gudha Haveli, Mukundgarh

It is one of the oldest *Havel*is in Mukundgarh. The owner's son, Babulalji Gudha who extended the *Haveli* in 1913 (originally constructed in 1820) is survived by a wife, four sons and four daughters. At present his old wife is staying in the *Haveli* which is now in dilapidated condition. The *Haveli* has a typical ground floor. Only a small portion of first floor is constructed towards west. It is open on all the four sides. On north and west is the open area belonging to other *Havel*is. Front is towards east which is a street. On south of the *Haveli* is nohra which is connected to the *Haveli* through a passage from outer courtyard. The exquisitely carved door frames and remaining paintings on outside wall towards street clearly indicate that *Haveli* owner had a wealthy status. The *Haveli* has large surface area exposure because of open area on all four sides. It is a single storied building, hence terrace also contributes large amount of heat gain. *Haveli* has openings only towards south. The walls on all other sides do not have any opening. This helps in reducing the heat gain by increasing the thermal mass. The *Haveli* is not symmetric about the central axis which is against the characteristic feature of *Shekhawat*i *Havel*is. The asymmetry in design is evident only in the arrangement of rooms in west direction; remaining part follows symmetry.

2. Bhagirathmal Kedarmal Goenka, Dundlod

It is one of the *Havel*is having large inner courtyard. Most of the double-courtyard *Havel*is have 7X7 arched inner courtyards. It has 9X9 arched courtyard. It is open on all four sides with a boundary enclosing it from two sides with an approximate setback of 30'. It has a high plinth used for storage and other ancillary works. It has two floors. First floor has *Jharokhas* projecting on two sides. It faces west. The open area on north belongs to some other *Haveli*. Thus the *Jharokhas* is present towards east and south only. First floor is constructed only around inner courtyard. Most of the *Haveli*s which have large inner courtyards have two bays of constructed area around the courtyard. However here, constructed area on north, south and west have single bays. Easter side has double bay construction. Because of being exposed on all four sides, it has greater surface area.

3. Bissau Haveli

Documented *Haveli* from Bissau is a large *Haveli* with open area on all four sides. Uniquely, the *Haveli* owns the open area on all the four sides. It has only one main activity floor raised above a high plinth. The inner courtyard is large with 9X9 arches and two bays on all sides of courtyard. The owned open area on all sides allowed construction of *Jharokhas* on all the four sides. Thus all the rooms in this *Haveli* have windows opening to outside. The *Haveli* faces west and is completely symmetrical about the central axis. It has large ground coverage and receives fairly high amount of radiation because of being exposed on all four sides. Because of being single storied, the terrace contributes significantly to the total heat gain of the building.

4. Damodar Prasad Morarka, Mukundgarh

It is a modest *Haveli* facing east. It is open on three sides. On the northern side, it has shops which open onto the main market road. The other three sides are open. Open area at the back (west side) is not owned by the owners. Hence *Jharokhas* are present only towards south. The constructed area around inner courtyard has single bay of rooms on north and south side and double bay construction on west. The *Haveli* is completely symmetrical. It is still used as residence by the sixth generation of owner who constructed the *Haveli*. The *Haveli*s in Mukundgarh usually have low plinth, hardly 2-3 feet high. Usually a ramp is provided at the main entrance on street to reach the plinth level. This *Haveli* has no paintings and is completely white washed with lime.

5. *Haveli used as Gymnasium, Dundlod*

It is an old and large *Haveli* which has remained abandoned for a long time. It has two courtyards and two floors. It faces east and is open on three sides- east, north and west. The open area on North and west belongs to owner. Thus *Jharokhas* open in these two directions. The plan is not symmetrical about central axis. At present gymnasium exercise machines have been installed in tibaris in inner courtyard. The sals are not used presently. Yet no structural change has been done. Against the mandatory prescription of not planting trees inside the building, this building has trees in inner courtyard as well as outer courtyard. The trees keep the courtyard shaded throughout the day. The plinth of this *Haveli* is not high. Hence the storage areas in plinth are sunken in ground to achieve workable height.

6. *Seth Arjun Das Goenka Haveli, Dundlod*

The *Haveli* was constructed by Seth Arjun Das Goenka in 1875 and took nearly ten years to complete. The whole building was erected at one time and there were no additions later on.. It is a two courtyard *Haveli* with two floors and high plinth. All the external walls of *Haveli* including walls of inner courtyard are completely painted. The *Haveli* faces west and is open on all sides. On its south is the main road of Dundlod town which leads to the fort. It clearly indicates the important status of the owner of *Haveli*. The rooms in plinth opening towards main road house shops. The nohra of *Haveli* is at the back towards east. *Haveli* has *Jharokhas* on north and south side. The *Haveli* has high plinth unlike other *Haveli*s in Dundlod. It has been converted into museum. The museum displays the traditional utensils, dresses, storage units, furniture, carriages etc. It is maintained by Sh. Basant Kumar Goenka who owns the *Haveli* presently but lives in Calcutta.

7. *Harkaran Das Mangilalji, Bagad*

It is a two courtyard *Haveli* facing west. It has high plinth. It has two floors with first floor present only on half of the floor. It is open on all sides and has *Jharokhas* opening towards all sides except east. It has greater surface area exposure and occupies large area on g round. The *Haveli* has not many paintings left on its walls. It has a unique platform in front of the baithak in outer courtyard. The platform is at plinth level.

8. *Ishwardas Modi Haveli, Jhunjhunu*

This is an elaborately painted *Haveli*. It was constructed in 1933 and took around ten years to complete. It faces west and is located on main road of *Jhunjhunu* town connecting famous Satya Narain temple and Royal *Chattris*. The rooms in plinth on south side are used as shops. The *Havelis* is open on all four sides and has *Jharokhas* towards all directions. The *Haveli* has only one floor above plinth. But the openings in *Jharokhas* are arranged in such manner that it gives an impression of double storied building from outside. *Haveli* has more windows than usual. All the external walls are painted including inner courtyard walls. Colored glass has been used to ornament. It has been used for small openings and making ornamental railing which looks interesting when light falls through windows. All rooms in this *Haveli* have double floor on *Jharokhas* which gives the impression of double storied building.

9. *Jaigopal Goenka Haveli, Mandawa*

It is one of the oldest *Havelis* in Mandawa. It was constructed by Jaigopal Goenka around 1800 AD. It is evident from the design and colors of paintings. It has an asymmetrical plan which many other *Havelis* also had in the later period. But unique thing is that the pauli of the *Haveli* is not in the centre. In all other cases, pauli always occupies the central three arches as it was the first space to be located. It seems that traditional design principles of *Shekhawat*i *Haveli*s were in experimentation stage at that time. Therefore we see such a variation from the commonly followed design principles. The colours used in paintings are also lesser than other *Haveli*s of later period. The *Haveli* is presently occupied by the eighth generation of the owner and a generation tree is also available. The *Haveli* is open on all sides. it faces east but has main entry to the building from north. It is located on an undulated ground where street on south is lower than street on north. This allows construction of rooms in plinth on south sides which are now used as shops. All the walls of *Haveli* were painted earlier but they are now visible only on the external walls in outer courtyard. Internal courtyard and rooms have been white washed.

10. Kariwala Haveli, Nawalgarh

There is a *Haveli* complex which comprises of eight *Haveli*s. All these *Haveli*s were built around 1860. These were owned by eight friends who purchased the land and divided it in eight plots. The *Haveli*s face internal roads. The backs of *Haveli*s face the town streets. This ensured safety as the entry to the complex was restricted and there were only two entry points. Kariwala *Haveli* is one of those eight *Haveli*s. It faces west and is open on all four sides. It has internal streets towards north and west and Town Street towards east. It has open area towards south where storage rooms are built in plinth. The plinth also has two rooms in front which were used as consultation room as the owner was a doctor. The constructed spaces around inner courtyard are arranged in two bays. The chaughara inside *Haveli* has four interconnected rooms with thick walls. It is different from the typical design of chaughara where the four spaces were combined to form one big room. The structure was supported through the use of arches and wooden beams. It has two floors. all external walls were exquisitely painted which is clear from the remains of the paintings.

11. Pilani Haveli

The *Haveli* from Pilani is a modest *Haveli* with single floor. The main entry to the building premises is from north while building faces west. Initially only the inner courtyard and rooms around it were constructed. Baithak was added much later which is also evident from the construction. It is open from all sides. There is street on north, open area of *Haveli* on west and south and open area belonging to some other *Haveli* on east. Inner courtyard has single bay of constructed spaces around it except in east direction. It has no plinth and no *Jharokhas*. It has very less windows. Windows open towards north and south only. Baithak was added later and has not been connected with the main building properly. It has all surfaces exposed to outside.

12. Shekhsaria Haveli, Nawalgarh

Shekhsaria *Haveli* is one of the *Haveli*s from 'Eight *Haveli* Complex' in Nawalgarh. It is the largest *Haveli* in 'Eight *Haveli* Complex'. It is an asymmetric building facing east. It has open area on three sides. South, West and east sides are open to streets. There is another *Haveli* on north. It is a double storied *Haveli* with high plinth. However not many rooms are constructed in the plinth space. The *Haveli* has *Jharokhas* on two sides-south and west. It has large ground floor area but lesser wall area exposure to outside. It is a symmetrical plan in inner courtyard. Outer courtyard has baithak on south side only. North side is kept open which was used for keeping cattle.

13. Virdichand Gaurilalji, Sikar

This *Haveli* has two courtyards and two floors. First floor is constructed till half. It faces east and has open areas on all the four sides. Open area on the west is used as nohra while other three sides have streets. Despite being open to all sides, there is no *Jharokhas* on any side. Windows are provided only on north and south walls. *Chajja* is not provided on all sides which is against the usual practice in *Shekhawat*i. This increases the exposure of walls to solar radiation and increases the heat gain considerably. It has basement under both baithaks which are unlike any other *Haveli* in *Shekhawat*i. Other *Haveli*s have construction in plinth which is on ground floor level only but surrounded by an earth filling. While here the basement is actually underground.

14. Shridhar Gangadhar Morarka, Mukundgarh

This *Haveli* covers large area on ground. It is open on all sides and owns vast open ground adjacent to its building which houses a well also. Ownership of a well was the reflection of prosperity in earlier days. The *Haveli* faces west and is open on all four sides. It has street in front and open areas demarcated with boundary on north and south. The vast open land extends further in south direction. East side also has open area which is owned by another owner. It has a unique design where rooms have been extended out of the rect*Angula*r boundary of building to form gateways. It gives a look of a small fort. The *Haveli* was constructed around 1880 and was painted in original style paintings. It was however repainted later. The present colour scheme and painting style suggests a renovation in paintings.

15. Nawalgarh unidentified Haveli

This *Haveli* is situated on one of the busy road junctions in Nawalgarh. It has main streets on three sides and has its open area on the fourth. It faces east and has open area towards south. It has two completely constructed floors. ground floor has no opening towards outside because there is no plinth in the building. Windows could not be opened onto the streets without a high plinth. There windows and *Jharokhas* have been provided on first floor in all directions. Because of these reason, the first floor of this *Haveli* is used more than the ground floor. It is surrounded by high *Haveli*s from all sides but it doesn't receive shadow from any building.

16. Surajgarh Haveli

This *Haveli* faces west and is open on two sides. it has a street in front and nohra at the back. Nohra is accessed through a passage provided in the centre. It has *Haveli*s on east and west side. It has two completely constructed floors. it has lesser surface area exposed to outside hence it receives lesser amount of radiation. It is in a neglected state and needs maintenance. The paintings on walls have vanished and are under several coats of white wash. Constructed spaces around inner courtyard are organized in two bays.

3.8.2.3 Triple Courtyard Havelis

These were the most exquisite *Haveli*s. These *Haveli*s were larger in size and belonged to wealthy owners. They reflected the status of owner. These *Haveli*s were usually complete in all respects. Upper floors were completed with the ground floor and there was no later addition or alteration. There were paintings on external walls, inner courtyard, baithak and ceilings, almost everywhere. One can find the use of gold and silver in paintings too.

1. Gulabrai Ladia Haveli, Mandawa

This is a two floor *Haveli* facing east. It has street on east and south while there is open area on west. Third courtyard is towards north. It has elaborate Taj at the entrance of third courtyard. There is a continuous shed on north boundary wall which was used for keeping cattle. The front part has been constructed to accommodate baithak and tibari. This courtyard was mainly used for cattle and for attending daily visitors. It was also used sometimes as rest area for male visitors from far distances. The open area towards west has rooms in the plinth height which were used by servants. The *Haveli* has *Jharokhas* on all sides. It has larger wall area exposure. The total ground coverage of the main building is not very large.

2. *Morarka Haveli, Nawalgarh*

The status of owner of this *Haveli* is reflected from its location. It is located in the centre of the city at the end of the main market road. It has the main Ram temple of Nawalgarh across the street and occupies considerable large area on ground. It faces north and is open on all four sides. It has streets on north and west, third courtyard towards east and narrow open area towards south. Like Three courtyard *Haveli* from Mandawa, third courtyard in this *Haveli* was also used to keep cattle and house servants. Rear potion has shed for keeping cattle. Front and rear housed baithak and servant areas. It has beautiful paintings on its walls which are being restored. The *Haveli* has been converted into museum. It is properly maintained by Morarka foundation, presently headed by Shri Kamal Morarka. The plot for this building is not rect*Angula*r. It is in the shape of a rhombus and required extra skills to plan a symmetric building. Yet from outside, it is impossible to make out the angles in the plot. There are no irregular rooms in the building except for small storage areas.

3. *Vishwanath Goenka Haveli, Mandawa*

It is a unique *Haveli* in terms of design. It has three courtyards where two courtyards are used as inner courtyards. This *Haveli*s was constructed by two brothers. The front courtyard which looks more like an open ground is common to both. Inside the building, two identical courtyards are placed side by side. These are internally connected by a passage. Unlike other *Haveli*s, this *Haveli* housed two families. Hence it has a unique plan. It faces east and has open area on all four sides. The rooms below plinth were used as servant quarters at the back and as cattle shed and storage unit on sides. It has two floors and the whole building was completed at once without any later amendments. It was elaborately painted which is evident from the remaining paintings on outside walls.

3.9 INFERENCES

In response to such climatic conditions, the *Haveli*s were designed for controlled light, heat and dust. The high exterior walls prevent the heat and dust from being carried inside and a system of openings at multiple levels allows the circulation of air. The internal open to sky courtyards bring in much needed light and ventilation to the interior spaces on the ground and first floor through semi covered areas such as verandahs and balconies respectively. Shading devices such as *Jharokhas* and *Chajja*s helps in shading the walls against sun. Despite larger area being exposed to outside, the walls and windows remain shaded for most of the time during day. However during night, the larger surface area implied larger heat loss through convective cooling.

Inside also, the internal courtyard is surrounded by high mass from all sides thus ensuring shade. Since the internal courtyard remained shaded most of the time during day, it remained cooler. This helped in cooling of constructed spaces around the courtyard by air circulation. Courtyard also facilitated night time cooling. The exposure of walls to the courtyard helps in convective cooling during night when the outside temperature is lower than the building temperature.

Windows are small and are provided at two levels. They have thick wooden shutters. Since the day time temperature of air is very high, air from outside is not preferred inside the building during day. Hence the windows opening towards outside are kept closed during day. All the windows were opened during night. This helped in increasing the air movement inside the building during night when the air temperature is lower than building temperature. This helps in night time cooling of building. Openings at different levels facilitate air movement within a room even if cross ventilation is not possible for some reasons.

Walls, roofs and floors have thick and heavy construction thereby increasing the thermal mass of the building. This helps in delaying the heat transferred to inside. The structure also absorbs considerable amount of heat which helps in keeping the building cool even when outside conditions are extremely hot.

*Shekhawat*i *Haveli*s were designed based upon the rules set in *Vaastu* treatises. It was brought to knowledge by some local craftsmen and masons during previous visits to *Shekhawat*i. After thorough investigation of the *Haveli*s in *Shekhawat*i and understanding of *Vaastu* principles, it was derived that *Shekhawat*i *Haveli*s were designed based upon *Vaastu*. The extent to which the *Vaastu* principles have been followed is to be analyzed.

Chapter 4

EVOLVING METHODOLOGY

4.1 INTRODUCTION

*Haveli*s of *Shekhawat*i were surveyed at different times of the year. First visit was in monsoon season when the humidity levels were high and outside temperature was within comfortable range. Second visit was around beginning of summers in *Shekhawat*i. The temperature is already hot and radiation is unbearably high at this time of the year. Last visit was around beginning of winters. It is not severely cold but considerably cold at night. On all visits, it was observed that *Haveli*s maintained a comfortable environment. Once the windows were opened and air circulated inside a space, the environment became comfortable. Need for mechanical means of ventilation or cooling was felt only in extremely hot conditions. It was interesting to see these traditionally designed and constructed *Shekhawat*i *Haveli*s performing in an energy efficient manner.

From preliminary survey it was clear that *Shekhawat*i *Haveli*s incorporated passive design features which maintained comfortable environment inside throughout the year. Besides passive design features, it was also gathered that *Shekhawat*i *Haveli*s conformed to the principles of *Vaastu*. Objective of this research is to understand if the principles of *Vaastu* lead to energy conservation; or in other words, to establish a relationship between *Vaastu* and energy efficiency. For achieving this objective a methodology has to be evolved. This requires a clear understanding of application of *Vaastu* prescriptions and Passive design parameters in context of *Shekhawat*i *Haveli*s.

4.2 VAASTU AND SHEKHAWATI HAVELIS

4.2.1 Coding of case studies and *Vaastu* prescriptions-

The *Vaastu* text which was followed in this region is *Rajvallabhmandanam* by *Sthapati Sutradhar Mandan*. The prescriptions of *Vaastu* which could be manifested physically have been understood and listed in literature review. Each case study was analyzed to check the presence of *Vaastu* prescriptions. Wherever a *Vaastu* prescription has been followed, '1' has been awarded to the case otherwise '0' has been awarded. For the purpose of tabulation, the prescriptions of *Vaastu* and the cases under study have been given a reference code. The codes are devised to avoid the repetition of same text in the report and there is no scientific rationale behind coding.

Table 4.2.1.1 Coding of *Vaastu* prescriptions

S. No.	*Vaastu* prescription	Code
1	Presence of courtyard in the centre	Court
2	Size of courtyard- should be 55% of the total width of the building.	Court_size
3	If site is sloping, the slope should be towards E, NE or N. It implies all water from building should be collected towards these directions. And open area if needed for collection should also be in these directions only.	Slope
4	Building should be facing East	Bldg_E
5	Building should be facing North	Bldg_N
6	Building should be facing West	Bldg_W
7	Building should not be facing South.	Bldg_S
8	Trees are not prescribed to be planted inside the building.	Tree_inside

Table 4.2.1.1 - *Continued*

9	Thorny, milk bearing and fruit bearing trees are not to be planted around the building.	Trees_thorny
10	Yellow colored flowering trees and plants should not be planted around building.	Trees_yellow
11	Huge trees like Peepal, Bargad, Fig and Kapittha should be planted around the building.	Trees_huge
12	Building should not receive shadow of any other building after 3 pm.	Shadow
13	Apron should be constructed all around the building.	Apron
14	Minimum width of the apron for smallest size of building is 60cm	Apron_width
15	A platform should be constructed above the apron of minimum height equal to $1/8^{th}$ of building height.	Apron_platform
16	All buildings must have plinth. Larger buildings should have higher plinth. The entrance gateway should have a maximum height of 14 hands.	Plinth
17	Entrance doors should preferably open towards east.	Entry_door
18	Larger buildings should have larger doors.	Doors
19	Entrance door should be the largest door in a building.	Entrydoor_size
20	Doors on the upper floors should be smaller in size than the doors on lower floors.	Door_storey
21	Ventilators should preferably be placed in north.	Ventilator
22	There should not be any common walls/ columns or any other structural member between two buildings.	Walls_common
23	Square columns should be used in the residential buildings.	Column
24	*Chajja* should project from all sides of building.	*Chajja*

Table 4.2.1.1 - *Continued*

25	Minimum width of *Chajja* should be 1/5th of the floor height.	*Chajja*_width
26	Stone should be avoided in residences. But it can be used in external walls, foundation and column base.	Stone
27	*Jharokhas* must be present in buildings.	*Jharokhas*
28	Residential buildings should not have more than 3 floors.	Floors
29	Height of upper floors should be less than lower floors.	Floors_height
30	Mortar should be strong enough to bind bricks together.	Mortar
31	Larger buildings should have thicker walls.	Walls_thickness
32	Guest room and external rooms should be decorated with paintings while habitable rooms should be simple and without much ornamentation.	Ornamentation
33	Walls should be thicker at base and should go on decreasing with height.	Walls_variation
34	Plaster should be even on all surfaces.	Plaster

Following arrangement of spaces in a residence is preferred-

35	Prayer Room- NE	Prayer_NE
36	Bathing- E	Bath_E
37	Main entrance- E	Entry_E
38	Music Room- SE	Music_SE
39	Kitchen – SE	Kit_SE
40	Dining- S	Dining_S
41	Bedroom – S (towards interior courtyard)	Bed_S
42	Toilets- SW/ NW	Toilet_SW/NW

Table 4.2.1.1 - *Continued*

43	Family room/ Entertainment Room- W	Family_W
44	Study- SW	Study_SW
45	Store for edibles- E of SE at the back of kitchen	Ediblestore_E/SE
46	Store of valuables- N/SW	Valuablestore_N/SW
47	Store of other things- NW	Store_NW

Table 4.2.1.2 Coding of Case Studies

S. No.	Name of the Case study	Coding
Chapter 1	Babulalji Gudha *Haveli*,Mukundgarh	Babulalji
Chapter 2	Bhagirathmal Kedarmal Goenka, Dundlod	Bhagirathmal
Chapter 3	Bissau *Haveli*	Bissau
Chapter 4	Chiranjilalji Daima, Fatehpur	Chiranjilalji
Chapter 5	Harsukhrai Pansari, Chirawa	Harsukhrai
Chapter 6	Damodar Prasad Morarka, Mukundgarh	Damodar
Chapter 7	*Haveli* used as Gymnasium, Dundlod	Gym_Dundlod
Chapter 8	Seth Arjun Das Goenka, Dundlod	ArjunDas
Chapter 9	Gulabrai Ladia JI ki *Haveli*, Mandawa	Gulabrai
Chapter 10	Harkarandas Mangilalji, Bagad	Harkarandas
Chapter 11	Ishwardas Modi, *Jhunjhunu*	Ishwardas
Chapter 12	Jaigopal Ji Goenka, Mandawa	Jaigopal
Chapter 13	Kariwala *Haveli*, Nawalgarh	Kariwala
Chapter 14	Morarka *Haveli* Museum, Nawalgarh	Morarka
Chapter 15	Pilani *Haveli*	Pilani
Chapter 16	Ramgarh *Haveli*	Ramgarh
Chapter 17	Muslim *Haveli*, Ratannagar	Ratannagar

Table 4.2.1.2 - *Continued*

Chapter 18	Sahuman Khetan, Mehansar	Sahumal
Chapter 19	Shekhsaria *Haveli*, Nawalgarh	Shekhsaria
Chapter 20	Shridhar Gangadhar Morarka, Mukundgarh	Shridhar
Chapter 21	Sidhkaran Ji Morarka, Mukundgarh	Sidhkaran
Chapter 22	Nawalgarh Unidentified *Haveli*	Nawalgarh
Chapter 23	Surajgarh *Haveli*	Surajgarh
Chapter 24	Virdichandji Gaurilalji, *Sikar*	Virdichand
Chapter 25	Vishwanath Goenka, Mandawa	Vishwanath

4.2.2 Assumptions-

While analyzing the case studies for presence of *Vaastu* prescriptions some assumptions have been made-

- The spatial arrangement of ground floor which is the main activity level only has been considered. It is so because kitchen, dining room, prayer room etc were located on ground floor level. First floor housed either bedrooms or family rooms and the rooms constructed in plinth were used either for storage or for housing servants and cattle. In cases where plinth was considerably high such as in Ratannagar or *Sikar*, rooms on plinth level which faced road were also used as shops. Therefore ground floor was the only floor which had variety of spaces needed in a residence and variation in spatial arrangement was possible.
- If trees were present within the building compound, they have been accounted irrespective of whether they have been planted or have grown on their own later. It is so because many *Haveli*s which have been documented are lying abandoned and many tree species present in the *Haveli*s grow on their own. In absence of residents in the *Haveli*s, it was difficult to know whether the trees were deliberately planted or not.

- The entry to the building compound is interpreted as the orientation of entrance, while the building orientation is the orientation of front of *Haveli*.
- Width of building is taken as width of main building excluding the construction in third courtyard (wherever applicable as all cases did not have a third courtyard).
- Though the site is flat but levels have been created inside the building. Inner courtyard is higher than outer courtyard which is higher than street. Hence slope of the drain is interpreted as slope of the building.
- The sun is very low at the time of sunset. Buildings would therefore receive shadow of surrounding buildings and application of *Vaastu* prescription relating to receiving of shadow in afternoon (i.e. after 2 pm) is uniformly violated in all cases. Therefore for consideration of 'Shadow', the buildings have been analyzed only up to 4:30 PM. Shadow received by *Haveli* after this time has been ignored.
- The cases where there is no open space between two *Haveli*s, it has been assumed that the wall is common.
- Information on lime mortar composition was gathered from survey of the region. It has been assumed to be uniformly applied to all cases.
- The layout of the *Haveli*s is symmetrical about central axis. Hence all *Haveli*s had each space located in two orientations. If any of the spaces was placed in the right orientation, then a point has been awarded. If none of the spaces was in the desired orientation, only then a zero has been awarded. Toilets were not present in all *Haveli*s, thus the point has been awarded only where toilets are present and in the desired orientation.

4.2.3 Preliminary *Vaastu* Score-

Assuming the above, all the case studies were analysed for presence of *Vaastu* prescriptions and a table has been prepared (Table 4.2.3.1). The scores obtained by each case study against *Vaastu* prescriptions are then added to get preliminary *Vaastu* score.

Table 4.2.3.1 Preliminary *Vaastu* Score

S. No.	*Vaastu* prescription	Babulalji	Bhagirathmal	Bissau	Chiranjilalji	Harsukhrai	Damodar	Gym_Dundlod	ArjunDas	Gulabrai	Harkarandas	Ishwardas	Jaigopal	Kariwala	Morarka	Pilani	Ramgarh	Ratannagar	Sahumal	Shekhsaria	Shridhar	Sidhkaran	Nawalgarh	Surajgarh	Virdichand	Vishwanath
1.	Court	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2.	Court_size	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0
3.	Slope	1	0	0	1	0	1	1	0	1	0	0	1	0	1	0	0	0	1	1	1	0	1	0	1	1
4.	Bldg_E	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	1
5.	Bldg_N	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
6.	Bldg_W	0	1	1	0	1	0	0	1	0	1	1	0	1	0	1	1	0	0	0	0	1	0	1	0	0
7.	Bldg_S	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8.	Tree_inside	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9.	Trees_thorny	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10.	Trees_yellow	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11.	Trees_huge	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
12.	Shadow	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	0	1	1
13.	Apron	1	0	1	1	1	0	0	1	1	1	0	0	1	1	0	1	0	0	1	1	0	1	1	1	1
14.	Apron_width	1	0	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0	0	1	1	0	1	1	1	1
15.	Apron_platform	0	0	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	1	1	1	1
16.	Plinth	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1

Table 4.2.3.1Continued

17.	Entry_door	1	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	1	1	1	0	1	0	1	1
18.	Doors	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19.	Entrydoor_size	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20.	Door_storey	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21.	Ventilator	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	1	1	1	0	1	0
22.	Walls_common	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
23.	Column	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.	*Chajja*	0	0	1	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	1	0	1	0	0	1
25.	*Chajja*_width	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1
26.	Stone	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27.	*Jharokhas*	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1
28.	Floors	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29.	Floors_height	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30.	Mortar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31.	Walls_thickness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32.	Ornamentation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
33.	Walls_variation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
34.	Plaster	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35.	Prayer_NE	1	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
36.	Bath_E	1	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0	1	1	0	1	0	1	1
37.	Entry_E	1	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	1	1	1	0	1	0	1	1
38.	Music_SE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.2.3.1Continued

39.	Kit_SE	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	0	1	0	1	1	1	1	1
40.	Dining_S	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1
41.	Bed_S	0	0	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1
42.	Toilet_SW/NW	1	0	1	0	0	1	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0	1	0	1	1
43.	Family_W	1	0	0	0	0	1	1	0	1	1	0	1	0	1	0	0	1	1	1	1	1	1	1	1	1
44.	Study_SW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45.	Ediblestore_E/SE	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	1	0	0	0	0	0
46.	Valuablestore_N/SW	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	0	1	0	1	0
47.	Store_NW	1	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	0	1	0	1	0

The scores awarded against each prescription for all the cases were added to get a corresponding score for each parameter. The scores are as shown in Table 4.2.3.2.

Table 4.2.3.2 Presence of *Vaastu* Prescriptions in *Shekhawati Havelis*

S. No.	*Vaastu* prescription	Score
1.	Court	25
2.	Court_size	6
3.	Slope	13
4.	Bldg_E	10
5.	Bldg_N	4
6.	Bldg_W	11
7.	Bldg_S	25
8.	Tree_inside	24
9.	Trees_thorny	25
10.	Trees_yellow	25
11.	Trees_huge	5
12.	Shadow	20
13.	Apron	16
14.	Apron_width	17
15.	Apron_platform	10
16.	Plinth	22
17.	Entry_door	11
18.	Doors	25
19.	Entrydoor_size	25
20.	Door_storey	25
21.	Ventilator	14
22.	Walls_common	22
23.	Column	0
24.	*Chajja*	11
25.	*Chajja*_width	21

Table 4.2.3.2 -*Continued*

26.	Stone	25
27.	*Jharokhas*	20
28.	Floors	25
29.	Floors_height	25
30.	Mortar	25
31.	Walls_thickness	25
32.	Ornamentation	25
33.	Walls_variation	25
34.	Plaster	25
35.	Prayer_NE	5
36.	Bath_E	10
37.	Entry_E	11
38.	Music_SE	1
39.	Kit_SE	19
40.	Dining_S	23
41.	Bed_S	19
42.	Toilet_SW/NW	11
43.	Family_W	16
44.	Study_SW	1
45.	Ediblestore_E/SE	7
46.	Valuablestore_N/SW	18
47.	Store_NW	10

From table 4.2.3.2, it is clear that 24 prescriptions (out of a total of 47) of *Vaastu* are followed in 75% or more number of case studies. This implies that *Shekhawat*i *Haveli*s were designed based upon principles of *Vaastu*.

4.2.4 Locally followed design principles-

While surveying the *Shekhawat*i region, an old mason was identified who worked on design and construction of lastly constructed *Haveli*s. In practice, the name of designer was usually kept a secret. The old mason assisted chief designer in design and construction of many *Haveli*s. Interaction with him revealed some new rules which were religiously followed in *Shekhawat*i *Haveli*s but are not written in *Vaastu* literature. Such rules have not been analyzed while analyzing the *Shekhawat*i *Haveli*s for conformation to *Vaastu* prescriptions. Following are those locally applied rules-

48. The *Haveli*s should be symmetrical about central axis. In this manner, any mistake in design is countered by the mirror image in other half of the design.
49. There should not be three continuous doors in the same line. This brings loss of fortune to the family.
50. There should be a window or a niche opposite to a door opening. This maintains the flow of energy, health and wealth.
51. The courtyard should have equal number of arches on all sides. The size may vary slightly but equality of number should be maintained.

4.3 COMPARISON OF PASSIVE DESIGN PARAMETERS AND VAASTU PRESCRIPTIONS

From literature study, all passive parameters that can be employed in buildings in Hot-dry climates were listed. All the case studies were analyzed for the presence of passive design parameters. Passive design parameters were then compared with *Vaastu* prescriptions and results were tabulated (Table 4.3). Passive design parameters which are followed in *Shekhawat*i *Haveli*s and are also prescribed in *Vaastu* prescriptions were coloured in green colour. The parameters which are neither followed in *Shekhawat*i

Havelis nor in *Vaastu* have been coloured in red. The rest which are followed in either *Shekhawati Havelis* or are followed in *Vaastu* text have been coloured as blue.

Out of the total 47 passive design parameters, 34 parameters are followed in *Shekhawati Havelis* and are prescribed in some or the other form in *Vaastu* text also. This provides a firm base that *Vaastu* prescriptions have a rational background which might not be reflected in its language but the intent. Other 8 are followed in *Shekhawati Havelis* but not prescribed in *Vaastu* text which shows that *Shekhawati Havelis* incorporate many passive design features prescribed by modern day climatologists. Hence the observation that *Shekhawati Havelis* remained comfortable in all seasons is fully justified.

Table 4.3 Passive Design Parameters in *Shekhawati Havelis* and Prescribed in *Vaastu* Text

S. No.	Parameter	*Shekhawati Havelis*	*Vaastu*
1.	**Topography**		
	1.1 If the land is flat, any orientation can be chosen.	1	1
2.	**Vegetation**		
	2.1 Deciduous or evergreen trees should be planted around the building.	1	1
	2.2 Shady trees should be preferred.	1	1
	2.3 Shady trees should be planted in western direction to cut off low sun and shade the building.	-1	-1
3.	**Water bodies**		
	3.1 Water body is preferable in buildings in any direction, preferably in the path of prevailing wind direction.	-1	-1
4.	**Streets**		
	4.1 Streets should have lesser width to height ratio.	-1	-1
	4.2 Streets should preferably be oriented North-South to cut off low sun from East and West.	1	1

Table 4.3 - *Continued*

5.	**Open spaces and built form**		
	5.1 Low heat producing settlements should be compactly planned OR In case of high heat producing buildings, ample open space must be left around buildings.	1	
	5.2 Open spaces should have soft cover and vegetation.	1	1
	5.3 Open spaces shall be enclosed by appropriate building mass so that they remain shaded most of the time during day and radiate heat at night.	1	1
	5.4 Linear and deep courtyards shall be preferred to square courtyards.	-1	-1
6.	**Ground Character**		
	6.1 Ground shall have soft cover and should be kept green to minimize heat gain.	1	1
	6.2 In case hard surfaces are unavoidable, light colored and rough textured pavements shall be used.	1	
7.	**Plan Form**		
	7.1 Closed circular, rect*Angular* and square forms should be preferred as they have lesser Perimeter to Area ratio.	-1	-1
8.	**Plan Elements**		
	8.1 Courtyards should be integrated inside the building.	1	1
	8.2 Verandahs shall be used to cut off direct sun from entering the habitable spaces.	1	1
	8.3 Overhangs and projection/*Chajja*s shall be used to shade walls and other surfaces	1	1
	8.4 Storage areas shall be planned towards heat receiving directions i.e. S and W to act as barrier for transfer of heat.	1	1
	8.5 Plinths should be made high to cut off ground reflected radiation and sand.	1	1

Table 4.3 - *Continued*

9.	**Building Orientation**		
	9.1 Longer sides of the building should be oriented E-W to face North and South.	1	1
10.	**Surface to Volume Ratio**		
	10.1 Surface area which receives radiation should be minimized.	1	1
	10.2 However optimum increase in shaded surfaces should be made to allow night time and re-radiative cooling while allowing heating by convection and conduction only (not radiation)	1	1
11.	**Fenestration pattern**		
	11.1 Openings should be placed high on the walls to cut off ground reflected radiation.	1	1
	11.2 Openings should be small in size. If they are increased in size for night cooling purpose, they should be shaded from sun.	1	1
	11.3 Openings should be staggered to increase the air movement in a room.	1	1
	11.4 Partitions should not be placed in front of the windows.	1	1
12.	**Fenestration Orientation**		
	12.1 Openings are preferred in North to minimize the amount of solar radiation entering the interiors.	1	1
13.	**Fenestration Control**		
	13.1 Openings should have thick shutters made of materials having low U value; such as wood.	1	1
	13.2 All openings should be shaded from sun.	1	1
	13.3 Glazing should be avoided in openings.	1	1
	13.4 Window section should be increased towards inside to reduce the wind speed. In case air is already cooled by shading or other means, section may be decreased to increase the wind speed inside.	1	

Table 4.3 - *Continued*

14	**Walls**		
	14.1 Walls should be thick and massive.	1	1
	14.2 Walls should be made of materials having low U value.	1	1
	14.3 Walls should be shaded from direct radiation.	1	1
15	**Roof**		
	15.1 Roofs should be made of materials having low U value.	1	1
	15.2 Roofs should have light color or a reflective layer on the top to reflect maximum incident radiation.	1	
	15.3 Parapet on roof should be perforated to allow ventilation on the roof to take away the heat.	1	
16	**Roof Form**		
	16.1 Domical roofs should be preferred because they have large surface area for same floor area. However for practical reasons domical roofs are not constructed. Hence flat roofs should be preferred.	1	1
	16.2 Flat roofs should be made thick and insulated.	1	1
	16.3 Daylight through roof is not desired. There should not be any opening in the roof.	1	1
17	**External colors and textures**		
	17.1 External surfaces should be light colored.	1	1
	17.2 The surfaces should be rough in texture as they facilitate inter granular shading and more surface area for cooling. In case rough texture is not possible, very smooth light colored surface should be preferred to reflect the radiation.	1	
18	**Internal finishes**		
	18.1 Internal surfaces should be light in color.	1	1
	18.2 Internal surfaces should be smooth.	1	
19	**Internal Planning**		

Table 4.3 - *Continued*

	19.1 Toilets should be provided in the west and south direction to act as buffer spaces.	1	
	19.2 Balconies and Verandahs should be used to cut off sun	1	1
	19.3 All spaces should have optimum ventilation and day lighting.	1	1

4.4 EVOLVING METHODOLOGY

From table 4.3, it is evident that passive design features are integrated in *Vaastu* prescriptions also. This implies that greater adherence to *Vaastu* principles means incorporation of more passive design features in buildings. Incorporation of passive design features in buildings in Hot-dry climates brings down the heat exchange through building envelope. This would imply lower ambient air temperatures inside the building in summers (in comparison with outside temperatures) thus requiring lesser amount of external energy to maintain comfortable environment inside. Since *Vaastu* prescriptions incorporate passive design parameters, application of *Vaastu* prescriptions in building design may also effect the thermal comfort inside the building and hence its energy performance. To establish the effect of *Vaastu* prescriptions on energy efficiency of a building, the following hypothesis is assumed-

"Buildings designed as per *Vaastu* design principles are more energy efficient"

To approve or reject the hypothesis, a proper research methodology has to be followed to reach a conclusion. To establish whether *Vaastu* prescriptions help in improving energy efficiency, two aspects related to the cases under study have to be established- one is the level of *Vaastu* compliance and the other is the energy efficiency. Once both aspects related to the cases are quantified, a correlation between the two can be established to know the effect of one on the other.

In previous section of literature study and this chapter, all the prescriptions of *Vaastu* which could be physically manifested have been listed. A table (Table 4.2.3.1) was prepared where all the cases have been analyzed for the presence of *Vaastu* prescriptions and scores have been assigned. It has been further analyzed to calculate the final *Vaastu* score as per the methodology mentioned in following sections of this chapter. The *Vaastu* score determined the extent to which *Vaastu* has been followed in a case study. Thus the first task of calculating *Vaastu* compliance was achieved.

For determining the energy efficiency of these buildings, it was important to fix a criterion. The criterion should to be comprehensive yet simple. It should be able to reflect the energy performance of the buildings. The quantity used for assessment of energy efficiency is usually taken as energy consumption. But it was difficult to ascertain the energy performance of case studies as these do not consume energy from any external source. Hence a direct comparison of energy consumption which could have been the best measure was ruled out. Within a building energy could be consumed for various activities- thermal comfort, lighting, household activities such as cooking, recreation etc, and miscellaneous services such as plumbing and others. Amongst these, energy needed for thermal comfort and lighting only could be altered with the help of design. Other requirements normally remain constant depending upon the occupancy, activity and usage. For the purpose of this study, the scope of energy performance has been limited only to thermal comfort. It is because of the following reasons-

- During survey of the buildings it was observed that almost all the spaces (except storage areas) received fair amount of light during day either through windows on external wall or through courtyard. Thus requirement of energy for artificial lighting was substantially reduced.

- Since most of the daytime activities were performed in semi open and open spaces such as tibaris and courtyard, the inner spaces were hardly used. These areas being open to outside always received daylight. The enclosed spaces were hardly used during day. Therefore the need to analyze the daylight levels was not felt.

4.5 CALCULATION OF VAASTU SCORE

Vaastu scores for the cases have been calculated following proper statistical methodology. The scores have been calculated in a five step process. It included the quantified data related to presence of *Vaastu* prescriptions as well as the qualitative understanding of the subject of *Vaastu*.

4.5.1 Score for Individual Prescription

As the first step a table (Table 4.2.3.1) was prepared. A '1' was marked if a prescription was followed in a case and a '0' if it was not followed. The score simply implied the presence of a prescription in a case. Once the exercise was done, the scores were added in horizontal as well as vertical direction. This yielded the preliminary scores for the prescriptions. (Table 4.2.3.2)

4.5.2 Preliminary weightage

While calculating preliminary weightage for the prescriptions, it has been assumed that the prescriptions which are more important have been followed in more number of cases. The ones which are not of mandatory nature have been omitted in more number of cases. An inverse importance has been assumed in this case for calculating the weightage of prescriptions. It has been done because the rules which were of mandatory nature have been prescribed in the *Vaastu* texts with increased ferocity of the associated consequences (in case a prescription is not followed). The consequences were presented in a religious language. Since the society was god fearing, the mention of consequences often resulted in the implementation of these rules and prescriptions. Hence the prescriptions which are followed in more number of cases reflect the importance/weight attached with it.

The total score obtained for each prescription was divided by 25 i.e.the total number of case studies. Thus the maximum weightage of a prescription would be 1 and minimum would be zero depending upon the number of cases which have incorporated the prescription. In this manner the preliminary weightage was calculated. (Table 4.5.2)

Table 4.5.2 Preliminary weightage for Vaastu prescriptions

S. No.	*Vaastu* prescription	Score	Preliminary Weightage (Score/25)
1.	Court	25	1
2.	Court_size	6	0.24
3.	Slope	13	0.52
4.	Bldg_E	10	0.4
5.	Bldg_N	4	0.16
6.	Bldg_W	11	0.44
7.	Bldg_S	25	1
8.	Tree_inside	24	0.96
9.	Trees_thorny	25	1
10.	Trees_yellow	25	1
11.	Trees_huge	5	0.2
12.	Shadow	20	0.8
13.	Apron	16	0.64
14.	Apron_width	17	0.68
15.	Apron_platform	10	0.4
16.	Plinth	22	0.88
17.	Entry_door	11	0.44
18.	Doors	25	1
19.	Entrydoor_size	25	1
20.	Door_storey	25	1

Table 4.5.2 –*Continued*

21.	Ventilator	14	0.56
22.	Walls_common	22	0.88
23.	Column	0	0
24.	*Chajja*	11	0.44
25.	*Chajja*_width	21	0.84
26.	Stone	25	1
27.	*Jharokhas*	20	0.8
28.	Floors	25	1
29.	Floors_height	25	1
30.	Mortar	25	1
31.	Walls_thickness	25	1
32.	Ornamentation	25	1
33.	Walls_variation	25	1
34.	Plaster	25	1
35.	Prayer_NE	5	0.2
36.	Bath_E	10	0.4
37.	Entry_E	11	0.44
38.	Music_SE	1	0.04
39.	Kit_SE	19	0.76
40.	Dining_S	23	0.92
41.	Bed_S	19	0.76
42.	Toilet_SW/NW	11	0.44
43.	Family_W	16	0.64
44.	Study_SW	1	0.04
45.	Ediblestore_E/SE	7	0.28
46.	Valuablestore_N/SW	18	0.72
47.	Store_NW	10	0.4

4.5.3 Weighing on Hundred

The score for all the parameters were then added and equaled to hundred. This was done to achieve the *Vaastu* scores for the case studies on a scale of hundred. The weightage revealed the importance of each prescription. However it was noticed that many prescriptions have the same weightage. For example the presence of courtyard and construction related prescriptions such as wall thickness etc., both have the preliminary weightage of 1 (table 4.5.4). While from qualitative judgment it is clear that presence of courtyard holds greater importance as compared to construction. This was corrected in the next step.

4.5.4 Ranking

Once the weightage for each prescription was calculated on a scale of hundred, rank (based upon qualitative understanding of climatology and *Vaastu*) was assigned to each prescription. The higher rank signified greater importance as per *Vaastu*. The rank thus assigned was then multiplied with the respective weightage on a scale of hundred for each prescription. The scores thus obtained for each prescription were again scaled on hundred to achieve the final weightage for each prescription. This resulted in the corrected weightage of the prescriptions based upon actual data collected through survey and also the qualitative screening of the text. (Table 4.5.4)

Table 4.5.4 Rank Based Final weightage for *Vaastu* Prescriptions

S. No.	*Vaastu* prescription	Weightage on a scale of 100	Rank	Final weightage on a scale of 100
1.	Court	3.31	47	6.14
2.	Court_size	0.79	43	1.35
3.	Slope	1.72	42	2.85
4.	Bldg_E	1.32	46	2.4

Table 4.5.4 –*Continued*

5.	Bldg_N	0.53	44	2.59
6.	Bldg_W	1.46	45	0.92
7.	Bldg_S	3.31	41	5.36
8.	Tree_inside	3.18	6	0.75
9.	Trees_thorny	3.31	4	0.52
10.	Trees_yellow	3.31	5	0.65
11.	Trees_huge	0.66	3	0.08
12.	Shadow	2.65	30	3.14
13.	Apron	2.12	32	2.68
14.	Apron_width	2.25	31	2.76
15.	Apron_platform	1.32	21	1.1
16.	Plinth	2.91	33	3.8
17.	Entry_door	1.46	38	2.19
18.	Doors	3.31	25	3.27
19.	Entrydoor_size	3.31	36	4.7
20.	Door_storey	3.31	35	4.57
21.	Ventilator	1.85	8	0.59
22.	Walls_common	2.91	19	2.19
23.	Column	0.00	2	0
24.	*Chajja*	1.46	22	1.27
25.	*Chajja*_width	2.78	29	3.18
26.	Stone	3.31	27	3.53
27.	*Jharokhas*	2.65	7	0.73
28.	Floors	3.31	34	4.44
29.	Floors_height	3.31	37	4.84
30.	Mortar	3.31	28	3.66
31.	Walls_thickness	3.31	23	3.01
32.	Ornamentation	3.31	1	0.13
33.	Walls_variation	3.31	24	3.14
34.	Plaster	3.31	26	3.4
35.	Prayer_NE	0.66	39	0.82

Table 4.5.4 –*Continued*

36.	Bath_E	1.32	12	0.56
37.	Entry_E	1.46	40	2.3
38.	Music_SE	0.13	10	1.69
39.	Kit_SE	2.52	17	2.16
40.	Dining_S	3.05	18	2.09
41.	Bed_S	2.52	20	0.52
42.	Toilet_SW/NW	1.46	9	1.25
43.	Family_W	2.12	15	0.51
44.	Study_SW	0.13	11	1.51
45.	Ediblestore_E/SE	0.93	14	0.68
46.	Valuablestore_N/SW	2.38	16	0.82
47.	Store_NW	1.32	13	0.56

4.5.5 Final *Vaastu* score

Once the final weightage for each prescription was calculated, the table prepared initially was revised. Against each prescription, wherever '1' was assigned, it was replaced with the final weightage of respective prescription. The total score of all prescriptions for a case was called ***Vaastu* score**. In this manner the *Vaastu* score for all the cases was calculated and the scores were obtained as reported in table 4.5.5.

Table 4.5.5 Table Showing Final *Vaastu* Score for All the Documented Cases

S. No.	Case study	Final *Vaastu* Score
1.	Babulalji	89.52
2.	Bhagirathmal	72.03
3.	Bissau	71.48
4.	Chiranjilalji	81.38
5.	Harsukhrai	73.66
6.	Damodar	83.96
7.	Gym_Dundlod	86.02

Table 4.5.5 –*Continued*

8.	ArjunDas	83.42
9.	Gulabrai	92.65
10.	Harkarandas	80.56
11.	Ishwardas	76.88
12.	Jaigopal	86.49
13.	Kariwala	83.77
14.	Morarka	83.51
15.	Pilani	78.95
16.	Ramgarh	78.56
17.	Ratannagar	81.13
18.	Sahumal	77.84
19.	Shekhsaria	91.96
20.	Shridhar	89.36
21.	Sidhkaran	73.85
22.	Nawalgarh	83.87
23.	Surajgarh	76.15
24.	Virdichand	83.31
25.	Vishwanath	90.97

The final *Vaastu* score calculated for case studies suggests that-

1. 75% of *Vaastu* prescriptions are followed in all the cases thus resulting in a high score.
2. The range of *Vaastu* score is not wide (ranging between 71-93). This might cause problems in establishing a correlation between *Vaastu* score and energy efficiency of the case.
3. *Vaastu* (as understood through the text under study) was an integral part of design of residential buildings.

4.6 PUHOS- PERCENTAGE OF UNCOMFORTABLE HOURS INSIDE AGAINST OUTSIDE IN SUMMERS

To establish a relationship between *Vaastu* compliance (measured in terms of *Vaastu* score) and energy efficiency performance of the cases, energy efficiency had to be quantified. Quantification of energy performance is not a difficult task and there are many parameters which can be used for comparative studies of modern buildings such as- annual energy cost, energy consumed for air conditioning, mechanical ventilation and lighting etc. However since these *Haveli*s did not consume any external energy, it was not considered realistic to simulate these *Haveli*s for energy consumption and then compare the values. Instead a slightly longer but more realistic quantity was selected. It was called 'Percentage of uncomfortable hours inside against total uncomfortable hours outside in summers (PUHos).

PUHos is defined as

$$\text{PUHos} = \frac{\text{Total Number of Uncomfortable Hours Inside the Building in Summers}}{\text{Total number of uncomfortable hours outside in summers}} \times 100$$

PUHos determined the number of hours when various spaces in the *Haveli* remained uncomfortable. Lesser was PUHos, better was the performance of *Haveli*.

The index of thermal comfort used is TSI- Tropical Summer Index. TSI was developed taking Indian subjects into account. Hence it is considered most accurate for the study of thermal comfort related issues in Indian context. Since air temperature is not the only parameter which affects the feeling of comfort, thermal comfort indices has been used. For using TSI, the extended comfort rang has been used. The comfort range is prescribed between 25-30 TSI and tolerable limits are from 19 to 34 TSI. The comfort range considered here is taken from 19-34 TSI. To calculate PUHos and TSI, the detailed hourly air temperatures, air velocity and Relative humidity values were required. This required either real time monitoring of the cases under study or computer simulation. Due to time and resource constraint, computer simulation was adopted to calculate the detailed annual hourly temperatures inside *Haveli* spaces. Air velocity for each room in all the case studies was calculated manually referring to the relevant codes in Indian practice and available climatological data. Relative humidity was taken from the climatological data. Hourly TSI was then calculated using these three quantities.

$$TSI = 0.308T_w + 0.745T_g - 2.06\sqrt{V + 0.841}$$ [Ref. 23,24 pp. 49]

Tw is Wet Bulb Temperature

T g is Globe Temperature (Assumed to be equal to Dry Bulb Temperature for internal spaces where no radiation is received)

V is Air Velocity

The hours which were out of the comfort range were identified and number was counted and PUHos was calculated. The details of simulation and calculation procedure of TSI and PUHos are discussed in following chapters.

After simulation, the annual data was generated. But for establishing the effect of *Vaastu* on Energy efficiency, data for summers only has been considered. It is because the prime concern for buildings in *Shekhawat*i climate is hot summer. As discussed earlier, while it is possible to gain heat from natural sources, it is almost impossible to reject the heat gained. Hence the performance of buildings was analysed only for summers in the form of PUHos. The other reason is that the *Vaastu* prescriptions as prescribed in the texts prevalent in this region also correspond to the passive design parameters effective in hot climates and warm seasons. Thus the effect of such prescriptions in winters will not help in achieving energy efficiency. It would then eventually hamper the establishment of relationship between *Vaastu* and energy efficiency performance of *Shekhawat*i *Haveli*s.

4.7 INFERENCES

The two quantities needed to establish the relationship between *Vaastu* and energy efficiency have been finalized as *Vaastu* score and PUHos. While *Vaastu* score has been calculated within this chapter, the calculation of PUHos requires detailed simulation of each case study which has been discussed in following chapters. After simulation, analysis of simulated data for generation of hourly TSI has to be carried out. Once TSI is calculated, PUHos would be calculated and desired relationship would be established.

Chapter 5

WHOLE BUILDING SIMULATION

5.1 INTRODUCTION

For determining PUHos ('Percentage of uncomfortable hours inside against total uncomfortable hours outside in summers) and TSI (Tropical Summer Index) of each case, accurate air temperature in each space is needed. This requires accurate simulation of the case studies. A detailed survey of the available whole building simulation programs suggests that it is easily possible with the help of certain programs as would be discussed in following sections of this chapter.

Before starting upon details of whole building simulation of selected case studies for the purpose of this research, it is important to understand what Whole Building Simulation means. Whole Building Simulation is a Computer Simulation which is defined by experts as follows-

1. Hinton, 1978: 'A simulation package is based on a known model of physical phenomena. The model, usually in the form of a mathematical relationship, can be set up within a computer program and the student can simulate the phenomena or process by controlling and observing the output.'
2. MacArthur, 1984: 'A simulation is simply a model of some aspects of reality to focus on points of interest.'
3. Manning and Potter, 1984: 'The objective of simulation models is to present a simplified version of reality, whereby a complex system is distilled to only its most important elements or variables.'
4. Shaw, 1984: 'A computer simulation is a simplified representation of a real event or thing that recreates pertinent characteristics.'

A computer simulation program can be made to assess any phenomenon using computer based upon the input supplied by the user. Once the input has been given, the program performs mathematical calculations based upon the already entered equations and relations and gives the output. The authenticity of output depends upon-

- The details of input and its proximity to the real time data. The more detailed and realistic is the input, the more accurate output is expected.
- The mathematical equations which establish the output based upon the input. The accuracy of flowcharts and mathematical equations governs the accuracy of output.

The computer simulation package used to estimate the overall energy performance of a complete building using computer simulation and modeling techniques is known as Whole Building Simulation Program. Realistic information regarding building (such as geometry, construction, occupancy, surroundings etc.) is supplied as input. Input is supplied in a simplified manner but the output is calculated based upon complicated equations which are already fed in the program.

5.2 WHOLE BUILDING SIMULATION PROGRAM- A HISTORICAL PREVIEW

Until the severe energy crisis of 1973, energy efficiency in buildings was not a prime concern. It has now become an important issue in the wake of depleting energy resources and degrading environment. Since buildings consume considerable amount of energy and emit pollutants, it is important to ensure the performance of buildings even before they are built. Thus the need for Whole Building Simulation tools arises.

The need was felt even before energy crisis was experienced. The need gave birth to Building Simulation tools almost 50 years back. For the past 50 years, a wide variety of building energy simulation programs have been developed, enhanced and are in use throughout the building energy community. These tools provide a variety of solutions and assess different building performance parameters such as day lighting, energy auditing, heat load, HVAC system sizing, component simulation and many others. However the core tools in the building energy field are the whole-building energy simulation programs which provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs. The performance of the building is analysed based upon the input data which is user defined. This includes- climatological data, details of building envelope, building usage, internal heat gain due to occupancy, equipments, activity, surrounding environment including buildings and trees, equipment details and many others. The performance of building is affected by all these factors. The basics of determining heat transfer through different components of the building remain same as in theory.

There are two load calculation methods which are used- one is room weighting factor approach and other is heat balance approach. Both approaches are widely used for whole building simulation. Each program which uses these methods comprises hundreds of subroutines working together to simulate heat and mass energy flows throughout a building. They yield accurate results in some cases and do not report accuracy in certain others. It is because each method has its own limitation. The most serious defect was inaccuracy in prediction of indoor air temperatures. It was because of lack of feed back from system (mechanical) to update the temperature profile.

In view of these deficiencies, the best program would incorporate modules from both these methods to overcome the shortcomings of one over the other in a complementary manner. After years of research and development, US Department of Energy (they are a pioneer in developing building simulation programs) finally developed the program which incorporated the modules of both the methods and incorporated the features and capabilities of all the existing programs. The program is known as Energy Plus. Energy plus is a Fortran based comprehensive Whole Building Simulation program which is capable of performing most of the desired calculations as possible with the help of many other building simulation programs collected together.

5.3 BENEFITS OF WHOLE BUILDING SIMULATION PROGRAMS

There are a number of Whole Building Simulation programs available in the field today. They perform a variety of functions such as calculation of indoor air temperature, dew point temperature, radiant temperature, solar gain, heat transfer through conduction, convection and radiation, day light simulation, natural ventilation, infiltration and many others. Performing all these functions manually requires tremendous effort and time. Yet the calculations cannot be accurate because many of these factors affect each other. Accurate results can only be achieved through a re-iterative process. In view of such difficulties, whole building simulation programs offer a better solution. The apparent benefits of whole building simulation are-

Quality of calculations –

Computer simulations are able to quantify the values based upon multi staged repeated calculations. This results in improved accuracy of the results and enhances the depth of analysis.

Reduced time –

Since computer has pre recorded equations for performing calculations; it is much faster to do same calculations. Thus within the same time, it is possible to get more data from the building simulation as compared to manual calculations.

Ease of supplying input data-

All these programs have generalized input format. The format has all the required fields which a user might tend to omit while performing the calculations manually. But all these input fields are clearly listed in whole building simulation tools. Under each head of input data, possible options are also listed. It helps in supplying data for prototype cases where innovative systems or features are not incorporated. In case innovative techniques are to be incorporated, user defined values can also be input.

Easy to modify-

Once a simulation model of a building is made, it is much easier to change one or more components and repeat the calculations. It is because whole building simulation requires user only up to the feeding of input data. The input file can be saved and modifications can be made with very less efforts. The parameters which have not changed can be kept the same and calculations can be performed to get the output data.

5.4 COMPARISON OF POPULAR WHOLE BUILDING SIMULATION PROGRAMS

A variety of whole building simulation programs have been developed over the last half century. These are in use and are popular for different functions. A comprehensive list of twenty (20) most popular programs (till year 2005) is given below. The analysis of capabilities of all these programs is based upon the comparative report published by US Department of Energy (USDOE) (Appendix 7).

1. **BLAST Version 3.0 Level 334, August 1998** (www.bso.uiuc.edu/BLAST)
2. **BSim Version 4.4.12.11** (www.bsim.dk)
3. **DeST Version 2.0, 2005** (www.dest.com.cn, Chinese version only)
4. **DOE-2.1E Version 121, September 2003** (simulationresearch.lbl.gov)
5. **ECOTECT Version 5.50, April 2005** (www.ecotect.com)
6. **Ener-Win Version EC, June 2005** (members.cox.net/enerwin)

7. **Energy Express, Version 1.0, February 2005** (www.ee.hearne.com.au)
8. **Energy-10 Version 1.8, June 2005** (www.nrel.gov/buildings/energy10)
9. **EnergyPlus Version 1.2.2, April 2005** (www.energyplus.gov) - EnergyPlus is a modular, structured code based on the most popular features and capabilities of BLAST and DOE-2.1E. It is a simulation engine with input and output of text files. Loads calculated (by a heat balance engine) at a user-specified time step (15- minute default) are passed to the building systems simulation module at the same time step. The Energy Plus building systems simulation module, with a variable time step, calculates heating and cooling system and plant and electrical system response. This integrated solution provides more accurate space temperature prediction—crucial for system and plant sizing, occupant comfort and occupant health calculations. Integrated simulation also allows users to evaluate realistic system controls, moisture adsorption and desorption in building elements, radiant heating and cooling systems, and interzone air flow.
10. **eQUEST Version 3.55, February 2005** (www.doe2.com/equest)
11. **ESP-r Version 10.1, February 2005** (www.esru.strath.ac.uk/Programs/ESP-r.htm)
12. **HAP Version 4.20a, February 2004** (www.commercial.carrier.com)
13. **HEED Version 1.2, January 2005** (www.aud.ucla.edu/heed)
14. **IDA ICE Version 3.0, build 15, April 2005** (www.equa.se/ice)
15. **IES <VE> Version 5.2, December 2004** (www.iesve.com)
16. **Power Domus Version 1.5, September 2005** (www.pucpr.br/lst)
17. **SUNREL Version 1.14, November 2004** (www.nrel.gov/buildings/sunrel)
18. **Tas Version 9.0.7, May 2005** (www.edsl.net)
19. **TRACE 700 Version 4.1.10, November 2004** (www.tranecds.com)
20. **TRNSYS Version 16.0.37, February 2005** (sel.me.wisc.edu/trnsys)

A comparative analysis of above listed softwares was carried out by USDOE based upon the information provided by the program developers in the following categories: general modeling features; zone loads; building envelope and day lighting and solar; infiltration, ventilation and multizone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions; economic evaluation; climate data availability, results reporting; validation; and user interface, links to other programs, and availability. The study revealed that Energy Plus is able to perform most of the desired calculations and with greater accuracy. Hence it was decided that whole building simulations of the selected case studies would be performed using Energy Plus. However since Energy Plus is a Fortran based program, input of complex building geometry (such as of *Shekhawati Havelis*) by co-ordinate method takes considerably long time. Thus the popular user-interface of Energy plus is used which is Design Builder. While Energy Plus is free software, Design Builder is available commercially. However for educational purposes the software is available for free use for one month. The simulation of the cases was carried out using free software during one month period. Yet, only a part of simulation was completed. Remaining work was completed using licensed Design Builder software through the employer company- Green Build Energy Pvt. Ltd.

5.5 SIMULATION

5.5.1 Input

The information for each case is input under six different heads which cover all parameters of building affecting energy consumption. When same set of conditions are to be used for a number of cases such as in this case where 25 cases were to be simulated with similar conditions, the input details can be saved in the form of templates. The templates can be easily attached to the zones and complete information will automatically be percolated to relevant areas. The six heads are explained in detail as follows-

5.5.1.1 Location and weather data-

All the cases are assumed to be located in Jaipur. It is because weather data for only 58 Indian cities is available through ISHRAE which does not include *Sikar*, *Jhunjhunu* and

Churu districts. Weather station which is closest to the case studies in terms of proximity and similarity of weather is Jaipur. Following weather data for Jaipur has been used for simulation of case studies-

Table 5.5.1.1.1 Location Details of Jaipur Station

Statistics for IND_Jaipur_ISHRAE
Location -- Jaipur *Rajasthan* INDIA
{N 26° 49'} {E 75° 48'} {GMT +5.5 Hours}
Elevation -- 390m above sea level
Standard Pressure at Elevation -- 96727Pa
Data Source -- ISHRAE

Table 5.5.1.1.2 Monthly Statistics for DBT (°C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	26.4	33.4	36.6	42.5	42.9	42.7	40.7	37.4	39.6	37.9	33.6	27
Day:Hour	30:15	26:15	28:15	21:16	24:15	17:16	19:15	10:14	14:14	15:15	15:12	10:14
Minimum	3.7	6.7	13.4	16	21.6	22.8	22.9	23.2	21.4	15.6	9.4	5.7
Day:Hour	1:06	19:06	3:06	5:05	5:08	13:05	4:04	10:23	26:04	21:05	30:05	27:06
Daily Avg	15.6	17.8	23.8	30.2	33.4	33.4	30	28.7	29.2	26.9	21.9	16.1

Table 5.5.1.1.3 Monthly Statistics for RH (% Percentage)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	99	79	77	59	92	98	98	98	98	89	77	99
Day:Hour	16:04	4:06	15:06	14:03	5:08	29:18	7:03	7:03	3:03	9:06	28:07	23:03

Minimum	20	12	16	8	14	15	31	36	17	16	15	32
Day:Hour	25:15	20:15	28:15	14:20	20:11	16:08	8:14	5:18	30:15	22:15	11:13	5:13
Daily Avg	58	40	39	29	39	49	69	77	60	48	43	63

Table 5.5.1.1.4 Monthly Wind Direction-(Percentage in Corresponding Direction)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North	40	30	25	41	15	31	19	25	29	45	52	24
NorthEast	15	12	15	11	8	7	7	10	10	12	13	13
East	17	14	19	10	9	5	7	10	7	17	9	23
SouthEast	16	12	16	9	17	4	14	12	7	11	8	20
South	4	6	5	4	6	5	7	6	4	5	6	6
SouthWest	3	6	6	8	5	4	8	6	4	2	4	4
West	2	7	6	9	10	10	20	10	8	5	4	5
NorthWest	2	12	7	8	29	33	17	21	31	4	4	6

Table 5.5.1.1.5 Monthly statistics for Wind Speed (M/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	22	7.8	6.3	8.2	9.4	11	10	10	7.7	5.3	4.5	6.7
Day:Hour	31:05	18:14	31:09	25:16	15:08	11:20	20:17	26:14	16:12	15:15	17:10	27:02

Table 5.5.1.1.6 Monthly Statistics for Solar radiation Wh/m2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Direct Avg	5108	5770	5547	5148	4791	3681	2813	2948	4926	6670	6233	5215

Direct Max	6796	7520	7314	7478	7668	7619	4956	5377	6955	7974	7428	6913
Day	2	11	20	22	20	16	18	4	11	14	11	4
Diffuse Avg	1732	1981	2393	2795	3057	3203	3234	3135	2897	2504	2074	1770
Global Avg	3957	4823	5552	6069	6332	5804	5101	4792	5501	5773	4706	3712

5.5.1.2 Layout

The building geometry is created under this head. The geometry can be accurately modeled by importing the AutoCAD .dxf file which acts as the base of the model. Spaces which have same construction and other parameters governing heat gain/loss can be treated as one zone. Otherwise each enclosed space is automatically treated as one zone which interacts with surrounding zones. The central open to sky courtyard is not treated as a zone by the software because it automatically assumes prevailing environment conditions for the courtyard. All surrounding zones interact with courtyard in a similar manner as outside. For convenience, each zone is named as the space designated in the building.

Information on windows, doors, cut-outs, ventilators and additional mass within a zone is added under layout head. Additional features on the external surfaces such as projections and shading devices over openings which contribute to shading but do not add as a thermal mass to the building are modeled as components. These components are not included in heat balance equations but they affect the shading pattern over the external surfaces of the building thereby affecting the amount of heat gained.

Layout of the surrounding buildings is also input here. The surrounding building can be modeled as a box of same dimension as that of the building. Surrounding buildings only affect the shading pattern and reflected radiation component upon the building under study hence details such as projections etc do not need to be modelled.

Each case was modeled separately as per the documented details collected during survey. Accurate model was created as per the drawings (Appendix 8). More is the number of zones, more is the complexity of heat balance calculations as each zone interacts with all other surrounding zones until it reaches a state of equilibrium. Still, all the cases have large number of zones. Each room was modeled as a separate zone since the cases under study are naturally ventilated. It was done to ensure most realistic thermal interaction between the zones as natural ventilation affects the heat transfer.

5.5.1.3 Activity

Once the layout is complete, activity is assigned to each zone depending upon its usage. Activity in a space determines the heat load due to occupancy and the activity level of occupants. Activity consists of following sub-heads where data input is required for simulation -

1. Type of Zone- All the rooms are selected as standard which implies an enclosed room. Other possible options include semi exterior room, plenum zone and cavity. For a zone selected as standard zone, heat transfer is calculated between all the surrounding zones and the specified zone, while in case of plenum and cavity zones, heat transfer is restricted.
2. Occupancy – For the purpose of research, the occupancy has been selected as zero. It has been done so to quantify the effect of heat gain from outside and the heat loss through structure. Presence of any other heat load would have affected the results.
3. Activity- Since occupancy is zero; activity selection has no significance. However for other cases activity can be selected from a range of given activities such as standing, walking, sleeping, exercising, cooking, eating, office work, machine work

and many more. One can also select whether the activity is being performed by men, women or children as metabolic rates of all are different. Type of clothing can also be selected which can vary for different seasons. This also affects the metabolic rate and in turn the heat load through occupants.

4. Equipment load- In case the zone has computers or any other machinery, it can also be accounted and the corresponding heat load is added to the zone. However for the purpose of present research, equipment load has again been assumed to be zero. It has been considered keeping in mind the actual conditions which prevailed inside *Havelis*. There was no presence of any type of machinery and equipment.

5. Environmental controls- In case of air-conditioned zones, environmental conditions which would be maintained inside the building can be set here. However since all the cases for present research are naturally ventilated, the environmental boundary conditions do not have any significance.

5.5.1.4 Construction

Construction system for all components of the zone is assigned under this head. Usually, all zones in a building have same construction. Hence a template is formed and used for all the zones. Construction system (as per actual as documented during survey) for the cases under study is assigned for the following construction components-

1. External Walls- external walls are 45 cm thick made of hand made bricks in lime mortar with 50mm thick coat of lime plaster on both internal and external surface. Lime plaster is made from lime which is locally available mixed with brick powder, crushed stone dust, organic compound such as *Urad Dal* or Jaggery and water. All the ingredients are mixed together and left for at least one week before use. The mixture is then sieved through coarse cloth to make a uniform paste which is then applied as plaster. From the data collected for traditionally used lime plasters,

following properties of lime plaster and brick have been assumed (Table 5.5.1.4). Overall surface to surface U-value of external brick wall with these specifications is calculated to be 1.487 W/m2-K.

Table 5.5.1.4 Detailed properties of Materials

	Lime Plaster (1cm thick)	Brick (1cm thick)	Ceramic Porcelain Tiles (1cm thick)
Conductivity (W/m-K)	0.730	0.690	1.30
Specific Heat (J/Kg-K)	970	1000	1070
Density (Kg/m3)	1642	1700	2300
Colour	White	Cherry	White
Texture	Smooth	Rough	Smooth
Visible Absorptance	0.5	0.7	0.1
Solar Absorptance	0.5	0.7	0.5
Thermal Absorptance	0.4	0.9	0.5

2. Roof Slab – Roof slab is 25 cm thick made of hand made bricks in lime plaster with 25mm thick lime plaster on both internal and external surfaces. On top of outer plaster, a layer of 10mm porcelain tiles is fixed. The plaster composition and brick properties are same as that of external walls while properties of ceramic porcelain tiles is used directly from the software as given in table 5.5.1.4.1. Overall surface to surface U-value of external terrace roof with these specifications is calculated to be 2.301 W/m2-K.

3. Internal Partitions- Internal partitions have the same composition as that of external walls but the thickness of brick is reduced to 25cm. This results in overall surface to surface U-value of 2.429 W.m2-K.

4. Internal Floor Slab- Internal Floor slab has the same composition as that of roof slab without ceramic porcelain tiles. This results in an overall surface to surface U-value of 2.321 W/m2-K.

5. Ground floor slab- Ground floor slab consists of four layers. Topmost layer is 25mm thick lime plaster over a 30cm thick layer of brick. Beneath the brick is a 50cm thick layer of sand and gravel which is laid on top of 75cm compacted earth. Overall assembly results in an overall U-value of 0.742 W/m2-K. Ground floor slab remains in contact with ground and acts as a heat sink.

6. Component block- Though concrete as a material was not used in those times, all component blocks which are used to create shade over windows, plinth, platforms, parapet etc. are assumed to be created of lightweight concrete. It is because thermal properties of components do not affect the heat gain of the building. Only surface properties of components play a vital role as they determine the reflected component of solar radiation. Light weight concrete has similar surface properties as that of white washed stone which is used in *Shekhawati Havelis* for construction of *Chajjas*, *Jharokhas* and small parapets. Visible and solar absorptance of lightweight concrete is assumed to be 0.6. The surface is assumed to be rough and light gray in colour.

7. Airtightness- The structure is assumed to be loosely sealed. An infiltration rate of 3 air changes per hour is assumed in addition to the calculated natural ventilation rate.

5.5.1.5 Openings

Openings account for the maximum heat gain/loss in a building. Therefore details of openings have been placed under a separate head. Following are the subheads under which information is supplied-

1. Glazing type- The material used for glazing is specified under this head. The limitation of the program is that there is no opaque material which can be used as glazing. Thus by default some glass type is attached to the window glazing material. It has been taken care of by adding opaque blinds to the glass under the head of window shading. Thus glass type actually did not affect the heat gain. Hence a 3mm thick single layer clear float glass has been used for all the windows.
2. Layout- Windows can also be prescribed as percentage area of wall (which is however not the case here). Hence 'no windows' were selected so that no window is added by default. All the windows were added wherever they were present as per the documentation of case studies.
3. Frame and Dividers- 20 cm thick painted wooden frame made of locally available wood has been used for frame and divider (sash bars). Only one divider in the centre has been assumed.
4. Window shading- Opaque window blinds have been added to all windows to accommodate thick wooden shutters of traditional windows. Blinds are positioned outside the windows so that glass does not receive any radiation. The blinds and windows follow same schedule of opening. They remain closed during summer days and winter nights and opened during summer nights and winter days. This facilitates night time flushing of the structure during summer nights and cuts off inflow of warm air inside the building.

5.5.1.6 Lighting

No artificial lighting has been assumed inside the *Haveli* cases under study. It is because these *Haveli*s did not have any artificial means of lighting. During night, oil wick lamps were used for lighting inside the rooms. But the duration of lighting oil lamps was very less. Occupants usually had dinner before or around sunset and slept early. This limited the time of use of oil wick lamps. Hence for simulation purposes, no heat load has been assumed on account of artificial lighting.

5.5.1.7 HVAC

No mechanical system for cooling, heating or ventilation has been used. Only natural ventilation is assumed. The rate of air change has been calculated automatically by the software based upon wind flow data for supplied information on windows.

Once all the information is input into the model, simulation is run. Simulation may be carried for complete year or for a part of the year. Cases under study have been simulated for seven months which included all seasons. The Simulation was run from April 1 to August 30 and December15 to February 22. This included summer months, monsoon months, winter months and spring season of February. Breaking up simulation in two parts also facilitated faster simulation. Since the geometry of most of the cases was complicated and there were large number of zones to be modeled, annual simulation took considerably long. Also the output files for annual simulation were heavier than the part files.

5.5.2 Output

Simulation was carried out for above stated period at hourly interval. Daily and monthly totals were also calculated. Since the cases were considered to be naturally ventilated and there was no HVAC system used, no energy consumption requirement was calculated. The output was reported in both tabular and graphical formats and consisted zone wise hourly details of following quantities-

a. Internal Ambient Air temperature

b. Radiant temperature of the surface

c. Operative temperature

d. Outside Dry-bulb temperature

e. Heat gain/loss through

- Walls
- Ground floor
- Roof
- Internal partition
- External Infiltration
- External Natural Ventilation
- Relative Humidity

Above listed quantities were calculated and generated in tabular format for all zones in each case study. However for analysis, only the data for habitable rooms was needed. Data was sorted as per the requirement of research. Following sorting was carried out-

5.5.2.1 Zone selection

Each case study had many zones ranging from minimum 6 in number to 50 and more. It was however not possible to study the conditions in each zone of all the case studies. Thus certain zones were selected from each case study. The zones were selected based upon following parameters-

i. Only habitable zones such as- Sal, Tibari, Baithak, Rasoghada, Kamra etc were selected. Zones used for storage purposes were not selected such as Kothri.

ii. Zone used for cattle shed and servant quarters were not studied; however overall performance of basement was recorded.

iii. If there were two or more zones having same layout and conditions such as orientation, exposure to outside, surrounding rooms, construction and activity, only one was selected to represent the typical inside conditions.

iv. Only the zones on ground floor were used to analyze the results.

5.5.2.2 Output Data Collection

Data for each short listed zone of all cases was saved as a separate file. Relative Humidity and Dry-Bulb Temperature was substituted from the output obtained from simulation.

5.6 DATA PROCESSING

Wet Bulb Temperature was calculated from these two quantities. Air speed was calculated manually using calculation procedures for estimating probable indoor wind velocity as stated in 'Handbook on Functional Requirements of Buildings (Other than Industrial Buildings), Bureau of Indian Standards' (Appendix 9). TSI is dependant upon Relative Humidity (which is reported by Wet Bulb Temperature), ambient air temperature (reported as Dry-Bulb Temperature) and prevailing air speed. DBT and RH were obtained through simulation and air speed was manually calculated. These were then substituted in the formula to calculate TSI for each zone (Since hourly data for all of these quantities was calculated for all the habitable zones, it was not possible to include the data in printed form. Hence it has been appended in soft format in the enclosed CD-ROM). TSI was also calculated for outside by using outside relative humidity, outside wind velocity and outside DBT. The TSI thus calculated reports the TSI values for outdoors under shade. It is because globe temperatures for outside were not available. Thus DBT was used and TSI was calculated.

The preliminary values for the three variables obtained for each zone were saved in separate files. Desired data was then combined in one sheet which consisted of DBT, relative humidity and Air speeds for all the zones. Hourly TSI was calculated based upon above stated three values for each zone. Final sheet was prepared for each case study which consisted of TSI values for all habitable zones inside the building. Once TSI was calculated for all habitable zones for all the cases under study and also for outside, PUHos was calculated. As described earlier, PUHos is defined as -

$$\text{PUHos} = \frac{\text{Total number of uncomfortable hours inside the Case in summers}}{\text{Total number of uncomfortable hours outside in summers}} \times 100$$

Based upon the extended comfort range of TSI that is 19-34 TSI, the number of hours falling within, above and below the comfort range of TSI was calculated. Though the simulation has been performed for all seasons, the results have been analyzed only for summers as stated earlier.

In the consolidated sheets prepared for each case study (which contained hourly TSI values for all the habitable zones in each case study and also the TSI values for outdoors for the corresponding time), the TSI values falling within comfort range were colored as green. TSI values which imply hot conditions that is TSI values higher than 34 TSI were colored as red and TSI values less than 19 were colored as blue. TSI values for all zones were then analysed for each hour of the simulated period. Total number of uncomfortable hours in summers was calculated for outdoors. Correspondingly, TSI was checked for all zones. If any one zone in the building remained comfortable during the uncomfortable hour outside, the building was considered to be comfortable during that hour. It is because if any one zone remains comfortable at a time, occupants could shift to that particular zone and remain comfortable. While doing this exercise, basements were not included while calculating comfort zone in building even though basements remained most comfortable in summers. It is because in most of the *Haveli*s, basements were not used by occupants as habitable spaces and were often used for storage, cattle sheds or servant quarters. Once the total uncomfortable hours for the building were calculated, PUHos was calculated as per the formula given above.

5.7 INFERENCES

Analyzing building performance for only a limited period of the year might not yield the comprehensive result but it is needed to get specific results. For present study, the region under study is Hot-dry. Analysis of prevalent *Vaastu* text also reveals that most of the features employed in *Haveli*s under study and the text are in tune with the scientifically prescribed passive design parameters proposed for buildings in hot-dry region. The physiological objective of passive design parameters in hot-dry climates is to reduce solar radiation and to minimize heat transfer. Reduction in solar radiation during summer is definitely an advantage but it is not preferred in winters. However as stated earlier, duration and severity of summer is more in *Shekhawat*i region. Hence even if the relationship between *Vaastu* application and thermal comfort established for summers is not comprehensive, it will be important to note.

The thermal performance of *Haveli*s under study is totally dependant upon the whole building simulation through Energy Plus software. The relationship thus obtained based upon this result might vary if actual comfort data is collected from *Haveli*s after year long monitoring. Yet if the simulation model is accurate and all parameters have been reported as actual conditions, the variation will be very less.

The whole building simulation of case studies is carried out. The model was generated based upon the drawing prepared after survey. Details regarding construction were collected. The materials which are used for construction of these Havelis were not provided in the default templates. Hence all materials were created by collecting their thermal and surface properties. Accurate results could be achieved by this exercise.

The output was obtained for all habitable zones in each Haveli. The data comprised of hourly DBT and RH. Air velocity was manually calculated. WBT was calculated based upon DB and RH. Once hourly DBT, WBT and air speed was known for each zone, TSI was calculated. This generated enormous amount of data. TSI was then used to calculate PUHos for each case. Besides PUHos, Percentage of uncomfortable hours inside against outside in winters and Percentage of total uncomfortable hours inside against outside was calculated. The values of PUHos thus calculated was used to establish a relationship with *vaastu* score calculated in chapter 4.

Chapter 6

ANALYSIS

6.1 INTRODUCTION

In the previous chapters, all the necessary quantities (*Vaastu* score, TSI for individual zones and PUHos) for each case study are calculated. After calculations, the quantities have to be analyzed to establish significant relationships between above stated quantities. The analysis would reveal the efficiency of *Vaastu* prescriptions for achieving thermal comfort in *Shekhawati Havelis*.

6.2 VAASTU SCORE AND PUHOS

Vaastu score and PUHos calculated for the case studies are analyzed to establish any significant relationship. Although the percentage of uncomfortable hours inside the building against uncomfortable hours outside in winters is not to be reported, yet the relationship between percentage of uncomfortable hours in winters and *Vaastu* score is analyzed. Overall relationship between *Vaastu* score and total percentage of uncomfortable hours inside is also established. Establishing all relationships will help to identify the most appropriate implication of *Vaastu* parameters in residential buildings in hot-dry climates.

However while calculating the relationship using regression analysis, values for certain cases lie completely out of the prevailing trend. In such circumstances, those cases are removed for establishing correlation coefficient. Such cases are called outliers. For establishing relationship between *Vaastu* score and three variables namely PUHos, percentage of uncomfortable hours in winters and total uncomfortable hours, outliers have to be selected for each relationship. A case which acts as an outlier for establishing one relationship may not necessarily be the outlier for other relationships too. Relationship between two quantities is established assuming linear, second degree polynomial and logarithmic relationship. By doing this, best fitting relationship curve was drawn and corresponding correlation coefficient was reported.

Table 6.2 Final *Vaastu* Scores, PUHos, Percentage of Uncomfortable Hours in Winters and Percentage of Total Uncomfortable Hours

S. No.	Case study	Final *Vaastu* Score	Percentage of uncomfortable hours inside the building against uncomfortable hours outside in summers	Percentage of uncomfortable hours inside the building against uncomfortable hours outside in winters	Total percentage of uncomfortable hours inside the building against uncomfortable hours outside
1.	Babulalji	89.52	6.3	91.20	82.9
2.	Bhagirathmal	72.03	34.29	77.06	72.88
3.	Bissau	71.48	42.86	62.65	60.71
4.	Chiranjilalji	81.38	9.14	69.76	63.84
5.	Harsukhrai	73.66	2.86	59.49	53.96
6.	Damodar	83.96	10.86	86.21	78.85
7.	Gym_Dundlod	86.02	17.14	74.83	69.2
8.	ArjunDas	83.42	12.57	90.41	82.81
9.	Gulabrai	92.65	5.71	90.41	82.14
10.	Harkarandas	80.56	11.43	70.25	64.51
11.	Ishwardas	76.88	26.86	57.39	54.41
12.	Jaigopal	86.49	16	63.33	58.71
13.	Kariwala	83.77	9.14	64.38	58.98
14.	Morarka	83.51	10.86	94.43	86.27
15.	Pilani	78.95	15.43	89.67	82.42
16.	Ramgarh	78.56	18.29	98.21	90.4
17.	Ratannagar	81.13	34.86	57.2	55.02

Table 6.2 *Continued*

18.	Sahumal	77.84	17.14	67.04	62.17
19.	Shekhsaria	91.96	0	45.52	41.07
20.	Shridhar	89.36	41.71	97.84	92.35
21.	Sidhkaran	73.85	74.29	58.19	59.77
22.	Nawalgarh	83.87	25.71	69.94	65.63
23.	Surajgarh	76.15	21.71	87.76	81.31
24.	Virdichand	83.31	13.14	87.76	80.47
25.	Vishwanath	90.97	2.29	81.57	73.83

Regression analysis was carried out to calculate correlation coefficients between *Vaastu* Score and other three quantities. Although to establish significant relationship through statistical analysis, 25 cases are less. However in the present context where each case represents a complete class of *Haveli*s, requires enormous documentation and substantial time to calculate PUHos through computer generated whole building simulation, it is a substantial number.

6.2.1 *Vaastu* score and PUHos

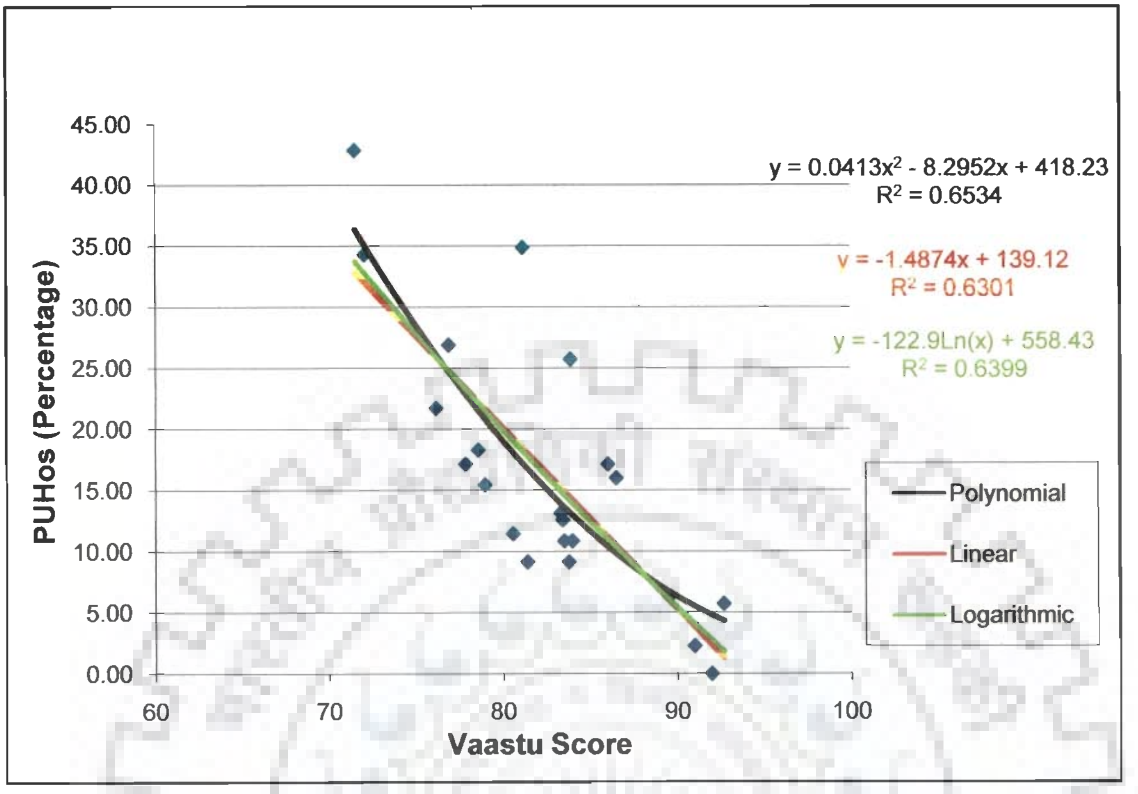

Figure 6.2.1 Correlation between *Vaastu* score and PUHos

Relationship between *Vaastu* score and PUHos was established where all three types of trends (i.e. Linear, Polynomial of order 2 and logarithmic) were fitted for the given data set and three outliers were identified (Figure 6.2.1). As per the codes assigned to *Havelis*, these were Harsukhrai, Sidhkaran and Shridhar. After removing the outliers from the data set, the correlation coefficients between *Vaastu* score and PUHos were obtained as follows-

Linear correlation	-	0.6301
Second degree Polynomial correlation	-	0.6534
Logarithmic correlation	-	0.6399

All the three relationship types resulted in almost same correlation coefficients. This confirms that correlation coefficient of 0.63 for a linear relationship would give accurate relationship between *Vaastu* score and PUHos. It signifies a moderate negative relationship which implies that as *Vaastu* score increases, the PUHos decreases. Hence a *Haveli* having greater compatibility with *Vaastu* prescriptions will be more comfortable in summers. This correlation is significant for 99% of observations.

The established negative relationship is fully justified. As established in chapter 4, 72% of the passive design features prescribed for hot-dry climates are followed in *Vaastu* prescriptions. Since physiological objective of passive design features in hot-dry climates is to reduce heat gain inside the building, *Haveli*s following more *Vaastu* prescriptions imply reduced heat gain and increased thermal comfort which is evident from the moderately significant relationship between *Vaastu* score and PUHos.

6.2.2 *Vaastu* score and Percentage of uncomfortable hours inside against outside in winters

When correlation was established between *Vaastu* score and Percentage of uncomfortable hours inside against outside in winters(Figure 6.2.2)., five cases were identified as outliers. These were Shekhsaria, Ramgarh, Ratannagar, Jaigopal and Surajgarh. Correlation coefficient was established for these two quantities assuming all three types of relationships (i.e. Linear, Polynomial of order 2 and Logarithmic). The three relationship types resulted in a correlation coefficient of approximately 0.44 and a positive relationship which implies that cases having higher *Vaastu* score remain uncomfortable for longer period in winters. Since the correlation coefficient is less than 0.5, the relationship is not significant from statistical point of view. However from analysis of passive design features and *Vaastu* prescriptions, it is established that the passive design features incorporated in *Shekhawat*i *Haveli*s help to reduce heat gain in summers. Except heavy thermal mass of *Haveli*s (which reduces heat loss from buildings in winters), all other passive design features reduce the heat gain in winters which results in lower temperatures inside[28]. Hence even though the correlation coefficient is less than 0.5, the relationship is fully justified.

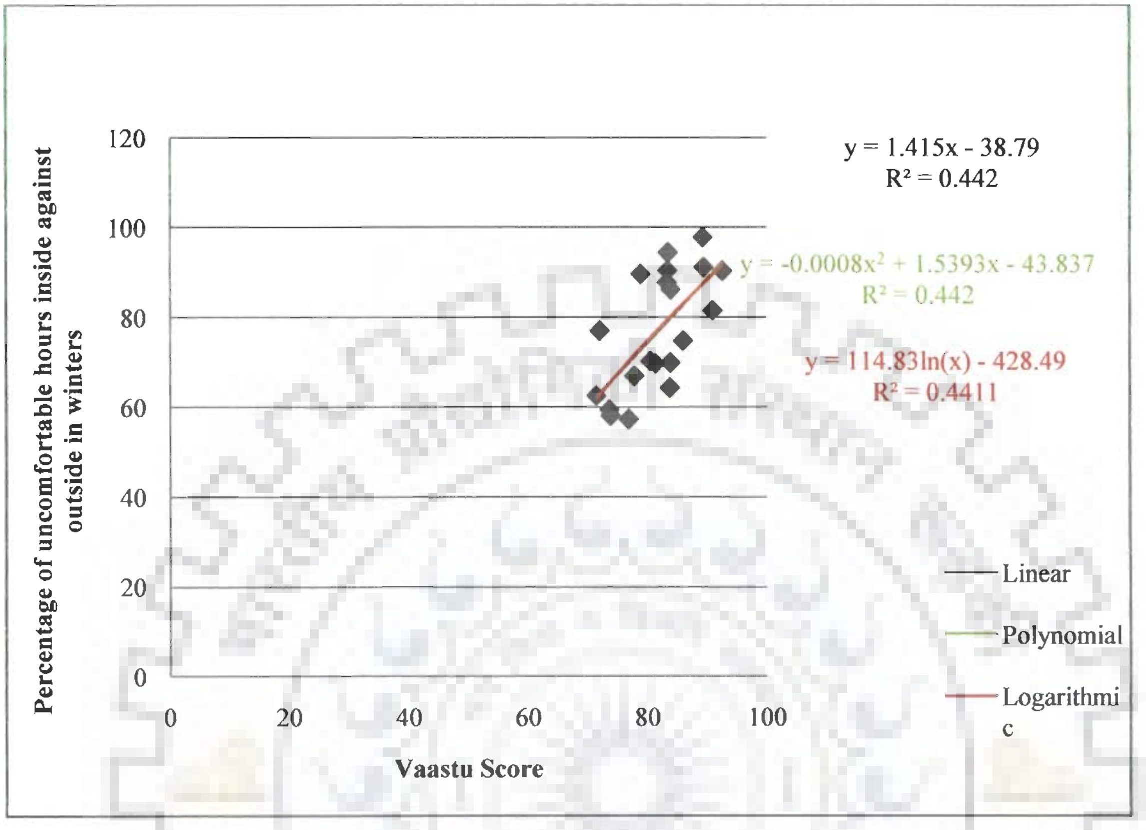

Figure 6.2.2 Correlation between *Vaastu* score and Percentage of uncomfortable hours inside against outside in winters

6.2.3 *Vaastu* score and Total percentage of uncomfortable hours inside against outside

Correlation between *Vaastu* score and Total percentage of uncomfortable hours inside against outside was established for previously discussed three types of relationships. In all the three cases, correlation coefficient was found to be 0.36 and a positive relationship. This implies that the cases having higher *Vaastu* score are more

[28] H. Safarzadeh and M N Bahadori, Passive cooling effects of courtyards, Building and Environemnt, 40 (2005), pp 89-104

uncomfortable throughout the year. However since correlation coefficient is only 0.36, it doesn't imply a significant relationship.

From correlations established between *Vaastu* score and percentage of uncomfortable hours inside against outside in summers, winters and throughout the year, it is evident that *Vaastu* prescriptions help in bringing comfort during summers. But the same strategies are not effective in winters. In fact *Vaastu* prescriptions reduce the comfort level inside *Havelis* in winters. Buildings receive reduced heat gain in winters also which is however required to increase the comfort level. Hence the buildings remain uncomfortable in winters while the comfort level increases in summers.

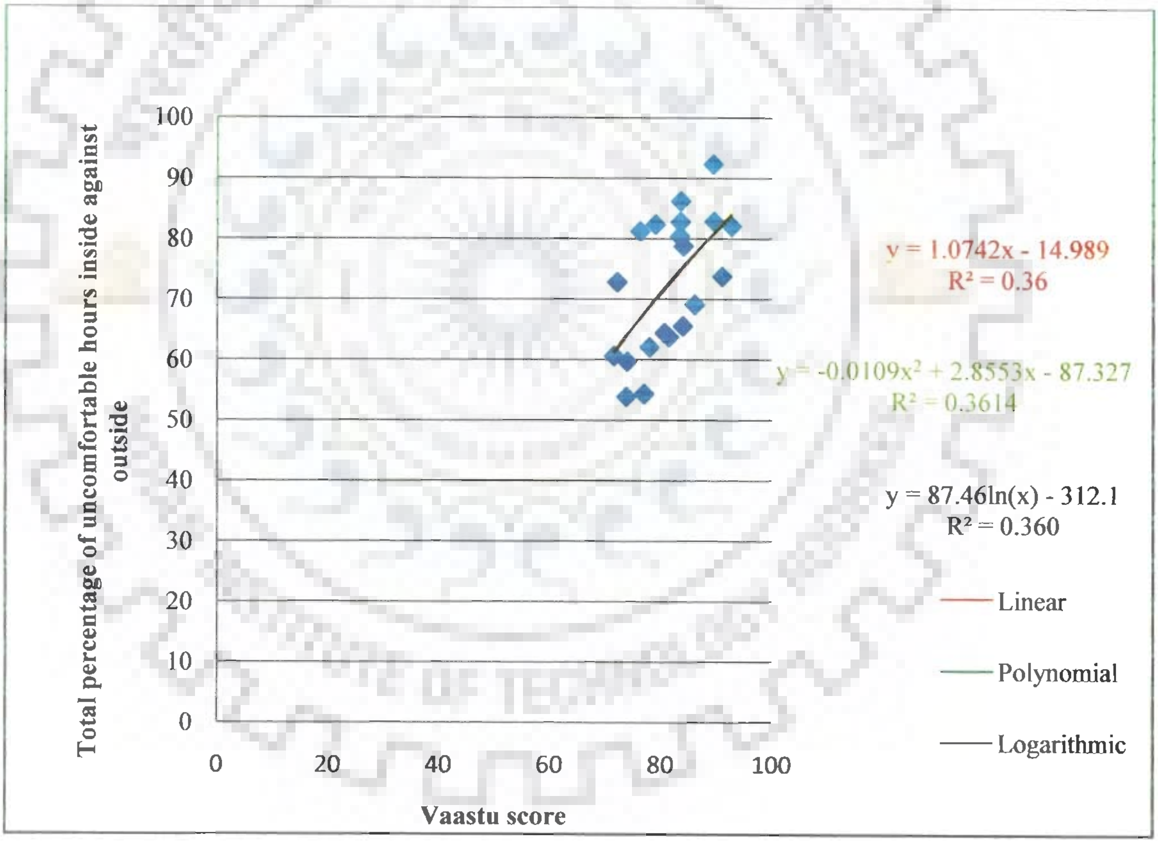

Figure 6.2.3 Correlation between *Vaastu* score and Total Percentage of uncomfortable hours inside against outside

Since the total number of uncomfortable hours in winters is much larger than the total number of uncomfortable hours in summers, total uncomfortable hours inside the building throughout the year is more in cases having higher *Vaastu* score.

6.3 EFFECT OF INDIVIDUAL VAASTU PARAMETER ON PUHOS

Once it is established that *Vaastu* prescriptions help in bringing in thermal comfort during summers, detailed analysis of *Vaastu* prescriptions is carried out for *Shekhawat*i *Havel*is. It is necessary to determine the effectiveness of each prescription in view of thermal comfort. From table 4.3, it is clear that all passive design parameters are not followed in *Vaastu* text. There are deviations from the scientifically and climatologically prescribed techniques which help in reducing heat gain inside buildings in summers. In fact there are many *Vaastu* prescriptions which are in absolute contrast to the passive design parameters. Therefore, regression analysis of dependence of PUHos on *Vaastu* prescriptions is carried out.

If regression analysis is carried out for score obtained against each prescription and PUHos, relationship curve cannot be drawn. It is because a case study can achieve either a zero or the weightage assigned to *Vaastu* prescription as listed in table 4.5.4. Hence the variation cannot be reported. Therefore *Vaastu* prescriptions were combined according to the applicability of the prescription under eight heads which are- Courtyard, Landscape, Orientation, Building Elements, Openings, Construction, Height/Storeys and Spatial Planning (Table 6.3.1). This resulted in variation in the score and reduction in the number of variables.

Table 6.3.1 Table Showing *Vaastu* Prescriptions Under Eight Heads

S. No.	*Vaastu* prescription	Code	Weightage	Head
1	Presence of courtyard in the centre	Court	6.14	Courtyard
2	Size of courtyard- should be 55% of the total width of the building.	Court_size	1.35	
3	If site is sloping, the slope should be towards E, NE or N. It implies all water from building should be collected towards these directions. And open area if needed for collection should also be in these directions only.	Slope	2.85	Orientation
4	Building should be facing East	Bldg_E	2.40	Orientation
5	Building should be facing North	Bldg_N	2.59	
6	Building should be facing West	Bldg_W	0.92	
7	Building should not be facing south.	Bldg_S	5.36	
8	Trees are not prescribed to be planted inside the building.	Tree_inside	0.75	Landscape
9	Around the building, thorny, milk bearing and fruit bearing trees are not to be planted.	Trees_thorny	0.52	
10	Yellow colored flowering trees and plants should not be planted around building.	Trees_yellow	0.65	
11	Huge trees like Peepal, Bargad, Fig and Kapittha should be planted around the building.	Trees_huge	0.08	
12	Building should not receive shadow of any other building after 3 pm.	Shadow	3.14	Building Elements
13	Apron should be constructed all around the building.	Apron	2.68	

Table 6.3.1 Continued

14	Minimum width of the apron for smallest size of building is 60cm	Apron_width	2.76	
15	A platform should be constructed above the apron of minimum height equal to 1/8th of building height.	Apron_platform	1.1	Building Elements
16	All buildings must have plinth. Larger buildings should have higher plinth max being 14 hands.	Plinth	3.80	
17	Entrance doors should preferably open towards east.	Entry_door	2.19	Orientation
18	Larger buildings should have larger doors.	Doors	3.27	Openings
19	Entrance door should be the largest door in a building.	Entrydoor_size	4.70	
20	Doors on the upper floors should be smaller in size than the doors on lower floors.	Door_storey	4.57	
21	Ventilators should be preferably placed in north.	Ventilator	0.59	Orientation
22	There should not be any common walls/ columns or any other structural member between two buildings.	Walls_common	2.19	Construction
23	Square columns should be used in the residential buildings.	Column	0.00	
24	*Chajja* should project from all sides of building.	*Chajja*	1.27	Building Elements
25	Minimum width of *Chajja* should be 1/5th of the floor height.	*Chajja*_width	3.18	
26	Stone should be avoided in residences. But it can be used in external walls, foundation and column base.	Stone	3.53	Construction

Table 6.3.1 – Continued

27	*Jharokhas* must be present in buildings.	*Jharokhas*	0.73	Building Elements
28	Residential buildings should not have more than 3 floors.	Floors	4.44	Height /Storeys
29	Height of upper floors should be less than lower floors.	Floors_height	4.84	Height /Storeys
30	Mortar should be strong enough to bind bricks together.	Mortar	3.66	Construction
31	Larger buildings should have thicker walls.	Walls_thickness	3.01	
32	Guest room and external rooms should be decorated with paintings while habitable rooms should be simple and without much ornamentation.	Ornamentation	0.13	Building Elements
33	Walls should be thicker at base and should go on decreasing with height.	Walls_variation	3.14	Construction
34	Plaster should be even on all surfaces.	Plaster	3.40	
	Following arrangement of spaces in a residence is preferred-			Spatial Planning
35	Prayer Room- NE	Prayer_NE	0.82	
36	Bathing- E	Bath_E	0.56	
37	Main entrance- E	Entry_E	2.3	
39	Kitchen – SE	Kit_SE	1.69	
39	Dining- S	Dining_S	2.16	
40	Bedroom – S (towards interior courtyard)	Bed_S	2.09	
41	Toilets- SW/ NW	Toilet_SW/ NW	0.52	
42	Family room/ Entertainment Room- W	Family_W	1.25	

Table 6.3.1 – Continued

43	Store for edibles- E of SE at the back of kitchen	Edible store_E/SE	0.51	
44	Store of valuables- N/SW	Valuable store_N/SW	1.51	
45	Store of other things- NW	Store_NW	0.68	

After combining prescriptions under these eight heads, already assigned scores for all case studies for each prescription were added to tabulate the score under the eight heads. Table 6.3.2 shows scores for all cases under these heads.

Table 6.3.2 Table showing scores for the eight heads for all cases under study

Case study	court yard	orientation	landscape	building elements	openings	construction	Height /storeys	spatial planning
Babulalji	6.14	12.80	1.92	13.28	12.54	18.93	9.28	11.49
Bhagirathmal	7.49	6.28	1.17	7.84	12.54	18.93	9.28	5.36
Bissau	6.14	6.28	1.92	9.11	12.54	18.93	9.28	7.28
Chiranjilalji	6.14	10.80	1.92	14.38	12.54	18.93	9.28	4.25
Harsukhrai	7.49	6.28	1.92	13.65	12.54	16.74	9.28	5.76
Damodar	7.49	12.80	2.00	7.11	12.54	18.93	9.28	10.67
Gym_Dundlod	6.14	13.39	2.00	7.84	12.54	18.93	9.28	12.76
ArjunDas	6.14	6.87	1.92	15.65	12.54	18.93	9.28	8.95
Gulabrai	6.14	13.39	1.92	14.55	12.54	18.93	9.28	12.76
Harkarandas	6.14	6.87	1.92	14.55	12.54	18.93	9.28	7.19
Ishwardas	6.14	6.87	1.92	9.11	12.54	18.93	9.28	8.95
Jaigopal	7.49	13.58	1.92	9.11	12.54	18.93	9.28	10.5
Kariwala	6.14	6.87	1.92	15.65	12.54	18.93	9.28	9.3
Morarka	6.14	10.80	1.92	15.65	12.54	18.93	9.28	8.25

Table 6.3.2 Continued								
Pilani	7.49	9.72	2.00	8.75	12.54	18.93	9.28	7.1
Ramgarh	7.49	6.28	1.92	14.38	12.54	16.74	9.28	6.79
Ratannagar	6.14	11.39	1.92	10.60	12.54	18.93	9.28	7.19
Sahumal	6.14	13.39	1.92	7.84	12.54	18.93	9.28	7.8
Shekhsaria	6.14	12.80	2.00	14.38	12.54	18.93	9.28	12.75
Shridhar	6.14	13.39	1.92	10.75	12.54	18.93	9.28	13.27
Sidhkaran	6.14	6.87	1.92	7.84	12.54	18.93	9.28	7.19
Nawalgarh	7.49	12.80	2.00	8.07	12.54	18.93	9.28	12.76
Surajgarh	6.14	6.28	2.00	13.65	12.54	16.74	9.28	9.52
Virdichand	6.14	11.39	1.92	11.20	12.54	18.93	9.28	8.77
Vishwanath	6.14	12.80	1.92	15.65	12.54	18.93	9.28	10.57

In the previous sections of this chapter, the correlation was established between PUHos and *Vaastu* score, which is the total of scores under above mentioned eight heads. Regression analysis for *Shekhawat*i *Haveli*s with PUHos as dependant variable and the eight heads as independent variable was carried out using SPSS software to establish the effect of each head on PUHos(Table 6.3.3, 6.3.4, 6.3.5, 6.3.6, 6.3.7 and 6.3.8).

Table6.3.3 Table showing procedure followed in SPSS for regression analysis

	Output Created	03-Mar-2009 21:27:01
	Comments	
Input	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	25

Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
	Syntax	REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT percentageofuncomfortablehrsinsummer /METHOD=ENTER courtyard orientation landscape buildingelements openings construction heightstoreys spatialplanning.
Resources	Processor Time	0:00:00.016
	Elapsed Time	0:00:00.110
	Memory Required	3988 bytes
	Additional Memory Required for Residual Plots	0 bytes

Warnings

For models with dependent variable percentage of uncomfortable hrs in summer, the following variables are constants or have missing correlations: openings, height/storeys. They will be deleted from the analysis.

Table 6.3.4 Table showing Variable entered and removed for regression analysis

Model	Variables Entered	Variables Removed	Method
1	spatial planning, building elements, construction, landscape, courtyard, orientation[a]	Openings, heights/storeys	Enter

a. All requested variables entered.

Table 6.3.5 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.770[a]	.593	.457	12.095

a. Predictors: (Constant), spatial planning, building elements, construction, landscape, courtyard, orientation

Table 6.3.6 ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3834.382	6	639.064	4.369	.007[a]
	Residual	2633.089	18	146.283		
	Total	6467.471	24			

a. Predictors: (Constant), spatial planning, building elements, construction, landscape, courtyard, orientation

b. Dependent Variable: percentage of uncomfortable hrs in summer

Table 6.3.7 Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	184.120	125.383		1.468	.159
	courtyard	-10.488	5.120	-.395	-2.049	.055
	orientation	-2.473	1.222	-.457	-2.023	.058
	landscape	-7.198	18.584	-.069	-.387	.703
	building elements	-4.078	.942	-.778	-4.330	.000
	construction	-.765	4.705	-.034	-.163	.873
	spatial planning	.409	1.307	.064	.313	.758

a. Dependent Variable: percentage of uncomfortable hrs in summer

Regression Results

Regression done using SPSS 17

Dependent Variable: Percentage of uncomfortable hrs in summer

Table 6.3.8 Table showing Coefficient of Correlation

Independent Variable	**Coefficient**	
(Constant)	184.120	Not significant
courtyard	-10.488**	Significant at 5%; negative
orientation	-2.473**	Significant at 5%; negative
landscape	-7.198	Not significant
building elements	-4.078***	Significant at 1%; negative
construction	-.765	Not significant
spatial planning	.409	Not significant
R^2	.593	Moderate
F	4.369***	Significant at 1%
*** 1% level, ** 5% level, * 10% level		

Regression analysis reveals the significance of each head and its effect on PUHos. While computing regression using SPSS17, a warning was received and two variables were removed from analysis, which were Openings and Height/Storeys. If we look at the table 6.3.2, it is clear that scores for all the case studies under these two heads are the same. This implies that no variation has been reported hence a correlation cannot be established and the two heads were removed from analysis. However it does not mean that these two parameters do not affect the PUHos. *Vaastu* score is affected by the prescriptions falling under these two heads.

Results obtained from regression analysis reveal that prescriptions under the heads- courtyard, building elements and orientation affect the PUHos most significantly. An increase in the score of these heads results in a decrease in the PUHos. It implies that the *Shekhawat*i *Haveli*s which follow *Vaastu* prescriptions relating to courtyard, building elements and orientation remain more comfortable during summers. The effect of these three heads is significant for 95% cases. The prescriptions covered under these six heads are analysed qualitatively to understand the effect of *Vaastu* prescriptions on PUHos.

6.3.1 Courtyard

In *Shekhawat*i *Havelis*, *Vaastu* prescriptions relating to courtyard are found to effect PUHos most significantly. Following prescriptions are covered here-

Prescription- <u>Presence of courtyard in the centre</u>

As per *Vaastu* prescriptions, courtyard should be present in the centre of the building and all *Shekhawat*i *Haveli*s invariably have central courtyards. Courtyard is desirable in hot-dry climates from climatic point of view as it helps in bringing controlled light and ventilation without exposing the structure to direct sun. As courtyard facilitates light and ventilation, openings on external walls are considerably reduced which helps in cutting off direct radiation entering inside the building. Though the surface area of walls increases through provision of courtyard, features like small projections and built mass around the courtyard keep the walls shaded. Courtyard and shaded walls around the courtyard re-radiate heat during night while not receiving much heat during the day thereby cooling the surrounding structure through night time ventilation. Beside climate regulation, courtyard also acts as an extended space which is used for a variety of purposes throughout the day and night. It provides comfort at the time (Nights, morning and evening) when the building mass is at uncomfortable temperature. Therefore it is justified that *Vaastu* prescription for presence of courtyard brings down the percentage of uncomfortable hours inside the building.

Prescription- Size of courtyard should be at least 55% of the total width of the building

Vaastu prescribes approximately 55% of the total width of the building to be left open in the centre. The ratio of width to length is taken as 1 as the central open courtyard was always prescribed to be a square in *Vaastu*. The research studies conducted to analyze the effect of size of courtyard on its thermal performance have so far analyzed width to length ratio or width to height ratio instead of only width as a parameter. A single parameter to establish optimum width is not available however the ratio of width to length has been explored. [29]

It is evident from research studies that a linear courtyard with width to length ratio of 1:10 will be most efficient for buildings in hot dry climate keeping the width to height

[29] A S Muhaisen and M B Gadi, Shadin performance of polygonal courtyard forms, Building and Environment, 41 (2006), pp. 1050-1059

ratio as same[30]. It is because courtyards with lesser width would cut off most of the direct sun. Square courtyards permit maximum direct solar radiation in the courtyard as compared to other forms. However in the context of present study, only the variation in width has been analyzed, since all *Haveli*s have square courtyards.

In such scenario, the *Haveli*s which have courtyard size as 55% of the total width of the building are found to be more comfortable than *Haveli*s which have very small or very large courtyards. Smaller courtyards remain shaded throughout the day but night time cooling is not possible while large courtyards gain more heat as compared to the night time loss. Hence the courtyard size of 45-60% which is as per *Vaastu* prescriptions would result in increased thermal comfort in *Shekhawat*i *Haveli*s.

6.3.2 Building Elements

Vaastu prescriptions relating to Building Elements effect thermal comfort in *Shekhawat*i *Haveli*s positively. Though the effect of all prescriptions would not be the same, the combined effect is significant. Prescriptions covered under head of Building Elements are discussed as follows-

Prescription- **<u>Building should not receive shadow of any other building after 3 pm</u>**

This prescription of *Vaastu* doesn't adhere to climatology principles. In hot dry climate, objective is to cut off as much solar radiation as possible *Vaastu* prescribes direct radiation after 3pm when the temperature is highest. This practice has been followed in most of *Shekhawat*i *Haveli*s and is adopted in buildings in hot-dry climates because of the

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[30] A S Muhaisen and M B Gadi, Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate in Rome, Building and Environment, 41 (2006), pp. 245-253

presence of central courtyard. The walls surrounding courtyard remain shaded so the quality of light entering surrounding rooms is diffused. Thus if shadow from surrounding building is received, the light levels inside the courtyard and surrounding rooms are further reduced. However the prescription has been stated only for evening because shadow from surrounding buildings would be received only when the altitude of sun is low. It helps in reducing the energy consumed to maintain optimum light levels inside the building but increases the exposure of building to solar radiation thereby increasing PUHos.

Prescription- Apron should be constructed all around the building; Minimum width of the apron for smallest size of building is 60cm; A platform should be constructed above the apron of minimum height equal to 1/8th of building height.

Vaastu prescription stating construction of apron with a raised platform all around the building conforms to the passive design requirement. Minimum 60cm wide apron with raised platform is prescribed for effective control of rain, dust, sand and ground reflected component of radiation. Apron less than 60cm wide would look disproportionate to the scale of the building and would not be effective in protecting the walls from rain. Hence a minimum width of 60cm has been prescribed which is in line with prescriptions in NBC (National Building Code). However, the width of apron has no effect on thermal comfort if platform is not constructed above it. The platform above the apron cuts off the ground reflected component of radiation falling on the walls, absorbs the heat and reradiates it to outside during night. Therefore the buildings which have platform over the apron would remain more comfortable. However the change in comfort conditions would not be significant because in most of the cases under study, the plinth was raised equal to the height of a storey and was used either for storage or as a shed for cattle. Consequently thermal comfort of habitable rooms for *Shekhawat*i *Haveli*s which have high plinth is not significantly affected. But in cases where there are habitable rooms on ground floor level, the variation might be significant.

Prescription- *Chajja* should project from all sides of building; Minimum width of *Chajja* should be 1/5th of the floor height

Provision of *Chajja* on all sides of building is mandatory as per *Vaastu* and *Shekhawat*i *Haveli*s also have *Chajja* projected from all sides. *Chajja* is an effective passive design strategy for buildings in hot dry climate. It helps to cut off the radiation falling on the walls thus reducing the heat gain significantly. The walls which remain shaded during the day reduce the heat gain and help in night time cooling through re-radiation thereby doubling the effect. Therefore *Chajja* helps in increasing thermal comfort.

Prescription- *Jharokhas* must be present in buildings

Jharokhas shade the windows against direct solar radiation and facilitate natural ventilation and diffused lighting. Otherwise windows are preferred to be closed during daytime in Hot-dry climate. *Jharokhas* improve air movement inside which lowers down the effective temperature and increases thermal comfort. *Shekhawat*i *Haveli*s incorporate *Jharokhas* as an integral part of design. Hence thermal comfort increases with provision of *Jharokhas* in *Shekhawat*i *Haveli*s.

Prescription- Guest room and external rooms should be decorated with paintings while habitable rooms should be simple and without much ornamentation

There is no direct relationship between ornamentation of rooms with thermal comfort. However colour on walls effect day light levels. It implies that rooms with light coloured walls and ceiling would require lesser windows for natural lighting of a space which would imply reduced heat gain. *Vaastu* prescription is however more justified from social point of view. Since guest rooms received the guests, they were supposed to be ornamented, while other habitable rooms inside the *Haveli*s were supposed to be simple and without much ornamentation. *Shekhawat*i *Haveli*s too had richly ornamented guest rooms while inner rooms were simply painted with white lime. Guest rooms also had many large windows which allowed light, ventilation and heat while inner rooms had smaller and lesser number of windows also for privacy and security. Thus thermal comfort increased with a decrease in ornamentation (which was eventually related to the size and number of openings).

6.3.3 Orientation

As concluded through regression analysis, *Vaastu* prescriptions relating to orientation help in increasing thermal comfort. Following prescriptions are covered under this head-

Prescription - <u>If site is sloping, the slope should be towards E, NE or N. It implies that water from building should be collected towards these directions. And if open area is needed for collection, it should also be in these directions only.</u>

An open area in E, NE and N implies solar radiation in morning when intensity is not very high. Open area towards these directions also implies increased natural ventilation as *Shekhawat*i region receives wind from NE for majority of the year. If the slope of drain is maintained towards these directions, the air entering the building will gain moisture and hence the temperature would be reduced. But it would be significant only if the scale of project is considerably large; for small buildings such as *Shekhawat*i *Haveli*s under study, it would not make much of a difference.

*Shekhawat*i *Haveli*s face either east or west and in very few cases north. Most of the *Haveli*s have open areas towards North, East and North-east which allowed openings in habitable rooms in N, NE and E directions. This facilitated increased natural ventilation thereby increasing thermal comfort.

Prescription- <u>Building should be facing East, North and West in the order of preference while south should be completely prohibited</u>

Buildings in hot dry climate should have longer side facing North-South because East and west sun is most difficult to cut off because of low altitude, solar radiation is not received from north and it can be easily blocked from south by providing small roof projection or projection over opening. Therefore buildings having smaller side facing East/West would remain most comfortable. Most of the *Shekhawat*i *Haveli*s are rect*Angula*r in shape with smaller entrance side facing street and East/West direction. Very few *Haveli*s face north and none is found to be facing south. As a result thermal comfort in *Shekhawat*i *Haveli*s is found to be increasing in preferential order of orientation of building as prescribed in *Vaastu*.

Prescription- <u>Entrance doors should preferably open towards east</u>

In *Shekhawat*i *Haveli*s, entrance door opened into *Pauli* which provided staggered entry to the inner courtyard. Since wind is received from NE direction in *Shekhawat*i, entrance door in East would imply forced ventilation which would help in cooling the inner courtyard which in turn draws warm air from surrounding rooms. This helped in achieving Thermal comfort. Therefore *Shekhawat*i *Haveli*s which have entrance door facing East remained more comfortable.

6.3.4 Landscape

Prescription - Trees are not prescribed to be planted inside the building; Thorny, milk bearing and fruit bearing trees are not to be planted around the building; Yellow colored flowering trees and plants should not be planted around building; Huge trees like Peepal, Bargad, Fig and Kapittha should be planted around the building.

Regression analysis reveals that *Vaastu* prescriptions relating to Landscape do not affect thermal comfort in *Shekhawat*i *Haveli*s significantly. From theoretical understanding, it is evident that plantation of shady trees (similar to the trees prescribed in *Vaastu* such as Peepal, Bargad, Fig and Kapittha) outside the building helps in reducing the heat gain of building. Plantation of trees inside is prohibited because it would reduce the light levels in courtyard and defeat the purpose of providing central courtyard (diffused lighting and natural ventilation). Thorny, milk bearing and fruit bearing trees and trees bearing yellow flowers are also prohibited. Such qualities of trees cannot be directly related to thermal comfort. However since most of the *Shekhawat*i *Haveli*s do not have trees around them, thermal effect of trees has not been reported properly.

6.3.5 Construction

Most of the *Shekhawat*i *Haveli*s have same construction technique and materials resulting in same score under this head. Regression analysis results in a meaningful relationship only when a variation in score is reported which is not the case here. Hence *Vaastu* prescriptions related to construction have resulted in an insignificant relationship with PUHos. However theoretical understanding of subject suggests that construction techniques and materials would significantly affect thermal comfort in buildings. Each *Vaastu* prescription covered under this head is analyzed to understand its effect on thermal comfort.

Prescription- **<u>There should not be any common walls/ columns or any other structural member between two buildings.</u>**

This *Vaastu* prescription effects thermal comfort both favorably and adversely. While common wall reduces the exposed surface area of the building, it also reduces the air movement in spaces around the courtyard. Reduction in exposed surface area helps in cutting off solar radiation thereby increasing thermal comfort while reduction in air movement increases thermal discomfort. Very few *Shekhawat*i *Havel*is have common walls/columns and they remain shaded from outside through provision of *Chajja*s and *Jharokhas*, which reduces the exposed surface area of walls without compromising on air movement. Therefore this *Vaastu* prescription would not affect thermal comfort in *Shekhawat*i *Havel*is where projections have been provided.

Prescription- **<u>Square columns should be used in the residential buildings; Plaster should be even on all surfaces.</u>**

Shape of columns and evenness of plaster has no effect on thermal comfort.

Prescription- **<u>Stone should be avoided in residences. But it can be used in external walls, foundation and column base.</u>**

Stone has high heat capacity and it increases thermal mass in buildings. It helps to increase time lag and decrease heat transfer. Also because of limitations of construction techniques, stone walls are thicker thereby increasing the thermal mass in comparison to brick walls. But stone has been prohibited for residential use and it has been religiously followed in all *Shekhawat*i *Havel*is. Therefore this *Vaastu* prescription has a negative effect on thermal comfort.

Prescription- **Mortar should be strong enough to bind bricks together.**

Strength of mortar has no significance from thermal comfort point of view. However the strength of mortar is an outcome of composition of lime mortar and its thickness. Thus this *Vaastu* prescription effectively addresses these two aspects of lime mortar. Lime mortar absorbs moisture and remains cooler in summers resulting in increased thermal comfort. Increased thickness of mortar implies more cooling and thermal comfort. All *Shekhawat*i *Havel*is have used good quality of lime mortar laid as thick as brick which results in increased thermal comfort. However, since all *Shekhawat*i *Havel*is use similar mortar composition, the variation in the score has not been reported resulting in insignificant relationship with thermal comfort.

Prescription- **Walls should be thicker at base and should go on decreasing with height.**

Thickness of walls has a direct impact on thermal comfort as it increases thermal mass and reduces heat gain but variation in wall thickness with height of building cannot be related to thermal comfort. It has an impact on stability of structure more than thermal comfort. This prescription has been followed in all *Shekhawat*i *Havel*is but it doesn't result in a significant relationship with PUHos due to lack of variation in score.

6.3.6 Spatial Planning

Vaastu prescribes arrangement of habitable spaces in specific orientations as shown below-

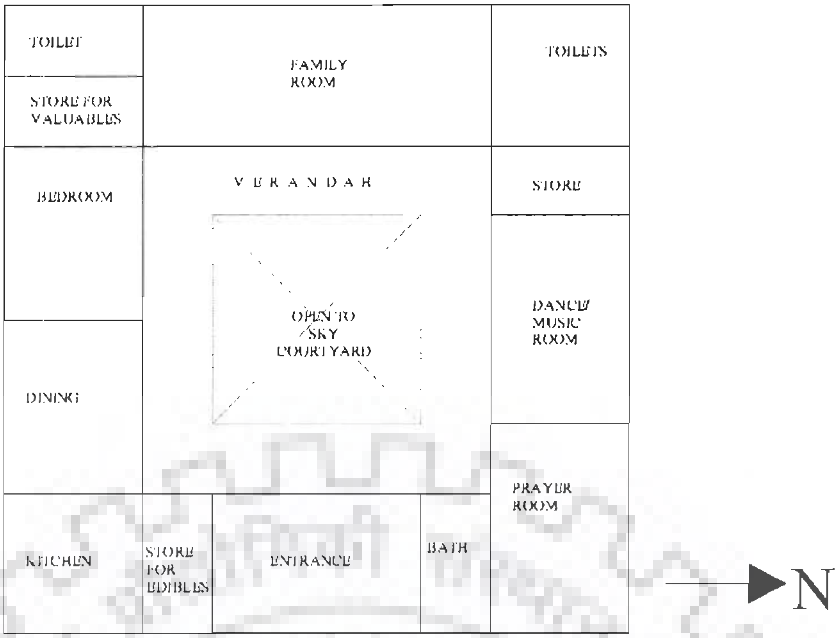

Figure 6.3.6 Arrangement of spaces as per *Vaastu*

As per *Vaastu*, spaces have been arranged as per the time of their use so that each space receives daylight at the time it is desired thereby reducing the energy requirement for lighting. However it has negligible effect on thermal comfort. It is because spaces enclosed by same construction will have same time when the peak temperature will be gained. The change in this pattern is brought by arrangement of openings which affects the air movement and in turn thermal comfort. Orientation would play a significant role if direct radiation is received. However in case of *Shekhawat*i *Haveli*s where walls remain shaded by projections and direct radiation is not received, orientation of spaces has little meaning. As a result, spatial planning is not found to have a significant effect on PUHos.

6.3.7 Openings

Prescription- **Larger buildings should have larger doors; Entrance door should be the largest door in a building; Doors on the upper floors should be smaller in size than the doors on lower floors.**

Openings have a significant effect on thermal comfort but *Vaastu* prescriptions do not affect thermal comfort significantly. The prescriptions regarding openings relate more to the proportioning of openings according to building height which doesn't relate to heat gain. However in *Shekhawat*i *Havel*is, openings have been provided wisely as per the physiological requirement of the climate. *Shekhawat*i *Havel*is have small openings provided with thick wooden shutters and projections which provide shade. This helps in cutting off direct radiation falling over windows hence enhancing thermal comfort. But no significant relation could be drawn on the basis of scores obtained by *Shekhawat*i *Havel*is against *Vaastu* prescriptions regarding openings.

6.3.8 Height/Storeys

Prescription- Residential buildings should not have more than 3 floors; Height of upper floors should be less than lower floors.

Height of floor significantly affects thermal comfort. Higher ceiling heights imply more air volume. It doesn't impact the heat gained by the building but more air volume implies more heat is required to increase the temperature. Therefore higher ceilings imply increased thermal comfort in hot-dry climate which is not prescribed in *Vaastu*. Hence *Vaastu* prescriptions regarding height of floors do not affect thermal comfort significantly.

More number of storeys also helps in reducing the heat gain by reducing the surface area of the building. *Vaastu* limits the number of storeys in residential buildings to three. It has been prescribed for structural stability in view of the prevalent construction system in those times. More number of storeys would have helped in bringing down the heat gain. Both the prescriptions under this head have been followed uniformly in all *Shekhawat*i *Havel*is resulting in same score. Consequently relationship could not be established.

6.4 EFFECT OF PASSIVE DESIGN PARAMETERS ON PUHOS

From analysis of *Vaastu* prescriptions in previous chapter, it is evident that most of the *Vaastu* prescriptions conform to passive design strategies. Therefore, after analyzing the effect of individual prescription of *Vaastu* on PUHos, it is important to analyze the effect of significant passive design strategies (employed in *Shekhawat*i *Haveli*s) on PUHos.

Significant passive design strategies are identified as follows-

Width to height ratio of courtyard (W/H) – Width to height ratio of courtyard determines the heat gain to the building[31] (Figure 6.4.1). It is an important parameter because courtyard is the most important climate regulating factor in buildings in hot dry climate and higher W/H allows direct solar radiation for a longer duration as the surrounding mass does not shade all of the wall area in courtyard. Therefore overall heat gain will increase with an increase in W/H.

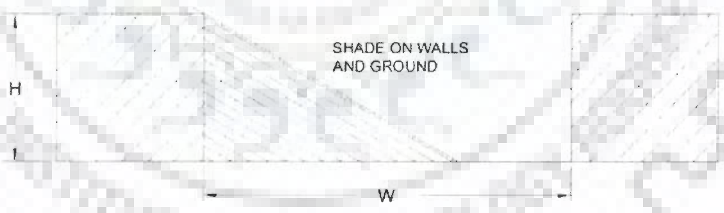

Figure 6.4.1 Increase in W/H increases heat gained by walls surrounding courtyard

i. Percentage of width of courtyard to total width of the building – Width of courtyard as a percentage total width of the building determines the surface area

[31] A S Muhaisen and M B Gadi, Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate in Rome, Building and Environment, 41 (2006), pp. 245-253

of walls in the courtyard. Courtyard walls are beneficial for the structure as they usually remain shaded if the W/H is optimum while re-radiate the heat during night and help in cooling the structure. However, if the courtyard is too wide, it would allow greater amount of solar penetration and the walls would start gaining heat. Hence an optimum percentage of width of courtyard has to be maintained.

ii. Total Window to Wall Ratio (WWR) in percentage – Increase in WWR would imply increased heat gain. It is because windows permit more heat inside the building as compared to walls and heavy thermal mass. As per the research studies, WWR as low as 20% is sufficient for buildings in hot dry climates. However for visual comfort, at least 30% WWR is needed. But an increase in WWR would increase the heat gain of the building thereby reducing the comfort.

iii. Total exposed surface area upon ground floor area – Total exposed surface area upon ground floor area is a measure of the exposure of building to external environment[32]. An increase in this value implies increased heat gain.

iv. Number of storeys – More number of storeys reduces the exposed surface area of roof as the roof of lower floor is used as floor for the upper floor thereby reducing heat gain. (Figure 6.4.2)

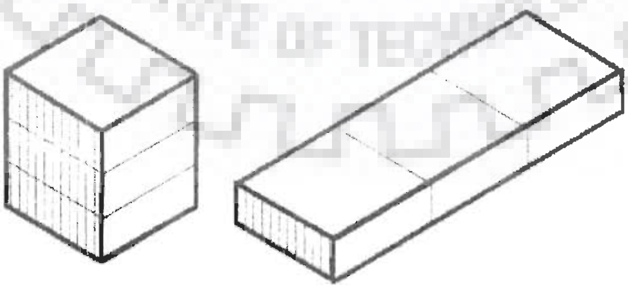

Figure 6.4.2 Increase in number of storeys reduces exposed surface area

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[32] S Sahu, Solar heat gain to buildings, A+D, November 2006, pp 120-129

v. Number of open sides around the building – In hot dry climates, compact planning is preferred. Buildings with common walls are preferred as it reduces the exposed surface area of walls. However if the walls are properly shaded, more open area would mean greater surface area reradiating during night. In case of *Shekhawat*i *Haveli*s, all the walls are shaded by using *Chajja*s and *Jharokhas*. Therefore more sides open to outside would mean increased comfort level.

For analyzing the effect of above stated parameters on PUHos, actual scores are calculated for *Shekhawat*i *Haveli*s under study and represented in a tabular format as shown in table 6.4.1. Regression analysis is then carried out to find out correlation coefficients between these parameters and PUHos.

Table 6.4.1 Table showing calculated values of all passive design parameters and PUHos for the cases under study

Case study	width to height ratio of courtyard	percent of width of courtyard to total width of building	total WWR in percent	surface area upon ground floor area	single storied/ double storied	number of open sides around	PUHos
Babulalji	2.1	44	9.99	2.19	2	4	6.3
Bhagirathmal	1.5	66.58	13.80	3.81	2	4	34.29
Bissau	2.9	52.05	14.74	1.66	1	4	42.86
Chiranjilalji	0.4	39.1	12.73	5.50	2	4	9.14
Harsukhrai	2.3/1.2	59.6	16.98	2.31	2	2	2.86
Damodar	2.3	60	20.06	1.97	1	3	10.86
Gym_Dundlod	1.1	42.9	14.15	2.82	2	3	17.14
ArjunDas	1.2	44.9	14.46	2.71	2	4	12.57
Gulabrai	1.2	43.4	20.11	3.05	2	4	5.71
Harkarandas	2.1/1.12	44.9	15.97	2.45	2	4	11.43
Ishwardas	2.3	48.2	16.23	1.62	1	4	26.86
Jaigopal	1.04	61.2	15.98	4.31	2	4	16

Table 6.4.1 Continued							
Kariwala	1.1	43.77	16.79	2.63	2	4	9.14
Morarka	1.2	42.9	16.50	2.17	2	4	10.86
Pilani	2.3	58.2	14.95	1.68	1	3	15.43
Ramgarh	1.9	51.7	30.33	0.95	1	1	18.29
Ratannagar	1.2	45.8	15.18	3.21	2	4	34.86
Sahumal	1.08/.52	36.5	17.85	2.15	2	2	17.14
Shekhsaria	1.54	50.76	16.83	2.56	2	3	0
Shridhar	1.8	42.7	16.48	1.84	1	4	41.71
Sidhkaran	2.6	46.9	24.62	1.06	1	2	74.29
Nawalgarh	0.98	59.6	12.12	4.84	2	4	25.71
Surajgarh	1.14	44.5	19.65	1.73	2	2	21.71
Virdichand	2.17/1.08	43.7	16.54	2.23	2	4	13.14
Vishwanath	0.97	52.3	15.49	3.75	2	4	2.29

When correlation coefficient is calculated between these quantities, following values are obtained as shown in table 6.4.2.

Table 6.4.2 Table showing Correlation Coefficients for relationship between Passive Design Parameters and PUHos

	width to height ratio of courtyard	percent of width of courtyard to total width of building	total WWR in percent	surface area upon ground floor area	single storied/ double storied	number of open sides around	percentage of summer uncomfortable hours
width to height ratio of courtyard	1.00						
percent of width of courtyard to total width of building	0.26	1.00					
total WWR in percent	0.24	-0.02	1.00				
surface area upon ground floor area	**-0.72**	0.16	**-0.56**	1.00			
single storied/ double storied	**-0.68**	-0.19	-0.45	**0.61**	1.00		
number of open sides around	-0.25	-0.07	**-0.75**	**0.53**	0.31	1.00	
percentage of summer uncomfortable hours	0.37	0.04	0.24	-0.28	**-0.53**	-0.12	1.00

From the correlation coefficients obtained in table 6.4.2, it is evident that amongst these six passive design parameters, PUHos is most significantly affected by number of storeys. More is the number of storeys; less is the number of uncomfortable hours inside a building. The result established is perfectly in line with the scientific understanding. Other parameters do not have a significant value of correlation coefficient to establish the relationship of PUHos with passive design parameters under study. However the nature of relationship can be determined with the positive and negative value of correlation coefficient calculated which concludes the following-

f. An increase in W/H implies an increase in PUHos

g. An increase in percentage of width of courtyard to total width of the building implies an increase in PUHos

h. Increase in WWR implies increase in PUHos

i. Increase in Surface area upon Ground floor area implies decrease in PUhos

j. Increase in number of open sides around the building implies an increase in PUHos

All the above findings are exactly in line with the scientific understanding. Because of lesser number of cases under study, the coefficients calculated do not have minimum level of significance. However the nature of effect has been established. From the values obtained above, a significant conclusion can be drawn as follows-

General understanding of passive design parameters in hot-dry climate is that buildings should be planned in a compact manner so that there is less space between buildings (to furnish mutual shading). However if the walls are properly shaded with the help of *Chajja* projections and *Jharokhas*, it adds to night time cooling without gaining much heat during the day as direct sun is cut off. Hence buildings can be planned with more surface area without increasing the heat gain.

This concept has worked well in *Shekhawati Havelis*. Therefore for the buildings which have more wall area exposed to outside, care should be taken to provide projections and shades over the walls and windows to cut off the direct radiation.

6.5 ANALYSIS OF ORIENTATION OF COVERED AND SEMI-COVERED ROOMS ON PUHOS

When whole building simulation was carried out for all the cases under study, results were recorded for all habitable spaces. Hourly temperature data was obtained for these spaces and TSI was calculated to determine the PUHos for each space. This data was used to compare the thermal comfort performance of covered and semi covered spaces in different orientations. However the comparative analysis carried out in this section is specifically applied to the spatial arrangement followed in *Shekhawati Havelis* only and generalization of spatial arrangement cannot be done based upon these findings.

PUHos was listed for covered and semi covered habitable spaces in each direction. In cases where a covered or semi covered space was not present in a certain direction, it was left blank. The total number of PUHos was calculated for covered and semi covered space for each direction. It was then divided by the number of cases in which habitable space was present to calculate the average PUHos for each type of space in each orientation. Rank was allotted in the increasing order of average PUHos obtained. (Table 6.5.1) Rank 1 (one) implies that the space remains comfortable for maximum duration in summers.

Table 6.5.1 Table showing number of uncomfortable hours in summer for habitable spaces in each orientation

Orientation	N		E		S		W		NE		SE		SW		NW	
Case study	Covered (C)	Semi Covered (SC)	(C)	(SC)	(C)	(SC)	(C)	(SC)	(C)	(SC)	(C)	(SC)	(C)	(SC)	(C)	(SC)
Babulalji	66.3	109.1	77.1		29.7	101.1	94.3	252.0	66.3		61.7		37.7		69.1	
Bhagirathmal		111.4	89.7	253.1	54.3	93.1	79.4		66.9		58.3				52.6	
Bissau	105.1		174.9	133.1	106.3		144.6			188.0		198.3		96.6		88
Chiranjilalji	9.1			95.4		49.1	21.7		16.6				12.6			
Harsukhrai		44.6	18.3	166.3		49.1	98.3		2.9		3.4		13.7		10.9	
Damodar		126.3	35.4			98.3	39.4	62.9	24.6		14.3		30.9		38.9	
Gym_Dundlod	17.7	101.7	37.1		20.6	100.0		288.6	20.0		25.7		80.6		48.6	
ArjunDas	32.6	110.3	80.6	131.4	20.0	85.7	78.3		37.1		33.7		58.9			
Gulabrai	9.1	101.1	86.9		17.1	138.3	35.4	208.6	34.9		42.9		15.4		10.9	
Harkarandas	12	110.3		324.0	30.9	106.3	54.9		21.1		36.0		20.6		15.4	
Ishwardas	67.4	174.9	96.0	140.6	43.4	169.7	39.4		172.0		151.4		33.7		59.4	
Jaigopal		223.4	126.9			129.7	125.7	290.9			44.0		51.4		65.1	
Kariwala	14.9	96.6	24.0	121.7	10.9	82.9	100.0		21.1		40.6		-		35.4	
Morarka	14.3		20.6	279.4	13.1	80.6	61.1	295.4	14.3		14.9		29.7		15.4	
Pilani	29.7	126.3	76.0	111.4	24.0	117.7	70.9						45.1		21.7	
Ramgarh	21.1		24.6	80.0	21.1		64.0		27.4				69.1		26.9	
Ratannagar	50.9		176.6	410.3	64.0	153.1	206.3	394.9	37.7		77.1		152.6		84.0	
Sahumal			22.3			142.9		74.9	42.3		21.1		22.9		59.4	
Shekhsaria	0	5.7	12.0			2.9	0	112	0		0		0		0	
Shridhar		44.6	130.9			42.9	120.6	181.1	42.3		43.4		104.6		98.3	

Sidhkaran	88	218.9	217.1	466.3	110.3	199.4	169.1		112.0		112.6		137.1		90.3	
Nawalgarh	52	141.1	88.0		51.4	138.9	77.7	240.6	69.7		69.1		61.1		64.0	
Surajgarh	37.1	146.3	154.9	465.7	36.6	142.9	202.3		28.0		36.0		43.4		48.0	
Virdichand	13.7		56.6	330.3	48.0	85.7		267.4	55.4		38.3				60.6	
Vishwanath																
TOTAL	641.1	1992.6	1826.3	3509.1	701.7	2310.3	1883.4	2669.1	912.6	188.0	924.6	198.3	1021.1	96.6	974.9	88.0
NO. OF ENTRIES	18	17	22	15	17	22	21	12	21	1	20	1	20	1	21	1
AVERAGE	35.6	117.2	83.0	233.9	41.3	105.0	89.7	222.4	43.5		46.2		51.1		46.4	
RANK	**1**	**10**	**7**	**12**	**2**	**9**	**8**	**11**	**3**		**4**		**6**		**5**	

From table 6.5.1, the covered and semi-covered spaces can be arranged in the decreasing order of comfort as following-

Covered areas in North
Covered areas in South
Covered areas in North East
Covered areas in South East
Covered areas in North West
Covered areas in South West
Covered areas in East
Covered areas in West
Semi Covered areas in South
Semi Covered areas in North
Semi Covered areas in West
Semi Covered areas in East

It is clear that covered areas remain more comfortable as compared to semi-covered areas. Amongst covered areas, the orientation receiving minimum amount of radiation remain most comfortable which is north. The result is reliable because the typical spatial plan of *Shekhawat*i *Havel*is has semi open areas arranged towards the courtyard and covered spaces arranged on outside. Therefore covered spaces receive radiation only from the direction to which they are open on the outside. Since north receives minimum amount of radiation, covered spaces in north remain most comfortable. On south, walls of building are easily shaded through the use of small projections; hence the direct radiation is cut off. However east and west sun is difficult to be cut off because of low altitude resulting in covered spaces in east and west receiving more heat and remaining comparatively less comfortable.

As compared to covered spaces, semi covered spaces received direct sun. But since the semi-covered spaces opened towards courtyard, the direction from which the sun is received is opposite to that in which the spaces are located. It means a space located in north would receive sun from south. Hence spaces in the direction opposite to the direction from which maximum sun in received would remain most uncomfortable. This is clear from the typical plan of *Shekhawati Havelis*. (Figure 6.5.1)

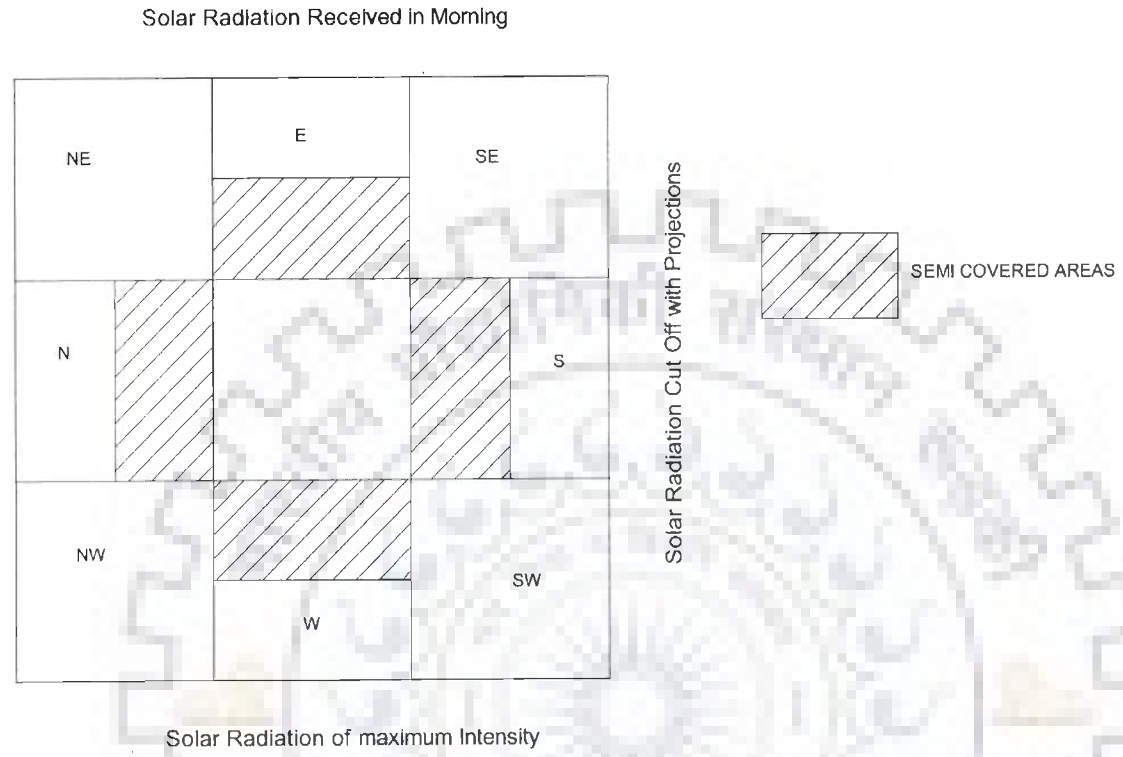

Figure 6.5.1 Typical arrangement of spaces in *Shekhawati Havelis*

It should be aptly noted here that walls in *Shekhawati Havelis* were heavy and built of bricks laid in lime mortar. The construction provided the desired time lag and reduced the heat transferred to inside. Hence in the morning, when outside environment is comfortable, semi covered spaces remained at the same temperature as outside and remained more comfortable than covered spaces. But during day when it is uncomfortable outside in summers, covered spaces remained cooler and more comfortable.

If hourly temperature profile of all habitable spaces is analysed it is found that some or the other space (covered or semi covered) remains comfortable throughout the day. Though night time has also been considered for comfort calculations, occupants generally spent their nights outside on terraces. It was because at night, the environment outside becomes comfortable while spaces inside are at much higher temperature than outside.

6.6 ANALYSIS OF HOURLY TEMPERATURE PROFILE OF HABITABLE SPACES

With the help of whole building simulation tool, *Shekhawat*i *Haveli*s under study were simulated to calculate hourly temperatures in habitable spaces. Using the generated temperatures, hourly TSI was calculated which was then plotted for all habitable spaces in each case along with the outside TSI to analyze the effect of structure on temperature (Appendix 10) . From the charts thus prepared following observations were recorded in general for all the cases-

1. The outside diurnal range of 13°C in summers and 14°C in winters was reduced to 4-5°C. The limits of diurnal range increase and decrease depending upon the season. On extreme hot days in summers the diurnal range is brought down to 32-36°C from 32-42°C. In winters from 5-19°C it is brought up to 12-17°C. Reduction in diurnal range makes it easy for occupants to adapt to the changes as the temperature doesn't vary much during the day.
2. The extreme temperature in summers is reduced by 5-6°C but the minimum temperature doesn't reduce further. It is because of the time lag. The structure gains heat during the day but due to heavy thermal the heat is not transferred to inside. Therefore the temperature inside remains low. The rise in the temperature is primarily due to convection which takes place due to natural ventilation. However during night when the temperature outside reduces, the structure begins to cool from outside while reradiating the heat towards inside. At the same time, the cool air also enters into the rooms. The balance allows the temperature of the rooms to remain at almost the same temperature as during the evenings. Hence the

minimum temperature does not rise. In cases where ventilation is optimum the minimum temperature still remains the same but the maximum temperature limit is further brought down. It happens because of the night time cooling. The structure gets properly cooled during the night. Hence during the day when structure begins to get heated, the maximum limit of heat capacity is reached quite late in the day almost at a time when outside temperature begins to fall.

3. Time of maximum and minimum temperatures inside the rooms almost coincides with the maximum and minimum temperatures outside. The time lag is visible in overall heating and cooling of structure but not in maximum and minimum temperatures. It is primarily because of the natural ventilation rate and loosely sealed structure. The convection rates nullify the effect of time lag created due to structural cooling and heating.

4. The above mentioned characteristics of interior spaces in *Shekhawat*i *Haveli*s vary depending upon the layout and design of individual room. It depends upon direct heat gain and rate of air movement. Semi-covered spaces which face west and south receive more radiation as compared to other spaces. Therefore the maximum temperature in these spaces is almost the same as on outside. However covered spaces which remain surrounded from all sides remain at much lower temperature as compared to outside. Similarly in winters during day, semi covered spaces remain almost at outside temperature because of higher rates of ventilation and direct radiation. In winter nights, covered spaces remain at much higher temperature as compared to outside temperatures because of reduced ventilation rates and reradiation from structure.

5. Summer diurnal range of 26-36TSI is reduced to 30-33 TSI. In winters, the extreme diurnal range of 3-16 TSI is increased to 11-16 TSI. The lower limit is

significantly increased while the upper limit of thermal comfort is not affected in winters. Hence it can be concluded that the diurnal range of thermal comfort is reduced to a narrow band which makes it easier for occupants to adapt to climatic changes.

6.7 INFERENCES

From the analysis of *Shekhawat*i *Haveli*s, it is clear that thermal comfort achieved in these *Haveli*s is affected by *Vaastu* prescriptions and passive design parameters both. However some of the passive design strategies are incorporated in *Vaastu* prescriptions while some are not.

The relationship established between PUHos and *Vaastu* score reveals that the two are interrelated. Greater adherence to *Vaastu* prescriptions implies increases thermal comfort in *Shekhawat*i *Haveli*s in summers. However, thermal comfort in winters decreases with an increase in PUHos. If statistics for whole year are concerned, *Vaastu* prescriptions result in more number of uncomfortable hours.

When individual *Vaastu* prescriptions were analyzed, it was found that prescriptions related to Courtyard, Building elements and Orientation affect the thermal comfort in summers quite significantly. Other prescriptions relating to landscape, construction, spatial planning, openings and height/storeys do not have significant impact on thermal comfort in winters.

Analysis of selected passive design parameters exposes that thermal comfort achieved in *Shekhawat*i *Haveli*s is directly related to passive design parameters. Since the number of cases under study was less to determine the significance of relationship, only nature of relationship could be established. It revealed that thermal comfort in *Shekhawat*i *Haveli*s is most dependant upon number of storeys. Other parameters taken into account i.e. W/H, percentage of width of courtyard to total width of the building, WWR, Total exposed surface area upon ground floor area, Number of storeys and number of open sides around the building, do not effect thermal comfort significantly.

Analysis of habitable spaces in *Shekhawat*i *Haveli*s reveals that in summers covered areas remain more comfortable than semi covered areas during daytime while semi covered areas remain more comfortable during night. In winters, semi covered areas remain more comfortable during day and covered areas during night. If orientation is considered, covered areas in north are most comfortable. On the contrary, semi covered areas in south remain most comfortable.

Analysis of hourly temperature profile of habitable spaces in *Shekhawat*i *Haveli*s reveals that *Vaastu* prescriptions and Passive design features bring about considerable change to thermal comfort in *Shekhawat*i *Haveli*s. Diurnal range is considerably reduced which makes adaptation much easier to the occupants. Yet time lag has not been reported which was otherwise expected in *Shekhawat*i *Haveli*s as these employ construction system resulting in high thermal mass. Infact occurrence of maximum and minimum temperature inside and outside is reported at the same time.

Thus it can be said that *Vastushastra* and passive design parameters significantly affect thermal comfort in *Shekhawat*i *Haveli*s. Greater adherence to both these principles would result in climate responsive architecture.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 OVERVIEW

From the analysis of results, it is concluded that "**There exists a positive relationship between *Vaastu* score and thermal comfort in residential buildings. In other words, residential buildings designed as per *Vaastu* require lesser energy to create thermal comfort.**" However, the conclusion stated above should not be interpreted in isolation. It should be comprehended when accompanied with a series of conclusions as follows.

7.2 CONCLUSIONS

- When regression analysis is carried out with 'Percentage of uncomfortable hours in summers inside the building against total number of uncomfortable hours in summers outside' (PUHos) and *Vaastu* score, it is found that buildings having higher *Vaastu* score i.e. complying to more *Vaastu* principles have lesser number of uncomfortable hours inside the building. Thus the buildings having higher *Vaastu* score remain comfortable for greater time and require lesser amount of energy for achieving thermal comfort inside the building. (Fig 7.2.1)
- After analysis, correlation coefficient is also calculated between PUHos and *Vaastu* Score and it establishes that a linear relationship. For the cases under study, linear, polynomial and logarithmic relationships were analyzed and R value of 0.6301, 0.6534 and 0.6399 was obtained respectively (Equation 7.2.1,7.2.2 and 7.2.3). Correlation coefficients obtained through all relationships fall within the same range. This proves that linear relationship can describe the relationship between PUHos and *Vaastu* score for *Shekhawat*i *Haveli*s. (Fig 7.2)

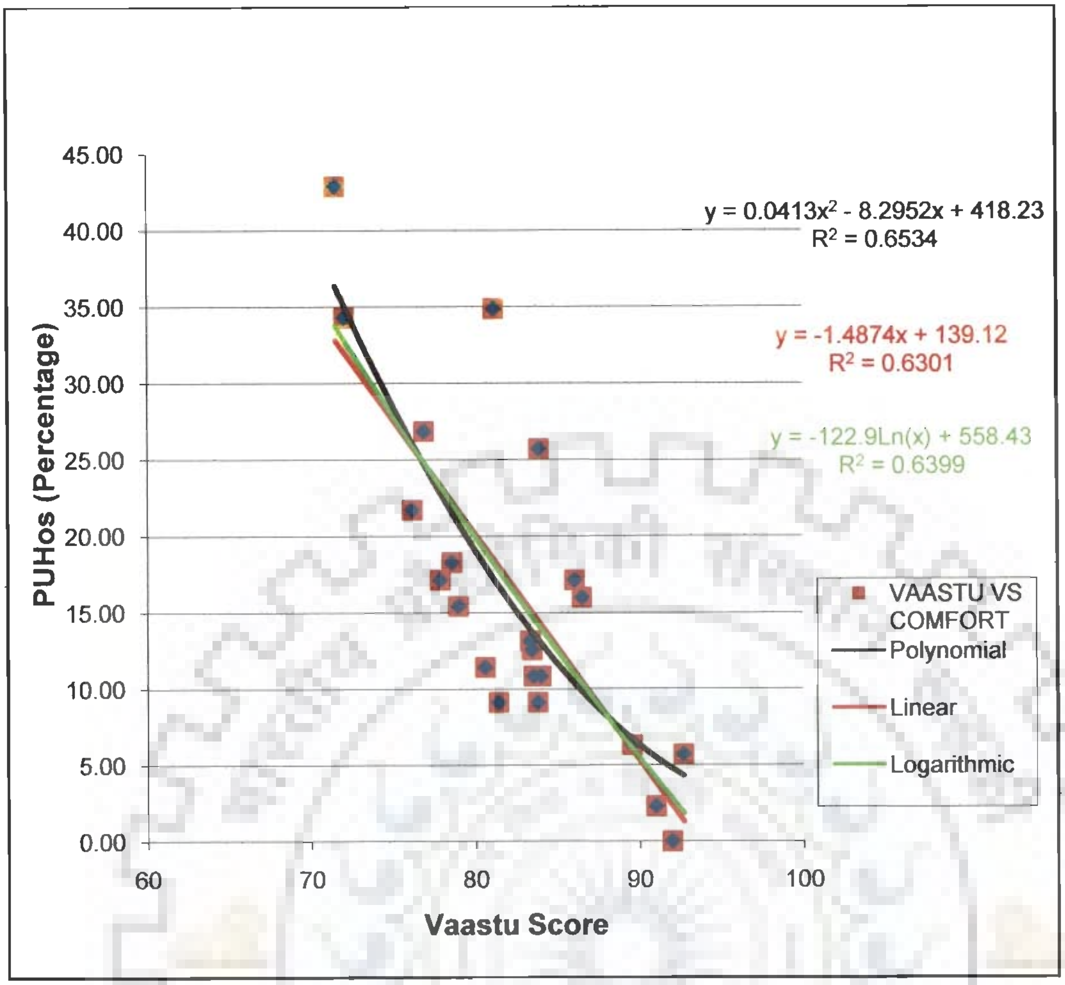

Figure 7.2.1 Graph Showing Correlation between *Vaastu* Score and PUHos

The equations and value of Correlation Coefficient obtained for different relationship types for the given data are as follows.

1. **Polynomial relation of the order two**

$y = 0.0413x^2 - 8.295x + 418.23$ (Equation 7.2.1)

$R^2 = 0.6534$

2. **Linear relation**

$y = -1.4874x + 139.12$ (Equation 7.2.2)

$R^2 = 0.6301$

3. Logarithmic relationship

$$y = -122.9Ln(x) + 558.43 \qquad \text{(Equation 7.2.3)}$$

$$R^2 = 0.6399$$

- Total *Vaastu* prescriptions were categorized under six heads - courtyard, orientation, landscape, buildings elements, construction and spatial planning.

Table 7.2.1 Table Showing Unstandardized Correlation Coefficient Values for Different Heads of *Vaastu* Prescriptions

Independent Variable (Heads of Vaastu Prescriptions)	*Unstandardized Correlation Coefficient*	*Significance of relationship*
Courtyard	-10.488**	Significant at 5%; negative
Orientation	-2.473**	Significant at 5%; negative
Landscape	-7.198	Not significant
Building Elements	-4.078***	Significant at 1%; negative
Construction	-.765	Not significant
Spatial planning	.409	Not significant
R^2	.593	Moderate
F	4.369***	Significant at 1%
(Constant)	184.120	
*** 1% level, ** 5% level, * 10% level		
Dependant Variable is PUHos		

Score for each head was calculated as a total of scores earned for all prescriptions under the respective head. Regression analysis was carried out between PUHos as dependant variable and the six heads as independent variables. Table 7.2 shows the values of unstandardized correlation coefficient for different independent variables and the nature of relation interpreted from the obtained value. It is observed that PUHos is more dependant upon courtyard, orientation and building elements; whereas Landscape, construction and spatial planning do not affect the PUHos significantly. The overall relationship between PUHos and independent variables was moderate (Table 7.2.1)

- While carrying out regression analysis, it is noted that the score for 'Construction' for all the cases was almost same. It is because all cases under study had almost same construction materials. This reported a neutral relationship between PUHos and 'Construction'. From theoretical understanding, construction system significantly affects the thermal comfort inside the building. However due to lesser variation in the score of '*Vaastu* prescriptions regarding Construction' of the analyzed cases, the relationship between *Vaastu* score and PUHos could not be established. (Table 7.2.1)
- Courtyard' is found to have a significant negative relationship with PUHos. It covers two principles of *Vaastu* - presence of courtyard in the centre and width of courtyard as a percentage of building width. Since courtyard is present in all cases, the variation in the score of 'Courtyard' is reported because of the change in size of courtyard. Consequently it can be concluded that *Vaastu* prescriptions regarding width of courtyard significantly affect the thermal comfort inside the building. (Table 7.2.1)
- Building elements' have a significant relationship with PUHos. Total nine prescriptions of *Vaastu* related to building elements, i.e. presence and width of *Chajja*s, apron around the building, width of apron, height of platform built over apron, distance of surrounding buildings, plinth, presence of *Jharokhas* and ornamentation of walls were covered under this head. The score under this head for each case was different as all the prescriptions were not followed in all cases. As a result a clear relationship was obtained. It shows that in cases where *Vaastu* prescriptions related to building elements have been followed, PUHos is less. This

concludes that *Vaastu* prescriptions regarding building elements affect thermal comfort inside the building significantly. (Table 7.2.1)

- Orientation significantly determines the PUHos which is also expected from theoretical understanding of climatology. Orientation of building, open areas around the building and entrance, all play an important role. *Shekhawat*i *Haveli*s are rect*Angula*r in shape. While comparing orientations of rect*Angula*r buildings, buildings having shorter side facing east/west gain lesser amount of heat as compared to buildings having shorter side facing South/North. Since most of the *Haveli*s in *Shekhawat*i face East/West, the heat gain is lesser. *Vaastu* also prescribes east as the best orientation for buildings. This implied that *Vaastu* prescription related to orientation of building is in line with climatic requirements. Regression analysis also establishes that *Vaastu* prescriptions regarding orientation affect the comfort inside the building significantly. (Table 7.2.1)
- From understanding of climatology, it is realized that presence of shady trees around the building contributes significantly to the comfort. Though *Vaastu* prohibits planting of trees inside the building, trees are allowed to be planted around the building. However since *Shekhawat*i is a dry region, growing trees is difficult. Variation in score under the head of landscape is hence not reported properly. It is also observed that *Vaastu* permits plantation of limited varieties of trees. Therefore relationship between *Vaastu* prescriptions relating to Landscape and PUHos establishes an insignificant relationship. (Table 7.2.1)
- Presently *Vaastu* has become synonymous with the spatial arrangement of spaces only. Scientifically spatial arrangement inside a building helps in adjusting the time at which solar radiation is received in a space. Spaces can be arranged to allow natural light and heat in a particular room when it is needed depending upon

the activity and use. Spatial arrangement affects the time at which maximum heating is received in a space depending upon the time and duration of exposure to direct solar radiation. However in case the structure remains shaded due to surrounding buildings, trees or building elements, most of the heat is gained due to convection because of air movement. In such a case spatial arrangement inside the building will not play a significant role as has been analyzed for *Shekhawat*i *Havel*is. *Vaastu* parameters relating to spatial planning do not contribute to thermal comfort in a significantly (Table 7.2.1). It is because of following features in *Shekhawat*i *Havel*is-

1. All spaces open towards inside courtyard as well as outside. This allows ventilation (even though it is negligible) even during day when windows on outside walls are closed. It cuts off the radiation but still facilitates air movement thereby maintaining comfort. Once the radiation is cut, the heat gain takes place through convection only which is independent of orientation.
2. Outside walls remain shaded by *Jharokhas* and *Chajjas*. Thus there is no direct heat gain from outside (emphasizing the above stated reason).
3. Thermal mass of walls and roof is very high in *Shekhawat*i *Havel*is. Whatever little radiation is received on surfaces, considerable amount of heat is absorbed by structure and reradiated during night. At night all the windows are opened and heat is flushed out with air movement.
4. Statistical analysis shows that the results stated above are valid for 95% of the observations. It implies that PUHos can also be calculated for other cases of *Shekhawat*i *Havel*is with 95% accuracy using the relationship equation calculated from regression analysis OR *Vaastu* score of other *Havel*is can be calculated if the PUHos is known for them.(Table 7.2.1)

Apart from *Vaastu* parameters, effect of passive design parameters on PUHos for the same cases under study was also analyzed. From literature study it is evident that there are many parameters which effect thermal comfort inside buildings. These include- shading of building by surrounding buildings, trees and building elements, water bodies, construction etc. However as stated earlier, quantification of all these parameters was not possible within the scope of this work. Therefore only six parameters, which are of significance in *Shekhawat*i *Havel*is and could be quantified for *Shekhawat*i *Havel*is are analyzed. The six parameters which have been quantified for study are-

1. Percentage of width of courtyard to the total width of the building,
2. Width to Height ratio of Courtyard (W/H),
3. Window to Wall Ratio (WWR),
4. Ratio of total surface area of walls (excluding roof area) to ground floor area,
5. Number of storey
6. Number of open sides around the building.

Table 7.2.2 Table Showing Correlation Coefficients between Six Passive Design Parameters under Study and PUHos

	Width To Height Ratio Of Courtyard	*Width Of Courtyard To Total Width Of*	*Total WWR In Percentage*	*Surface Area Upon Ground Floor Area*	*Single Storied/ Double Storied*	*Number Of Open Sides Around*	*Summer Uncomfortable*
Width To Height Ratio Of Courtyard	1.00						
Percentage Width Of Courtyard To Total Width Of Building	0.26	1.00					
Total WWR In Percent	0.24	-0.02	1.00				
Surface Area Upon Ground Floor Area	**-0.72**	0.16	**-0.56**	1.00			

Single Storied/ Double Storied	**-0.68**	-0.19	-0.45	**0.61**	1.00		
Number Of Open Sides Around	-0.25	-0.07	**-0.75**	**0.53**	0.31	1.00	
Percentage Of Summer Uncomfortable Hours (PUHos)	0.37	0.04	0.24	-0.28	**-0.53**	-0.12	1.00

- Statistical analysis was carried to establish the effect of above stated passive design parameters on PUHos. The results indicate that only these six parameters are not sufficient to establish a significant relationship with PUHos. (Table 7.2.2)
- Amongst the six passive parameters analyzed, it is found that PUHos is most significantly related to number of storey. More is the number of floors in a building, less is the PUHos. It is because of reduction in surface area of the building due to placement of one floor on top of other (which reduces the roof area that would otherwise be exposed to sun) thus resulting in lesser heat gain. (Table 7.2.2)
- PUHos is significantly dependant upon Width to Height ratio of Courtyard (W/H), Window to Wall Ratio (WWR) and Total surface area of walls to ground floor area.
- PUHos increases with an increase in W/H. It is because greater width of courtyard in comparison of height would allow more amount of direct radiation reaching the courtyard walls of the building thus increasing the heat gain.
- With an increase in WWR, there was a decrease in PUHos. Scientifically PUHos should increase with an increase in WWR. However after the analysis, it was found that the WWR in all cases under study varies between 10%-30%. This is the optimum range of WWR for hot climates. For this range of WWR, the increase in WWR would improve ventilation during night as the windows were closed during

daytime. This enhances night time cooling of building and brings in thermal comfort.

- With an increase in ratio of total surface area to ground floor area, PUHos is increasing. It is because greater surface area implies higher heat gain. (Table 7.2.2)
- The other two factors; Number of open sides around the building and Percentage width of courtyard to total width of the building, do not affect the PUHos significantly.

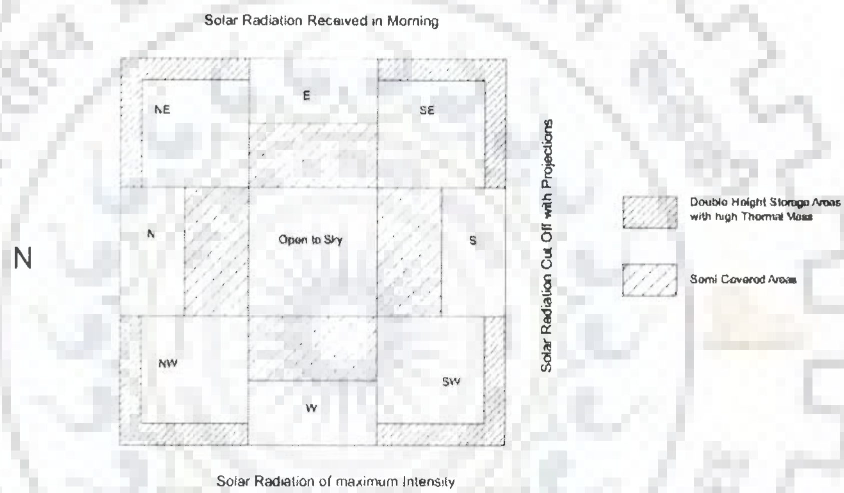

Figure 7.2.2 Figure Showing Typical Arrangement of Spaces in *Haveli*

- Comparative analysis of covered and semi-covered areas in *Haveli*s reveals that covered areas remain more comfortable during afternoons as compared to semi-covered areas. Among various directions, covered areas in North remain most comfortable followed in decreasing order of comfort by South, North East, South East, North West, South West, East and West. It is directly related to the amount of radiation received by these spaces during day. North remains coolest as it doesn't receive solar radiation from any direction. South walls remain shaded because of the presence of roof projections and higher angle of sun. East and West directions receive greater amount of radiation because of lower angle of sun which makes these walls exposed for a greater duration. Spaces in NE, SE, NW and SW remained cooler than East and West because most of these spaces had additional storage areas with high thermal mass as a thermal buffer. (Fig. 7.2.2)

- While analyzing semi-covered areas, it is observed that semi covered areas in South remain most comfortable followed by North, West and East directions. The results seem to be surprising but are valid for *Shekhawat*i *Haveli*s because of their spatial arrangement. The semi covered areas open towards courtyard and receive radiation from the opposite direction. For example a semi-covered area in North will remain covered from North and will receive radiation from South. Hence the results are justified as semi-covered area in South is actually exposed to North, North to South, West to East and East to West. (Fig. 7.2.2)
- From the study of *Vaastu* text, it is evident that the *Vaastu* principles help in bringing thermal comfort inside the residential building. However it is not easy to incorporate the principles in design of contemporary residences. It is because of the difference in socio-economic conditions. Today, individual houses are not affordable. Thus housing complexes are becoming more popular in the form of multistoried apartment, low rise apartments and row houses. In all cases, *Vaastu* prescriptions are difficult to be followed because of the reasons stated below-

i. The land has become a precious commodity thus maximum utilization of space is sought. Choosing orientation and open areas around the building has become a challenge in densely populated cities.

ii. With bye laws becoming more stringent, it leaves one with fewer choices in terms of space articulation so as to incorporate spatial planning according to orientation in small sized plots.

iii. *Vaastu* prescribes limited number of storeys (maximum four) in residential buildings which limits construction and spatial planning. It was also due to limited availability of materials in those times. However vertical development of buildings is now easily possible with structural and material innovations.

iv. Most products have now become standardized right from materials to structural members. With decreasing availability of time to erect a building; variation in height, wall thickness, plinth, door sizes, brick size etc. is practically not feasible. Making a user specific product not only costs higher but also requires much more time as compared to standardized products.

7.3 RECOMMENDATIONS

The following recommendations are based on this study hence these are confined only to the context under study. This includes residential buildings in hot dry climate.

1. The local bye laws must incorporate the climatic requirement of buildings along with fire safety, rain water harvesting and other issues. Flexible bye laws may be adopted to encourage the incorporation of *Vaastu* principles. Courtyard is the most important feature of *Vaastu* and it acts as a climatic regulator also. In hot climates, setbacks may be relaxed if internal courtyard is proposed. Similarly, extra ground coverage or FAR may be made permissible if a courtyard is added to the building.

2. *Vaastu* prescribes thick wall construction. Wherever load bearing structure is possible, we should encourage the use of thicker walls. Frame structure with half brick walls, permits more heat flow. However, thick wall construction increases the land cost as it consumes more space in construction and the additional cost to achieve comfort. But the recurring energy savings for the life time recover the initial investment in very less time. In case of multistoried apartments where

thicker walls would also imply increased dead load, thermal properties of thicker walls can be achieved by adding insulation to thin walls. This would decrease the dead load of structure while reducing the U-value.

3. Roof projections and shade over windows, which are now becoming less popular, must be incorporated in design. They help in shading the walls and windows against heat gain.

4. The buildings analyzed as part of study have not used glass. However in modern buildings, glass has become an integral part. Glass provides a better connectivity with the outdoors but also increases the heat gain of the building. It must be judiciously used in residential buildings in hot dry climates. It should be ensured that the glass doesn't receive direct radiation at any point of the day. This can be achieved with proper design of shading devices which include elements like *Chajja* and *Jharokha*. Moreover with availability of variety of glass types such as insulated glass, multilayered glass, tinted glass etc. and other innovative materials to reduce heat transfer such as films and screens, heat gain through openings can be reduced considerably.

5. For achieving thermal comfort in Hot-dry climate, we tend to reduce the openings which cut off light and ventilation also. But all the spaces in a house must be planned to receive direct sunlight and natural ventilation. This reduces the energy consumption required to provide artificial lighting and ventilation. Ventilation is not only required for health reasons but it also cools down the building as air movement increases thermal comfort.

6. Inhabitable spaces in the house such as toilets and stores should be planned in heat receiving directions such as west and south. It not only satisfies *Vaastu*

requirements but ensures minimum heat gain to the building as these areas act as buffers.

7. Open areas around the building must be landscaped with shady trees. Preferably deciduous trees should be planted in hot dry climates.

8. In multistoried apartments, a central courtyard common to all apartments can be planned instead of individual courtyard. Although it will not ensure equal benefit to all residences because of difference in orientation, but it would reduce the total heat gain.

7.4 SCOPE FOR FURTHER WORK

Every research and specially of this kind, where it has been tried to establish a relationship between the explored and unexplored, quantitative and qualitative, logical and mystical, avenues for further research are many. The study here is not an end but just a beginning and opens up many more possibilities-

1. For the same set of observations, the simulation results can be verified through physical monitoring and recording of the environmental data such as temperature, air velocity and humidity levels inside the *Haveli*s at different locations. It will further strengthen the relationship between *Vaastu* and Comfort.
2. Similar study can be taken up for different climatic zones and *Vaastu* texts prevalent in those regions.
3. To establish the comparative climate responsiveness of different texts prevalent in a region, *Vaastu* scores can be calculated for the same case studies based upon different *Vaastu* texts. Correlation can then be established between different *Vaastu* scores and PUHos.

4. Similar study can also be taken up for royal palaces and forts. Since palaces for kings were the most luxurious buildings and often followed *Vaastu* principles to the maximum (because of the luxury of land availability and resources at hand), it may be an interesting study which will establish the relationship between comfort and *Vaastu* to greater accuracy. This would however require enormous documentation and study.

5. For *Shekhawati* *Haveli*s, a comparative study between *Vaastu*, Comfort and embodied energy can also be taken up. Embodied energy of all the cases can be calculated and its relationship with comfort can be established. This will also determine the sustainability of these *Haveli*s.

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Appendix 1.1

Questionnaire for survey of practicing architects in Delhi and Jaipur.

Questionnaire

This questionnaire is meant purely for the research purpose related to the study of climate and its effect on architecture of various regions. Here the study is focused on the residential projects in Hot-Dry climate. Kindly answer the questions to the best of your knowledge and belief.

Personal details

1. Name of Architect ………………………………………………………

2. Name and address of the firm associated with

………………………………………………………………

………………………………………………………………

3. Age (in years) ……………………………

4. Years in practice ……………………………

5. Duration of holding the current designation ……………………

6. Year of completion of graduation ……………………………

7. Place of a) Birth ……………………………………

b) Bringing up ……………………………………

c) Education (schooling) ……………………

d) Education (Architecture) ……………………

8. Type of house in which spent childhood

a) Plotted

b) Flats / Apartments

c) Row housing

9. Handling projects mainly in which part of country (mention place) …………………

10. Practice area

a) Residential

b) Commercial

c) Institutional

d) Others

11. Percentage (not financially but in numbers) of the residential projects dealt with that of total projects handled

a) < 25%

b) 25-50%

c) 50-75%

d) >75%

Questions related to the subject (Answer the questions for a residential project in a Hot-Dry climate, comparable to or worse than Delhi)

1. Which month is most suitable for starting the construction of a project?..

2. Which type of soil supports most economic stable foundation for a residential building?

a) Clayey
b) Loamy
c) Silty
d) Sandy
e) Rocky

3. Does the unevenness of the plaster on bricks creates problems? Yes / No

4. Does the unevenness in the size of bricks affect construction? Yes / No

5. Which type of Trees/ Plants would you prefer on the site around the house?

a) Ornamental
b) Fruit Bearing
c) Thorny
d) Milk Bearing
e) Shade Giving

6. Would you prefer having a house adjacent to a temple or public building ? Yes / No

7. Which orientation would you prefer for a residence (Arrange in order of priority- first priority first)?

a)
c)
b)
d)

8. The plot should be open to roads on how many sides?

a) 01 (front)
b) 02 (front and back)
c) 02 (front and side)
d) 03 (front and sides)
e) 03 (front, rear and side)
f) 04 (All)

9. Construction and planning are easier in a square plot of a rectangular?

Square/ Rectangular

10. If leaving setbacks was not a mandatory norm, would you still leave setbacks?

Yes/ No

11. If yes, then how many sides (Assuming there is enough space for leaving setbacks)?

a) 01 (front)

b) 02 (front and back)

c) 02 (front and side)

d) 03 (front and sides)

e) 03 (front, rear and side)

f) 04 (All)

12.Do you often provide verandahs and balconies? Yes/ No

13. Do you often provide verandahs and balconies? Yes/ No

14. In which direction should a Verandah and Balcony be provided for comfort?

....

15. What should be the orientation of Staircase?

Clockwise/ Anticlockwise

16. Do you prefer providing courtyard inside the house if space permits?

Yes/ No

17. A combined Latrine-Bathroom is preferable or a detached one?

Combined/ Detached

18. Which areas of your can be designed without natural ventilation and daylight?

....

19. What is the desired duration of direct sunlight and daylight in each of the following areas inside the house? Also mention the preferable time of receiving the direct Sunlight during a day?

Table A-1.1.1Preferred Arrangement of Areas

	irect Sun light	f the day for sunlight	aylight

20. Are basement preferable from climatic point of view? Yes/ No

21. Should stone be used for house construction (leaving apart the economy and space constraint)? Yes/ No

22. The house should be constructed preferably with one/two materials and not more. Do you agree? Yes/ No

23. Should the old material be reused? Yes/ No

Appendix 1.2

Results from survey using above questionnaire.

The survey was conducted with practicing architects having minimum five years experience in practice. A questionnaire was prepared based on the guidelines of Vaastushastra. Since revelation of the actual topic of study could have hampered the actual fact finding, no *Vaastu* jargon was used in order to conduct an unbiased survey. The *Vaastu* principles and concepts were translated into attributes of design criteria and conditions.

The survey was conducted as a schedule. The questionnaires were filled personally by talking to the architects. The architects practicing in two cities- Delhi and Jaipur were chosen for survey. The reasons for choosing the two cities were-

a) Delhi being the national capital and Jaipur being the state capital has ample of architectural opportunities for architects giving them more exposure.

b) Jaipur has a Hot-Semi arid climate while Delhi has a composite climate more towards hot which is comparable to the region in which the text under study was prevalent.

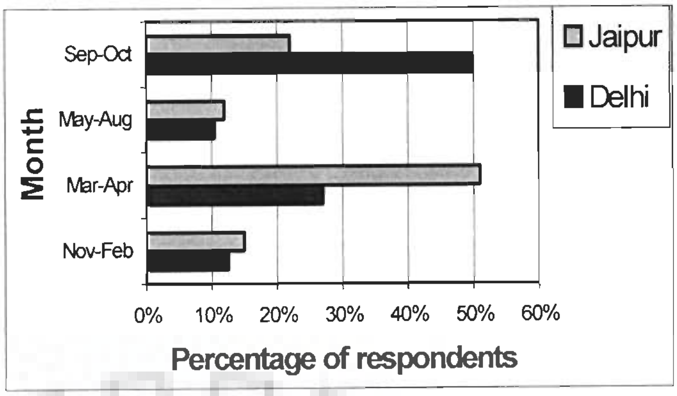
c) Both cities have a different culture because of more service industries in Delhi and Business industries in Jaipur. It was desired to know the variation in the experiences of architects owing to the differences in the cultural and geographical backgrounds of architects and their practice areas.

Of the intended 200 questionnaires in Delhi and 100 in Jaipur, only 97 in Delhi and 59 in Jaipur were collected back. As a result the survey size was reduced from 300 to 156. Overall response rate was 71% with response rate for Delhi being 60% and for Jaipur being 100%. There was not much difference in the educational background of the respondents. However more architects in Delhi spent their childhood in Flatted houses/Apartments and have more years in practice. Architects in Jaipur are more involved in residential design than the architects in Delhi. Since Delhi and Jaipur both have comparable climate except for the humidity levels, no changes were made in the questionnaire. This was also because the *Vaastushastra* prescriptions do not vary for Delhi as well as Jaipur.

<u>Results obtained</u>

The questions were arranged in the same order in which the guidelines were presented in the main text of reference- *Rajvallabhmandanam.*(RVM)

Q 1. Most architects in Delhi preferred September-October for start of construction because beginning in March-April created problems of drying in summers. (Fig A-1.2.1)However architects in Jaipur preferred to start in March-



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April as they felt that the structure receives first rain in monsoon, which makes it stronger.

Figure A-1.2.1 Preferred Month ofConstruction

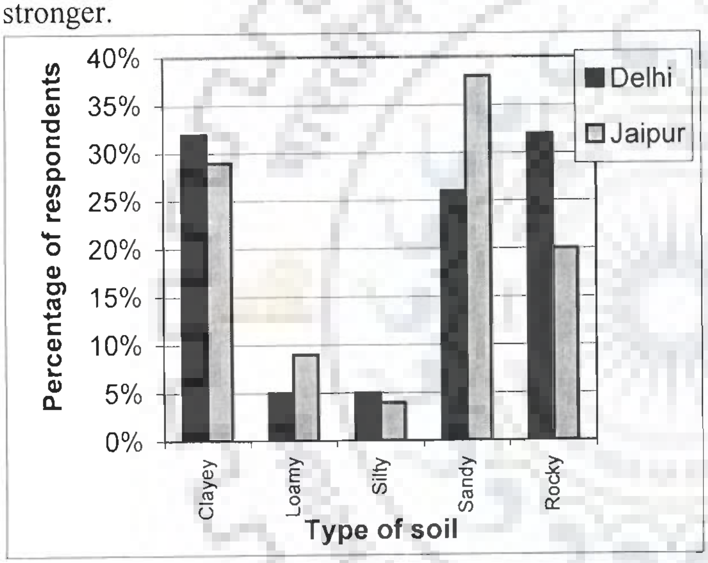


Figure A-1.2.2Preferred Type of Soil

Q2. Most architects both in Delhi and Jaipur were not sure of the preferable type of soil based upon the ease of working and stability for structure. However architects in Jaipur preferred sandy soil, as they did not experience any such problem while working with sandy soil, which is prevalent all over Rajasthan. (Figure A-1.2.2)

Q3. 75% respondents in Delhi and 63% in Jaipur agreed that the uneven ness of plaster and mortar thickness creates problems in structures.

Q4. 90% respondents in Delhi and 54% in Jaipur felt that the unevenness in the size of bricks creates problems to structures. The response of architects in Jaipur was motivated by the unavailability of good quality of bricks. They were frequently using uneven sizes of bricks, thus it did not seem to be a problem to most of them.

Q5. Exactly in line with the guidelines of RVM, architects in both the cities preferred to have ornamental and shade giving trees around the house. (Figue A-1.2.3) They also had apprehension about the direction in which a particular type of tree could be planted, which is again in line with the RVM. (Here in questionnaire, the question regarding the directional placement of tree was not placed.)

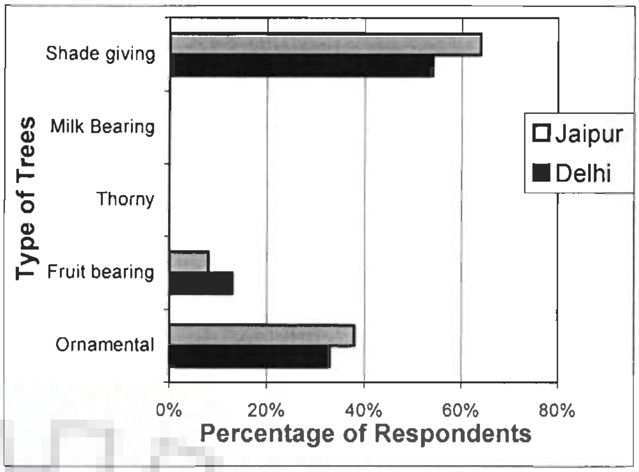


Figure A-1.2.3 Preference of Trees

Q6. 93% respondents in Delhi and 96% in Jaipur did not prefer having a house adjacent to a temple or a public building, coinciding the guideline of RVM.

Q7. Unlike the North being most preferred direction as per RVM, majority of architects in both the cities preferred east as it facilitated morning sun which brings ample light but doesn't heat the inside. Though there was no choice of SE, SW, NW and NE orientations, yet many of the respondents preferred SE orientation. (Figure A-1.2.4)

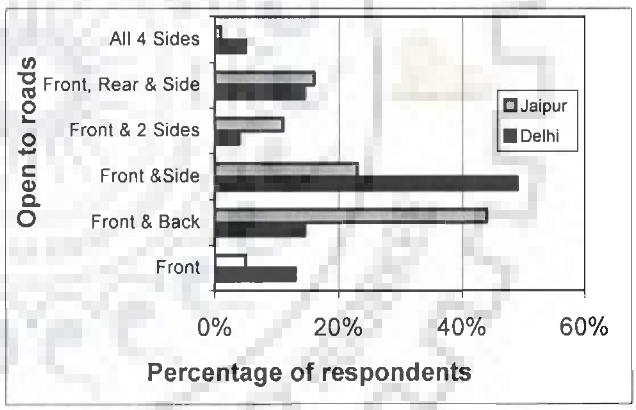


Figure A-1.2.4 Preference of Building Orientation

Q8. RVM states the presence of main streets and service streets in the front and back of the house respectively. Around 45% respondents in Jaipur agree with the same. Security was said to be main reason. However in Delhi, most architects preferred roads on front and side of the house which is slightly in contrast to that prescribed in RVM.

Q9. When asked about the preference for a square or a rectangular plot, 89% architects in Delhi and 91% in Jaipur preferred rectangular plots. However they had reservations regarding the proportions of the rectangle, which according to majority should not exceed 1:2.

Q10. In case the mandatory law of leaving setbacks was relaxed, still 97% architects in Delhi and 95% in Jaipur preferred to leave set backs.

Q11. When asked, on how many sides preferably shall setback be left if space permitted? More than 60% respondents in both cities preferred leaving setbacks on all four sides, which is in line with the guidelines of RVM. (Figure A-1.2.5)

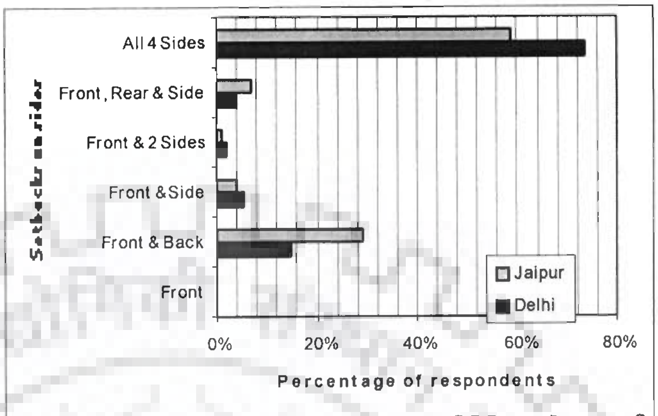


Figure A-1.2.5 Preference of Number of Sides Open

Q12. More than 95% architects in both the cities provide verandahs and balconies in the residences from comfort point of view.

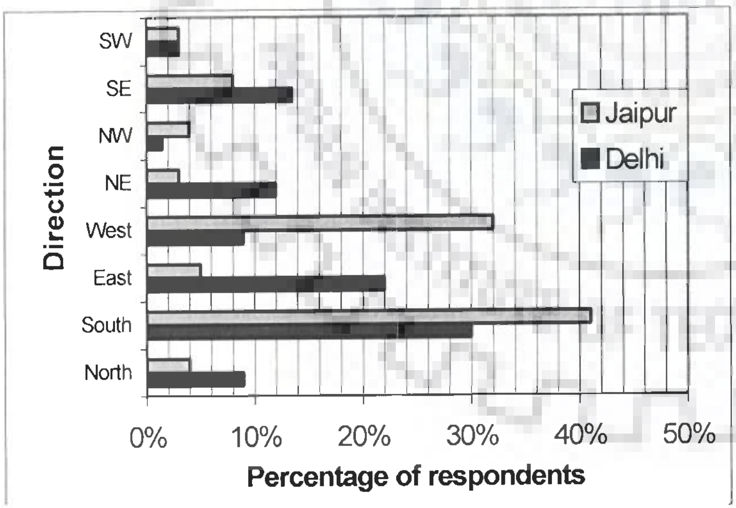


Figure A-1.2.6 Direction of Verandah and Balcony

Q13. While providing balcony and verandah, architects in Jaipur provided it with an intention to cut off direct hot sun from west and south. Architects in Delhi provided balcony with an intention of providing a space to sit out and enjoy outside sun, thus providing it in the east, south and SE. RVM suggests the provision of verandah all around the house. (Figure A-1.2.6)

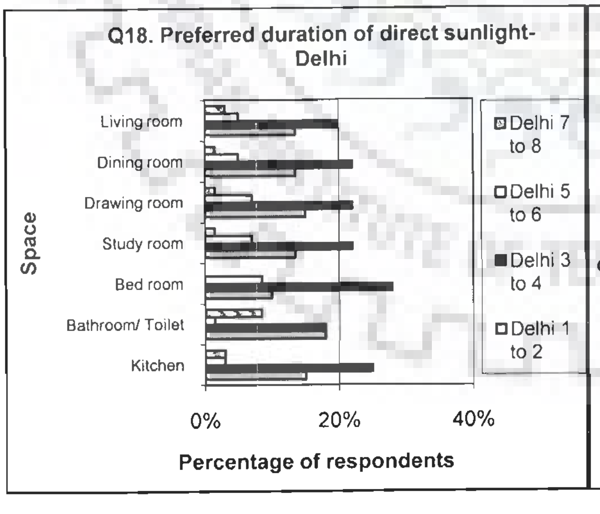
Q14. 89% Architects in Delhi and 93% in Jaipur prefer to provide staircase in clockwise orientation.

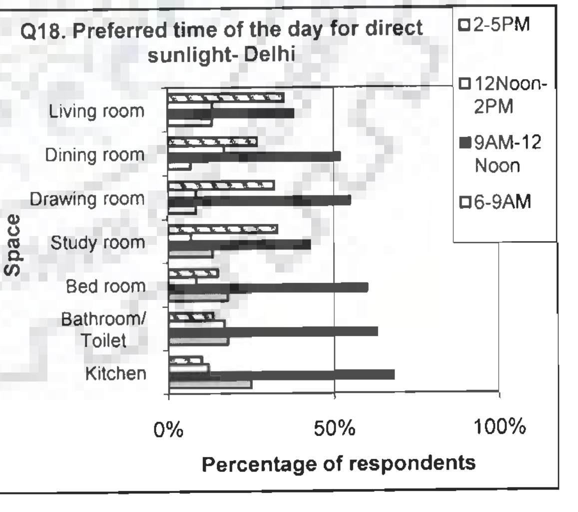
Q15. 93% in Delhi and 82% in Jaipur provide courtyard inside the house if the space permits. However, if space is a limitation, provision of courtyard is omitted.

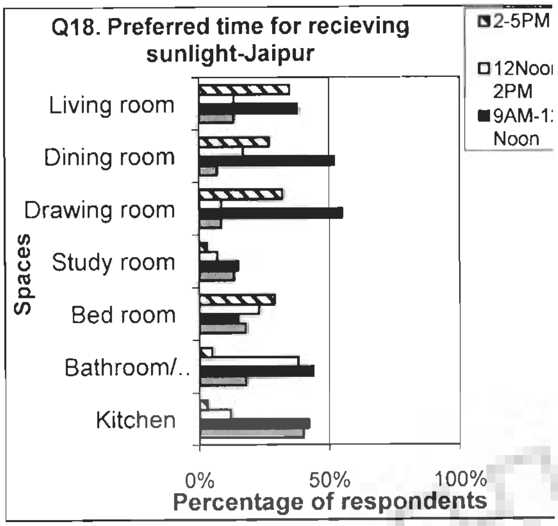
Q16. Cent percent architects in both cities provide toilets attached to the bedroom. Though 26% in Delhi and 38% in Jaipur prefer to provide separate cubicles for bathroom and latrine.

Q17. Though 24% respondents in Delhi and 19% in Jaipur feel that none of the spaces should be designed without natural ventilation and daylight, the rest agreed to provide only stores without natural ventilation and daylight.

Q18. It was desired to know the preferred direction for placement of various spaces inside the house. However, a direct question would have implicated the reference to Vaastu, which was not intended. Thus the answers were sought to the preference of duration of direct sunlight and time of the day when the sunlight is preferred in a particular space. Analysis of the response gave a clear picture of the arrangement sought inside the house from comfort point of view. (The percentage of respondents here may not total up to 100%, as many respondents did not prefer to answer this question. In some cases, respondents had two choices of answers. Thus both have been incorporated directly in the result compilation) (Figure A-1.2.7)







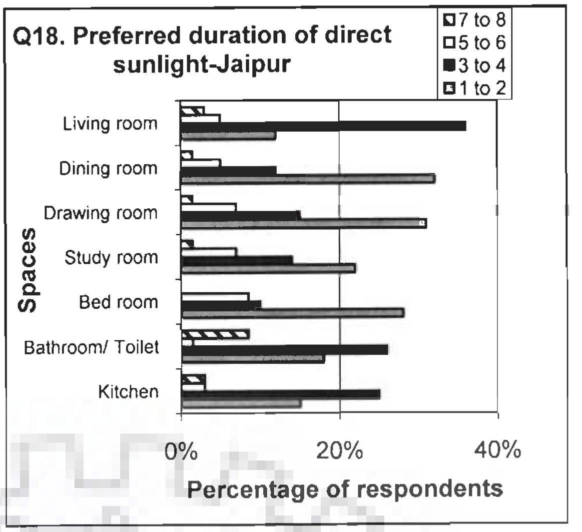


Figure A-1.2.7 Arrangement of Spaces as per Requirement of Light and Time

Q19. There was not a clear consensus on whether basements should be provided or not. 41% respondents in Delhi and 36% in Jaipur did not agree to providing basements considering stability during earthquakes.

Q20. 67% architects in Delhi and 41% in Jaipur chose to construct residential buildings in stone. Though according to RVM, the use of stone is strictly prohibited in inner walls of residential buildings.

Q21. Upholding the statement of RVM of using less number of materials, 56% architects in Delhi and 62% in Jaipur preferred to use lesser variety of materials in construction of house.
Q22. RVM prohibits the reuse of old materials in new house construction but to the contrary, 68% respondents in Delhi and 58% in Jaipur favored to reuse old material in new houses provided it had sufficient life left.

Q23. The last question was posed to them about their belief in Vaastushastra. 68% architects in Delhi and 39% in Jaipur did not believe in Vaastu principles.

Conclusions –The survey reveals that the current work practices and knowledge of practicing architects (of those who do not believe in or practice Vaastu also) correspond to the theories and guidelines set by Vaastu (RVM here).

Of the total 22 questions relating to the questionnaire, the following was the architects' compatibility-

- It is noteworthy that the architects who have been brought up in individual residences have more compatibility with Vaastu principles than those who have spent their childhood in flatted houses or apartments.
- The architects having more experience in residential design practice more similar to Vaastu guidelines.
- More architects in Jaipur practice similar to Vaastu than architects of Delhi. Main reason for that is the high-density growth in Delhi, which is promoting more multi, storied apartments allowing for less flexibility in design.
- Architects in both the cities felt that the choice of orientation and opening to roads is no more available and they have to design in all circumstances, most of the times, which are unfavorable.
- As against the North as the most beneficial orientation according to Vaastu, most architects preferred East facing plots, as plots generally have only front opening or front and back opening. A frontage in east allows for optimum amount of sunlight.
- Similar to Vaastu, most architects preferred rectangular plots but not exceeding the ratio of 2:1. Most respondents preferred leaving open area on all sides around the house.
- In line with Vaastu, most architects felt that none of the areas inside the house can be designed without natural ventilation and daylight except store. For the same reason, they preferred having a courtyard inside the house but not necessarily in the center. However respondents felt that the size of the courtyard should be sufficient to bring in light but should be able to be shaded by surrounding mass.
- Despite local availability of stone in Jaipur, most architects in Jaipur felt that the stone should not be used for house construction while architects in Delhi felt that the same can be used for house construction. Architects in both places agreed to use old materials in new houses.
- The respondents from Delhi were not able to give a clear picture of the space arrangement, as they preferred all spaces to receive 3-4 hours of sunlight in the morning around 9am to 12 noon. According to the respondents' from Jaipur, preference of timing and duration of direct sunlight desired in the spaces, the evolved space arrangement matched with that of the ideal Vaastu model. They preferred 1-2 Hrs of direct sunlight inside the house except kitchen, living room and bathroom. It was also agreed that bedrooms and study could receive afternoon sun for 1-2 Hrs.

The survey reveals that the practicing architects have subconsciously adopted the Vaastu principles OR the Vaastu principles are based upon the logics of science thus they match with the practice despite architects not even being aware of existence of Vaastu in their works. This leads us to believe that Vaastu theories are not merely a religious mystery but a science that can be applied in architectural design.

Appendix 2

Prevalent Vaastushastras

The basic knowledge of Vaastushastras is derived from Vedas. Vedas were further understood and elaborated in texts such as Puranas, Brahmans and Samhitas. The references of ancient architecture can be chronologically listed as follows-

1. **Vedas, Upvedas and Vedangas** (1500 BC)- casual references
2. **Brahmans** that followed Vedas and elaborated the same content in an easier language. They contain the details of geometry and mensuration.
3. **Puranas** (northern India- devoted primarily to the worship of Vishnu) and **Agamas** (southern India – devoted primarily to the worship of Shiva). They contain mentions of temples of the different sects.
4. **Samhitas & Sutras, which** contain the explanations of Vedas in a revised manner.

The above listed literature is the non-architectural reference that contributed significantly to the creation of Vaastushastra. The knowledge contained in above texts was absorbed and utilized by people in different regions of country and scripted in different languages with lot of regional impact. Thus we find a number of Vaastu texts available and used in different parts of the country.

30 Vaastu texts referred by Tamils

1. Visvakarmeeyam
2. Viswam
3. Viswasaram
4. Prabodam
5. Mayamatam
6. Twasta Tantra
7. Manusaram
8. Nalam
9. Mana vidhi
10. Mana kalpam
11. Mana saram
12. Behu srutam
13. Srusham
14. Mana bodham
15. Viswabodha janam
16. Adi saram
17. Vishaeakasham
18. Vastu bodham
19. Maha thantram
20. Vastu bidhyapati
21. Parasarayam
22. Kalajanapam
23. Chaityam
24. Chitram
25. Avaryam
26. Sadhaka sara samhita
27. Bhanumatam
28. Indramatam
29. Lokagnanam
30. Souram

Few more south Indian texts are

1. Isanam
2. Vrutham
3. Bhargavam
4. Vastu vidya
5. Para Srayam
6. Chitra Kasyapam
7. Markandam
8. Prayoga Mnajari
9. Gopalan
10. Peruhitam
11. Naradeeyam
12. Boudhamatam
13. Naranareeyam
14. Gouthamam
15. Kasyapam
16. Kutalam
17. Chitrayamatam
18. Vasishtham
19. Chitrabahulam
20. Manokalpam
21. Desikam

Texts prevalent in Kerala are

1. Shilaparatna of Srikumara
2. Shilpa Ratnakara
3. Manushyalaya Chandrika
4. Sarvastha Shilpa Chintamani
5. Saraswateeyam

Texts popular in Sourashtra, western and northern India are as follows-

1. Vastu Raja Vallabham
2. Aparajita Prachcha
3. Rupa Mandanam
4. Diparnavam
5. Prasada manjari
6. Kothanda Mandanam
7. Samrangana Sutradhar
8. Visvakarma Vastu Prakasham

Appendix 3

System of measurement in Vaastu texts

In all texts the basic dimension of human use is described as *angula.* Satapatha Brahman and Mayamata describe *angula* as the middle phalanx of middle finger of the user (*yajmana*) or the offering priest. *Angula* itself is an increment of units, which can be perceived only by learned sages or through microscope as a modern interpretation. Smallest dimension is *paramanu* or the unit of atoms.

8 *paramanus*	=	*1 rathadhuli* (cardust)
8 rathadhulis	=	*1 balagra* (hair end)
8 balagras	=	*1 liksha* (nit)
8 likshas	=	*1 yuka* (louse)
8 yukas	=	*1 yava* (barley corn)
8 yavas	=	*1 uttam angula or matra* (digit)

Angula itself is of three types depending upon the user and the use, uttam (8 yavas), madhyam (7 yavas) and adham (6 yavas). All the above stated units were not popular for architectural construction. These were to be used for very small objects like small sculptures, artifacts and objects of use. The architectural and general use measurements were made starting from *angula* (any of the three classifications of angula)

Mansara and Mayamata

12 angulas	=	1 vitasti
2 vitastis/24 angulas	=	1 kishku hasta (small cubit- for popular use and measurement of couches and conveyances)
25 angulas	=	1 prajapatya hasta (for measurement of vimana and shikhara)
26 angulas	=	1 dhanurmushti hasta (for measurements of buildings)
27 angulas	=	1 dhanurgruha hasta (for measurements of settlements)
4 hastas	=	1 danda
8 dandas	=	1 rajju

There is no explanation of what a Vitasti or Hasta is. But the usage of different units is very specific and clear. This is made very clear in the mensuration and geometry in ***Satapatha Brahman*** *and* ***Taittriya Brahman.***

Units of measurement as per Satapatha Brahman and Taittriya Brahman

Angula is the smallest unit of measurement. It is of three types- largest measuring 8 barley seeds, medium one measuring 7 barley seeds and smallest measuring 6 barley seeds. Angula is the length of middle part of middle finger.(Figure A-3.1)

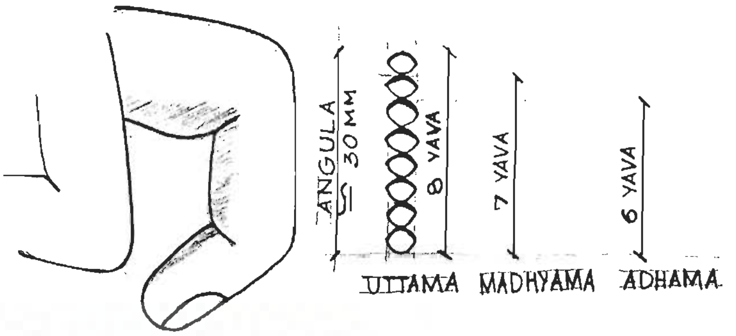


Figure A-3.1 Angula

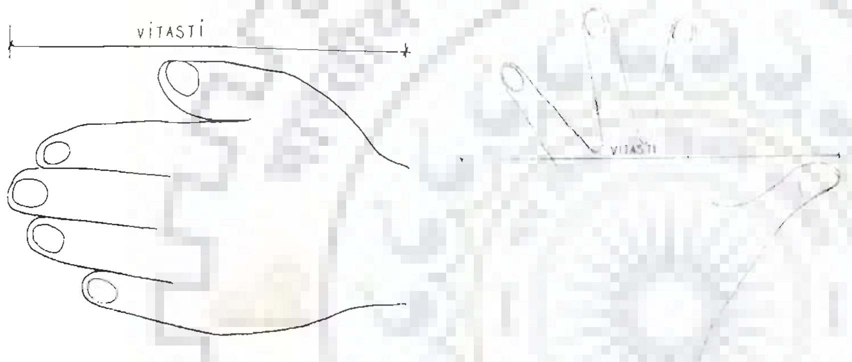


Figure A-3.2 Vitasti

Vitasti equals 13 Angula, which is the distance between thumb and little finger of a stretched palm or from the wrist to the tip of the middle finger. (Figure A-3.2)

Pradesa equals 12 Angula, that is the distance between index finger and thumb of a stretched palm.

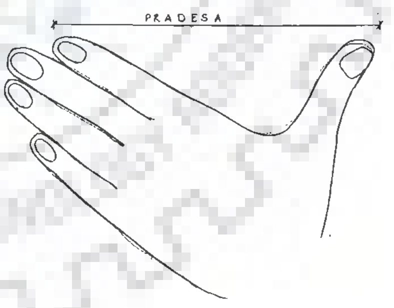


Figure A-3.3 Pradesa

Aratni/Cubit is equal to 24 Angula that is the distance between tip of middle finger to elbow. (Figure A-3.4)

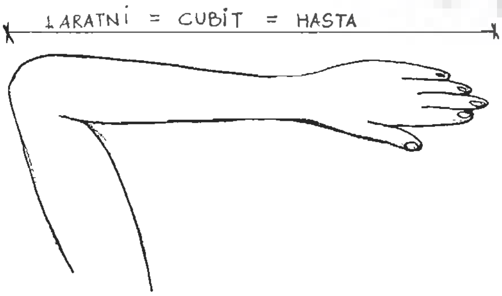


Figure A-3.4 Aratni

Vyama equals 5 cubits = 10 pradesa = 120 Angula that is the distance between the tips of the two middle fingers of a man standing with his arms outstretched **it is equal to Purusa which** is the height of a man. (Figure A-3.5) It is also stated to be a surface measure where one Purusa means 1sq. Purusa or a square of one Purusa side each. For measuring distances, following units were used-

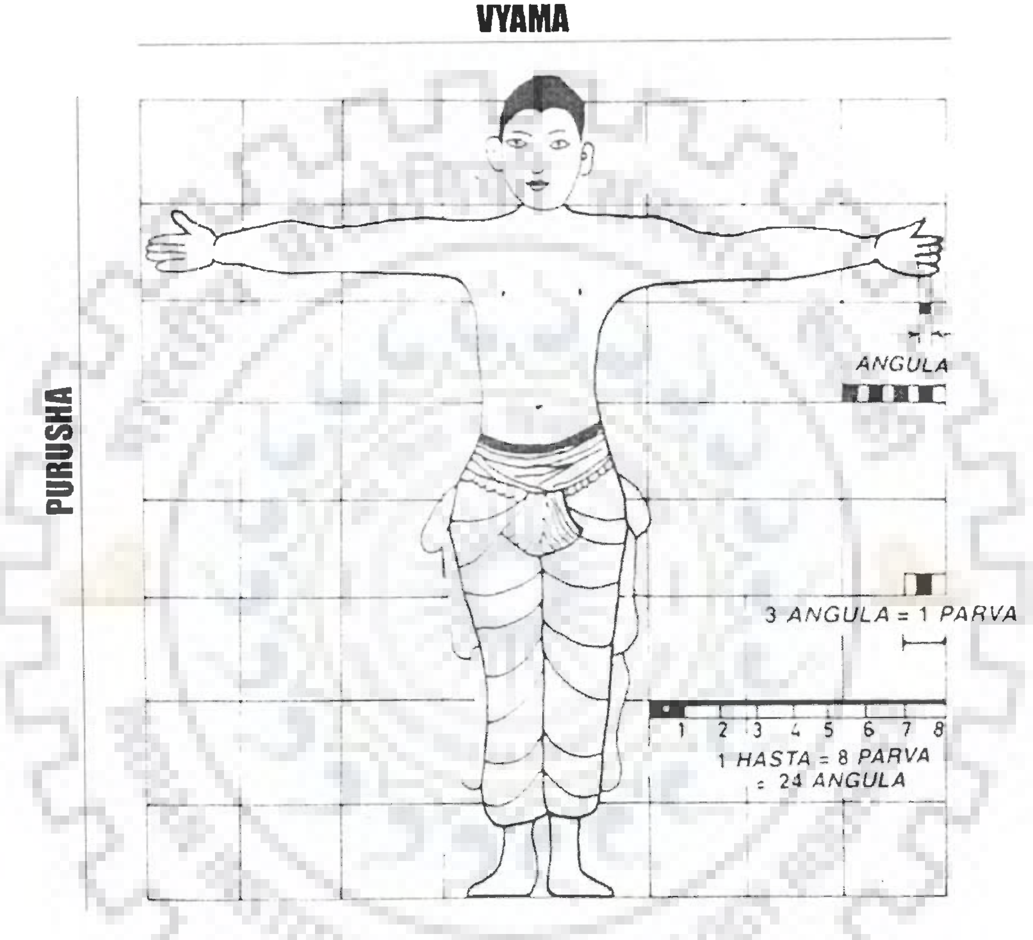


Figure A-3.5 Vyama

Pada is the length of a feet equal to 15 Angula.

Prakrama that is equal to 2 Pada equal to 30 Angula.

***Vitasti* is taken as 12 angulas in Mansara and Mayamata while in Satapatha Brahman it is said to be equal to 13 angulas.**

Samrangana Sutradhar

The initial system of small dimensions and measurement is exactly the same as other texts. It also mentions the same three types of angula. Further dimensions are as follows-

1 angula	=	*matra*	*14 angula*	=	*Pada*
2 angula	=	*Kala*	*21 angula*	=	*Ratni*
3 angula	=	*Parv*	*24 angula*	=	*Aratni/hast*
4 angula	=	*Mushti*	*42 angula*	=	*Kishku*
5 angula	=	*Tal*	*82 angula*	=	*Purusha*
6 angula	=	*Kar-pad*	*96 angula*	=	*Chap*
7 angula	=	*Dishti*	*106 angula*	=	*Danda/Dhanusha*
8 angula	=	*Tushni*	*3 danda*	=	*1 Nalva*
9 angula	=	*Pradesha*	*1000 danda*	=	*1 kos*
10 angula	=	*Shayatal*	*2 kos*	=	*1 gavyuti*
11 angula	=	*Gokarn*	*4 gavyuti*	=	*1 yojan = 8000 danda*
12 angula	=	*Vitasti*			

1 Danda is equal to 96 angula in Mansara while in Samrangana Sutradhar it equals 106 angula.

It also describes the marking of a one Hast long measuring scale. The scale is said to be of 1, 1 ½ or 2 angula wide and ½ angula thick made out from a specific wood. It is divided into 8 equal parts of three angula each called parv. 4 parvas are kept as such with making of flowers on the marking. From the center, the fifth angula marking is divided into two parts, the eighth angula marking into three parts and twelfth into four parts. Every parv marking is to be ornamented with a flower.

Rajvallabh Mandan

The smaller dimensions up to angula measurement and the types of angulas are again the same here. There is a slight variation in the larger dimensions from the other text. (Figure A-3.6)

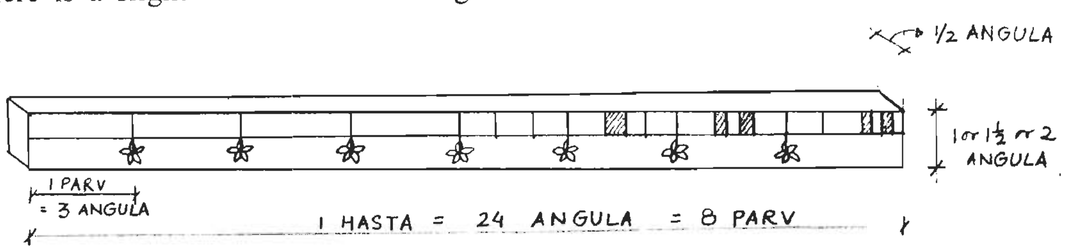


Figure A-3.6 Hasta Scale

12 angulas	=	*1 Tal /Balisht /Vitasti*
2 Vitasti (24 angulas)	=	*1 Hasta*
1 ¾ Hasta(42 angulas)	=	*1 Kishku*
4 hasta (96 angulas)	=	*1 Chap*
2000 danda	=	*1 Kos*
2 Kos	=	*1 gavyuti*
2 gavyuti	=	*1 Yojan*
100 yojan	=	*1 Koti*

It varies from Samrangana Sutradhar (SS) in its measurement of Kos and Gavyuti while Yojan comes to the same dimensions equal to 8000 dandas.

Manushyalaya Chandrika

Manushyalaya Chandrika has a different nomenclature for the basic dimensioning also. Though at the end the Angula comes to be of the same size but the naming is slightly different. Paramanu is the same smallest unit.

8 paramanu	=	*1 trasrenu* against rathrenu in Mansara (M.)
8 trasrenu	=	*1 liksha* against balagra in M.
8 liksha	=	*1 yuka* against liksha in M.
8 yuka	=	*1 tila* against yuka in M.
8 tila	=	*1 yava* similar to yava of M.
8 yava	=	*1 angula* similar to M.
8 angula	=	*1 pada* (while 1 pada equals 14 angula in SS)
8 pada (64 angula)	=	*1 vyama* (while 1 vyama equals 120 angula in Satapatha Brahman)

Similar to Mansara, Mayamata and Samrangana Sutradhar, it has-

24 angula	=	*1 kishku hasta*
25 angula	=	*1 prajapatya hasta*
26 angula	=	*1 dhanurmushti hasta*
27 angula	=	*1 dhanurgruha hasta*

Addition here is

28 angula	=	*1 Pracya hasta*
29 angula	=	*1 Vaidehi hasta*
30 angula	=	*1 Vaipulya Hasta*
31 angula	=	*1 Prakirna Hasta*

Also

12 pada	=	96 angula	=	1 danda same as in M.

Square of 200 danda is 1 yojan (thus yojan is treated here to be a surface unit)

Vishnu Purana also mentions 1 yojan as 4 kos.

Appendix 4

Paintings on Shekhawati Havelis

Shekhawati Havelis are world famous for their painted Havelis which give the streets a look of open air art gallery. The paintings were created at least a century back but these have retained the colours and charm even today. following is the method, material and technique of painting.

Artists

In Shekhawati the fresco painters were called *Chiteras* who belonged to the cast of *Kumhars* (potters). They were also called *Chejaras* (masons) as they also performed the function of building along with painting. The task of painting a Haveli or a Temple was done by a group of three to four painters who worked under the supervision of a master.

Materials and Techniques

In Rajasthan, the method of fresco buono is known as *Ala Gila* or *Arayish*. This method was so definitely mastered by the local masons of Shekhawati that the resultant frescos became as durable as the building it adorned.

The walls of bricks or stone were covered by mortar made from very fine clay. A centimeter thick layer of this mixture was plastered on the wall and was allowed to dry which then followed by the second layer. The third layer of mortar consisted of finely grounded powder of marble which was smoothed on the wall. This was done at intervals before the surface dried so that the layers of plaster which was to follow could remain adhere to the mortar.

Layers of plaster were applied after the walls were thoroughly drenched. First layer of plaster consisted of ¼ of *Kali* Lime and ¾ of Gravels or Brick dust. Second layer consisted of ¼ of Lime and ¾ of Marble Dust. This layer of plaster was allowed to set followed by the final layer. Final layer of plaster was applied on the wet wall, which consisted of filtered Lime Dust mixed with *Chhachh* (sour buttermilk) and *Gur* (jaggery).

Between each plastering layer the surface was burnished with Agate or a White Stone. While the final layer of plaster was still damp the design was drawn and painted. As the wall dried a chemical reaction occurred between the plaster and the pigment which sealed the painting with the plaster and they became one. The colours were mixed in the lime water or lime plaster and were then applied on the walls.

A method of tracing was devised to avoid penitent, which sometimes peep through thin layers of paint. A stencil was created by pin-pricking a drawing along the outline of a design. This stencil was known as *Khaka*. This stencil was then placed against the wall and was rubbed with a charcoal or brick dust to produce a dotted line design. This served as base for the black out line which was later filled in with colours.

After the drying the final layer touch was given by rubbing Agate, which fixed the colours followed by a coat of coconut oil or simply rubbing crushed coconut, applied with a soft cloth. The fresco was thus covered and protected with a transparent layer of oil.

Colours

Natural pigments were used in painting the frescos on the buildings. The colours were obtained as follows-

Black: *Kajal* (lamp black)

White: *Safeda* (chalk), *Chuna* (lime)

Blue: *Neel* (indigo)

Green: *Harabhata* (terra verte)

Red: *Geru* (red stone powder)

Brown: *Hirmich* (earthy mineral)

Orange: *Kesar* (saffron)

Yellow ochre: *Pevri* (yellow clay)

The yellow colour was even obtained by evaporating the cow's urine that was fed for 10 days on mango leaves. The resultant paste was then used to make *golis,* which gave brilliant yellow on diluting in water. This method was banned later on. These colours were generally preserved in the dried form and were used when required in a paste form and applied directly on the wet wall.

Subjects

A study of the thematic content of the Shekhawati frescos from the earliest examples in 1750 to the later ones of the British period reveals the changing tastes of the artists and their patrons. Subjects varied from religious to social issues of sati practices. They were fond of '*Airawatas*' or white elephant of *Indra* and horses which they drew mostly on the exterior wall surfaces. Compositions done in the interiors were based on

Vishnu, while others depicted *Rag-Raginis* (Lord *Krishna* with *gopis*). Few other deities were also painted in various themes. Some frescos also reflected the lifestyle of the period when the frescos were done.

Framing each of these themes were playfully painted floral patterns which also defined arched openings, recessed arched panels and were used to differentiate between several themes painted on the same panel. Common festivals like *holi* and kite flying were also depicted. Other visuals were that of guards in Mughal attire, mahouts and the nawabs. The fact that Muslim subjects were painted on Marwaris' havelis makes it evident that the patrons were quite tolerant and they respected the artist's choice of subject.

There were also European portraits painted from photographs such as Queen Empress Victoria, George V and Queen Mary, English gentlemen riding bicycles, much bejeweled ladies with low neck lines. They thought that to emulate the British was to rise in social hierarchy that worked for the content of frescos as well. Now there were motor cars, strolling *Sahibs* and *Memsahibs*, their pet dogs tied on a leash, clumsy trains and cars drawn from imagination carried wealthy Marwaris and aeroplanes, sailing ship and telephones found place on the walls as well.

Categories of subjects:

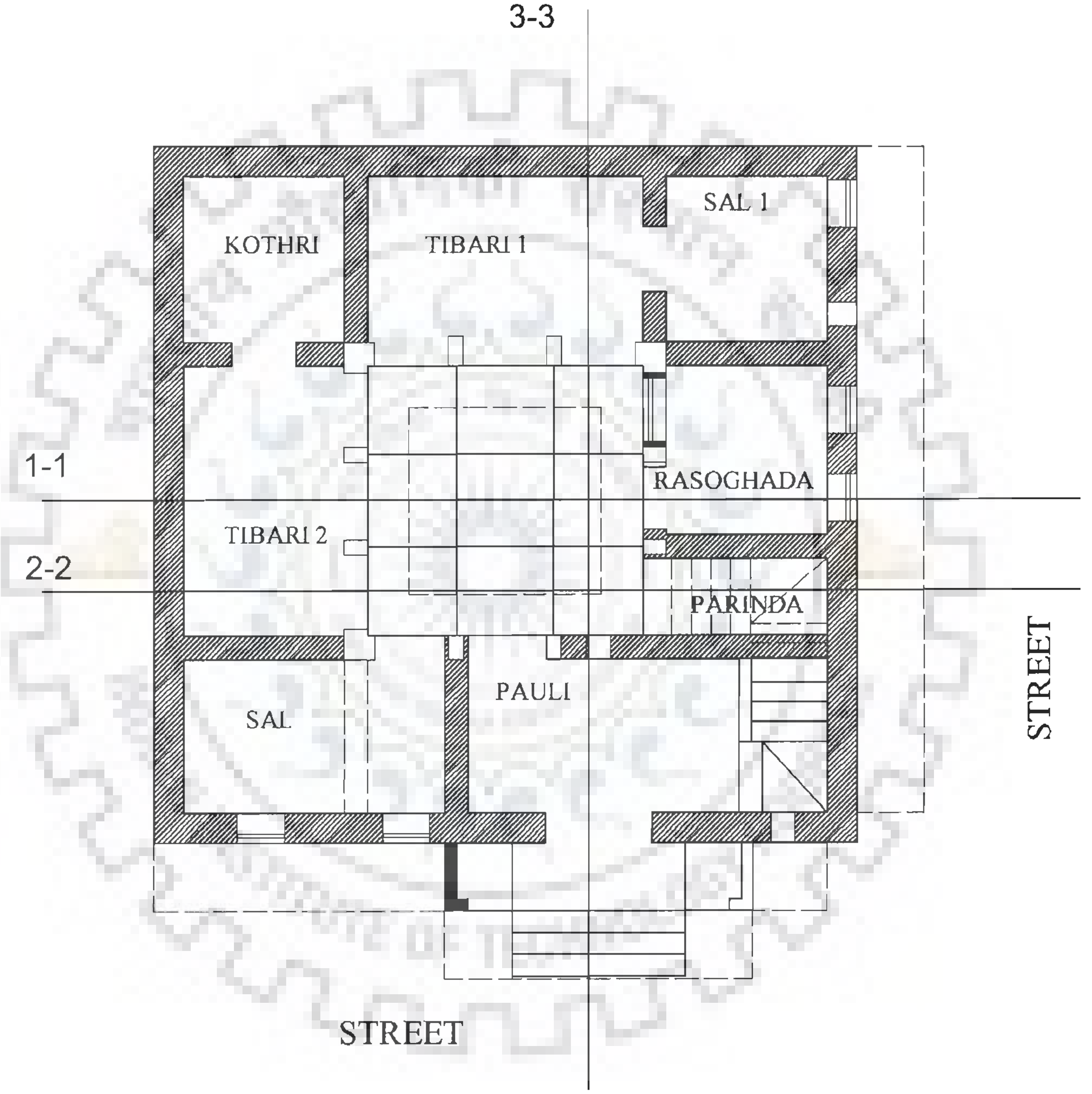
- Religious
- *Ragamala*
- Folk mythology
- Historical events and personages
- Lifestyle and surrounding environment
- Flora and fauna
- Erotica
- Maps and places
- British and their contraption
- Decorative designs

The choice of the subject or theme largely depended on the artists, though the patrons did intervene some times. It has been noticed that the choice of subject was very much related to the surface where the painting was to be done. Also the scale and proportions of the paintings varied accordingly. The ones painted on the exterior walls were large in size as compared to that painted in the interiors. The frescos painted in the interior areas were more intricate having varied themes depending upon the use or function of that specific area.

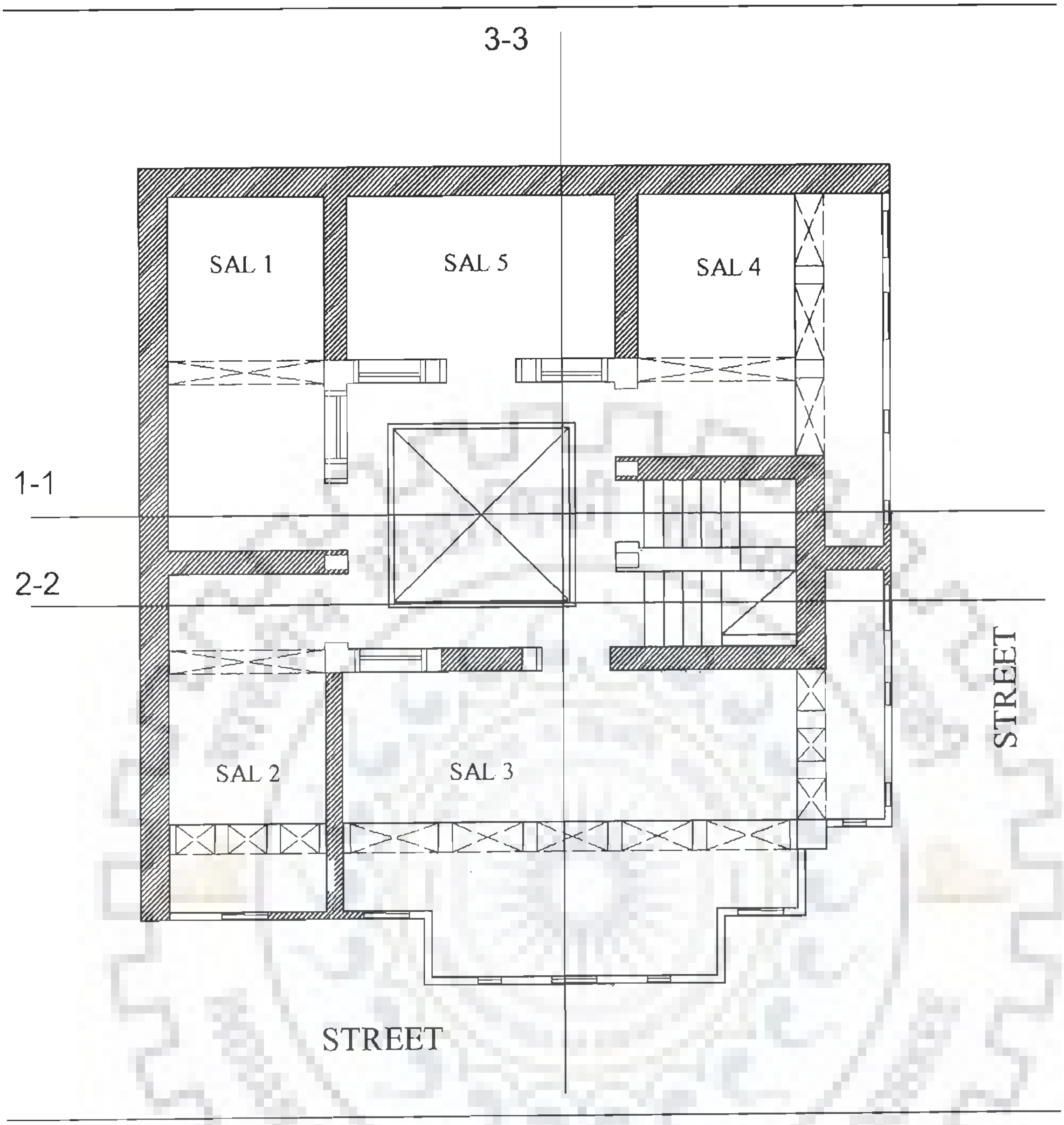
Appendix 5

Drawings of Case Studies

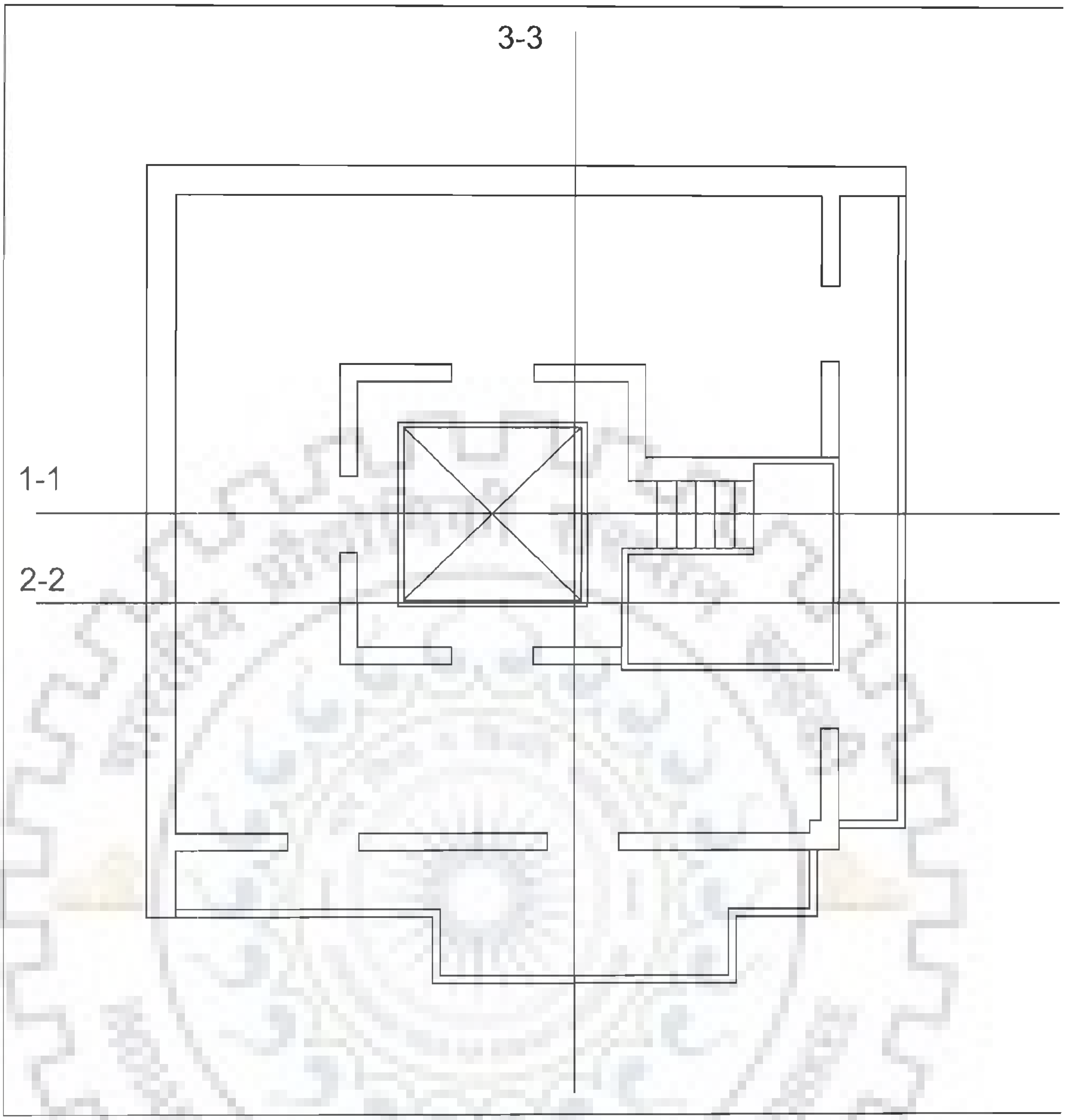
1. Chiranji Lalji Daima Haveli, Fatehpur



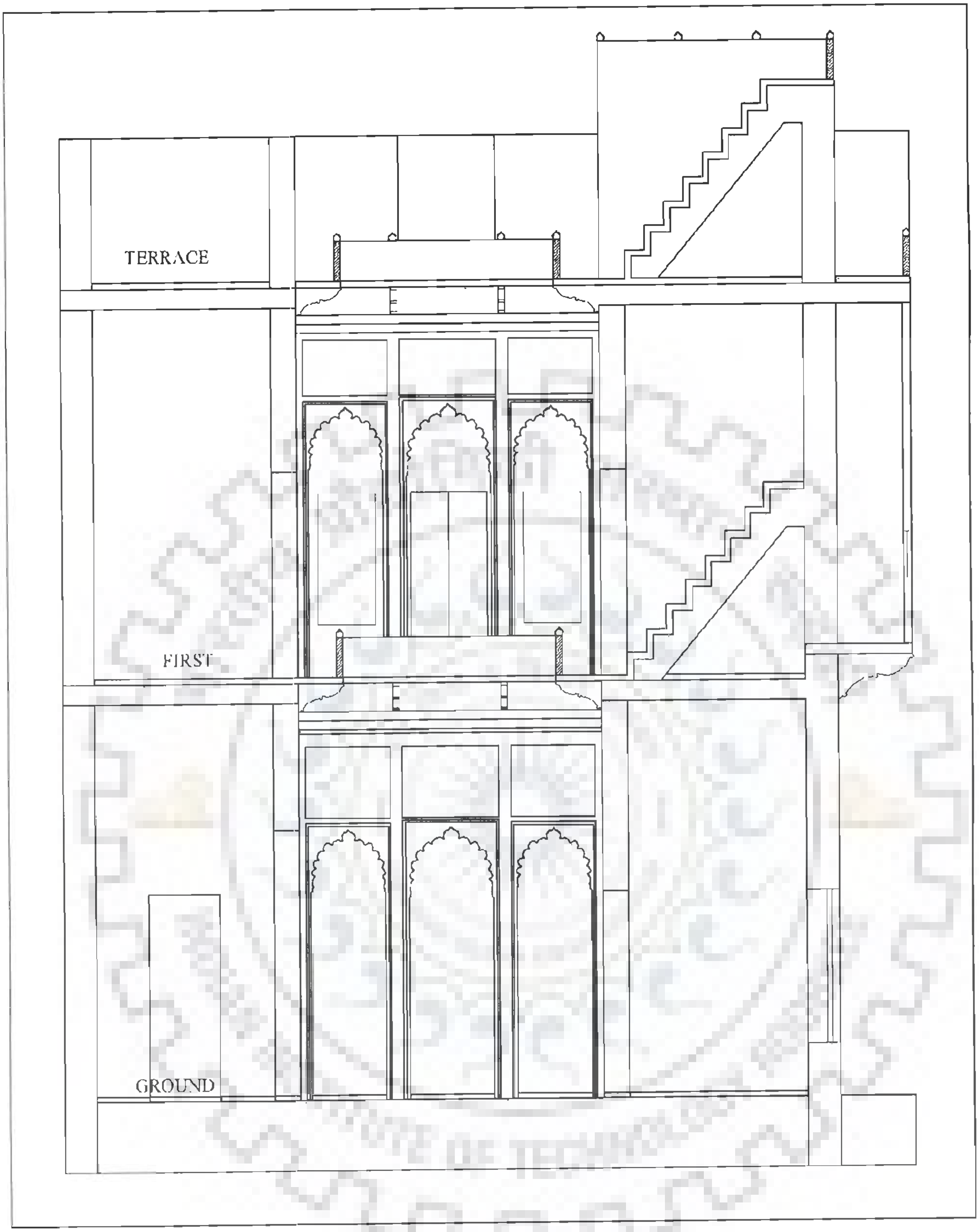
Drawing A-5.1-1: Ground Floor Plan



Drawing A-5.1.2: First Floor Plan

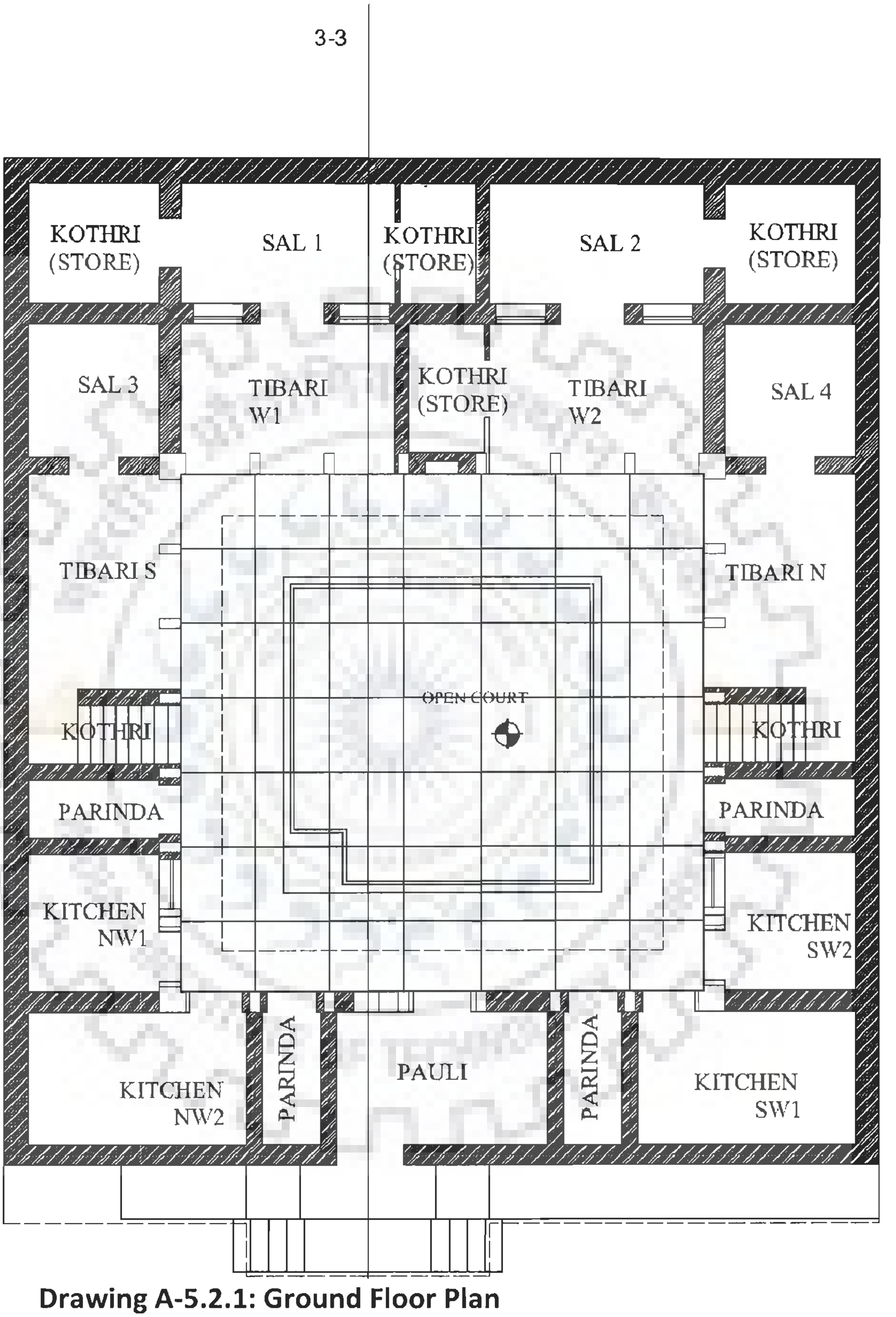


Drawing A-5.1.3: Terrace Floor

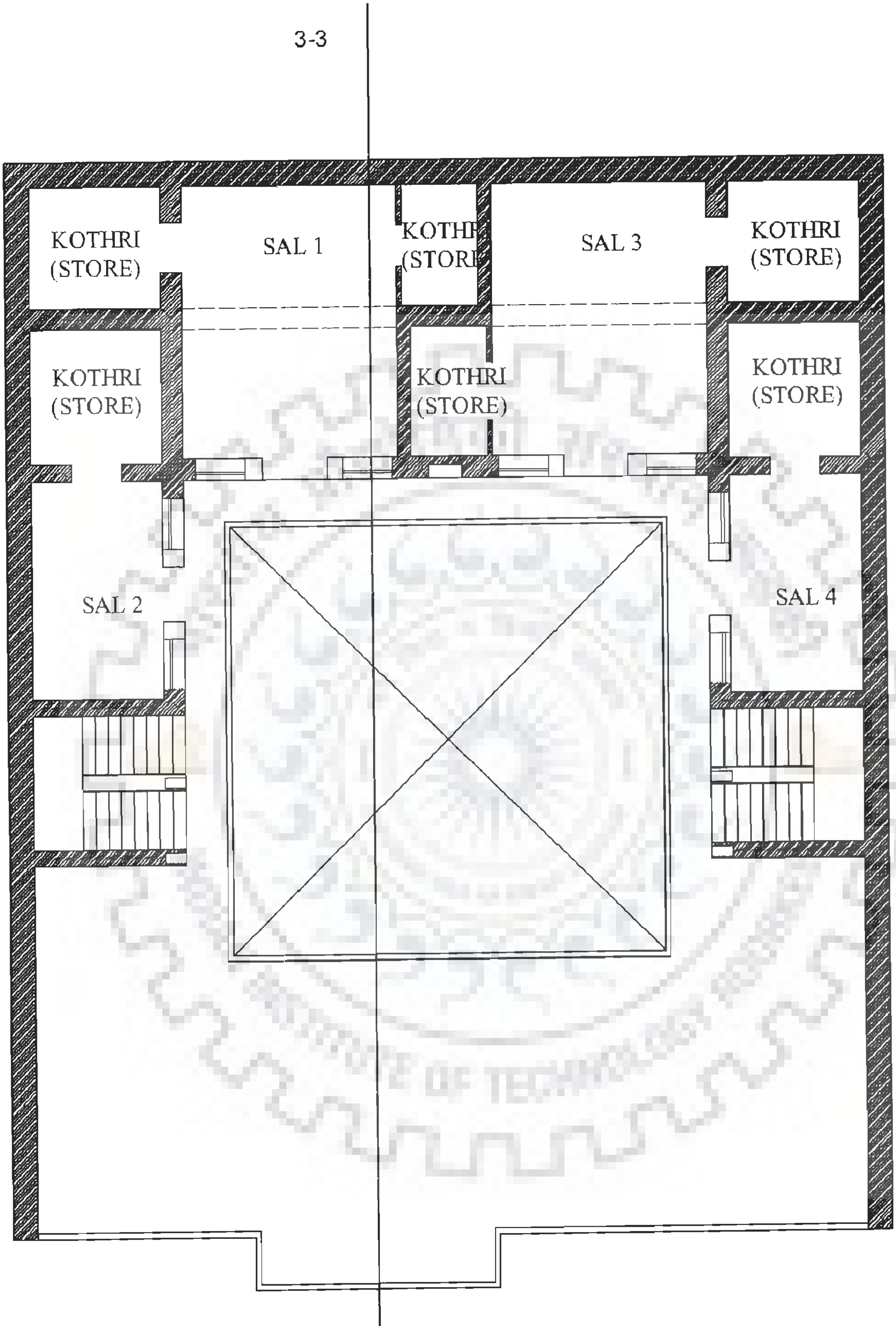


Drawing A-5.1.4: Section 1-1

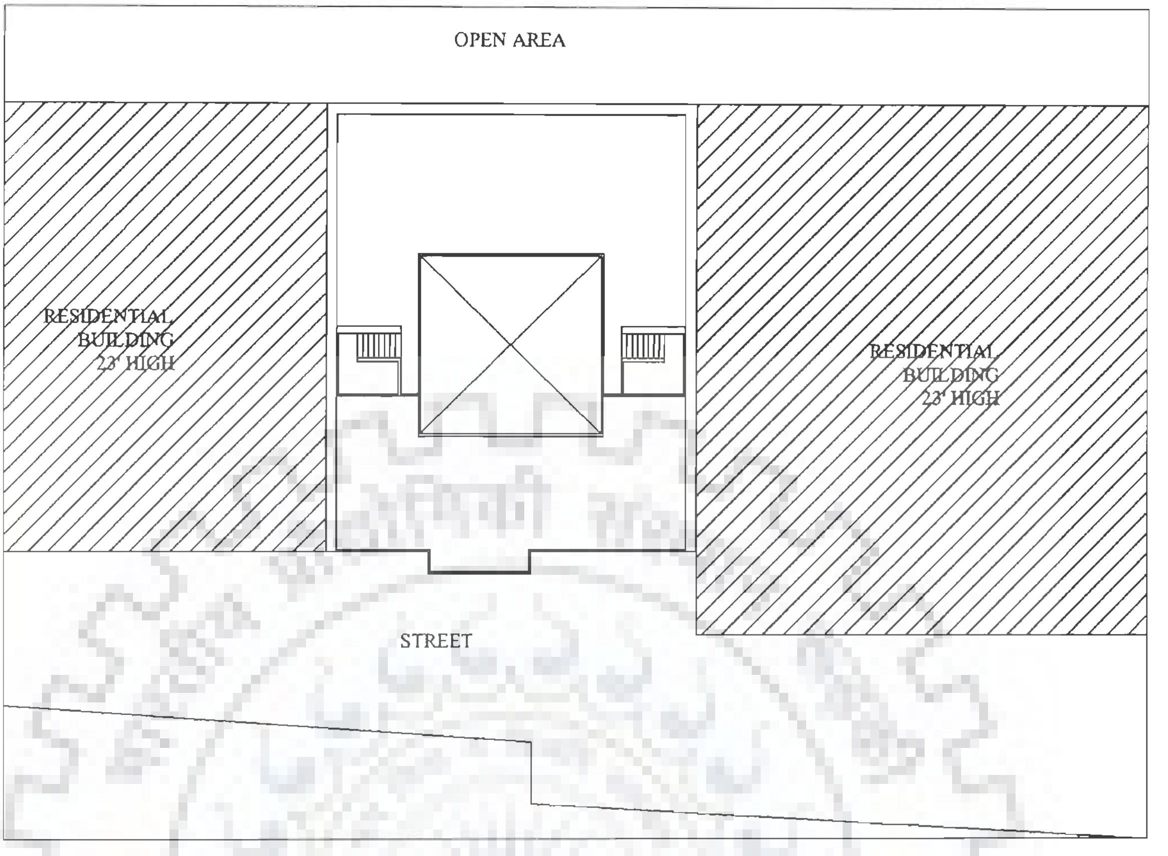
2. Harsukhrai Pansari Haveli, Chirawa



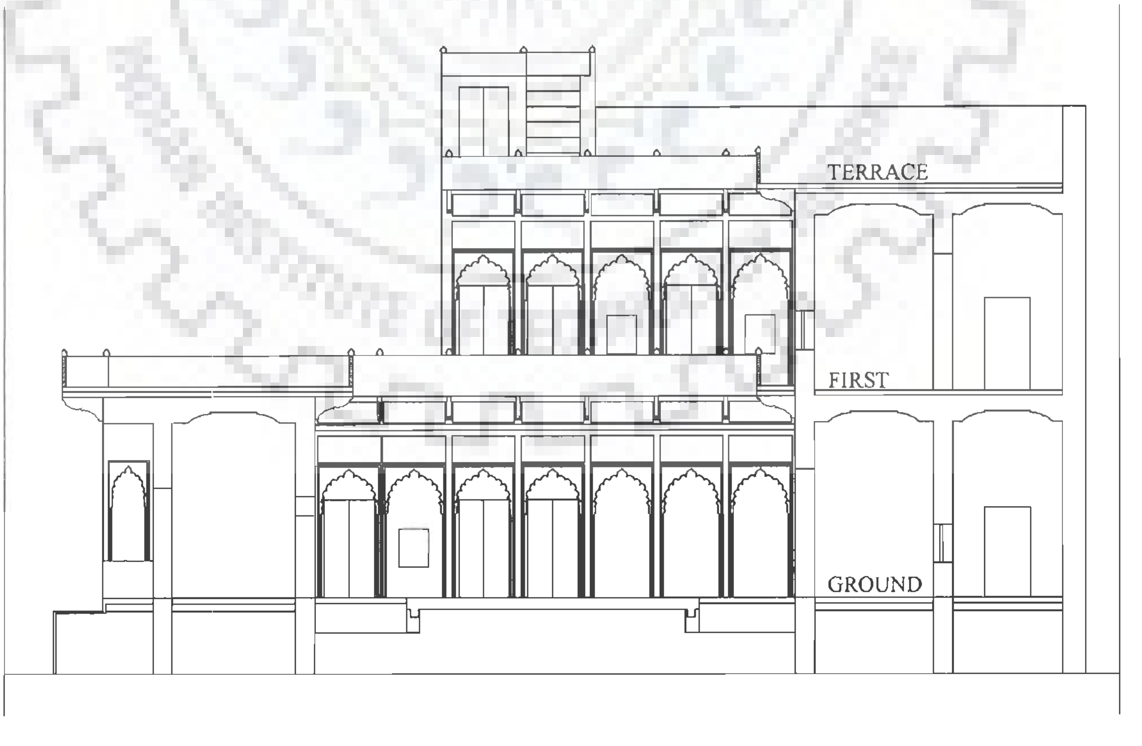
Drawing A-5.2.1: Ground Floor Plan



Drawing A-5.2.2: First Floor Plan

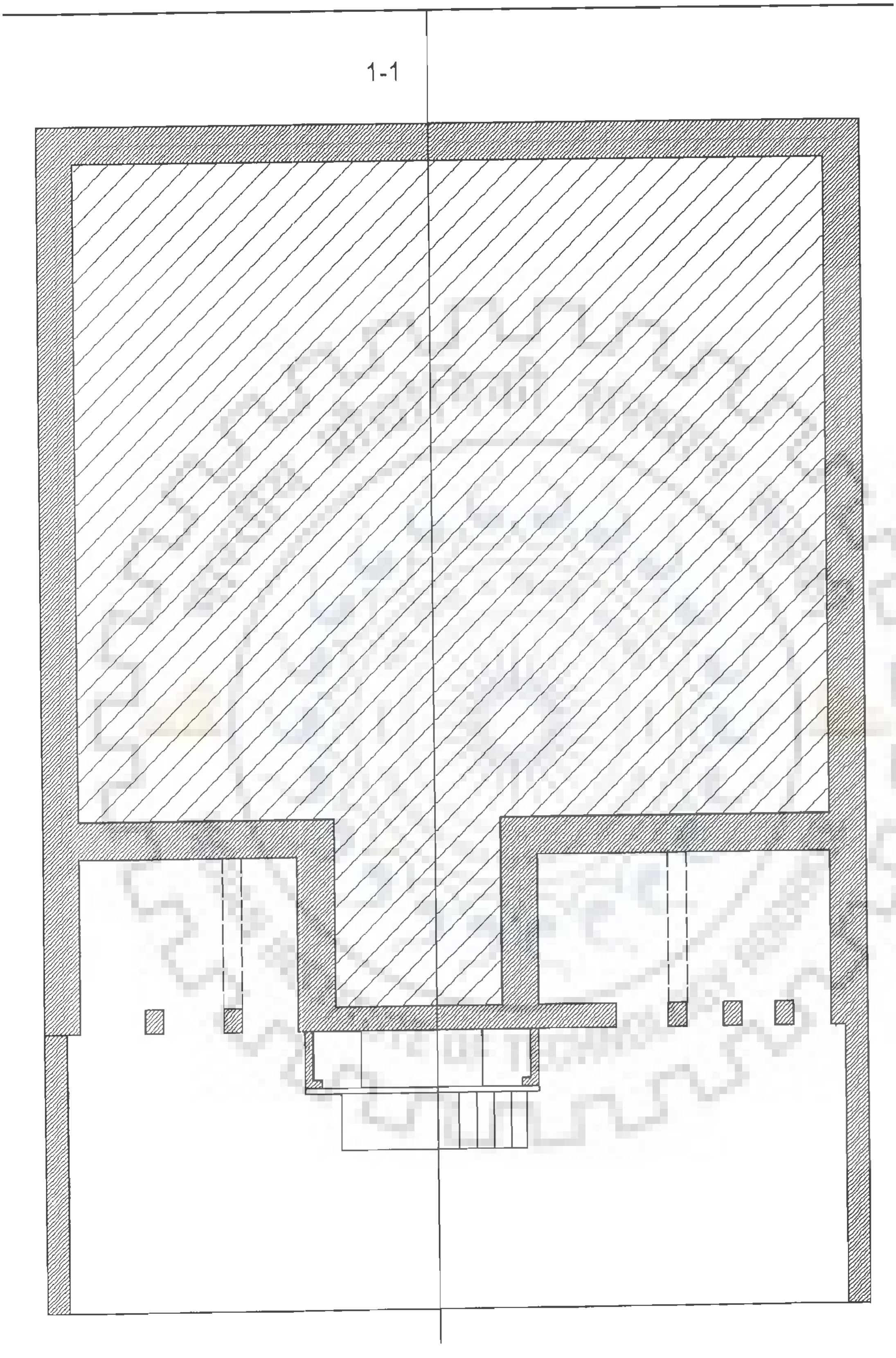


Drawing A-5.2.3: Terrace Floor Plan

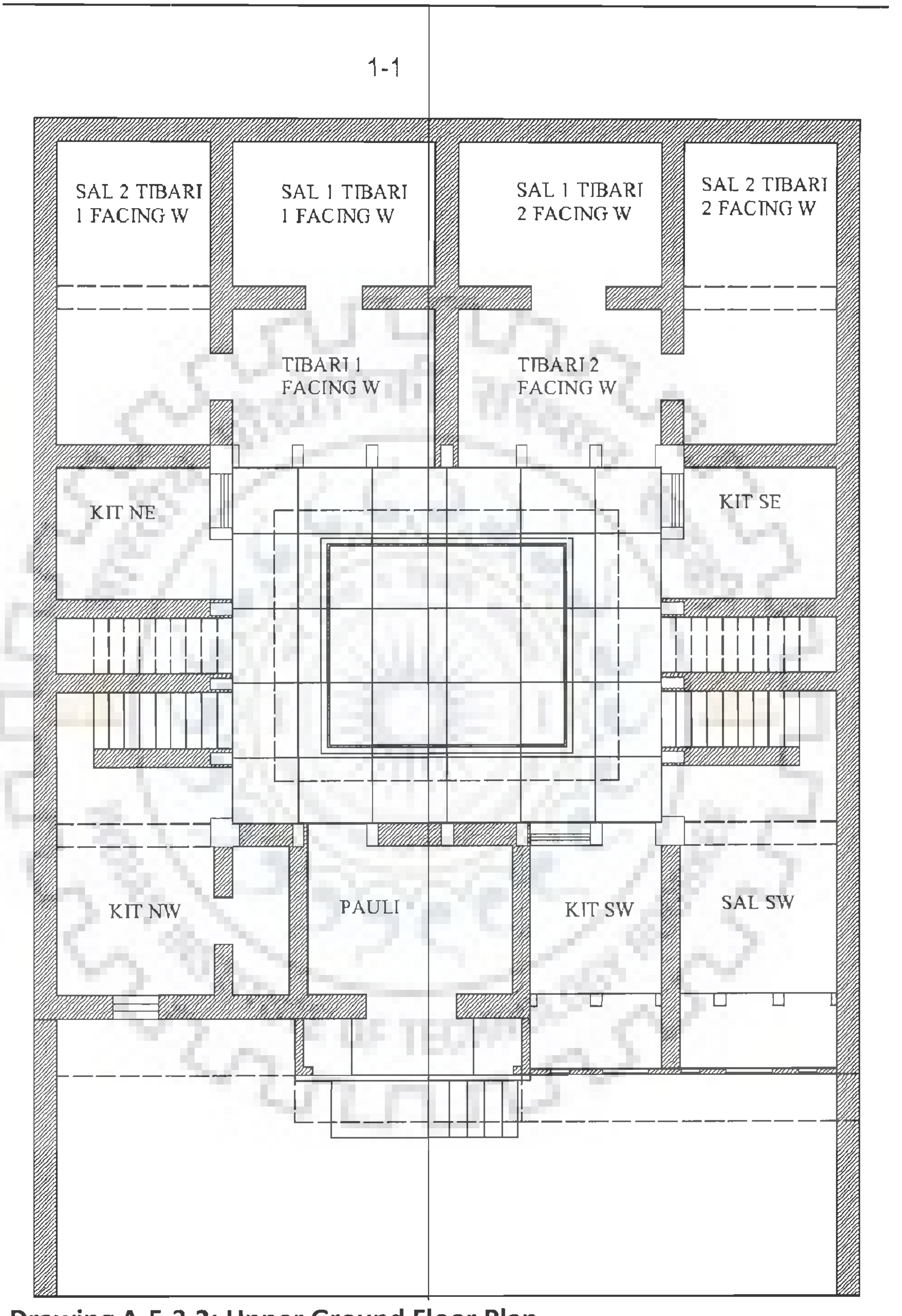


Drawing A-5.2.4: Section 3-3

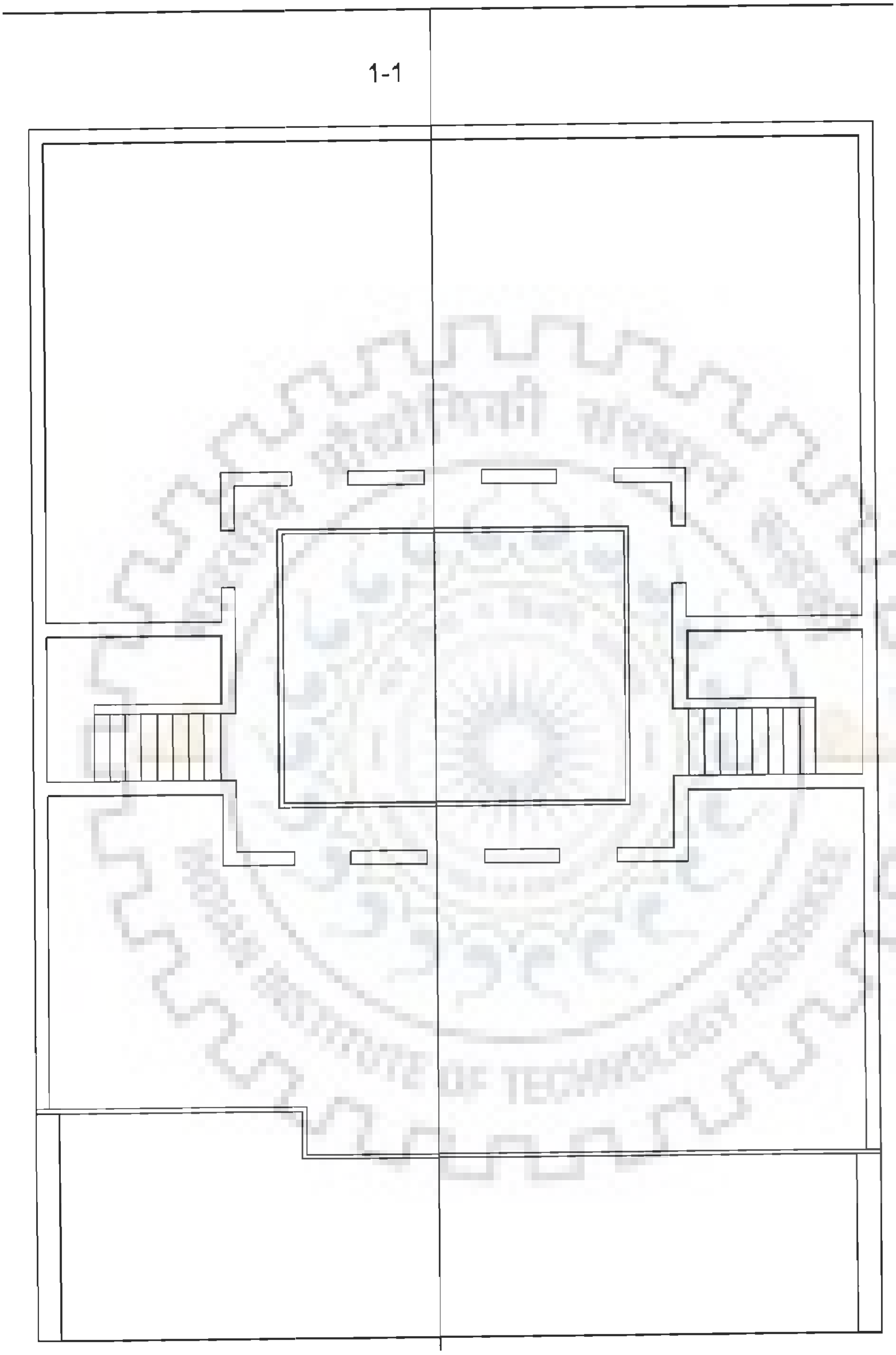
3. Ramgarh Haveli



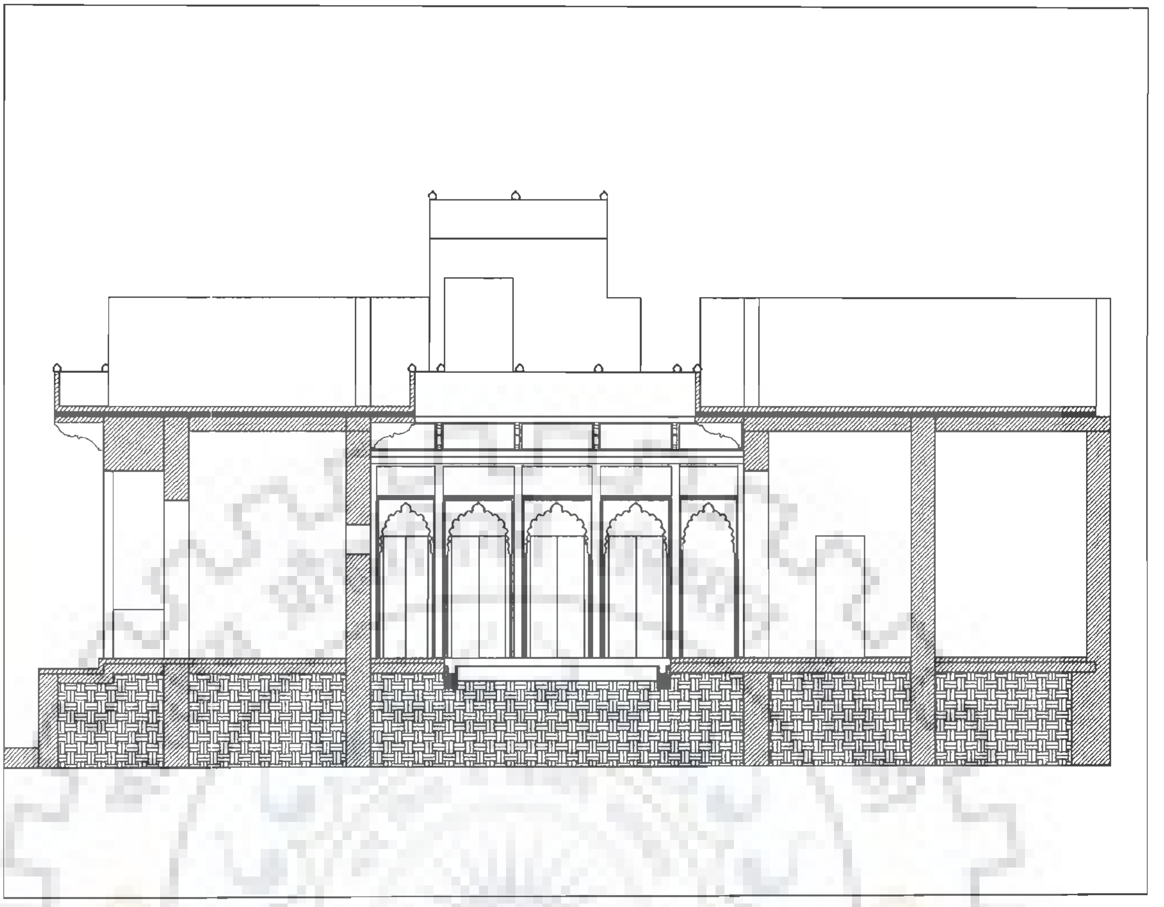
Drawing A-5.3.1: Lower Ground Floor Plan



Drawing A-5.3.2: Upper Ground Floor Plan

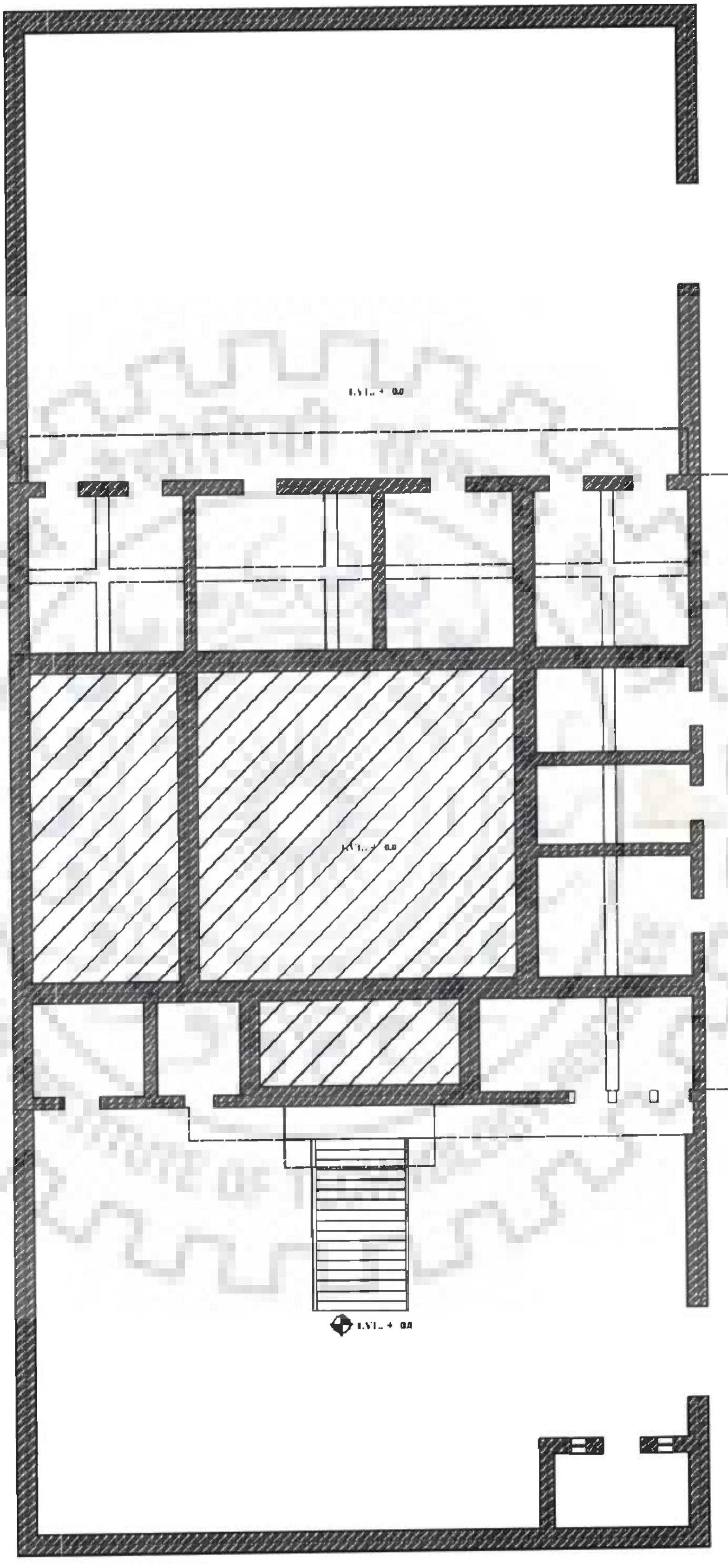


Drawing A-5.3.3: Terrace Floor Plan

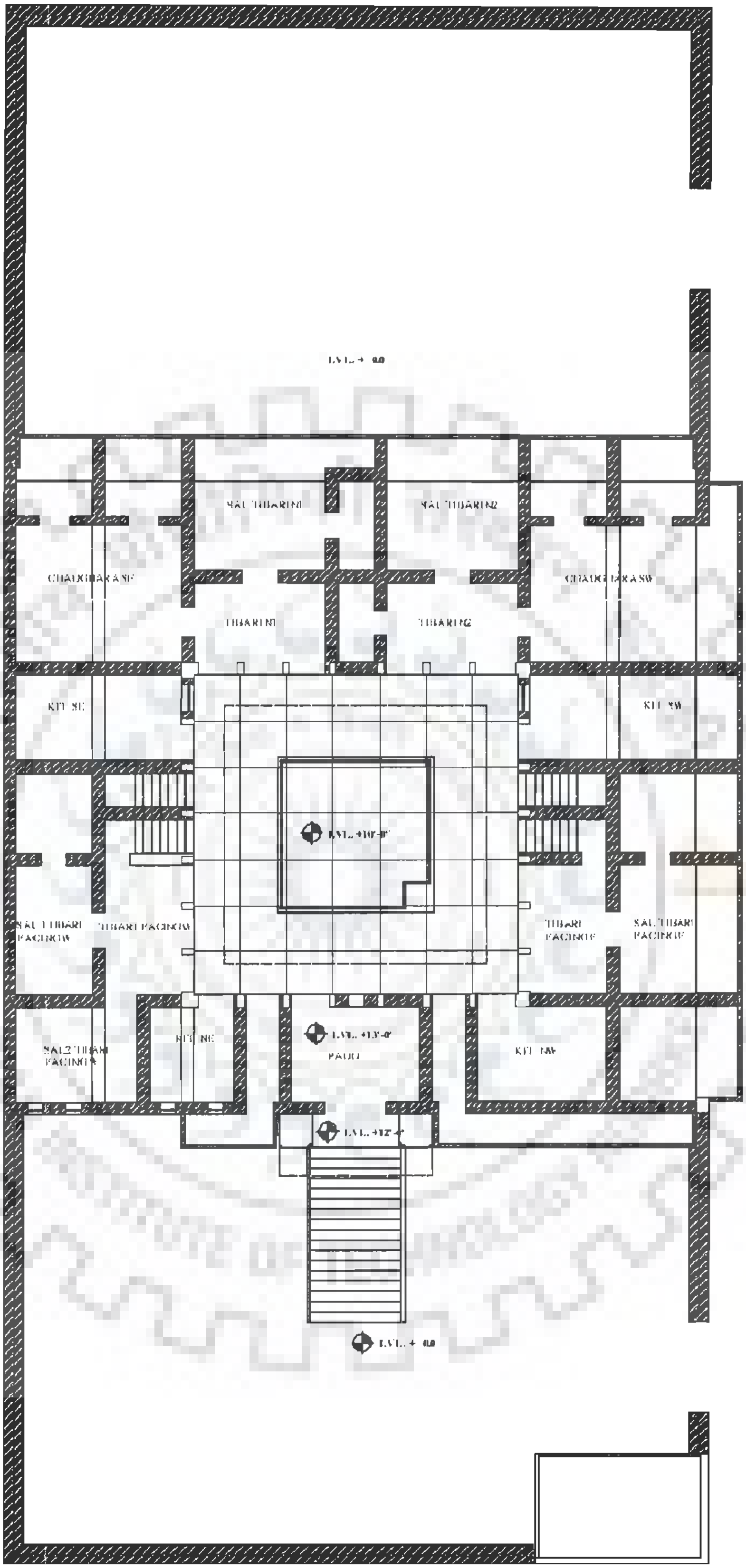


Drawing A-5.3.4: Section 1-1

4. Muslim Haveli, Ratannagar



Drawing A-5.4.1: Lower Ground Floor Plan



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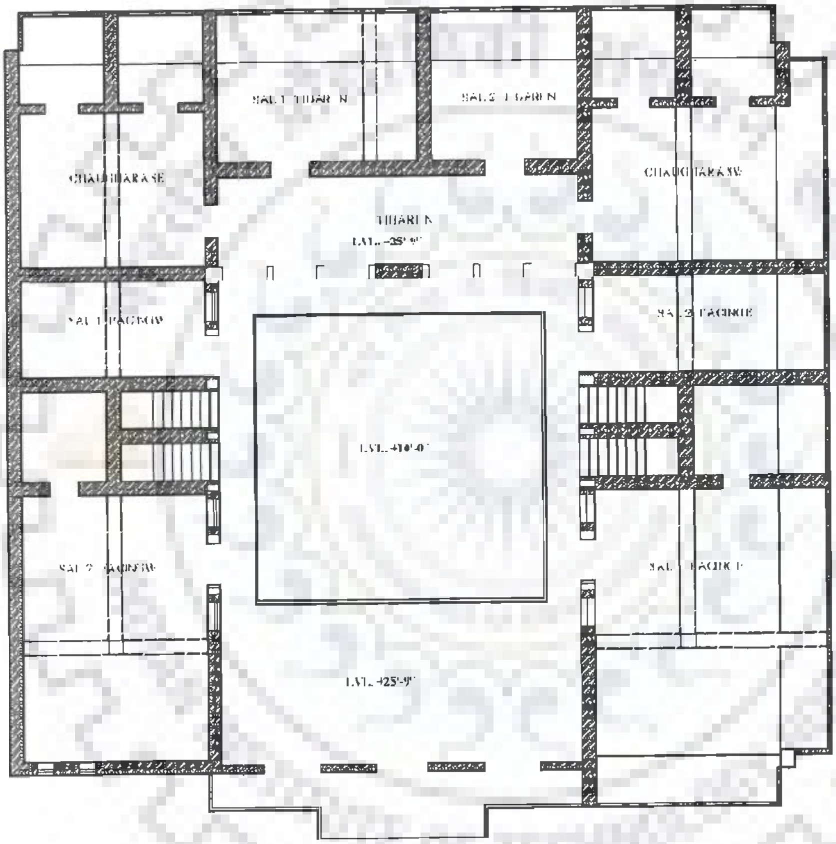
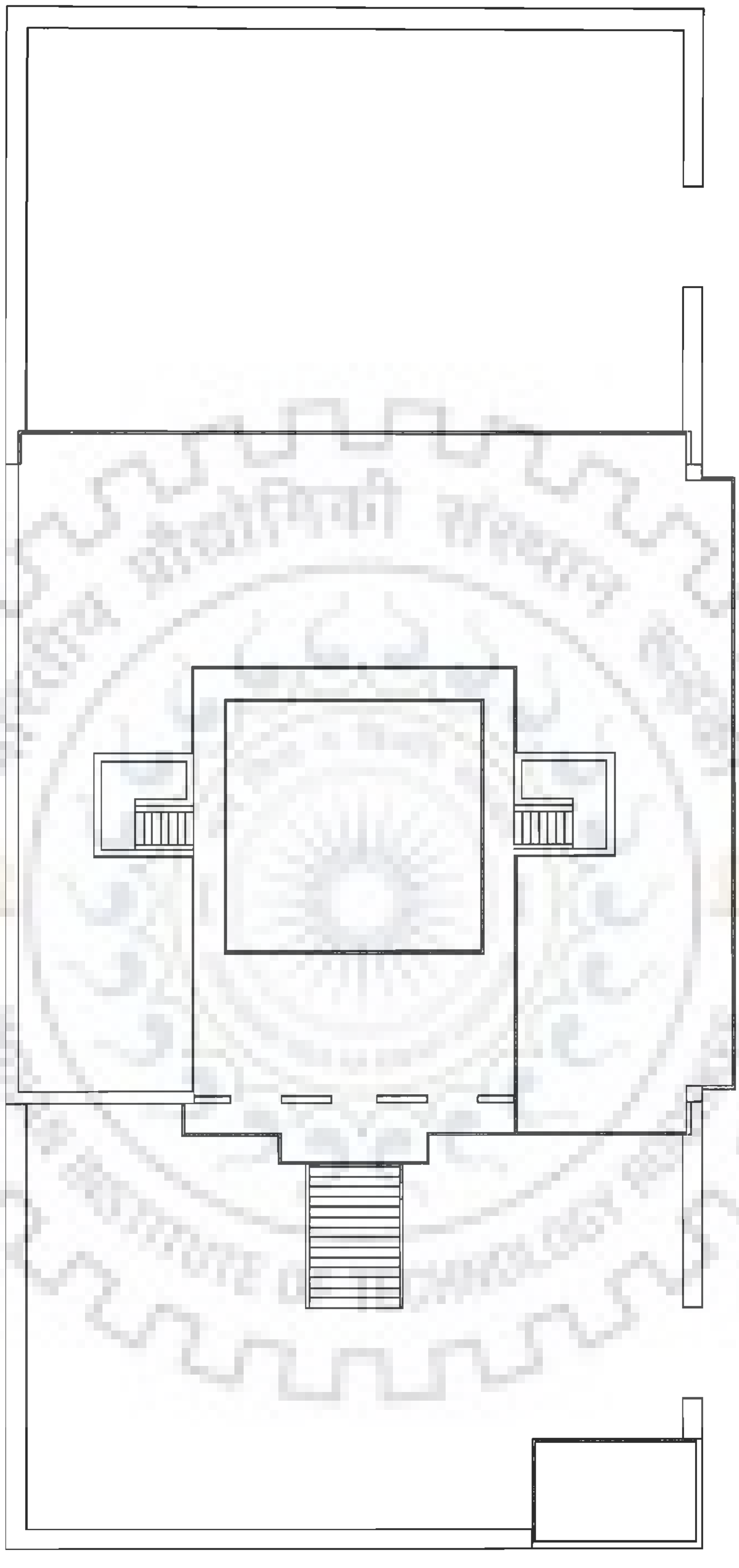
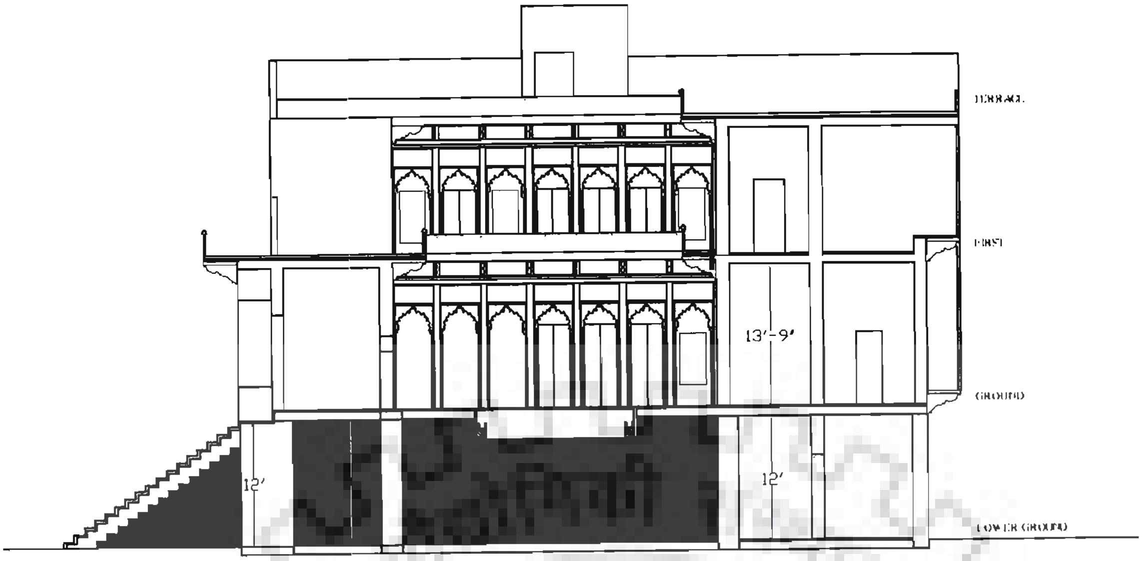


Drawing A-5.4.3: First Floor Plan

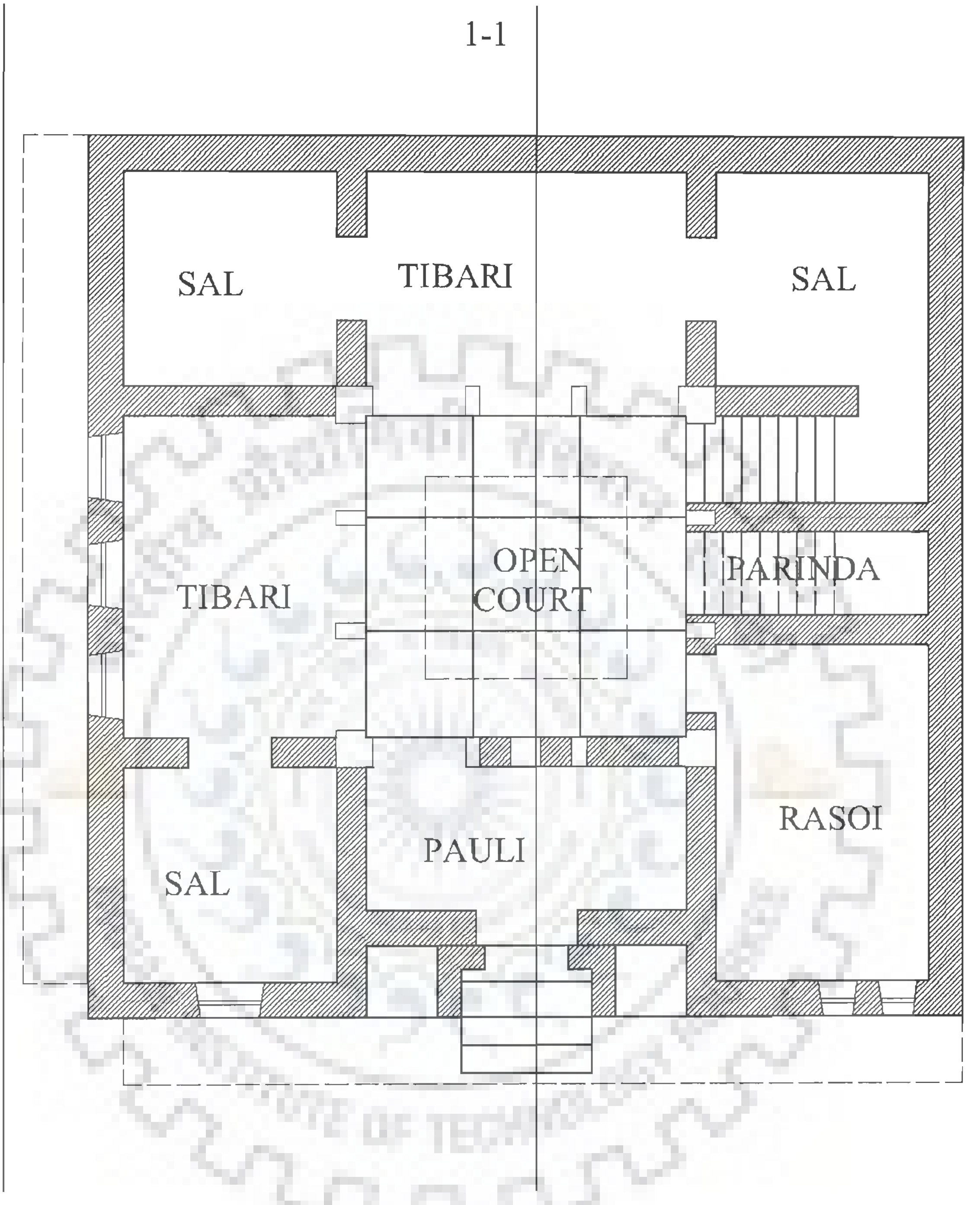


Drawing A-5.4.4: Terrace Floor Plan

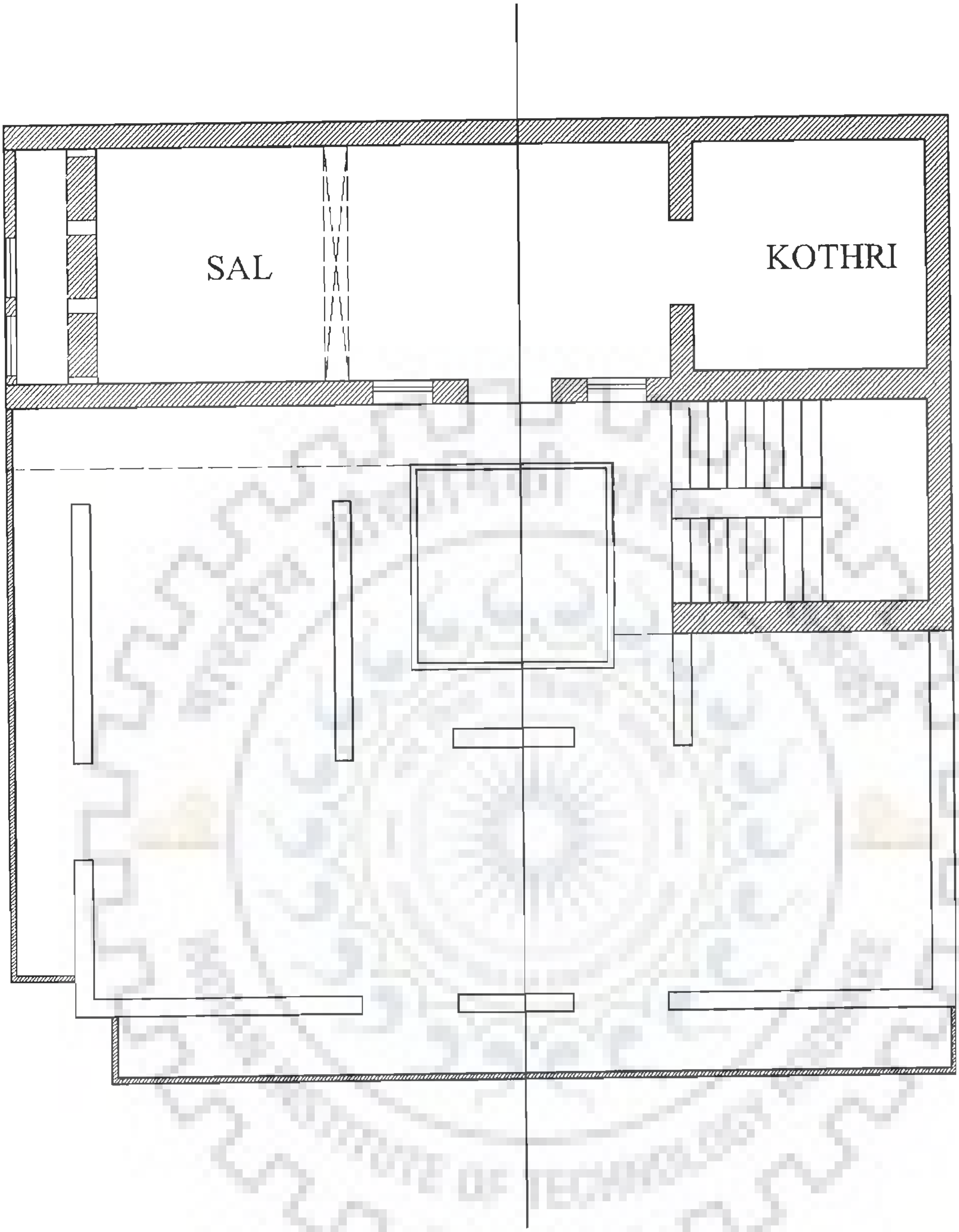


Drawing A-5.4.5: Section 1-1

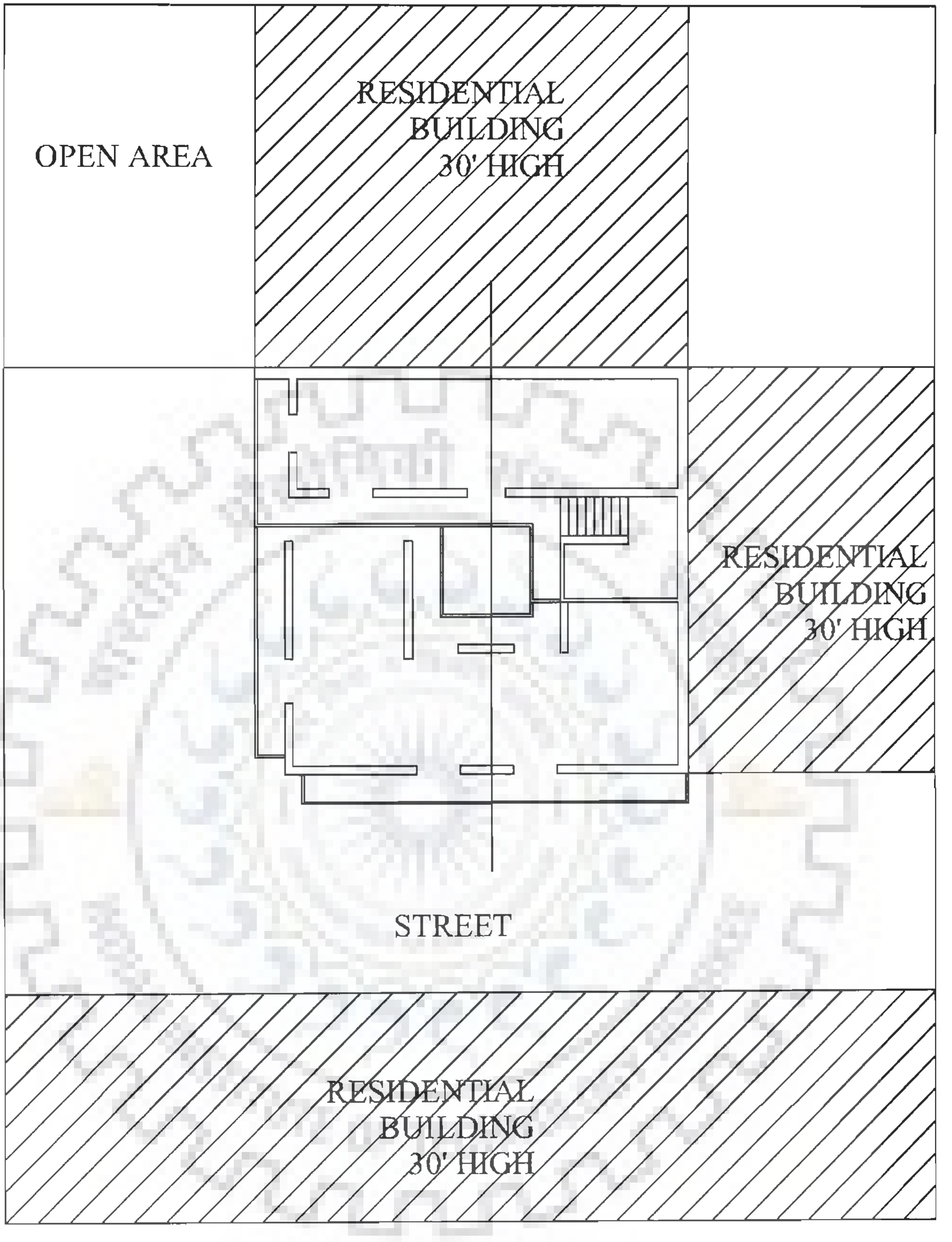
5. Sahumal Khetan Haveli, Mahensar



Drawing A-5.5.1: Ground Floor Plan



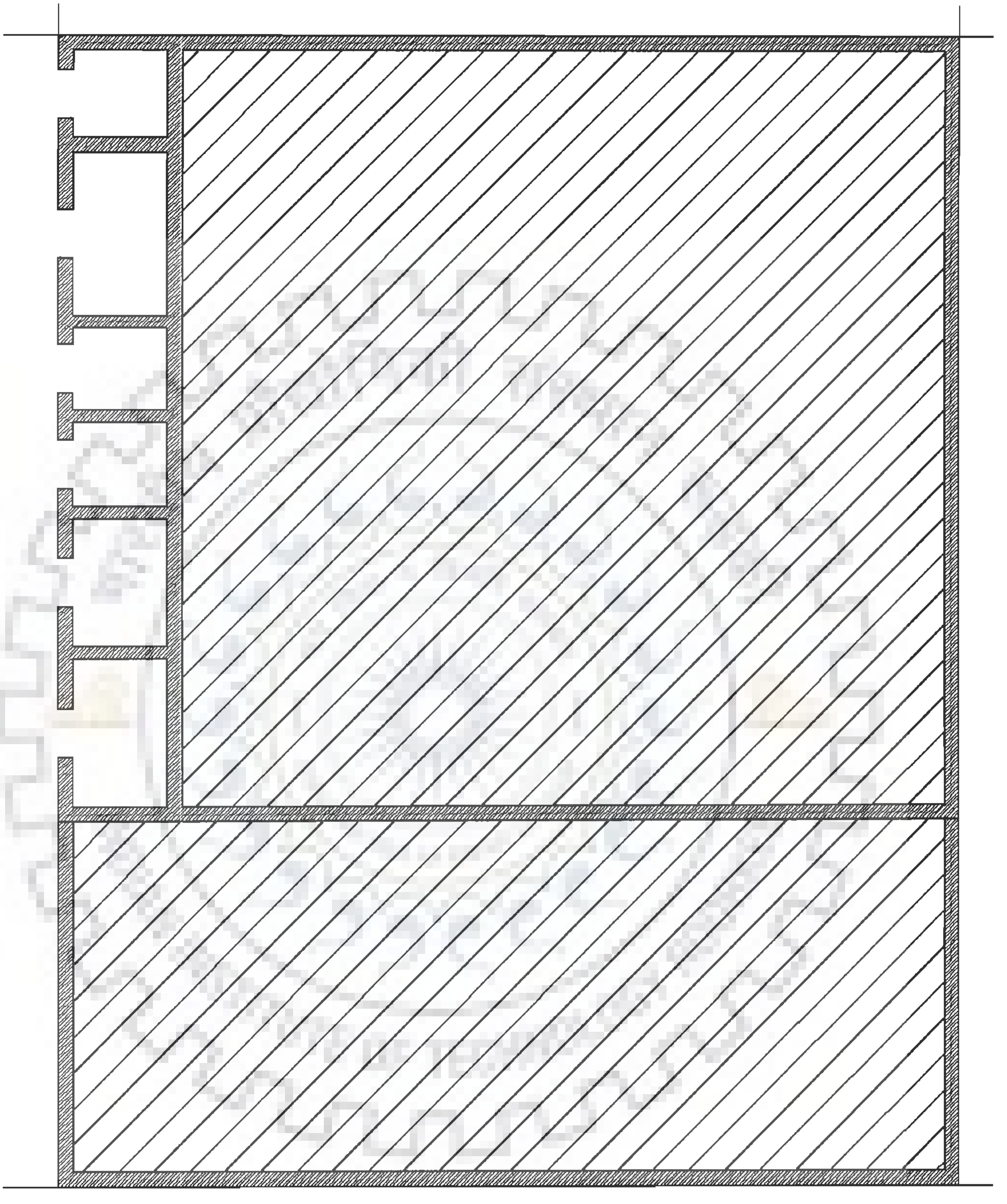
Drawing A-5.5.2: First Floor Plan



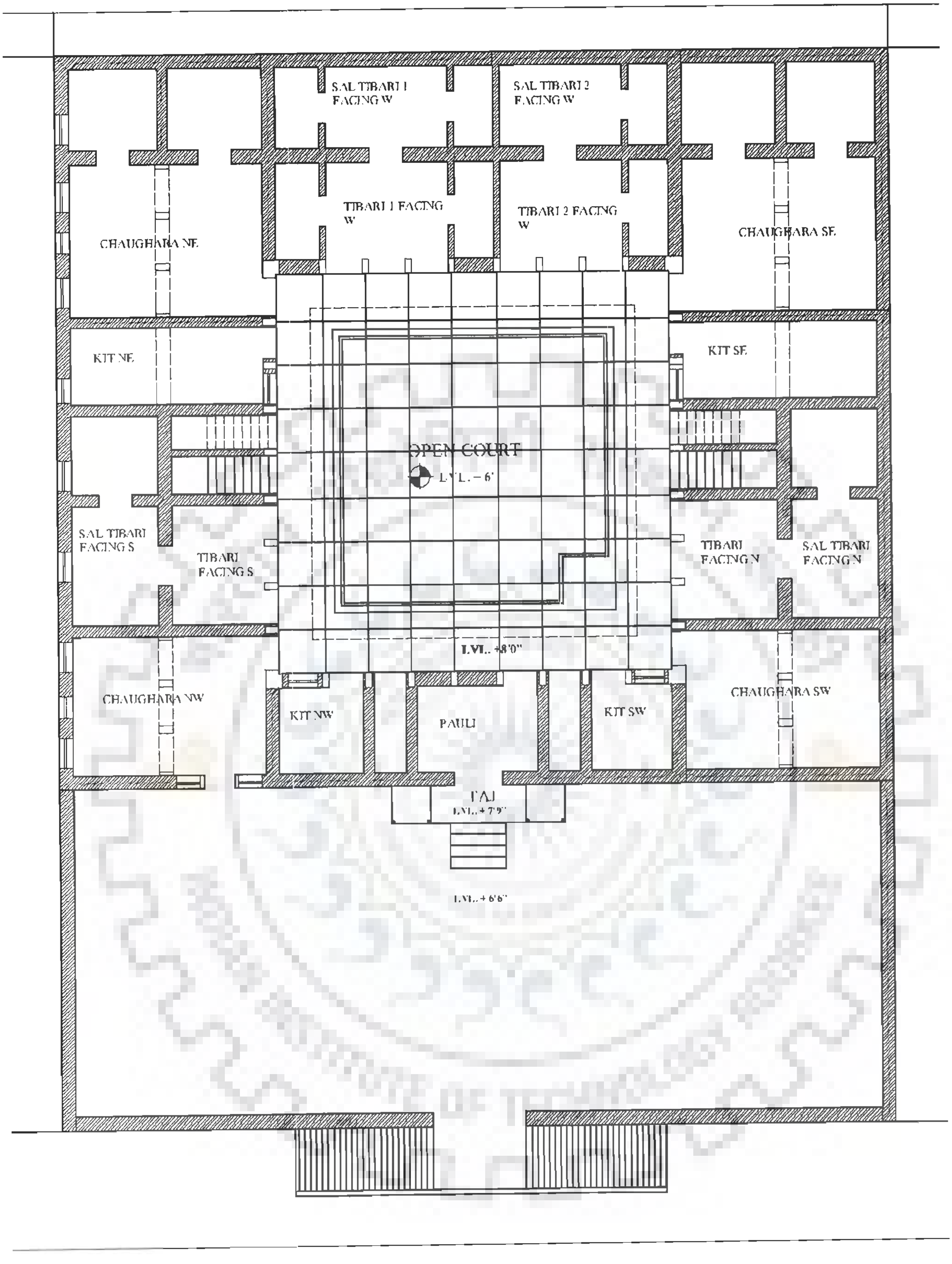
Drawing A-5.5.3: Terrace Floor Plan

Drawing A-5.5.4: Section 1-1

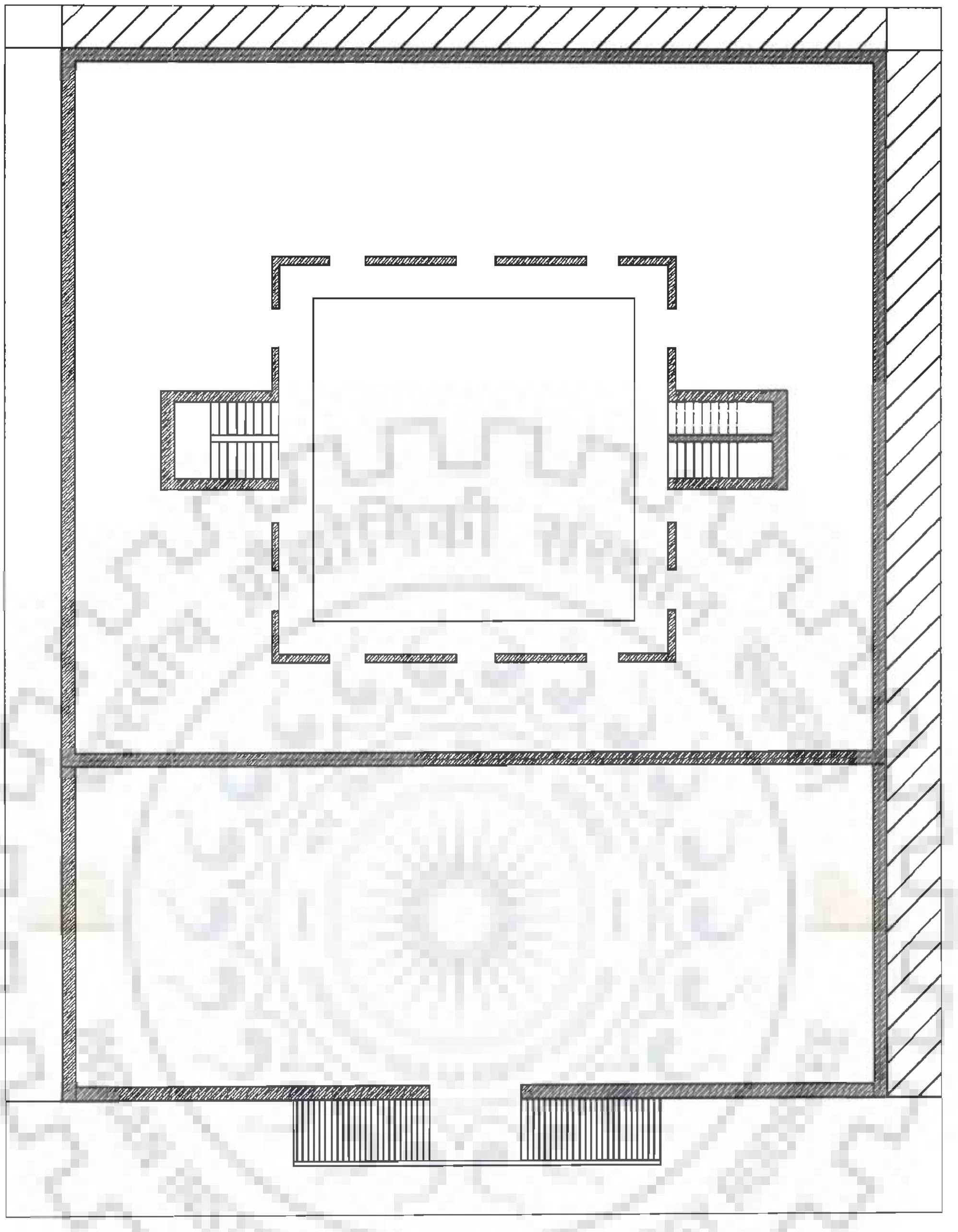
6. Sidhkaran ji Morarka Haveli, Mukundgarh



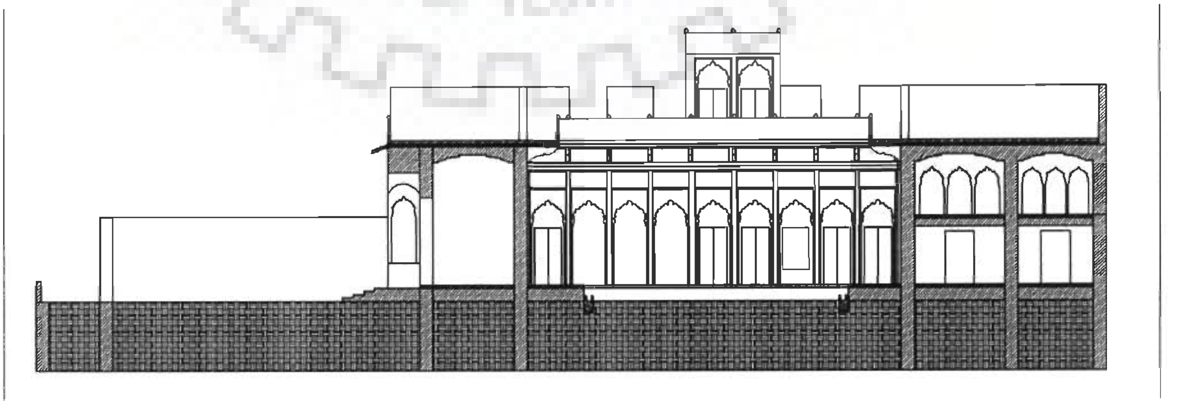
Drawing A-5.6.1: Lower Ground Floor Plan



Drawing A-5.6.2: Upper Ground Floor Plan

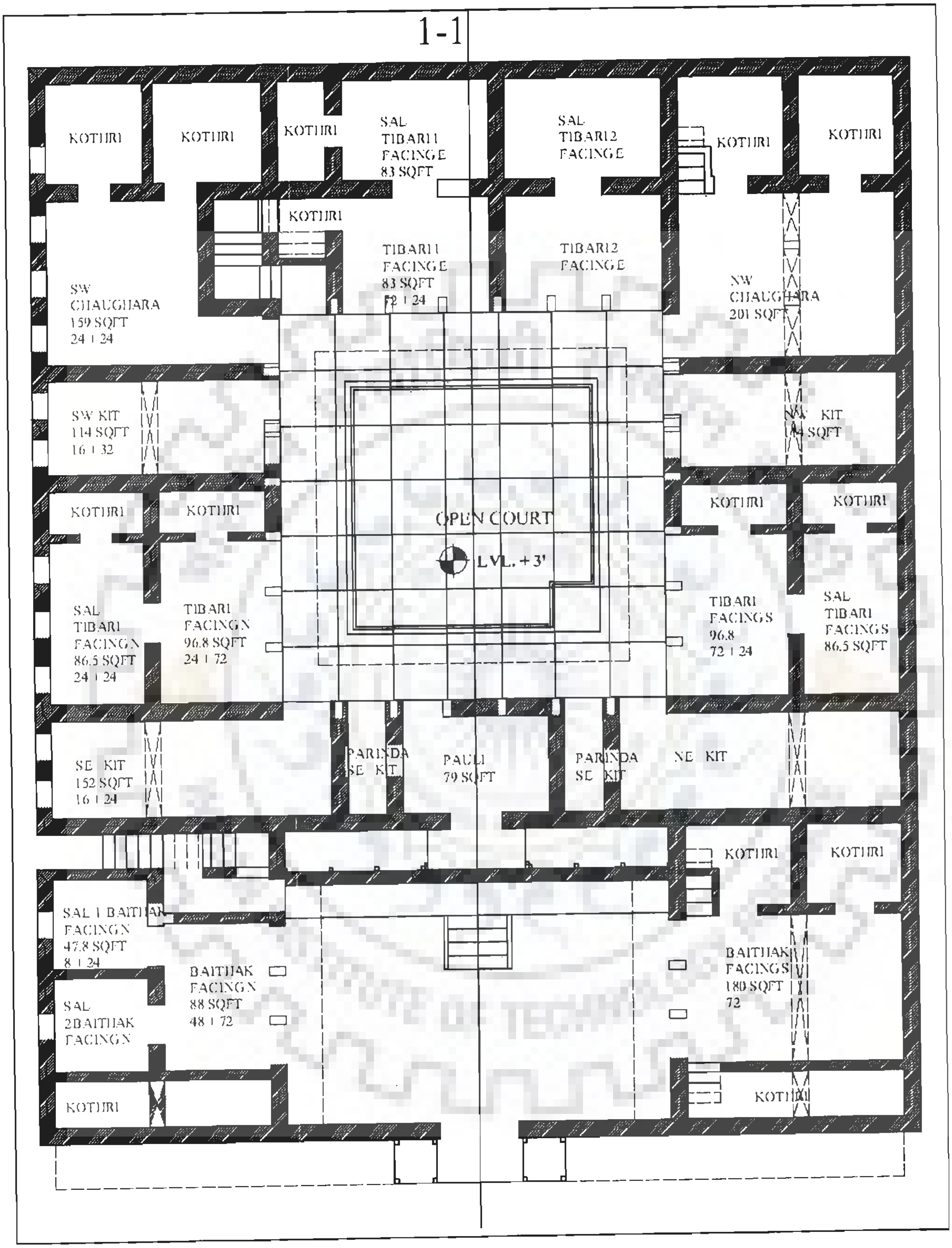


Drawing A-5.6.3: Terrace Floor Plan

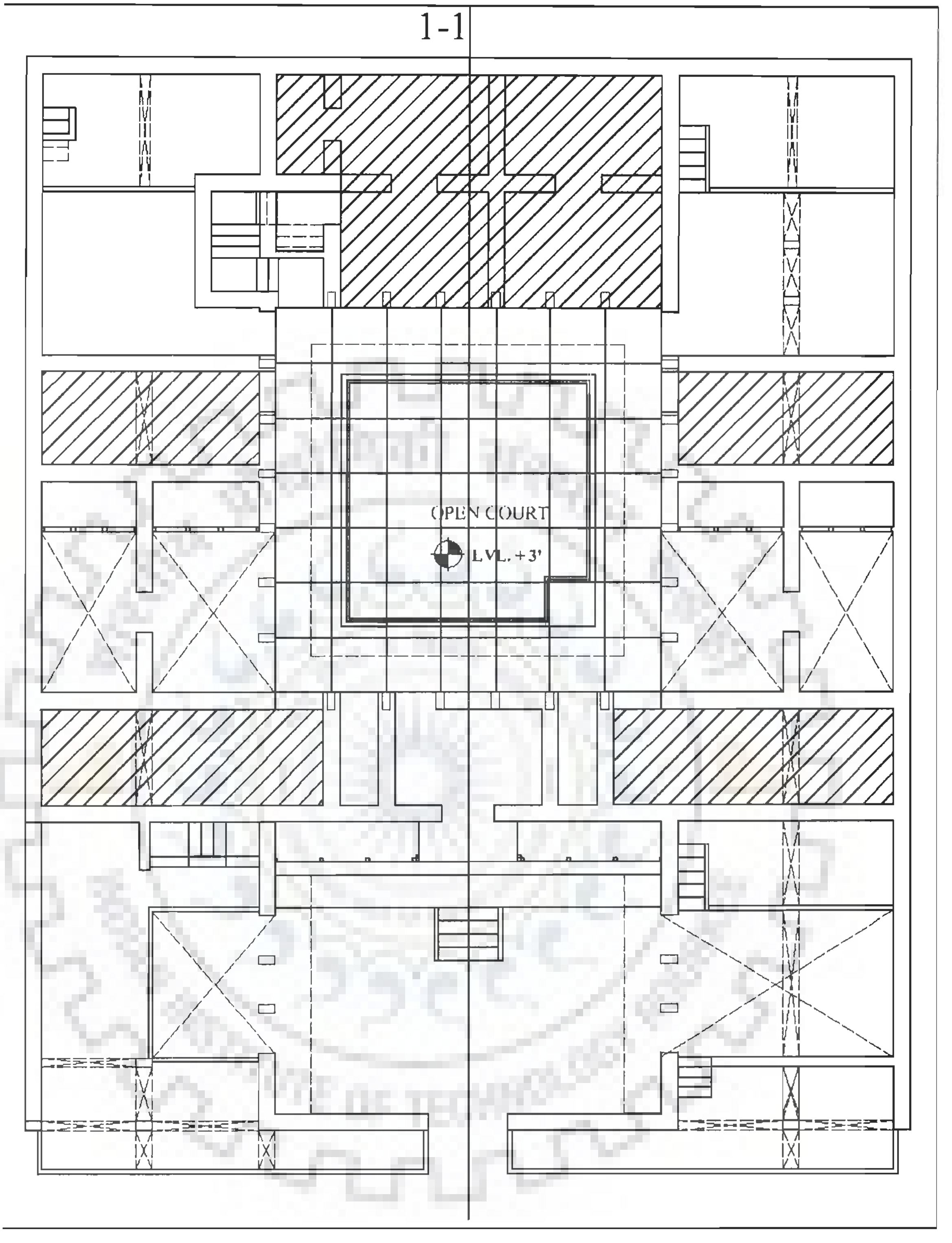


Drawing A-5.6.4: Section 1-1

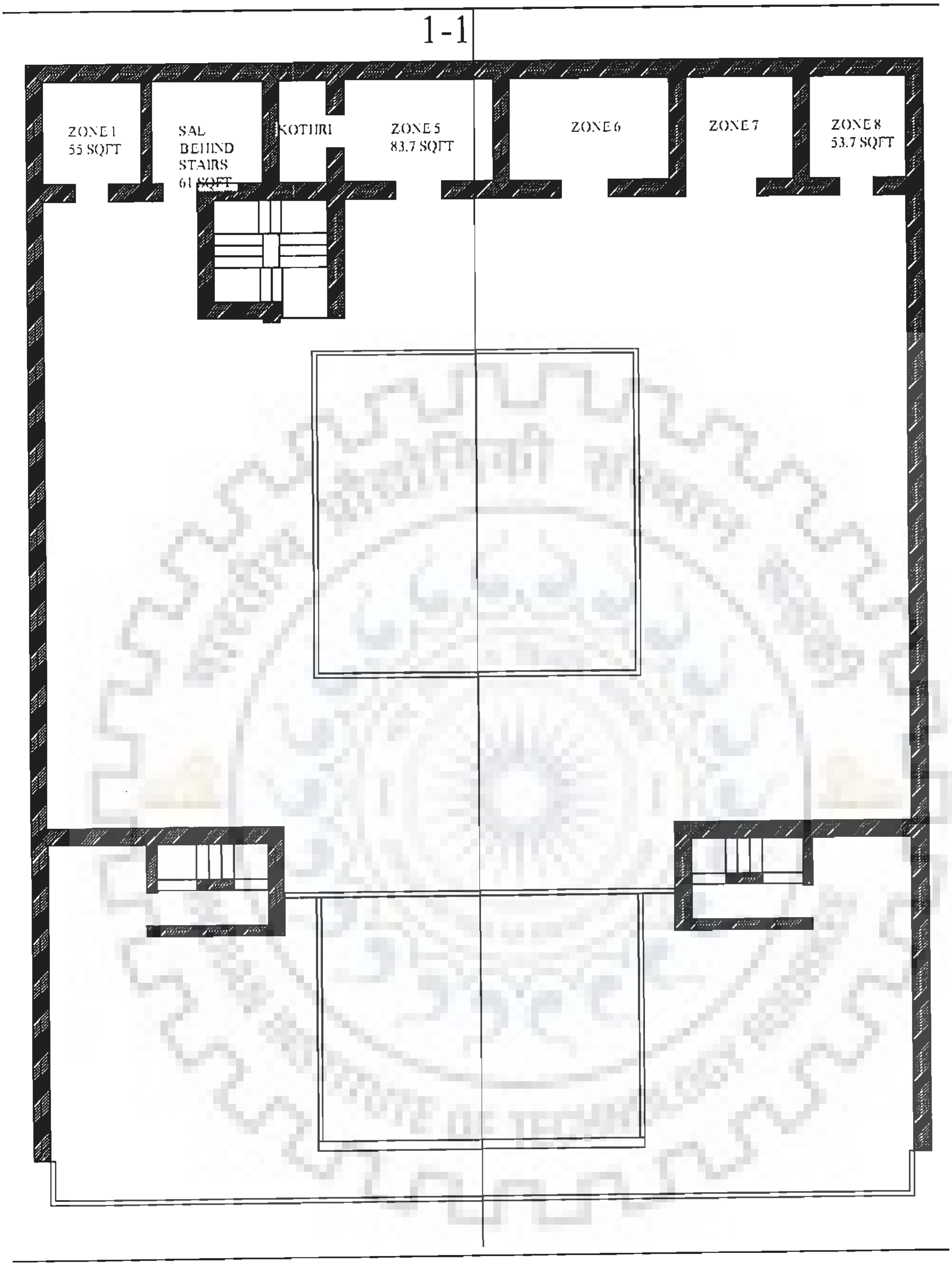
7. Babulal ji Gudha Haveli, Mukundgarh



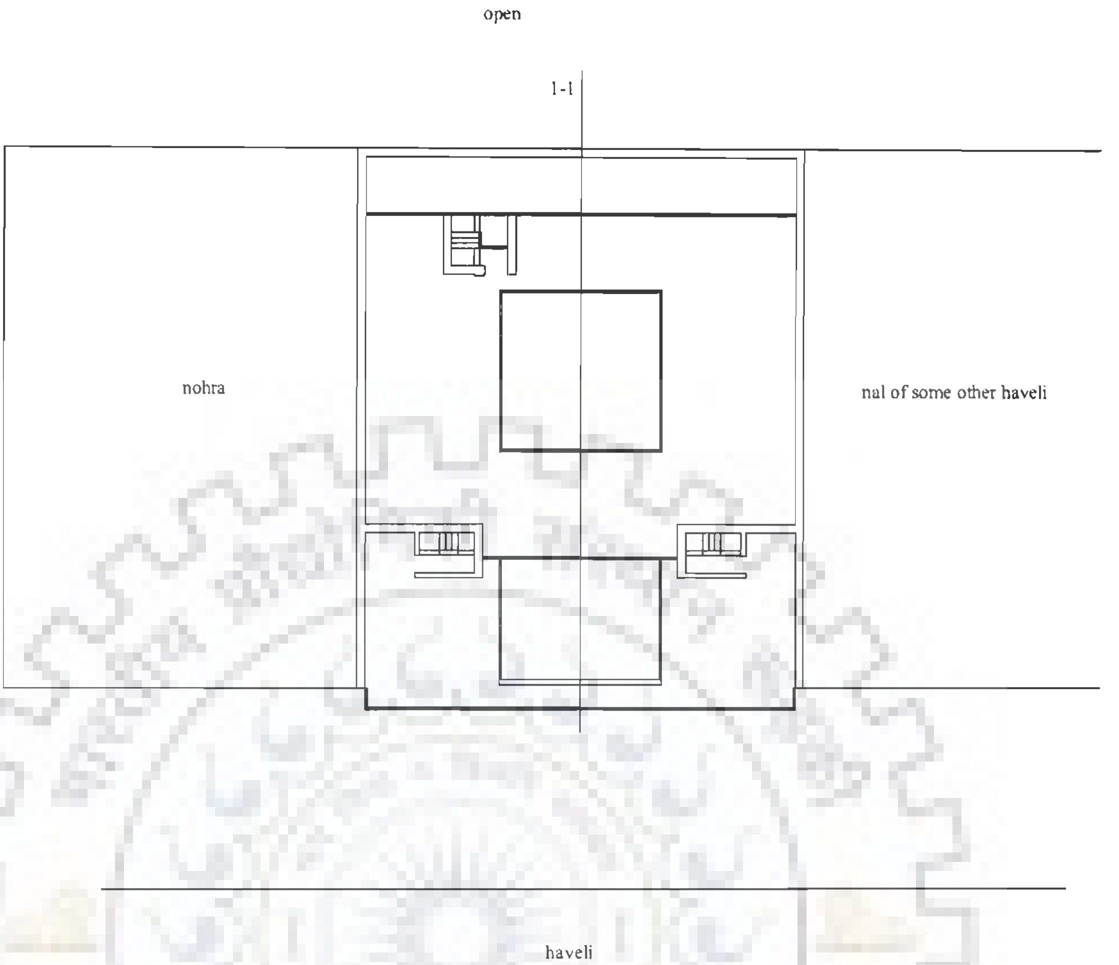
Drawing A-5.7.1: Upper Ground Floor Plan



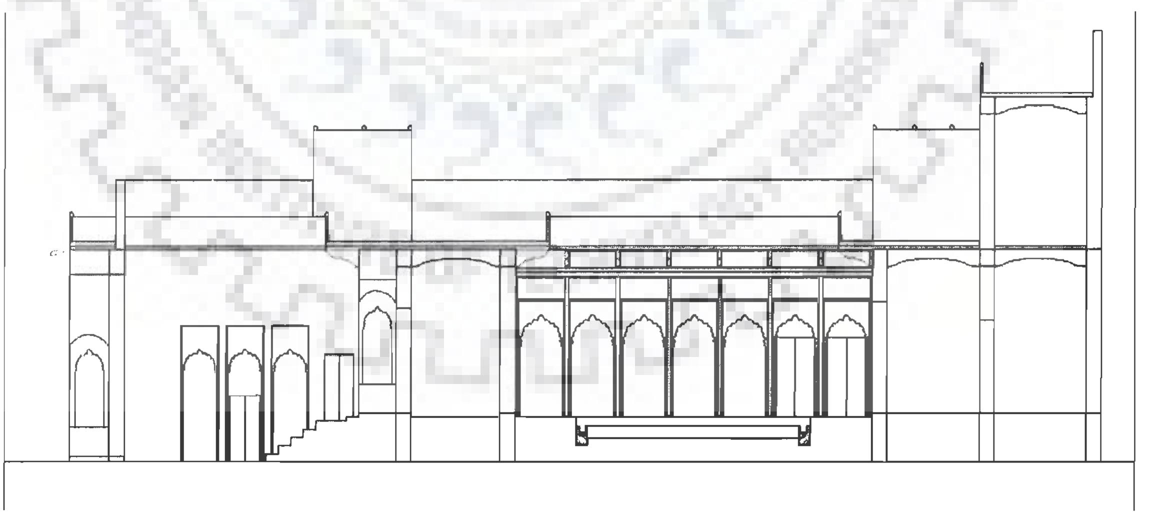
Drawing A-5.7.2: Mezzanine Floor Plan



Drawing A-5.7.3: First Floor Plan

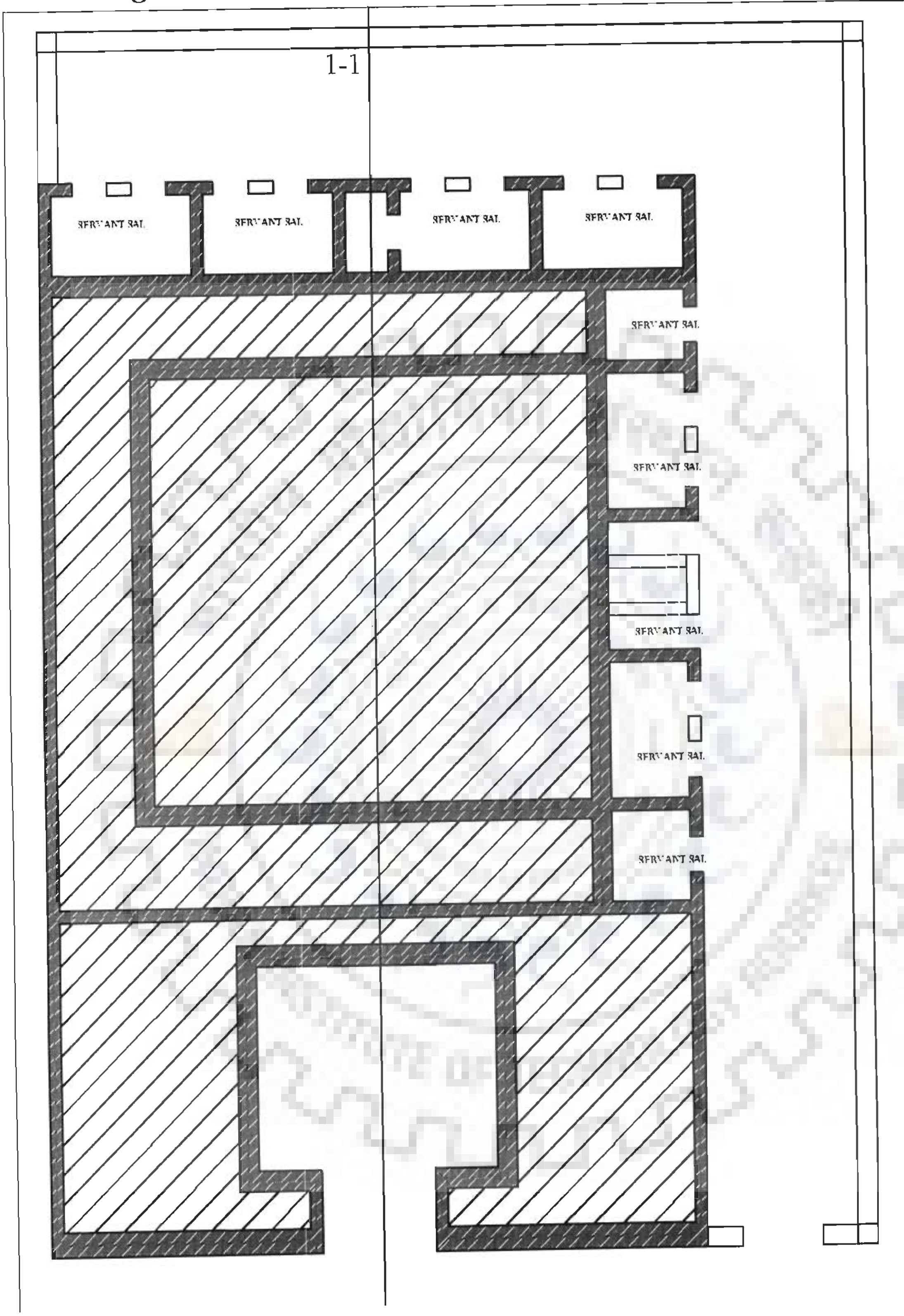


Drawing A-5.7.4: Terrace Floor Plan

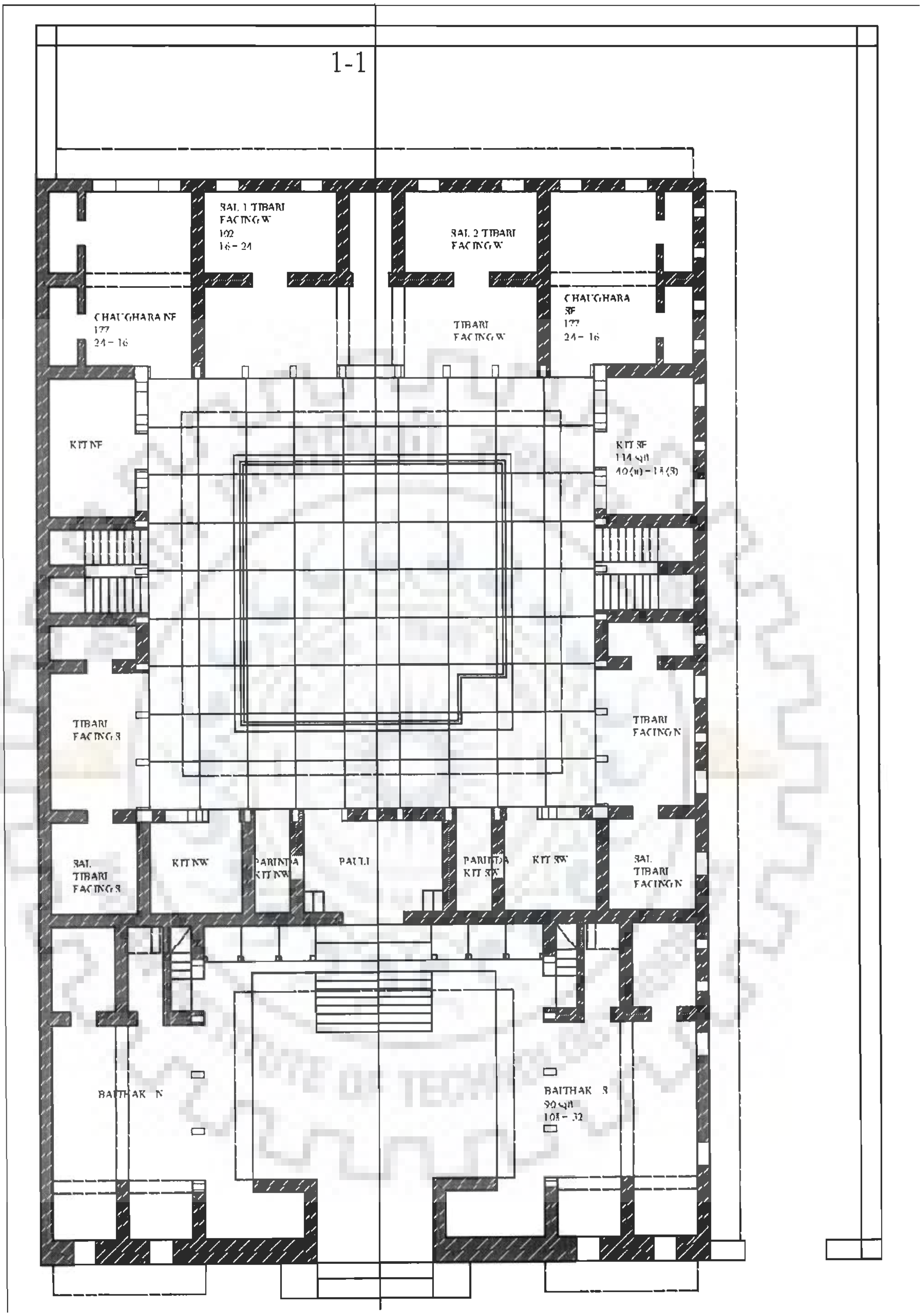


Drawing A-5.7.5: Section at 1-1

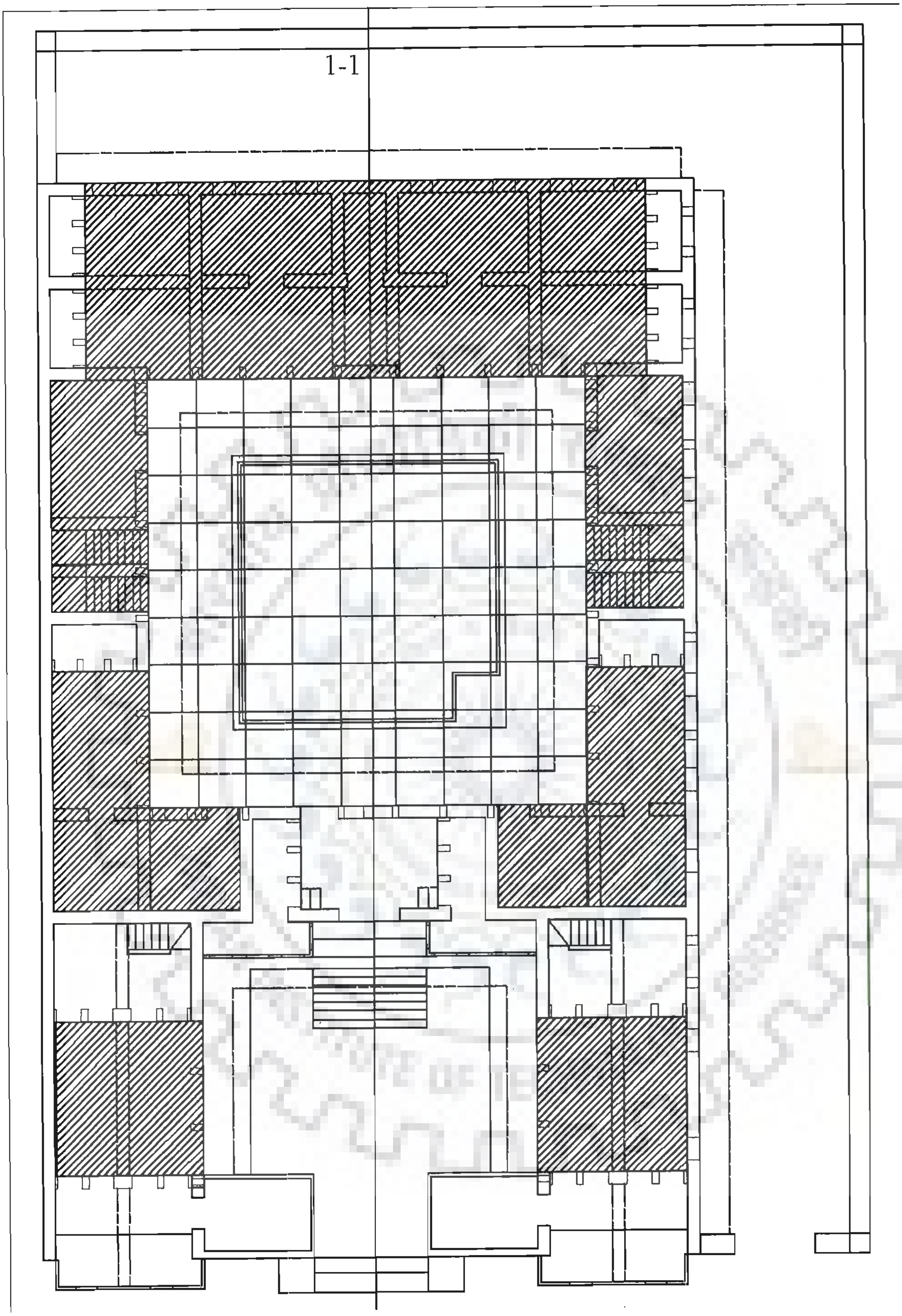
8. Bhagirath Kedarmal Goenka Haveli, Dondlod



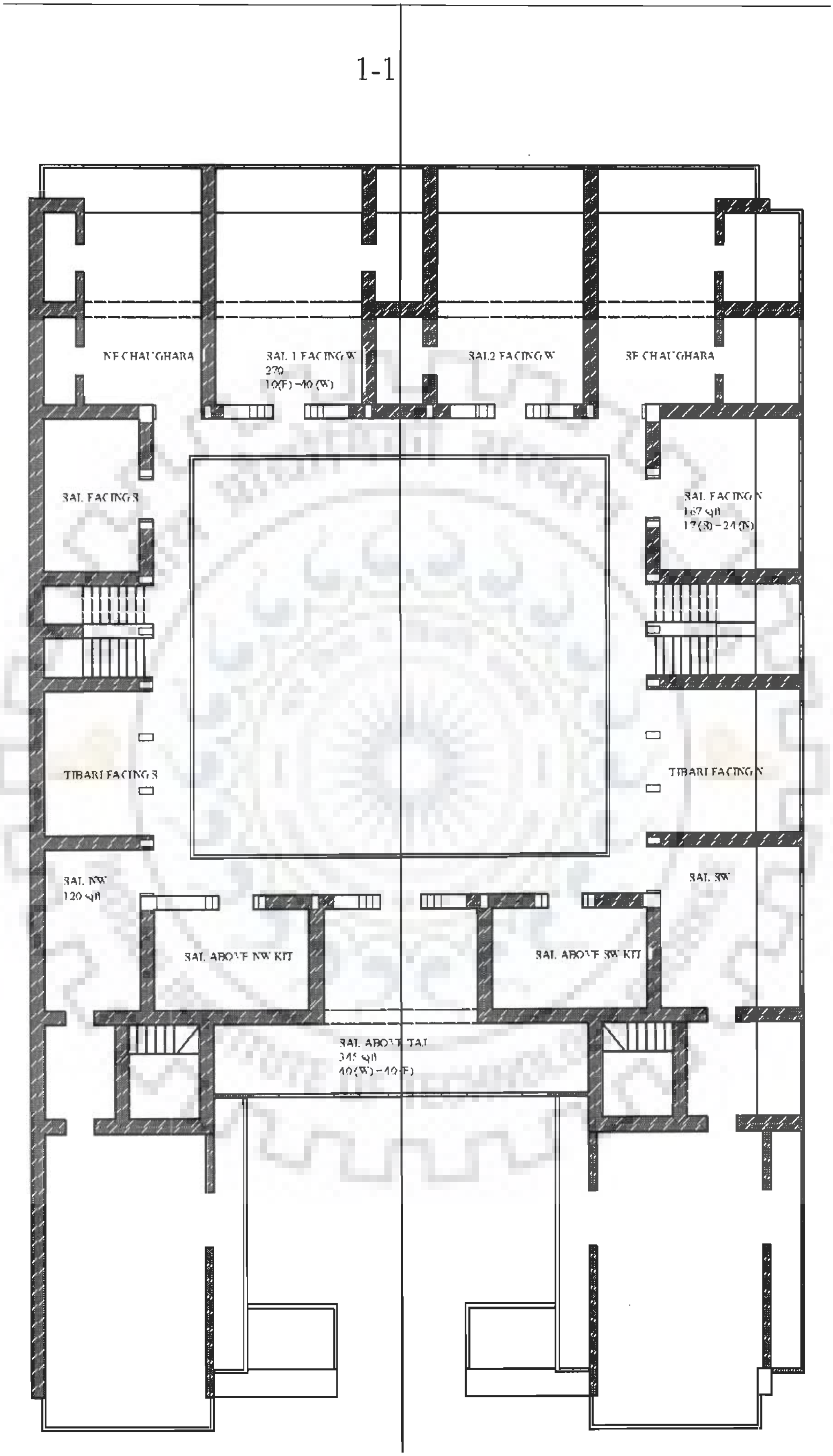
Drawing A-5.8.1: Lower Ground Floor Plan



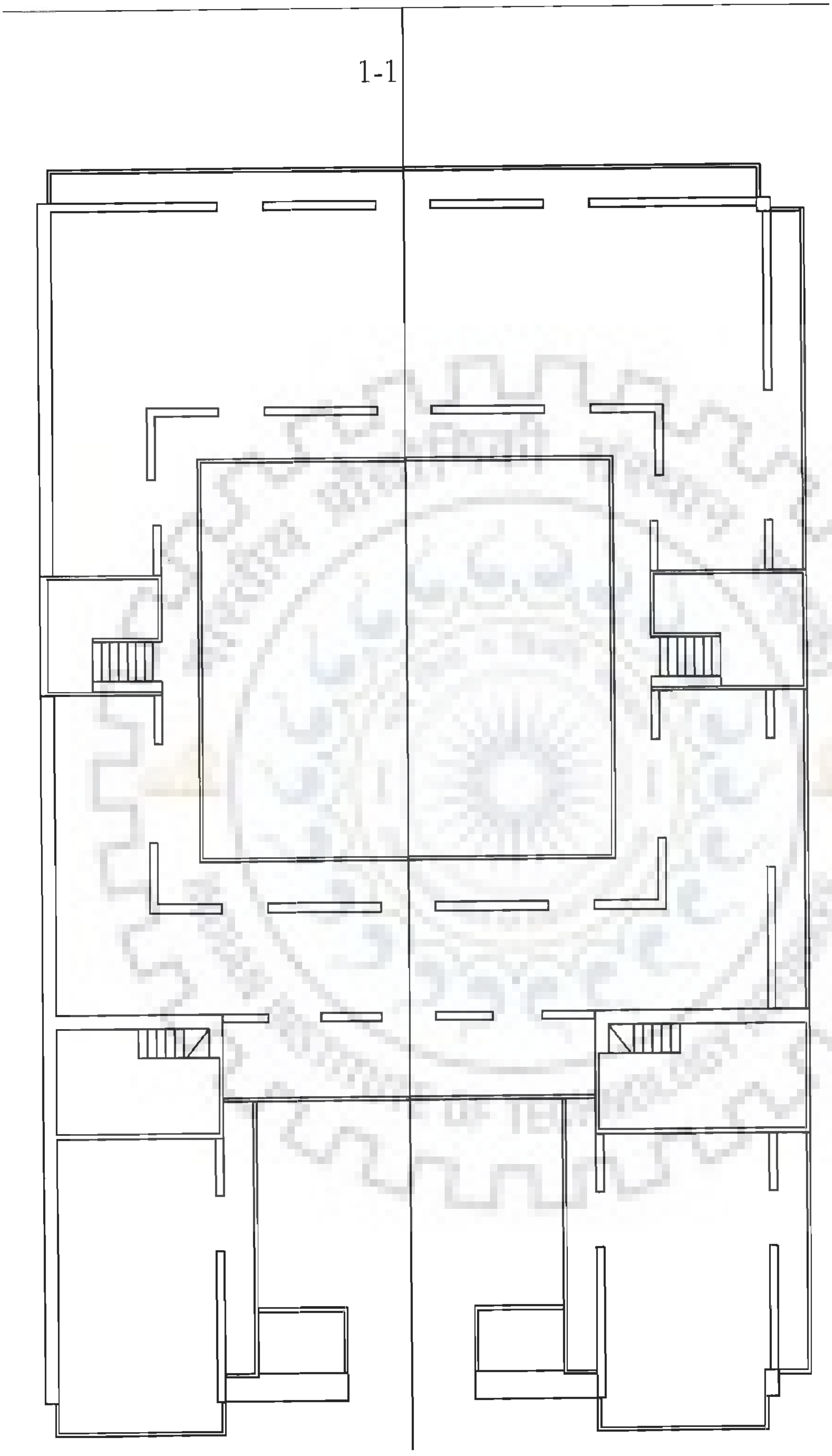
Drawing A-5.8.2: Upper Ground Floor Plan



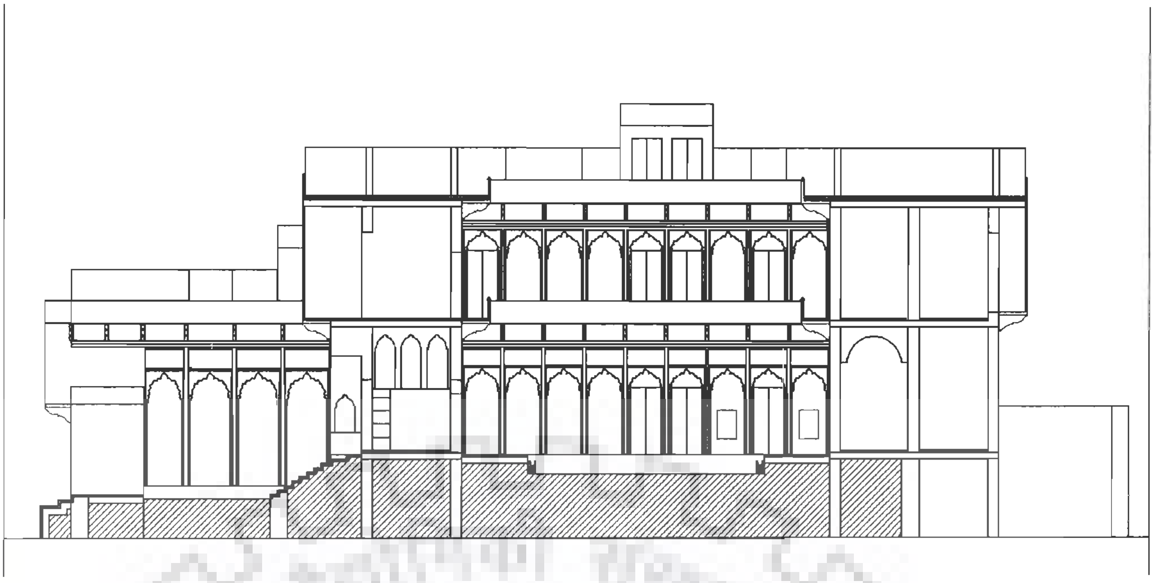
Drawing A-5.8.3: Mezzanine Floor Plan



Drawing A-5.8.4: First Floor Plan

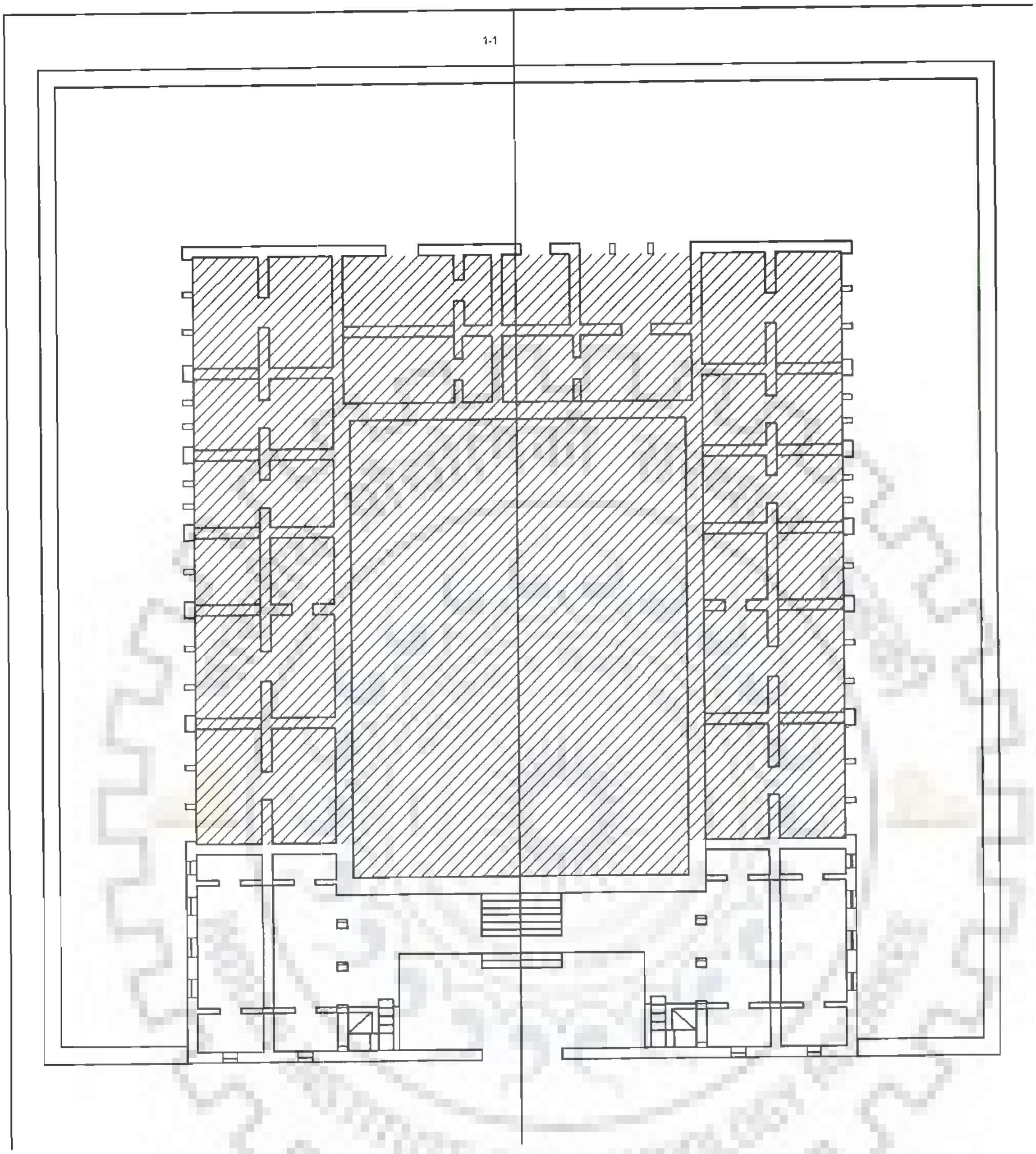


Drawing A-5.8.5: Terrace Floor Plan

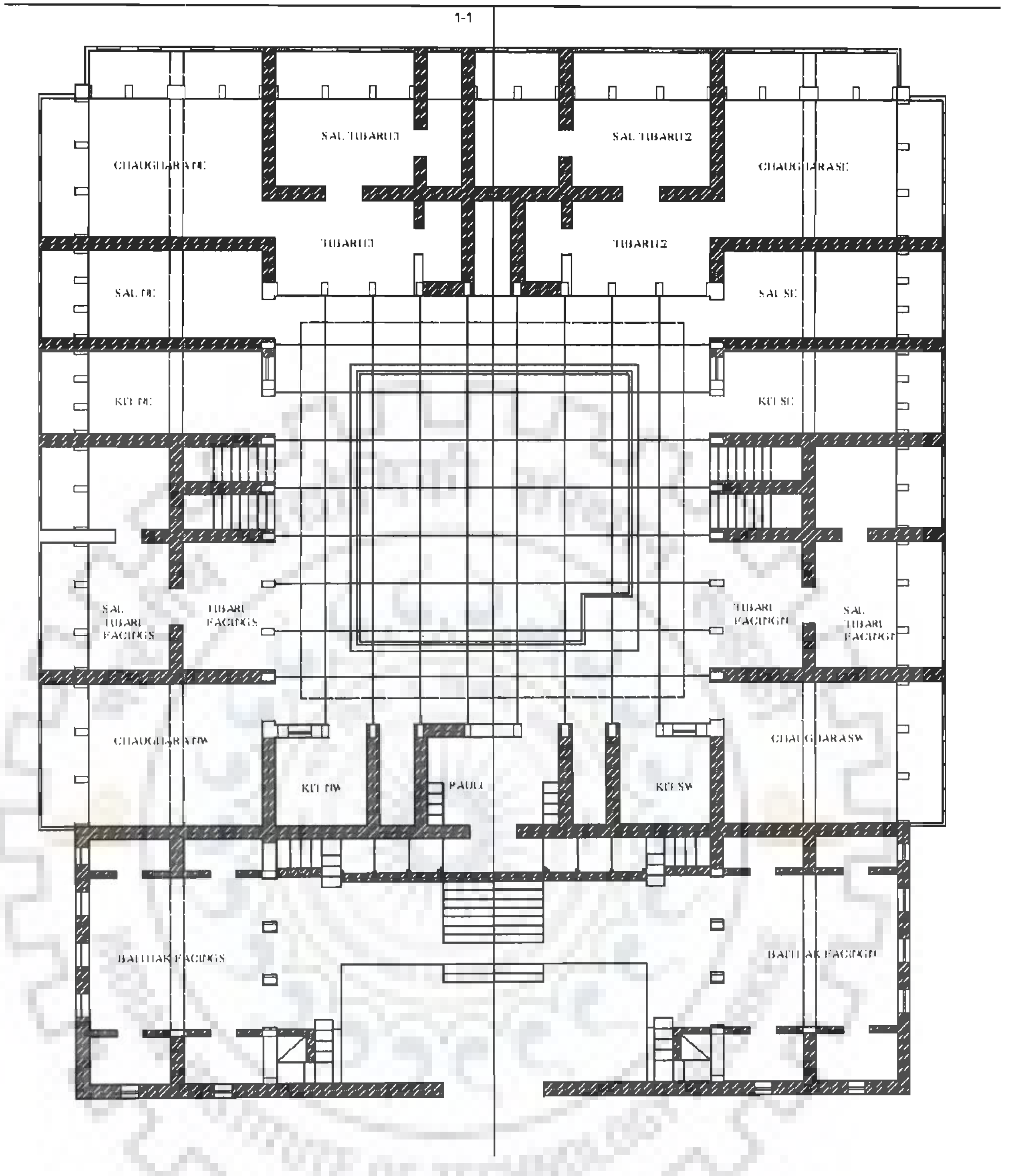


Drawing A-5.8.6: Section at 1-1

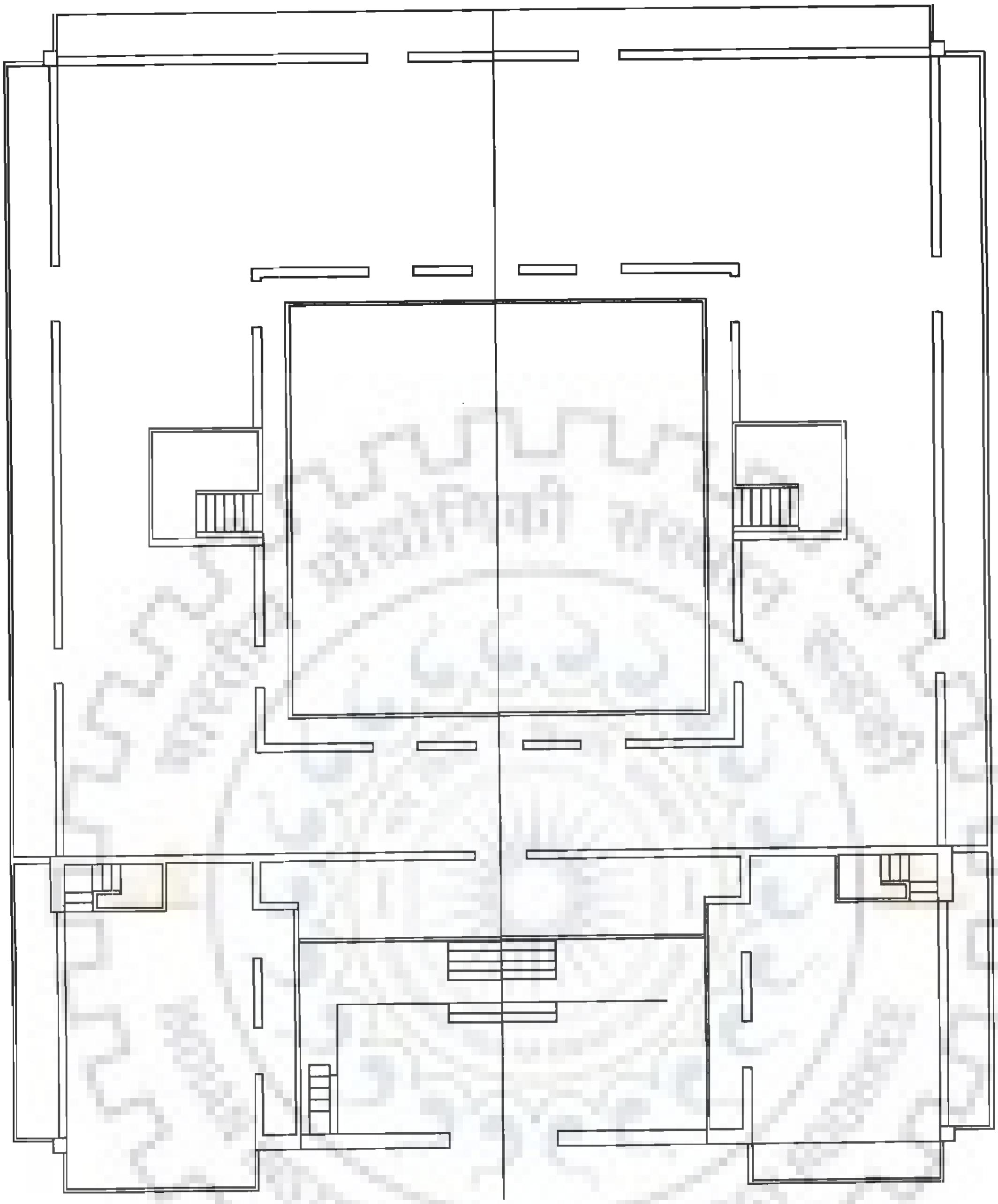
9. Bissau Haveli



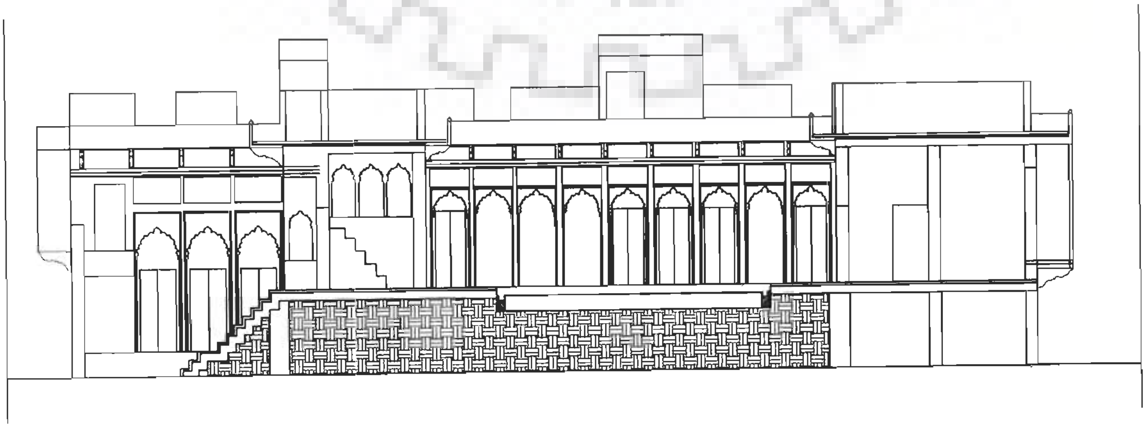
Drawing A-5.9.1: Lower Ground Floor Plan



Drawing A-5.9.2: Upper Ground Floor Plan

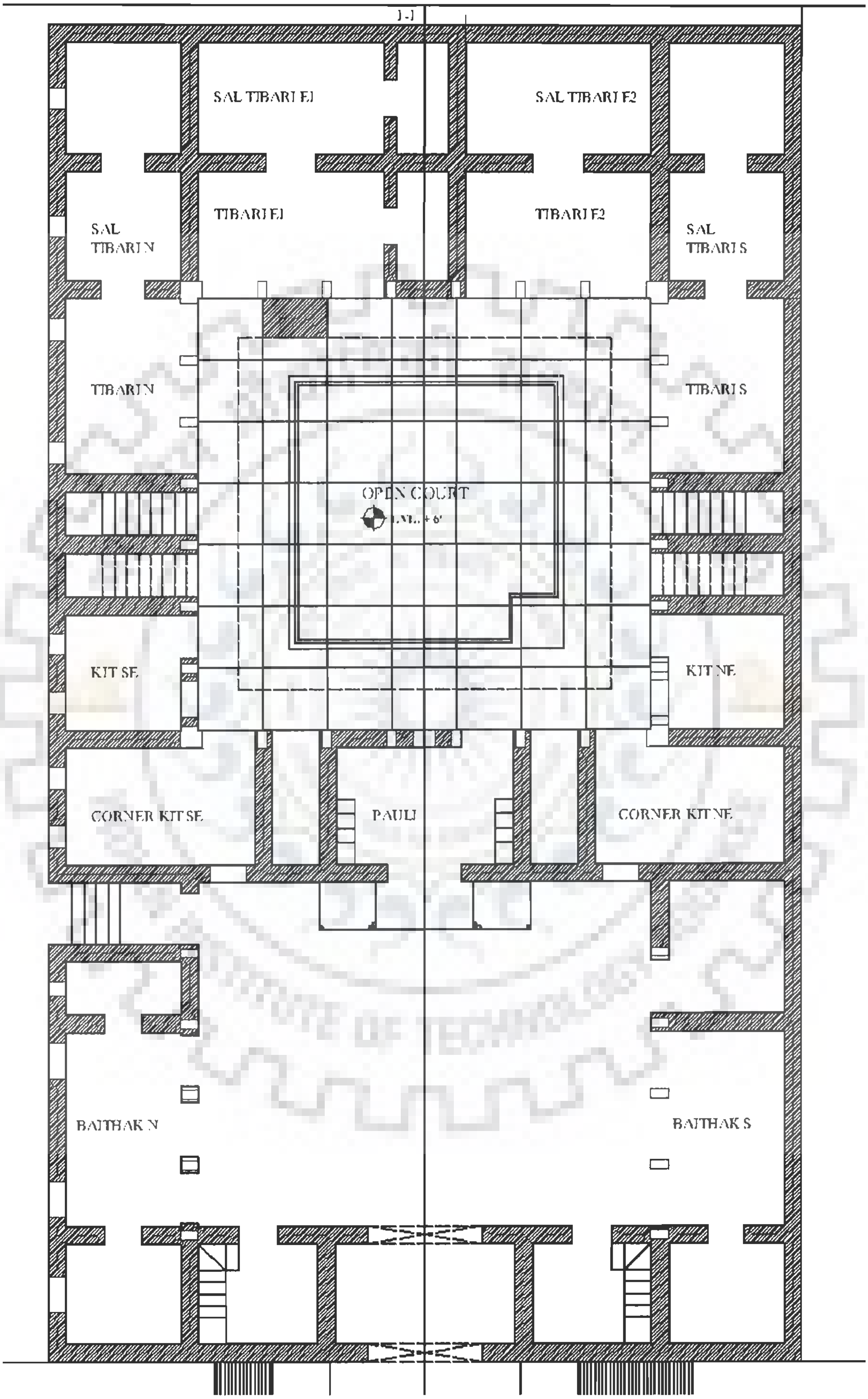


Drawing A-5.9.3: Terrace Floor Plan

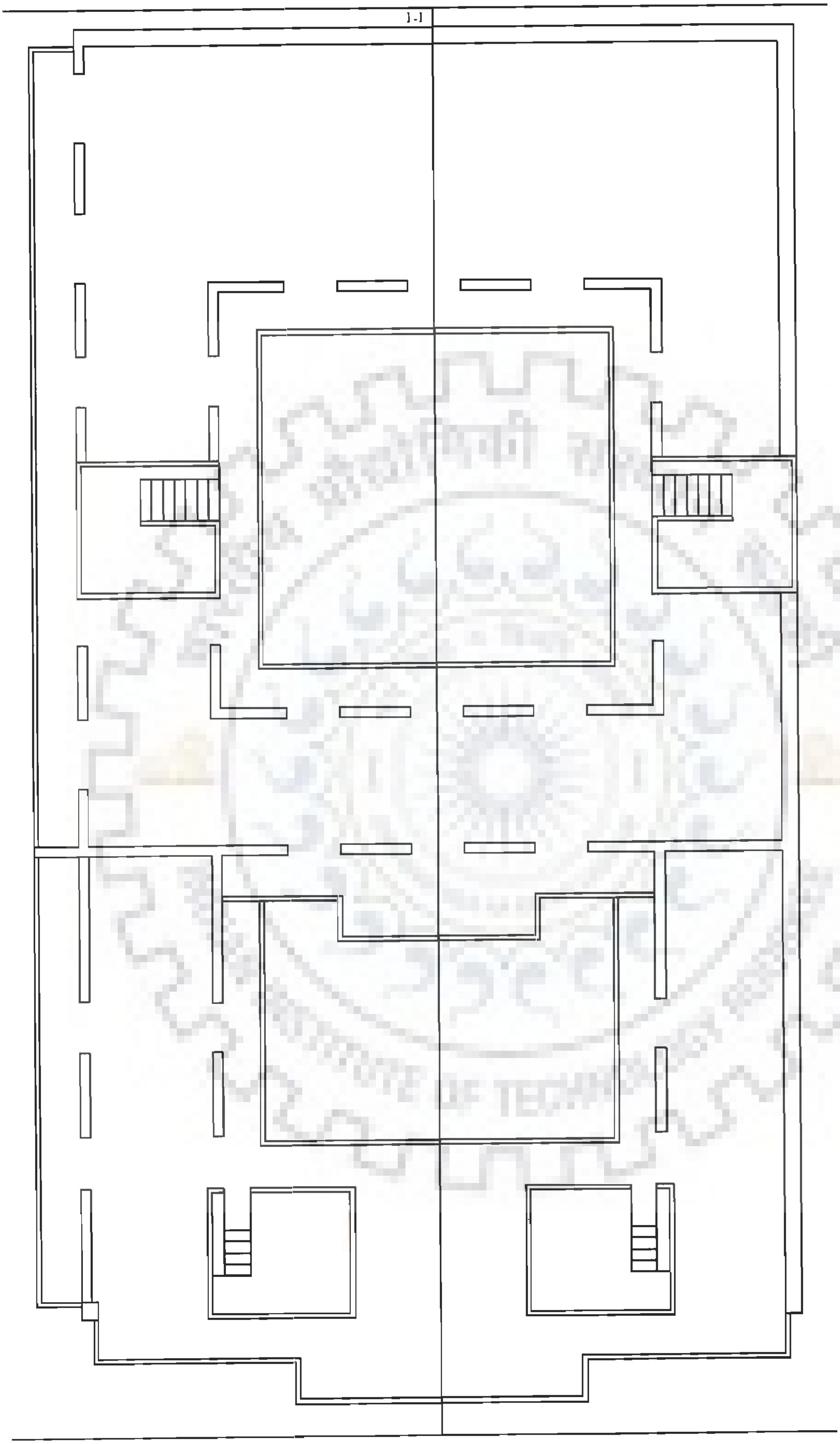


Drawing A-5.9.4: Section 1-1

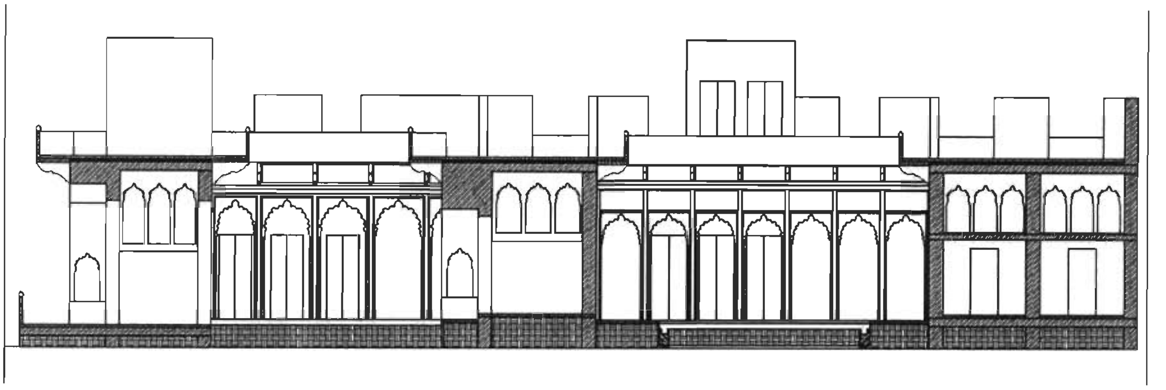
10. Damodar Prasad Morarka Haveli, Mukundgarh



Drawing A-5.10.1: Ground Floor Plan

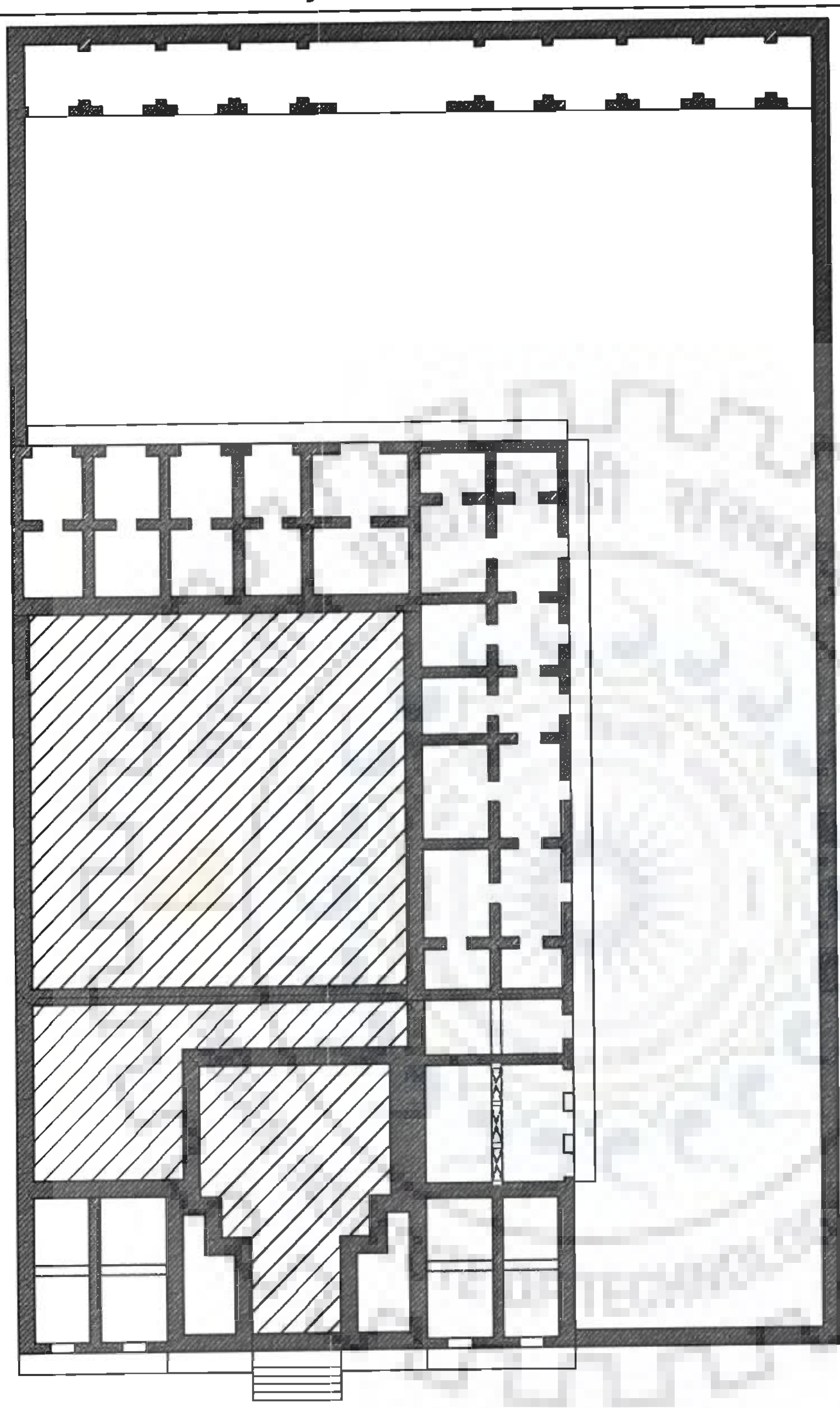


Drawing A-5.10.2: Terrace Floor Plan

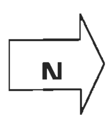


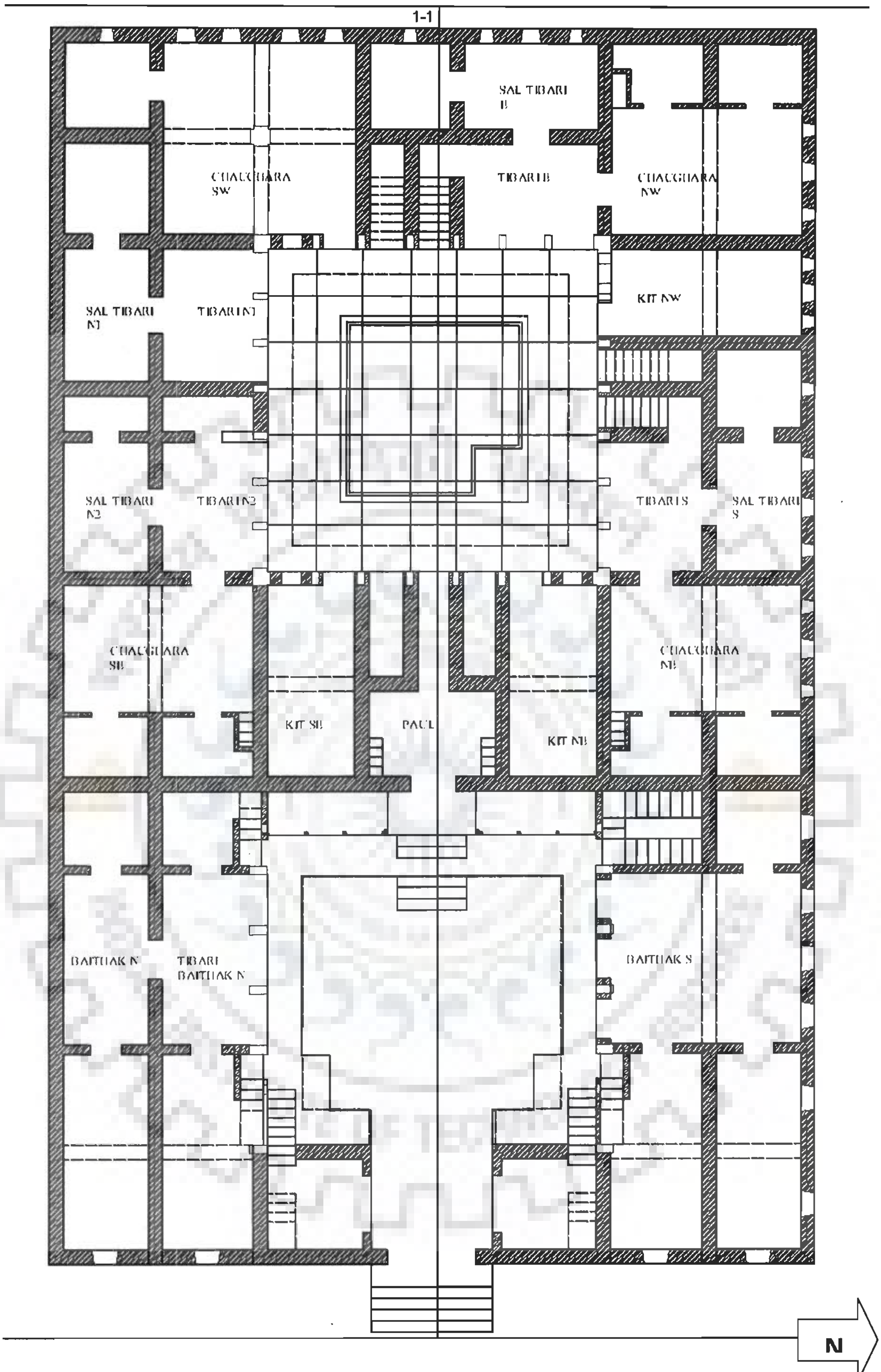
Drawing A-5.10.3: Section 1-1

11 Haveli used as Gymnasium, Dundlod

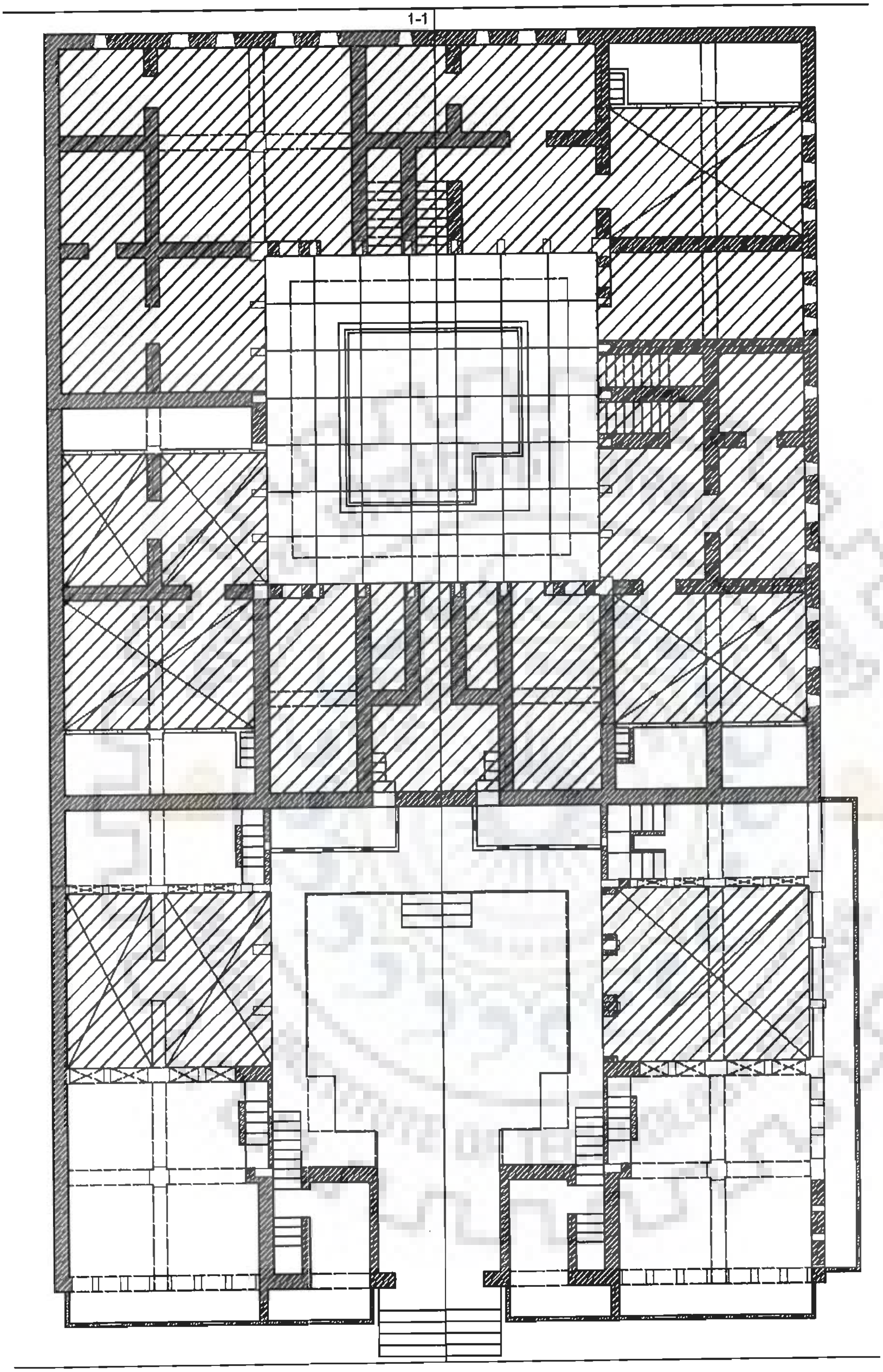


Drawing A-5.11.1: Lower Ground Floor Plan

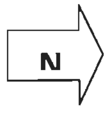


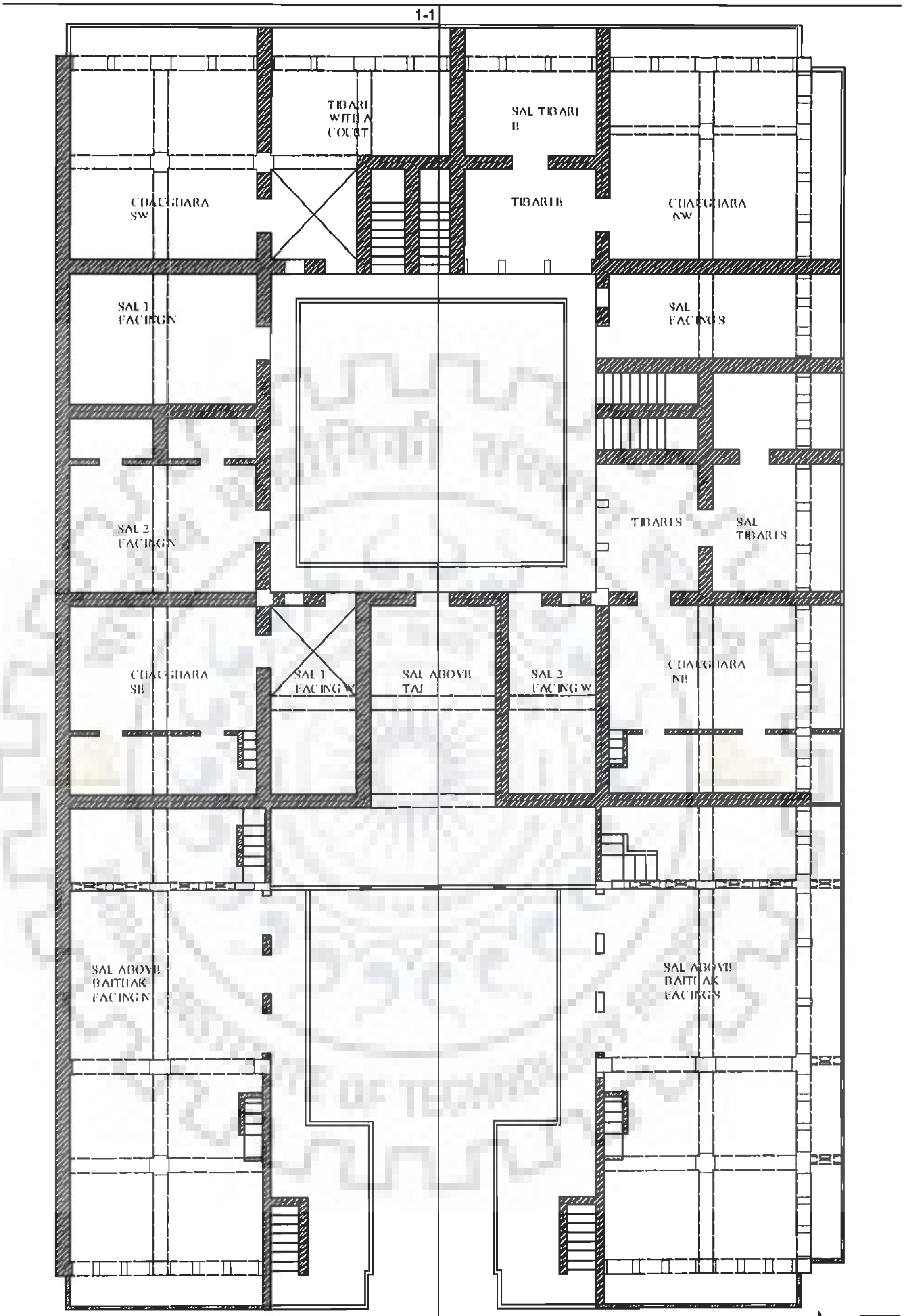


Drawing A-5.11.2: Upper Ground Floor Plan

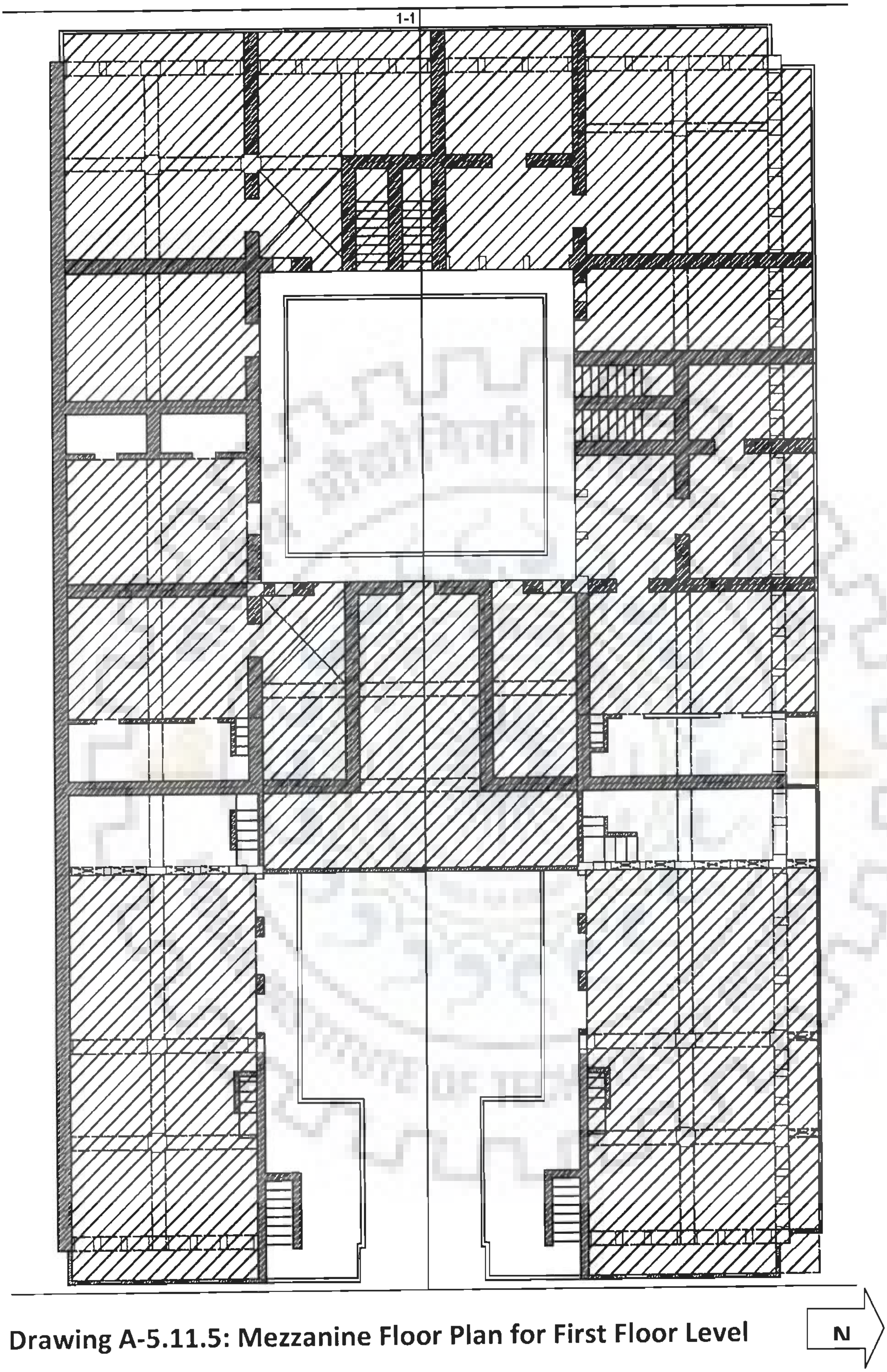


Drawing A-5.11.3: Mezzanine Floor Plan for Upper Ground Level

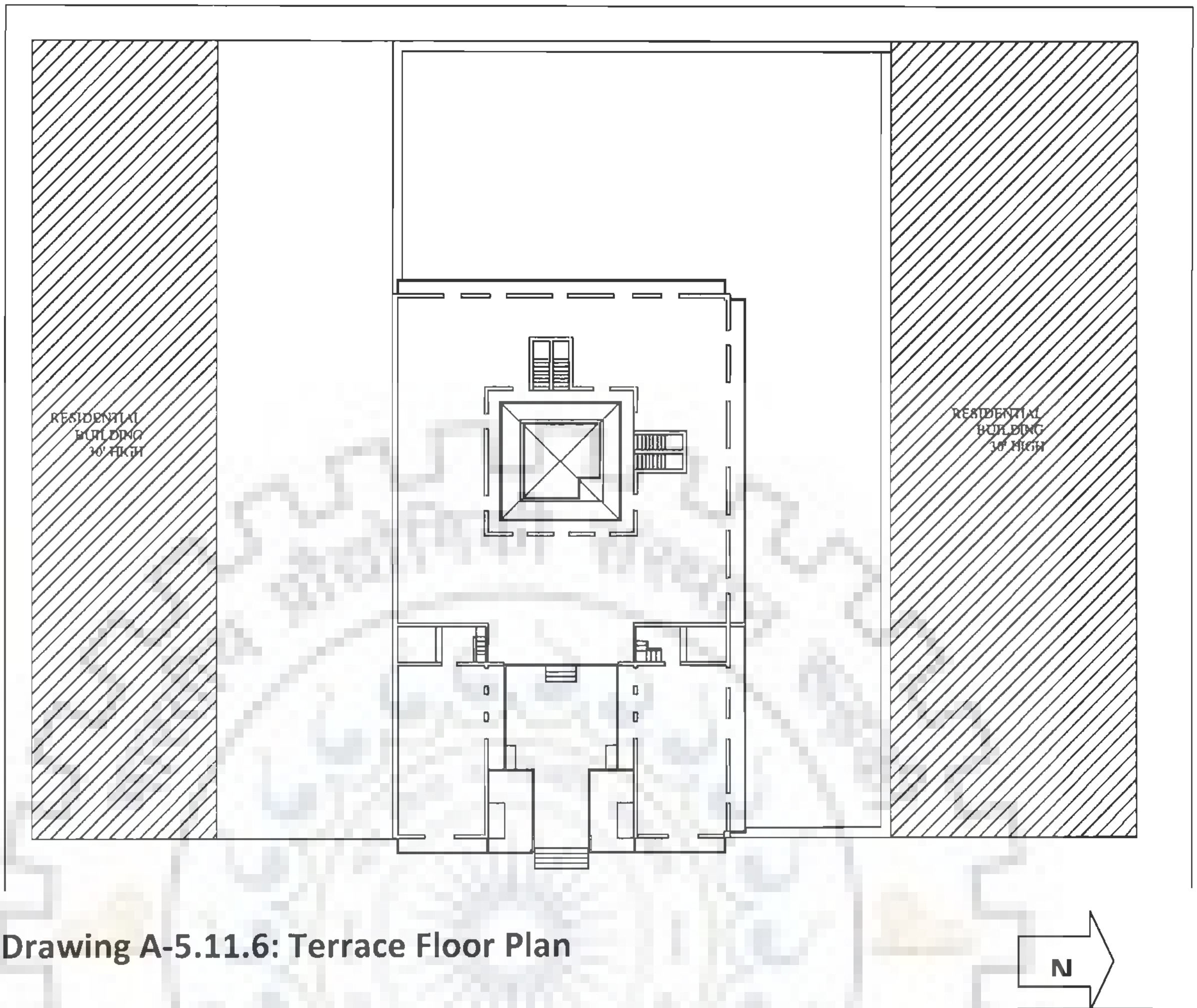




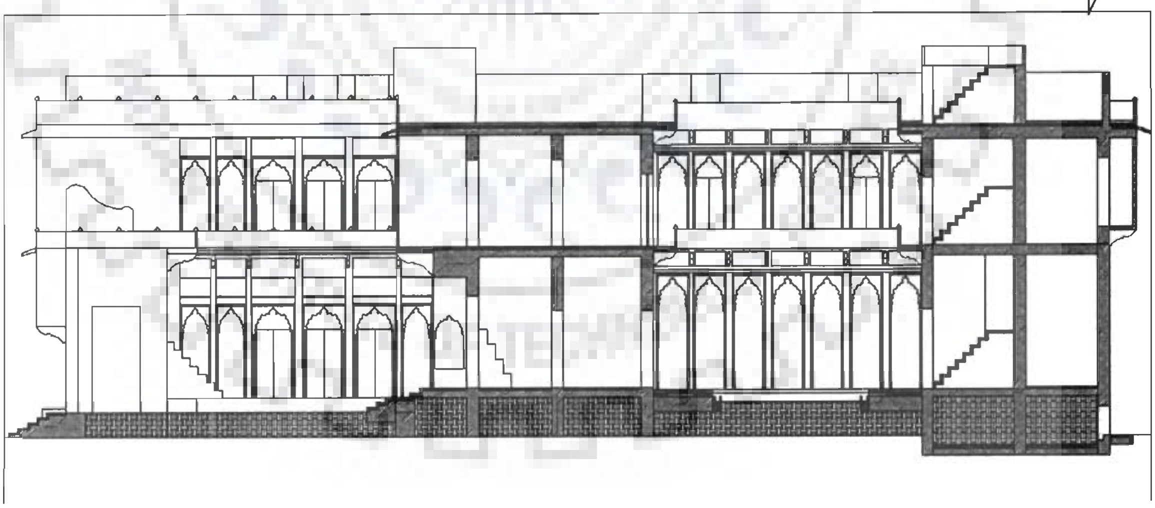
Drawing A-5.11.4: First Floor Plan



Drawing A-5.11.5: Mezzanine Floor Plan for First Floor Level

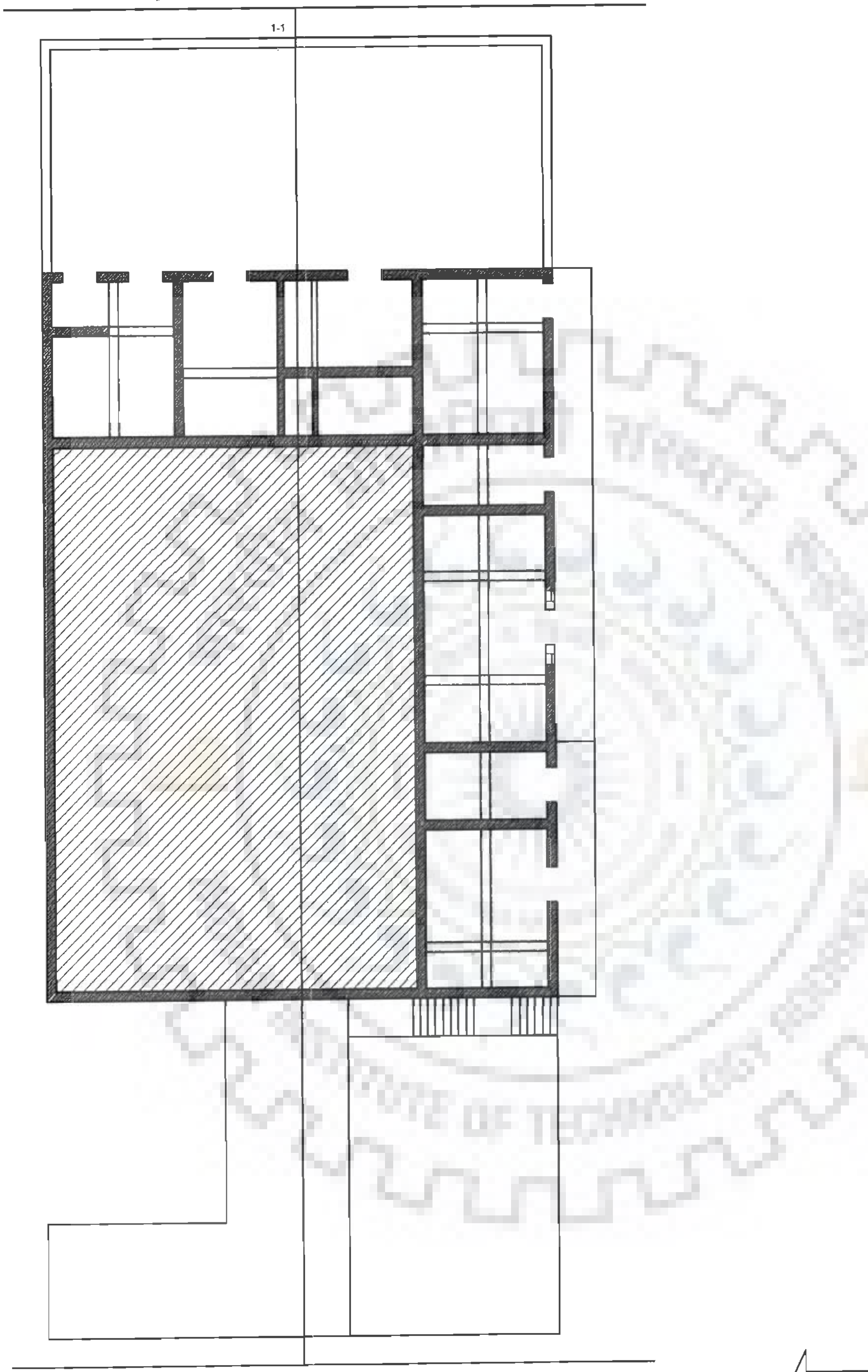


Drawing A-5.11.6: Terrace Floor Plan

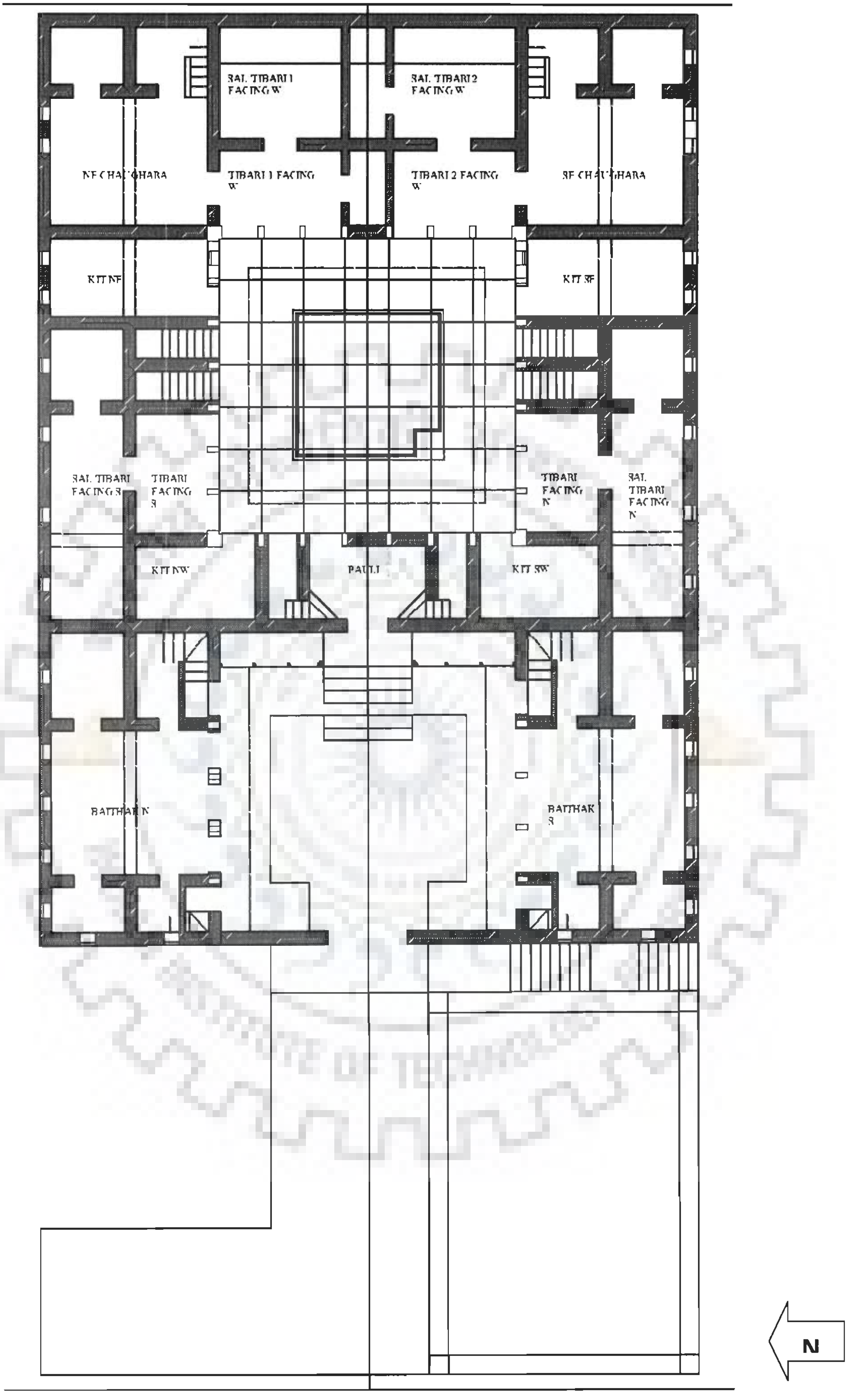


Drawing A-5.11.7: Section 1-1

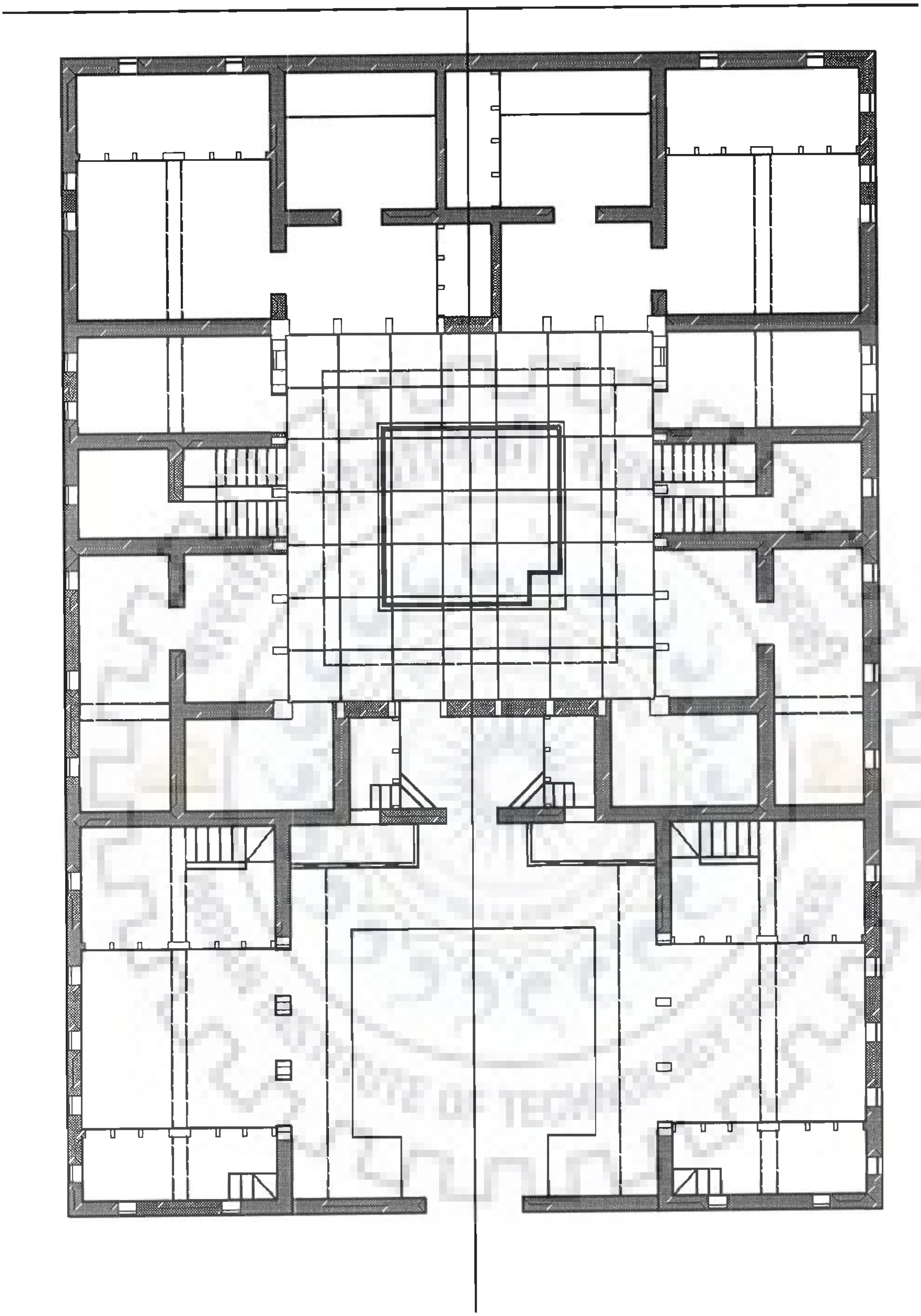
12 Seth Arjundas Goenka Haveli, Dundlod



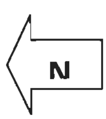
Drawing A-5.12.1: Lower Ground Floor Plan

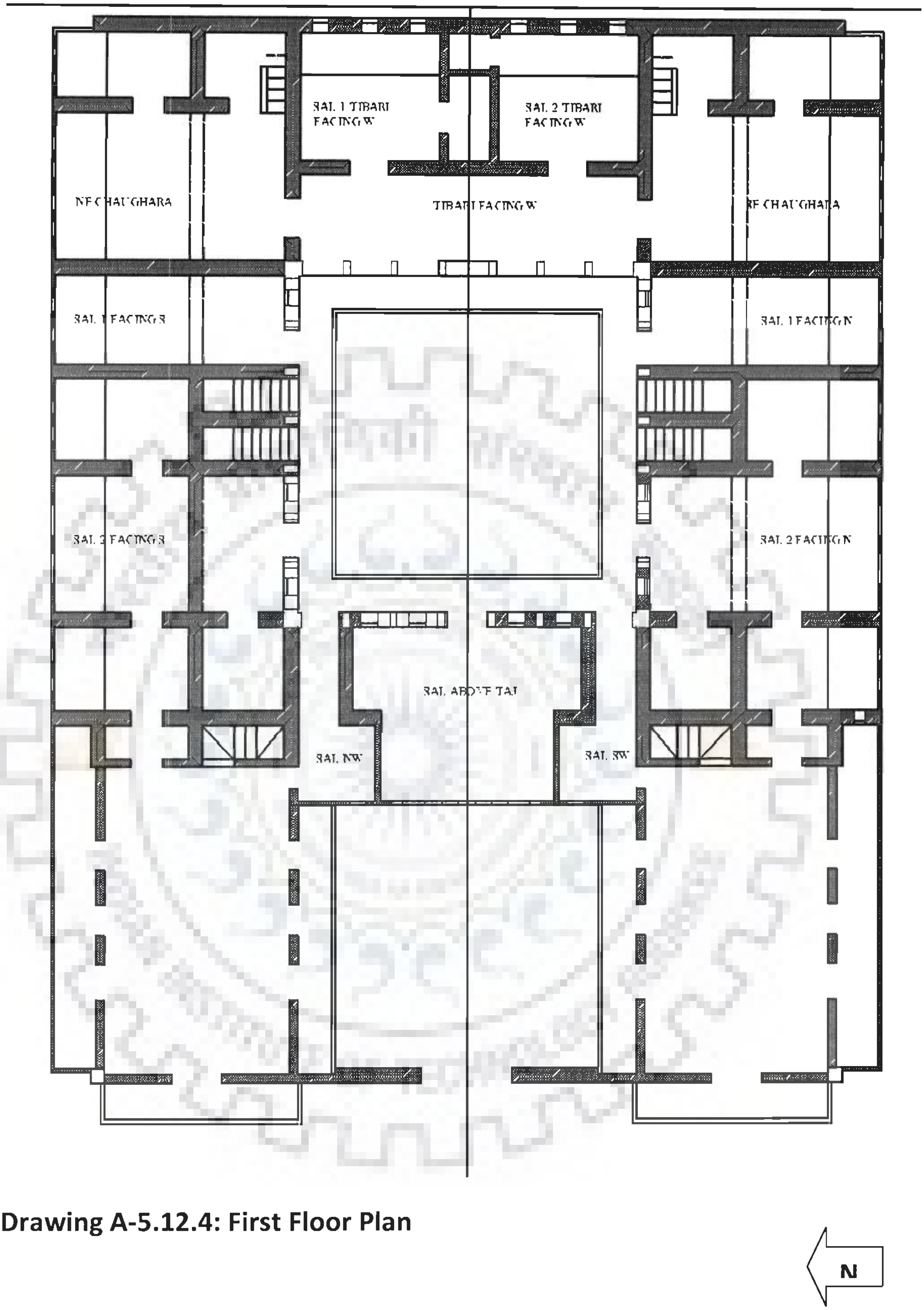


Drawing A-5.12.2: Upper Ground Floor Plan

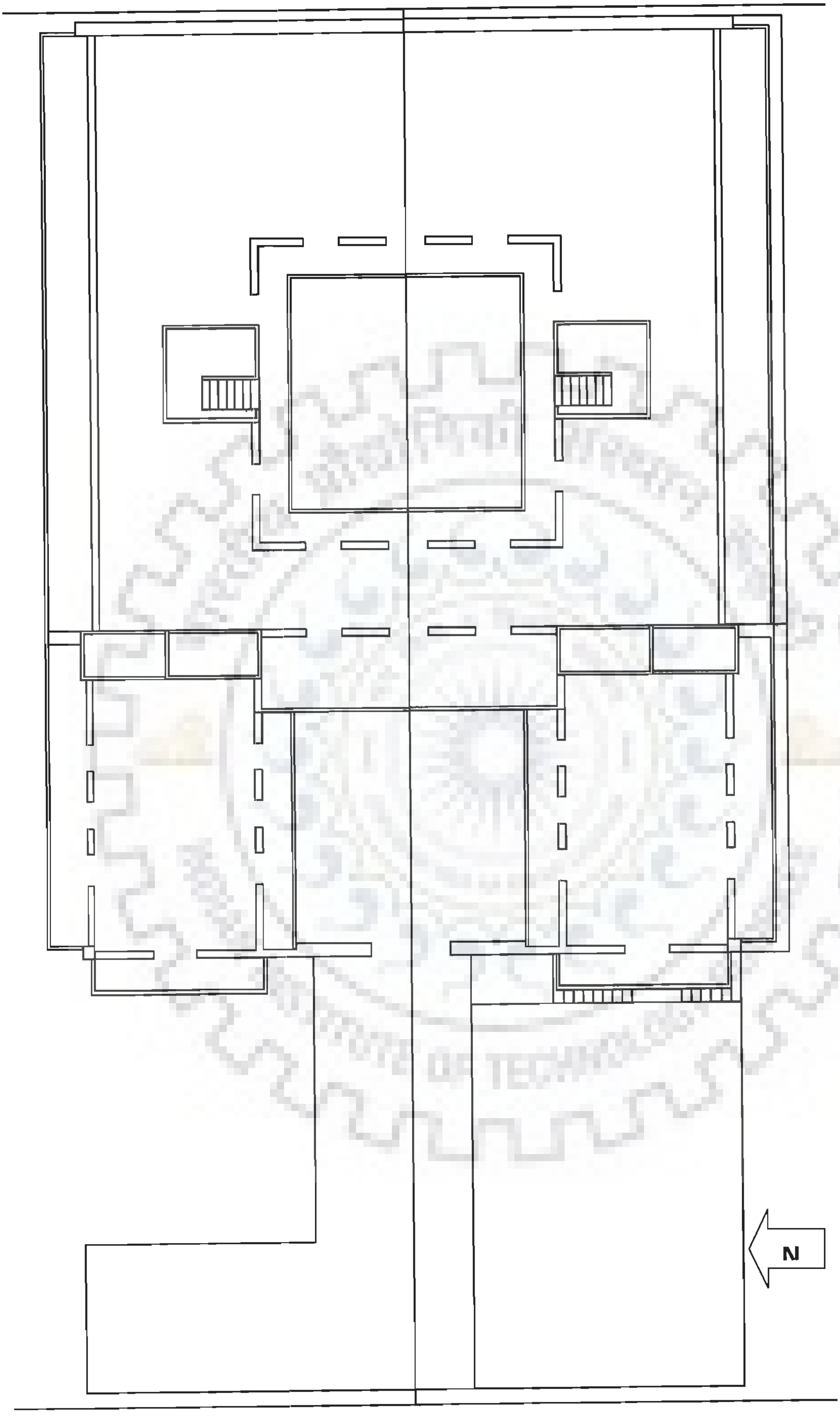


Drawing A-5.12.3: Mezzanine Floor Plan for Upper Ground Level

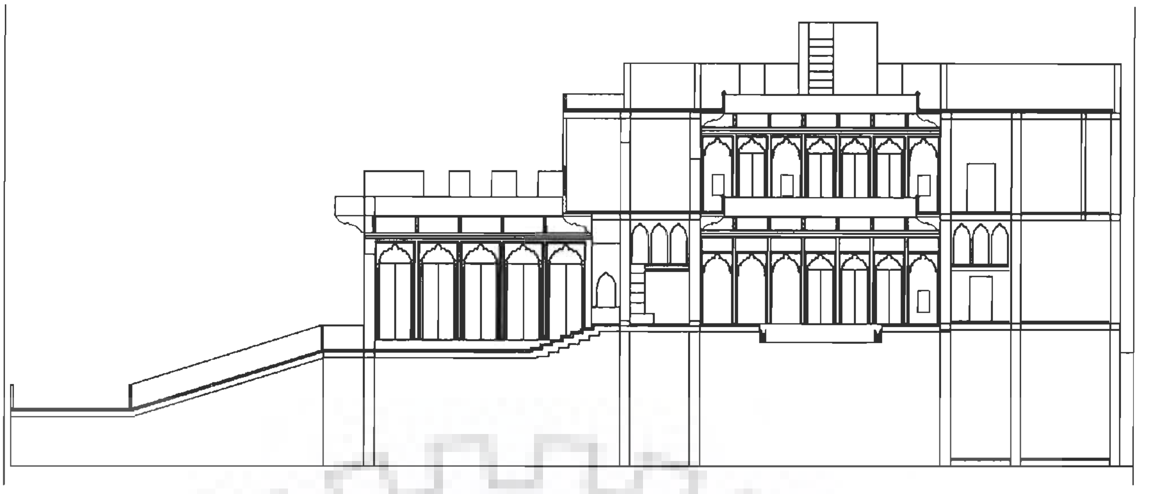




Drawing A-5.12.4: First Floor Plan

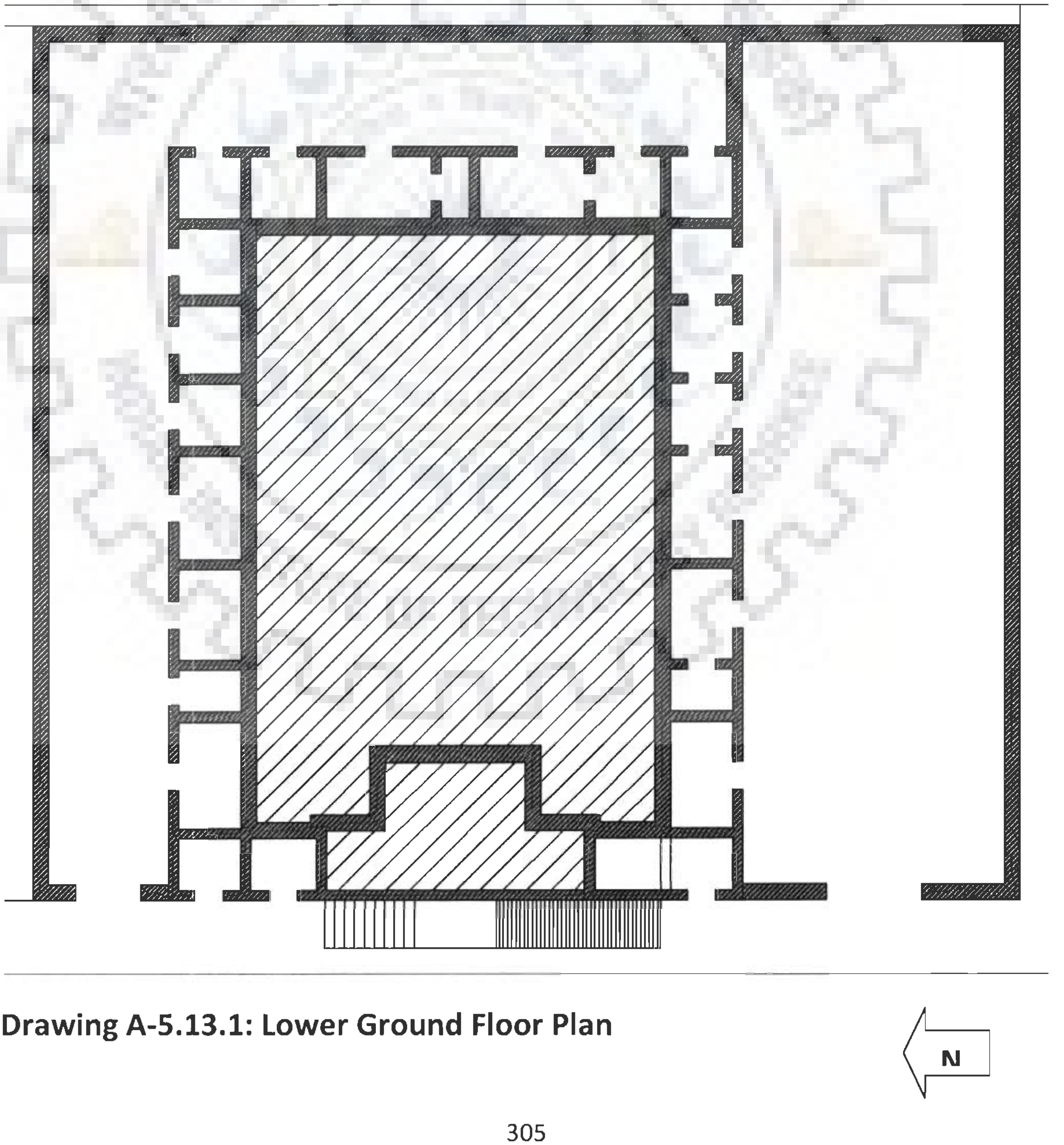


Drawing A-5.12.5: Terrace Floor Paln

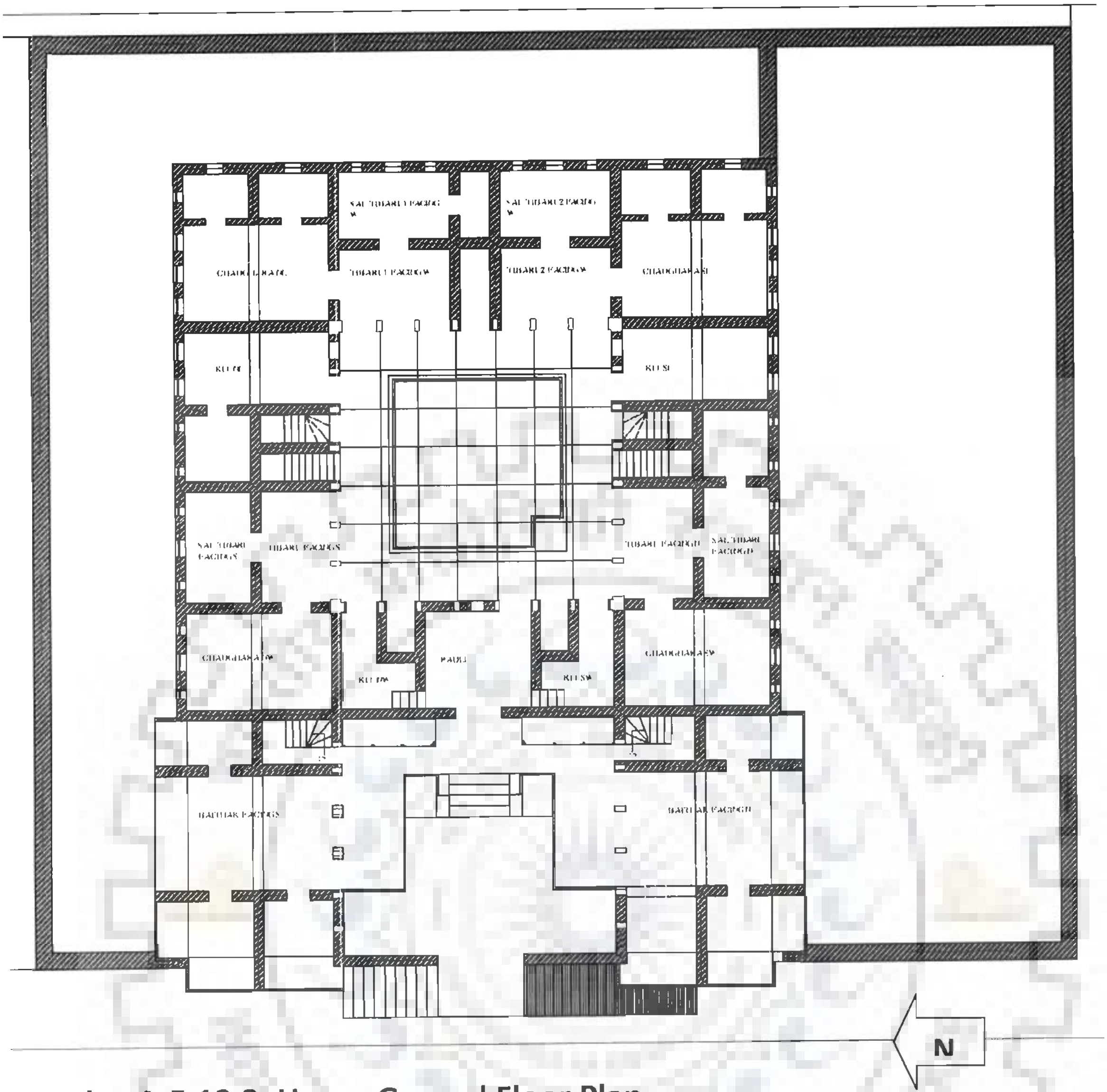


Drawing A-5.12.6: Section 1-1

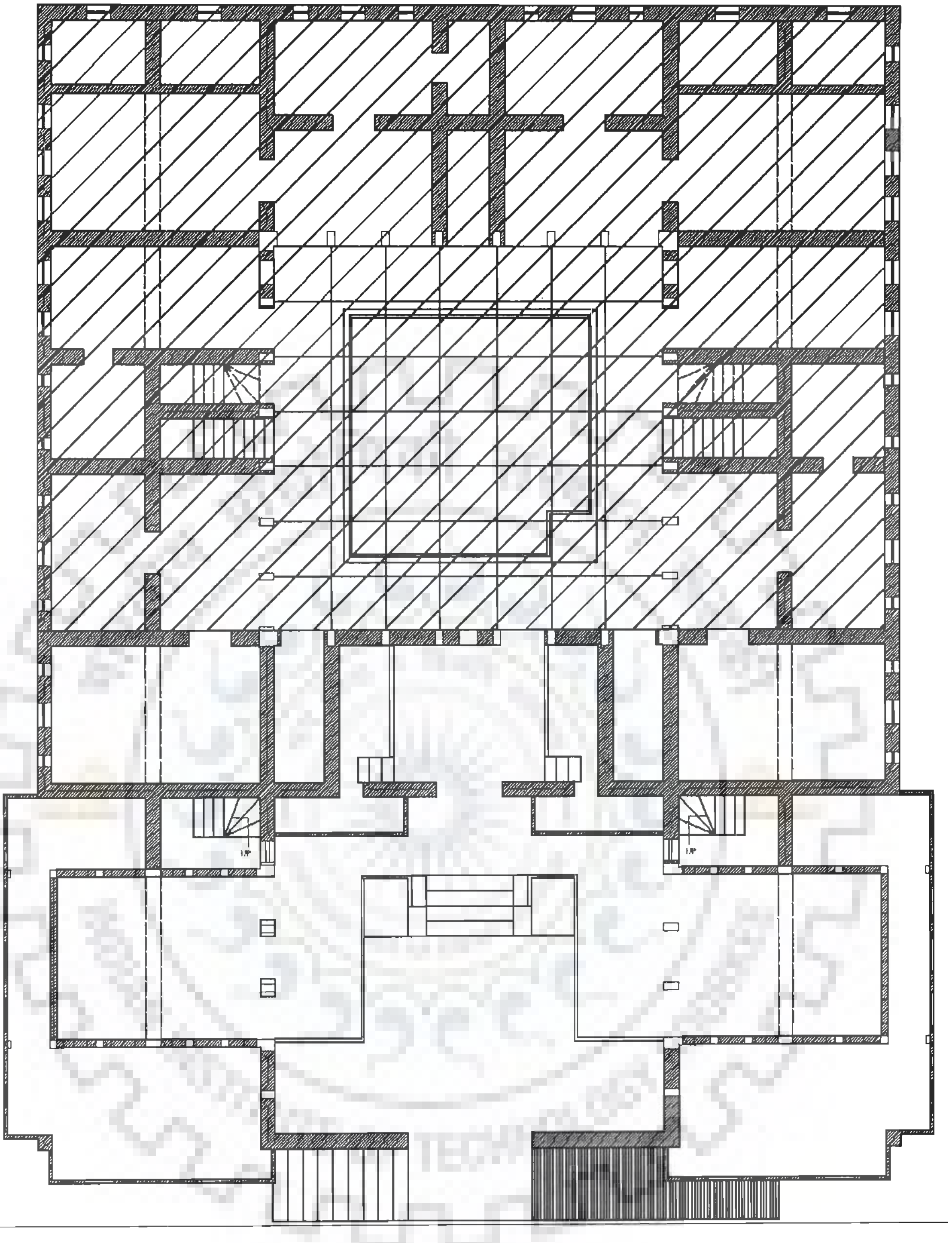
13 Harkarandas Mangilalj Haveli, Bagad



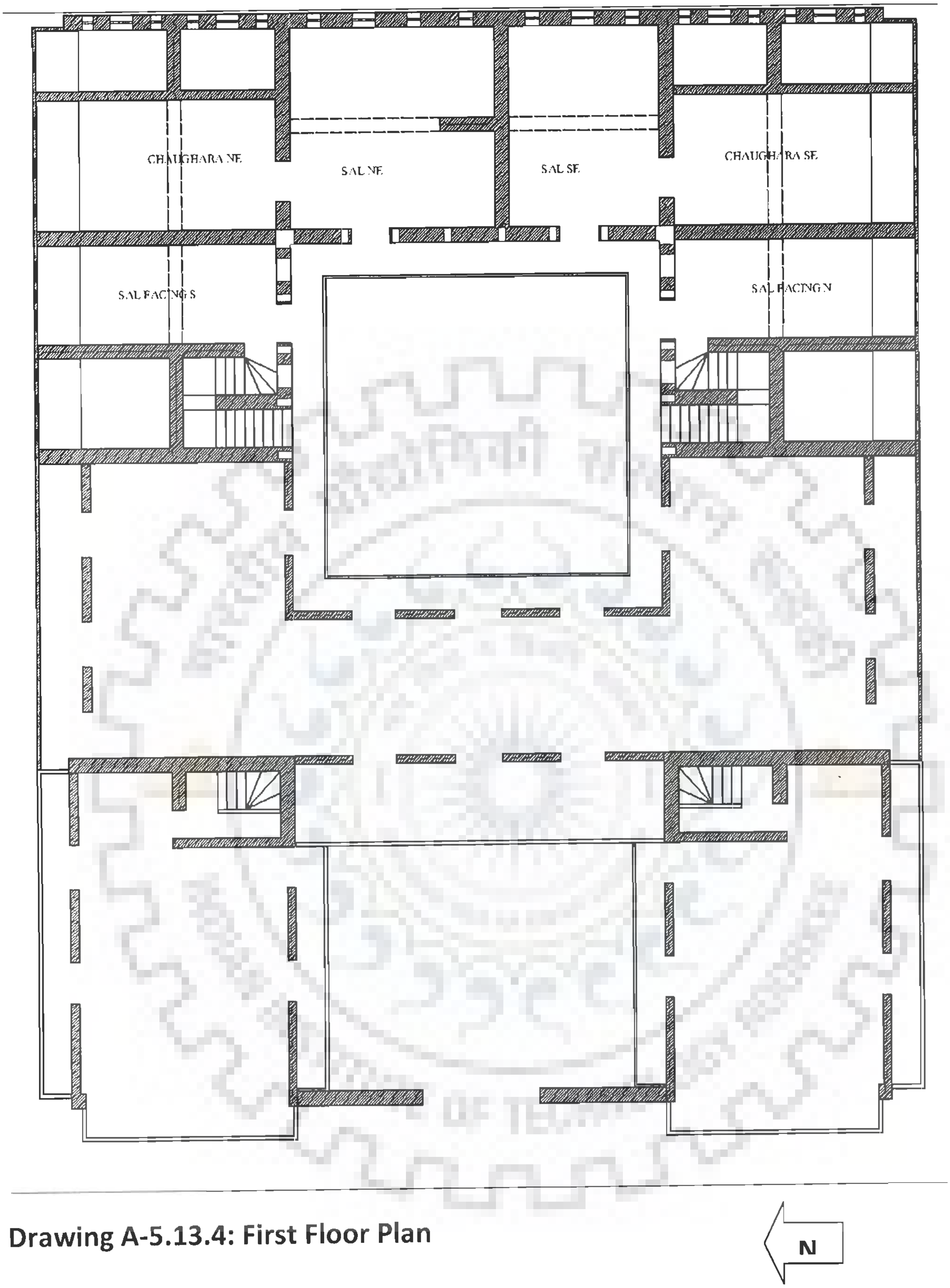
Drawing A-5.13.1: Lower Ground Floor Plan



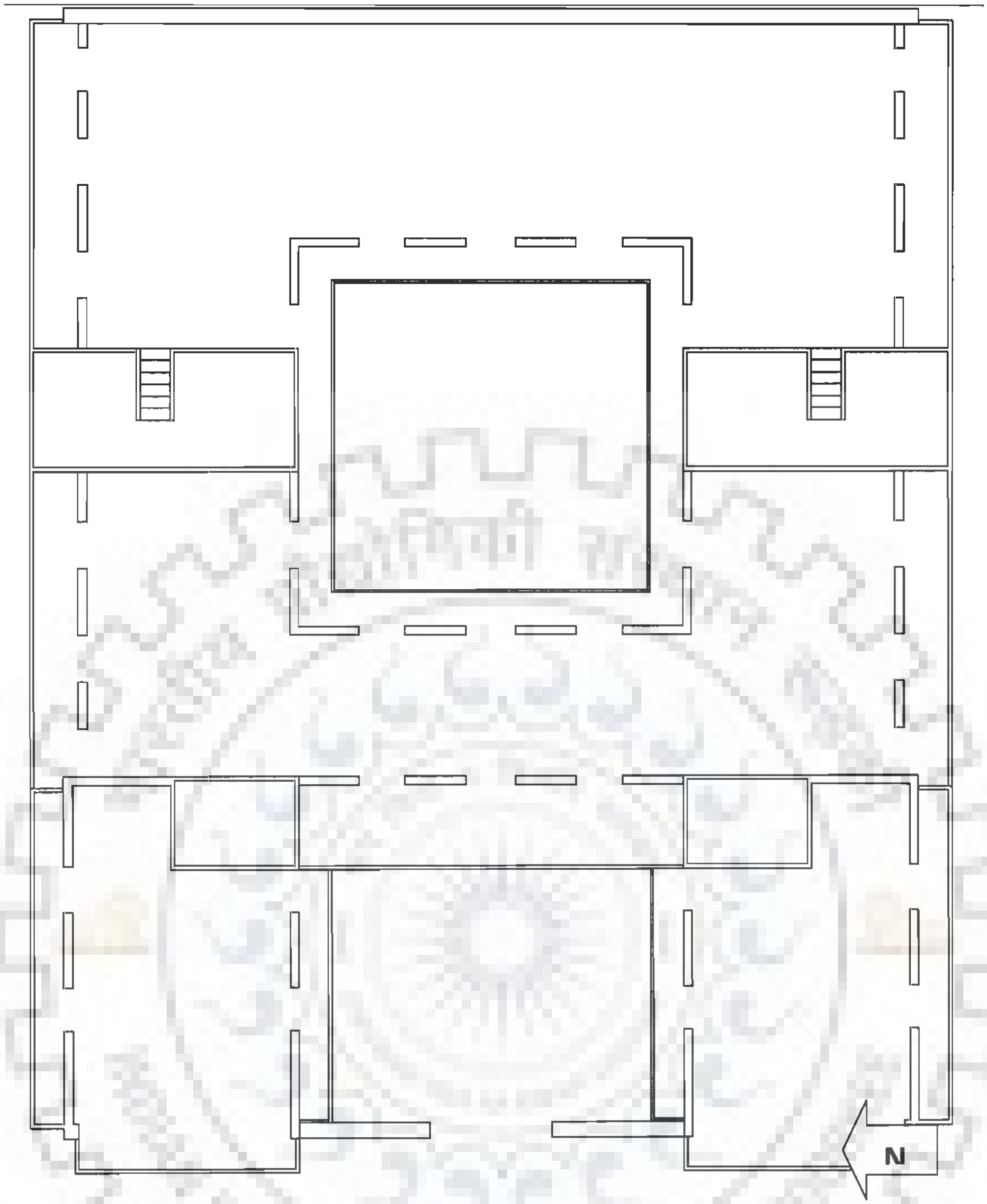
Drawing A-5.13.2: Upper Ground Floor Plan



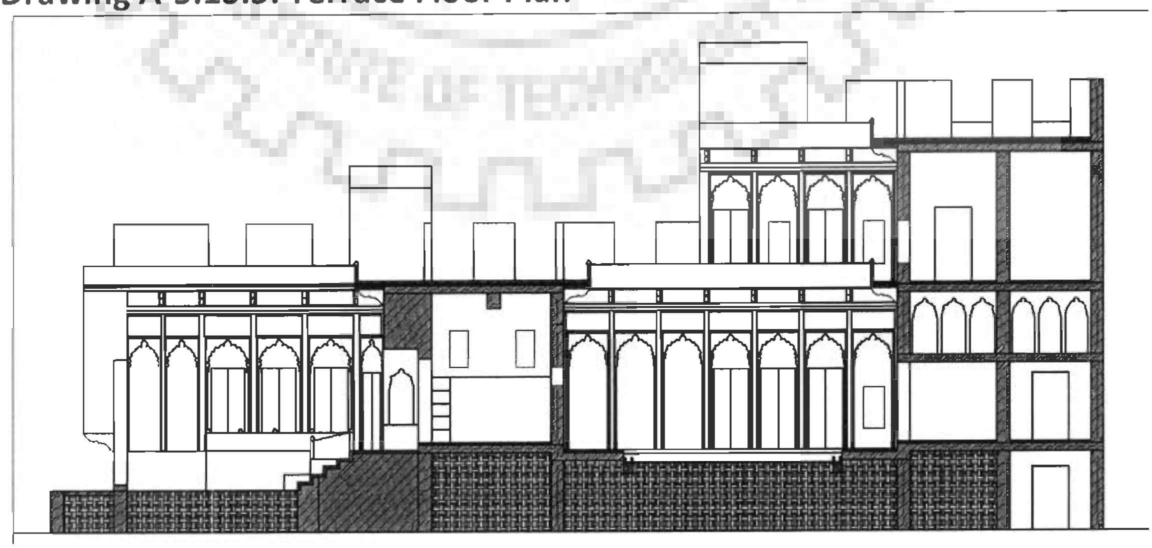
Drawing A-5.13.3: Mezzanine Floor Plan for Upper Ground Level



Drawing A-5.13.4: First Floor Plan

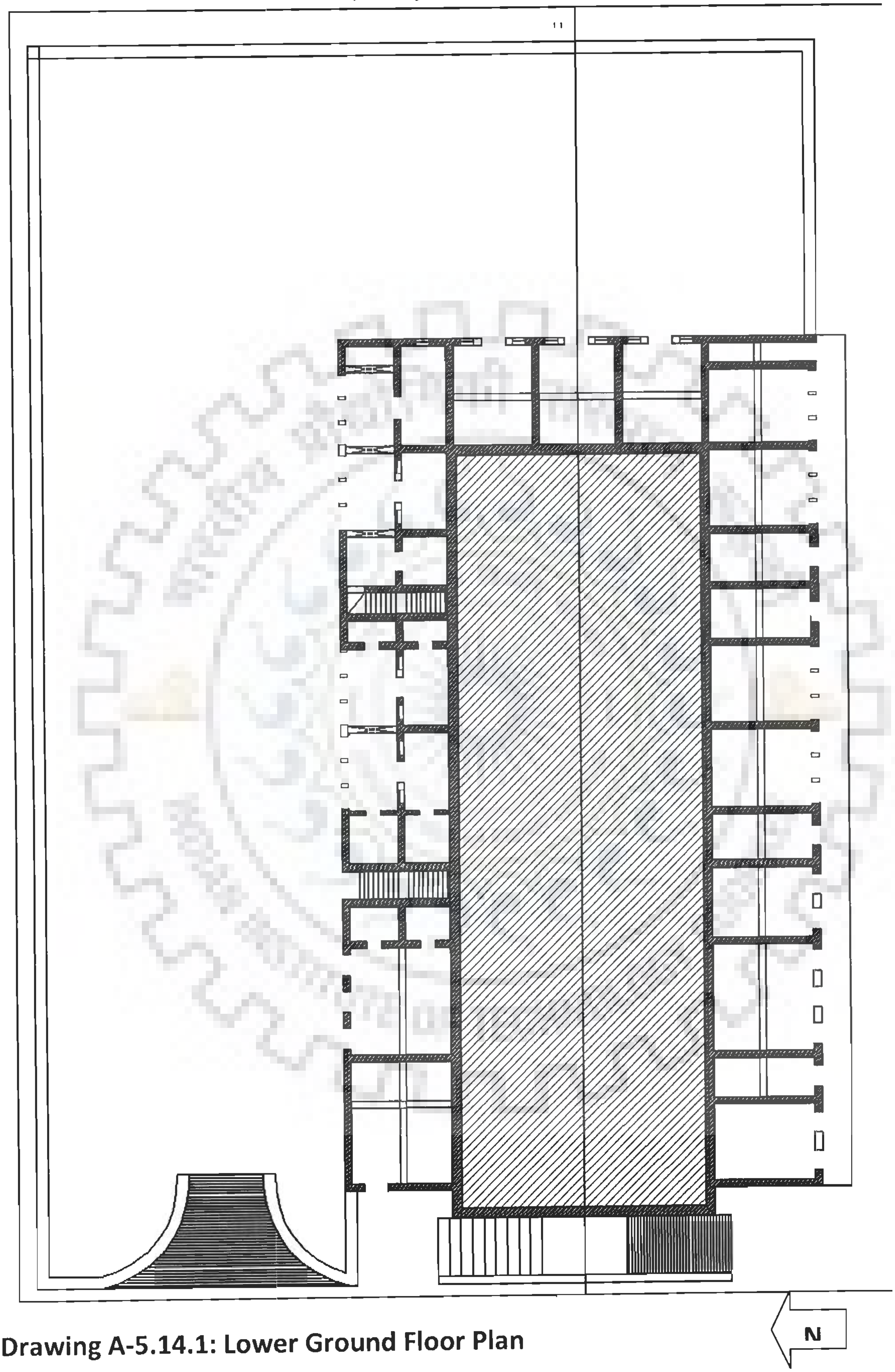


Drawing A-5.13.5: Terrace Floor Plan

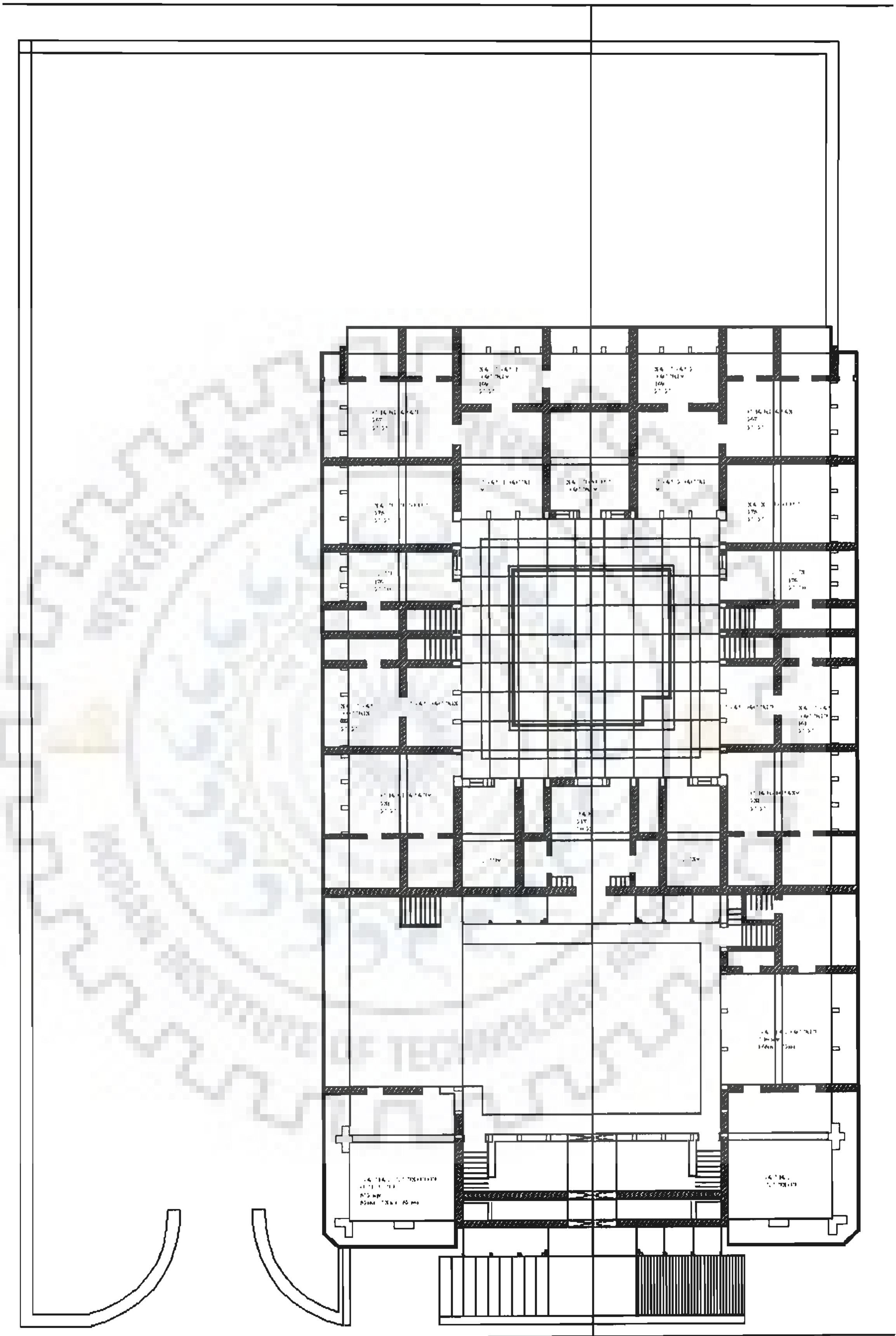


Drawing A-5.13.6: Section 1-1

14 Ishwardas Modi Haveli, Jhunjhunu

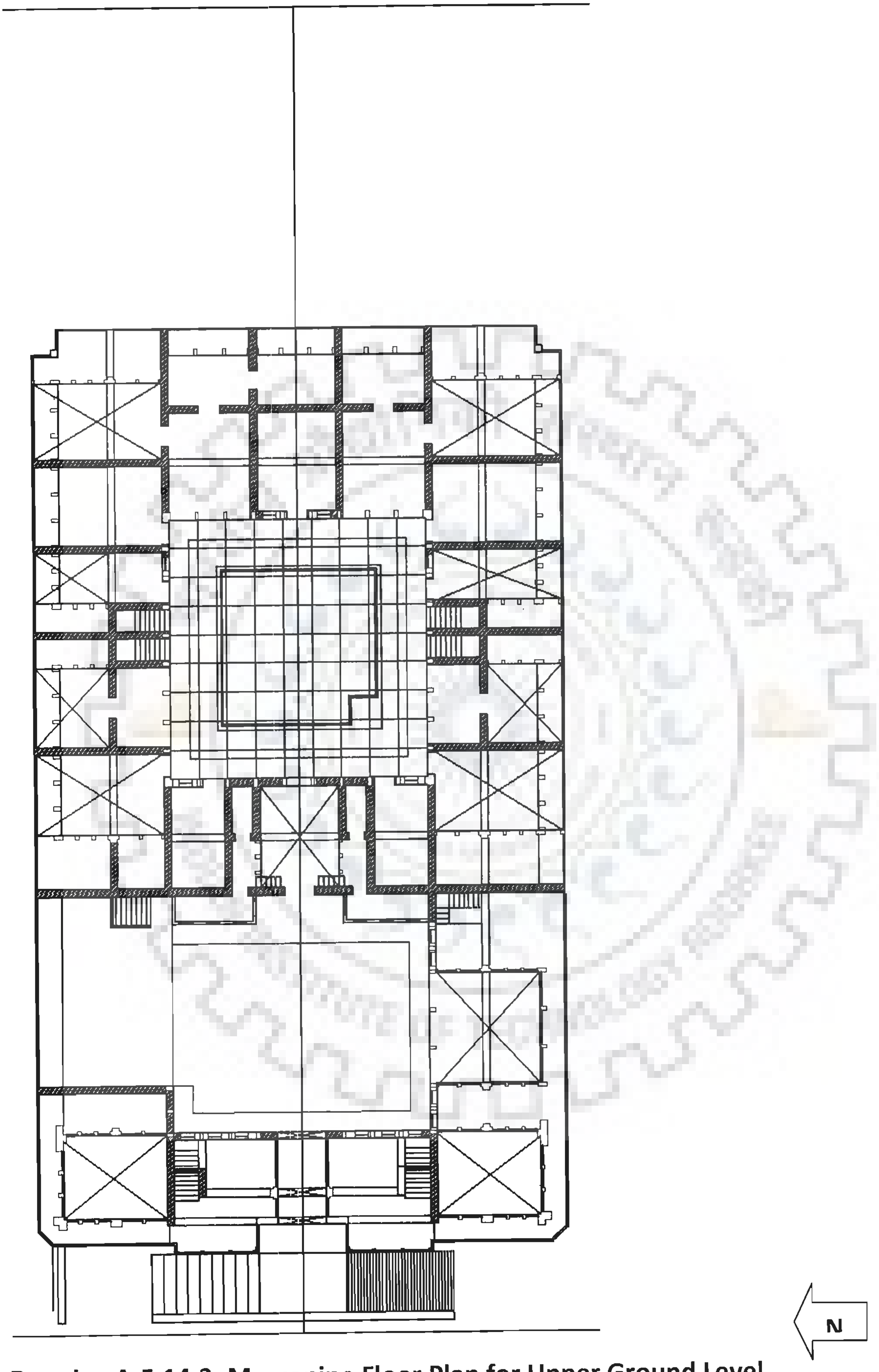


Drawing A-5.14.1: Lower Ground Floor Plan

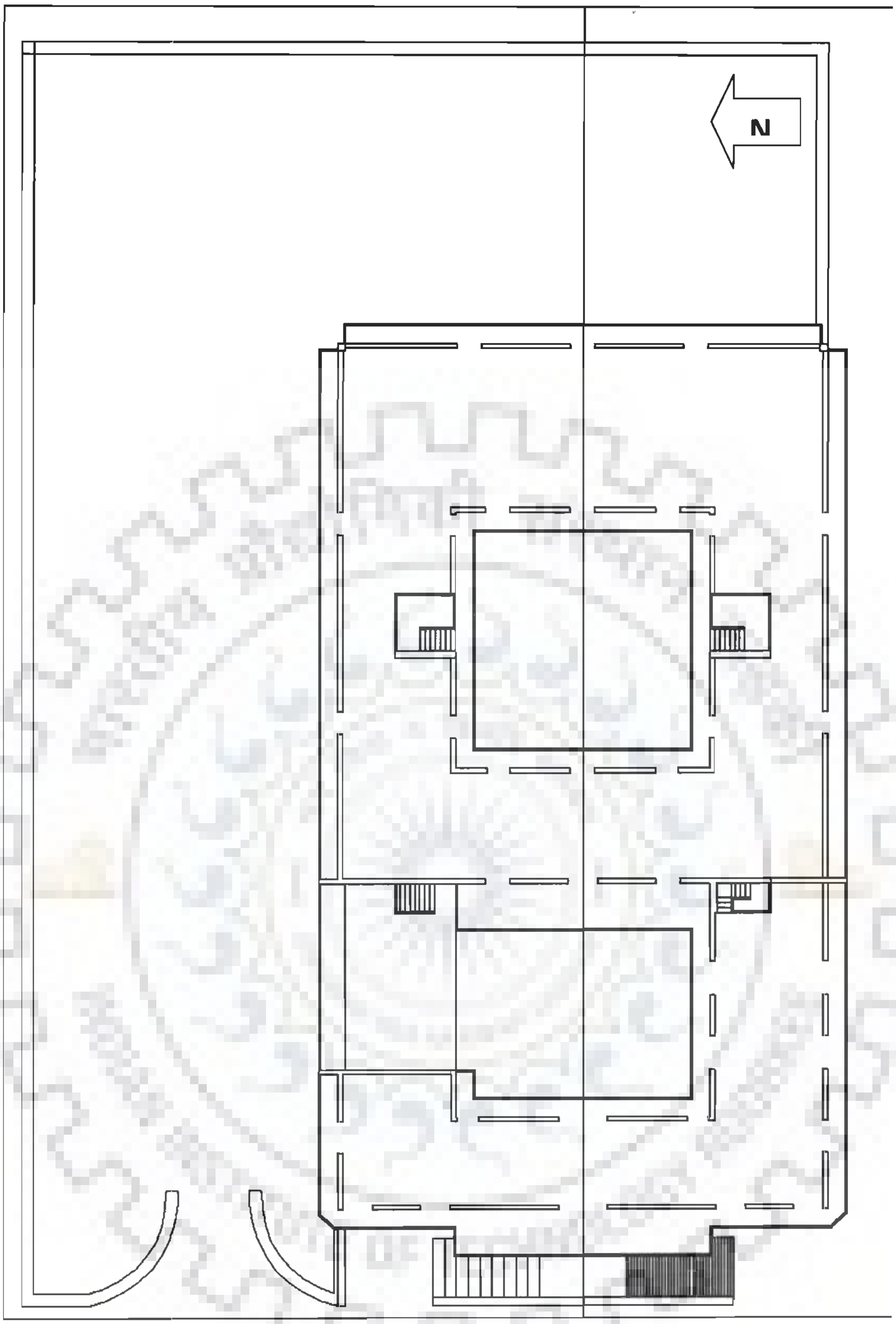


Drawing A-5.14.2: Upper Ground Floor Plan

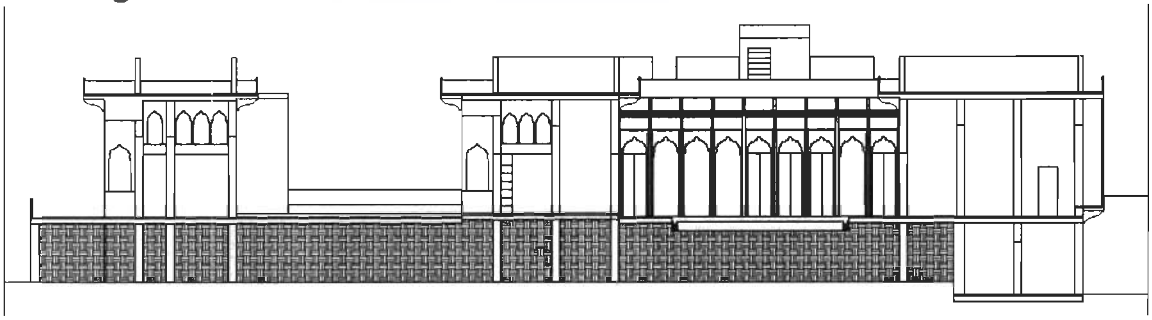
N



Drawing A-5.14.3: Mezzanine Floor Plan for Upper Ground Level

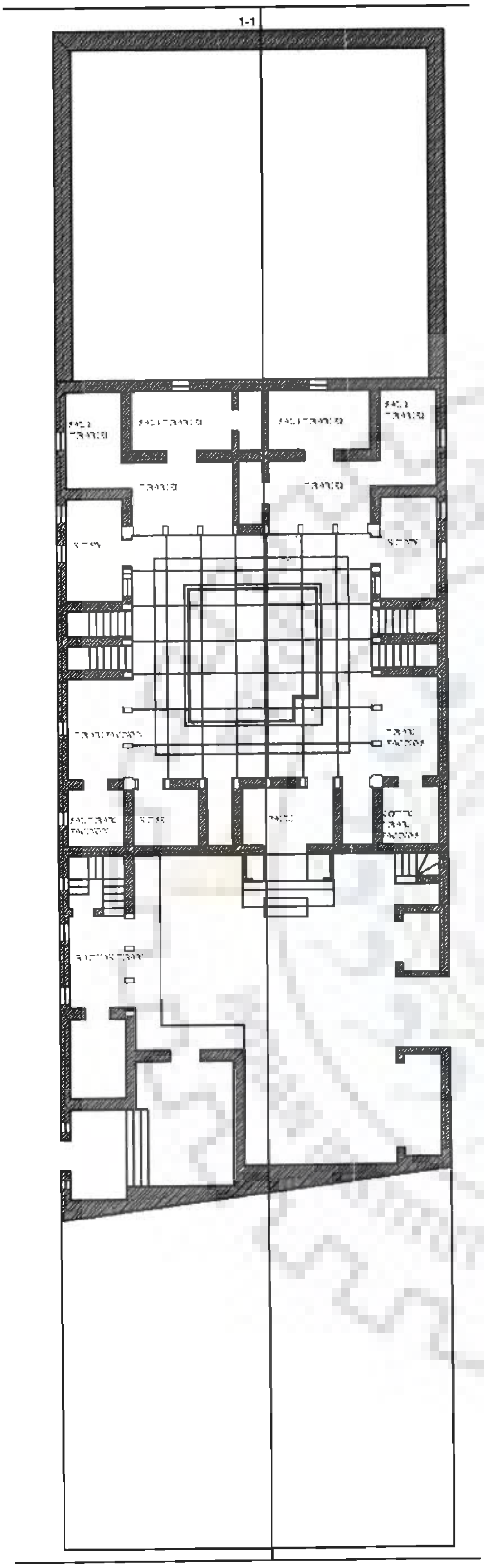


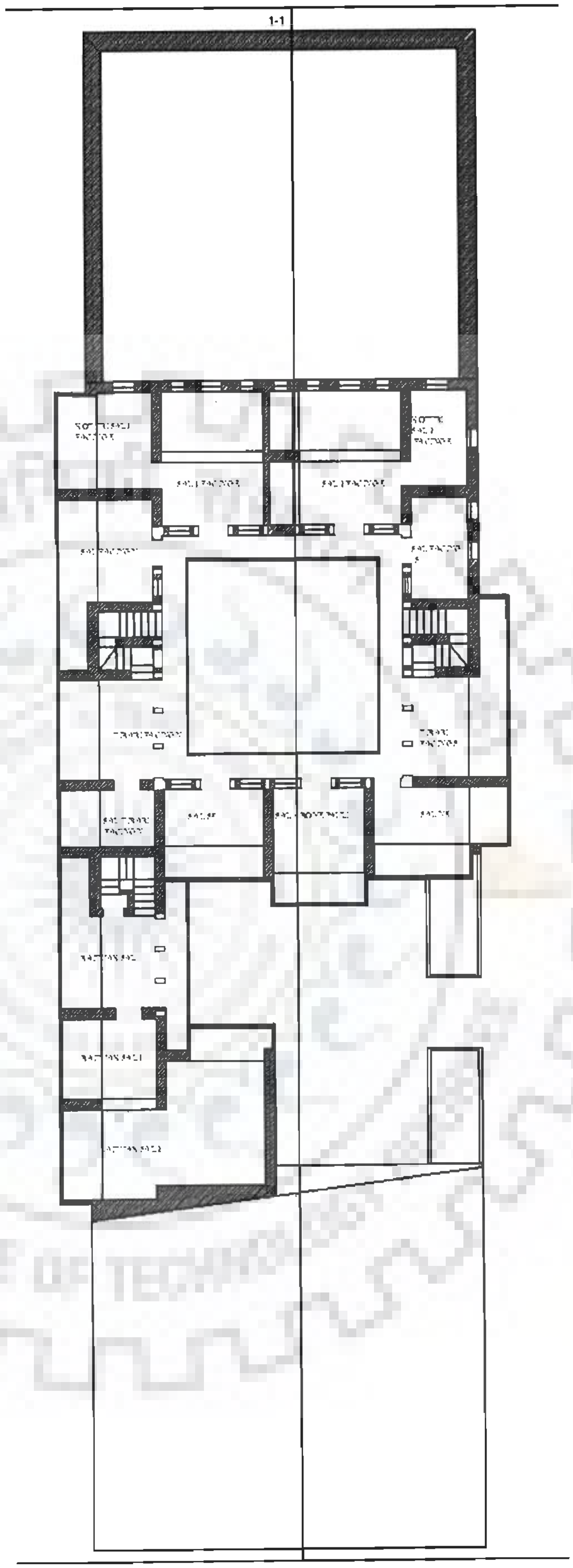
Drawing A-5.14.4: Terrace Floor Plan



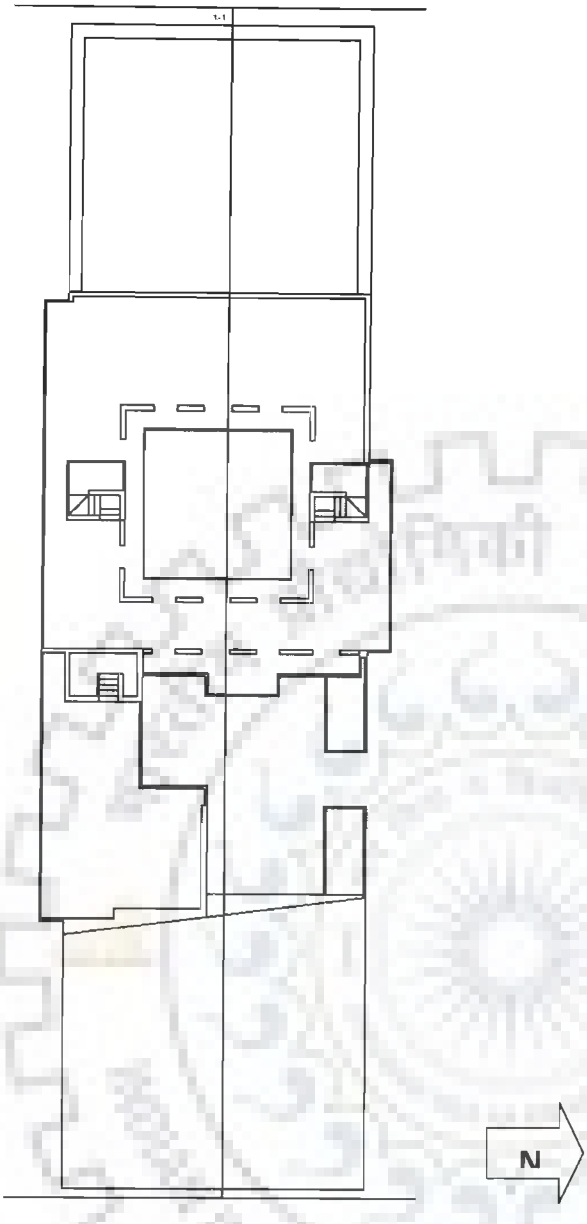
Drawing A-5.14.5: Section 1-1

15 Jaigopal Ji Goenka, Mandawa

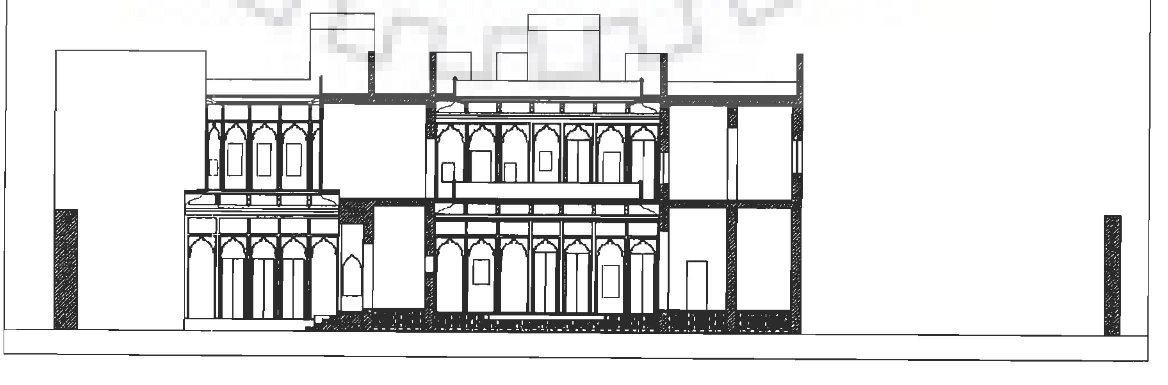




Drawing A-5.15.1: Ground Floor Plan Drawing A-5.15.2: First Floor Plan

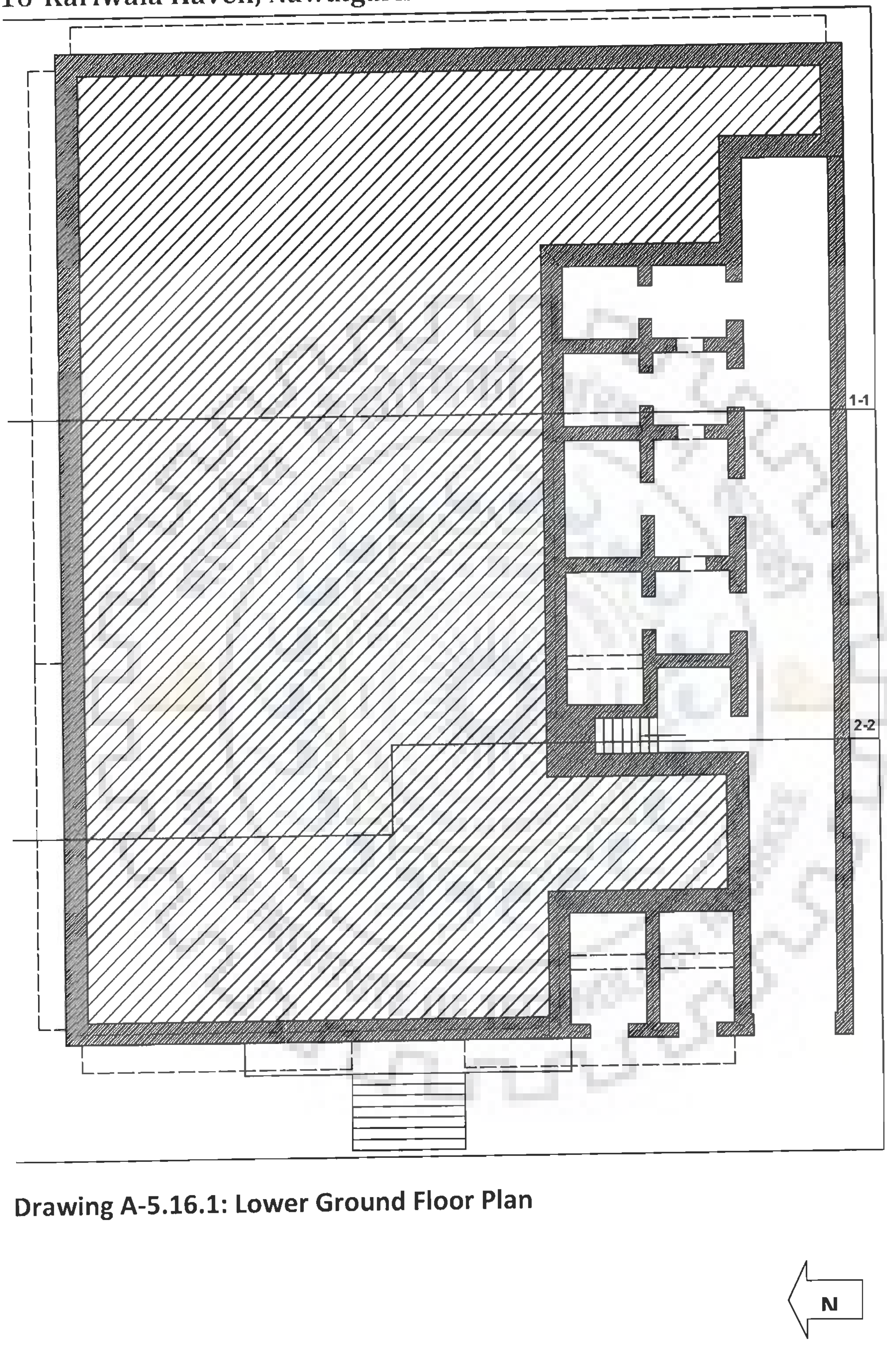


Drawing A-5.15.3: Terrace Floor Plan

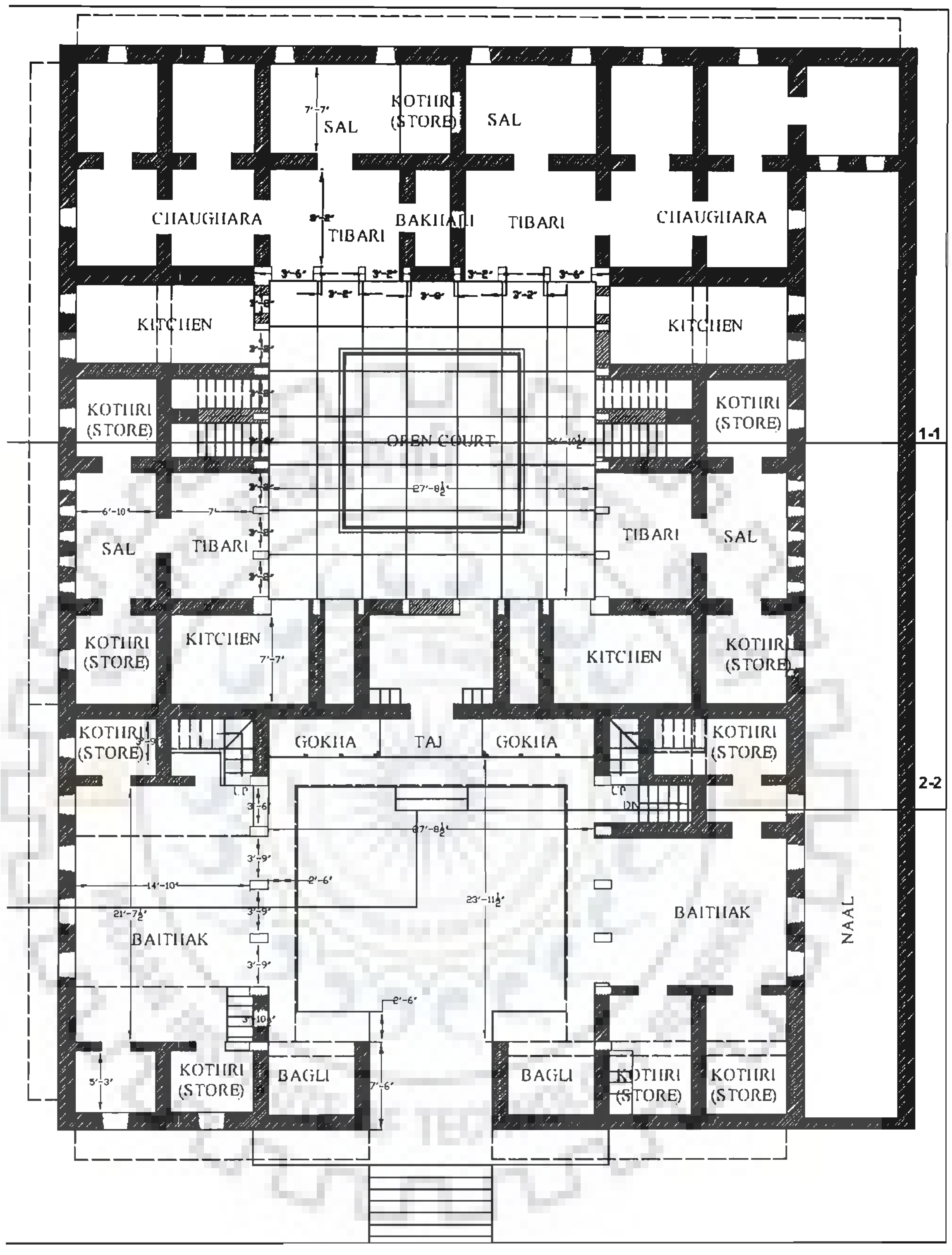


Drawing A-5.15.4: Section 1-1

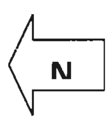
16 Kariwala Haveli, Nawalgarh

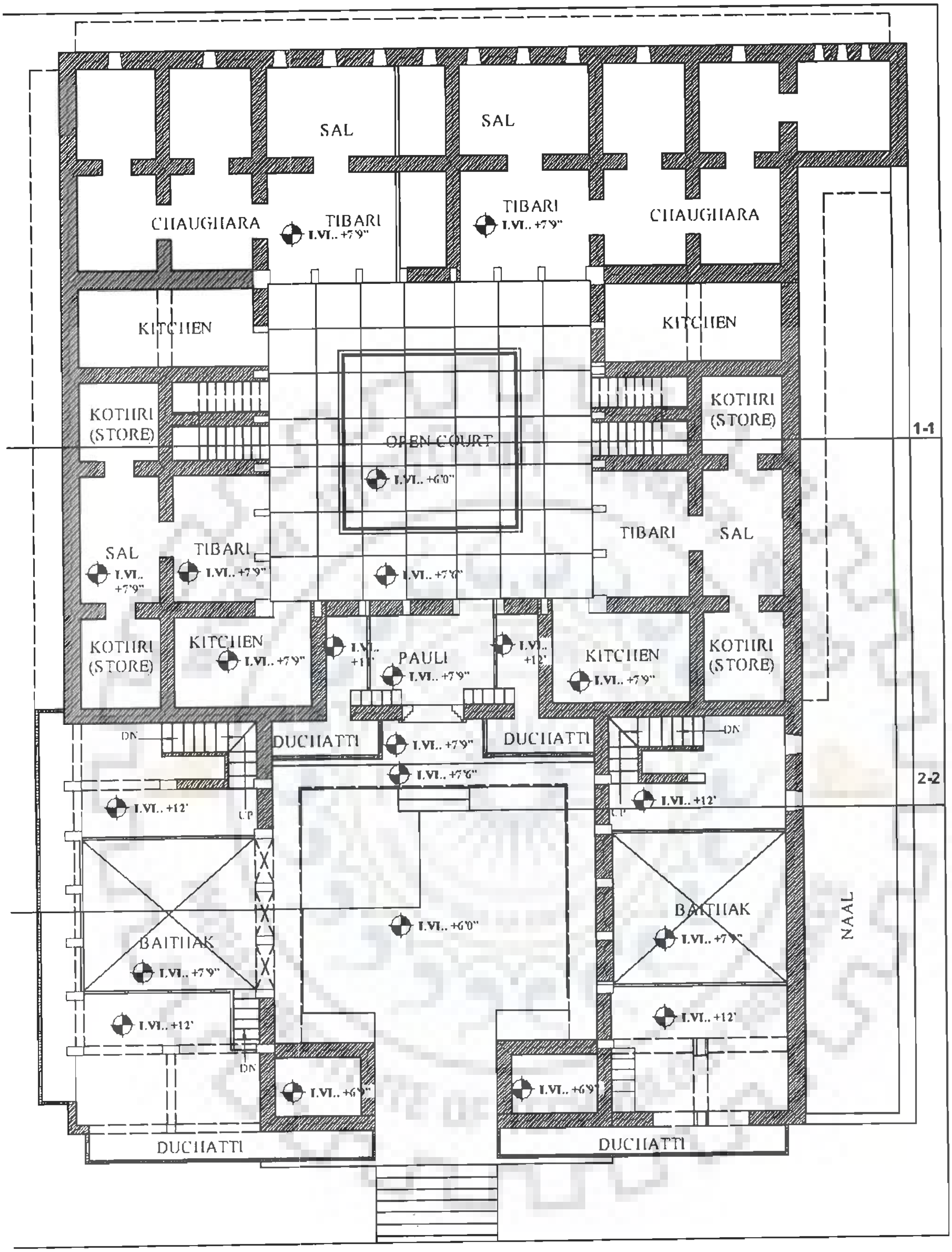


Drawing A-5.16.1: Lower Ground Floor Plan

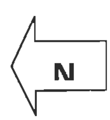


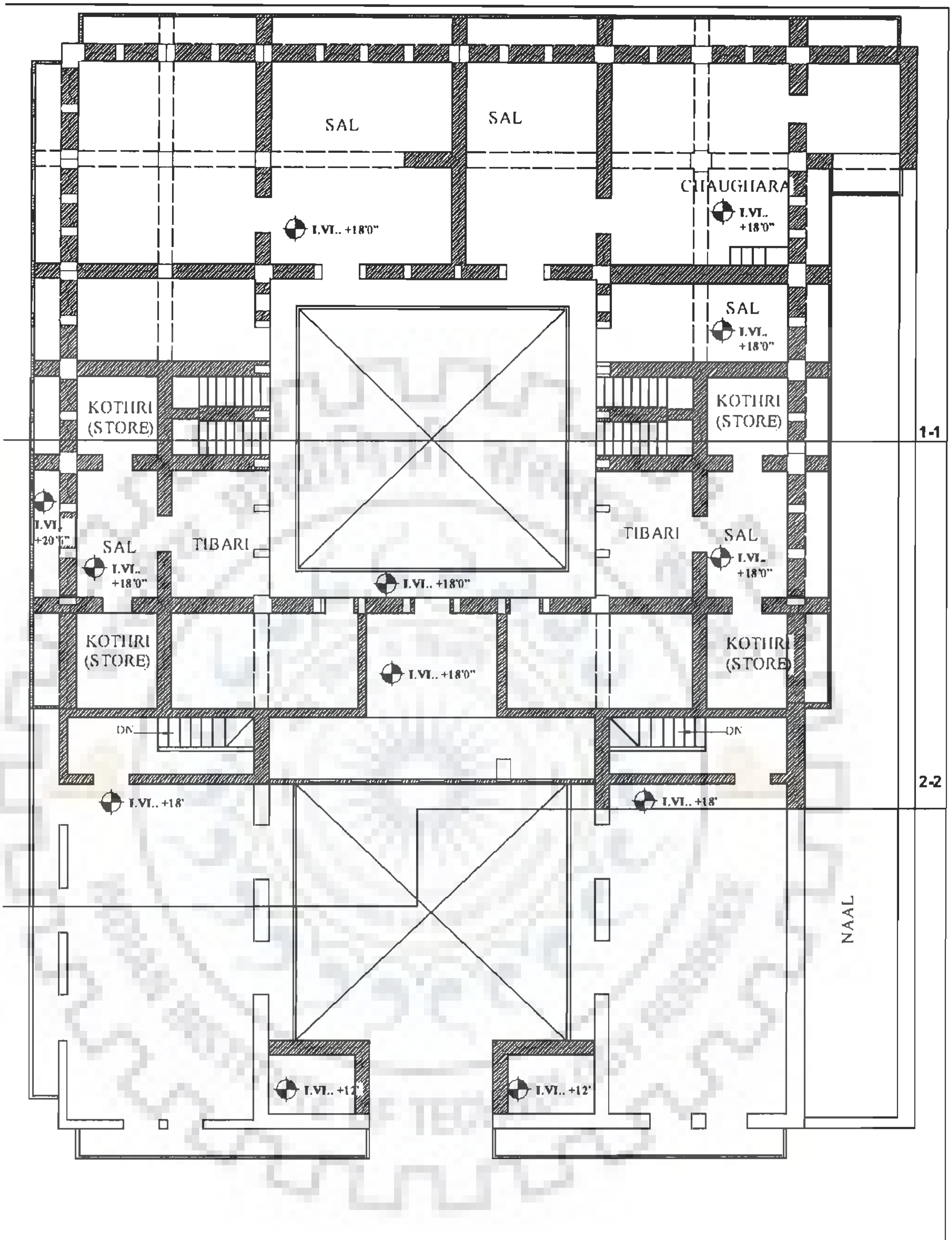
Drawing A-5.16.2: Upper Ground Floor Plan





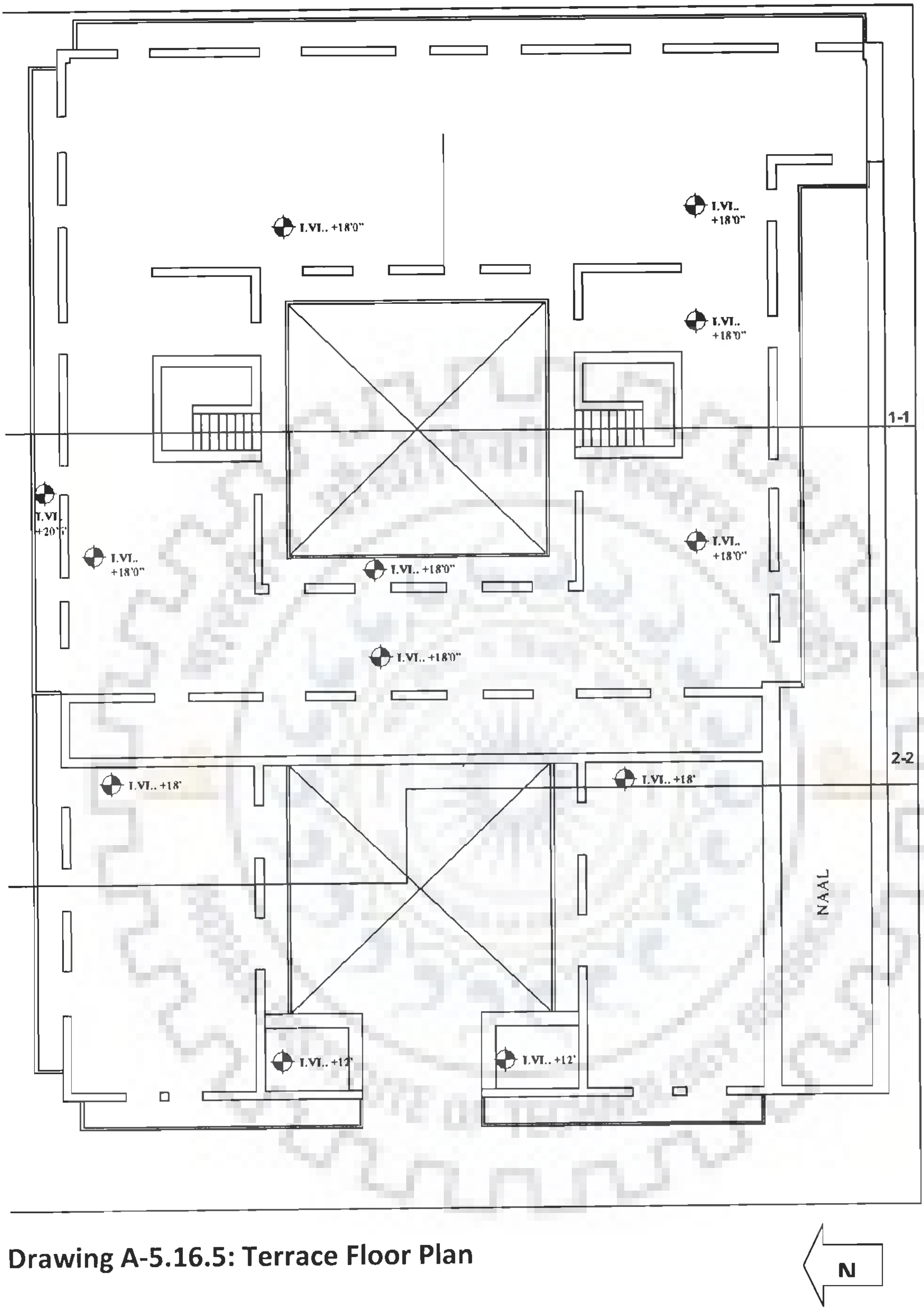
Drawing A-5.16.3: Mezzanine Floor Plan for Upper Ground Level



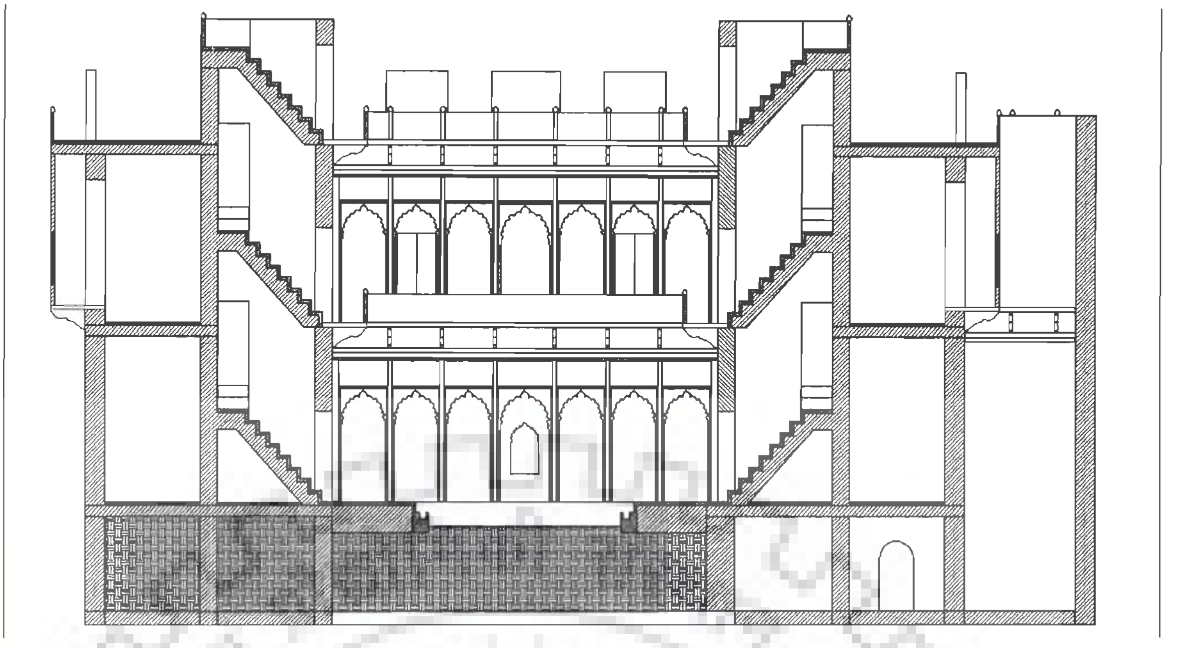


Drawing A-5.16.4: First Floor Plan

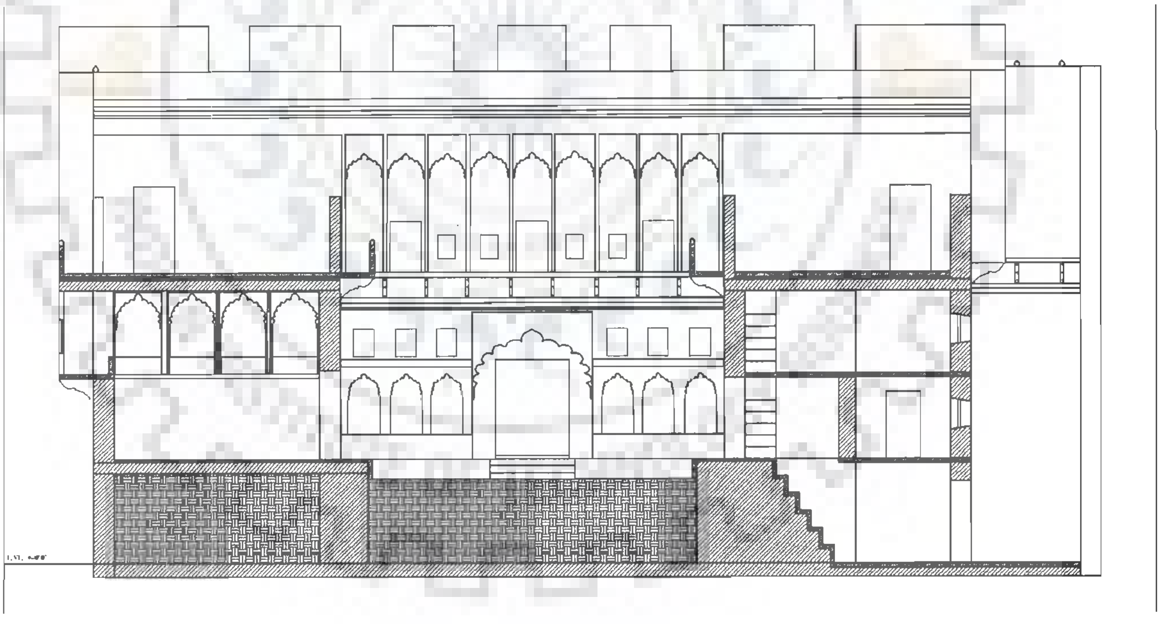
N



Drawing A-5.16.5: Terrace Floor Plan

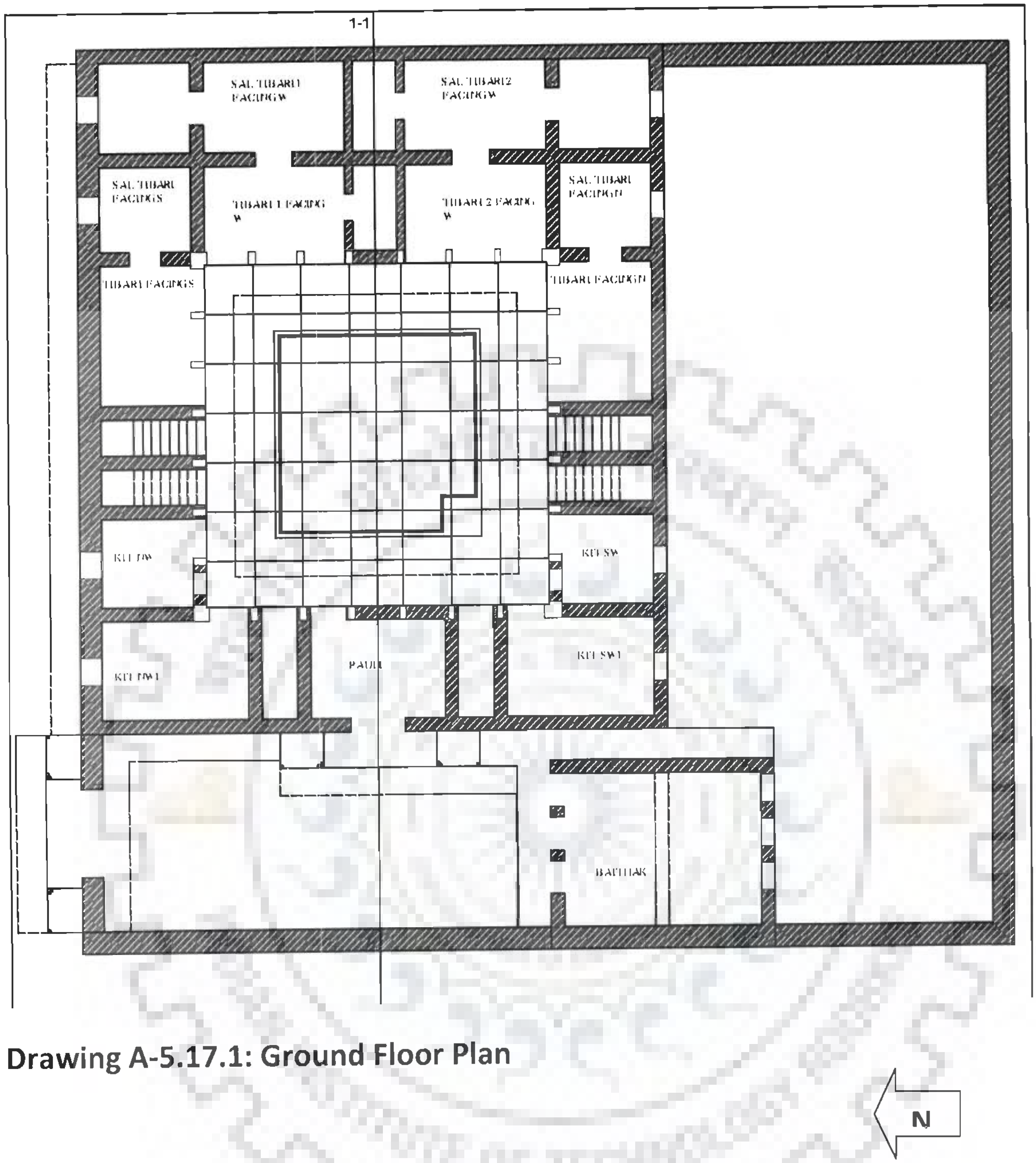


Drawing A-5.16.6: Section 1-1

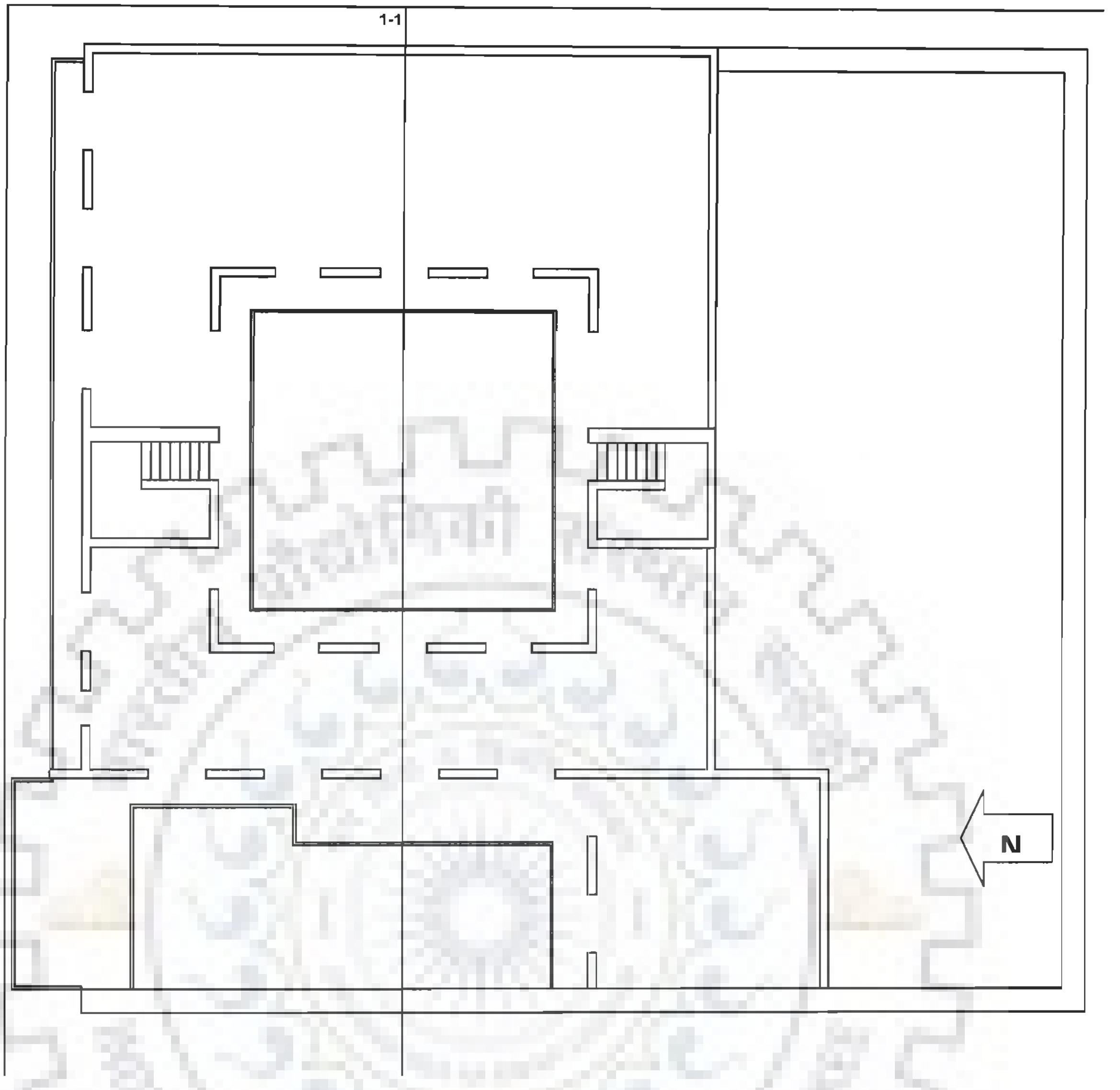


Drawing A-5.16.7: Section 2-2

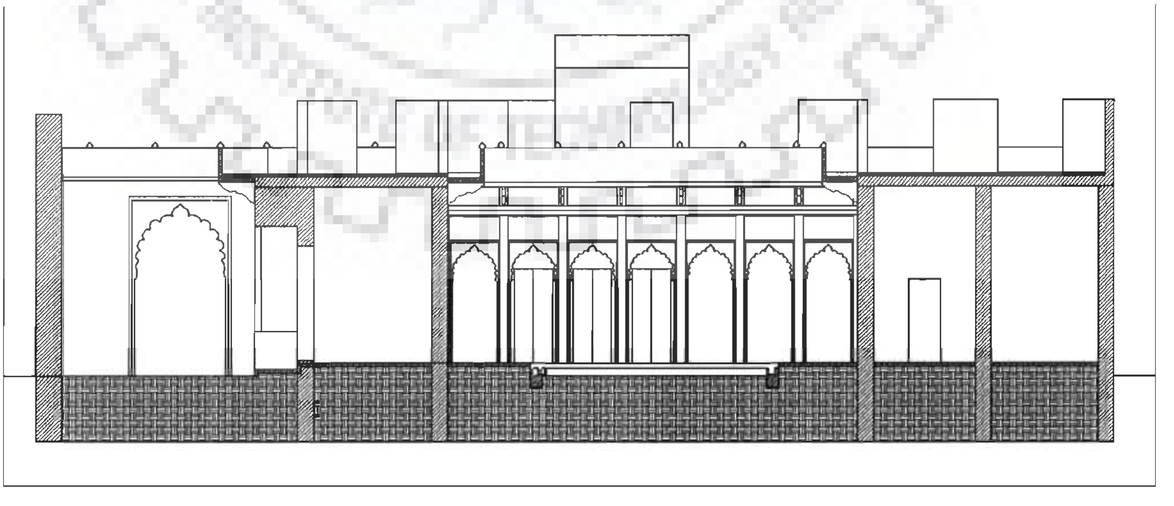
17 Pilani Haveli



Drawing A-5.17.1: Ground Floor Plan

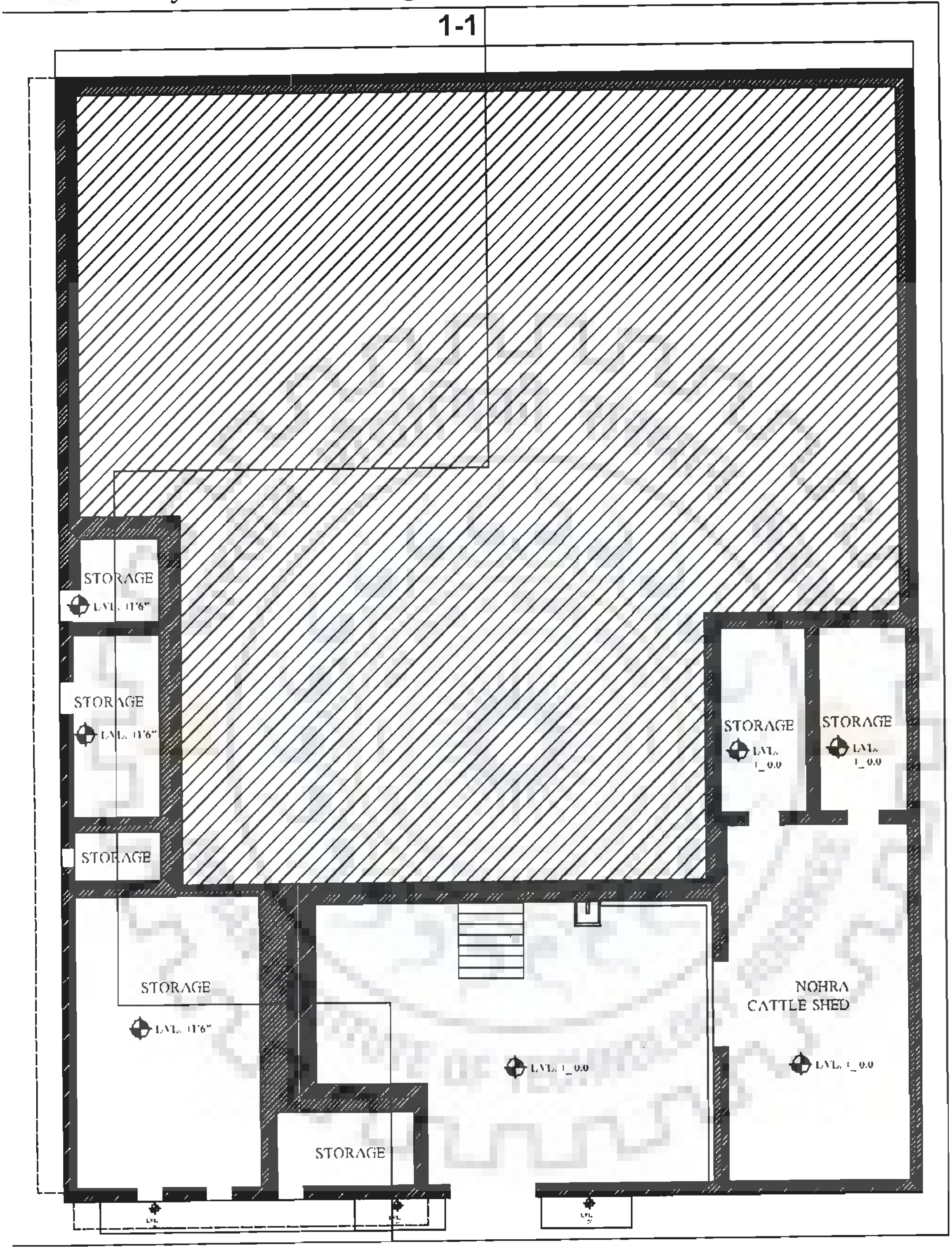


Drawing A-5.17.2: Terrace Floor Plan

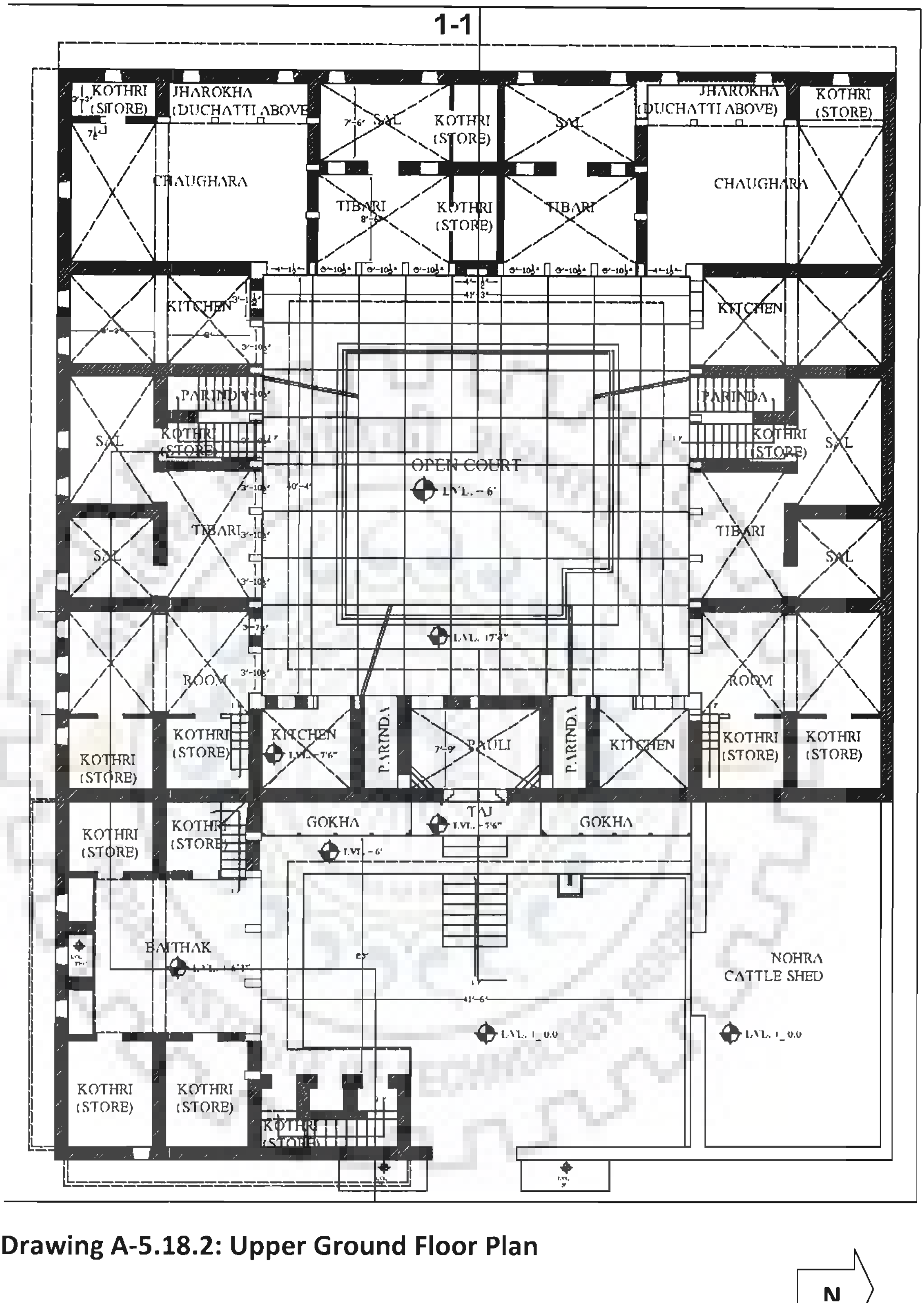


Drawing A-5.17.3: Section 1-1

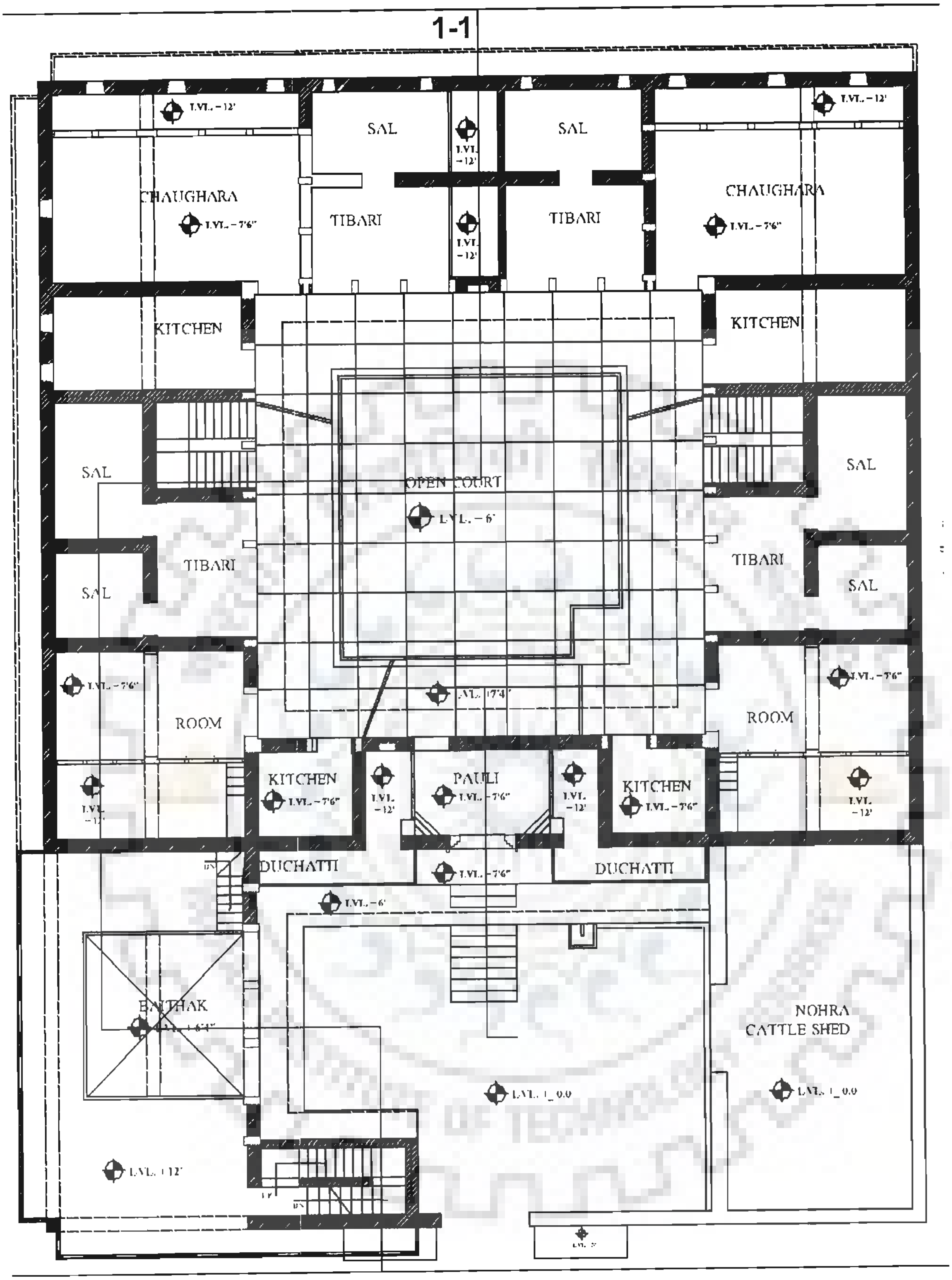
18 Shkhsariya Haveli, Nawalgarh



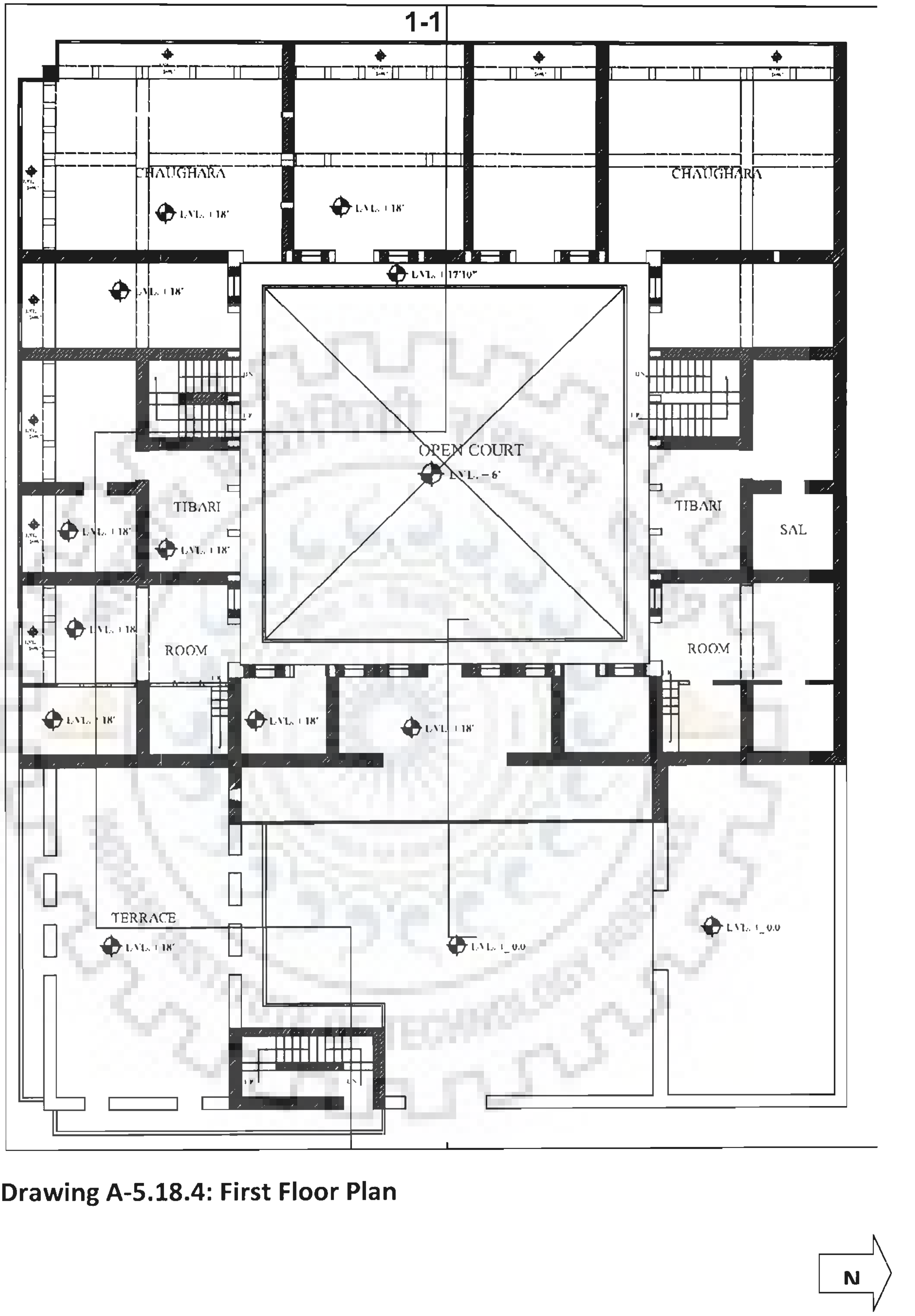
Drawing A-5.18.1: Lower Ground Floor Plan



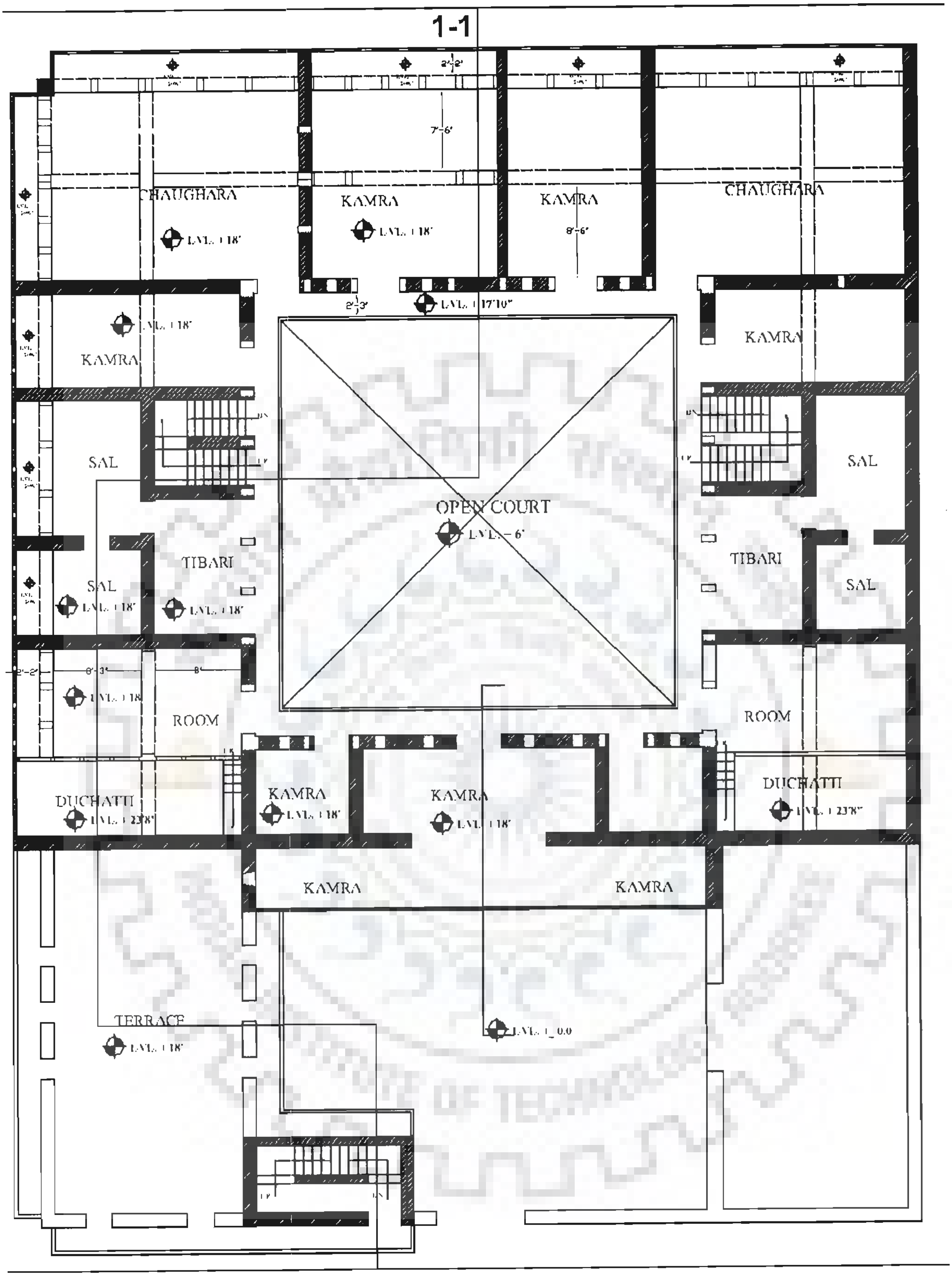
Drawing A-5.18.2: Upper Ground Floor Plan



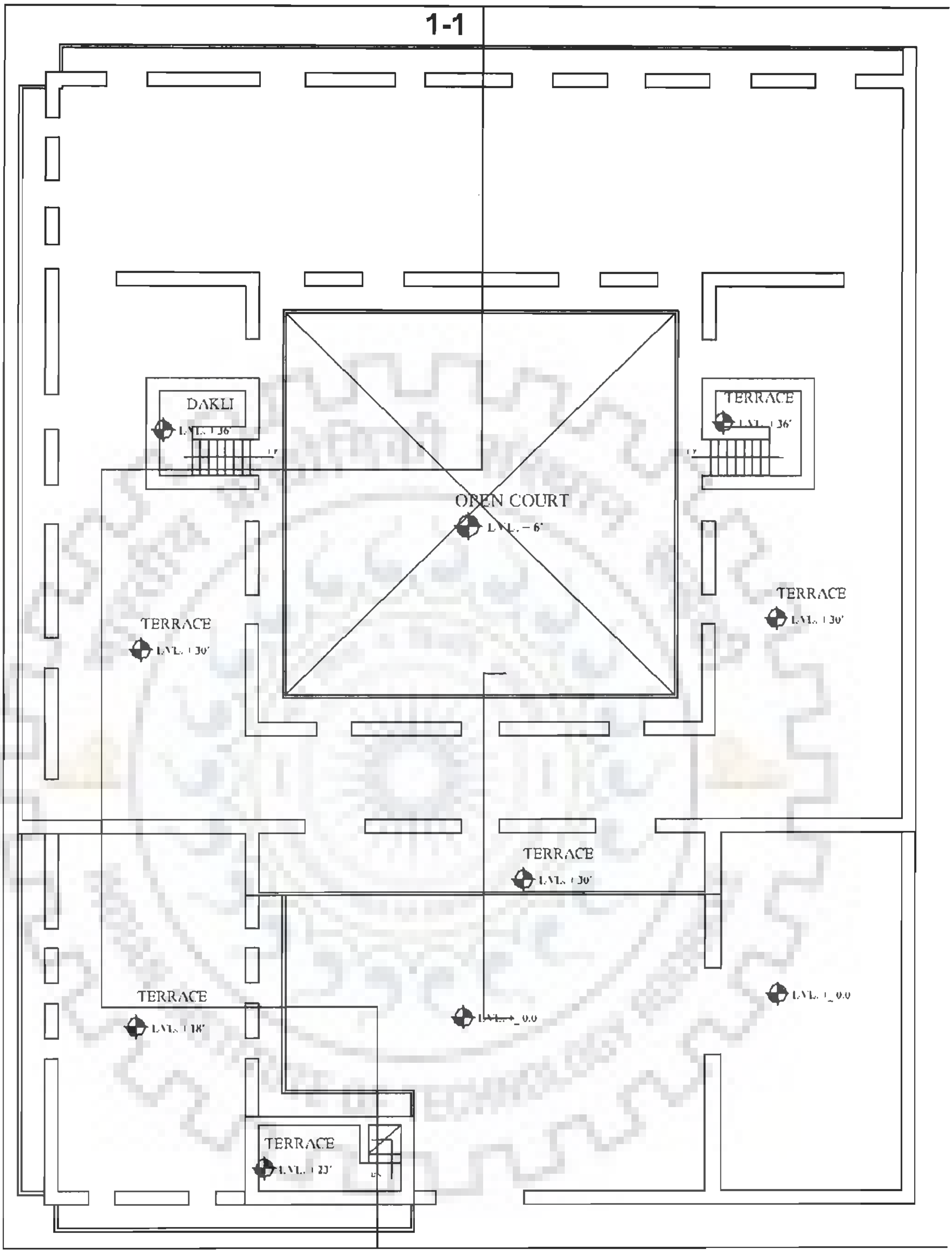
Drawing A-5.18.3: Mezzanine Floor Plan for Upper Ground Level



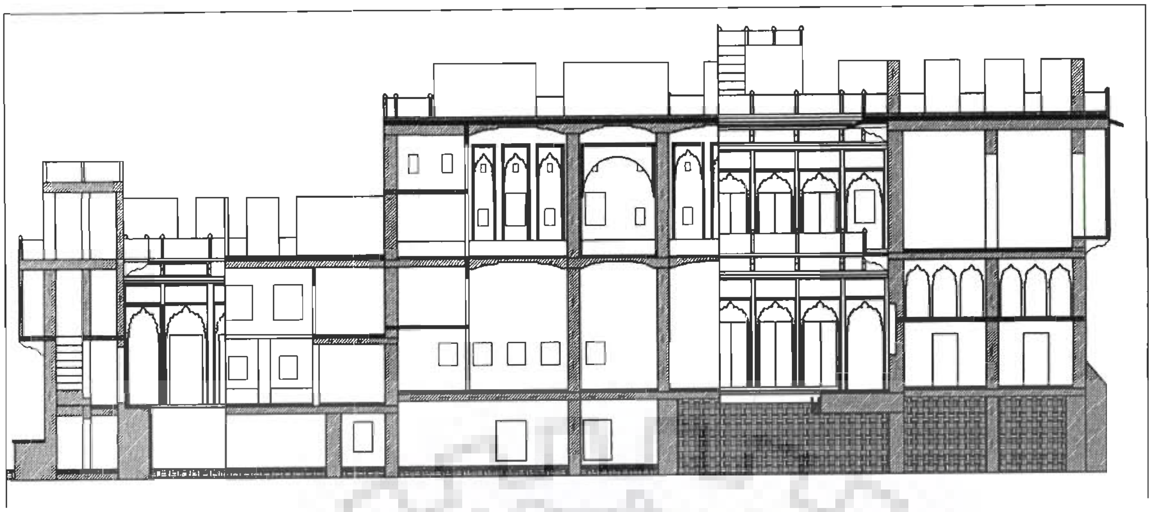
Drawing A-5.18.4: First Floor Plan



Drawing A-5.18.5: Mezzanine Floor Plan for First Floor Level

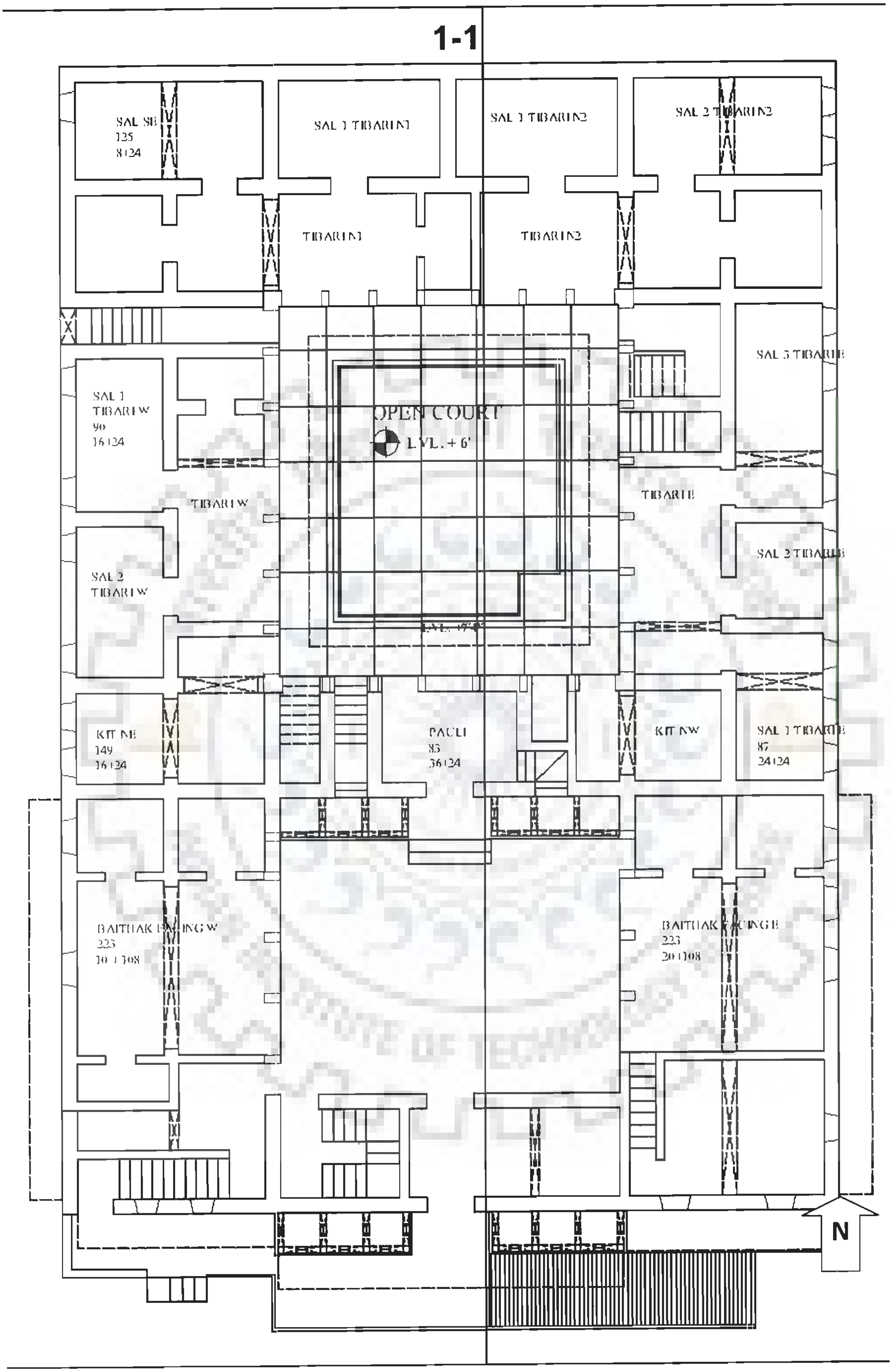


Drawing A-5.18.6: Terrace Floor Plan

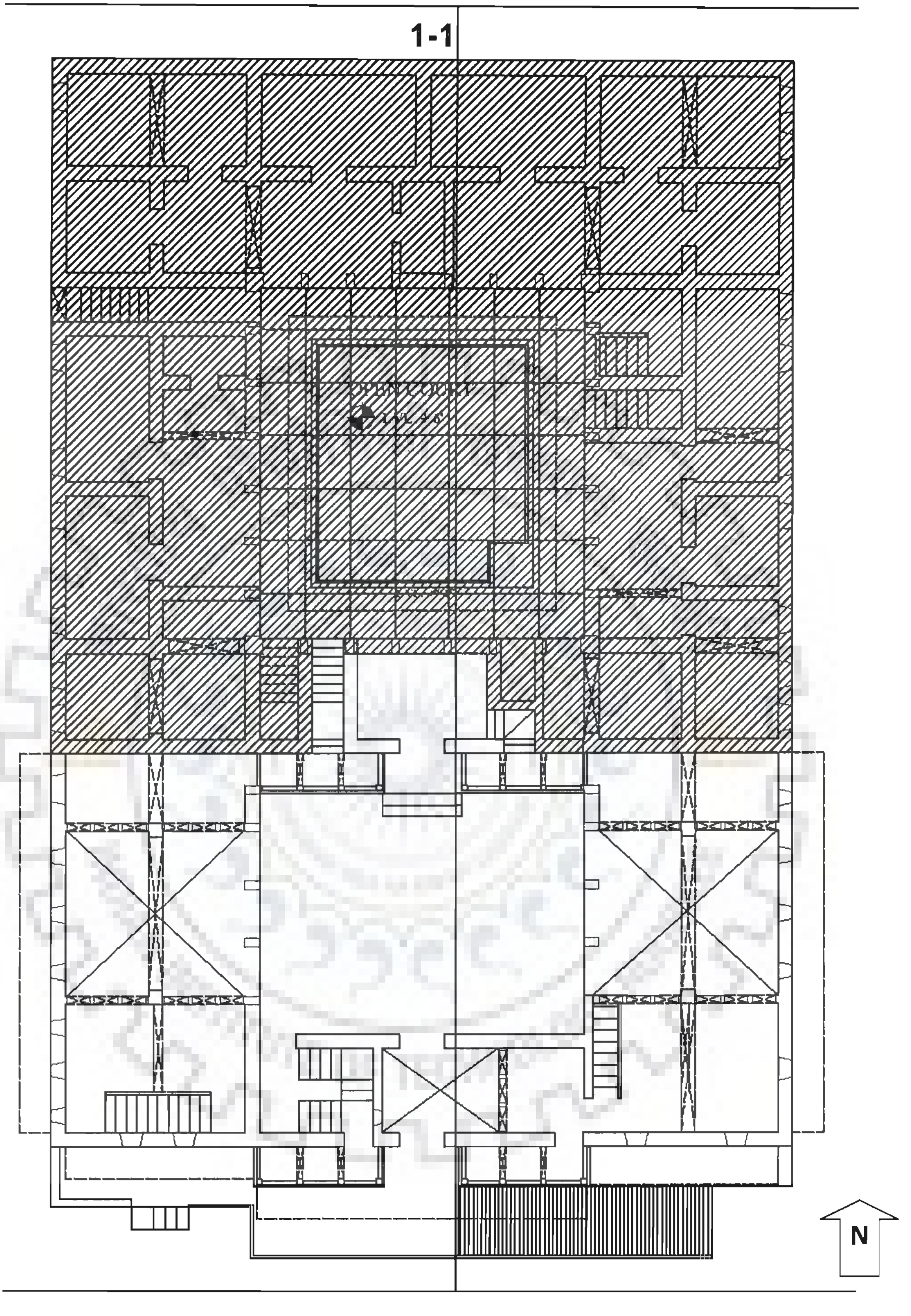


Drawing A-5.18.7: Section 1-1

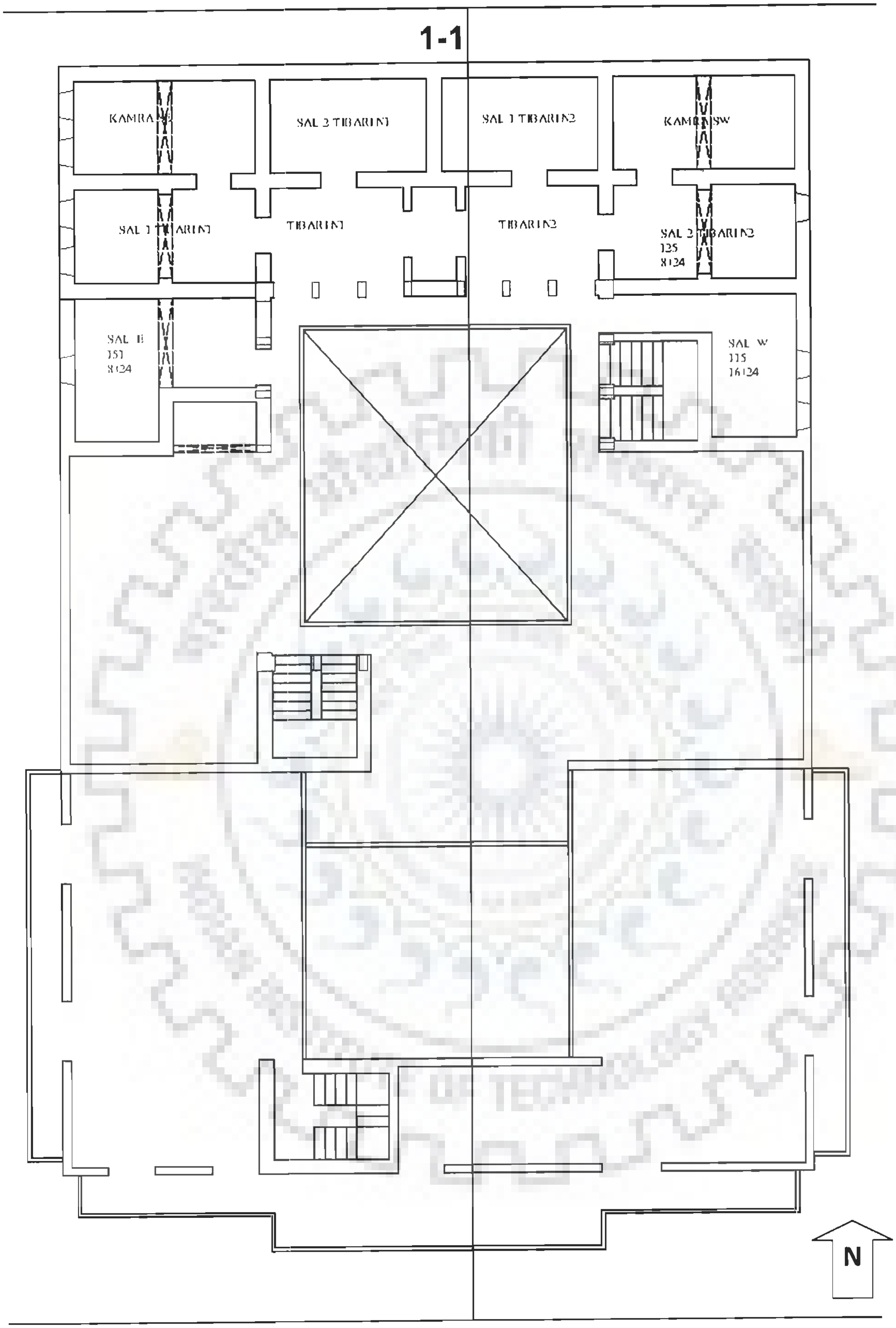
Drawing A-5.19.1: Lower Ground Floor Plan



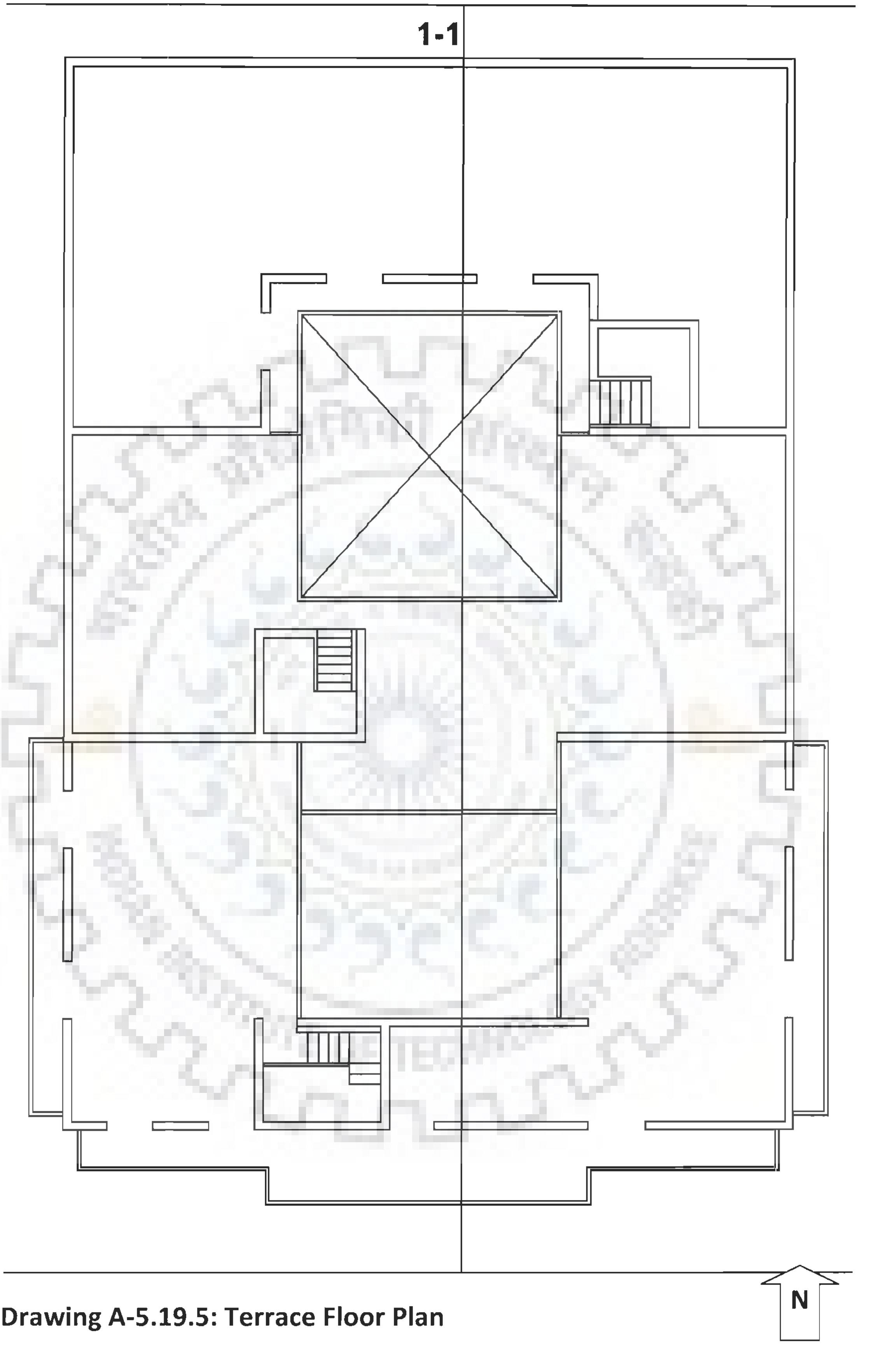
Drawing A-5.19.2: Upper Ground Floor Plan



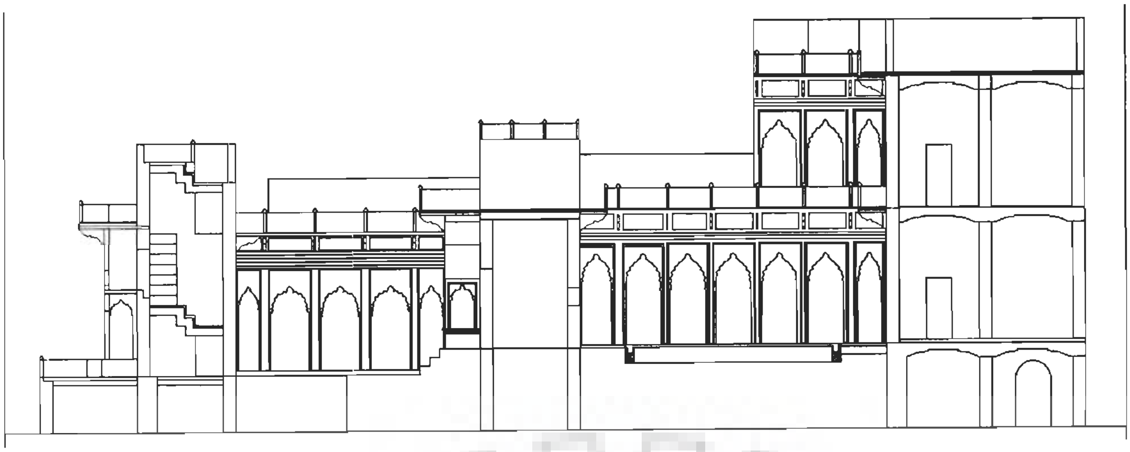
Drawing A-5.19.3: Mezzanine Floor Plan for Upper Ground Floor Level



Drawing A-5.19.4: First Floor Plan

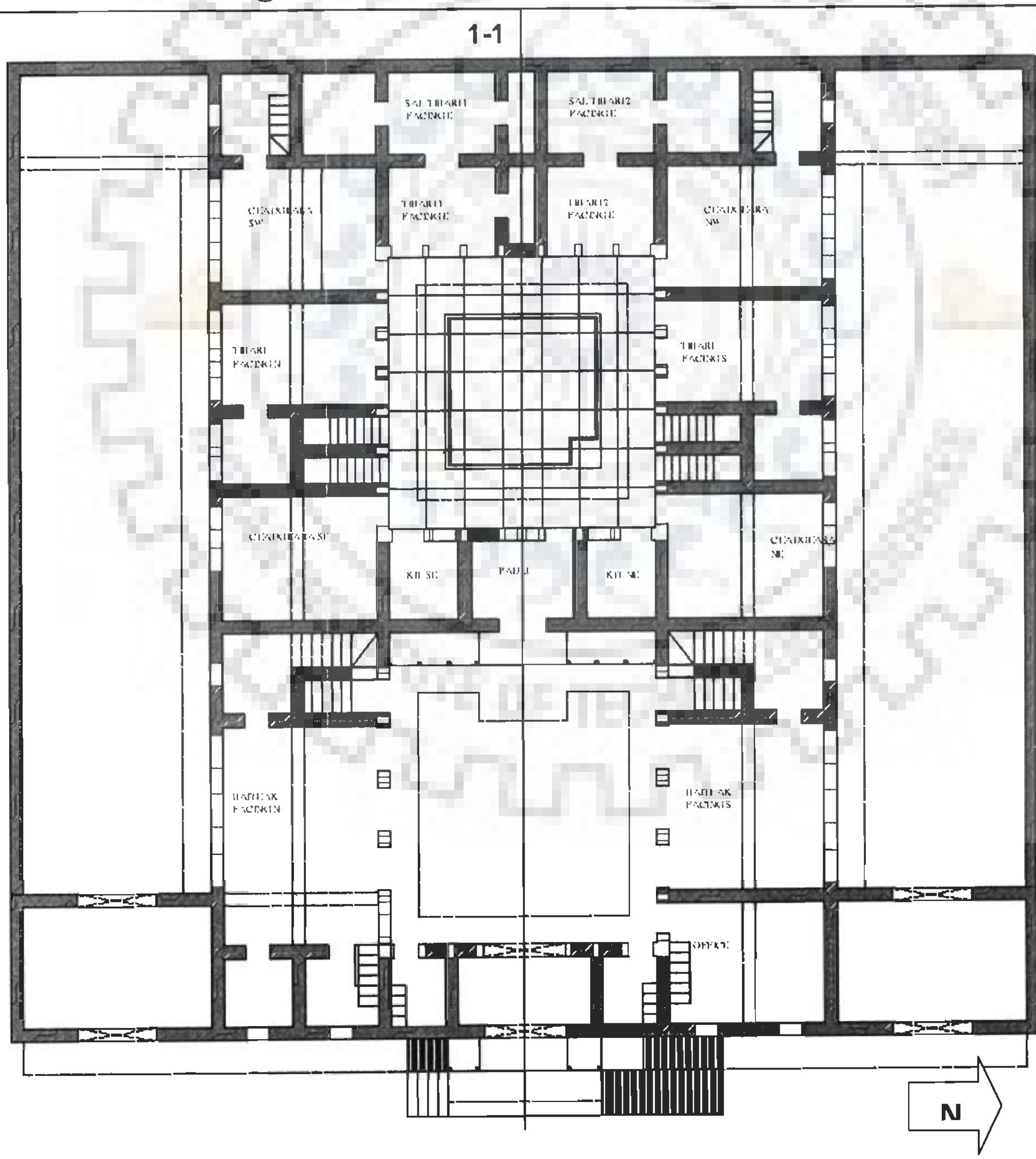


Drawing A-5.19.5: Terrace Floor Plan

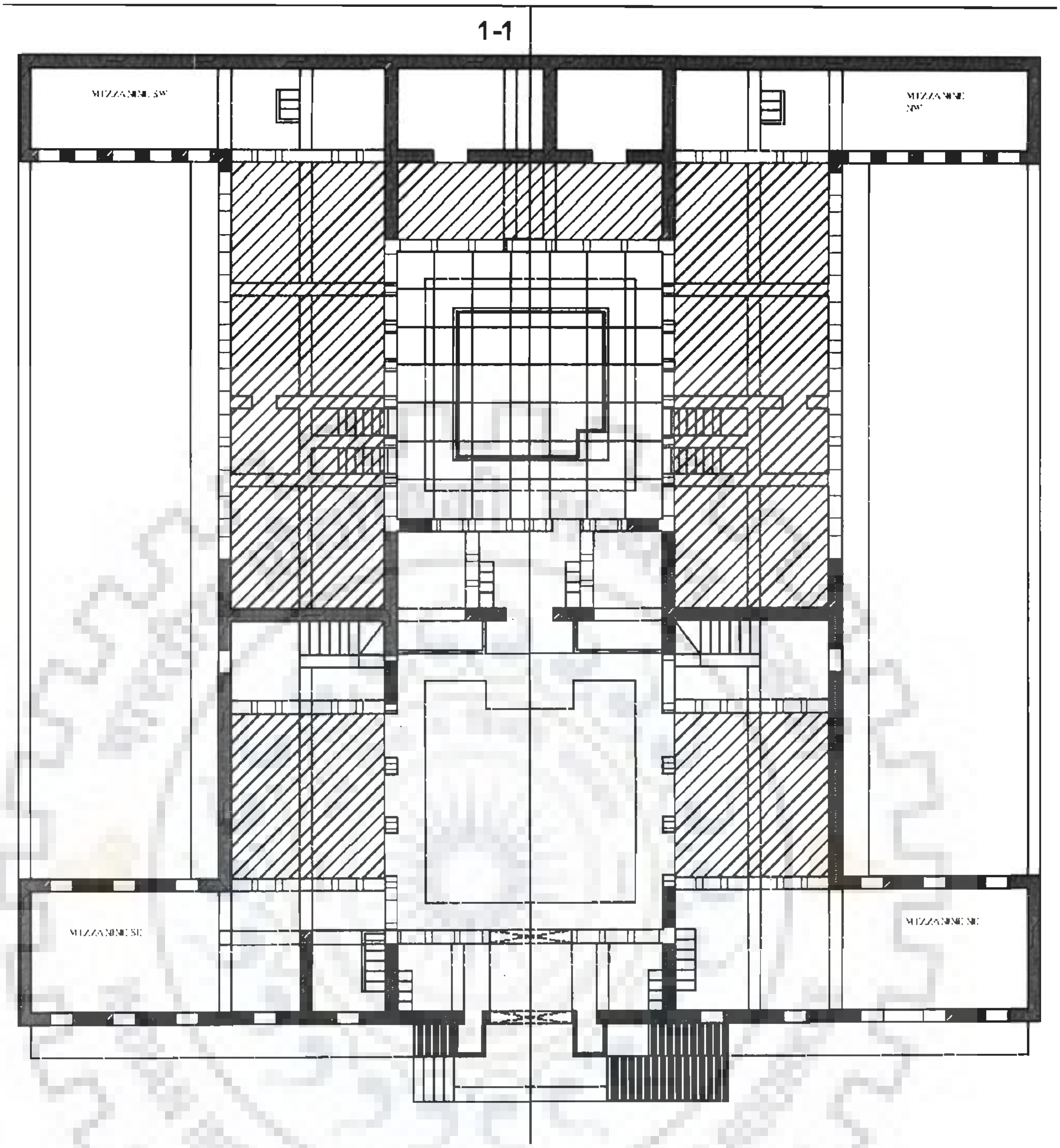


Drawing A-5.19.6: Section 1-1

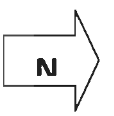
20 Shridhar Gangadhar Morarka Haveli, Mukundgarh

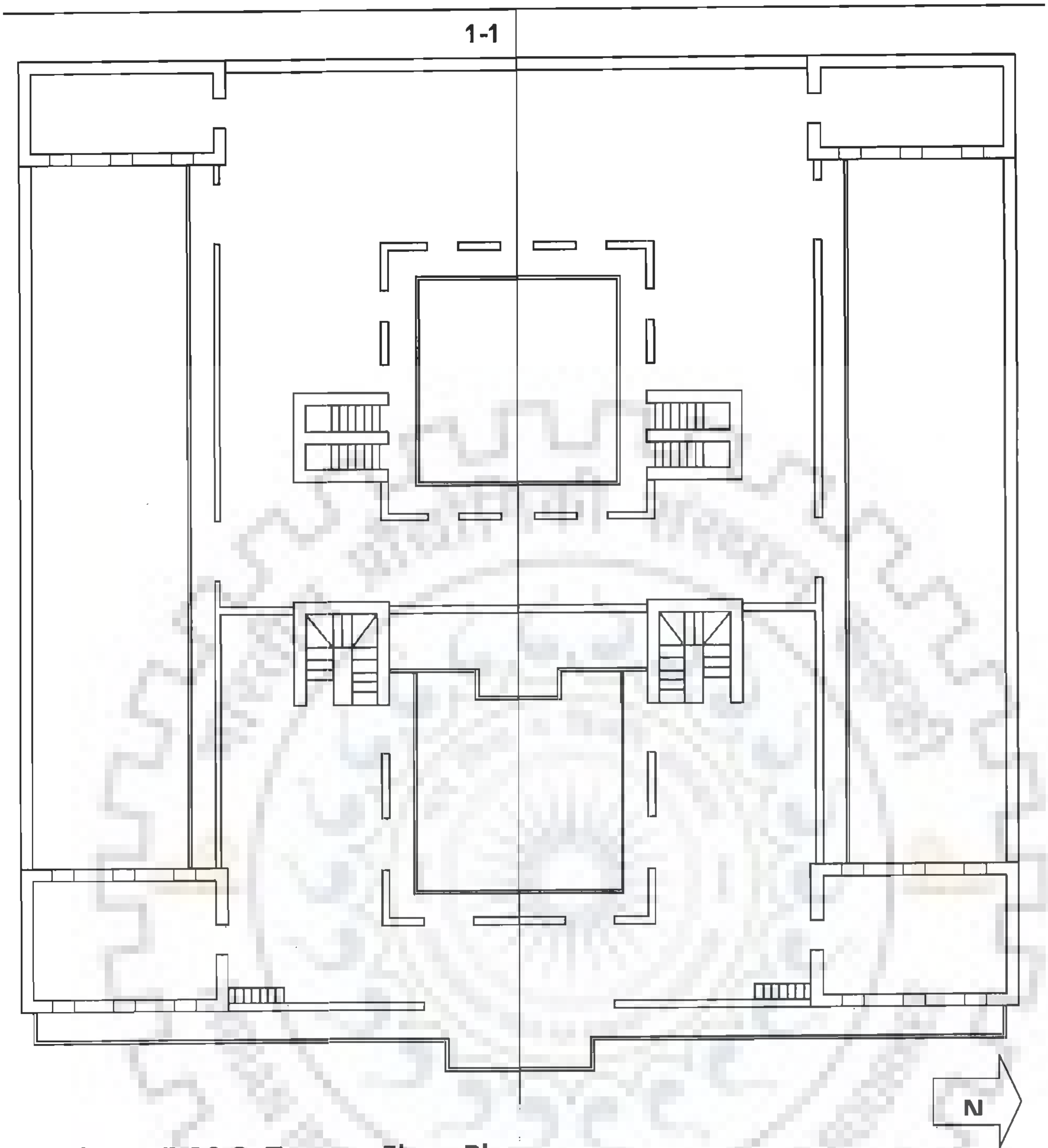


Drawing A-5.20.1: Ground Floor Plan

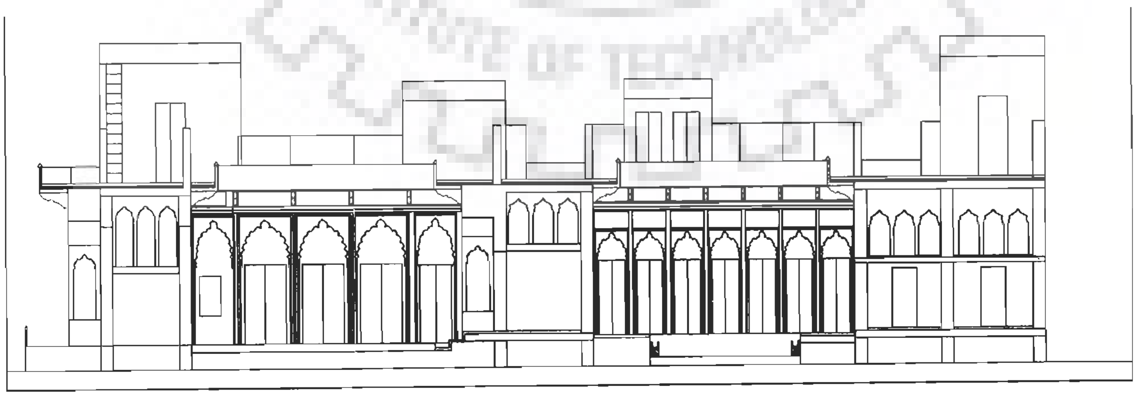


Drawing A-5.20.2: Mezzanine Floor Plan for Ground Level



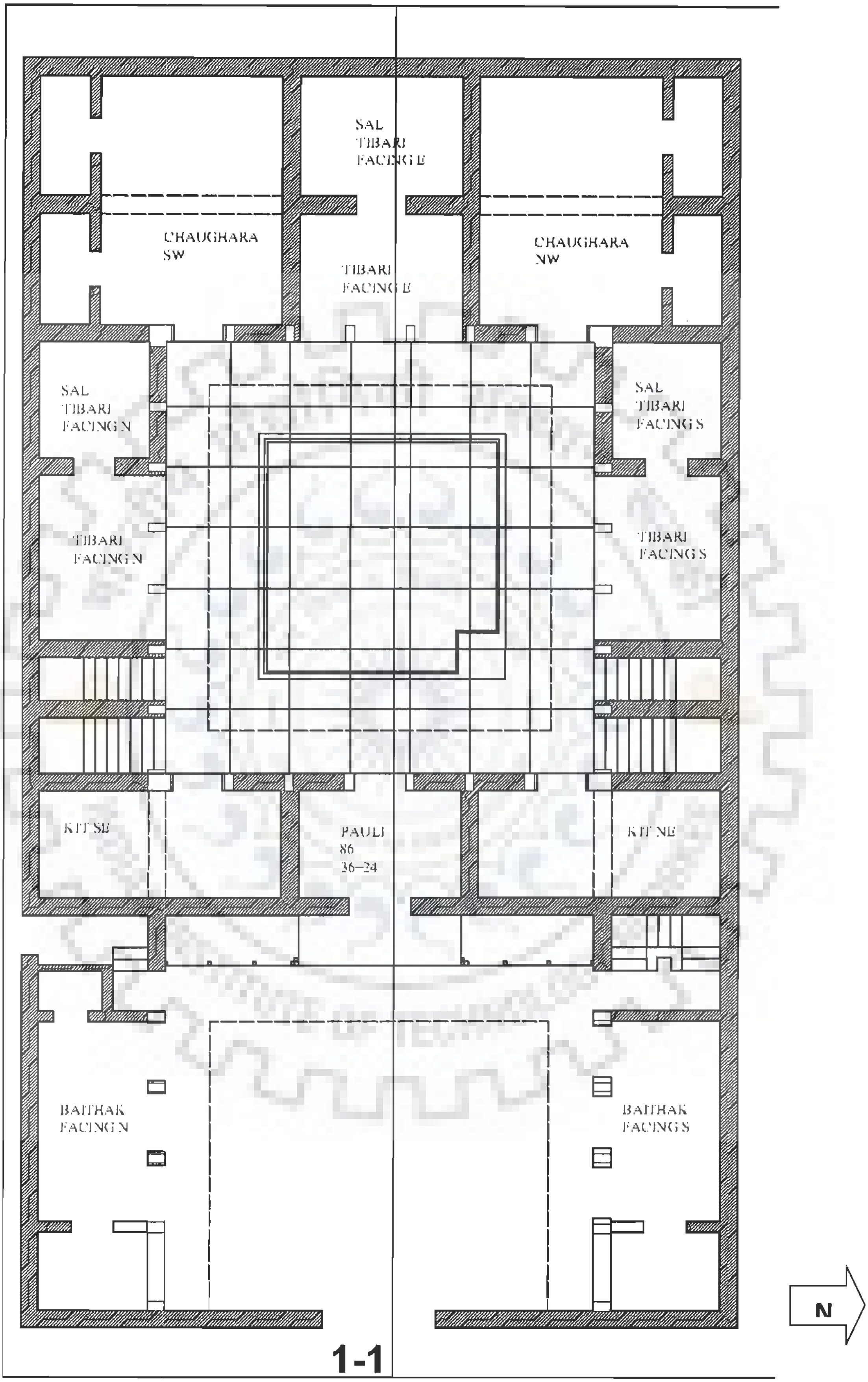


Drawing A-5.20.3: Terrace Floor Plan

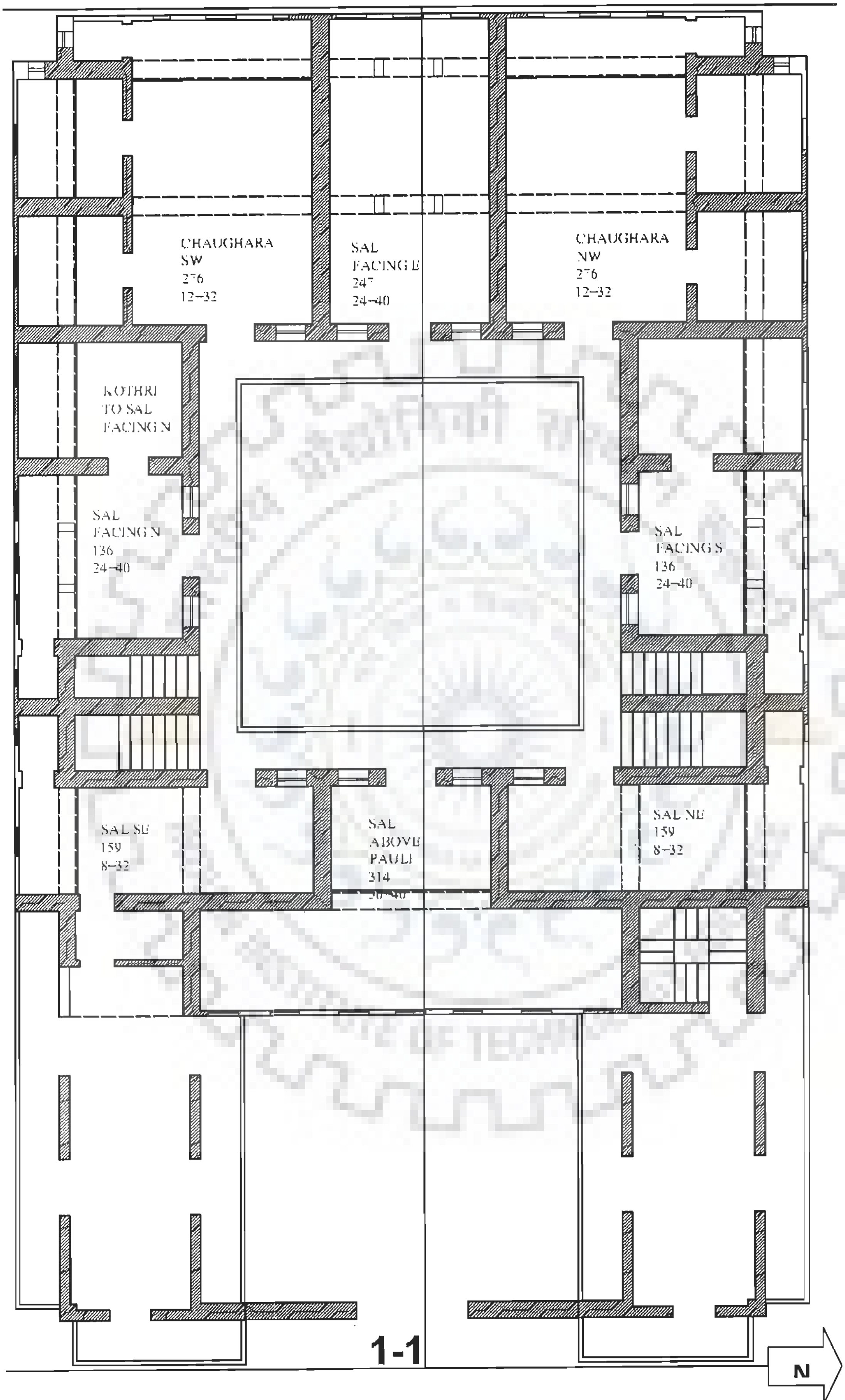


Drawing A-5.20.4: Section 1-1

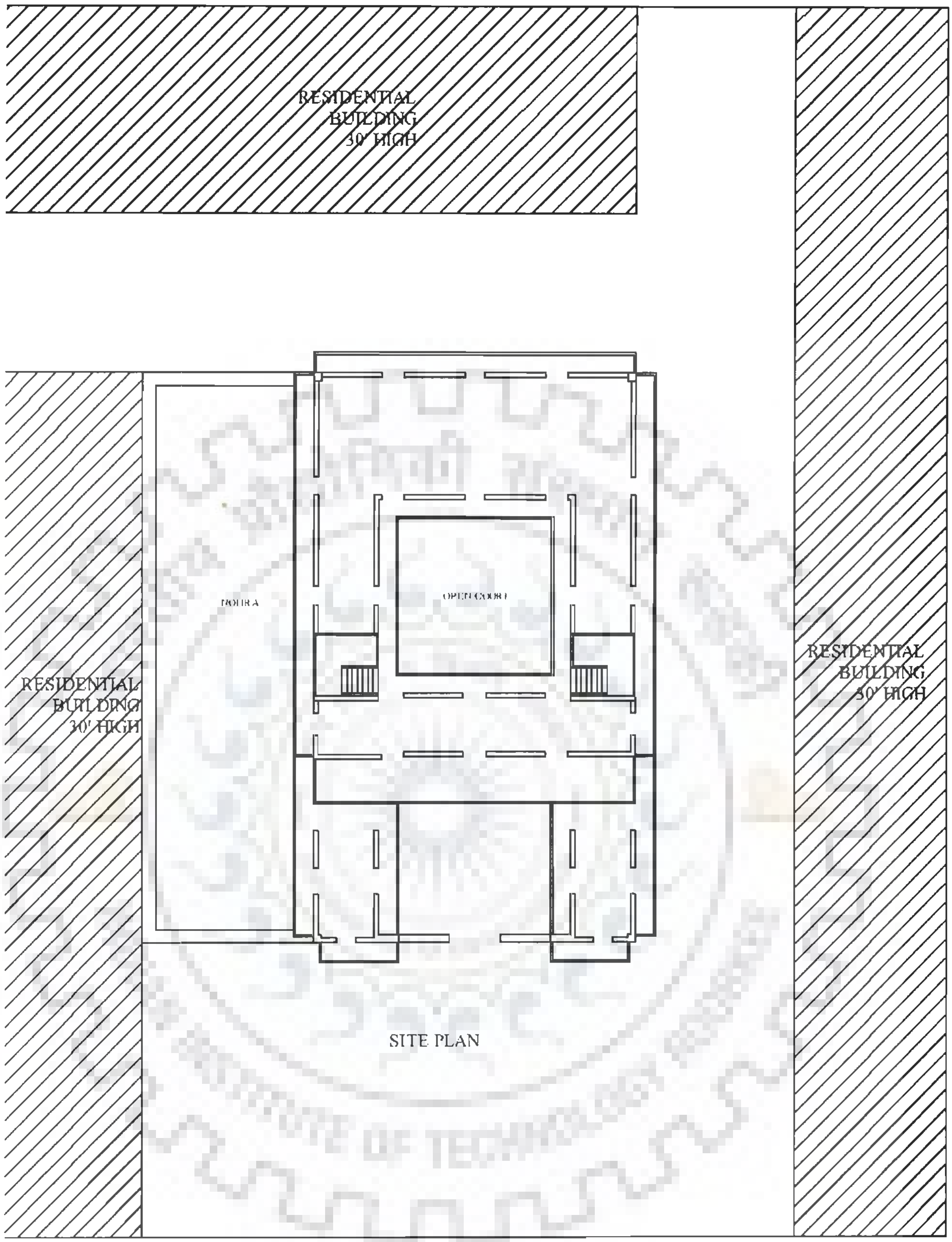
21 Navalgarh unidentified Haveli



Drawing A-5.21.1: Ground Floor Plan

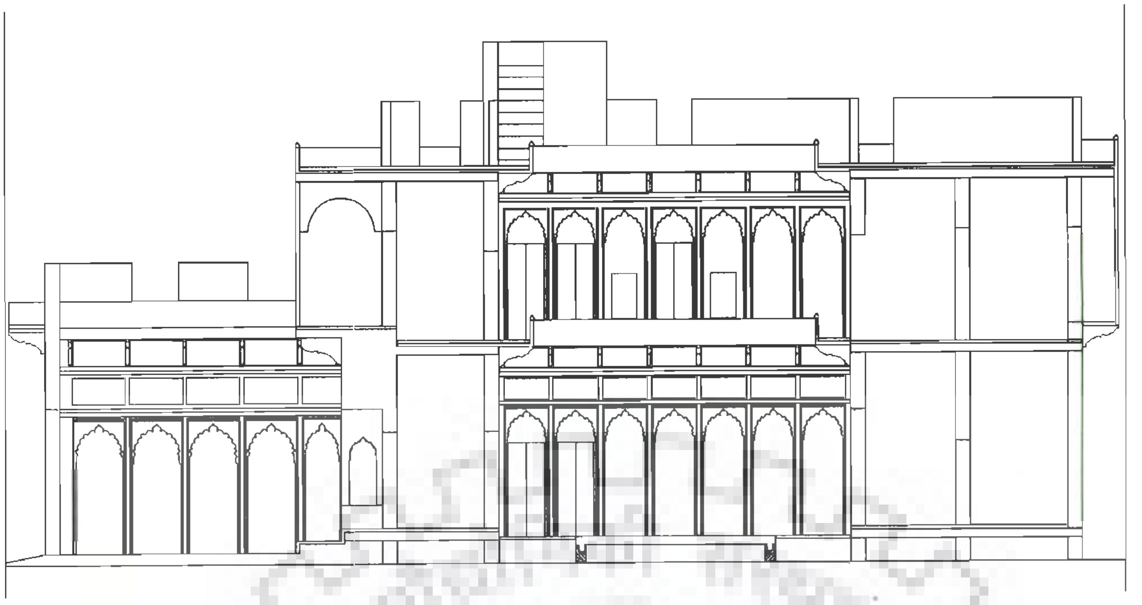


Drawing A-5.21.2: First Floor Plan



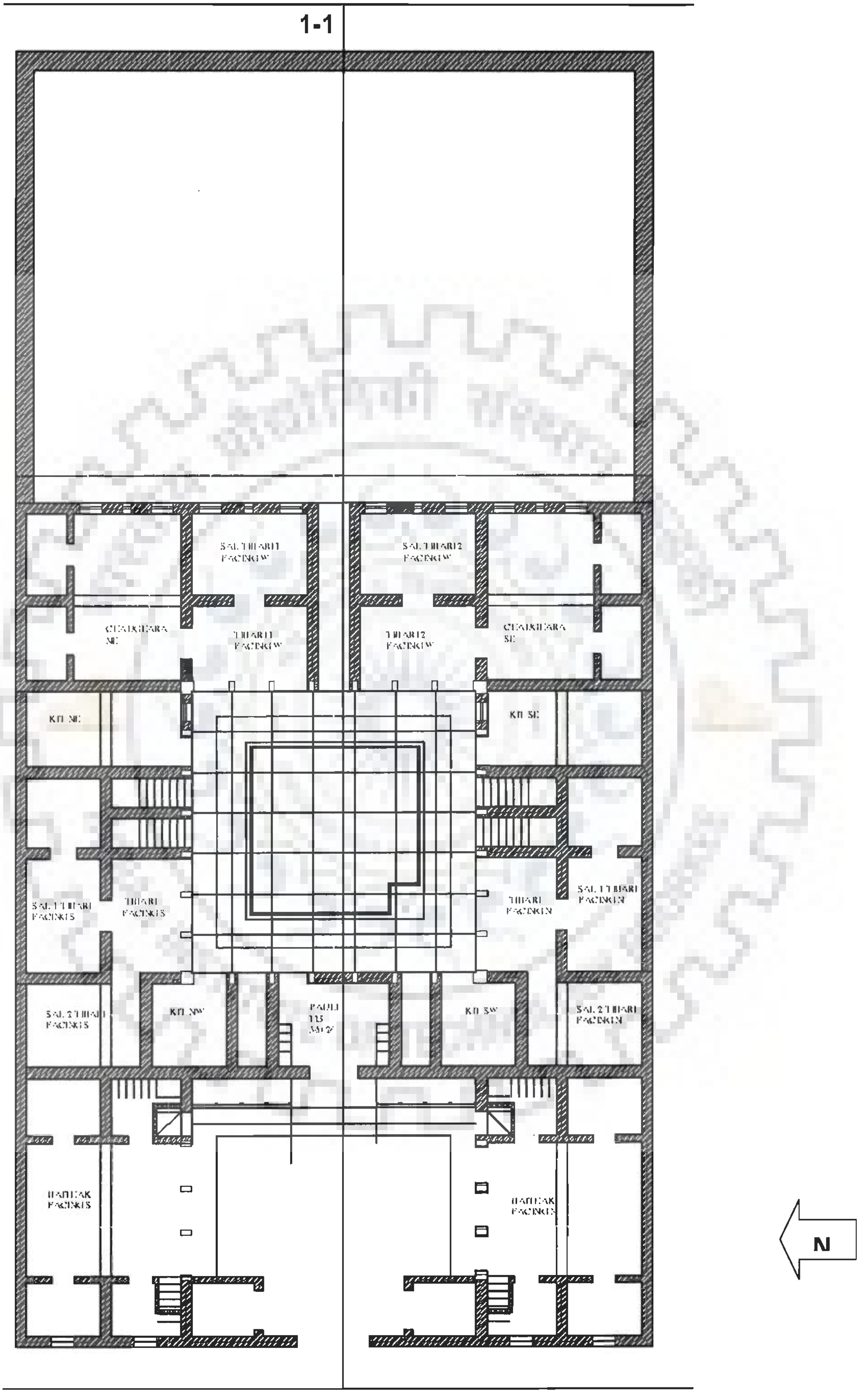
Drawing A-5.21.3: Terrace Floor Plan

N

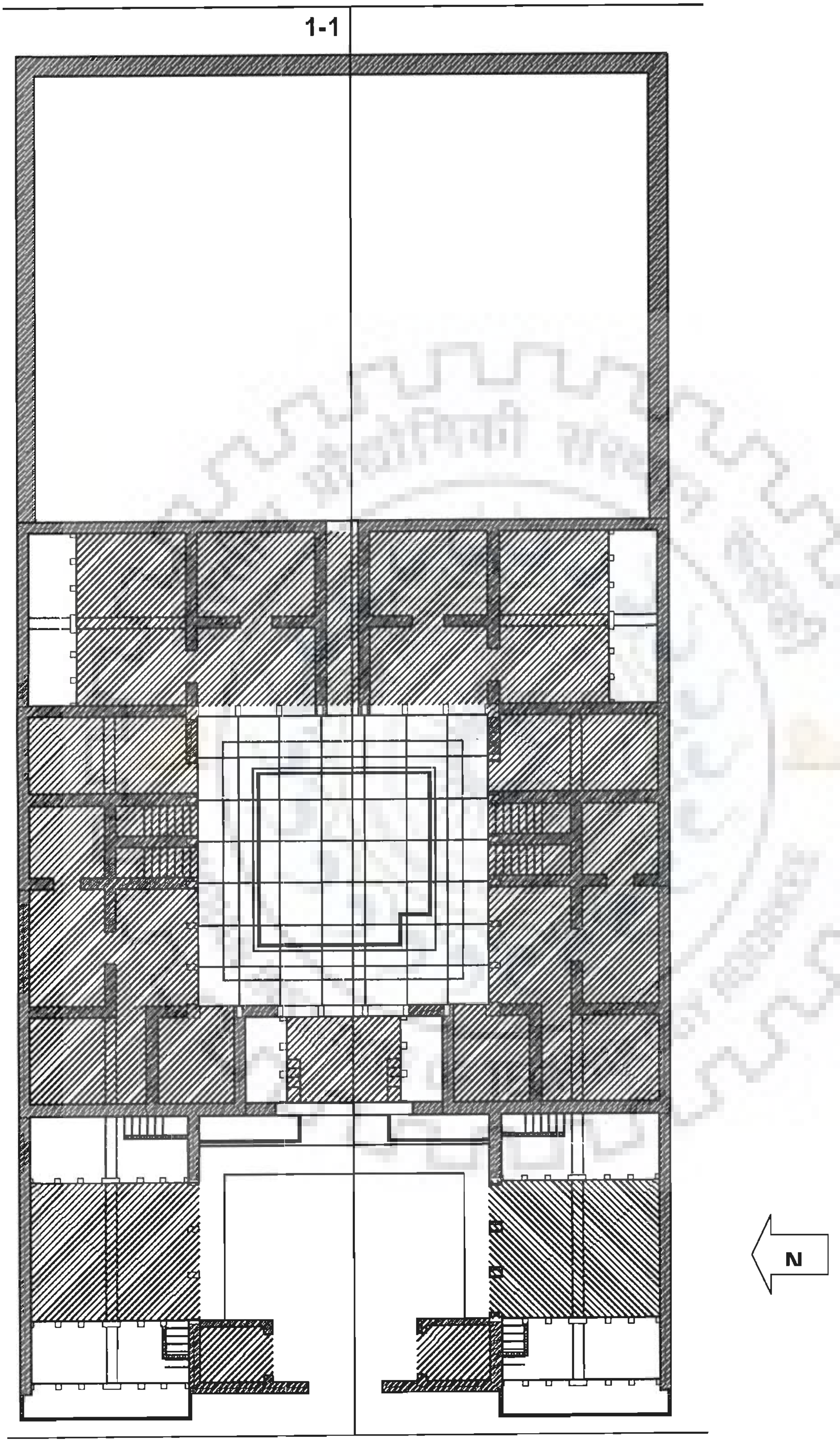


Drawing A-5.21.4: Section 1-1

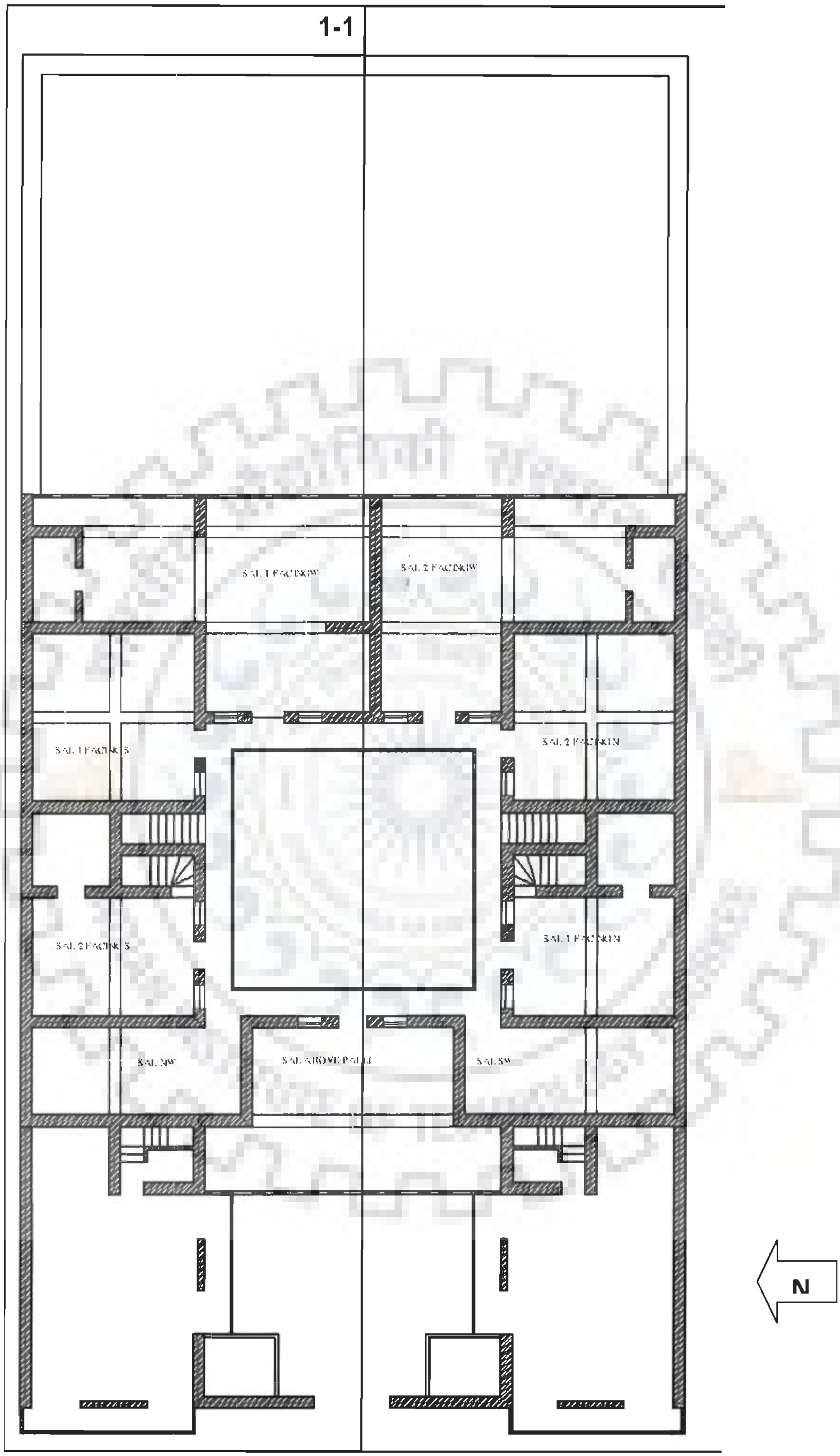
22 Surajgarh Haveli



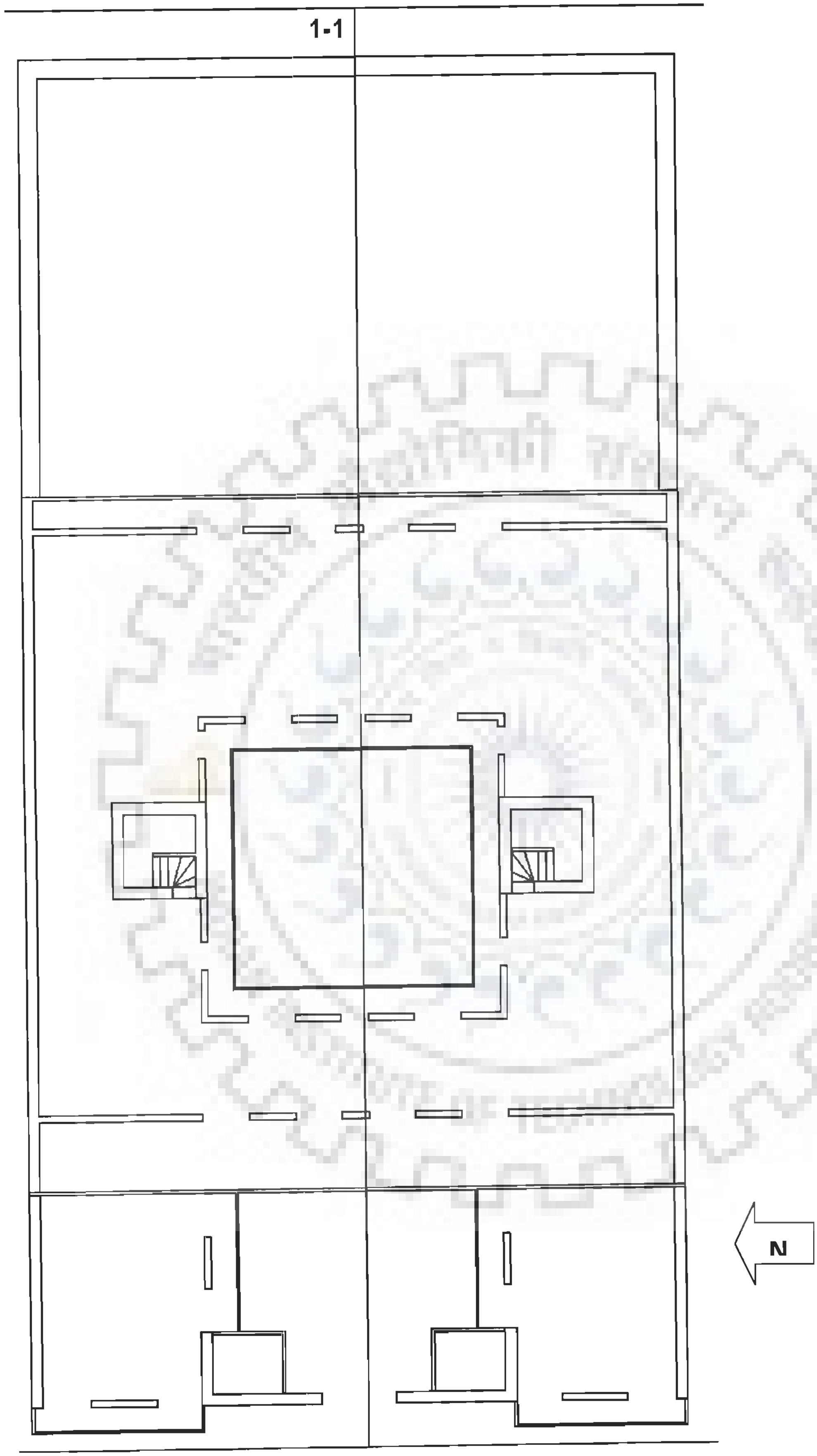
Drawing A-5.22.1: Ground Floor Plan



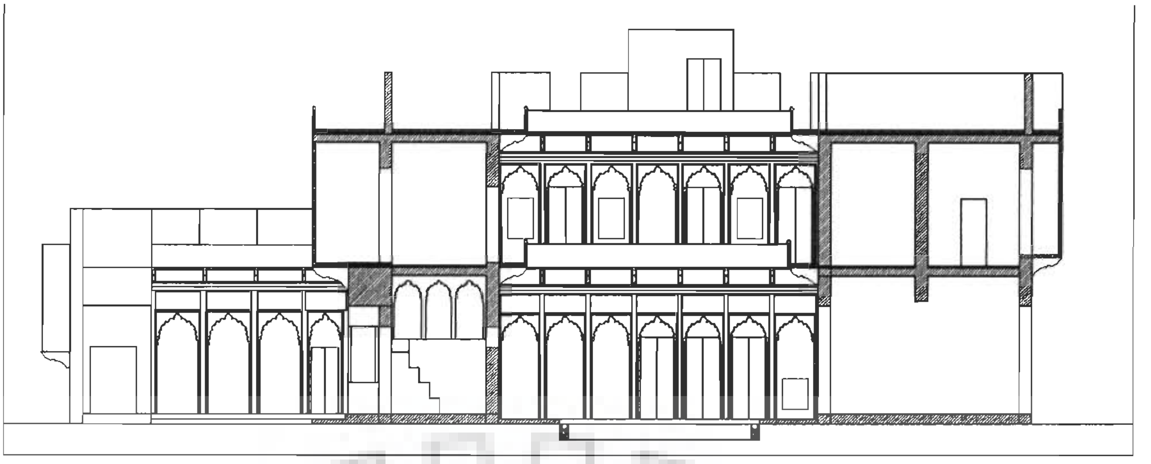
Drawing A-5.22.2: Mezzanine Floor Plan for Ground Level



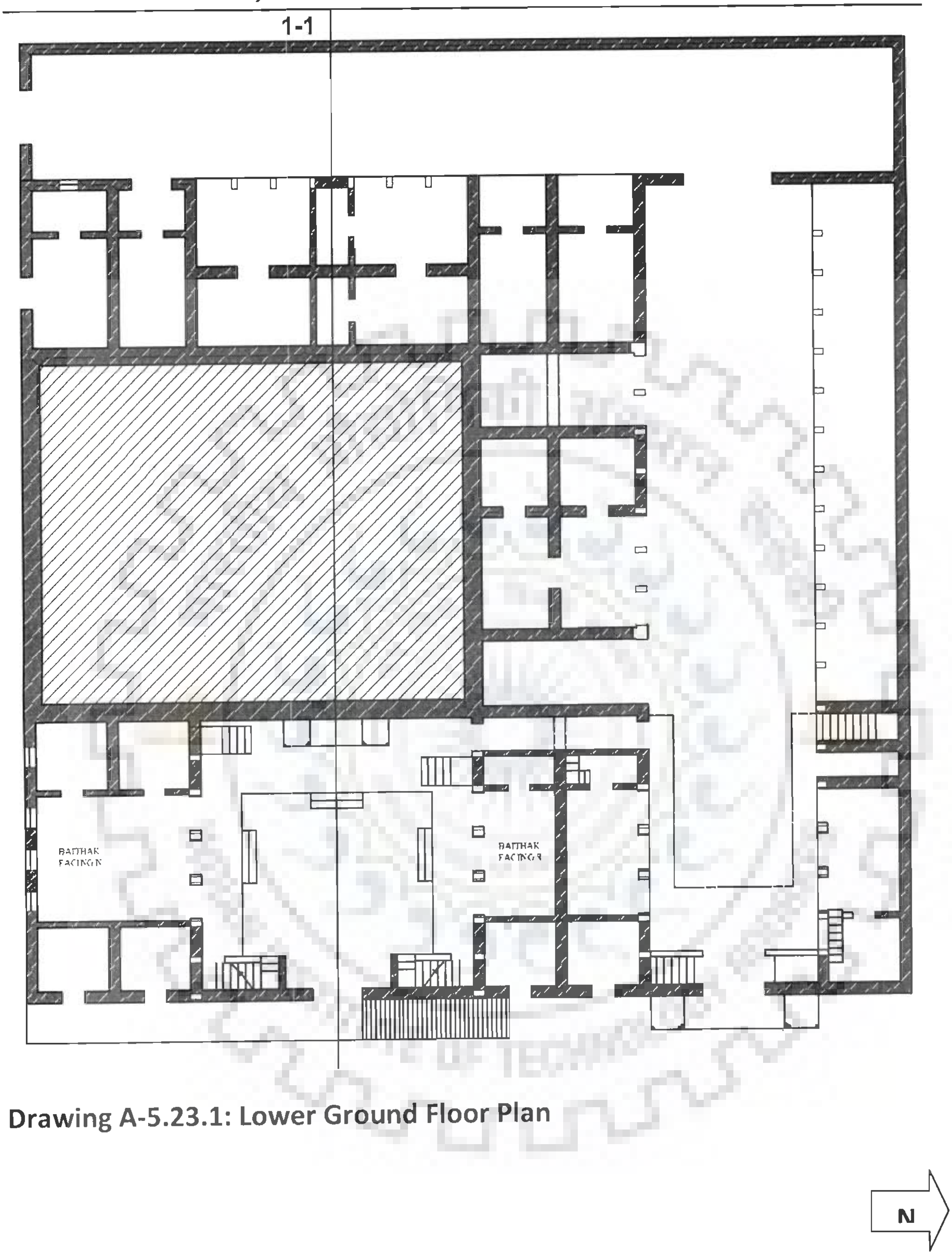
Drawing A-5.22.3: First Floor Plan



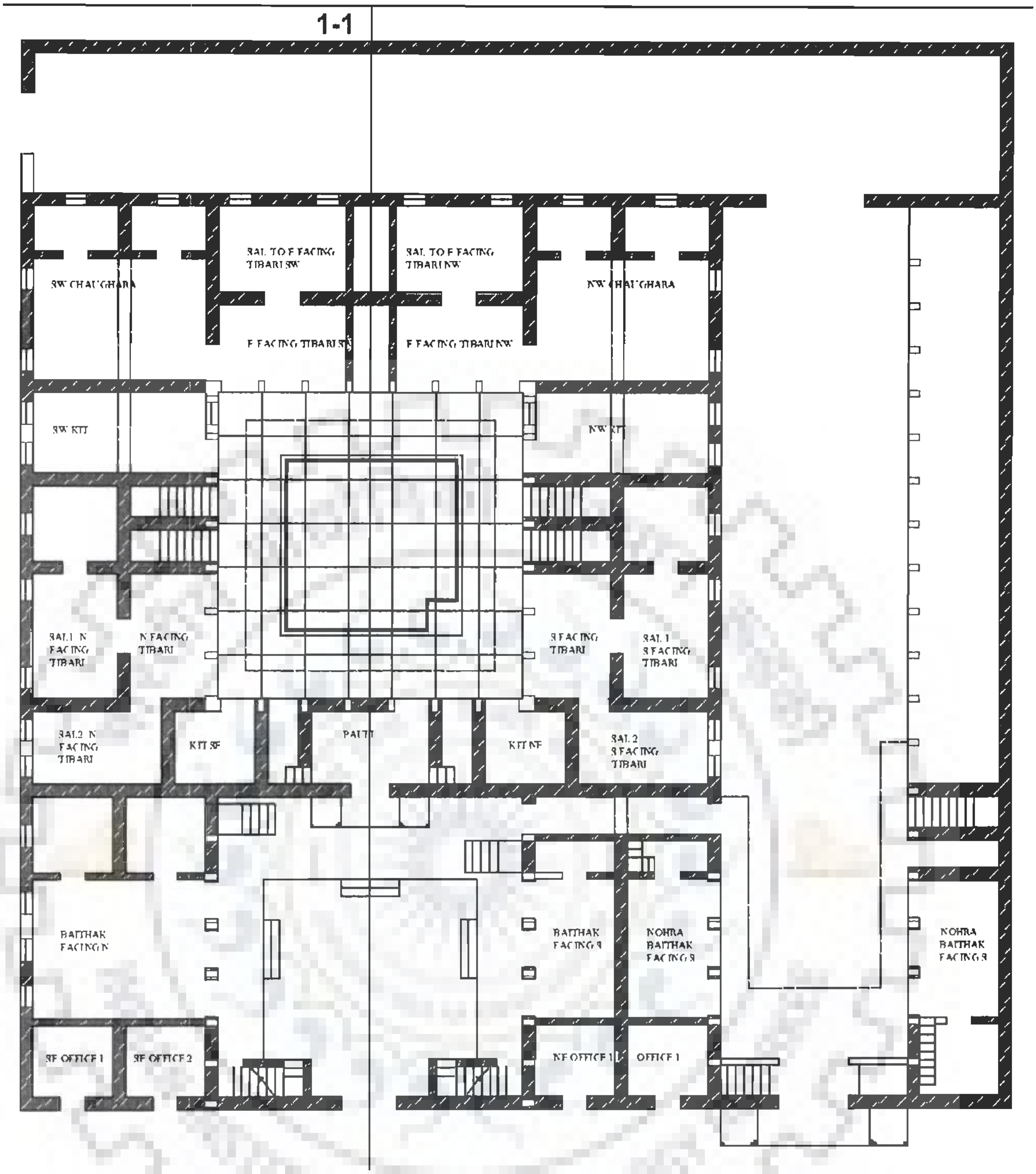
Drawing A-5.22.4: Terrace Floor Plan



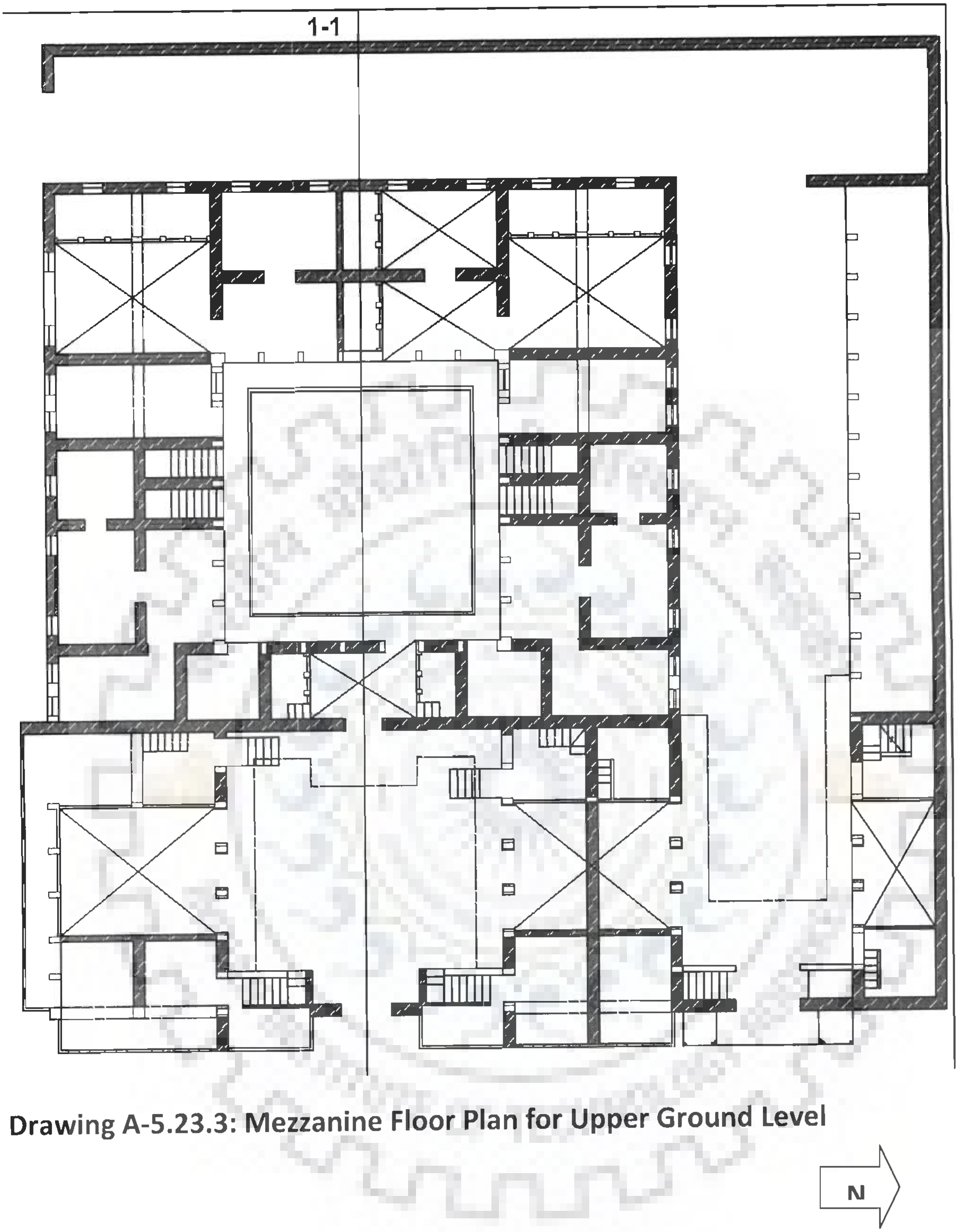
Drawing A-5.22.5Section 1-1



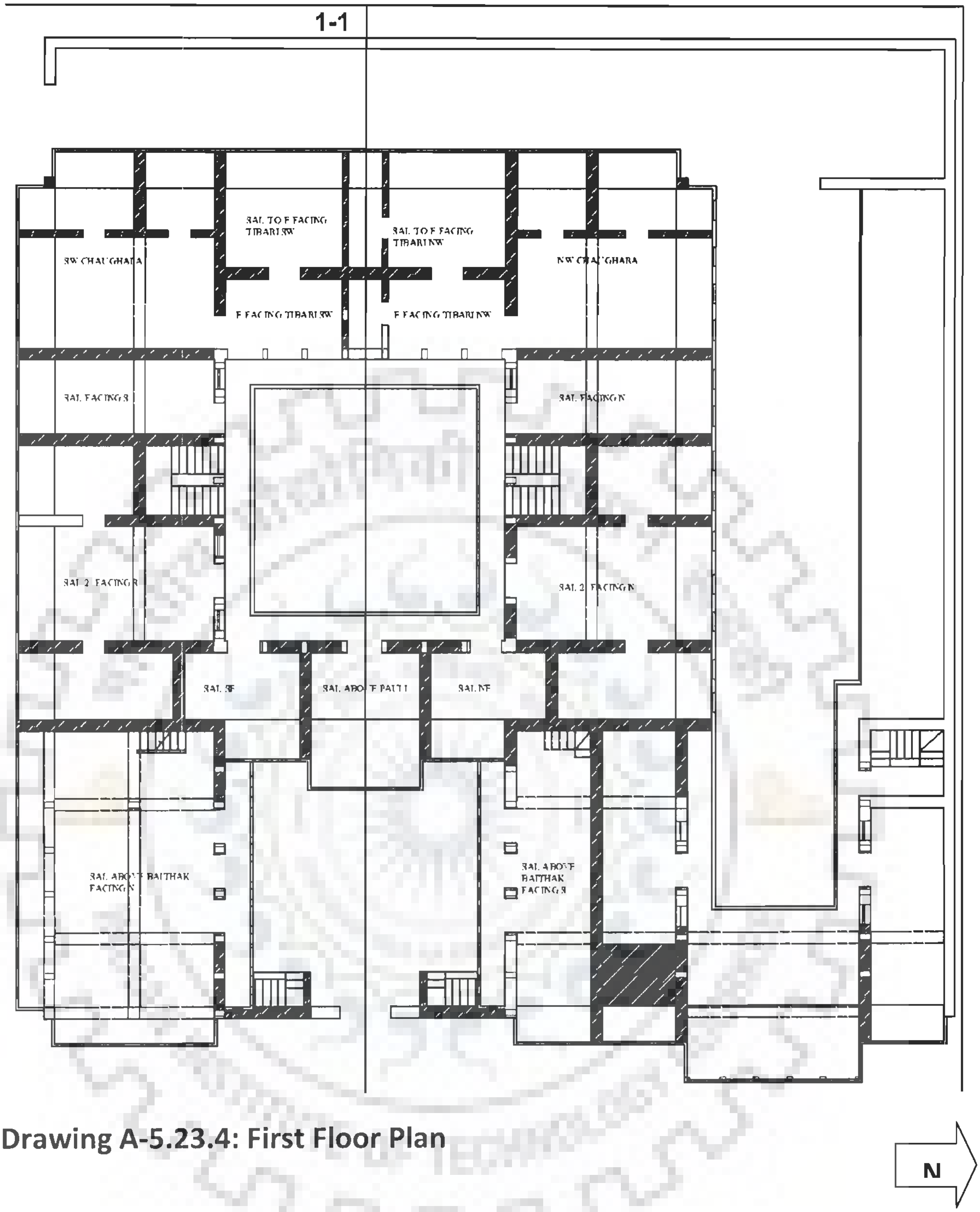
Drawing A-5.23.1: Lower Ground Floor Plan



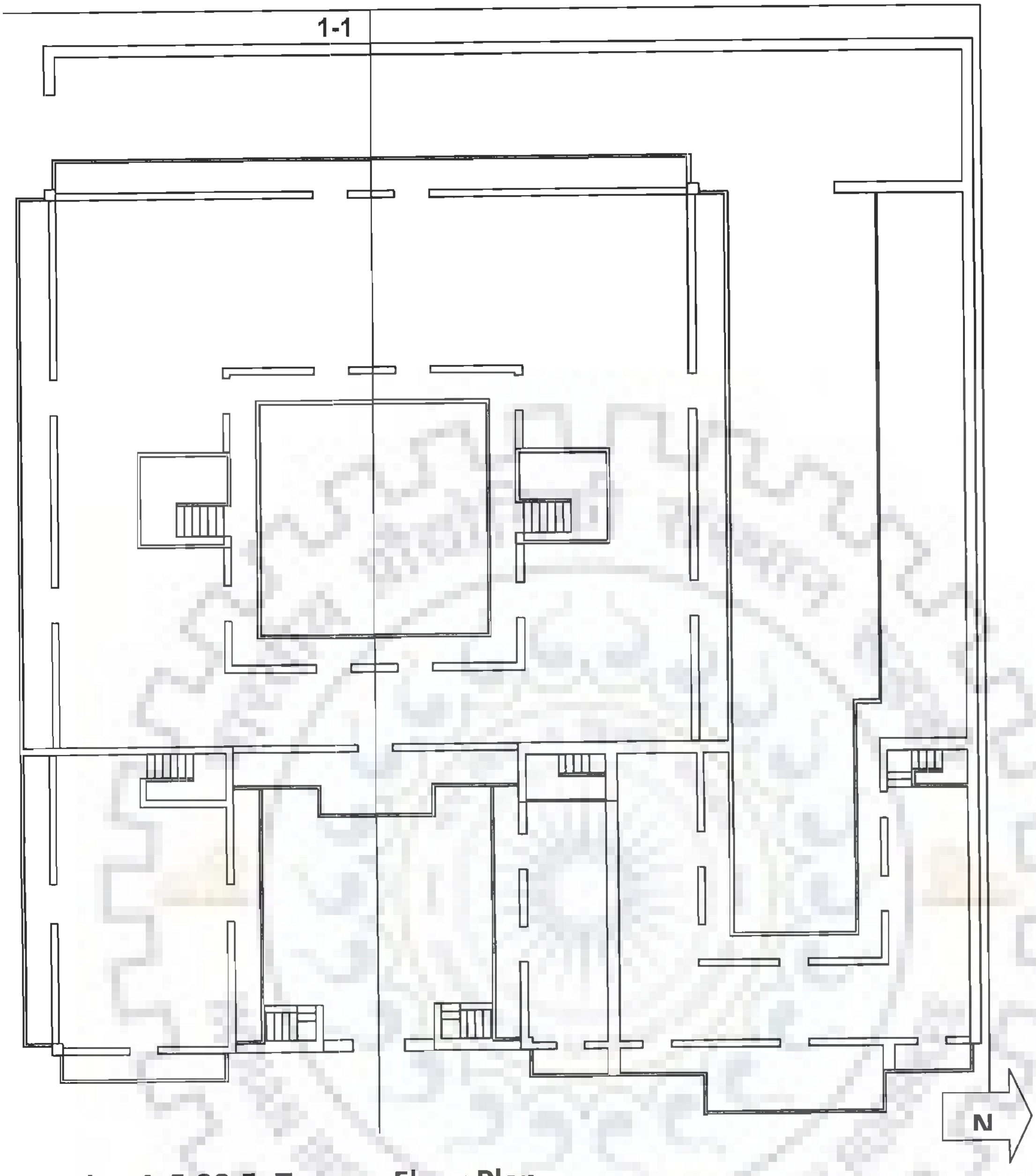
Drawing A-5.23.2: Upper Ground Floor Plan



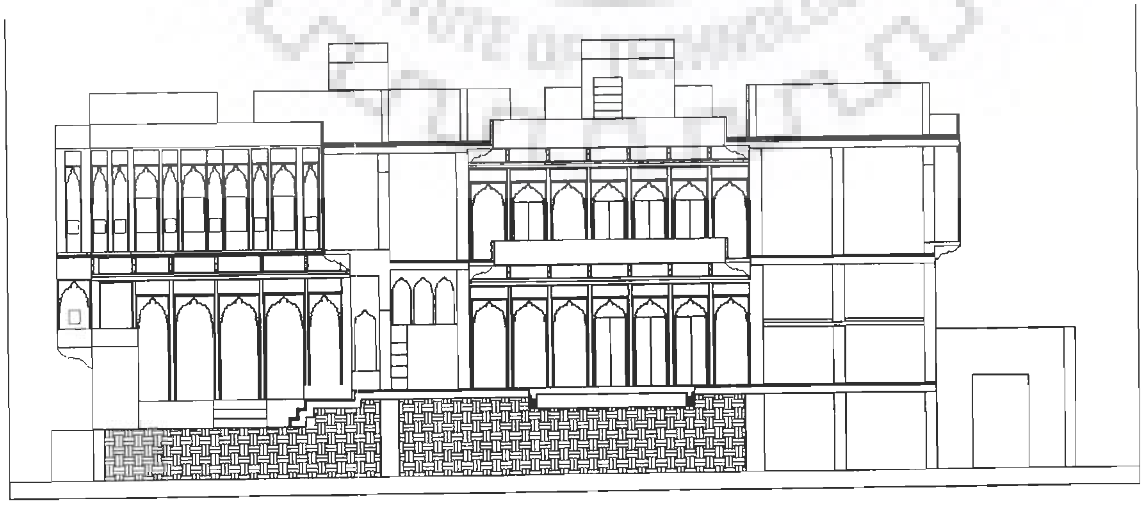
Drawing A-5.23.3: Mezzanine Floor Plan for Upper Ground Level



Drawing A-5.23.4: First Floor Plan

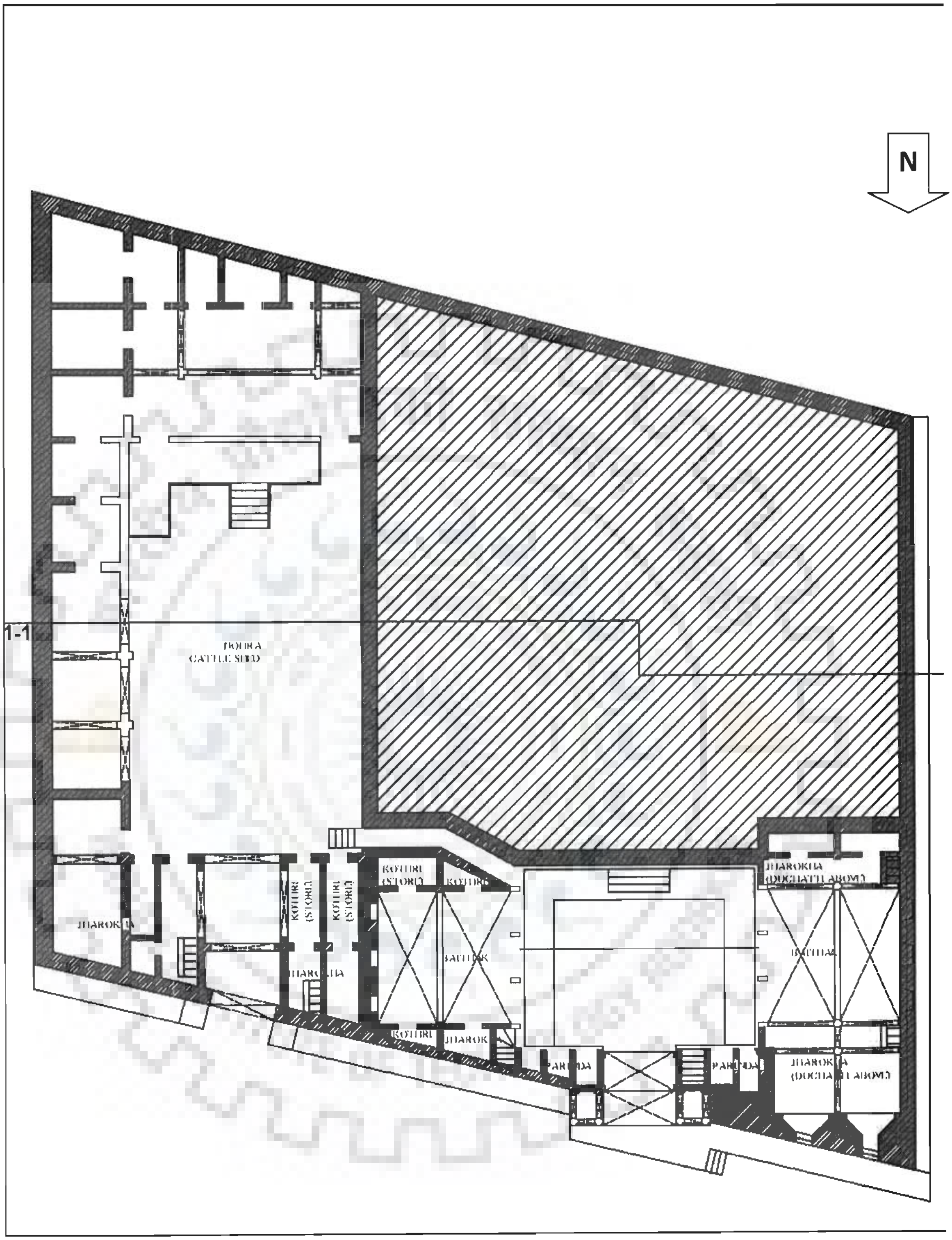


Drawing A-5.23.5: Terrace Floor Plan

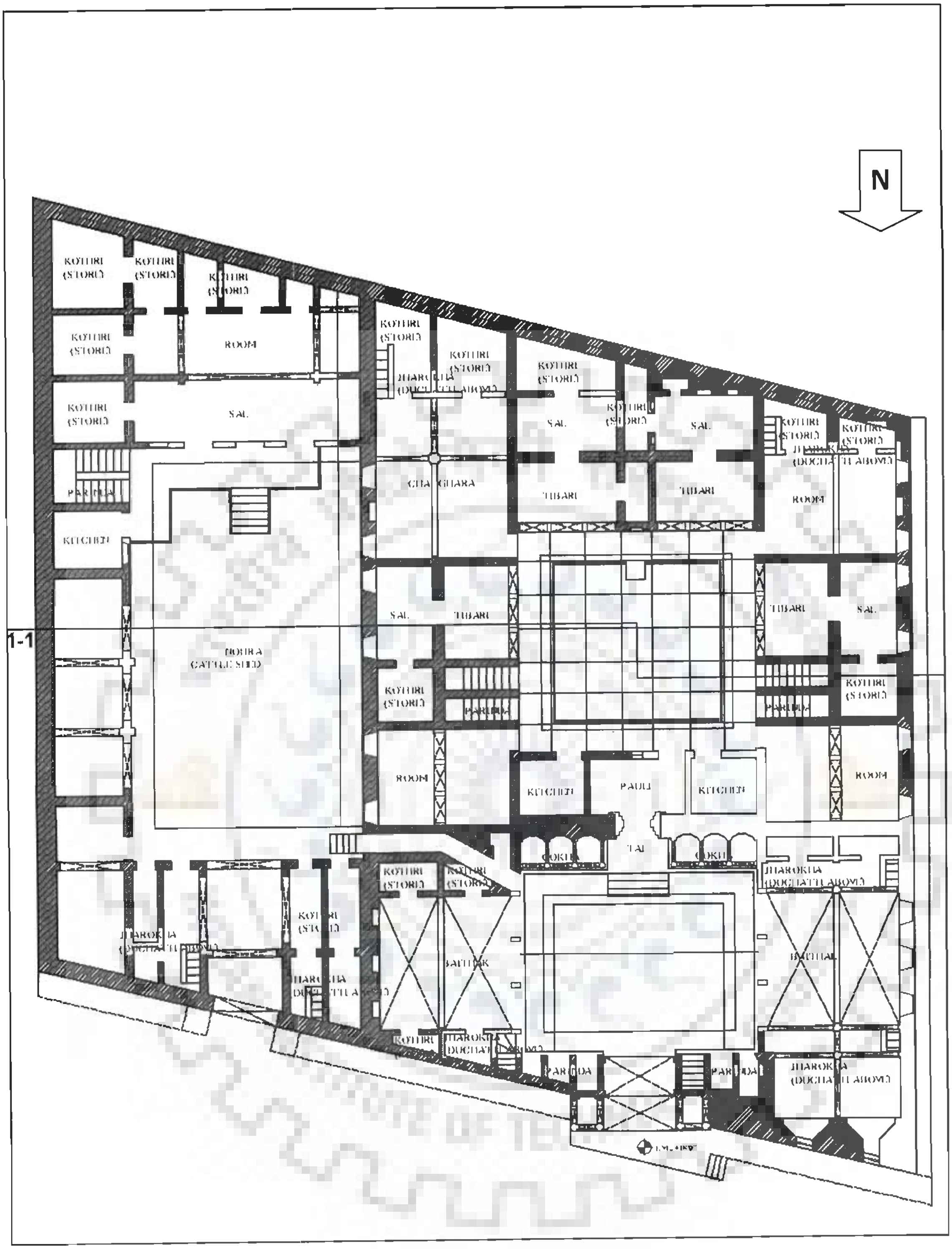


Drawing A-5.23.6Section 1-1

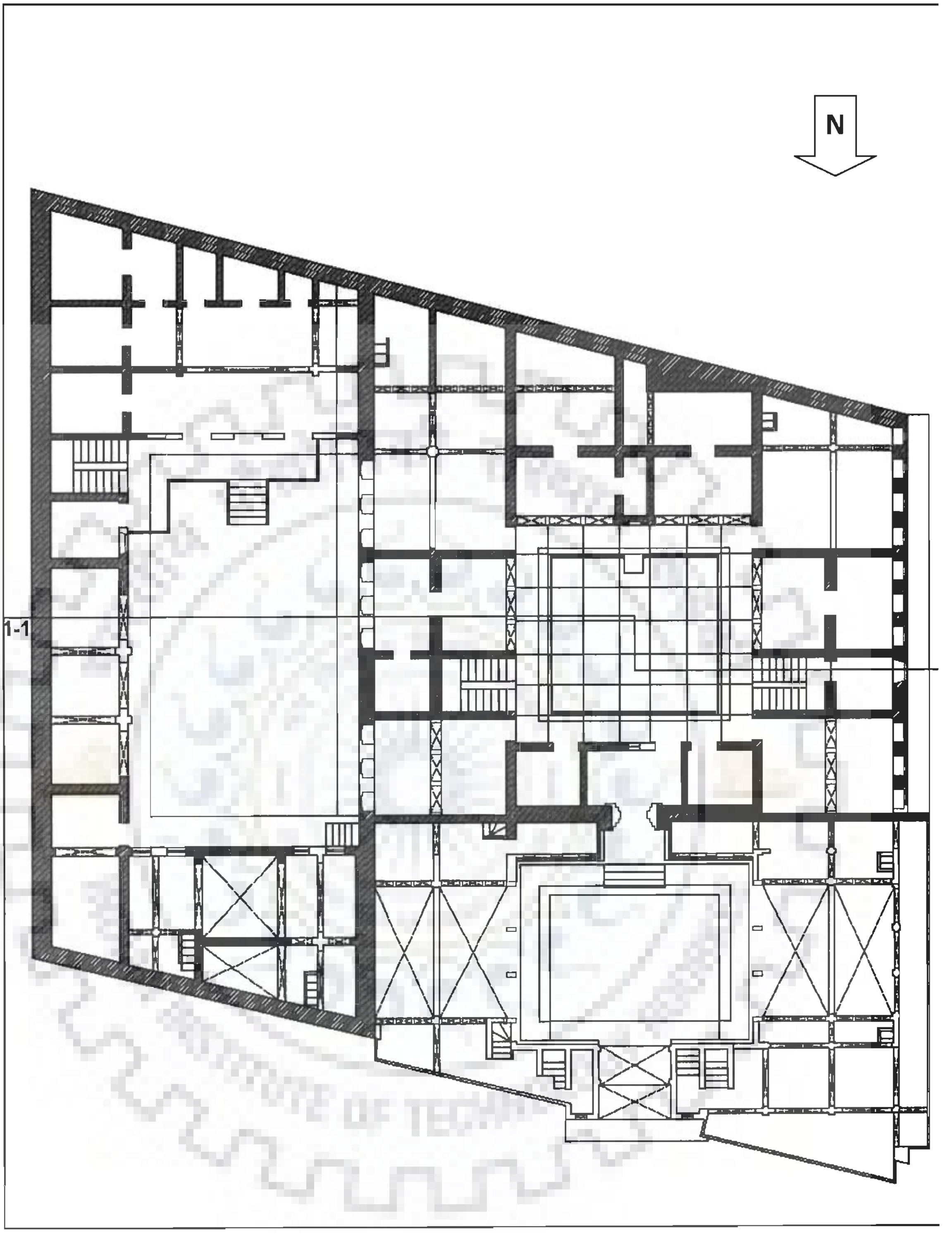
24 Murarka Haveli, Nawalgarh



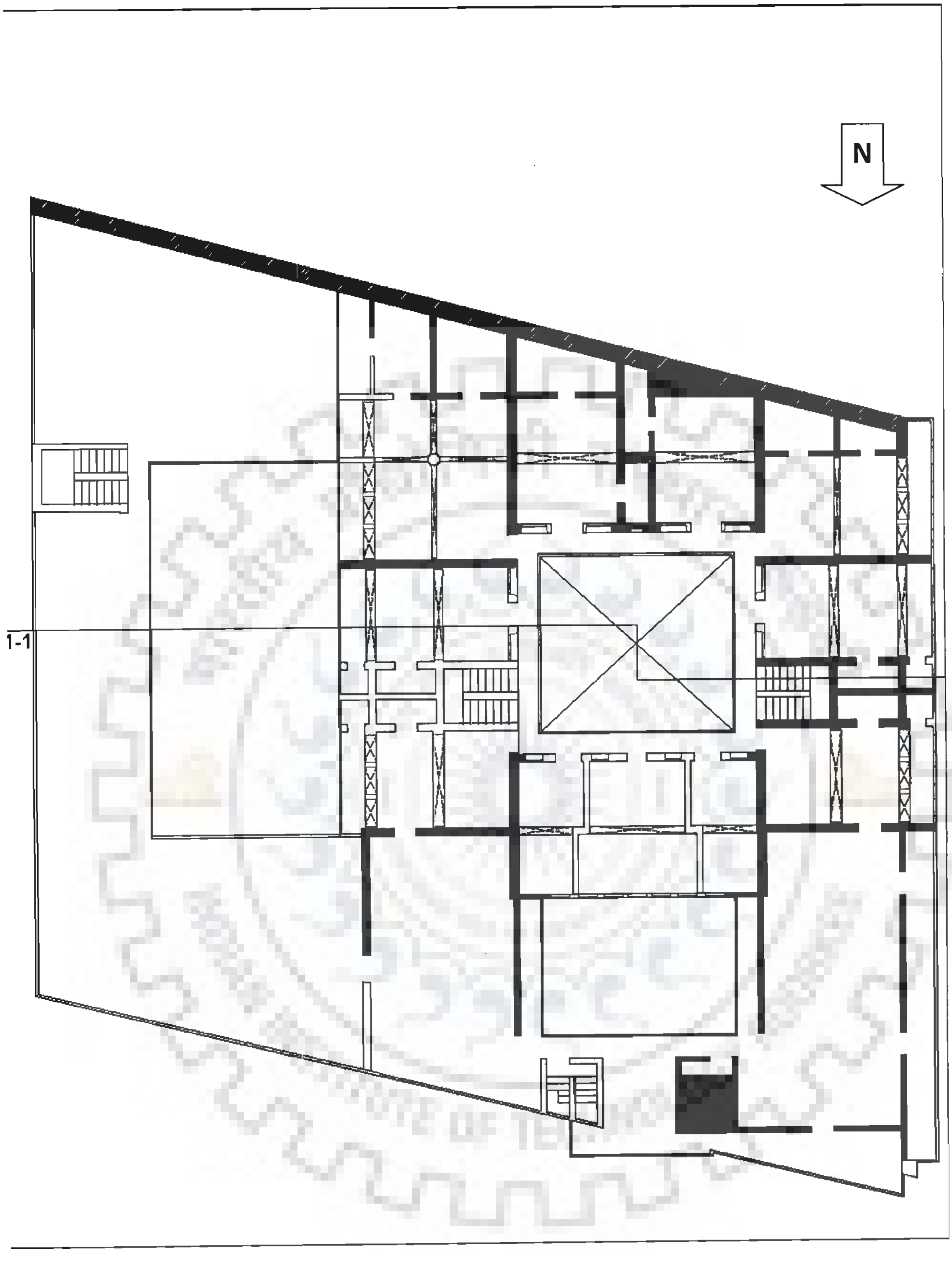
Drawing A-5.24.1: Lower Ground Floor Plan



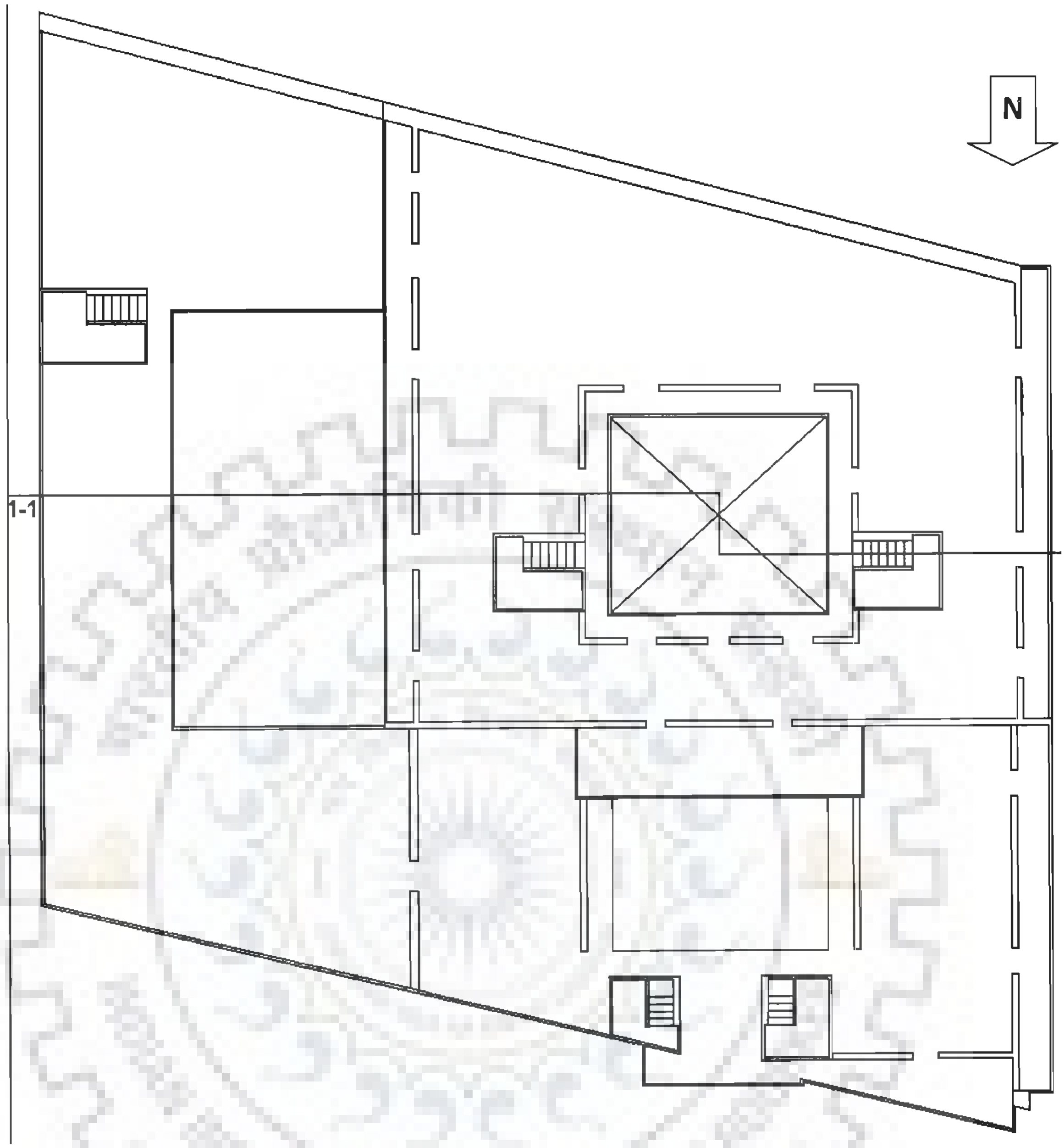
Drawing A-5.24.2: Upper Ground Floor Plan



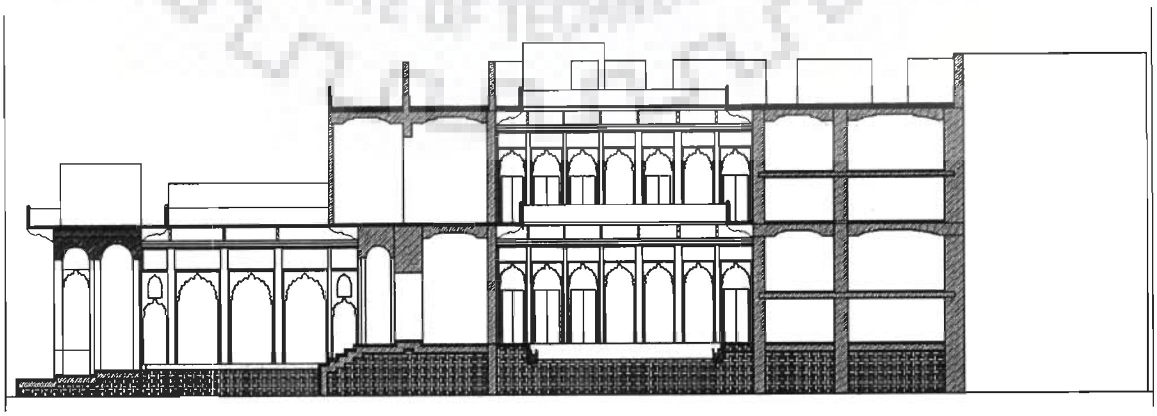
Drawing A-5.24.3: Mezzanine Floor Plan for Upper Ground Level



Drawing A-5.24.4: First Floor Plan

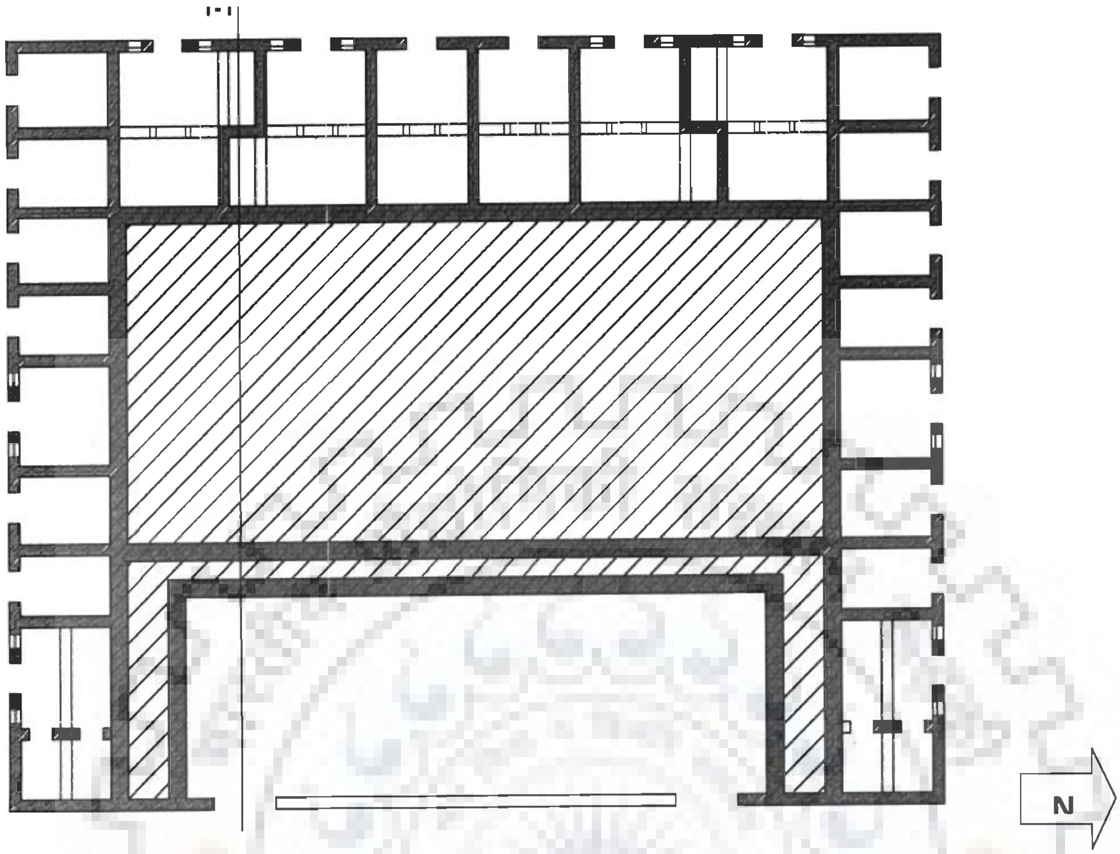


Drawing A-5.24.5: Terrace Floor Plan

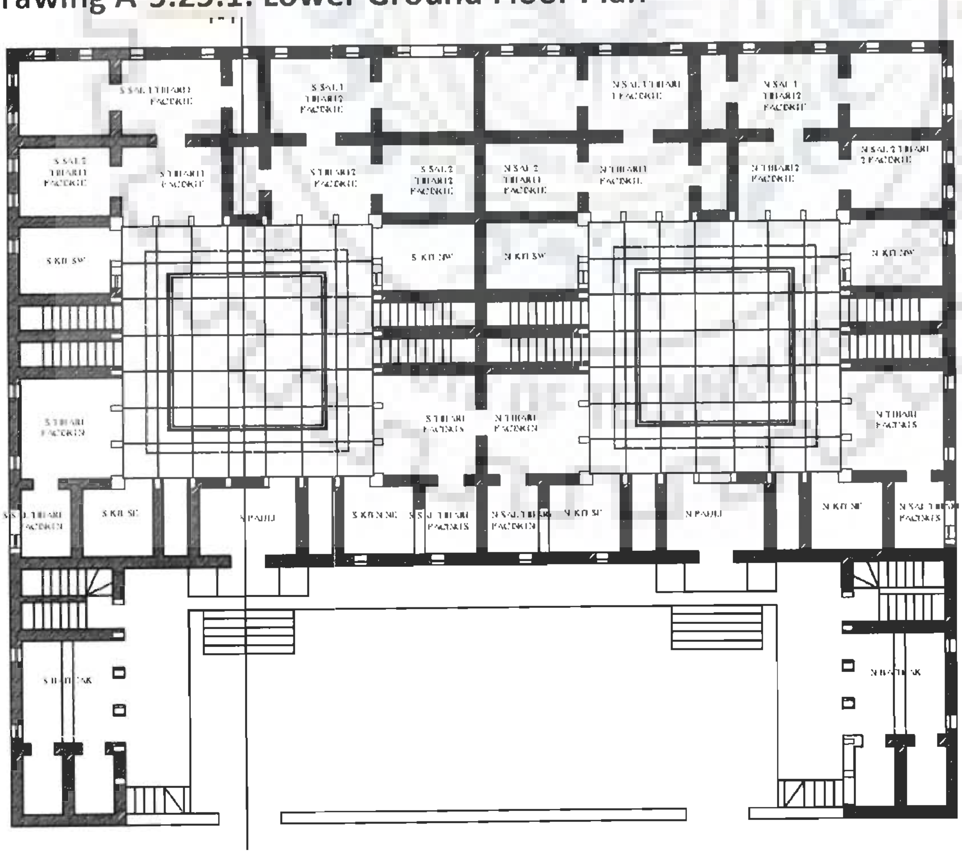


Drawing A-5.24.6: Section 1-1

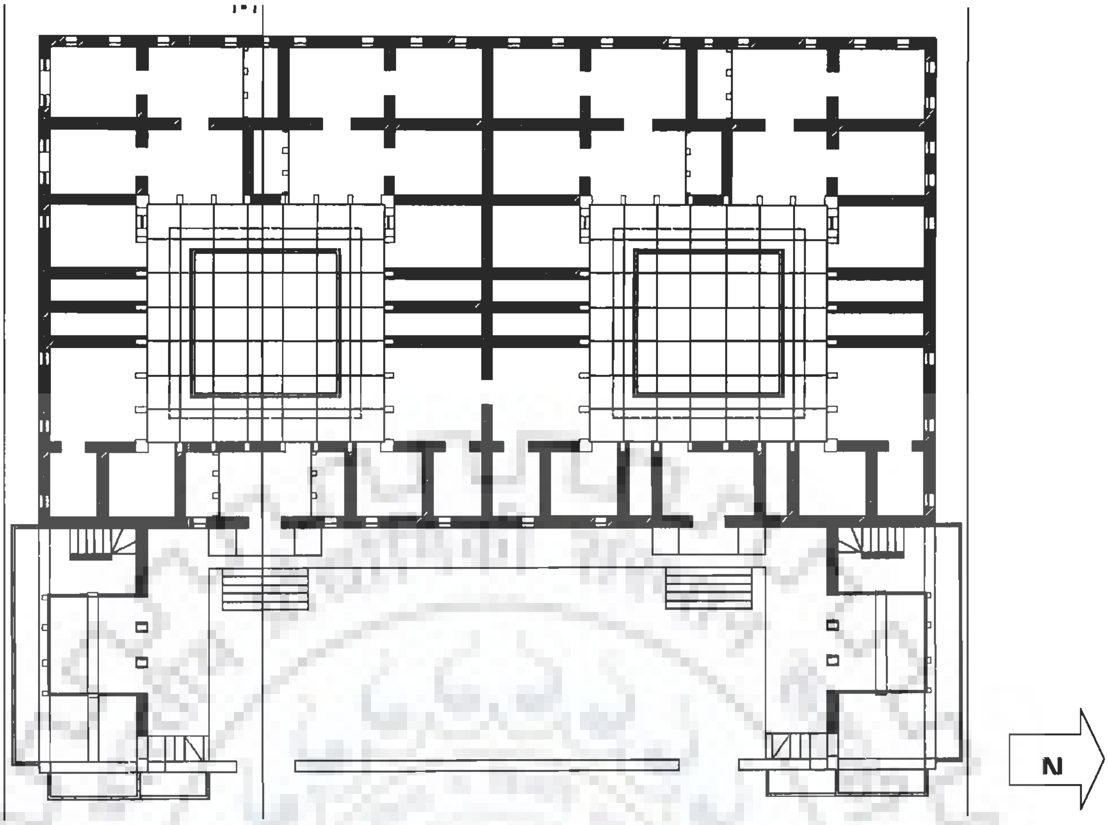
25 Vishwanath Goenka Haveli, Mandawa



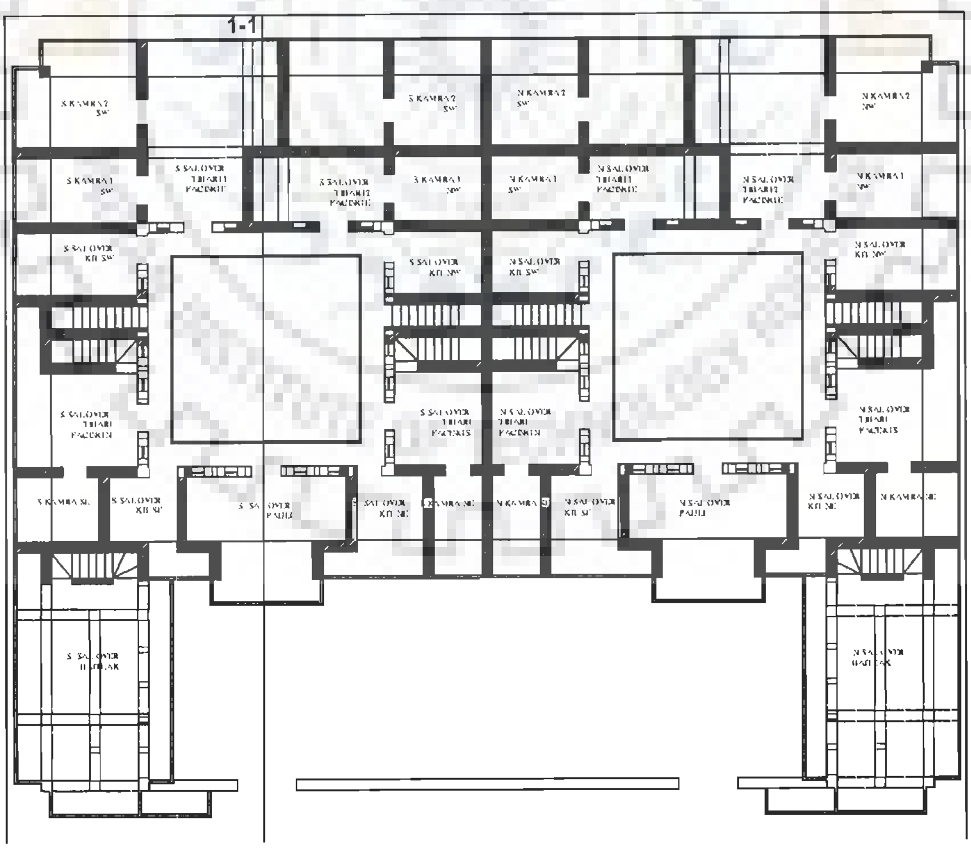
Drawing A-5.25.1: Lower Ground Floor Plan



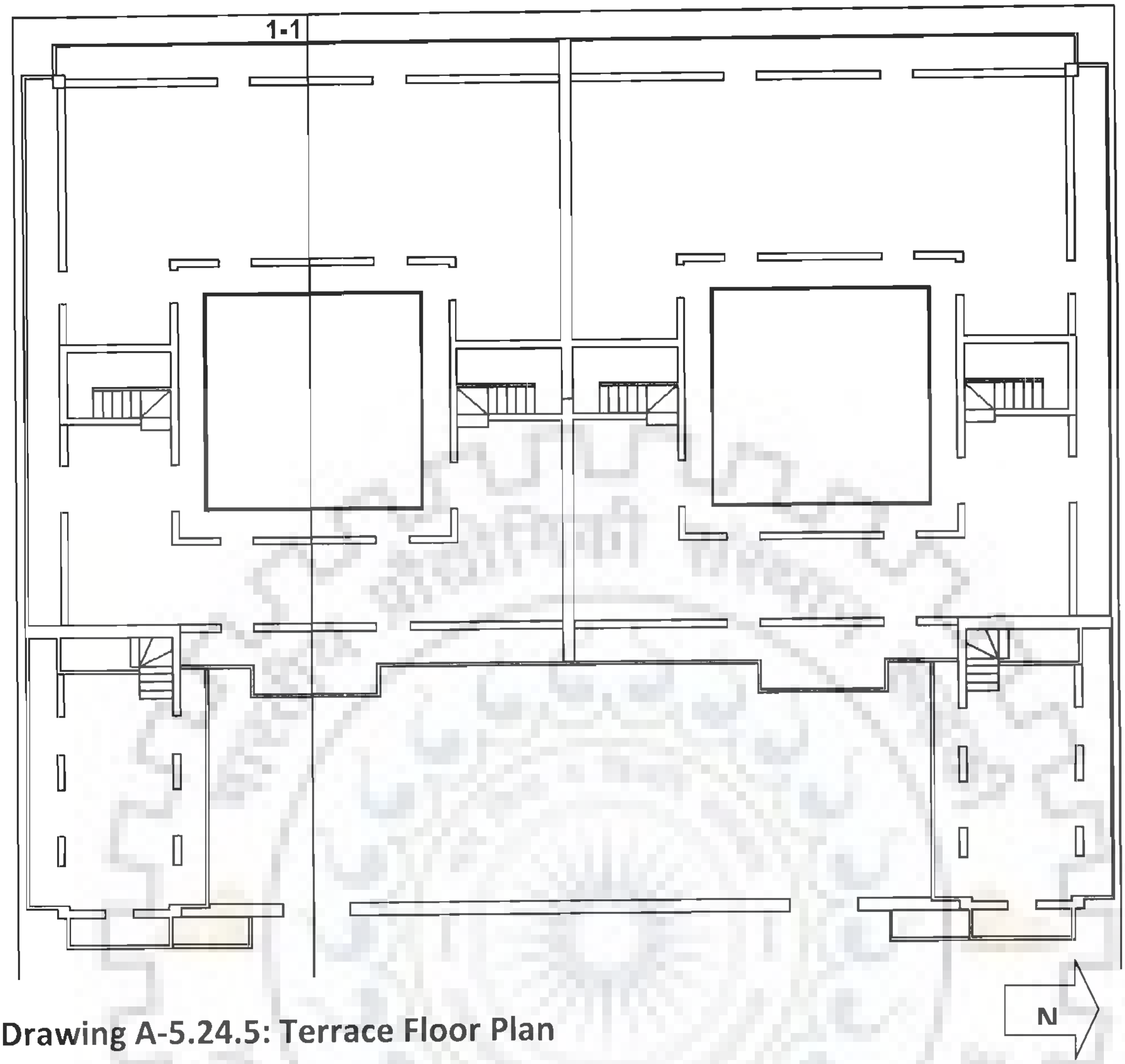
Drawing A-5.25.2: Upper Ground Floor Plan



Drawing A-5.25.3: Mezzanine Floor Plan for Upper Ground Floor Level



Drawing A-5.25.4: First Floor Plan



Drawing A-5.24.5: Terrace Floor Plan

Drawing A-5.24.6: Section 1-1

Appendix 6 –Photographs of Case Studies

A6-1. Chiranji Lalji Daima Haveli, Fatehpur

Inner Court

Pauli

Front Facade

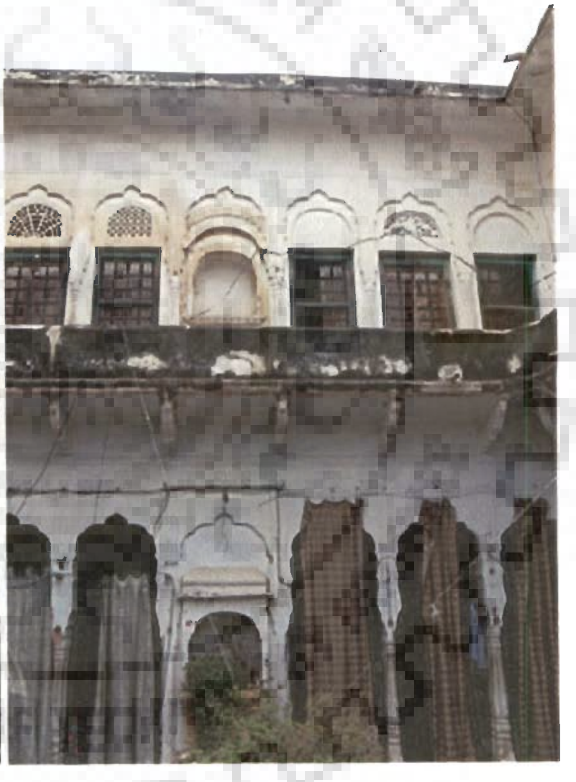
Westrn Facade

A6-2. Harsukhrai Pansari Haveli, Chirawa

Entrance

Kitchen, Parinda & Staircase

Partly constructed first floor



East facing side of inner court yard

A6-3. Ramgarh Haveli

Tibari

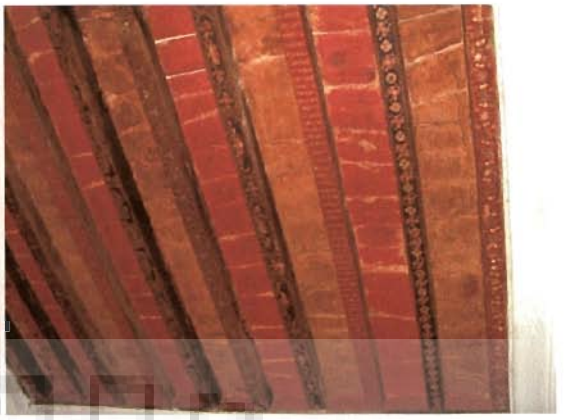
Front facade

Ornamental Entrance door

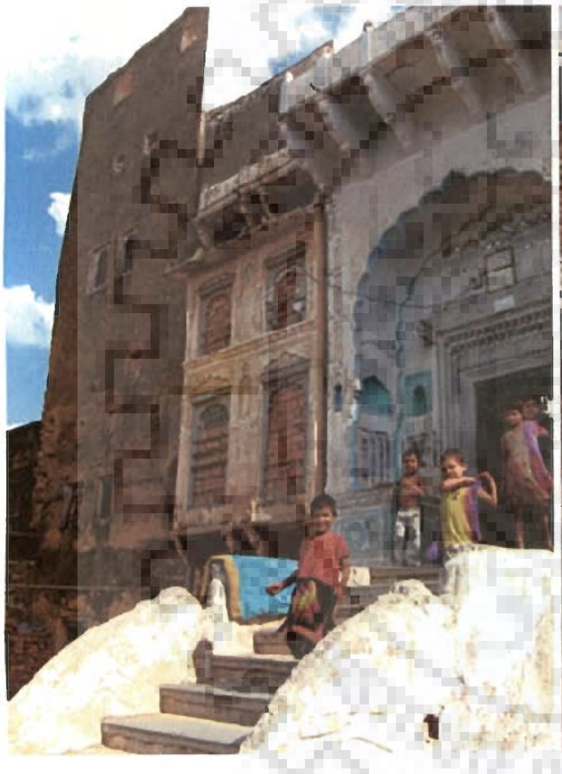
Soft paved inner court

A6-4. Muslim Haveli, Ratannagar

Inner court



Wooden joist in ceiling of Pauli



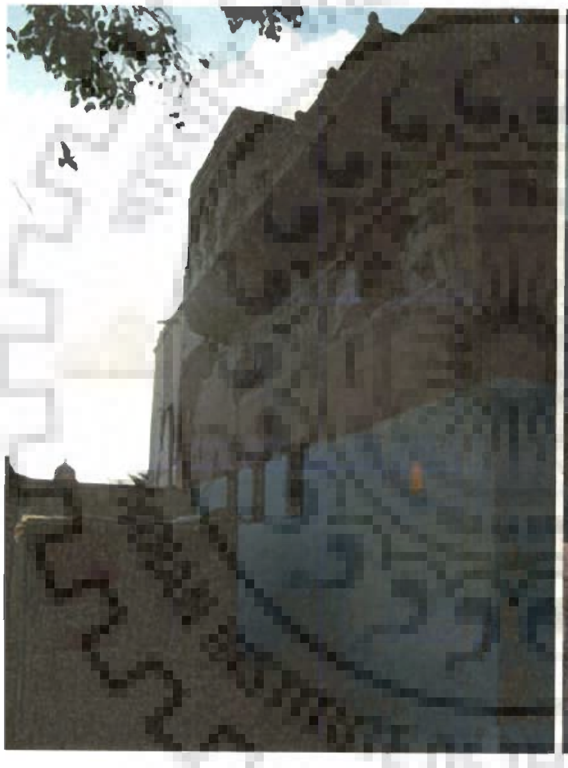
Steps leading to raised inner court

Windows on front facade

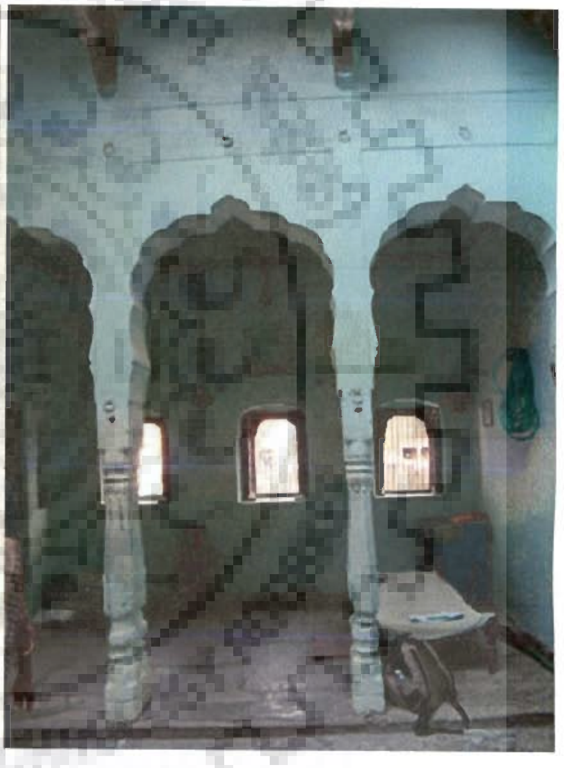
A6-5. Sahumal Khetan Haveli, Mahensar

Entrance

South facing tibari



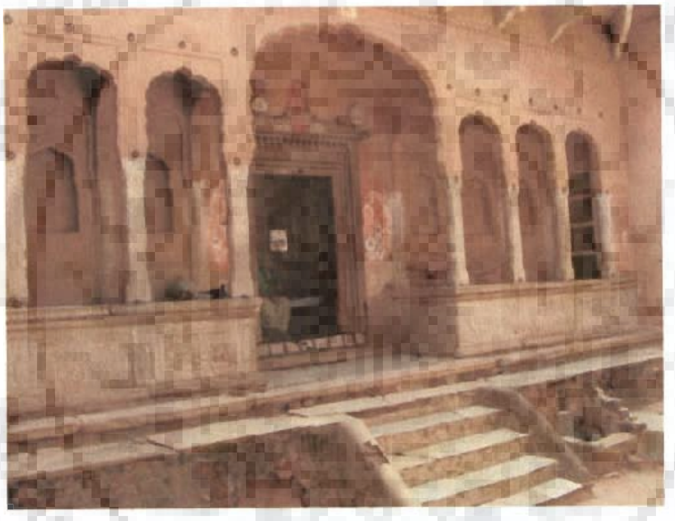
South facade



North facing Tibari

A6-6. Babulal ji Gudha Haveli, Mukundgarh

Front facade



Level difference between inner and outer courtyard

Exposed wall showing brick arrangement

Inner courtyard with Tulsi Plant

Painting beneath Chajja

Painting on outer facade

A6-7. Bhagirath Kedarmal Goenka Haveli, Dundlod

Inner court with plantation

Outer facade

Pauli

Baithak with viewing gallery

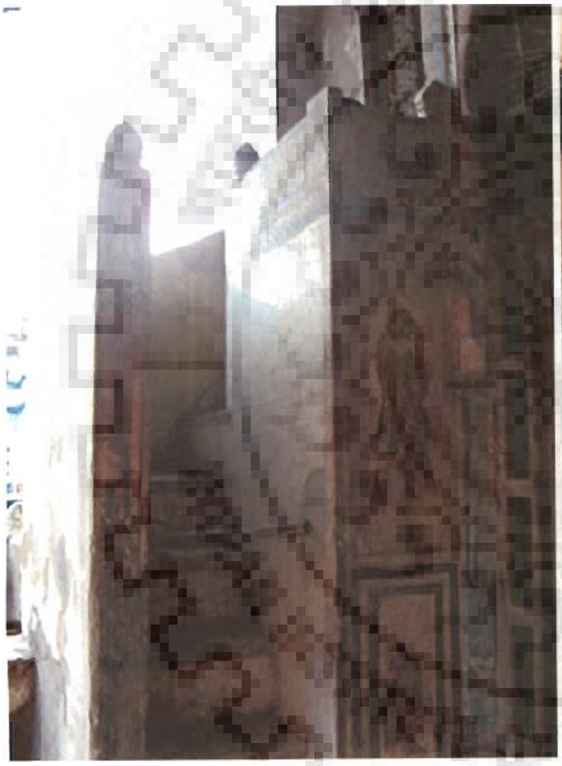
Outer court with plantation

Staircase leading to mezzanine in Baithak

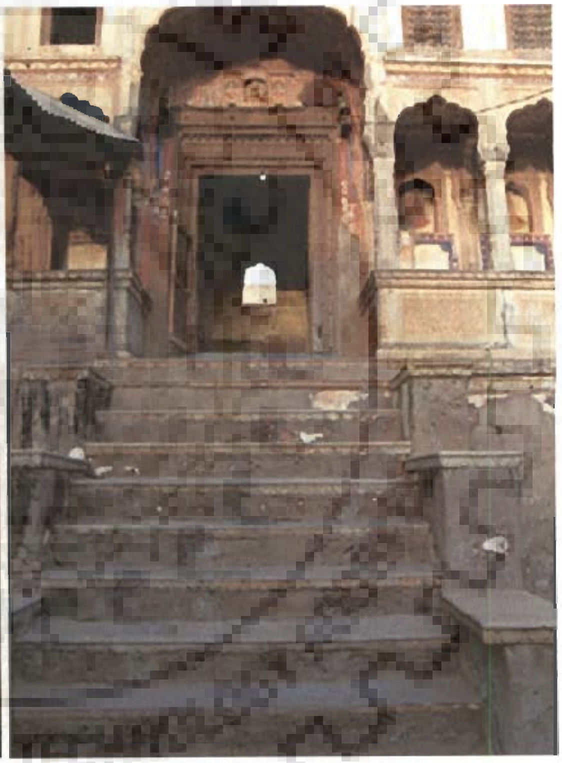
A6-8. Bissau Haveli

Inner court

Pauli



Staircase leading to mezzanine in Baithak

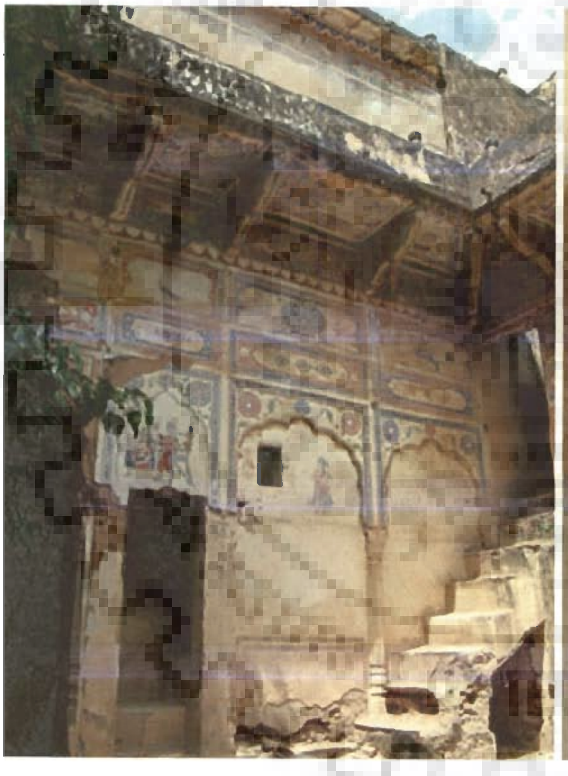


Steps leading tto inner court

A6-9. Haveli used as Gymnasium, Dundlod

Tibari

Outer court



Staircase leading to terrace of Bagli

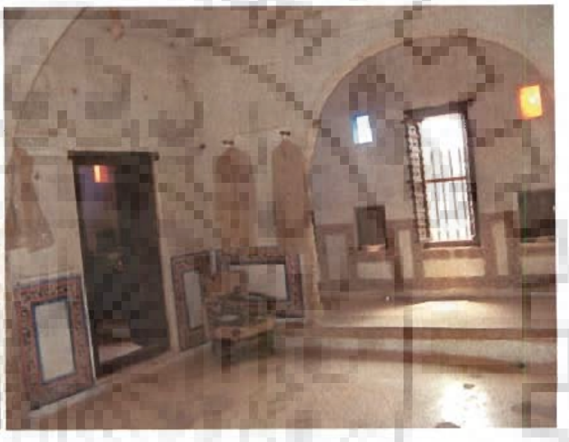
Pauli

A6-10. Seth Arjundas Goenka Haveli, Dundlod

Parapet screen on terrace of Baithak

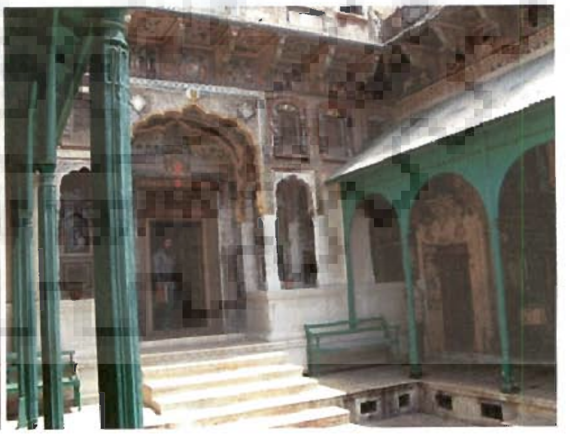
Pauli

Chimney ventilation on terrace

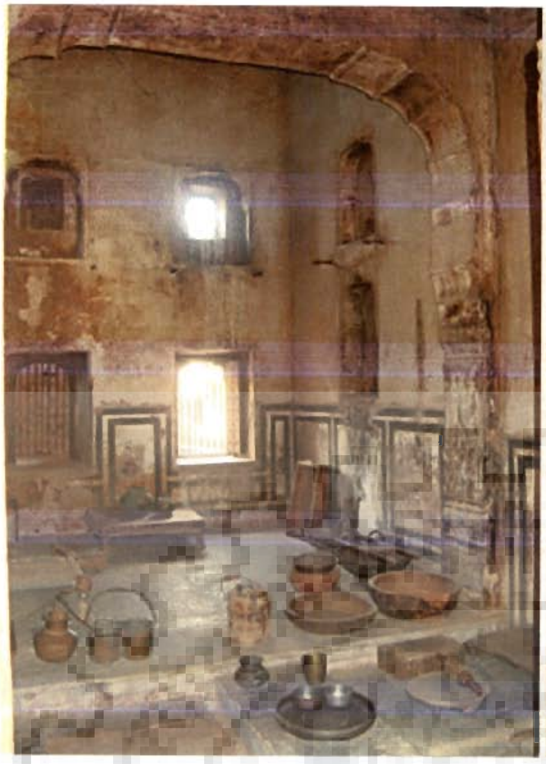


Finish lime flooring

Inner courtyard

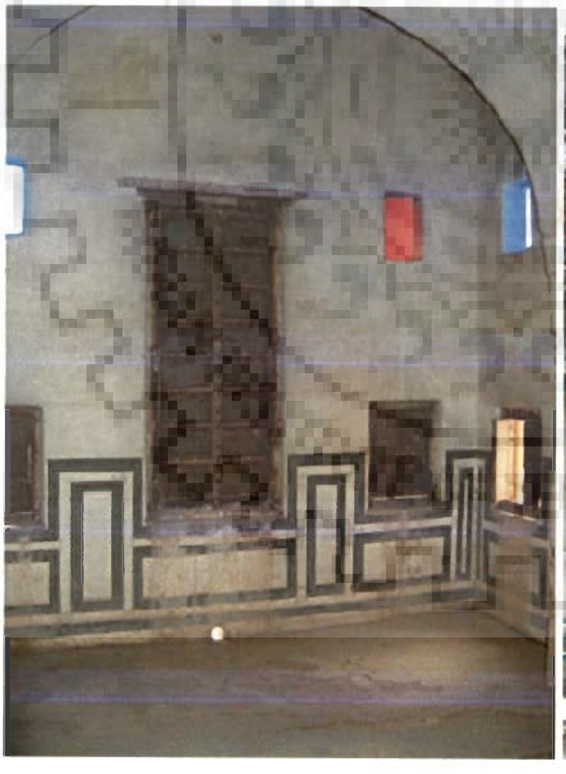


Outer court

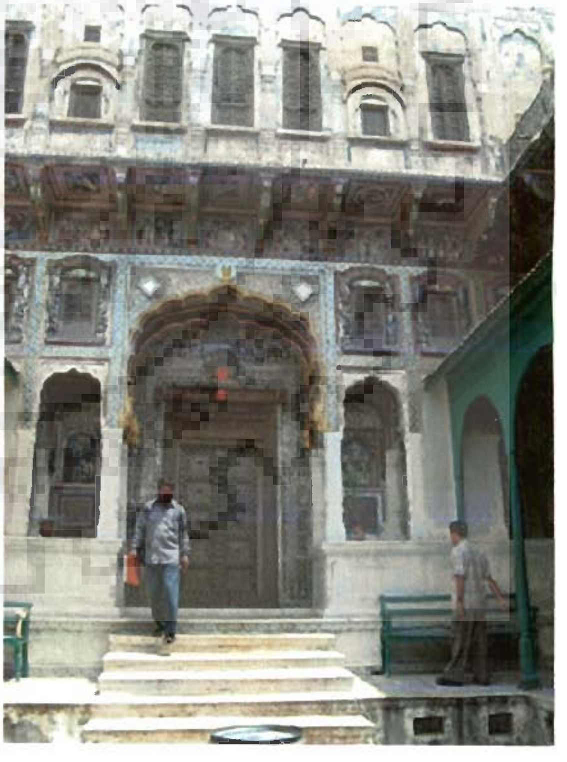


Kitchen

Chimney in kitchen



Effect of small windows



Elaborately ornamented Taj and Gokha

A6-11. Harkarandas Mangilalji Haveli, Bagad

Taj and Gokha

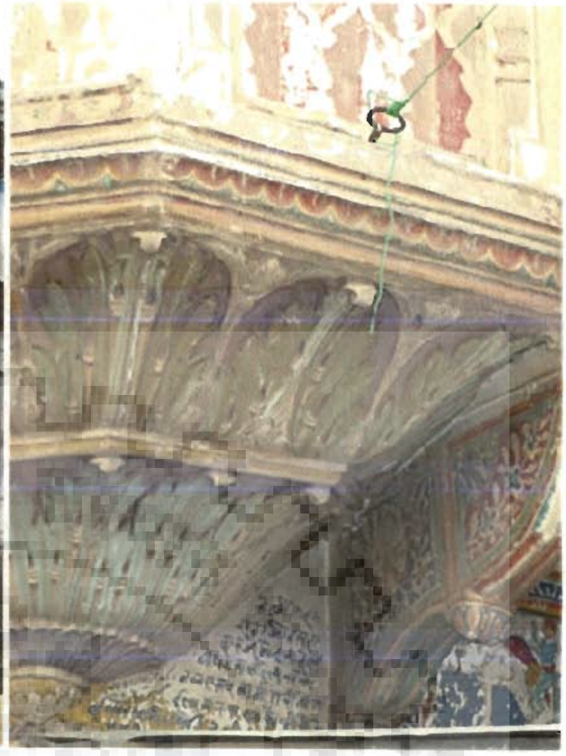
Viewing gallery in baithak

Inner court

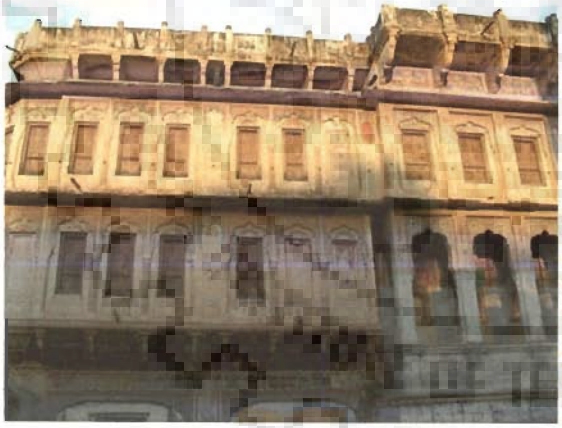
Pauli

A6-12. Ishwardas Modi Haveli, Jhunjhunu

SW corner detail

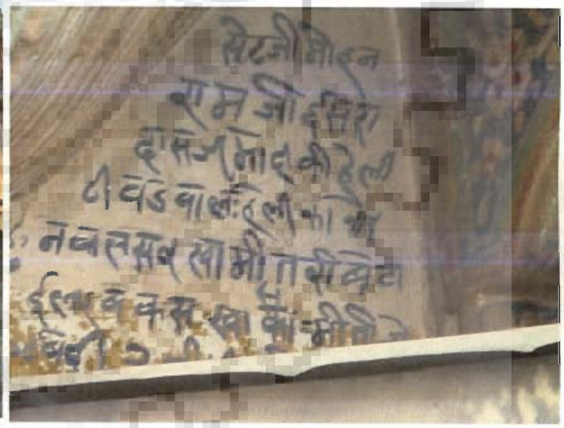


Camoflauzed detail mentioning designer

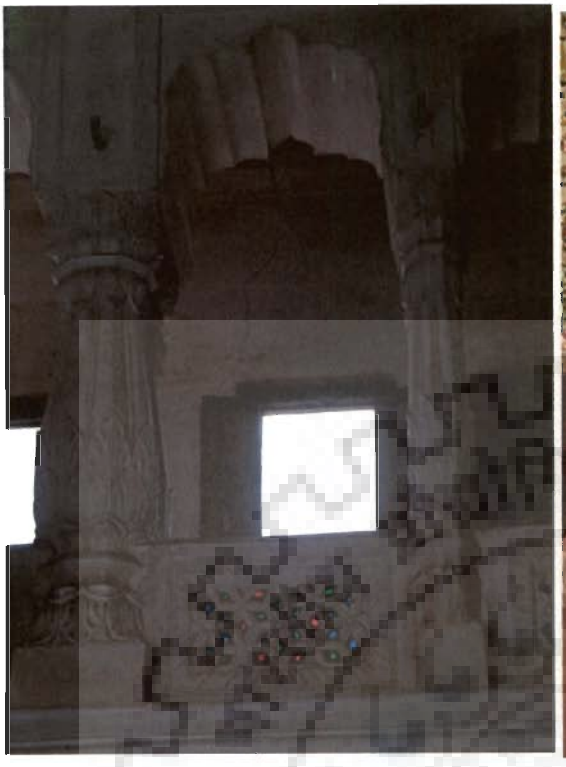


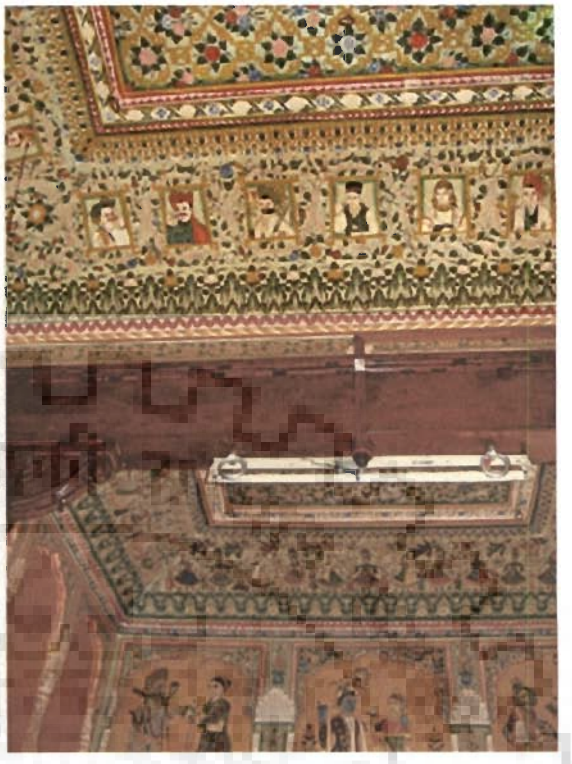
Windows on mezzanine level –

Effect of three storey building



Enlarged view





Ornamental paprapet in viewing gallery in Baithak

Decorated ceiling in Pauli

Entrance door- madeof five alloy

Gold plated miniature painting in Taj

Double bay Tibari

Entrance gateway

A6-13. Jaigopal Ji Goenka Haveli, Mandawa

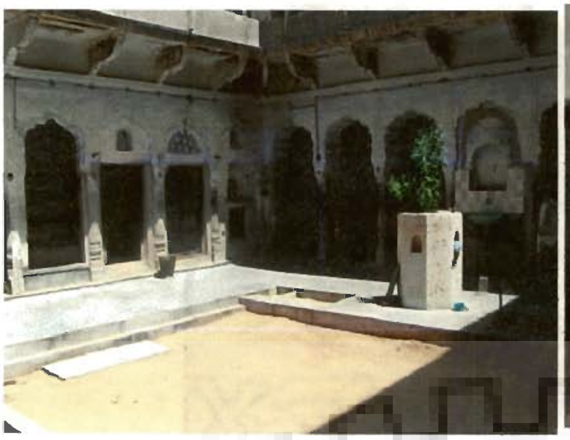
South Facade

North facade

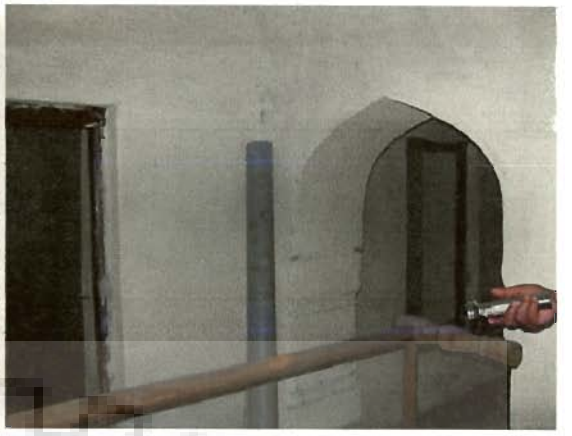
Pauli

Outer court with plantation

A6-14. Kariwala Haveli, Nawalgarh



Inner court



Storage room in plinth

Baithak

Nal

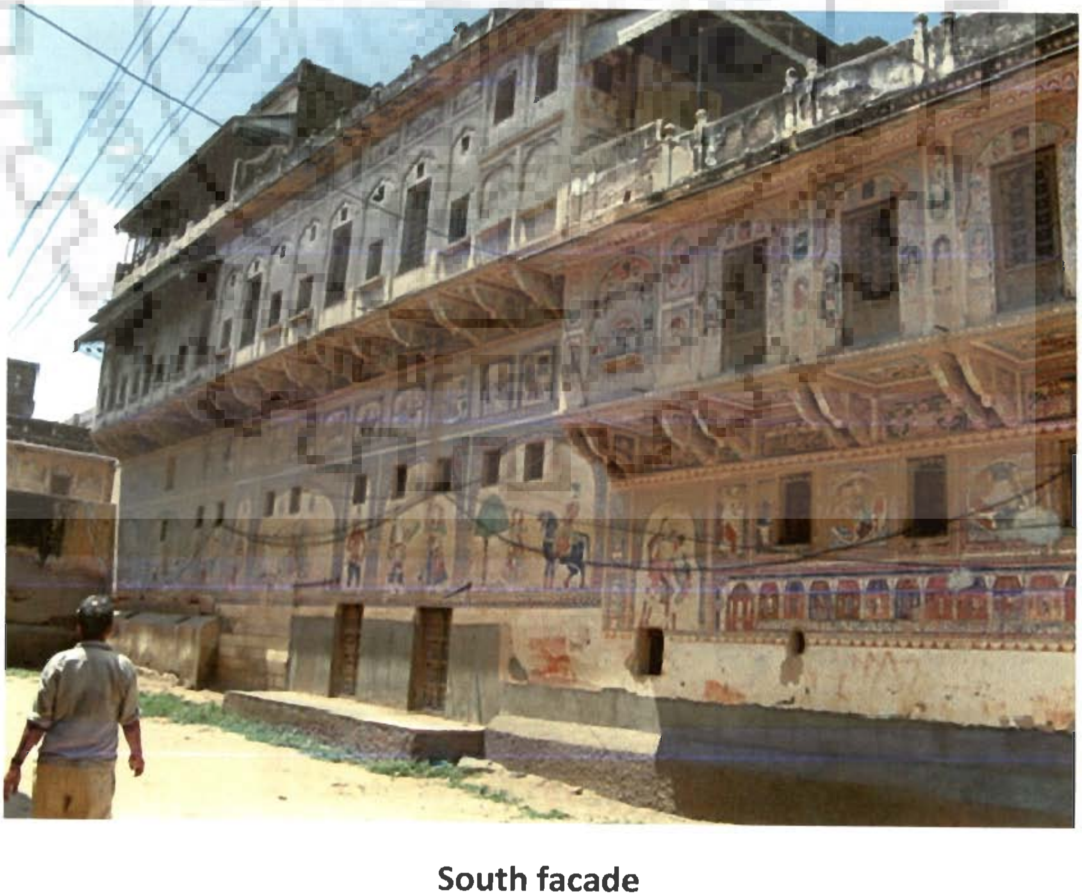
A6-15. Pilani Haveli

Front facade

Entrance gate

A6-16. Shkhsaria Haveli, Nawalgarh

East facade



South facade

A6-17. Shri Virdichandji Gaurilalji Haveli, Sikar

Front Facde with elevated plinth

Inner court

Front facade with elevated plinth

Inner court

Outer court

Taj and Gokha

Passage to Nohra

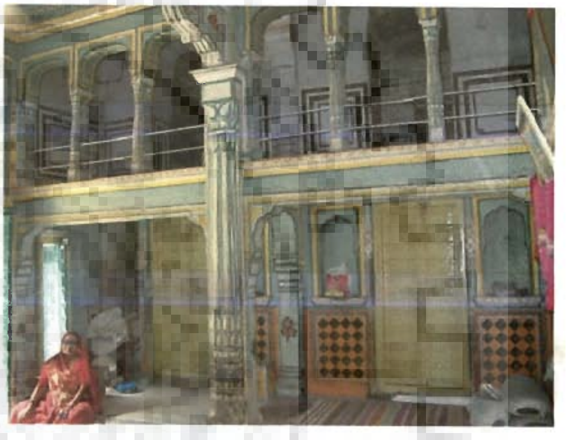
Decorated Taj

A6-18. Shridhar Gangadhar Morarka Haveli, Mukundgarh

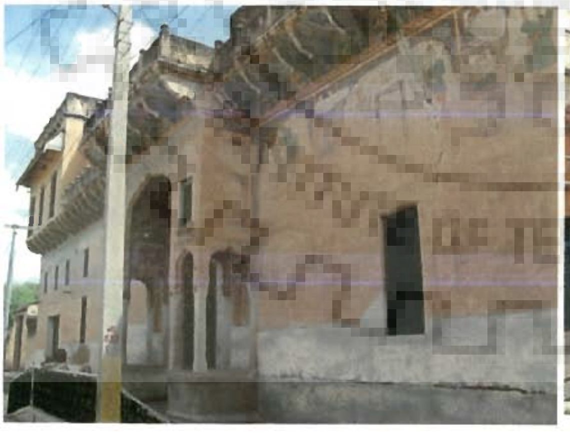
Passage to Nohra

Tubewell in adjoining Nohra

Taj and Gokha



Baithak

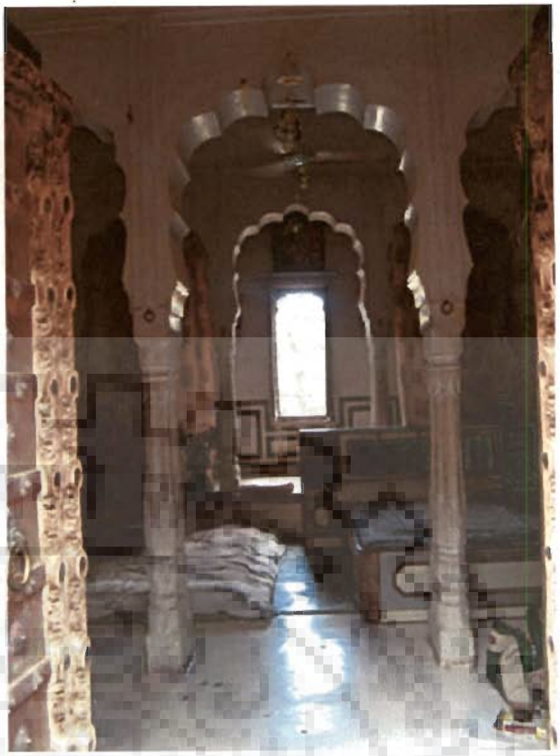


Front facade showing raised plinth

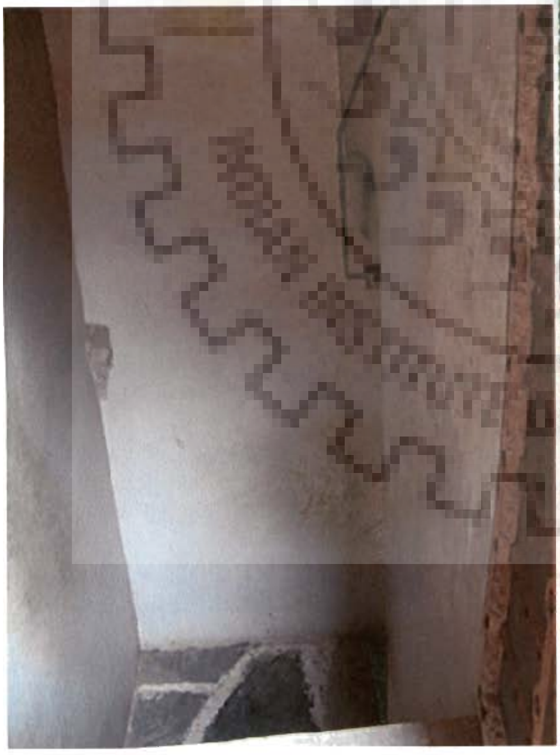
Inner court

A6-19. Nawalgarh unidentified Haveli

Sace above Jharokha



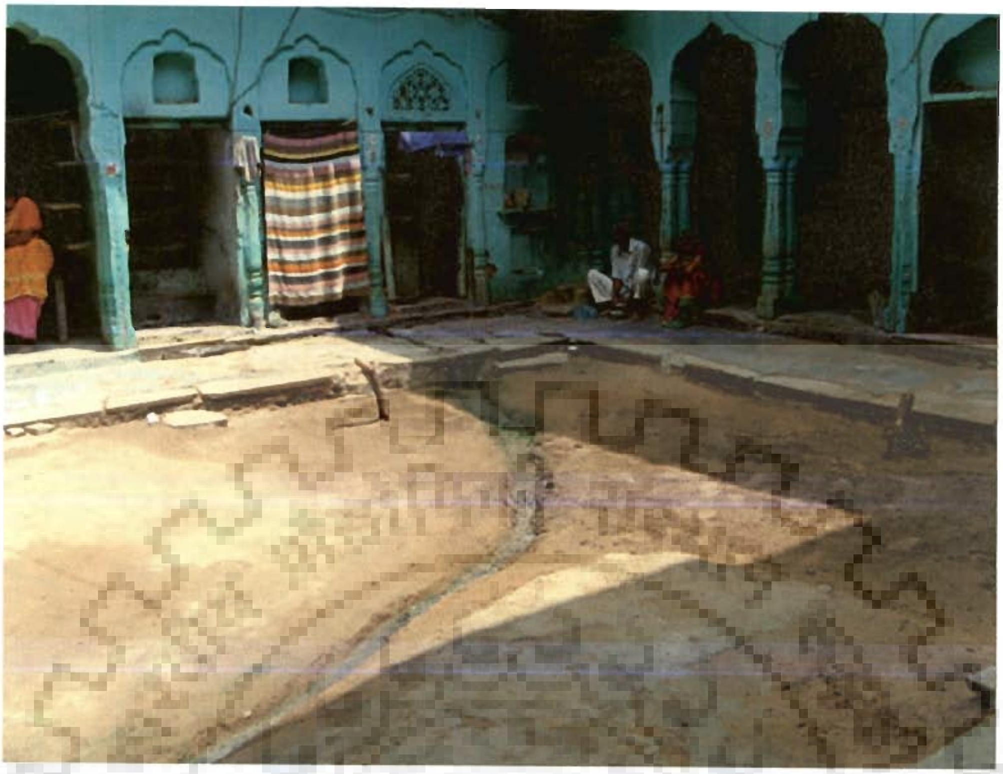
Polished Lime Flooring



Narrow staircase

Nal

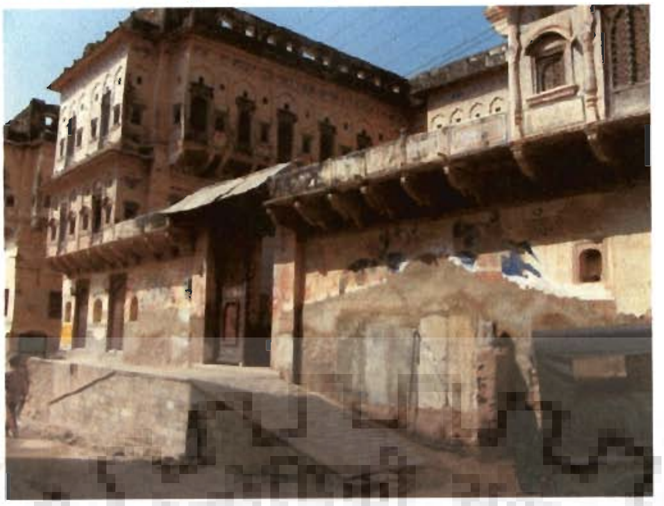
A6-20. Surajgarh Haveli



Inner courtyard

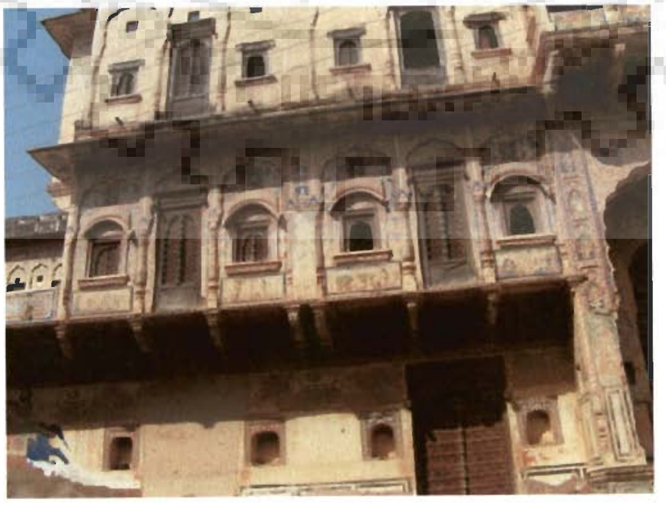
Passage to Nohra at back

A6-21. Gulabrai Ladiaji Haveli, Mandawa



Entrance facade

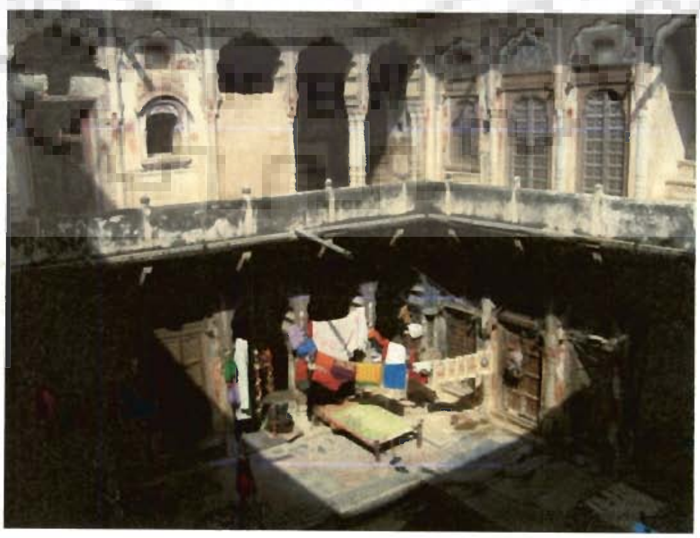
Taj in outer court



Windows on mezzanin level

Chajja and parapet

Typical arrangement of arches in inner courtyard



Corner- inner courtyard

A6-22. Murarka Haveli, Nawalgarh

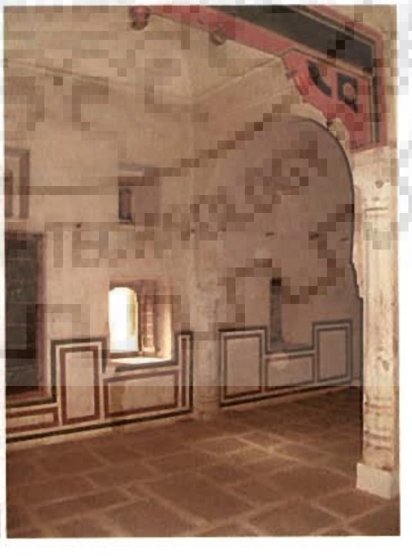
West facade

Baithak

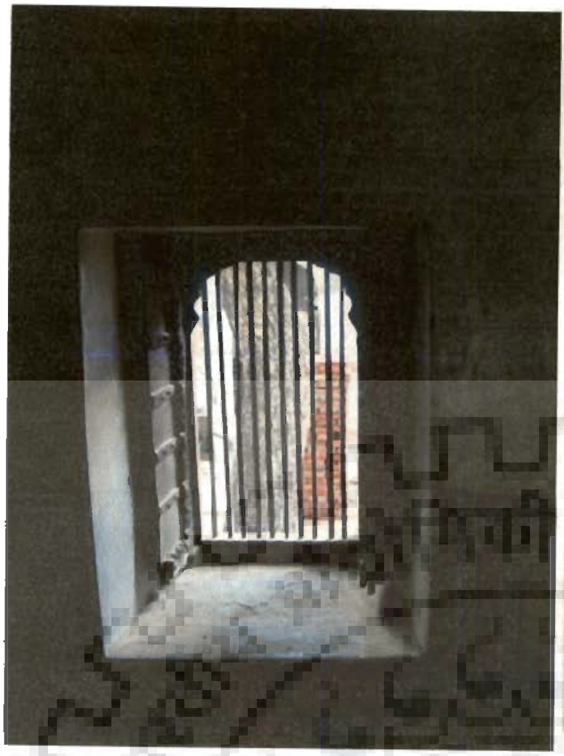
Front facade

Room at mid landing of staircase

Taj and Gokha



Chaughara



Thick wall

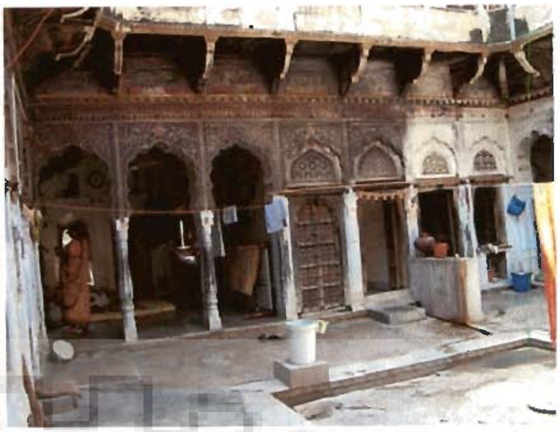
Parinda

Passage to Nohra

Chimney to kitchen

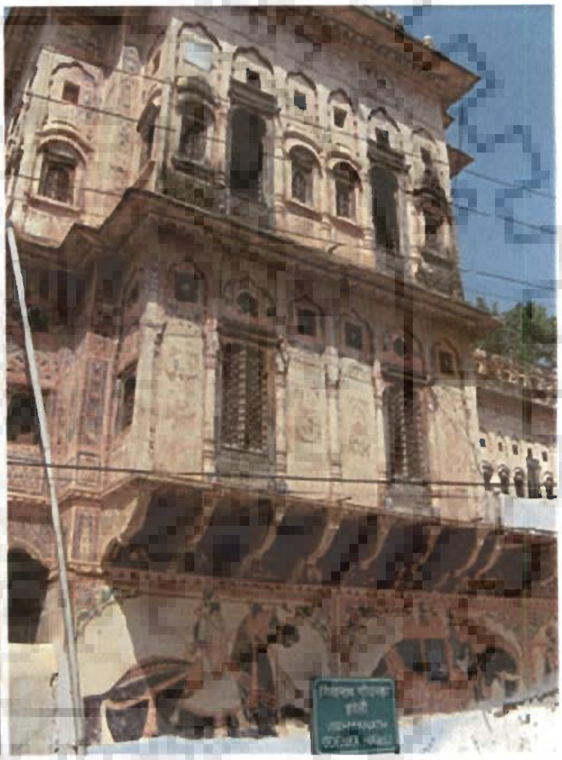
A6-23. Vishwanath Goenka Haveli, Mandawa

Front facade



Inner court

Baithak



Street side facade

Appendix 7

Contrasting the capabilities of building energy performance simulation programs

A comparison of capabilities and features has been done to find out the strength and weakness of twenty most popular programs. Brief introduction to capabilities of these softwares is mentioned as follows-

1. **BLAST Version 3.0 Level 334, August 1998** (www.bso.uiuc.edu/BLAST)- The Building Loads Analysis and System Thermodynamics (BLAST) system predicts energy consumption and energy system performance and cost in buildings. BLAST can be used to investigate the energy performance of new or retrofit building design options of almost any type and size.

2. **BSim Version 4.4.12.11** (www.bsim.dk)- BSim provides user-friendly simulation of detailed, combined hygrothermal simulations of buildings and constructions. BSim has been used extensively over the past 20 years, previously under the name tsbi3. Today BSim is the most commonly used tool in Denmark, and with increasing interest abroad, for energy design of buildings and for moisture analysis.

3. **DeST Version 2.0, 2005** (www.dest.com.cn, Chinese version only)- DeST (Designer's Simulation Toolkits) allows detailed analysis of building thermal processes and HVAC system performance. DeST has been widely used in China for various prestige large structures such as the State Grand Theatre and the State Swimming Centre.

4. **DOE-2.1E Version 121, September 2003** (simulationresearch.lbl.gov)- DOE-2.1E predicts the hourly energy use and energy cost of a building given hourly weather information, a building geometry and HVAC description, and utility rate structure. DOE-2.1E has been used extensively for more than 25 years for both building design studies, analysis of retrofit opportunities, and for developing and testing building energy standards in the U.S. and around the world. The private sector has adapted DOE-2.1E by creating more than 20 interfaces that make the program easier to use.

5. **ECOTECT Version 5.50, April 2005** (www.ecotect.com)- Ecotect is a highly visual architectural design and analysis tool that links a comprehensive 3D modeler with a wide range of performance analysis functions covering thermal, energy, lighting, shading, acoustics and cost aspects. Whilst its modelling and analysis capabilities can handle geometry of any size and complexity, its main advantage is a focus on feedback at the earliest stages of the building design process.

6. **Ener-Win Version EC, June 2005** (members.cox.net/enerwin)- Ener-Win, originally developed at Texas A&M University, simulates hourly energy consumption in buildings, including annual and monthly energy consumption, peak demand charges, peak heating and cooling loads, solar heating fraction through glazing, day lighting contribution, and a life-cycle cost analysis. Design data, tabulated by zones, also show duct sizes and electric power requirements.

7. **Energy Express, Version 1.0, February 2005** (www.ee.hearne.com.au)- Energy Express is a design tool for estimating energy consumption and cost at the design stage. The user interface allows fast and accurate model creation and manipulation. Energy Express includes a dynamic multi-zone heat transfer model coupled to an integrated HVAC model so that zone temperatures are impacted by any HVAC shortcomings.

8. **Energy-10 Version 1.8, June 2005** (www.nrel.gov/buildings/energy10)- Energy-10 was designed to facilitate the analysis of buildings early in the design process with a focus on providing a comprehensive tool suited to the design team environment for smaller buildings. Since Energy-10 evaluates one or two thermal zones, it is most suitable for smaller, 10,000 ft2 (1000 m2) or less, simpler, commercial and residential buildings. Energy-10 takes a baseline simulation and automatically applies a number of predefined strategies ranging from building envelope (insulation, glazing, shading, thermal mass, etc.) and system efficiency options (HVAC, lighting, daylighting, solar service hot water and integrated photovoltaic electricity generation). Full life-cycle costing is an integral part of the software.

9. **EnergyPlus Version 1.2.2, April 2005** (www.energyplus.gov)- EnergyPlus is a modular, structured code based on the most popular features and capabilities of BLAST and DOE-2.1E. It is a simulation engine with input and output of text files. Loads calculated (by a heat balance engine) at a user-specified time step (15- minute default) are passed to the building systems simulation module at the same time step. The Energy Plus building systems simulation module, with a variable time step, calculates heating and cooling system and plant and electrical system response. This integrated solution provides more accurate space temperature prediction—crucial for system and plant sizing, occupant comfort and occupant health calculations. Integrated simulation also allows users to evaluate realistic system controls, moisture adsorption and desorption in building elements, radiant heating and cooling systems, and interzone air flow.

10. **eQUEST Version 3.55, February 2005** (www.doe2.com/equest)- eQUEST is an easy to use building energy use analysis tool which provides high quality results by

combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module with an enhanced DOE-2.2- derived building energy use simulation program.

11. **ESP-r Version 10.1, February 2005** (www.esru.strath.ac.uk/Programs/ESP-r.htm)- ESP is a general purpose, multi-domain—building thermal, inter-zone air flow, intra-zone air movement, HVAC systems and electrical power flow—simulation environment which has been under development for more than 25 years. It follows the pattern of `simulation follows description` where additional technical domain solvers are invoked as the building and system description evolves. Users control the complexity of the geometric, environmental control and operations to match the requirements of particular projects. It supports an explicit energy balance in each zone and at each surface.

12. **HAP Version 4.20a, February 2004** (www.commercial.carrier.com)- Hourly Analysis Program (HAP) provides two tools in one package: sizing commercial HVAC systems and simulating hourly building energy performance to derive annual energy use and energy costs. Input data and results from system design calculations can be used directly in energy studies. HAP is suitable for a wide range of new design and retrofit applications.

13. **HEED Version 1.2, January 2005** (www.aud.ucla.edu/heed)- The objective of HEED is to combine a single-zone simulation engine with an user-friendly interface. It is intended for use at the very beginning of the design process, when most of the decisions are made that ultimately impact the energy performance of envelope-dominated buildings. HEED's strengths are ease of use, simplicity of input data, a wide array of graphic output displays, computational speed, and the ability to quickly compare multiple design alternatives.

14. **IDA ICE Version 3.0, build 15, April 2005** (www.equa.se/ice)- IDA Indoor Climate and Energy (IDA ICE) is based on a general simulation platform for modular systems, IDA Simulation Environment. Physical systems from several domains are in IDA described using symbolic equations, stated in either or both of the simulation languages Neutral Model Format (NMF) or Modelica.

15. **IES <VE> Version 5.2, December 2004** (www.iesve.com)- The IES <Virtual Environment> (IES <VE>) is an integrated suite of applications linked by a common user interface and a single integrated data model. The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimized with regard to comfort criteria and energy use.

16. **Power Domus Version 1.5, September 2005** (www.pucpr.br/lst)- Power Domus is a whole-building simulation tool for analysis of both thermal comfort and energy use. It has been developed to model coupled heat and moisture transfer in buildings when subjected to any kind of climate conditions, i.e., considering both vapor diffusion and capillary migration. Its models predict temperature and moisture content profiles within multi-layer walls for any time step and temperature and relative humidity for each zone. Power Domus allows users to visualize the sun path and inter-buildings shading effects and provides reports with graphical results of zone temperature and relative humidity, PMV and PPD, thermal loads statistics, temperature and moisture content within user-selectable walls/roofs, surface vapor fluxes and daily-integrated moisture sorption/ desorption capacity.

17. **SUNREL Version 1.14, November 2004** (www.nrel.gov/buildings/sunrel)- SUNREL is an hourly building energy simulation program that aids in the design of small energy efficient buildings where the loads are dominated by the dynamic interactions between the building's envelope, its environment, and its occupants. SUNREL has a simplified multizone nodal airflow algorithm that can be used to calculate infiltration and natural ventilation. The equipment and loads calculations are solved simultaneously, and the equipment capacities can be set to unlimited. Fans move a schedulable fixed amount of air between zones or from outside.

18. **Tas Version 9.0.7, May 2005** (www.edsl.net)- Tas is a suite of software products, which simulate the dynamic thermal performance of buildings and their systems. The main module is Tas Building Designer, which performs dynamic building simulation with integrated natural and forced airflow. Tas Systems is a HVACsystems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand. The third module, Tas Ambiens, is a robust and simple to use 2D CFD package which produces a cross section of micro climate variation in a space. Tas combines dynamic thermal simulation of the building structure with natural ventilation calculations which include advanced control functions on aperture opening and the ability to simulate complex mixed mode systems. Tas has 20 years of commercial use in the UK and around the world.

19. **TRACE 700 Version 4.1.10, November 2004** (www.tranecds.com)- TRACE is divided into four distinct calculation phases: Design, System, Equipment and Economics. During the Design Phase the program first calculates building heat gains for conduction through building surfaces as well as heat gains from people, lights, and appliances and

impact of ventilation and infiltration. Finally, the program sizes all coils and air handlers based on these maximum loads. During the System Phase, the dynamic response of the building is simulated for an 8760-hour (or reduced) year by combining room load profiles with the characteristics of the selected airside system to predict the load imposed on the equipment. The Equipment Phase uses the hourly coil loads from the System Phase to determine how the cooling, heating, and air moving equipment will consume energy. The Economic Phase combines economic input supplied by the user with the energy usage from the Equipment Phase to calculate each alternative's utility cost, installed cost, maintenance cost and life cycle cost.

20. **TRNSYS Version 16.0.37, February 2005** (sel.me.wisc.edu/trnsys)- TRNSYS is a transient system simulation program with a modular structure that was designed to solve complex energy system problems by breaking the problem down into a series of smaller components. TRNSYS components (referred to as "Types") may be as simple as a pump or pipe, or as complicated as a multi-zone building model. The simulation engine then solves the system of algebraic and differential equations that represent the whole system. In building simulations, all HVAC-system components are solved simultaneously with the building envelope thermal balance and the air network at each time step. The modular nature of TRNSYS facilitates the addition of new mathematical models to the program. In addition to the ability to develop new components in any programming language, the program allows to directly embed components implemented using other software (e.g. Matlab/Simulink, Excel/VBA, and EES). TRNSYS can also generate executables that allow non-expert to run parametric studies.

Appendix 8- Snapshots of models of case studies obtained from Design Builder

Chiranjilalji Daima Haveli, Fatehpur

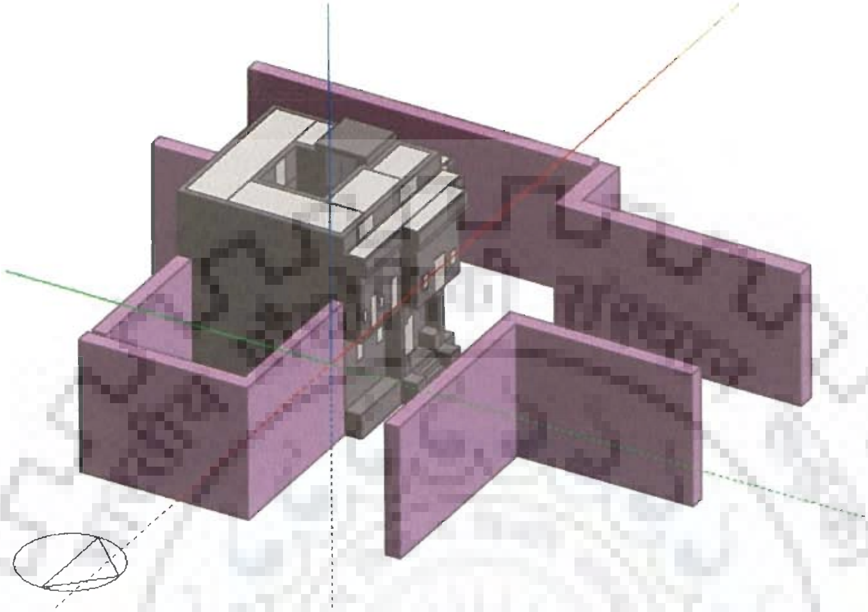


Figure A-8.1 View of Model

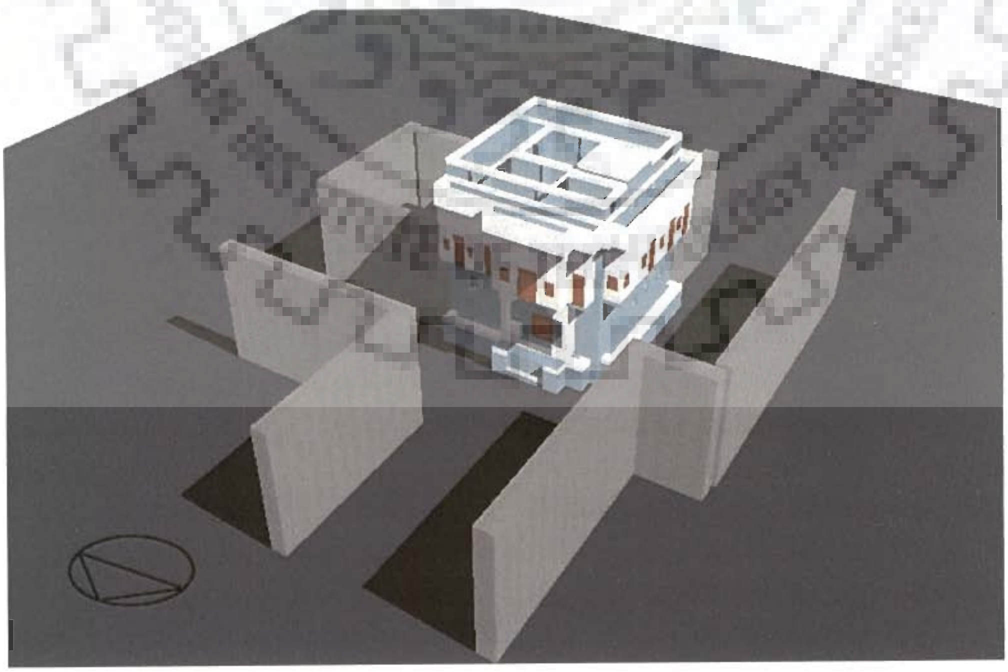


Figure A-8.2 Rendered View of Model

Harsukhrai Pansari Haveli, Chirawa

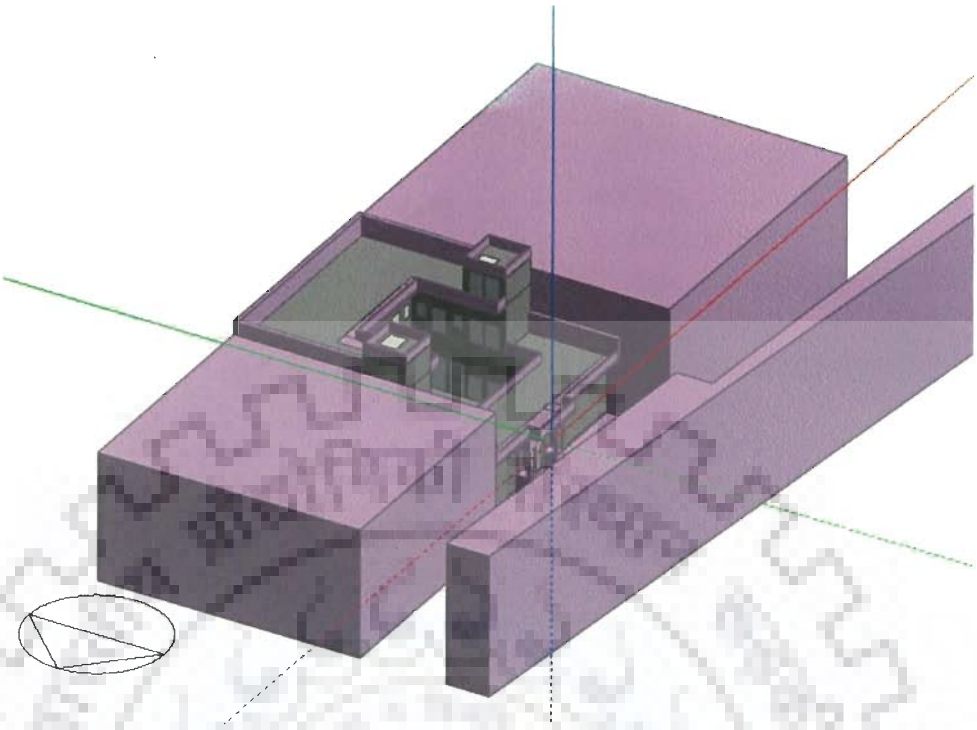


Figure A-8.3 View of Model

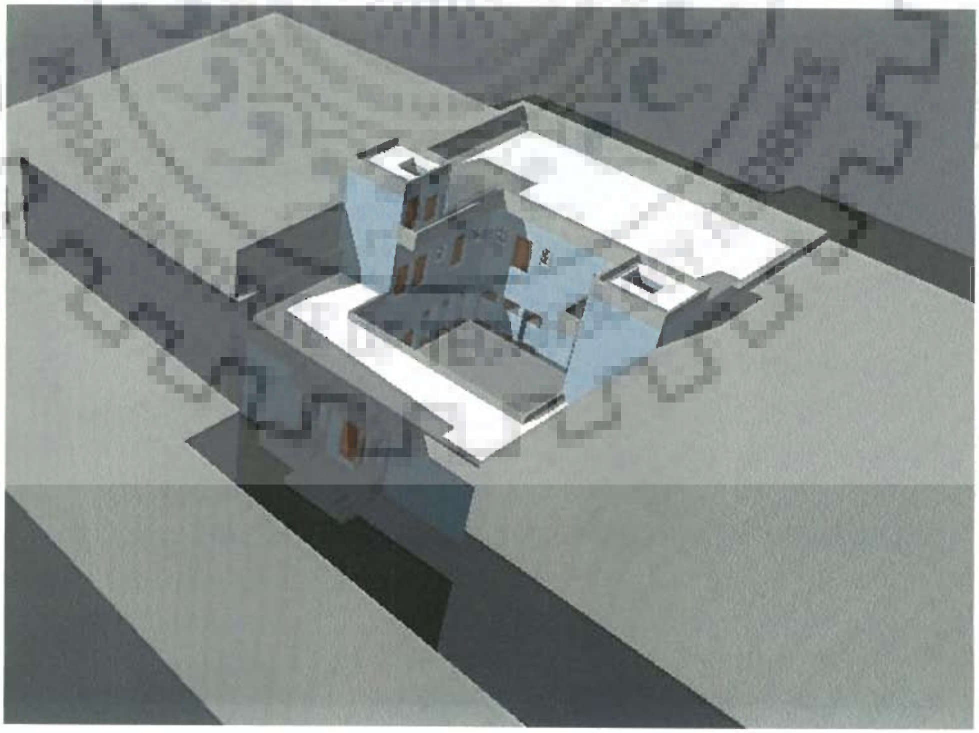


Figure A-8.4 Rendered View of Model

Ramgarh Haveli

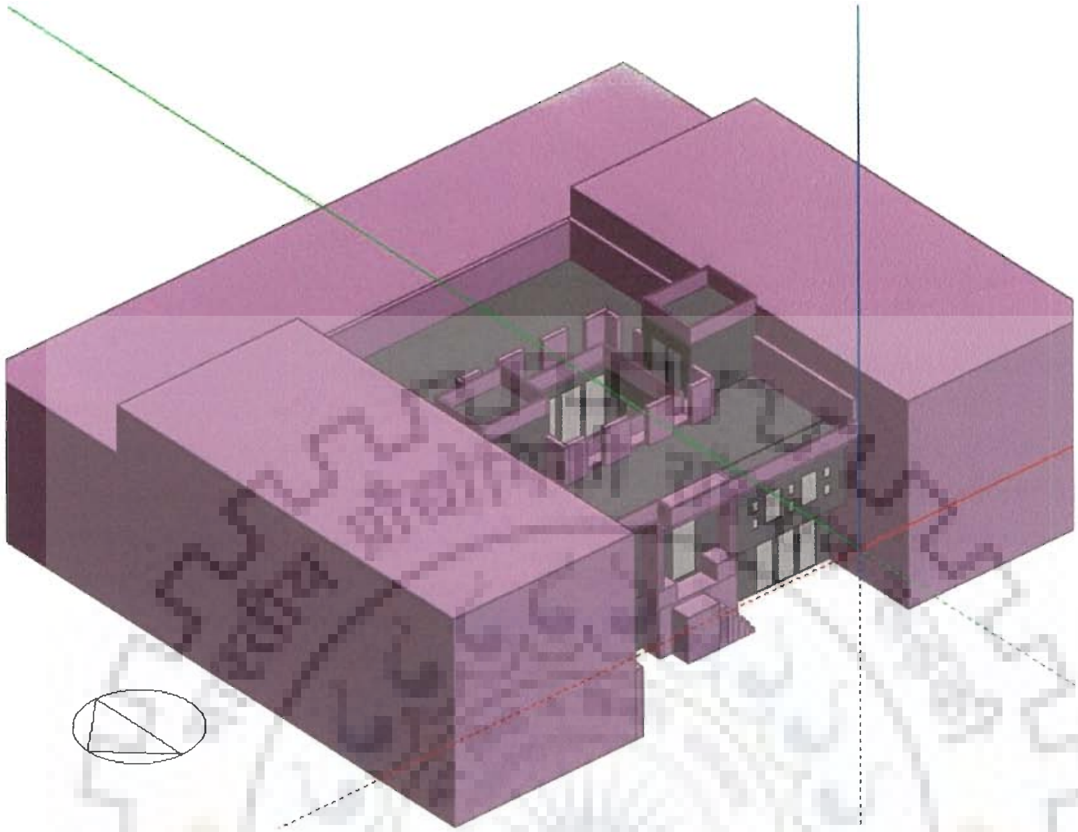


Figure A-8.5 View of Model

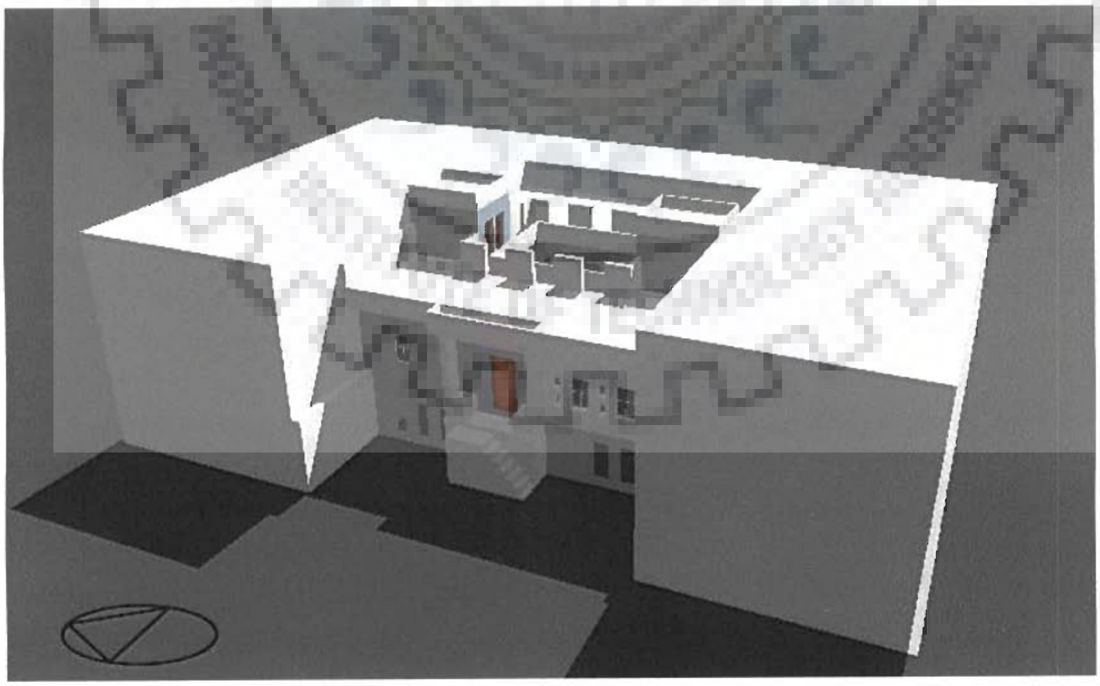


Figure A-8.6 Rendered View of Model

Muslim Haveli, Ratannagar

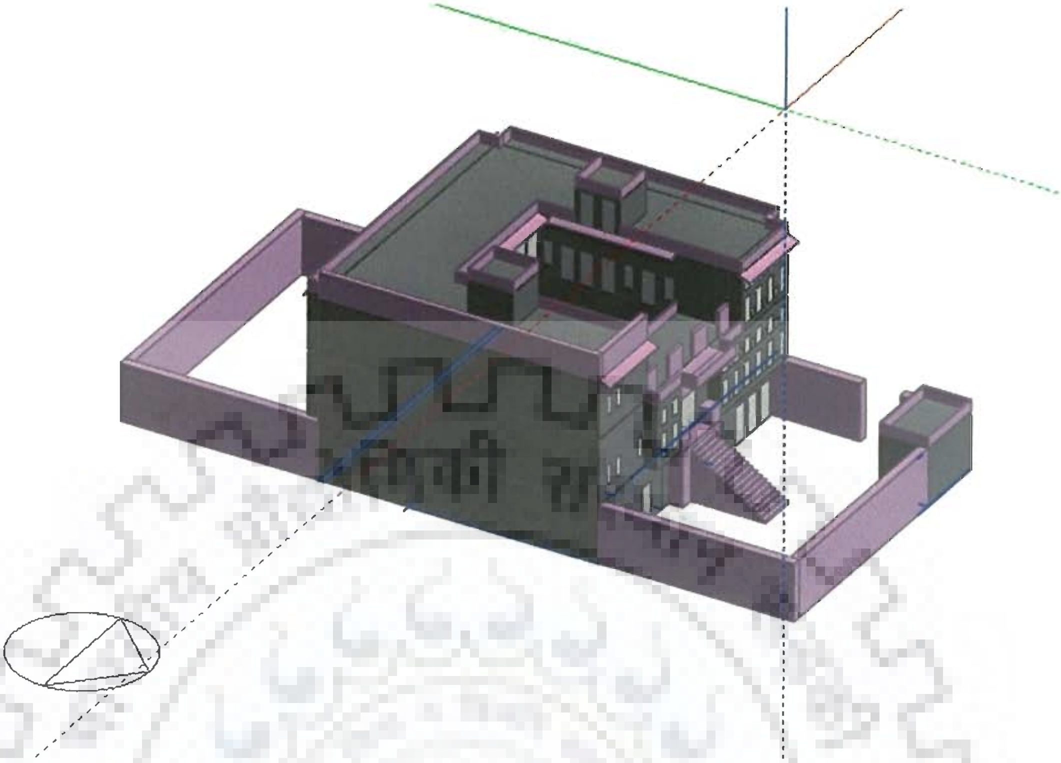


Figure A-8.7 View of Model

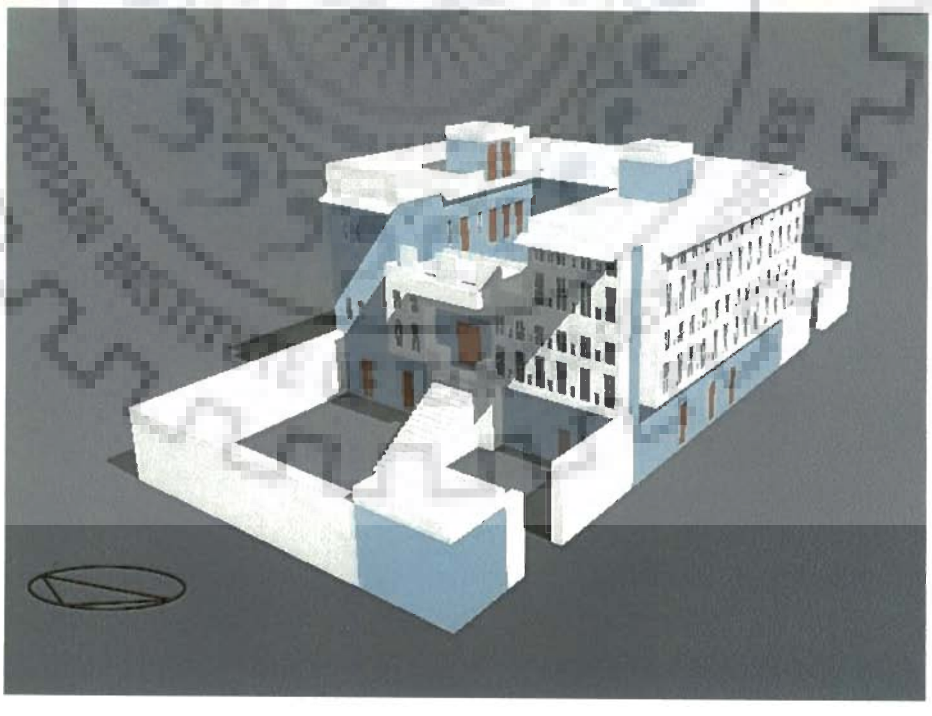


Figure A-8.8 Rendered View of Model

Sahumal Khetan Haveli, Mehansar

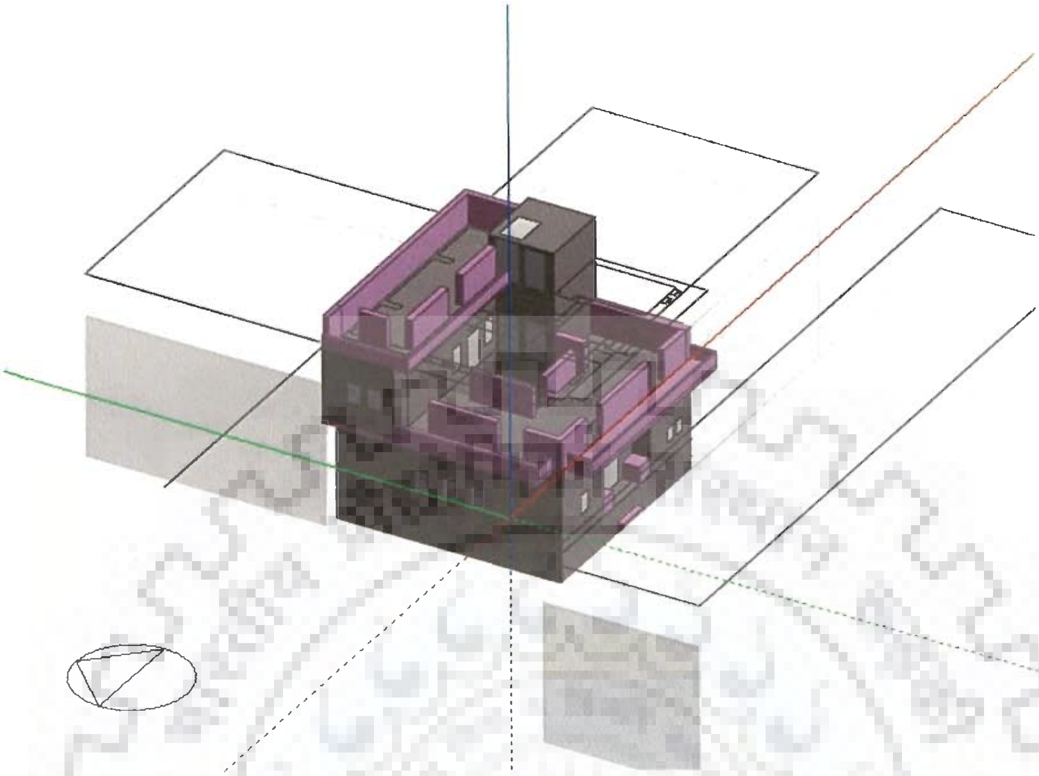


Figure A-8.9 View of Model

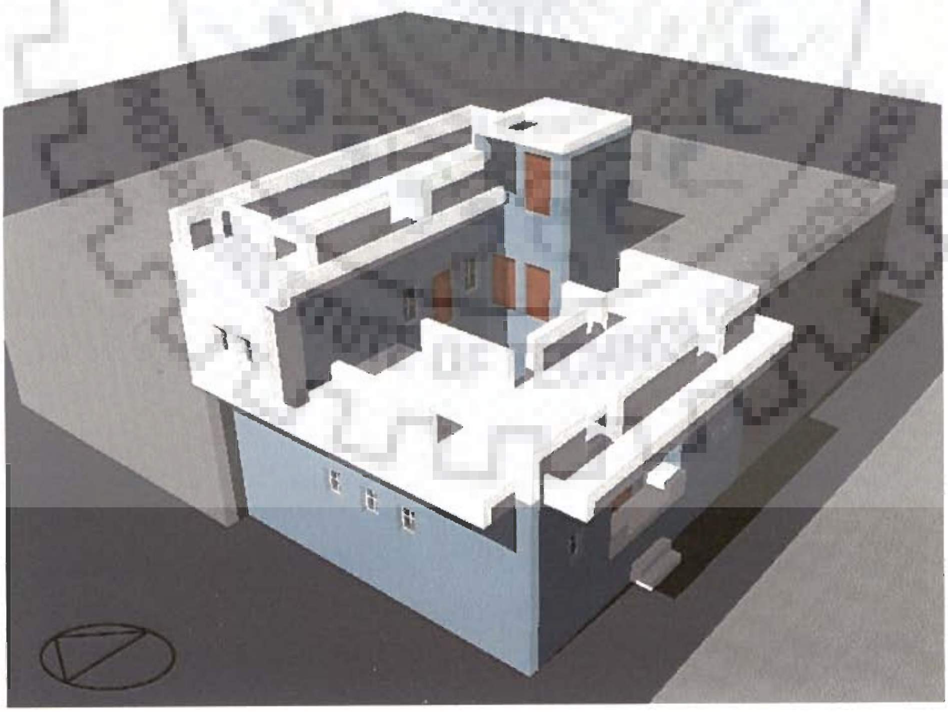


Figure A-8.10 Rendered View of Model

Sidhkaranji morarka Haveli, Mukundgarh

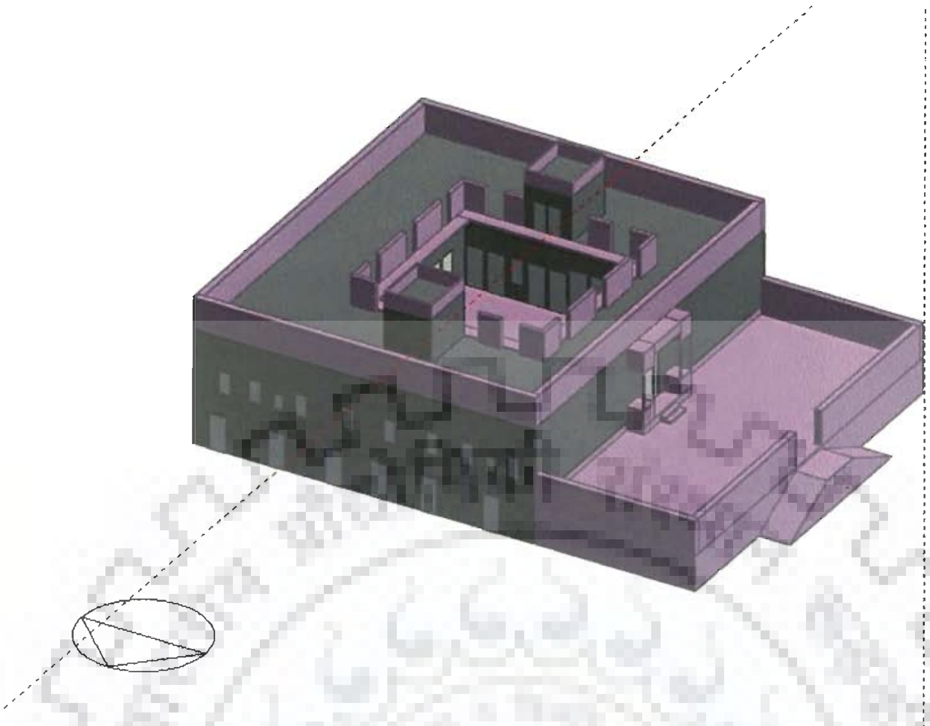


Figure A-8.11 View of Model

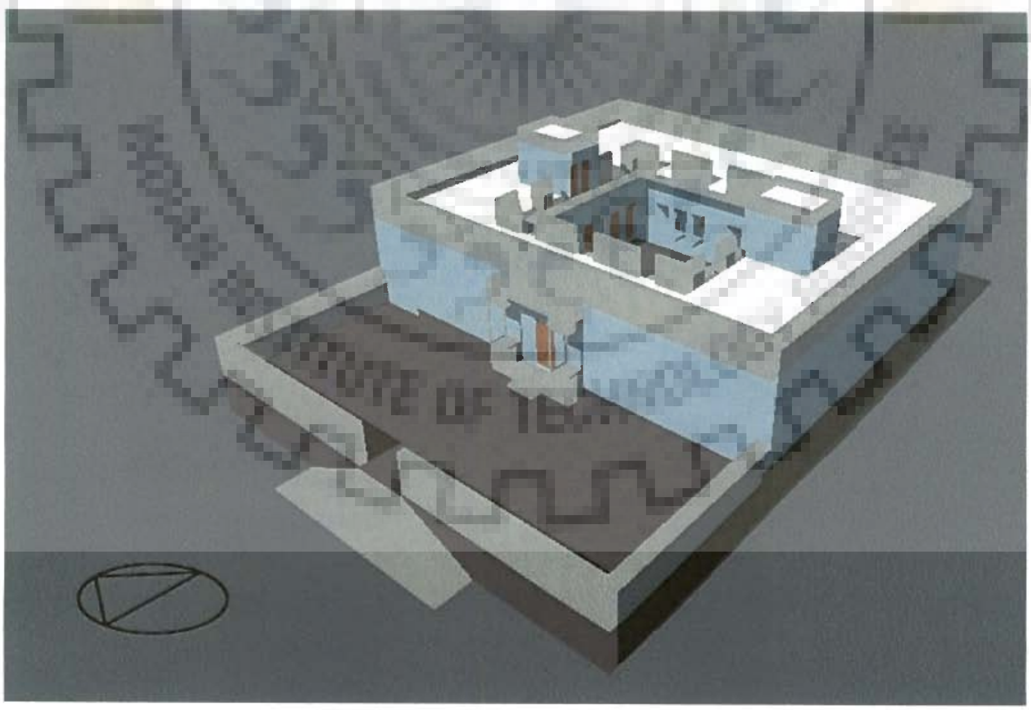


Figure A-8.12 Rendered View of Model

Babulalji Gudha Haveli, Mukundgarh

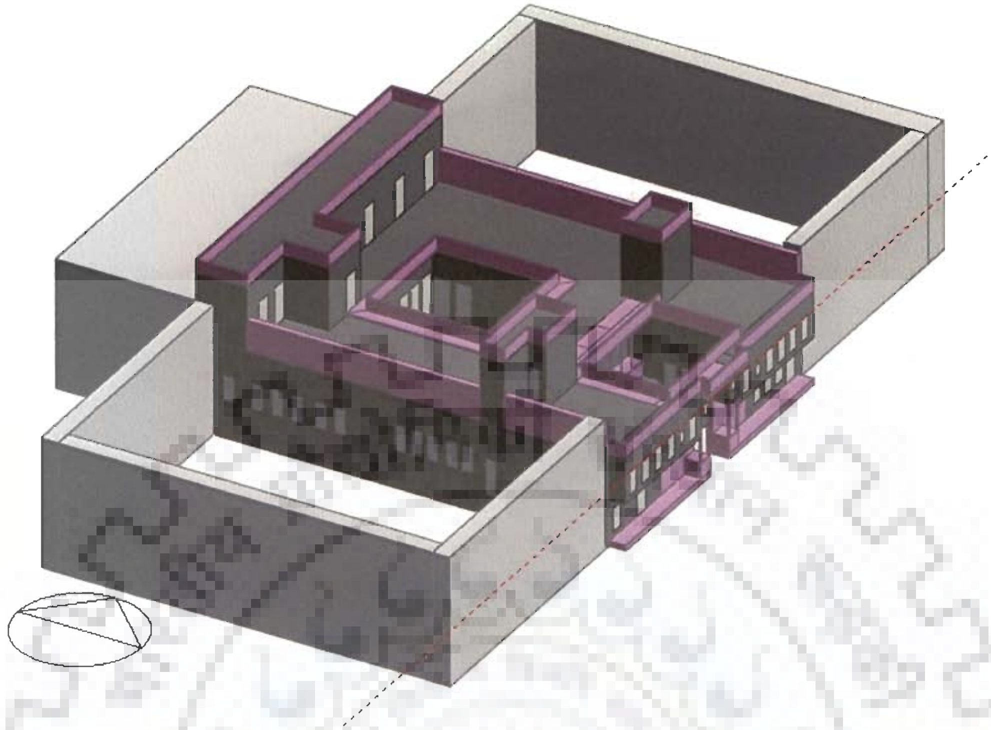


Figure A-8.13 View of Model

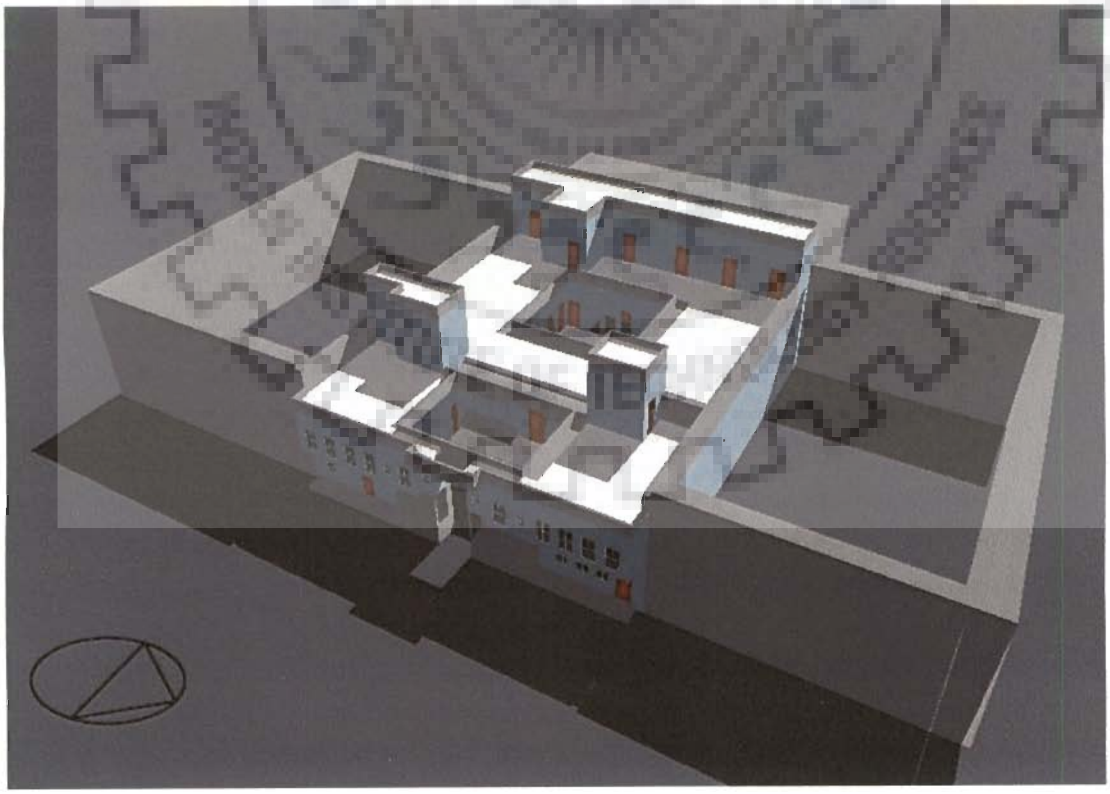


Figure A-8.14 Rendered View of Model

Bhagirathmal Kedarmal Goenka Haveli, Dundlod

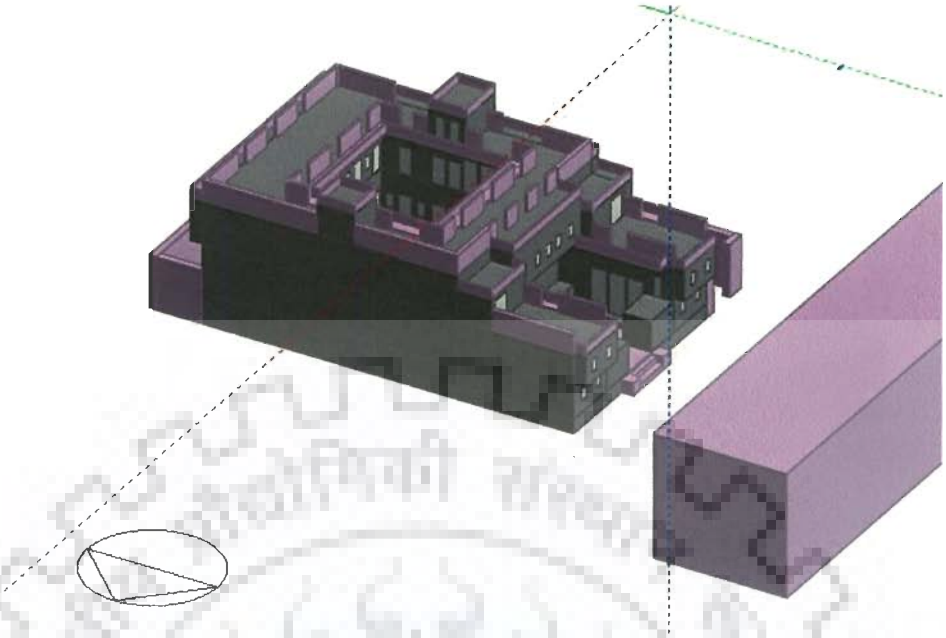


Figure A-8.15 View of Model

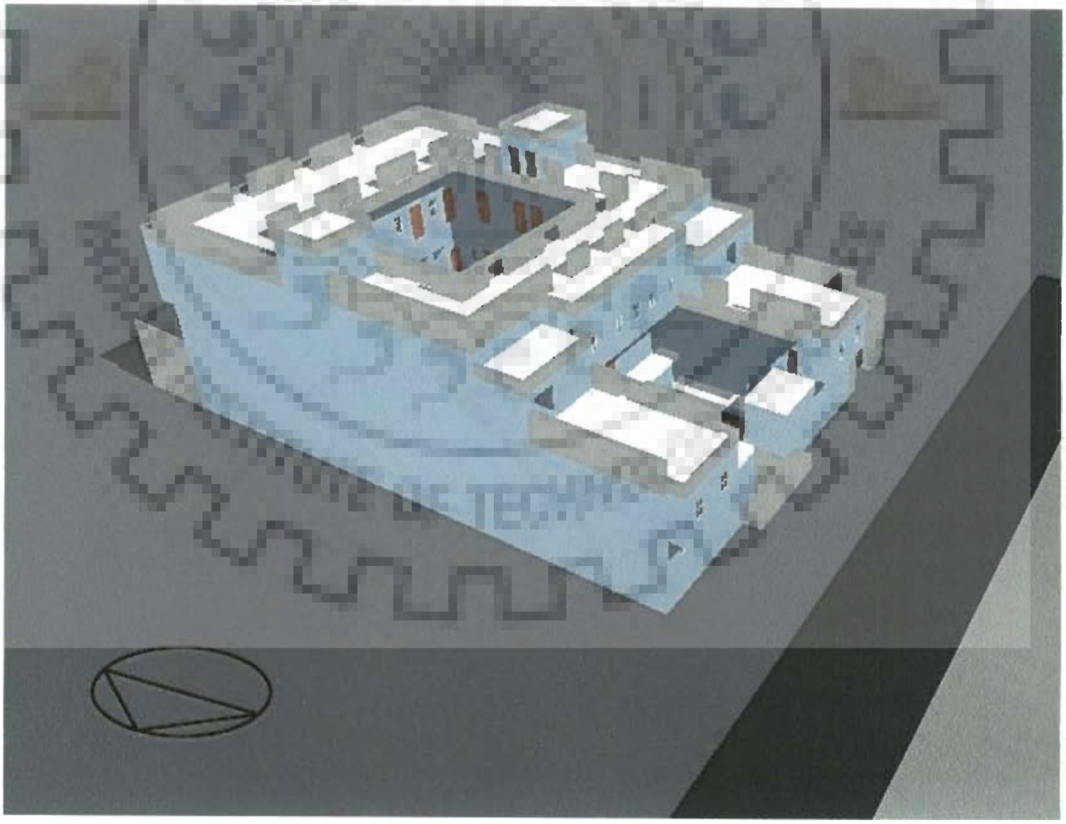


Figure A-8.16 Rendered View of Model

Bissau Haveli

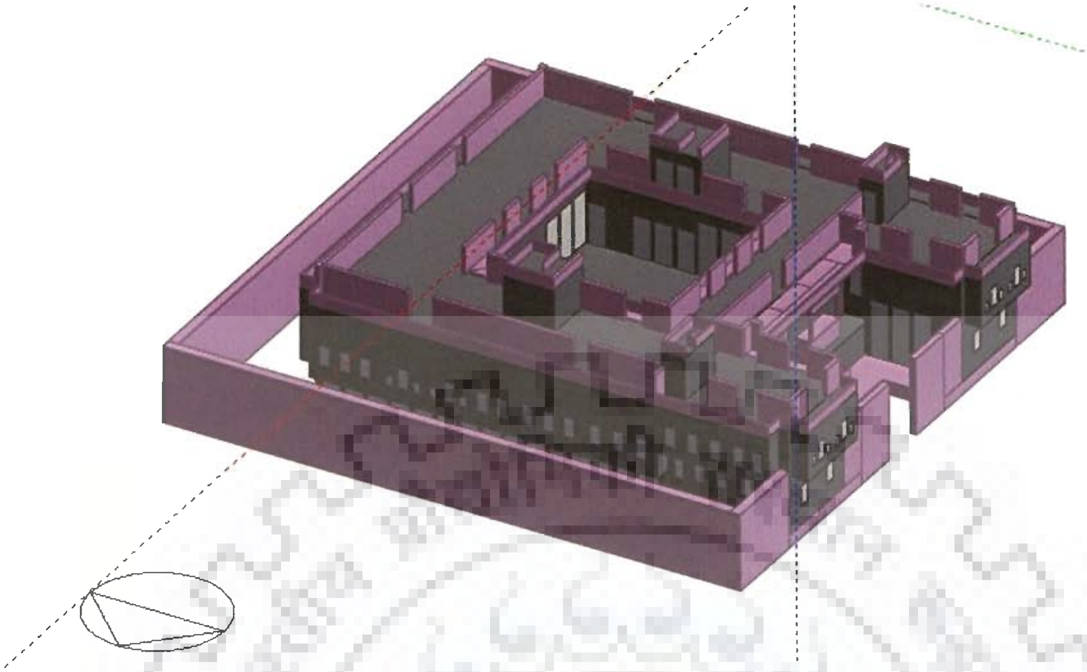


Figure A-8.17 View of Model

Figure A-8.10 Rendered View of Model

Damodar Prasad Morarka Haveli, Mukundgarh

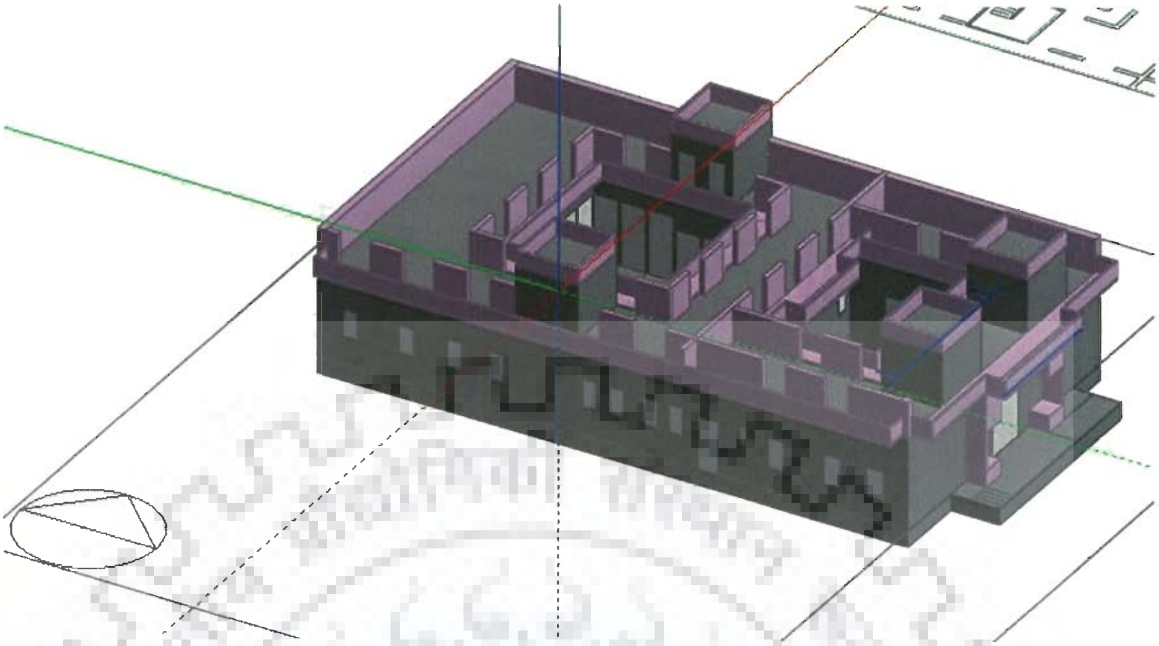


Figure A-8.19 View of Model

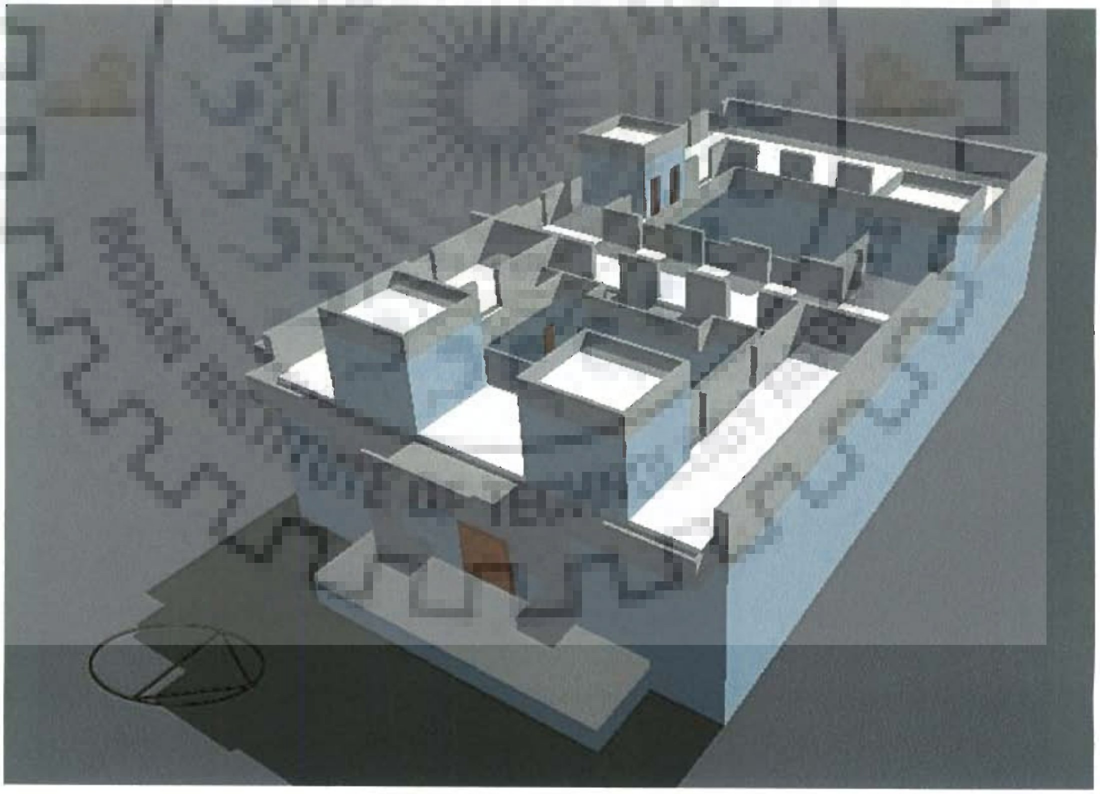


Figure A-8.20 Rendered View of Model

Haveli used as gymnasium, Dundlod

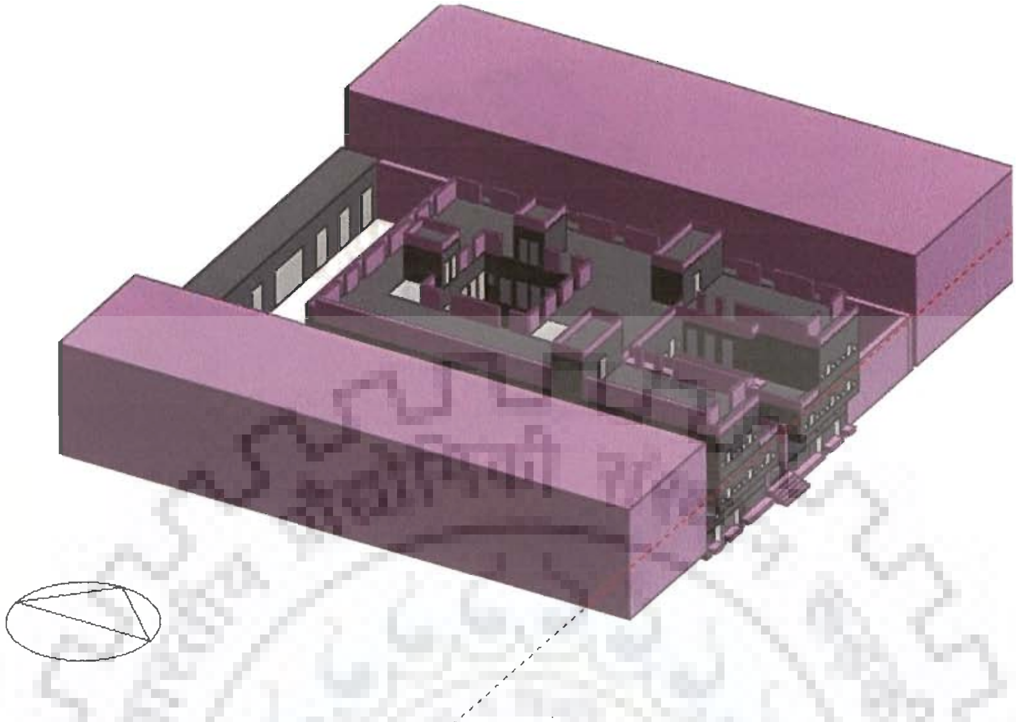


Figure A-8.21 View of Model

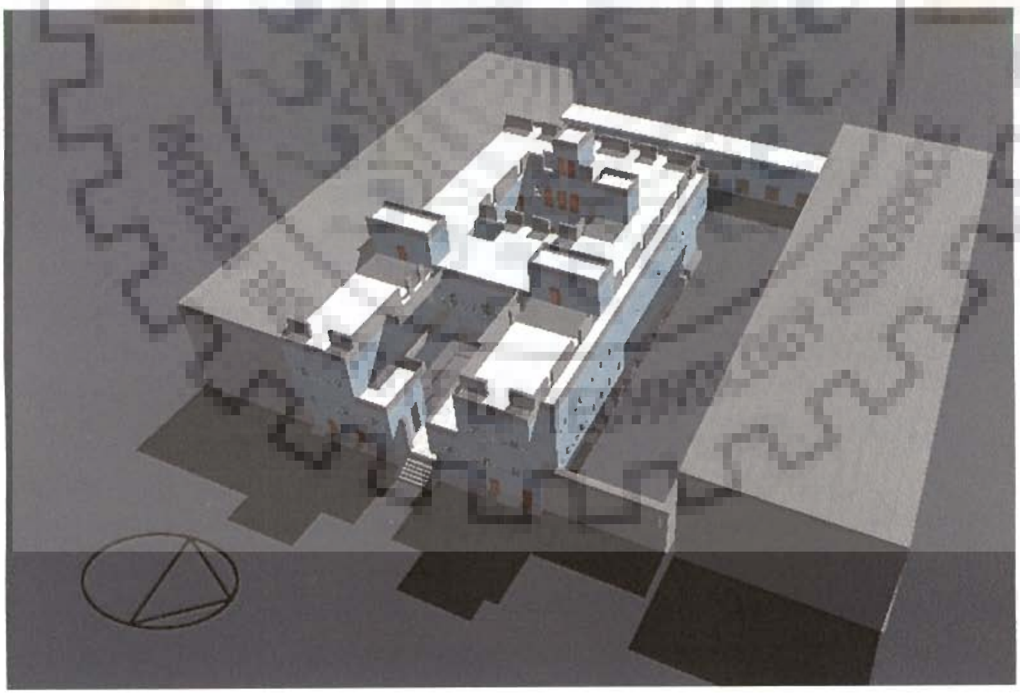


Figure A-8.22 Rendered View of Model

Seth Arjundas Goenka Haveli, Dundlod

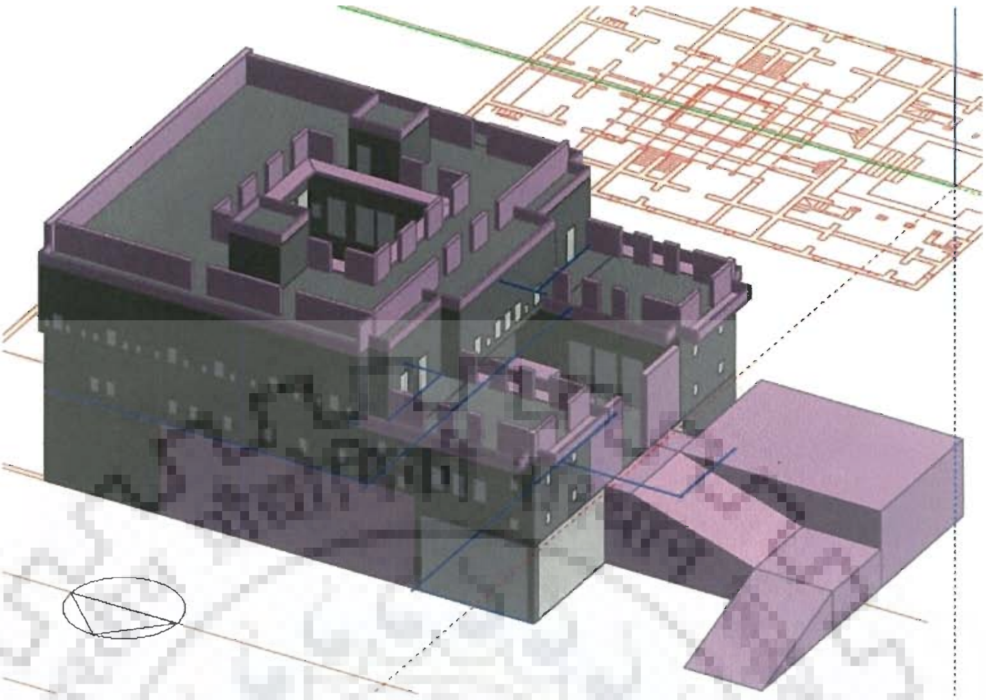


Figure A-8.23 View of Model

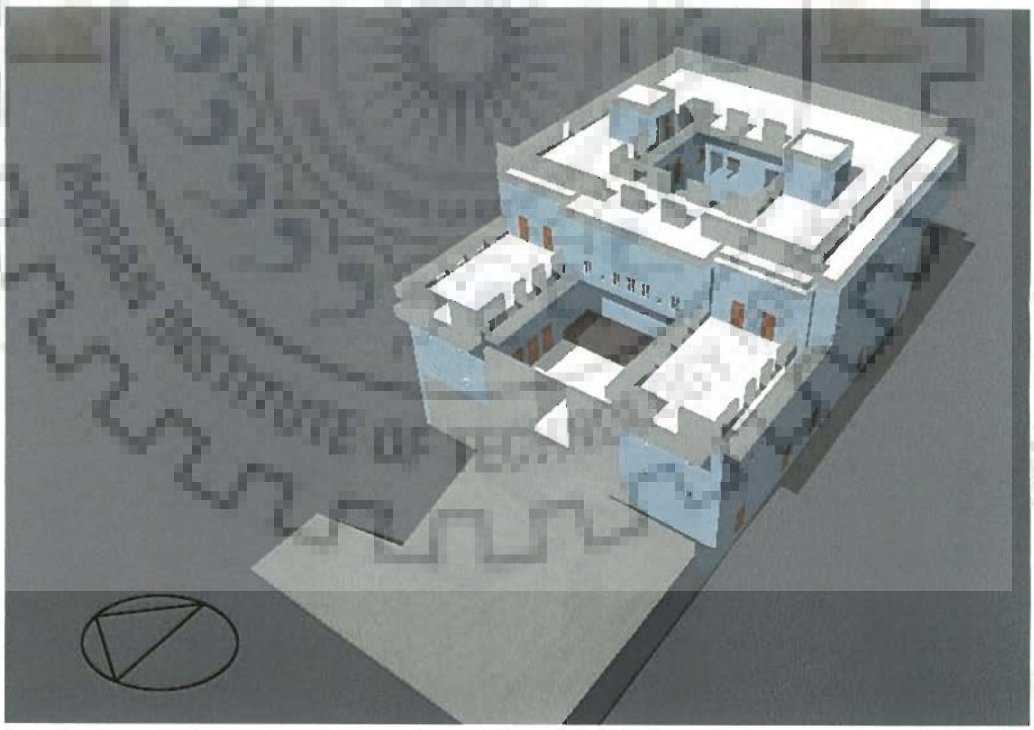


Figure A-8.24 Rendered View of Model

Harkarandas Mangilalji Haveli, Bagad

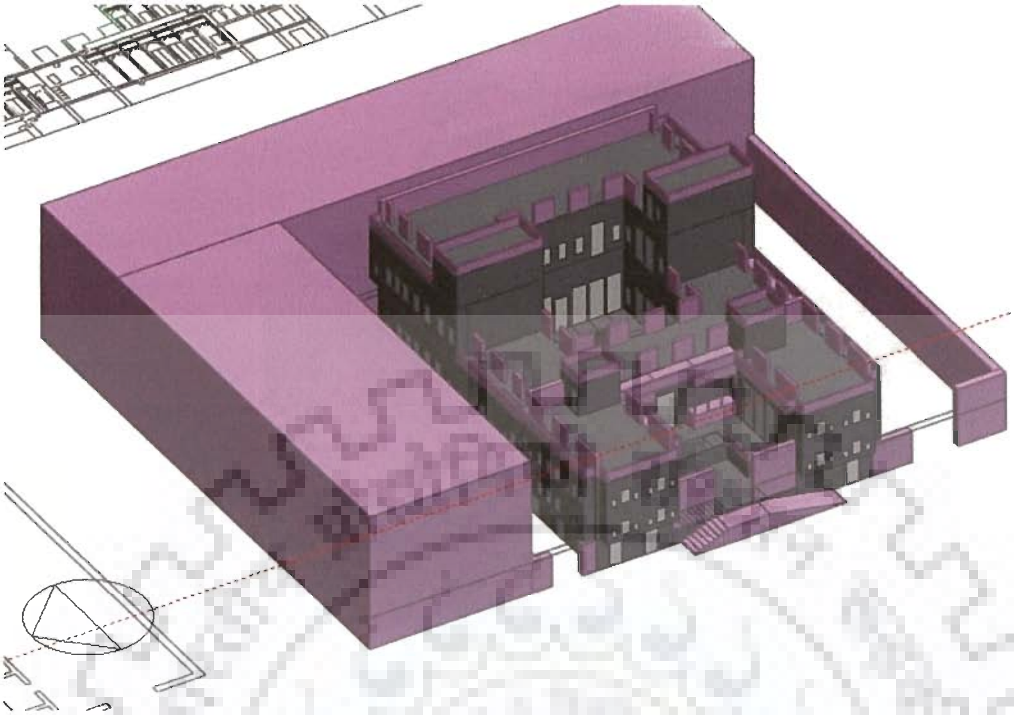


Figure A-8.25 View of Model

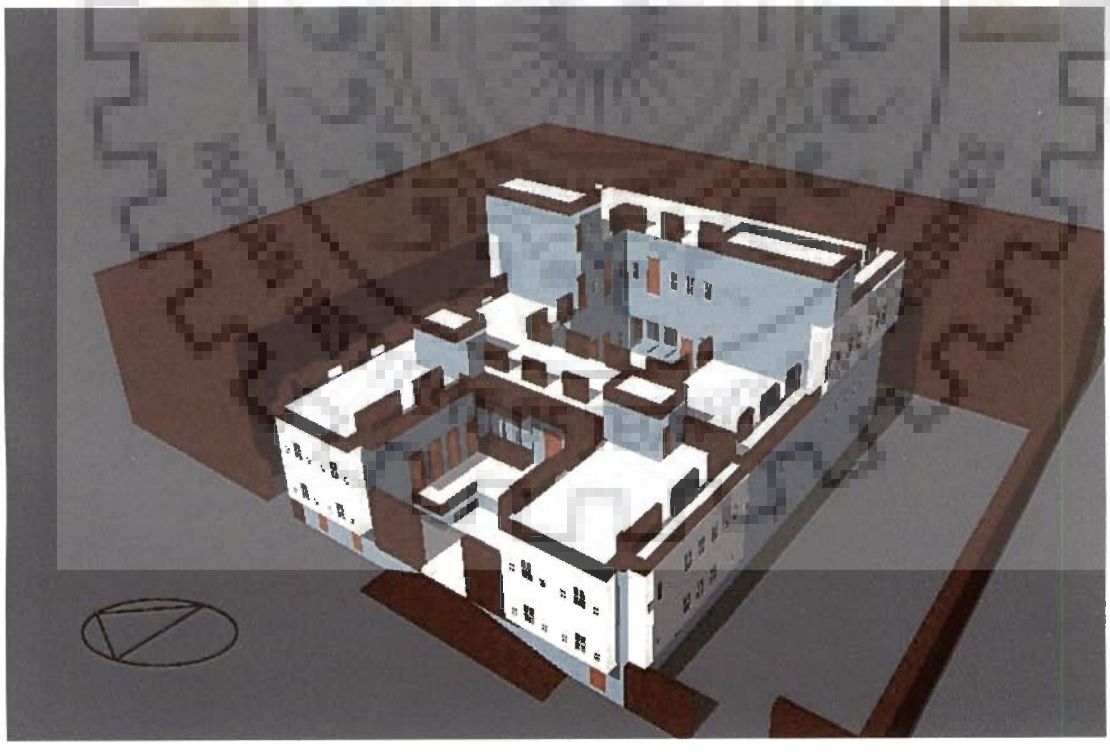


Figure A-8.26 Rendered View of Model

Ishwardas Modi Haveli, Jhunjhunu

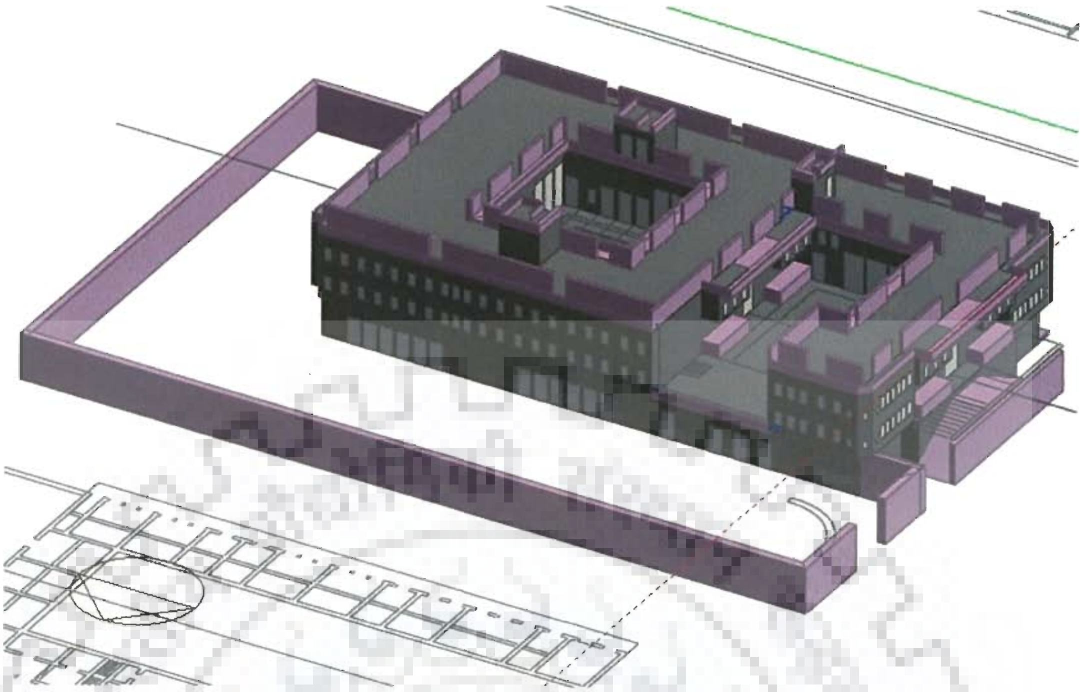


Figure A-8.27 View of Model

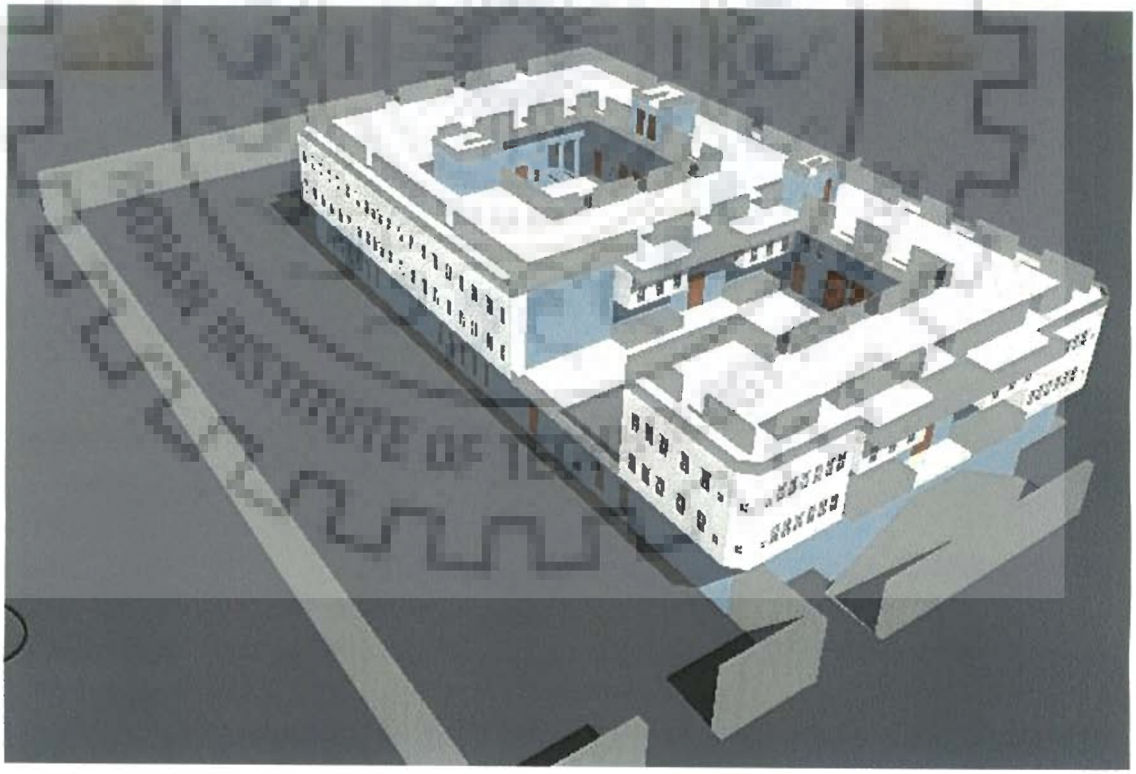


Figure A-8.28 Rendered View of Model

Jaigopal Goenka Haveli, Mandawa

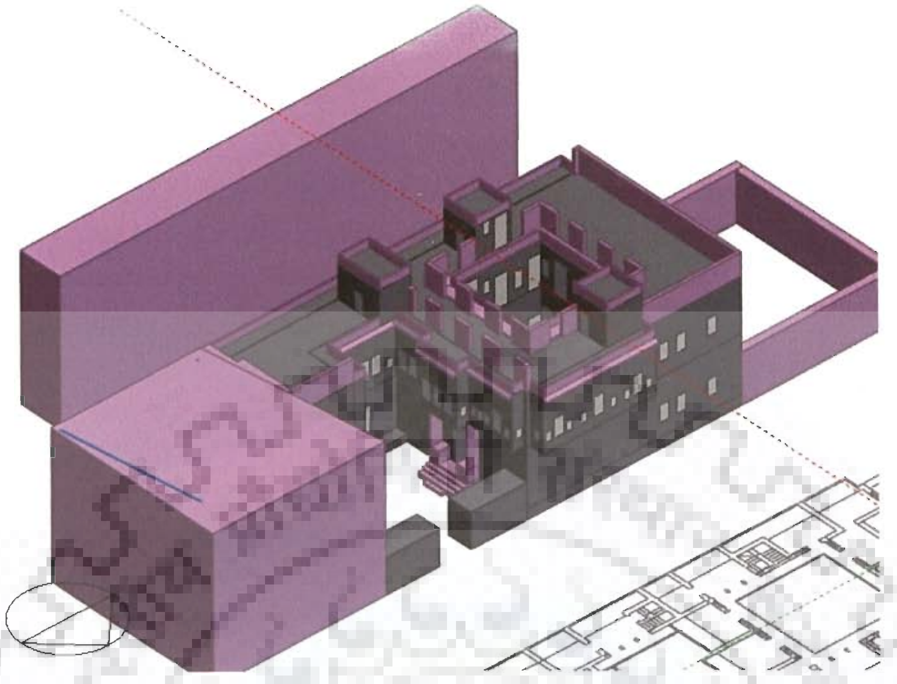


Figure A-8.29 View of Model

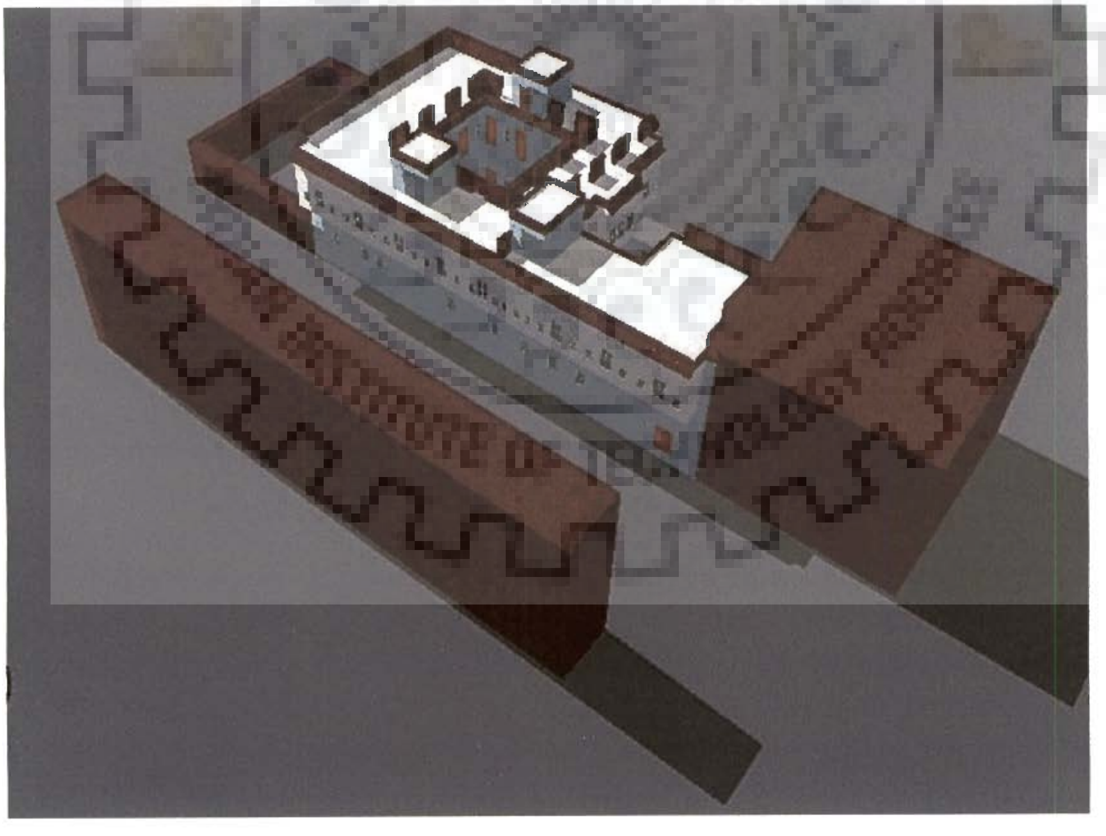
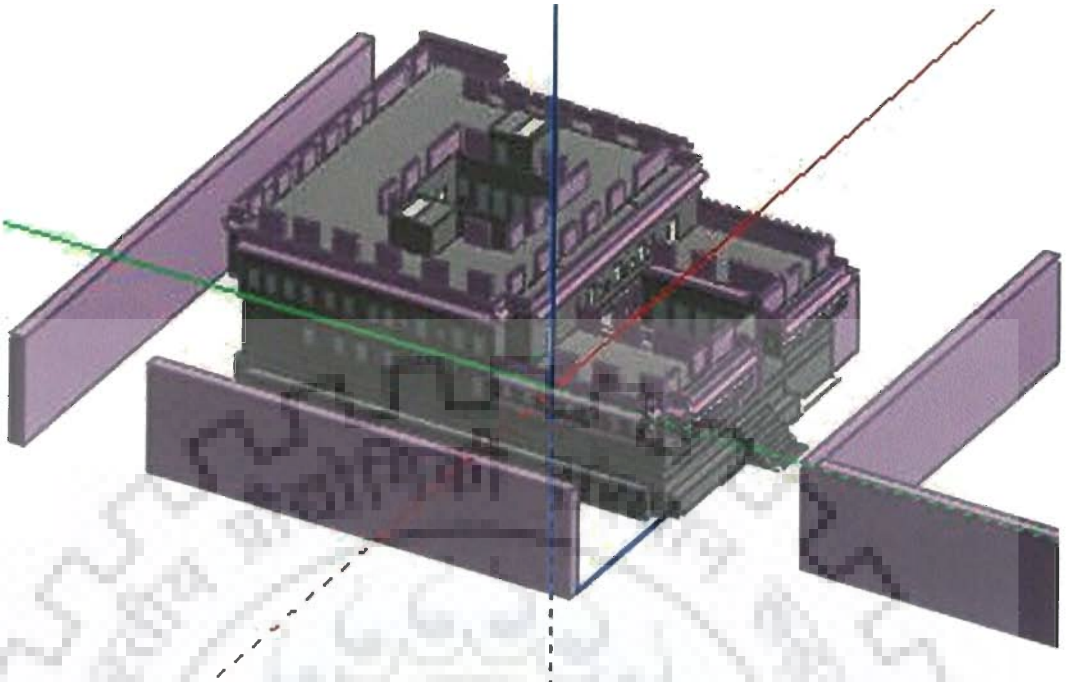


Figure A-8.30 Rendered View of Model

Kariwala haveli, Nawalgarh



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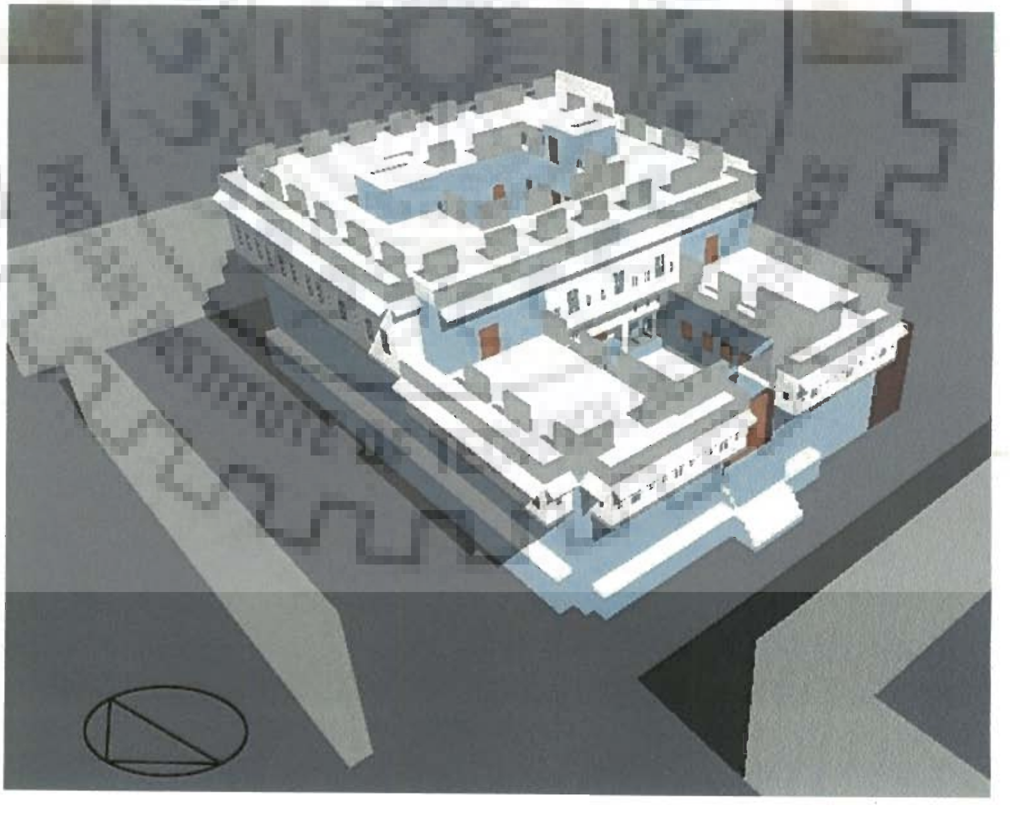
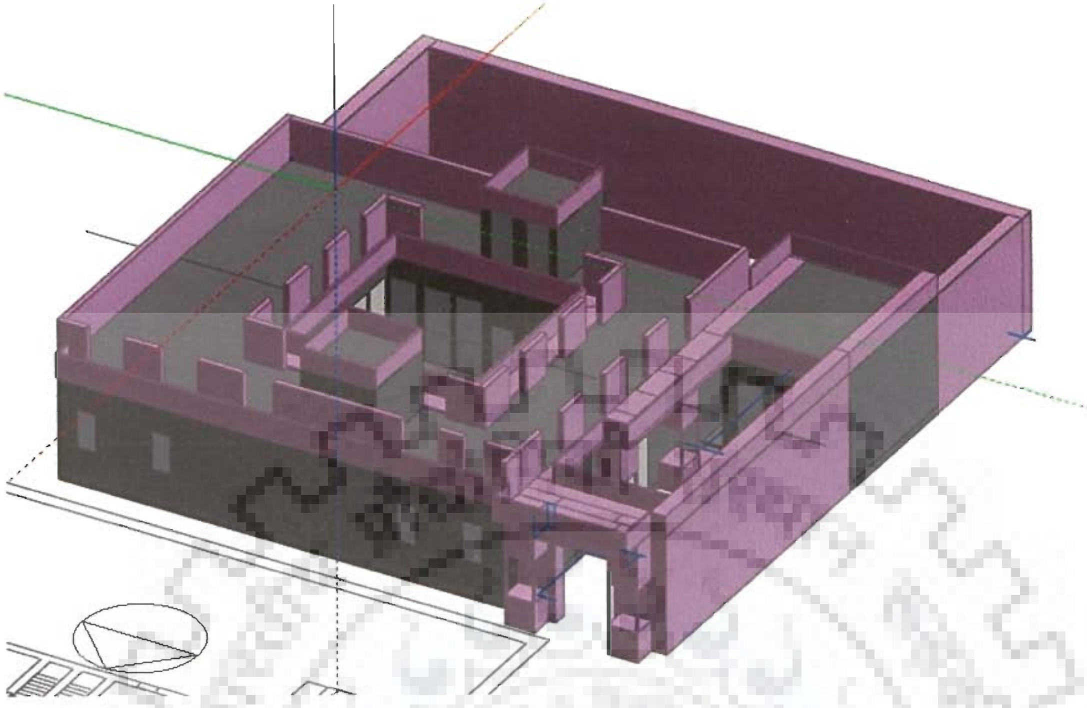


Figure A-8.32 Rendered View of Model

Pilani Haveli



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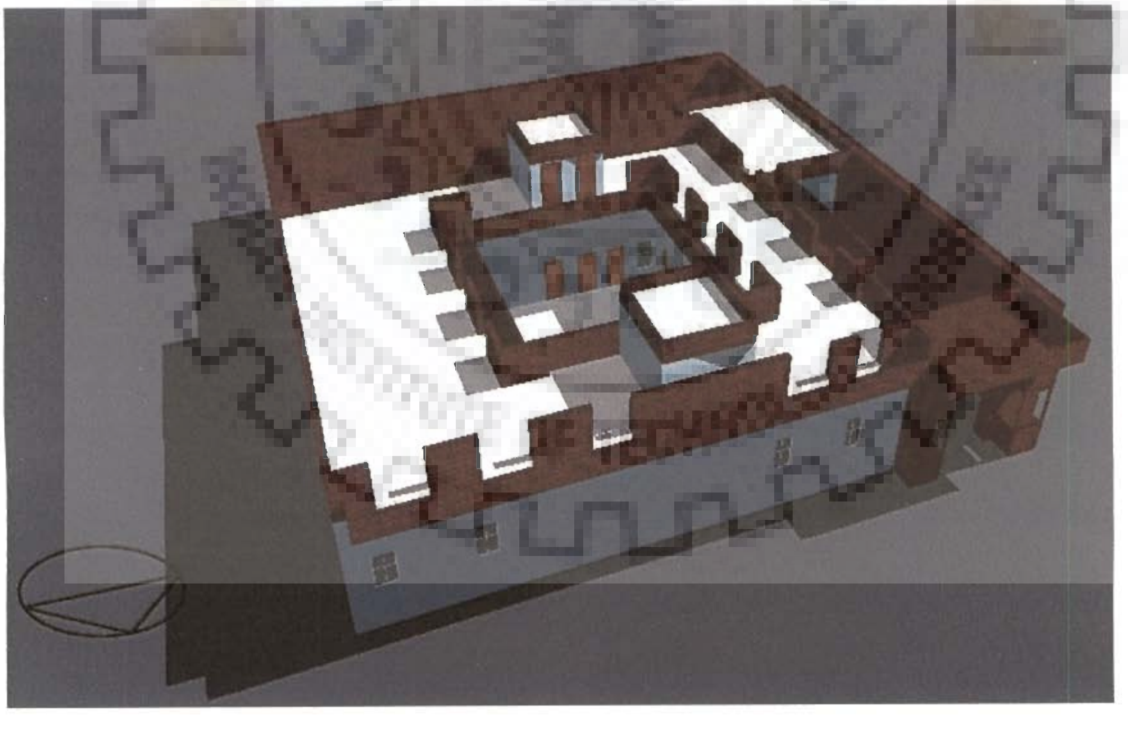


Figure A-8.34 Rendered View of Model

Shekhsaria Haveli, Nawalgarh

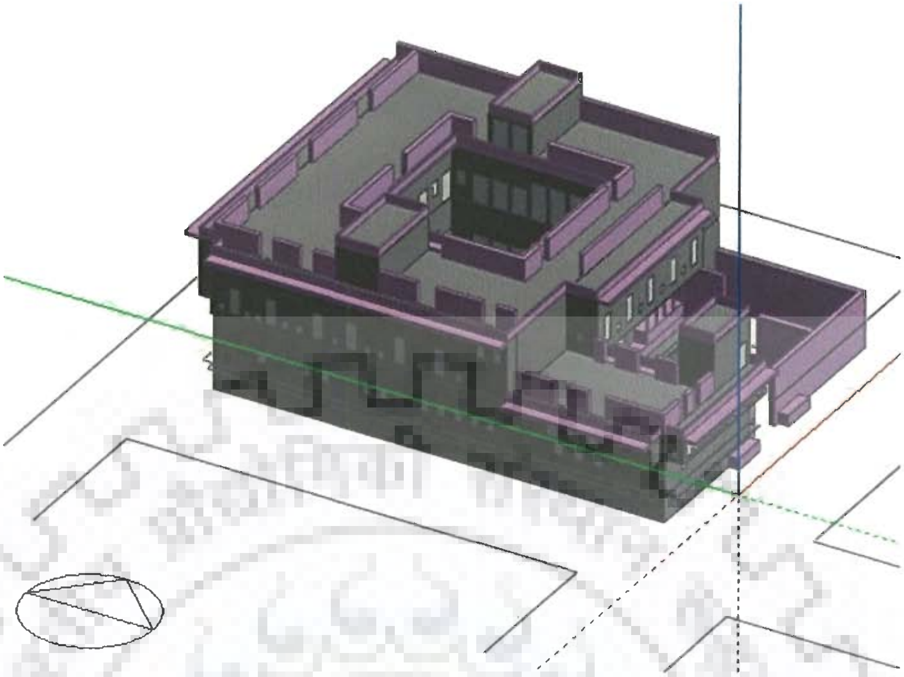


Figure A-8.35 View of Model

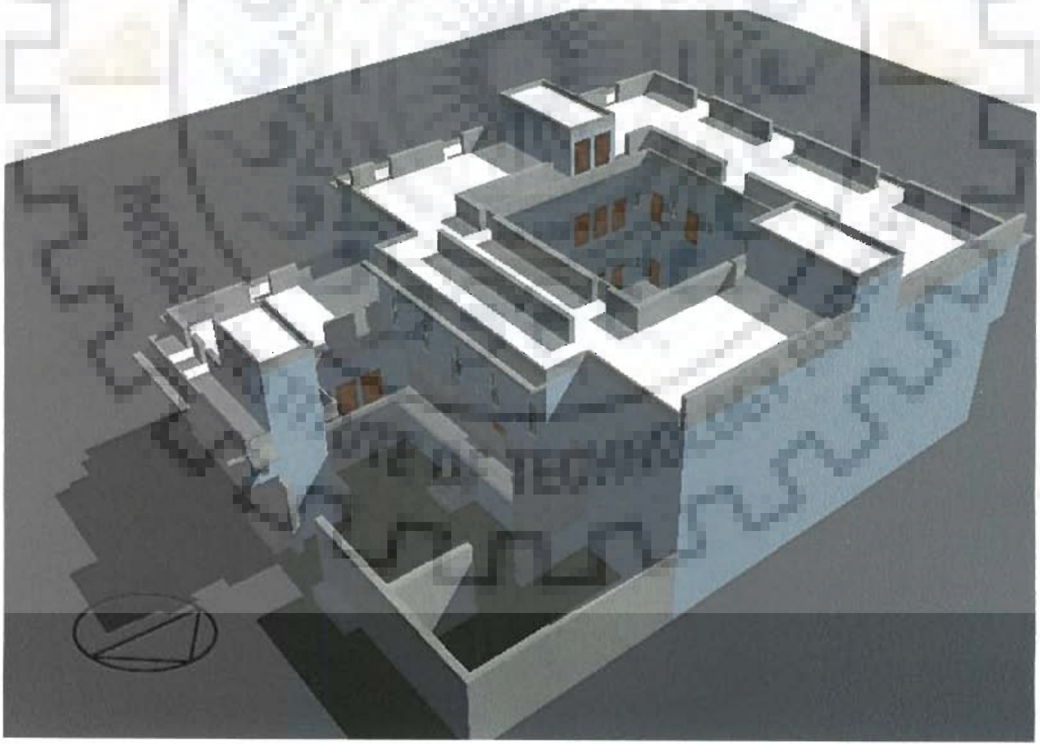


Figure A-8.36 Rendered View of Model

Virdichand Gaurilalji Haveli, Sikar

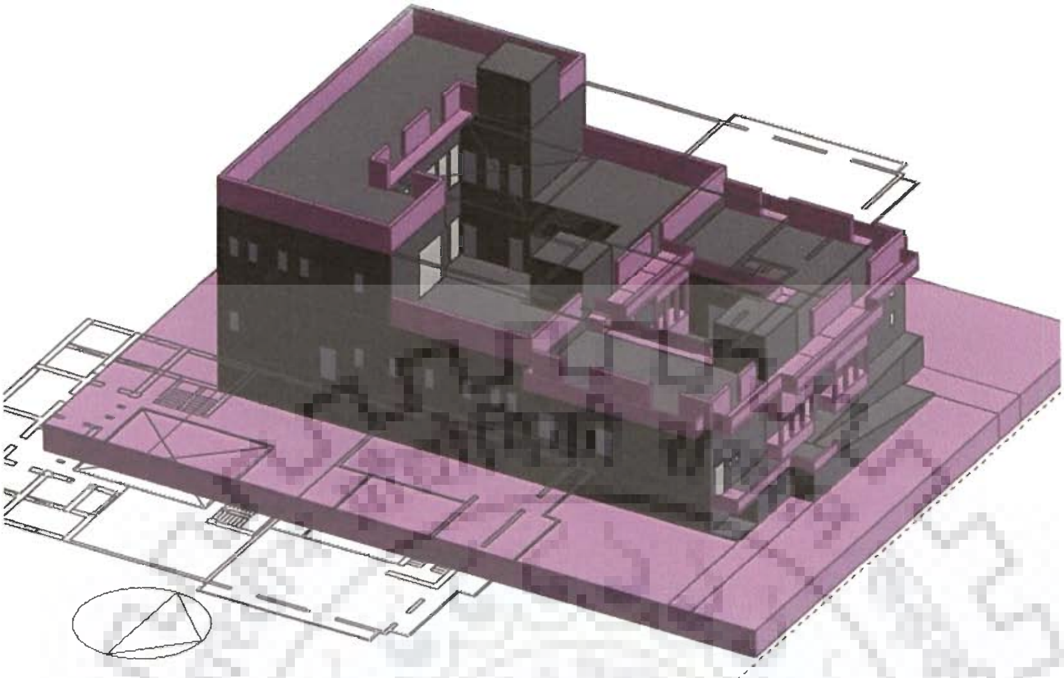
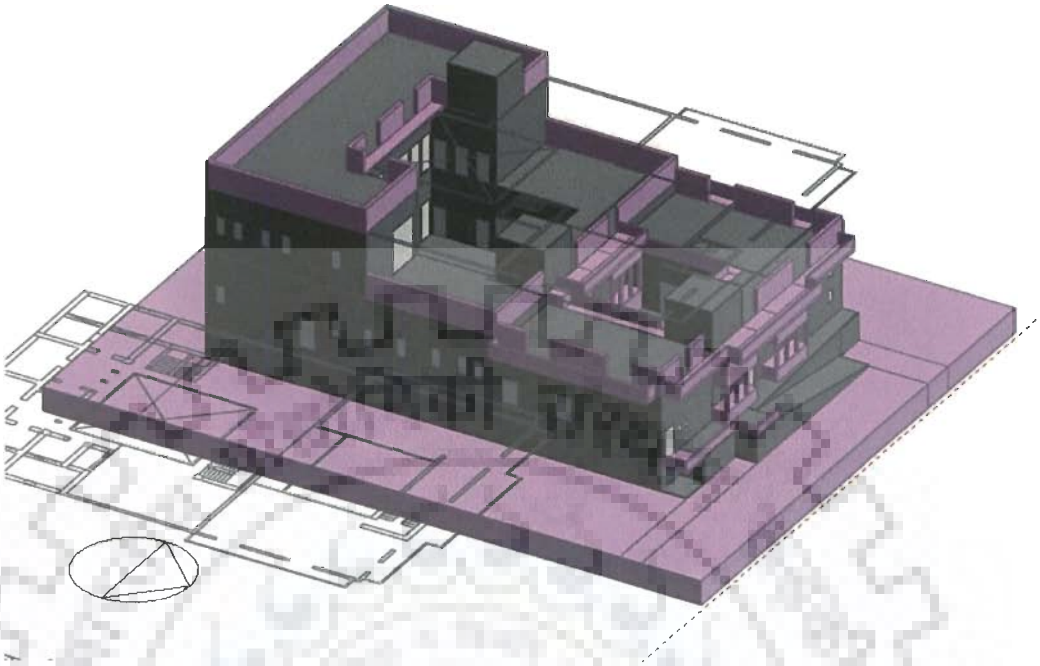


Figure A-8.37 View of Model

Figure A-8.36 Rendered View of Model

Shridhar Gangadhar Morarka, Mukundgarh



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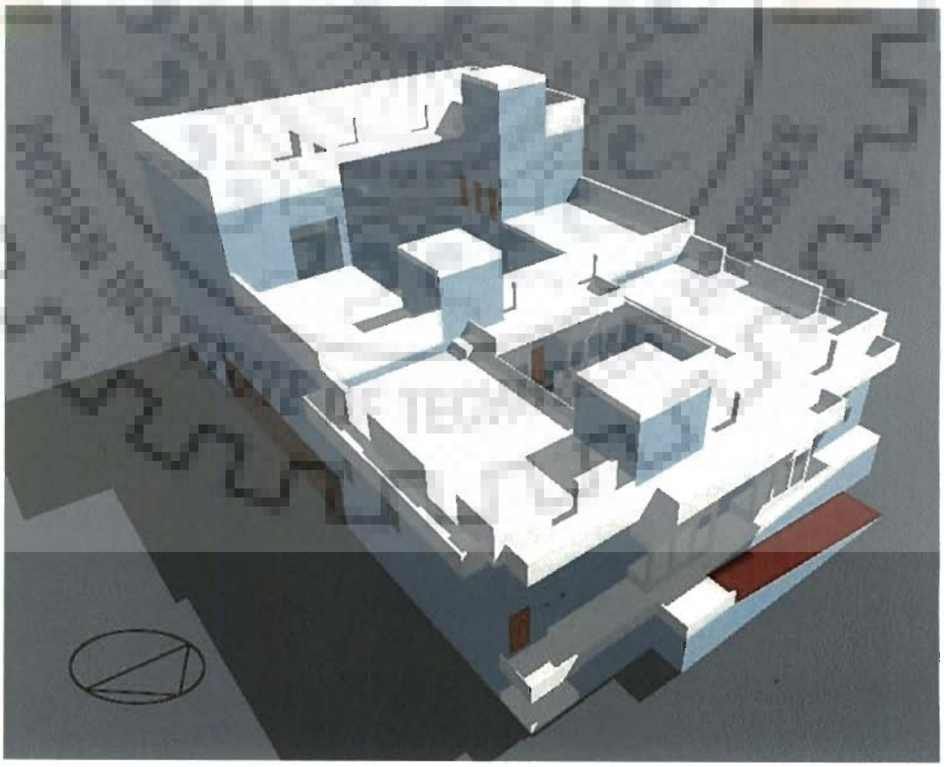


Figure A-8.40 Rendered View of Model

Nawalgarh Unidentified Haveli

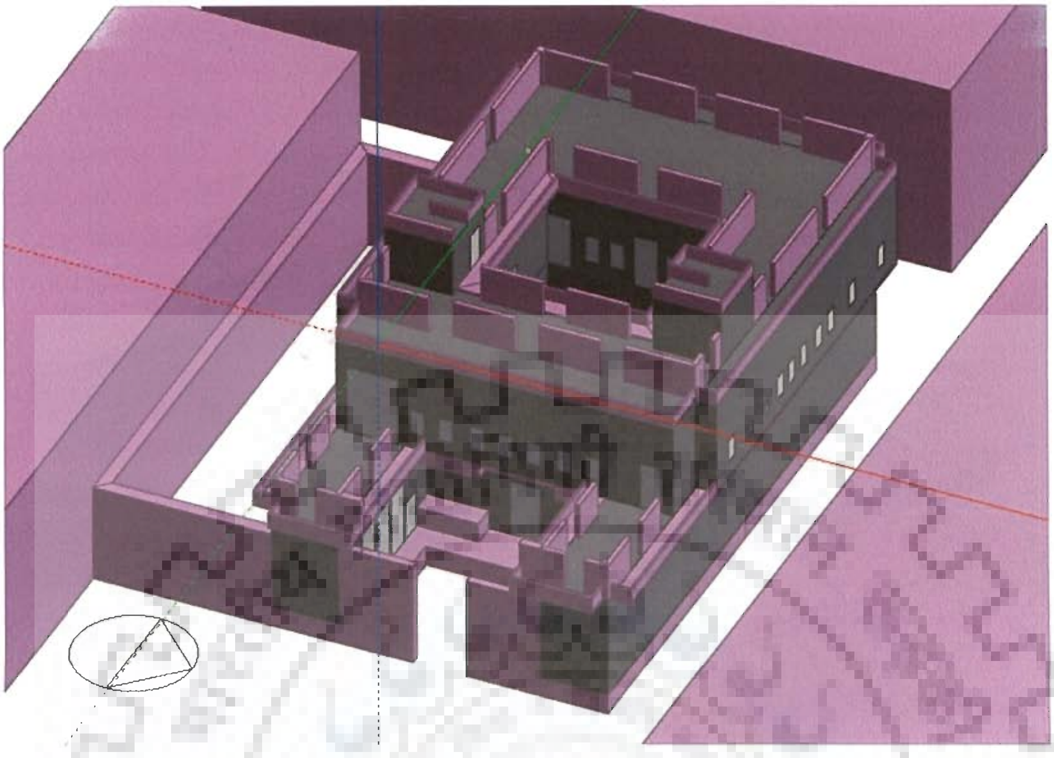


Figure A-8.41 View of Model

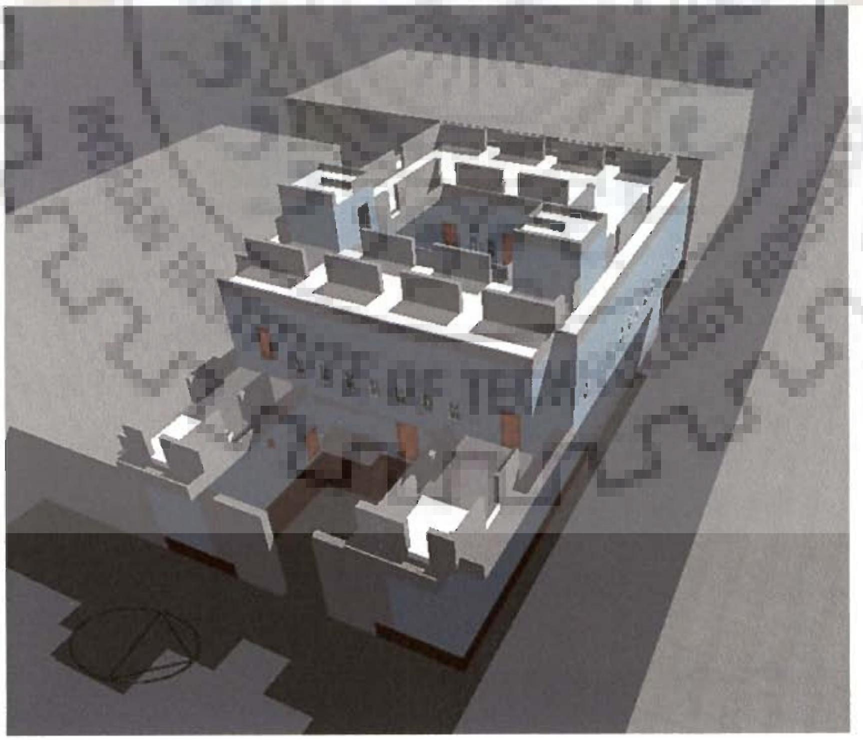


Figure A-8.42 Rendered View of Model

Surajgarh Haveli

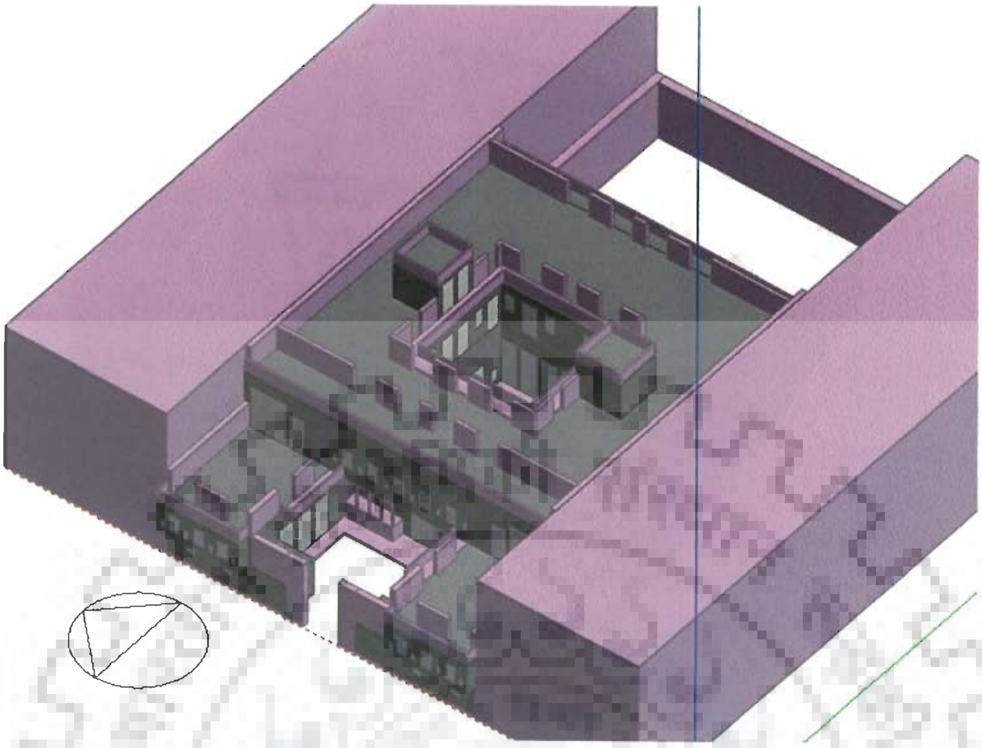


Figure A-8.43 View of Model

Figure A-8.44 Rendered View of Model

Gulabrai Ladia Haveli, Mandawa

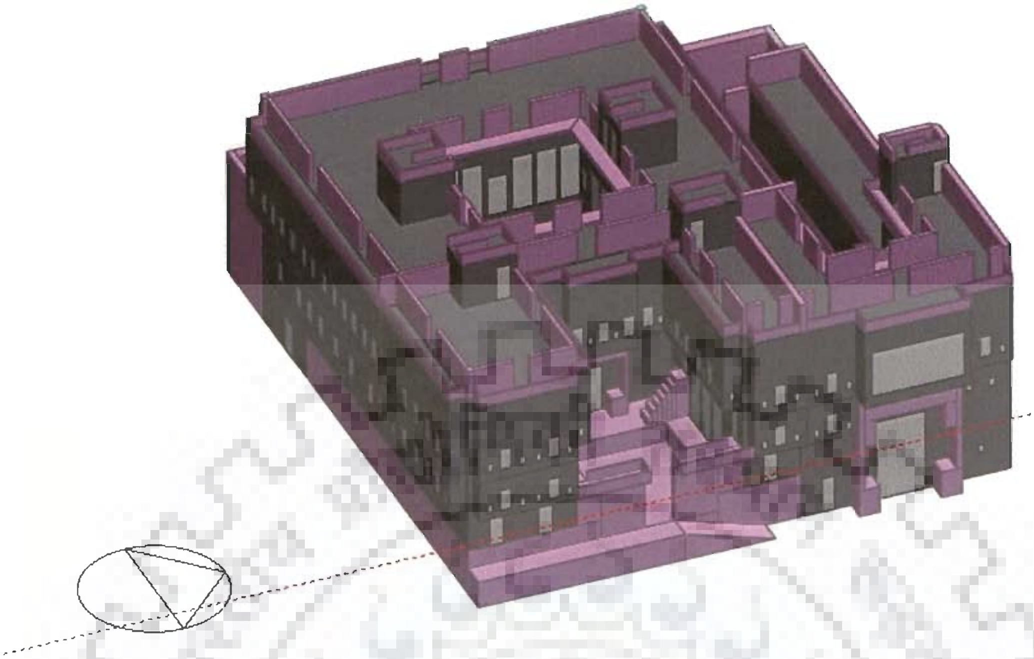


Figure A-8.45 View of Model

Figure A-8.46 Rendered View of Model

Morarka Haveli, Nawalgarh

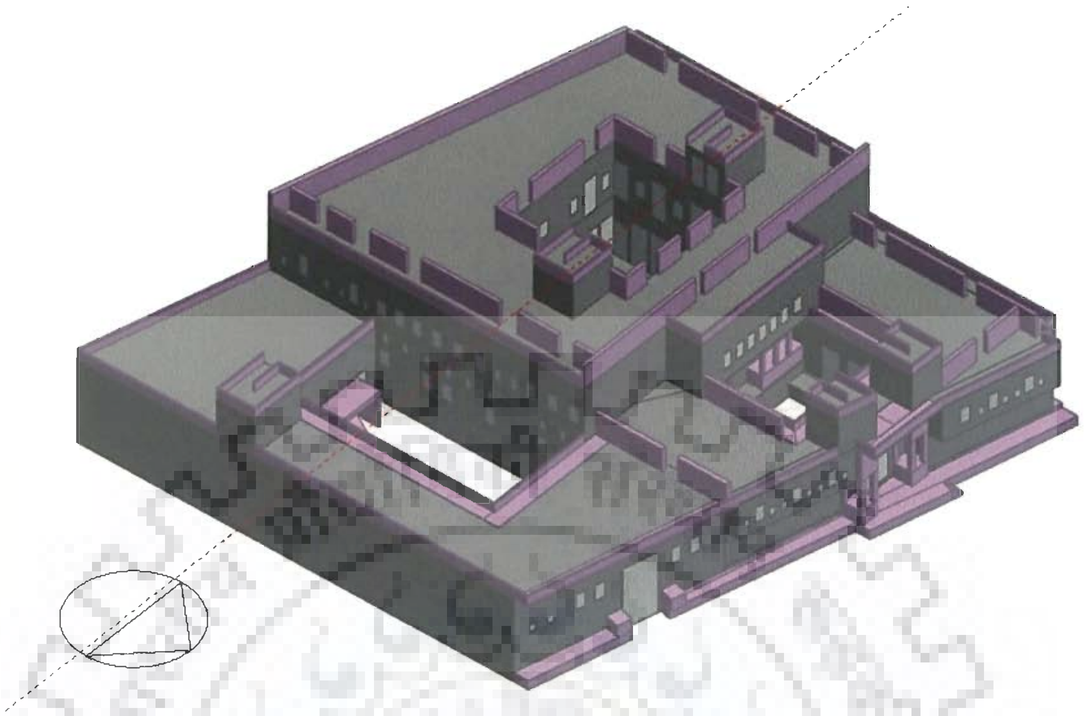


Figure A-8.47 View of Model

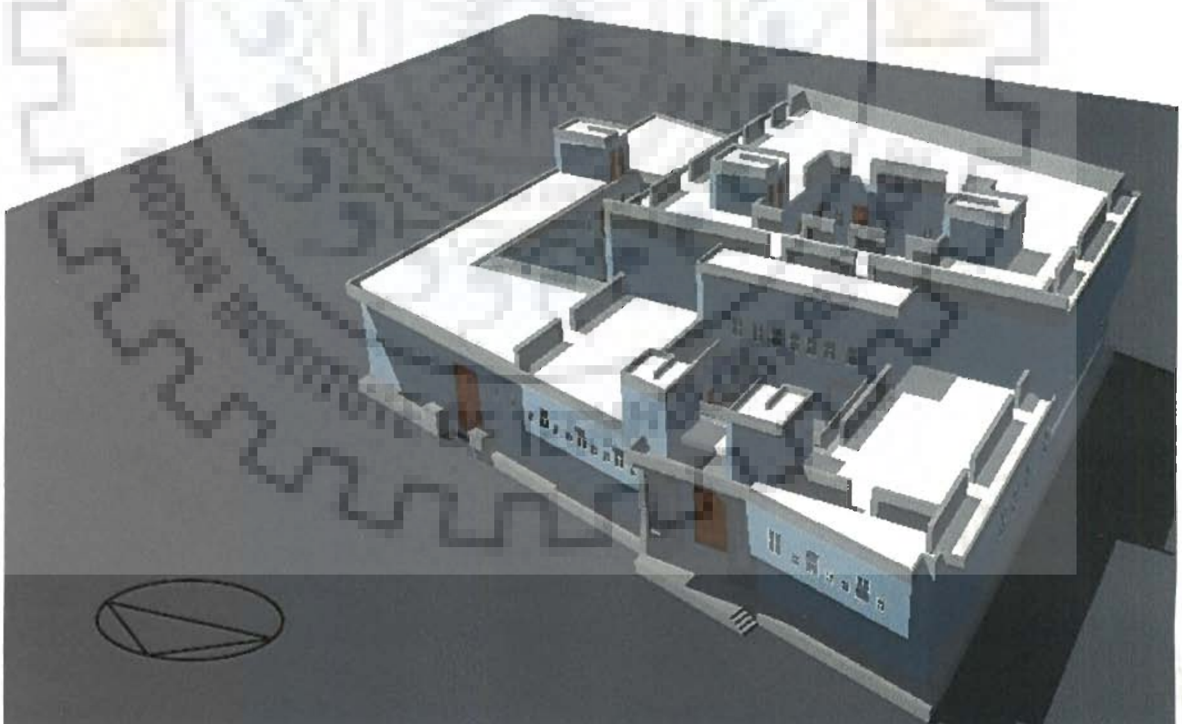


Figure A-8.48 Rendered View of Model

Vishwanath Goenka Haveli, Mandawa

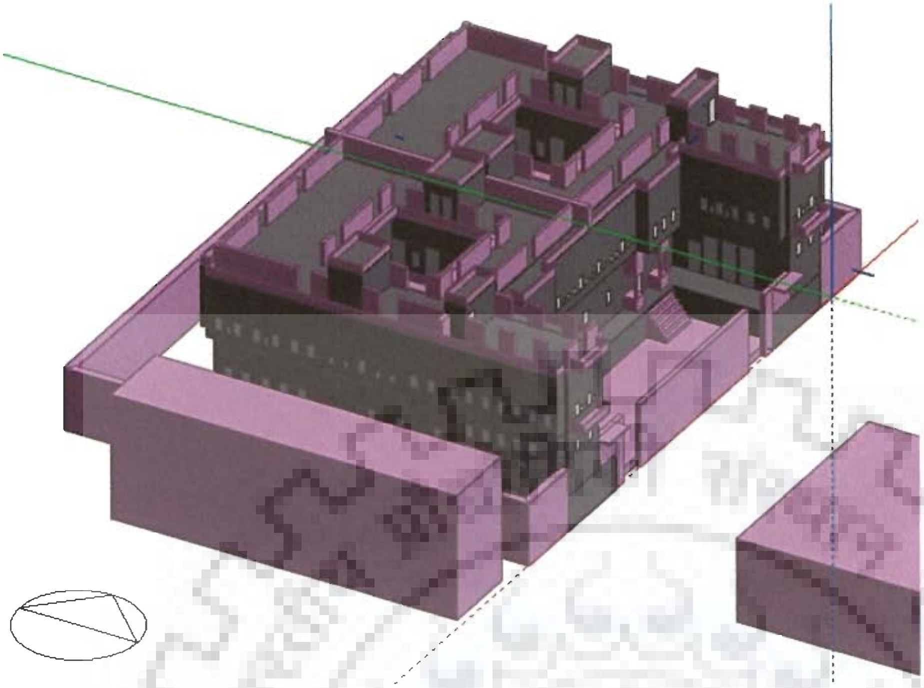


Figure A-8.49 View of Model

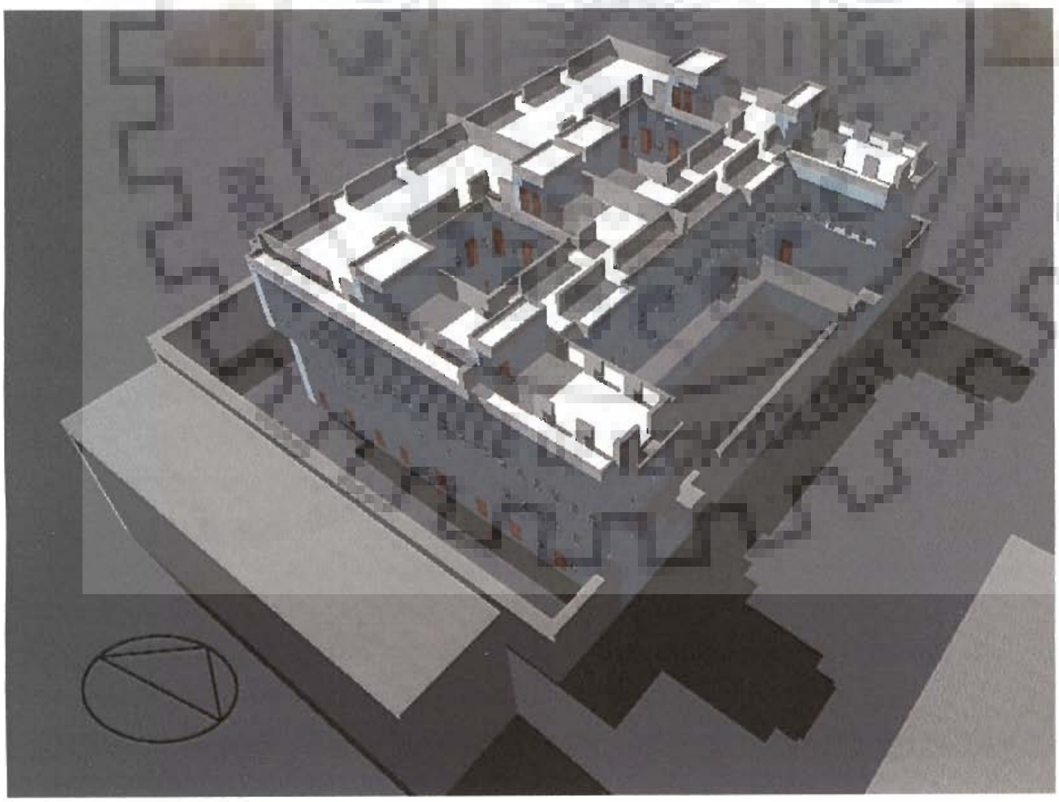


Figure A-8.50 Rendered View of Model

Appendix 9.1

Probable Indoor Air Speed Calculations as per SP-41

Air speed was calculated manually using calculation procedures for estimating probable indoor wind velocity as stated in 'Handbook on Functional Requirements of Buildings (Other than Industrial Buildings), Bureau of Indian Standards'. Since no mechanical ventilation was assumed, air movement was primarily due to natural ventilation. Natural ventilation inside a building is due to two reasons. One is due to thermal forces which arise due to difference in temperatures and the other is due to aeromotive forces which occur due to movement of air through the building and articulated spaces which create stack effect. All parameters which can possibly affect the movement and speed of wind are taken into account and indoor air speed is calculated. Following steps were followed to calculate the final sir speed-

i Number of sides in a room having windows- Rooms which have openings (doors/windows/ventilators) only on one side, receive about only 10 percent air speed of the prevailing wind speed outside. It is possible to increase the speed to 15 percent of outside wind velocity if the window is on windward side. In all the cases under study, all zones have their entry through courtyard and windows are provided on the external wall. Hence most of the rooms have openings on two walls. Few rooms which have opening only from courtyard side practically have no air movement inside. It is because air velocity in courtyard is much less than the outside wind velocity and it is further decreased inside the room. Thus for calculation purposes, wind velocity of all zones having openings only on single wall has been taken as zero. For rooms having windows on two or more side the calculation have been performed as per the following clauses.

ii Windows on opposite sides- When identical windows are provided on opposite walls and one of the windows faces normally incident wind, the average indoor velocity at a plane passing through the sill of the windows 0.9 m above the floor, is determined from Fig. A-9.1.

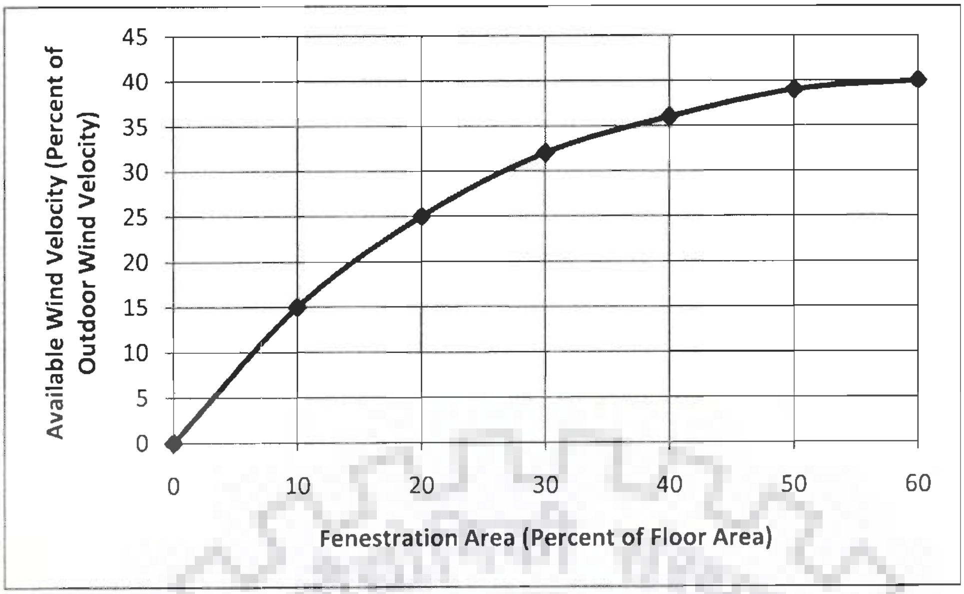


Figure A-9.1 Effect of Area of Openings on Average Indoor Wind Velocity

iii Varying sill height- For a different sill height, the available average velocity (V,) at the sill level may be computed using the equation:

$$V_s = V_{0.9} + 0.072(1 - S)V_0$$

$V_{0.9}$ = Average Indoor wind velocity in Km/h as determined in 5.6.2

V_0 = Outdoor wind velocity in Km/h

S = Relative sill height with reference to normal sill height of 0.9m.

However while calculating change in velocity due to change in sill height for the cases under study; it was observed that most of the cases are raised on a plinth equal to floor height. Thus the sill height is raised much above the normal 0.9m. In such cases, this clause doesn't hold good. Hence for all the cases this change in wind velocity due to change in sill height has been ignored.

iv When the sizes of inlet and outlet are not equal, the area of inlet is first expressed as percent of the total area of fenestration and the corresponding value of performance efficiency (E) is determined from Fig. A-9.2. The average indoor wind velocity *V* is then obtained by multiplying the value of *E* with that of *V*, calculated in *iii*.

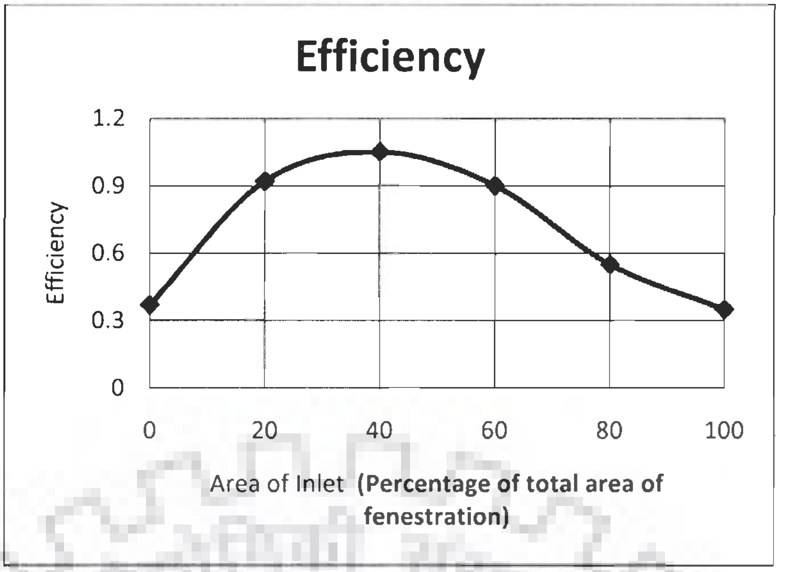


Figure A-9.2 Effect of size of Inlet on the performance Efficiency

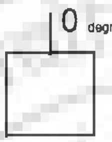
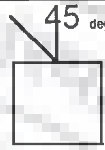
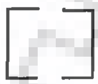
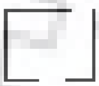
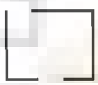
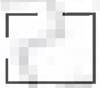
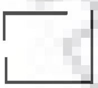
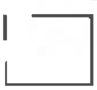
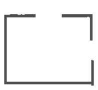
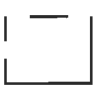
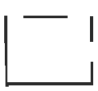
v For obliquely incident wind, the value obtained in *iv* is multiplied by a factor given in table A-8.1.

Table A-9.1 Effect of Orientation on Indoor Air Movement

Relative size of openings	Multiplying factor for 45° incidence
Inlet > Outlet	1
Inlet = Outlet	Varying from 0.8 for fenestration area 25 percent of floor area to 0.85 for fenestration of larger sizes.
Inlet < Outlet	0.7

vi The value of V thus obtained in *v* is considerably influenced by change in the location of openings with respect to outdoor wind. The factors representing the changes in V for some of the typical cases are given in table A-9.2. For a given window location and orientation, the average wind velocity may be obtained by adding the corresponding factor to the value of V obtained in previous steps.

Table A-9.2 Effect of Window Location on Indoor Air Motion

Orientation / Window Location	Change in %	
	0 degree wind 	45 degree wind 
	0	0
	-10	+40
	-10	-15
	-15	0
	-15	0
	0	0
	-10	-10
	0	-60
	-20	-10
	-20	-60

Appendix 9.2

Air Speed in Habitable Zones

Table A-9.2.1 Chiranjilalji Daima Haveli, Fatehpur

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.2	0.2	0.2	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.2
ground									0.2	0.2	0.2	0.2	0.7	0.6	0.6	0.5	0.5	0.1	0.1	0.2
pauli	74	70.0	42.8	27.2	0.4	0.9	1.0	-10.0	0.5	0.6	0.6	0.5	1.2	1.1	1.1	0.9	0.9	0.3	0.3	0.6
rasoghada	48	48.0	16.0	32.0	0.4	1.0	0.7	-15.0	0.0	0.0	0.0	0.0	0.8	0.7	0.7	0.6	0.6	0.0	0.0	0.0
sal 1	47	31.5	9.5	22.0	0.4	1.0	0.7	-10.0	0.0	0.0	0.0	0.0	0.9	0.8	0.8	0.7	0.6	0.0	0.0	0.0
sal	72	40.0	16.0	24.0	0.4	1.0	(1+.7)/2 =.85	-10.0	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
tibari 1									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari 2									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
first									0.2	0.2	0.2	0.2	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.2
sal 1	103								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal2	99	32.0	8.0	24.0	0.3	1.0	0.9	0.0	0.4	0.5	0.5	0.5	0.8	0.7	0.7	0.6	0.6	0.3	0.2	0.5
sal 3	274	75.5	39.5	36.0	0.3	1.0	1.0	0.0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal 4	129	43.0	19.0	24.0	0.3	1.0	0.7	-10.0	0.0	0.0	0.0	0.0	0.7	0.7	0.6	0.6	0.5	0.0	0.0	0.0
sal 5	81								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.2 Harsukhrai Pansari Haveli, Chirawa

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ground	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW2	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW1	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 1	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 3	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 4	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari S	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari W1	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	n	n	n	n	n	n	n	n												
first	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 1	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 2	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 4	n	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.3 Ramgarh Haveli

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
ground										0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
front office										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW	102	32.0	8.0	24.0	0.3	1.0	0.7	-10.0	40.0	0.3	0.4	0.4	0.3	1.2	1.1	1.1	0.9	0.9	0.2	0.2	0.4
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW	85	41.0	9.0	32.0	0.4	1.0	0.7	0.0	0.0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
pauli	88	56.0	32.0	24.0	0.4	0.9	1.0	-10.0	-15.0	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
sal 1 tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 2 tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal SW	135	34.0	10.0	24.0	0.3	1.0	0.7	-10.0	-10.0	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.4 Muslim Haveli, Ratannagar

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
first										0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.1	0.1	0.2
chaughara SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara SW	275	51.0	27.0	24.0	0.3	0.9	1.0	-10	-10.0	0.3	0.3	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
kit NE	76	29.0	5.0	24.0	0.4	0.9	0.7	-10	-10.0	0.3	0.4	0.4	0.4	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
kit NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW	170	48.0	16.0	32.0	0.3	1.0	0.7	0.0	0.0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
pauli	115	64.0	36.0	28.0	0.4	0.9	1.0	-10	40.0	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal 1 tibari facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing E	147	50.0	26.0	24.0	0.4	1.0	1.0	-10	-10.0	0.4	0.5	0.6	0.5	1.1	1.0	0.9	0.8	0.8	0.3	0.3	0.5
sal tibari N1	166	50.0	26.0	24.0	0.3	1.0	1.0	-10	-10.0	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
shops and cattle shed										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
second										0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
chaughara SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara SW	275	51.0	27.0	24.0	0.3	1.0	1.0	-10	-10.0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4
sal 1 facing E	537	102.0	62.0	40.0	0.3	0.9	1.0	40.0	40.0	0.4	0.5	0.6	0.5	1.1	1.0	0.9	0.8	0.8	0.3	0.3	0.5
sal 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 1 tibari facing N	227	59.0	35.0	24.0	0.3	0.9	1.0	-10.0	-10.0	0.3	0.4	0.4	0.4	0.8	0.8	0.7	0.6	0.6	0.2	0.2	0.4
tibari N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.5 Sahumal Khetan Haveli, Mehansar

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.3
ground										0.2	0.3	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.3
pauli	81	60	36	24	0.4	0.9	1	-10	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
kit	127	32	8	24	0.3	1	0.7	-10	-10	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
sal 1 tibari facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 2	81	32	8	24	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal 3										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari E facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N facing	121	114	24	90	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
first										0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.3
sal 1	268	56	40	16	0.25	0.75	1	-10	-10	0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.3
outdoor wind velocity										1.4	1.7	1.8	1.5	3.4	3.1	3.0	2.6	2.4	0.9	0.8	1.7

Table A-9.2.6 Sidhkaranji Morarka Haveli, Mukundgarh

	area of room	total area of	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.1	0.1	0.2	0.1	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.1
ground										0.1	0.1	0.2	0.1	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.1
chaughara NE	231	44	20	24	0.25	1	0.7	-10	-60	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3
chaughara NW	209	84	60	24	0.35	0.75	1	40	40	0.5	0.6	0.7	0.6	1.2	1.1	1.1	1.0	0.9	0.3	0.3	0.6
chaughara SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NE	115	32	8	24	0.27	1	0.7	-10	-10	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4
kit NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	81	60	36	24	0.4	0.9	1	-10	40	0.5	0.6	0.6	0.5	1.7	1.6	1.5	1.3	1.2	0.3	0.3	0.6
sal tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing S	81	32	8	24	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
servant										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.7 Babulalji Gudha, Mukundgarh

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.1
ground									0.2	0.2	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.1	0.1	0.2
baithak facing S	180.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW	114.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE	152.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW	114.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NW chaughara	201.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	79.0	60.0	36.0	24.0	0.4	0.9	1.0	40.0	0.7	0.9	0.9	0.8	1.7	1.6	1.5	1.3	1.2	0.5	0.4	0.9
sal 1 baithak facing N	47.8	32.0	8.0	24.0	0.4	1.0	0.7	-10.0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal tibari 1 facing E	83.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing N	86.5	48.0	24.0	24.0	0.4	1.0	0.8	-10.0	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal tibari facing S	86.5	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SW chaughara	159.0	48.0	24.0	24.0	0.3	0.8	1.0	15.0	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
tibari 1 facing E	83.0								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N	96.8								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S	96.8								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari of baithak facing N	88.0	120.0	72.0	48.0	0.4	0.9	1.0	-10.0	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
first									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
zone 8	53.7	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
zone 1	55.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal behind stairs	61.0	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
zone 5	83.7	n	n	n	n	n	n	n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.8 Bhagirathmal Kedarmal Goenka Havei, Dundlod

	area of room	of fenestrati	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.1	0.2	0.2	0.1	0.4	0.2	0.4	0.3	0.2	0.1	0.1	0.2
ground									0.1	0.1	0.1	0.1	0.3	0.2	0.3	0.3	0.2	0.1	0.0	0.1
baithak N									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
baithak S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE	114	58	40N/18S	18S/40N	0.4	0.8	0.7	0	0.3	0.4	0.4	0.3	0.8	0.0	0.7	0.6	0.0	0.2	0.0	0.4
lower ground servant sal									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE chaughara	177	40	16	24	0.25	1	0.7	-10	0.2	0.3	0.3	0.2	0.5	0.0	0.5	0.4	0.4	0.1	0.1	0.3
pauli	122	61	36	25	0.4	1	1	-10	0.0	0.0	0.0	0.0	0.7	0.7	0.7	0.6	0.5	0.0	0.0	0.0
sal 1 tibari facing W	102	40	16	24	0.35	1	0.7	-10	0.3	0.4	0.4	0.3	0.7	0.7	0.7	0.6	0.5	0.2	0.2	0.4
sal tibari facing S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE chaughara	177	40	16	24	0.25	1	0.7	-10	0.2	0.3	0.3	0.2	0.5	0.5	0.5	0.4	0.4	0.1	0.1	0.3
tibari facing N	113	126	18	108	0.4	0.8	0.7	0	0.3	0.4	0.4	0.3	0.8	0.0	0.7	0.6	0.0	0.2	0.0	0.4
tibari facing S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
first									0.2	0.2	0.2	0.2	0.5	0.2	0.5	0.4	0.2	0.1	0.1	0.2
sal 1 facing W	270	50	10	40	0.25	0.95	0.7	0	0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.3
sal above taj	345	80	40	40	0.25	1	0.8	0	0.0	0.0	0.0	0.0	0.7	0.6	0.6	0.5	0.5	0.0	0.0	0.0
sal facing N	167	41	24	17	0.25	1	1	0	0.4	0.4	0.5	0.4	0.9	0.0	0.8	0.7	0.0	0.2	0.2	0.4
sal facing S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal SW	177	36	12	24	0.25	1	0.7	-15	0.2	0.3	0.3	0.2	0.5	0.0	0.4	0.4	0.0	0.1	0.1	0.3

Table A-9.2.9 Bissau Haveli

	area of room	of fenestrati	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.2	0.3	0.3	0.2	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.3
ground									0.2	0.3	0.3	0.2	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.3
baithak N	238	132	24	108	0.4	0.9	0.7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
baithak S	238	132	24	108	0.4	0.9	0.7	0	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
basement storage									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara NE	344	72	48	24	0.25	0.8	1	40	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
chaughara NW	279	48	24	24	0.2	1	0.8	-10	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
chaughara SE	344	72	48	24	0.25	0.8	0.8	40	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
chaughara SW	279	48	24	24	0.2	1	0.8	-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE	162	36	12	24	0.25	1	0.7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	103	60	36	24	0.4	0.9	1	-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal NE	171	36	12	24	0.25	1	0.7	-10	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
sal tibari facing N	146	48	24	24	0.3	1	0.8	-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing S	146	48	24	24	0.3	1	0.8	-10	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
sal tibari E1	166	48	24	24	0.3	1	0.8	-10	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
tibari E1									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.10 Damodar Prasad Morarka Haveli, Mukundgarh

	area of room	of fenestrati	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.1	0.2	0.2	0.2	0.4	0.3	0.3	0.3	0.2	0.1	0.1	0.2
ground									0.1	0.2	0.2	0.2	0.4	0.3	0.3	0.3	0.2	0.1	0.1	0.2
baithak N	108	124	16	108	0.4	0.75	0.7	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
baithak S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
corner kit NE	106	32	8	24	0.3	0.9	0.7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
corner kit SE	106	36	12	24	0.3	1	0.7	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
kit NE									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE	64	36	4	32	0.4	0.75	0.7	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
pauli	99	64	38	26	0.4	0.9	1	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal tibari E1									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari N	66	42	2	40	0.4	0.4	0.7	-15	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.1	0.1	0.2
sal tibari S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari E1									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N	97	112	4	108	0.4	0.4	0.7	0	0.2	0.2	0.2	0.2	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.2
tibari S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.11 Haveli Used as Gymnasium, Dundlod

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.2	0.3	0.3	0.2	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.3
ground									0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
baithak N									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
baithak S	251	132	24	108	0.4	0.9	0.7	0	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
chaughara NE	186	36	12	24	0.25	1	0.7	-15	0.3	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.2	0.3
chaughara NW	186	36	12	24	0.25	1	0.7	0	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4
chaughara SE									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara SW	283	58	32	26	0.25	0.9	1	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
front office									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW	126	38	12	26	0.3	1	0.7	0	0.4	0.5	0.5	0.5	0.9	0.8	0.8	0.7	0.6	0.3	0.2	0.5
kit SE									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	109	76	40	36	0.4	0.9	1	0	0.5	0.6	0.6	0.5	1.2	1.1	1.1	0.9	0.9	0.3	0.3	0.6
sal tibari N2									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari S	84	36	12	24	0.4	1	0.7	0	0.6	0.7	0.7	0.6	1.2	1.1	1.0	0.9	0.8	0.4	0.3	0.7
servant quarters									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari E									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N2									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
first									0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.3
NW chaughara	410	84	60	24	0.25	0.75	1	40	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal 2 facing N									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 2 facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal above baithak facing N	769	98	26	72	0.15	1	0.7	-15	0.2	0.2	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.1	0.1	0.2

sal above baithak facing S	769	158	86	72	0.25	0.9	1	40	0.4	0.5	0.6	0.5	1.1	1.0	0.9	0.8	0.8	0.3	0.3	0.5
sal above taj	400	36	12	24	0.15	1	0.7	0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
sal facing S	156	38	12	26	0.25	1	0.7	0	0.4	0.4	0.5	0.4	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
SW chaughara	343	56	32	24	0.2	0.9	1	-15	0.2	0.3	0.3	0.2	0.5	0.5	0.5	0.4	0.4	0.1	0.1	0.3
tibari with a court	180	92	32	60	0.4	1	0.7	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6

Table A-9.2.12 Seth Arjundas Goenka Haveli, Dundlod

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.3	0.4	0.4	0.3	0.7	0.7	0.7	0.6	0.5	0.2	0.2	0.4
ground									0.3	0.3	0.3	0.3	0.6	0.5	0.5	0.5	0.4	0.2	0.1	0.3
baithak N	231	132	24	108	0.4	0.9	0.7	0	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
baithak S	231	132	24	108	0.4	0.9	0.7	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
kit SE	125	48	16	32	0.35	1	0.7	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
kit SW									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE chaughara	207	40	16	24	0.25	1	0.7	40	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
pauli	87	64	40	24	0.4	0.9	1	40	0.7	0.9	0.9	0.8	1.7	1.6	1.5	1.3	1.2	0.5	0.4	0.9
sal tibari 1 facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing N	154	48	24	24	0.3	0.9	0.8	-10	0.3	0.4	0.4	0.3	0.7	0.7	0.7	0.6	0.5	0.2	0.2	0.4
sal tibari facing S	154	48	24	24	0.3	0.9	0.8	-10	0.3	0.4	0.4	0.4	0.7	0.7	0.7	0.6	0.5	0.2	0.2	0.4
SE chaughara	207	40	16	24	0.25	1	0.7	40	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
shops									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari 1 facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
first									0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5

NE chaughara	265	40	16	24	0.2	1	0.7	40	0.4	0.5	0.5	0.4	0.8	0.7	0.7	0.6	0.6	0.3	0.2	0.5
sal 1 facing N	160	42	12	30	0.25	1	0.7	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
sal 1 facing S	160	42	12	30	0.25	1	0.7	0	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
sal 1 tibari facing W	138	48	24	24	0.35	1	0.8	0	0.4	0.5	0.6	0.5	1.1	1.0	0.9	0.8	0.8	0.3	0.3	0.5
sal above taj	272	84	36	48	0.3	1	0.7	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal SW	77	48	24	24	0.4	1	0.8	40	0.7	0.9	0.9	0.8	1.7	1.6	1.5	1.3	1.2	0.5	0.4	0.9
tibari facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.13 Harkarandas Mangilalji Haveli, Bagad

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.5	0.5	0.2	0.2	0.4
ground									0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
baithak facing N	280	141	33	108	0.4	1	0.7	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
baithak facing S	280	141	33	108	0.4	1	0.7	40	0.8	1.0	1.0	0.8	1.6	1.5	1.4	1.2	1.1	0.5	0.4	1.0
basement									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara NE	194	48	24	24	0.25	1	0.8	0	0.4	0.4	0.5	0.4	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4
chaughara NW	194	48	24	24	0.25	1	0.8	-10	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4
chaughara SW	194	48	24	24	0.25	1	0.8	-10	0.3	0.3	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
kit SW									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	140	62	36	26	0.35	0.9	1	40	0.6	0.7	0.8	0.7	1.5	1.4	1.3	1.1	1.1	0.4	0.4	0.7
sal tibari 1 facing W	101	36	12	24	0.35	1	0.7	40	0.6	0.7	0.7	0.6	1.4	1.3	1.2	1.1	1.0	0.4	0.3	0.7
sal tibari facing N	100	36	12	24	0.35	1	0.7	-10	0.3	0.4	0.4	0.4	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
sal tibari facing S	100	36	12	24	0.35	1	0.7	40	0.7	0.8	0.9	0.7	1.4	1.3	1.2	1.1	1.0	0.4	0.4	0.8
SE chaughara	194	48	24	24	0.25	1	0.8	0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4

SE kit	145	42	16	26	0.3	1	0.7	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
tibari 1 facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.14 Ishwardas Modi Haveli, Jhunjhunu

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.2	0.3	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.3
ground									0.2	0.3	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.3
baithak extension	532	152	52+48	52	0.3	0.8	1	40	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.9	0.8	0.3	0.3	0.6
baithak facing N	410	237	165	72	0.4	0.8	1	0	0.4	0.5	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.5
basement									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara NE	267	48	24	24	0.25	1	1	-10	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4
chaughara NW	281	48	24	24	0.25	1	1	-10	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4
chaughara SE	267	48	24	24	0.25	1	0.8	-15	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
chaughara SW	281	48	24	24	0.25	1	0.8	-20	0.3	0.3	0.3	0.3	0.6	0.6	0.5	0.5	0.4	0.2	0.1	0.3
kit NE	176	54	24	30	0.3	1	0.7	-10	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
kit NW									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE	176	54	24	30	0.3	1	0.7	-20	0.3	0.3	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
kit SW									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	217	58	30	24	0.3	1	1	40	0.6	0.7	0.8	0.6	1.4	1.3	1.3	1.1	1.0	0.4	0.3	0.7
sal facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal NE in court	275	48	24	24	0.25	1	0.8	-15	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
sal SE in court	275	48	24	24	0.25	1	0.8	-20	0.3	0.3	0.3	0.3	0.6	0.6	0.5	0.5	0.4	0.2	0.1	0.3
sal tibari 1 facing W	169	48	24	24	0.3	1	0.8	-10	0.3	0.4	0.4	0.4	0.8	0.8	0.7	0.6	0.6	0.2	0.2	0.4
sal tibari facing N	161	48	24	24	0.3	1	0.8	-20	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
sal tibari facing S	161	48	24	24	0.3	1	0.8	-10	0.3	0.4	0.4	0.4	0.8	0.8	0.7	0.6	0.6	0.2	0.2	0.4
tibari 1 facing W									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.15 Jaigopalji Goenka Haveli, Mandawa

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.4	0.4	0.5	0.4	1.0	0.9	0.8	0.7	0.7	0.2	0.2	0.4
ground										0.3	0.4	0.4	0.3	0.8	0.8	0.7	0.6	0.6	0.2	0.2	0.4
baithak tibari	69	91	16	75	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
kit NW	76	48	16	32	0.4	1	0.7	-10	40	0.4	0.5	0.6	0.5	1.6	1.5	1.4	1.2	1.1	0.3	0.2	0.5
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW	76	48	16	32	0.4	1	0.7	-10	-10	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
pauli	68	56	32	24	0.4	0.9	0.8	40	40	0.6	0.8	0.8	0.7	1.5	1.4	1.4	1.2	1.1	0.4	0.4	0.8
sal 1 tibari E2	80	32	8	24	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal 2 tibari E1	72	32	8	24	0.35	1	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
sal 2 tibari E2	72	32	8	24	0.35	1	0.7	-10	40	0.4	0.5	0.5	0.4	1.4	1.3	1.2	1.1	1.0	0.2	0.2	0.5
tibari E2										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N	74	92	8	84	0.4	0.6	0.7	0	0	0.3	0.3	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
first										0.4	0.5	0.5	0.4	1.1	1.0	0.9	0.8	0.8	0.3	0.2	0.5
baithak sal	151	28	12	16	0.25	1	0.7	0	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
sal 2 facing E	235	54	14	40	0.25	1	0.7	0	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
sal above pauli	139	68	28	40	0.4	1	0.7	0	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
sal facing N	128	44	12	32	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal facing S	76	48	16	32	0.4	1	0.7	-10	40	0.4	0.5	0.6	0.5	1.6	1.5	1.4	1.2	1.1	0.3	0.2	0.5
sal NE	143	54	30	24	0.35	0.9	0.8	40	40	0.6	0.7	0.7	0.6	1.3	1.2	1.2	1.0	1.0	0.4	0.3	0.7
tibari facing N	125	48	16	32	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
tibari facing S	125	48	16	32	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5

Table A-9.2.16 Kariwala Haveli, Nawalgarh

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.3
ground										0.2	0.2	0.2	0.2	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.2
baithak 1	326	112	28	84	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
baithak 3	186	108	24	84	0.4	1	0.7	0	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
chaughara 1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara 2										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
office										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	80	63	36	27	0.4	0.6	1	-10	-15	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4
kit 1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit 3	100	48	16	32	0.4	1	0.7	0	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
kit 4	100	48	16	32	0.4	1	0.7	0	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
sal tibari front	116	40	16	24	0.35	1	0.7	-10	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.2	0.2	0.5
sal tibari side 1	73	29	5	24	0.35	0.9	0.7	0	0	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
sal tibari side 2	73	29	5	24	0.35	0.9	0.7	0	0	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
storage for fodder										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari front 1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari front 2										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari side 1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari side 2										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.16 continued

first										0.3	0.3	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
chaughara 1	374	90	66	24	0.25	0.6	1	40	40	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.5	0.5	0.2	0.2	0.4
chaughara 2	340	73	49	24	0.25	0.7	1	40	40	0.3	0.4	0.4	0.4	0.8	0.8	0.7	0.6	0.6	0.2	0.2	0.4
sal 1	131	44	16	28	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal 2	113	34	10	24	0.3	1	0.7	0	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal 4	243	56	32	24	0.25	0.9	1	0	0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4
sal 5										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 6	113	34	10	24	0.3	1	0.7	0	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal 7	131	44	16	28	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal 8	228	34	10	24	0.3	1	0.7	0	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal 9	319	49	25	24	0.4	1	1	0	0	0.6	0.7	0.7	0.6	1.4	1.2	1.2	1.0	1.0	0.4	0.3	0.7
tibari 1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari 2										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.17 Pilani Haveli

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.2	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.2
ground										0.2	0.2	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.2
baithak	255	96	72	24	0.35	0.65	1	0	0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4
kit NW1	122	32	8	24	0.25	1	0.7	-10	40	0.3	0.3	0.3	0.3	1.0	0.9	0.9	0.8	0.7	0.2	0.2	0.3
kit SW1	122	32	8	24	0.25	1	0.7	-10	-15	0.3	0.3	0.3	0.3	0.6	0.6	0.5	0.5	0.4	0.2	0.2	0.3
pauli	112	60	36	24	0.4	0.9	1	-10	-15	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.6
sal tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing S	65	28	8	20	0.35	1	0.7	-10	-15	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
sal tibari N	65	28	8	20	0.35	1	0.7	-10	40	0.4	0.5	0.5	0.4	1.4	1.3	1.2	1.1	1.0	0.2	0.2	0.5
tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.18 Shekhsaria Haveli, Nawalgarh

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.1	0.2	0.2	0.1	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.2
ground										0.1	0.2	0.2	0.1	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.2
baithak N	260	132	24	108	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
chaughara NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara SW	307	32	8	24	0.15	1	0.7	-15	-15	0.1	0.2	0.2	0.1	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.2
kamra NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kamra SE	173	56	24	32	0.3	1	0.7	0	0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
kit NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW	148	48	16	32	0.3	1	0.7	0	0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
pauli	96	60	36	24	0.4	0.9	1	-10	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal tibari E1	94	56	16	40	0.4	1	0.7	0	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
sal tibari S facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari E1 facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari S facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
storage-lower ground										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.18 continued

first										0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.2
chaughara NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaugahar SW	531	63	39	24	0.15	0.9	1	40	40	0.3	0.3	0.3	0.3	0.6	0.6	0.6	0.5	0.5	0.2	0.2	0.3
kamra NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kamra SE	206	42	10	32	0.25	1	0.7	0	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
sal 1 tibari facing N	142	34	10	24	0.25	1	0.7	-10	-10	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
sal E1 facing	355	66	26	40	0.22	1	0.7	0	0	0.3	0.3	0.3	0.3	0.6	0.6	0.6	0.5	0.4	0.2	0.1	0.3
sal NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal over taj	418	102	46	56	0.27	1	0.7	-10	-10	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4
sal SW	176	42	10	32	0.27	1	0.7	0	0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
sal tibari S facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari S facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.19 Virdichand gaurilalji Haveli, Sikar

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.2	0.2	0.2	0.5	0.5	0.4	0.4	0.4	0.1	0.1	0.2
ground										0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.4	0.4	0.1	0.1	0.2
baithak facing E	223	128	20	108	0.4	0.9	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.9	0.8	0.7	0.7	0.2	0.2	0.5
baithak facing W	223	118	10	108	0.4	0.6	0.7	-15	-15	0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.5	0.4	0.2	0.1	0.3
basement										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NE	149	40	16	24	0.27	1	0.7	-60	-60	0.1	0.2	0.2	0.1	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.2
kit NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	83	60	36	24	0.4	0.9	1	-10	40	0.5	0.6	0.6	0.5	1.7	1.6	1.5	1.3	1.2	0.3	0.3	0.6
sal 1 tibari E	87	48	24	24	0.4	1	0.8	-15	-15	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal 1 tibari W	90	40	16	24	0.37	1	0.7	-10	40	0.4	0.5	0.5	0.4	1.5	1.4	1.3	1.1	1.1	0.3	0.2	0.5
sal SE	125	32	8	24	0.27	1	0.7	-10	40	0.3	0.4	0.4	0.3	1.1	1.0	1.0	0.8	0.8	0.2	0.2	0.4
sal tibari N1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari E1 facing										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari N1										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
first										0.1	0.2	0.2	0.2	0.5	0.4	0.4	0.3	0.3	0.1	0.1	0.2
kamra SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 1 tibari N2										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 2 tibari N2	125	32	8	24	0.27	1	0.7	-10	-10	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4
sal E	151	32	8	24	0.25	1	0.7	-15	-15	0.3	0.3	0.3	0.3	0.6	0.6	0.5	0.5	0.4	0.2	0.1	0.3
sal W	115	40	16	24	0.35	1	0.7	-15	40	0.4	0.4	0.5	0.4	1.4	1.3	1.2	1.1	1.0	0.2	0.2	0.4
tibari N2										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.20 Shridhar Gangadhar Morarka Haveli, Mukundgarh

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.3	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.3
ground										0.2	0.3	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.3
baithak facing N	251	132	24	108	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
baithak facing S	251	132	24	108	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
chaughara NE	184	40	16	24	0.25	1	0.7	-10	-10	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
chaughara NW	182	48	24	24	0.27	1	0.7	-10	40	0.3	0.4	0.4	0.3	1.1	1.0	1.0	0.8	0.8	0.2	0.2	0.4
chaughara SE	184	40	16	24	0.25	1	0.7	-10	-10	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
chaughara SW	182	48	24	24	0.27	1	0.8	-10	-10	0.3	0.4	0.4	0.3	0.7	0.7	0.7	0.6	0.5	0.2	0.2	0.4
kit NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
mezzanine NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
mezzanine SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
office	183	40	16	24	0.25	1	0.7	-15	-15	0.3	0.3	0.3	0.3	0.6	0.6	0.5	0.5	0.4	0.2	0.1	0.3
pauli	77	60	36	24	0.4	0.9	1	-10	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal tibari 1 facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari 1 facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N	153	92	20	72	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
tibari facing S	153	92	20	72	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5

Table A-9.2.21 Nawalgarh Unidentified Haveli

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
ground										0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
baithak facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
baithak facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	86	60	36	24	0.4	0.9	1	0	0	0.5	0.6	0.6	0.5	1.2	1.1	1.1	0.9	0.9	0.3	0.3	0.6
sal tibari facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SW chaughara										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.22 Surajgarh Haveli

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
ground										0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
baithak facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
baithak facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara NE	222	41	17	24	0.25	1	0.7	-15	-15	0.3	0.3	0.3	0.3	0.6	0.6	0.5	0.5	0.4	0.2	0.1	0.3
chaugahar SE	222	41	17	24	0.25	1	0.7	-15	-15	0.3	0.3	0.3	0.3	0.6	0.6	0.5	0.5	0.4	0.2	0.1	0.3
kit NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	115	60	36	24	0.4	0.9	1	0	-60	0.5	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.6
sal 1 tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 1 tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari 1 facing W	115	41	17	24	0.35	1	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
tibari 1 facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.22 continued

first										0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
sal 1 facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 1 facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal 1 facing W	400	58	18	40	0.2	1	0.7	0	0	0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.3
sal above pauli	444	86	46	40	0.25	1	1	-10	-10	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.4
sal NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.23 Gulabrai Ladia Haveli, Mandawa

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building									0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.30
ground									0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.22
E facing tibari SW									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
lower ground									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
N facing baithak	239	132	24	108	0.4	0.9	0.7	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.52
N facing tibari									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
NE kit									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
NE office 1									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
nohra baithak N									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
nohra baithak S									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
NW chaughara	207	40	16	24	0.25	1	0.7	40	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.60
pauli	84	60	36	24	0.4	0.9	1	40	0.7	0.9	0.9	0.8	1.7	1.6	1.5	1.3	1.2	0.5	0.4	0.86
S facing baithak									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
S f acing tibari									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
sal 1 N facing tibari	105	40	16	24	0.35	1	0.7	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.51
sal 1 S facing tibari	105	40	16	24	0.35	1	0.7	0	0.5	0.6	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.3	0.60
sal to E facing tibari NW	107	40	16	24	0.35	1	0.7	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.51
SE kit									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
SE office 2									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
SW chaughara	207	40	16	24	0.25	1	0.7	-10	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.33
SW kit	138	46	16	30	0.35	1	0.7	0	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.33

Table A-9.2.23 continued

first									0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.37
E facing tibari SW									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
NW chaughara	254	48	24	24	0.25	1	0.8	40	0.5	0.6	0.6	0.5	1.1	1.0	0.9	0.8	0.8	0.3	0.3	0.60
S facing sal 2	261	60	24	36	0.25	1	0.7	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.36
sal 2 E facing tibari SW	157	42	18	24	0.25	1	0.7	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.36
sal 2 N facing	261	48	24	24	0.25	1	0.8	0	0.4	0.4	0.5	0.4	0.8	0.7	0.7	0.6	0.5	0.2	0.2	0.43
sal above N facing baithak	749	110	62	48	0.2	1	1	40	0.4	0.5	0.5	0.4	1.0	0.9	0.8	0.7	0.7	0.3	0.2	0.48
sal above pauli	169	52	28	24	0.3	1	1	0	0.4	0.5	0.5	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.51
sal above S facing baithak	321	60	12	48	0.25	0.9	0.7	-10	0.2	0.3	0.3	0.3	0.6	0.5	0.5	0.4	0.4	0.2	0.1	0.29
SW chaughara	254	48	24	24	0.25	1	0.8	-10	0.3	0.3	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.34

Table A-9.2.24 Morarka Haveli, Nawalgarh

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.2	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 max to	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.3	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.3
ground										0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
baithak facing E	304	144	36	108	0.4	1	0.7	0	0	0.5	0.6	0.6	0.5	1.2	1.1	1.0	0.9	0.8	0.3	0.3	0.6
baithak facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
chaughara NE	218	40	16	24	0.25	1	0.7	-10	-10	0.3	0.3	0.3	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
chaughara NW	218	40	16	24	0.25	1	0.7	-10	40	0.3	0.3	0.3	0.3	1.0	0.9	0.9	0.8	0.7	0.2	0.2	0.3
chaughara SE	365	40	16	24	0.15	1	0.7	-10	-10	0.2	0.2	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.1	0.1	0.2
chaughara SW	227	40	16	24	0.2	1	0.7	-10	-10	0.2	0.3	0.3	0.2	0.5	0.5	0.5	0.4	0.4	0.1	0.1	0.3
kit NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	91	72	40	32	0.4	0.9	1	-10	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal tibari 1 facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing E	91	40	16	24	0.35	1	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
sal tibari facing W	91	40	16	24	0.35	1	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.5
tibari 1 facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing W										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-9.2.24 continued

first										0.3	0.3	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.3
chaughara NE	283	72	48	24	0.25	0.75	1	40	40	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
chaughara NW	283	72	48	24	0.25	0.75	1	40	40	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
chaughara SE	461	58	34	24	0.17	0.9	1	-10	-10	0.2	0.2	0.2	0.2	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.2
chaughara SW	295	48	24	24	0.2	1	0.8	-10	-10	0.2	0.3	0.3	0.2	0.6	0.5	0.5	0.4	0.4	0.1	0.1	0.3
sal 1 facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal above pauli	239	80	40	40	0.35	1	0.8	0	0	0.4	0.5	0.6	0.5	1.1	1.0	0.9	0.8	0.8	0.3	0.3	0.5
sal facing E	270	64	24	40	0.25	1	0.7	0	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
sal facing W	270	64	24	40	0.25	1	0.7	0	0	0.3	0.4	0.4	0.3	0.7	0.7	0.6	0.6	0.5	0.2	0.2	0.4
sal NE	134	40	8	32	0.3	0.9	0.7	-10	-10	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4
sal NW	134	40	8	32	0.3	0.9	0.7	-10	-10	0.3	0.4	0.4	0.3	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.4

Table A-9.2.25 Vishwanath Goenka Haveli, Mandawa

	area of room	total area of fenestration	area of inlet	area of outlet	factor A 5.2.1	factor A 5.2.3	factor A 5.2.4	factor A 5.2.5	factor A 5.2.5 may to sept	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
building										0.2	0.2	0.2	0.3	0.5	0.4	0.4	0.3	0.3	0.1	0.1	0.2
ground										0.3	0.3	0.3	0.5	0.6	0.6	0.5	0.5	0.3	0.1	0.2	0.3
basement										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
first										0.3	0.3	0.4	0.3	0.7	0.7	0.7	0.6	0.5	0.2	0.2	0.3
North block																					
baithak	120	121	13	108	0.4	0.75	0.7	-10	-10	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
kit NE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit NW	78	36	6.5	29.5	0.4	0.9	0.7	-10	40	0.4	0.5	0.5	0.4	1.5	1.3	1.3	1.1	1.0	0.2	0.2	0.5
kit SE	62	28	4	24	0.37	0.9	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.8	0.7	0.7	0.3	0.2	0.5
kit SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pauli	86	60	36	24	0.4	0.9	1	-10	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal 1 tibari 1 facing E	97	37	13	24	0.35	1	0.7	-10	40	0.4	0.5	0.5	0.4	1.4	1.3	1.2	1.1	1.0	0.2	0.2	0.5
sal 2 tibari 2 facing E	81	37	13	24	0.37	1	0.7	-10	40	0.4	0.5	0.5	0.4	1.5	1.4	1.3	1.1	1.1	0.3	0.2	0.5
sal tibari facing N	45	30.5	6.5	24	0.4	0.9	0.7	0	0	0.4	0.5	0.6	0.5	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal tibari facing S	45	30.5	6.5	24	0.4	0.9	0.7	-10	-60	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.5
tibari 1 facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari 2 facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing S	118	85	13	72	0.4	0.9	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.9	0.8	0.7	0.7	0.2	0.2	0.5

Table A-9.2.25 continued

sal above baithak	487	100	70	30	0.25	0.75	1	40	40	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal over kit NE	89	37	13	24	0.35	1	0.7	-60	-60	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
sal over kit NW	109	45	13	32	0.35	1	0.7	0	40	0.4	0.5	0.5	0.4	1.4	1.3	1.2	1.1	1.0	0.3	0.2	0.5
sal over kit SE	109	58	34	24	0.4	0.9	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.9	0.8	0.7	0.7	0.2	0.2	0.5
sal over kit SW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal over pauli	229	74	24	50	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal over tibari 1 facing E	282	72	35	37	0.27	1	0.7	0	0	0.3	0.4	0.4	0.3	0.8	0.7	0.7	0.6	0.6	0.2	0.2	0.4
sal over tibari facing N										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal over tibari facing S	165	57	20	37	0.33	1	0.7	0	40	0.4	0.5	0.5	0.4	1.3	1.2	1.2	1.0	0.9	0.3	0.2	0.5
south block																					
baithak	120	121	13	108	0.4	0.75	0.7	0	0	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
kit NE	62	28	4	24	0.37	0.9	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.8	0.7	0.7	0.3	0.2	0.5
kit NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SE										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kit SW	78	36	6.5	29.5	0.4	0.9	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.9	0.8	0.7	0.7	0.2	0.2	0.5
pauli	86	60	36	24	0.4	0.9	1	-10	-10	0.5	0.6	0.6	0.5	1.1	1.0	1.0	0.8	0.8	0.3	0.3	0.6
sal 1 tibari 1 facing E	97	37	13	24	0.35	1	0.7	-10	40	0.4	0.5	0.5	0.4	1.4	1.3	1.2	1.1	1.0	0.2	0.2	0.5
sal 1 tibari 2 facing E	97	37	13	24	0.35	1	0.7	-10	40	0.4	0.5	0.5	0.4	1.4	1.3	1.2	1.1	1.0	0.2	0.2	0.5
sal 2 tibari 1 facing E	81	37	13	24	0.37	1	0.7	0	0	0.4	0.5	0.6	0.5	1.1	1.0	0.9	0.8	0.8	0.3	0.3	0.5

Table A-9.2.25 continued

sal 2 tibari 2 facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal tibari facing N	45	30.5	6.5	24	0.4	0.9	0.7	-60	-60	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
sal tibari facing S	45	30.5	6.5	24	0.4	0.9	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.9	0.8	0.7	0.7	0.2	0.2	0.5
tibari 1 facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari 2 facing E										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tibari facing N	118	85	13	72	0.4	0.9	0.7	-10	-10	0.4	0.5	0.5	0.4	0.9	0.9	0.8	0.7	0.7	0.2	0.2	0.5
tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal over baithak	487	100	70	30	0.25	0.75	1	40	40	0.4	0.4	0.5	0.4	0.9	0.8	0.8	0.7	0.6	0.2	0.2	0.4
sal over kit NE	109	58	34	24	0.4	0.9	1	-10	-10	0.4	0.5	0.5	0.4	0.9	0.9	0.8	0.7	0.7	0.2	0.2	0.5
sal over kit NW										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sal over kit SE	89	37	13	24	0.35	1	0.7	-60	-60	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.2
sal over kit SW	109	45	13	32	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal over pauli	229	74	24	50	0.35	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.9	0.8	0.7	0.3	0.2	0.5
sal over tibari 1 facing E	303	80	43	37	0.27	1	1	0	40	0.4	0.5	0.5	0.4	1.3	1.2	1.1	1.0	0.9	0.2	0.2	0.5
sal over tibari facing N	165	57	20	37	0.33	1	0.7	0	0	0.4	0.5	0.5	0.4	1.0	0.9	0.8	0.7	0.7	0.3	0.2	0.5
sal over tibari facing S										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 10 Hourly Data for Tropical Summer Index

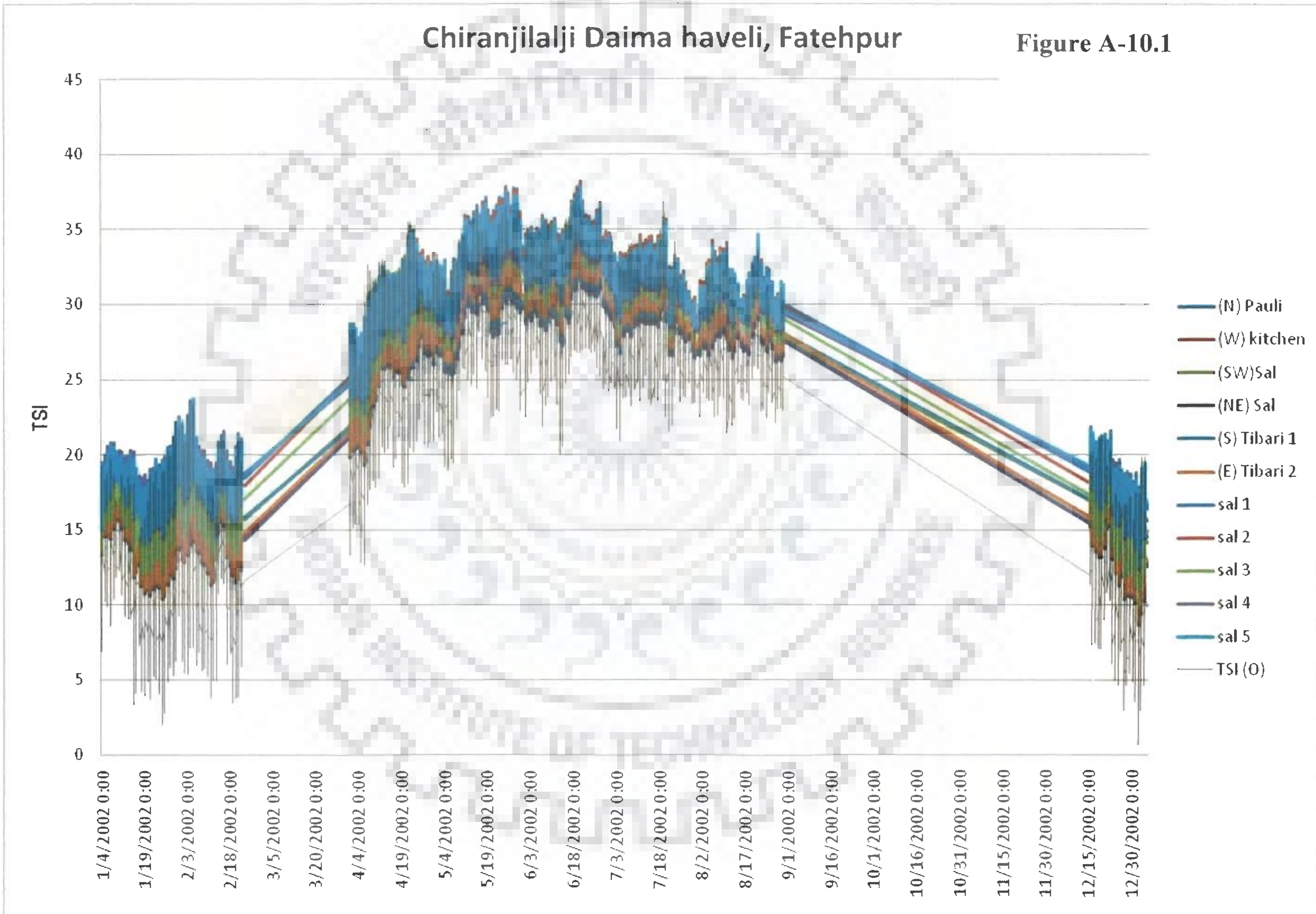
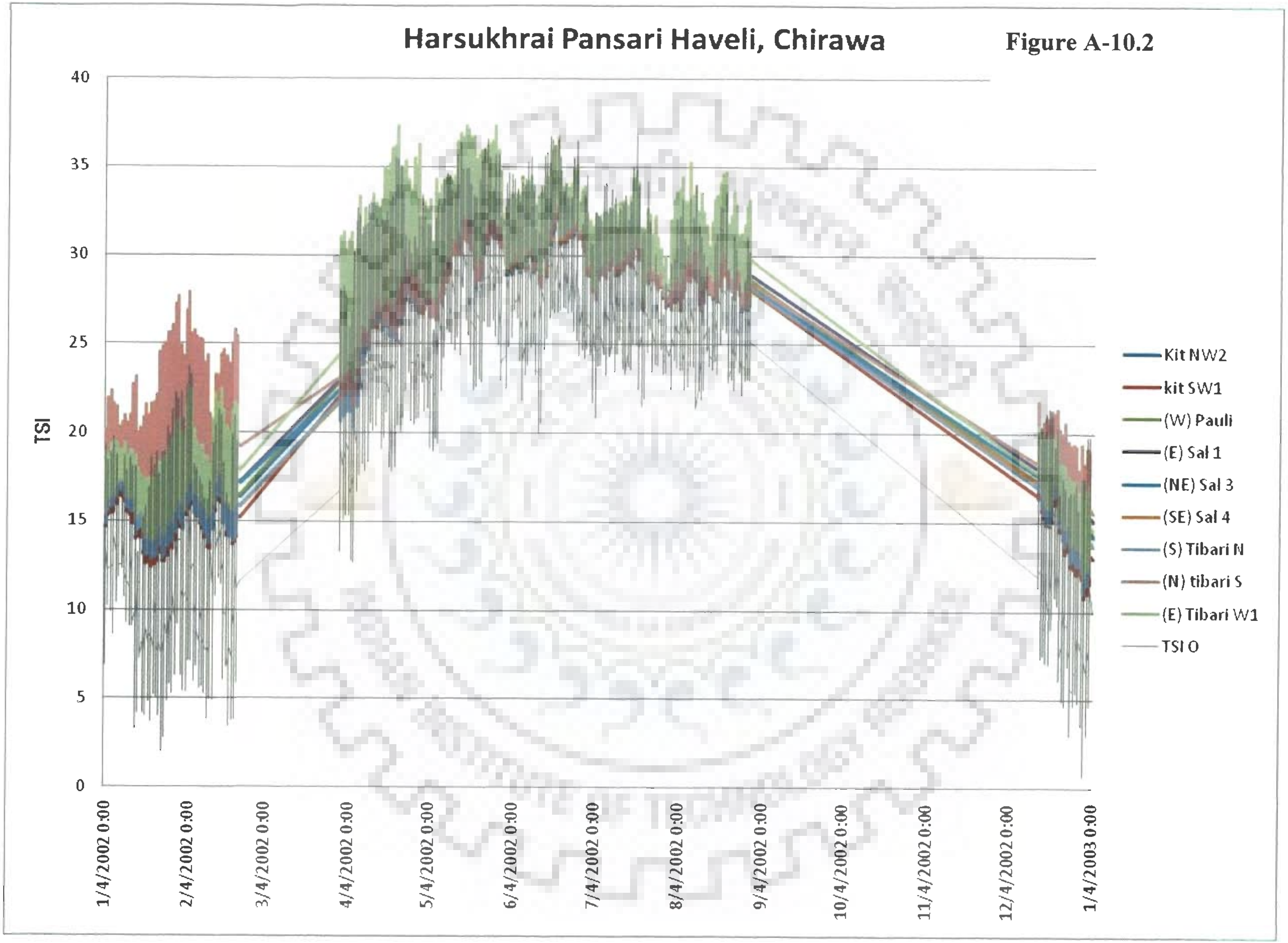


Figure A-10.2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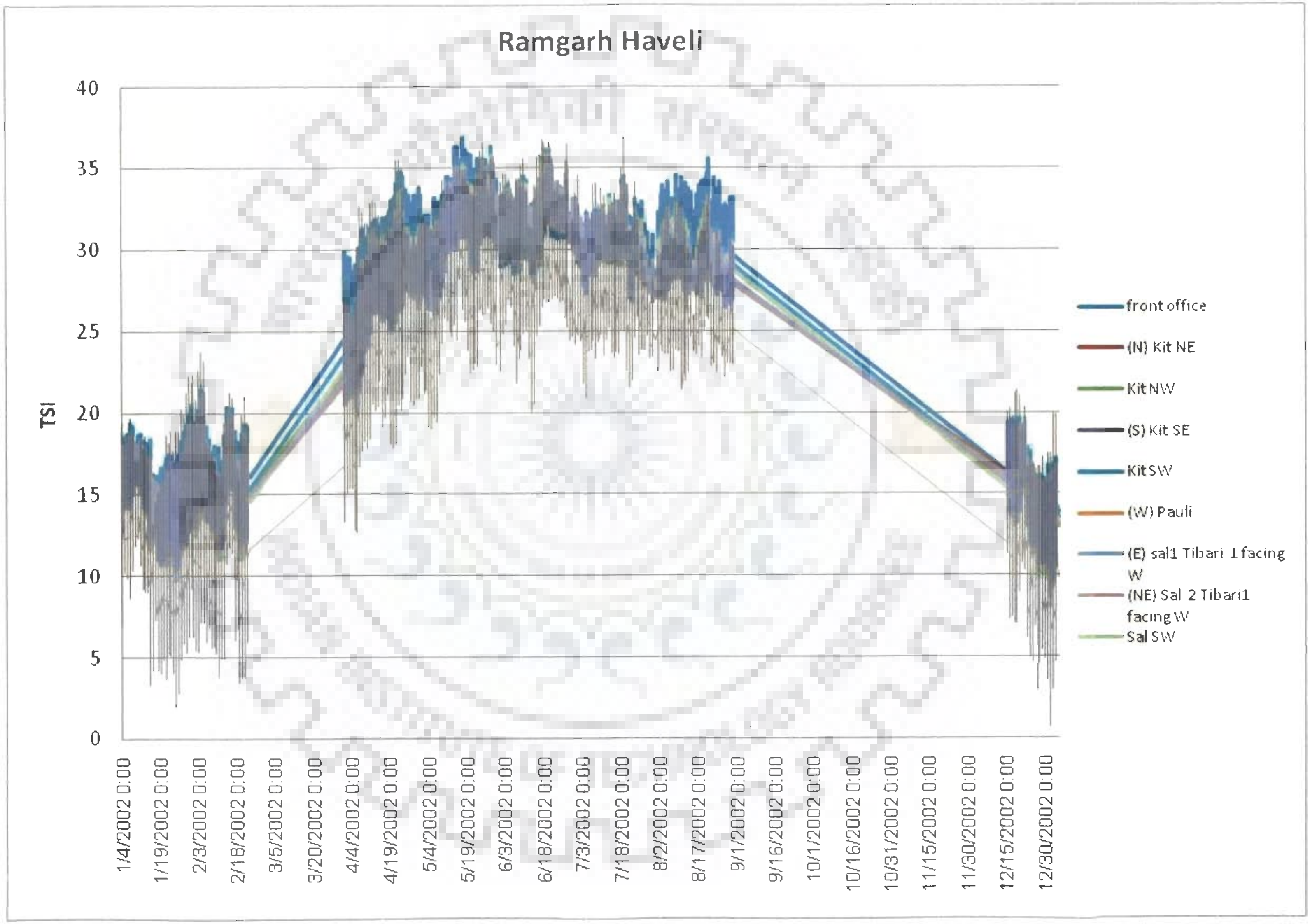
9/4/2002 0:00
10/4/2002 0:00
11/4/2002 0:00
12/4/2002 0:00
1/4/2003 0:00
Kit NW2
kit SW1
(W) Pauli
(E) Sal 1
(NE) Sal 3
(SE) Sal 4
(S) Tibari N
(N) tibari S
(E) Tibari W1
TSI O



Ramgarh Haveli
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12/15/2002 0:00
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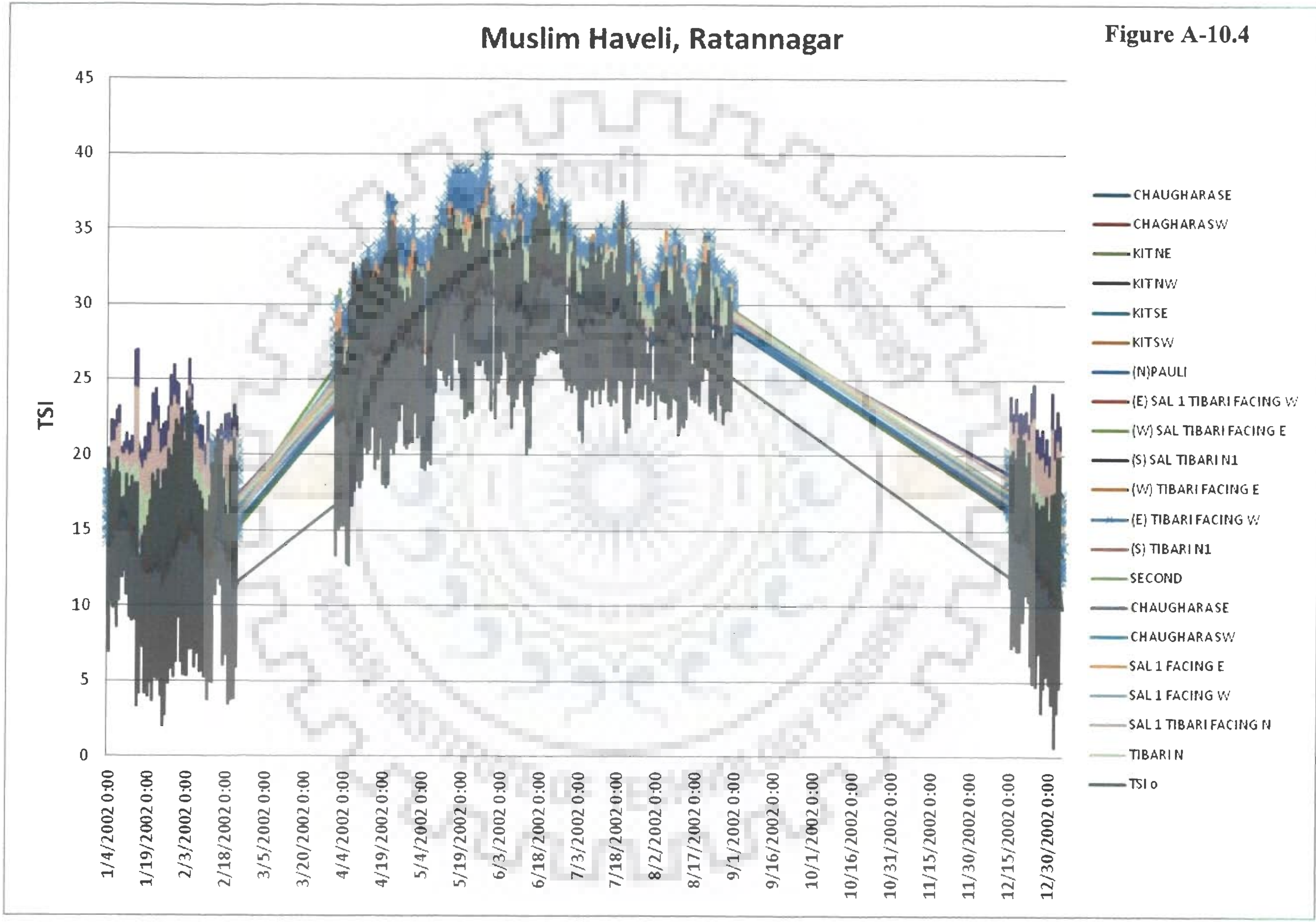
front office
(N) Kit NE
Kit NW
(S) Kit SE
Kit SW
(W) Pauli
(E) sal1 Tibari 1 facing W
(NE) Sal 2 Tibari1 facing W
Sal SW


Muslim Haveli, Ratannagar
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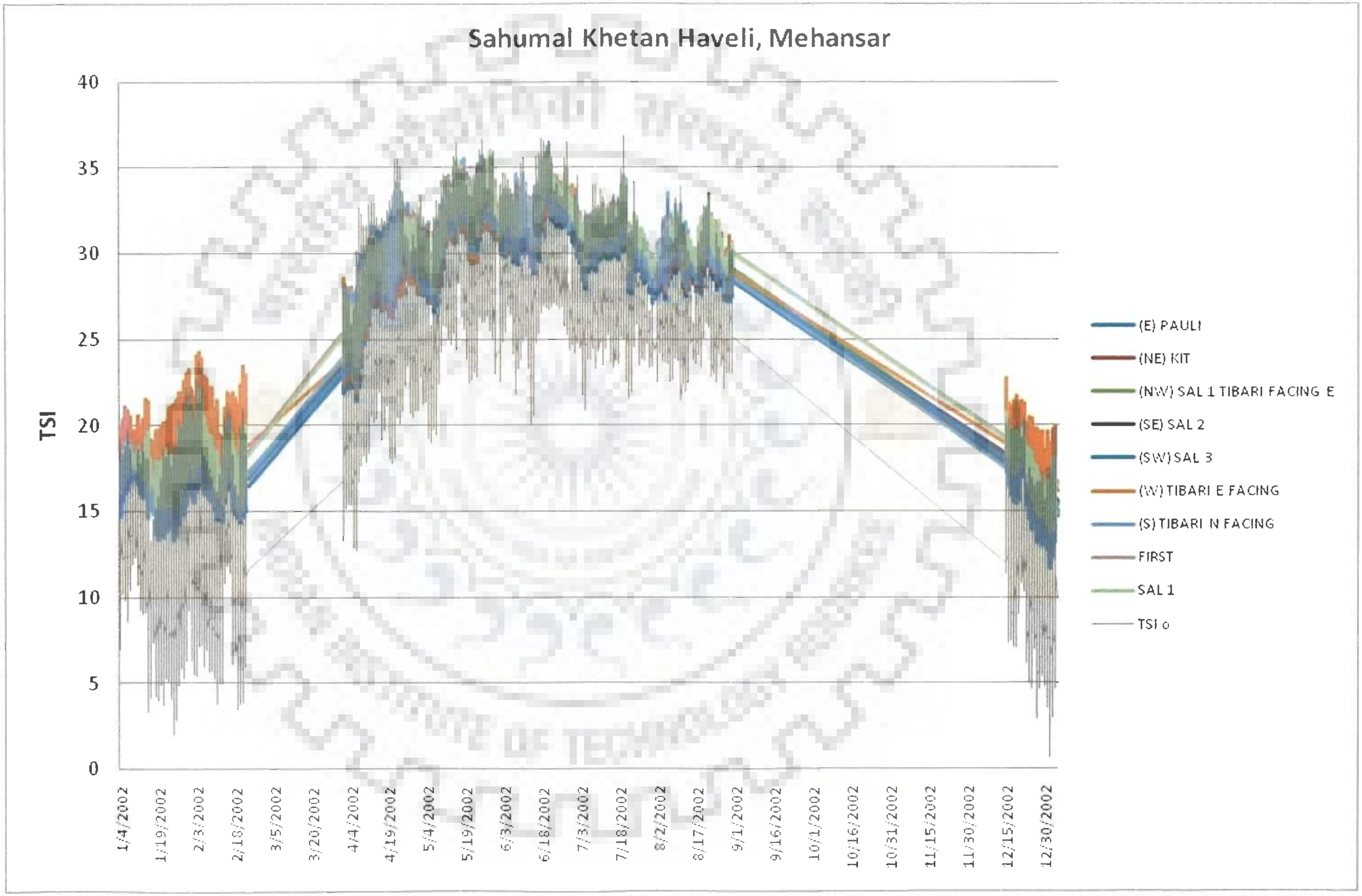
12/15/2002 0:00
12/30/2002 0:00
CHAUGHARA SE
CHAGHARA SW
KIT NE
KIT NW
KIT SE
KIT SW
(N)PAULI
(E) SAL 1 TIBARI FACING W
(W) SAL TIBARI FACING E
(S) SAL TIBARI N1
(W) TIBARI FACING E
(E) TIBARI FACING W
(S) TIBARI N1
SECOND
CHAUGHARA SE
CHAUGHARA SW
SAL 1 FACING E
SAL 1 FACING W
SAL 1 TIBARI FACING N
TIBARI N
TSI o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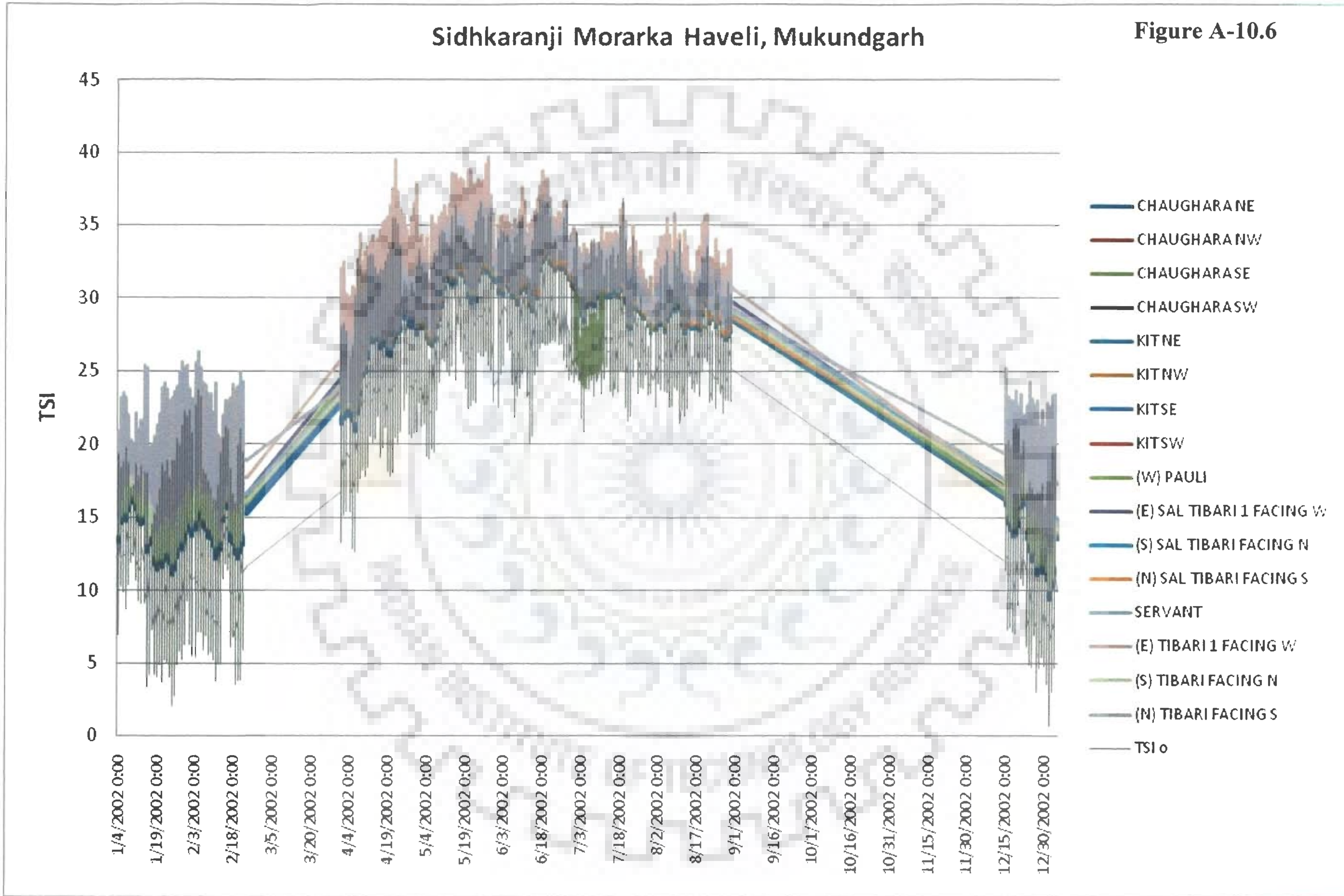
10/1/2002
10/16/2002
10/31/2002
11/15/2002
11/30/2002
12/15/2002
12/30/2002
(E) PAULI
(NE) KIT
(NW) SAL 1 TIBARI FACING E
(SE) SAL 2
(SW) SAL 3
(W) TIBARI E FACING
(S) TIBARI N FACING
FIRST
SAL 1
TSI o

Figure A-10.6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10/31/2002 0:00
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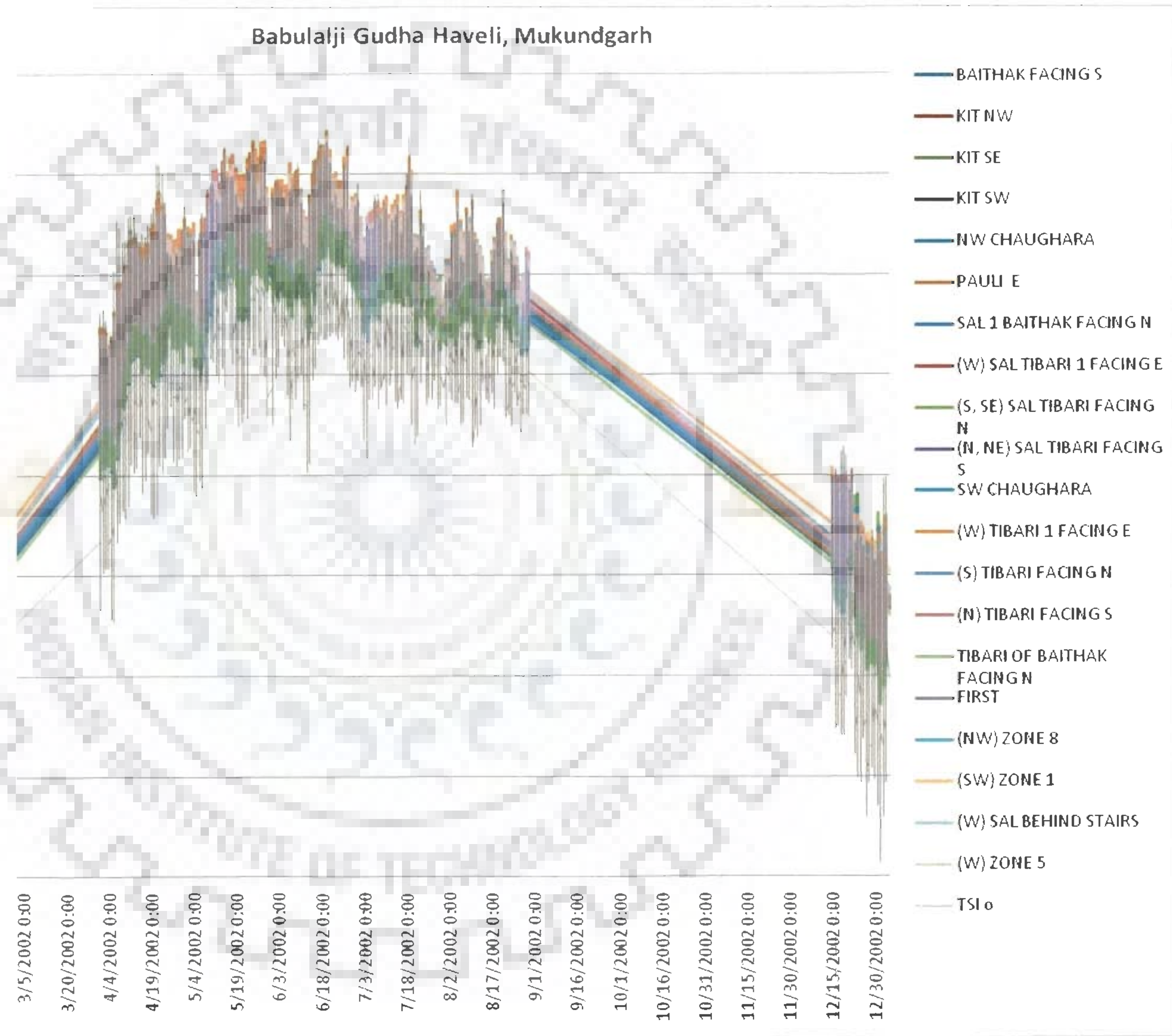
12/15/2002 0:00
12/30/2002 0:00
CHAUGHARA NE
CHAUGHARA NW
CHAUGHARA SE
CHAUGHARA SW
KIT NE
KIT NW
KIT SE
KIT SW
(W) PAULI
(E) SAL TIBARI 1 FACING W
(S) SAL TIBARI FACING N
(N) SAL TIBARI FACING S
SERVANT
(E) TIBARI 1 FACING W
(S) TIBARI FACING N
(N) TIBARI FACING S
TSI o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KIT SE
KIT SW
NW CHAUGHARA
PAULI E
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(W) SAL TIBARI 1 FACING E
(S, SE) SAL TIBARI FACING N
(N, NE) SAL TIBARI FACING S
SW CHAUGHARA
(W) TIBARI 1 FACING E
(S) TIBARI FACING N
(N) TIBARI FACING S
TIBARI OF BAITHAK FACING N
FIRST
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(SW) ZONE 1
(W) SAL BEHIND STAIRS
(W) ZONE 5
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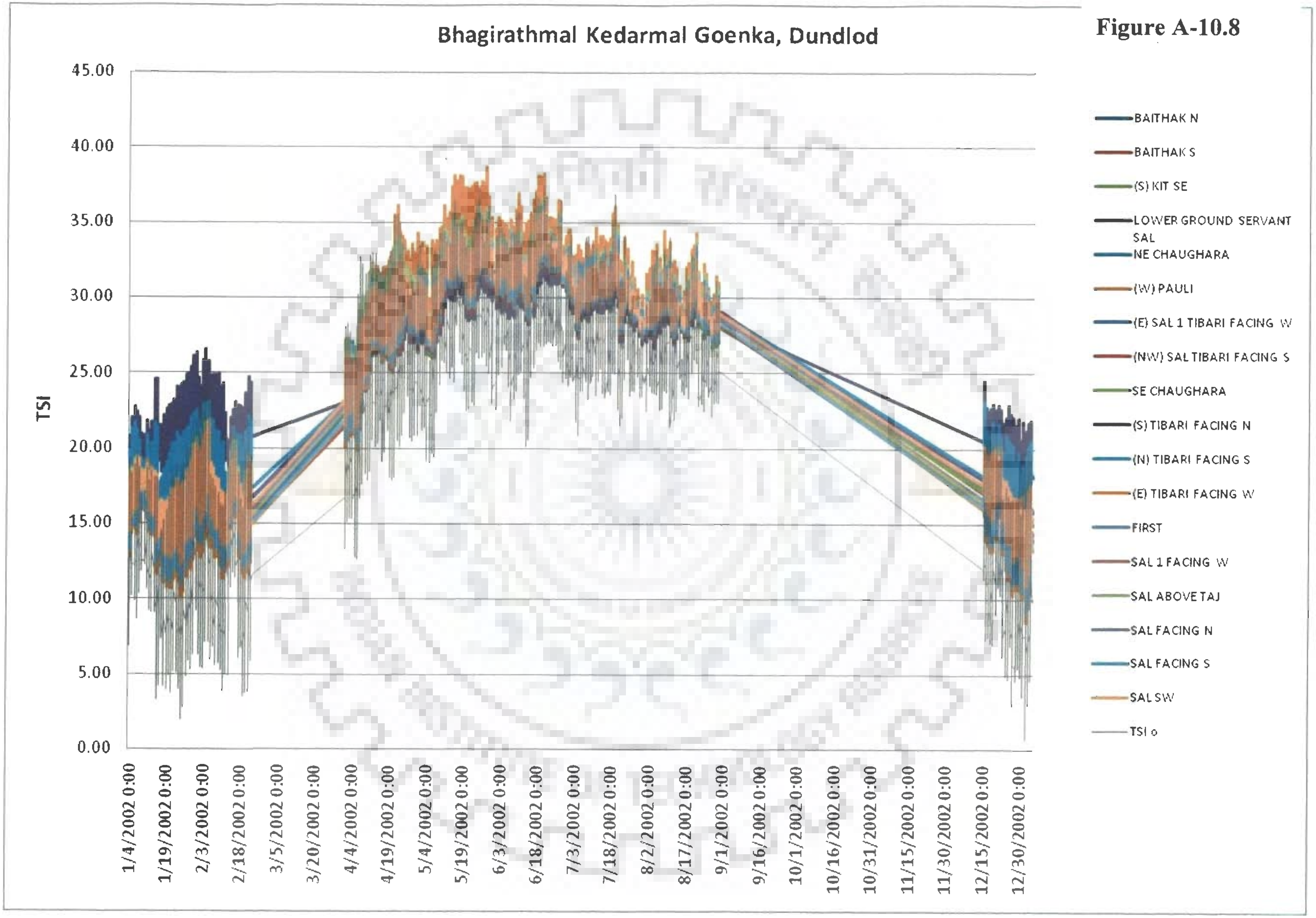
Figure A-10.8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BAITHAK S
(S) KIT SE
LOWER GROUND SERVANT SAL
NE CHAUGHARA
(W) PAULI
(E) SAL 1 TIBARI FACING W
(NW) SAL TIBARI FACING S
SE CHAUGHARA
(S) TIBARI FACING N
(N) TIBARI FACING S
(E) TIBARI FACING W
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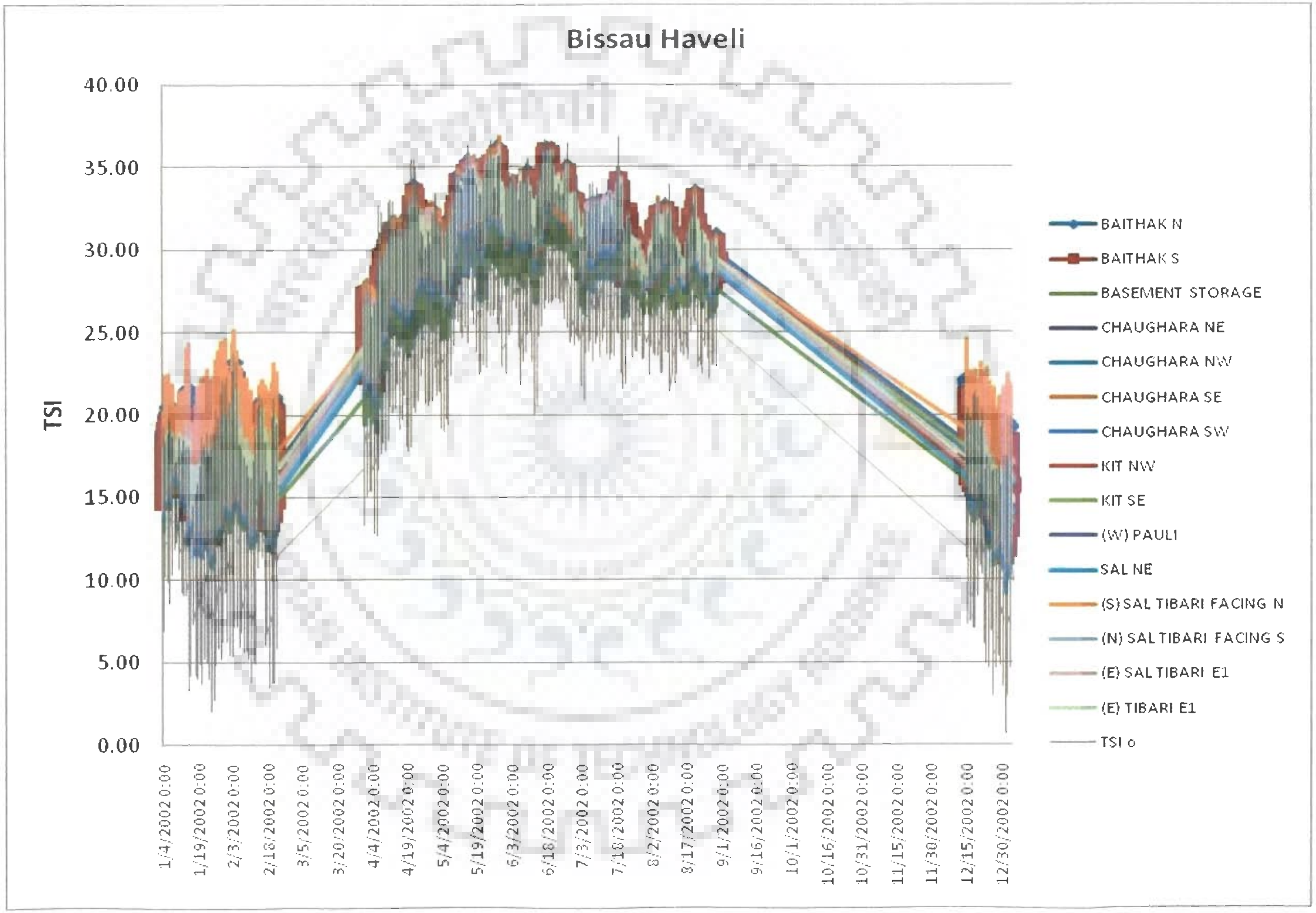
SAL 1 FACING W
SAL ABOVE TAJ
SAL FACING N
SAL FACING S
SAL SW
TSI o



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CHAUGHARA SE
CHAUGHARA SW
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KIT SE
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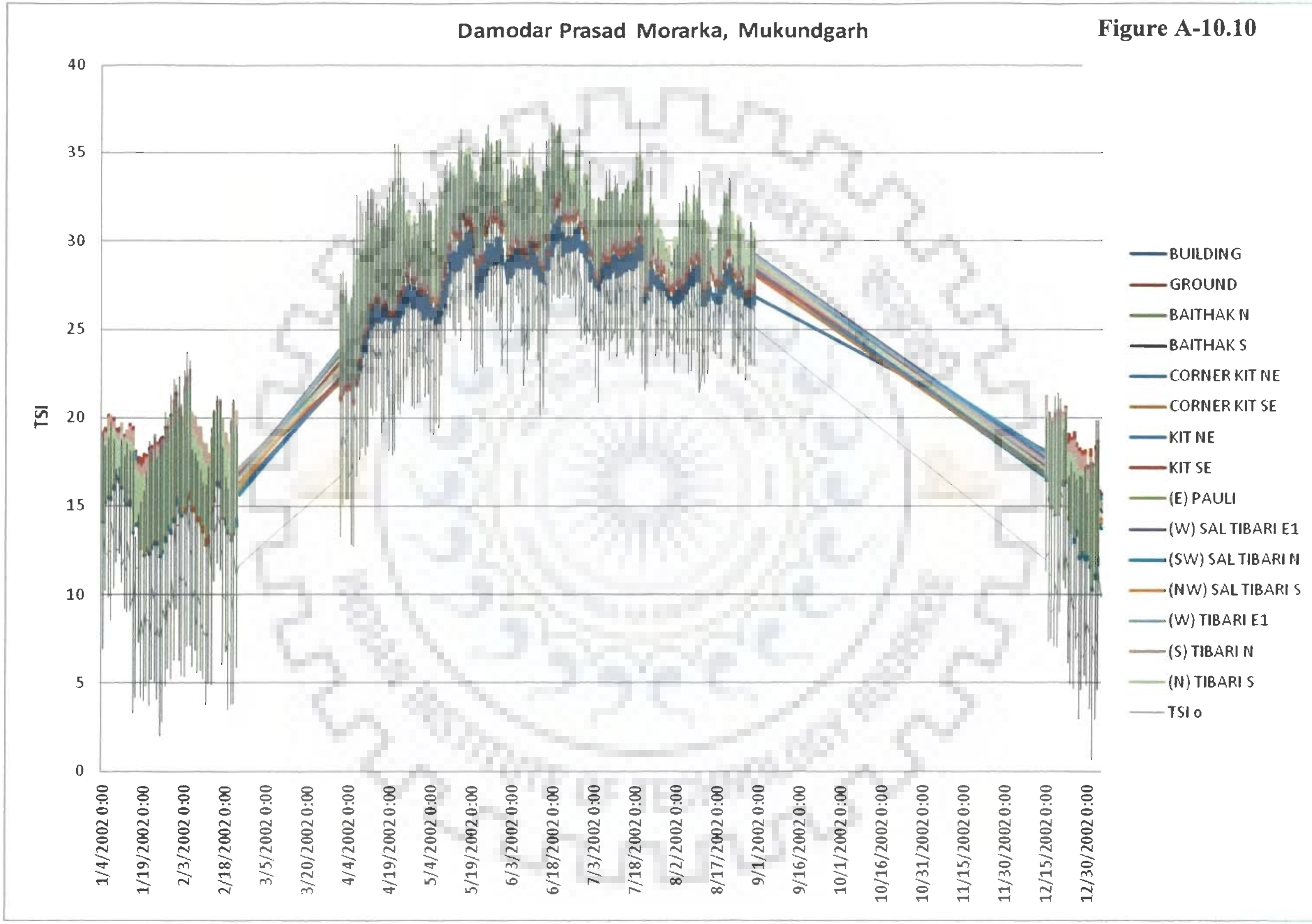
(E) SAL TIBARI E1
(E) TIBARI E1
TSI o



Damodar Prasad Morarka, Mukundgarh
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BUILDING
GROUND
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CORNER KIT SE
KIT NE
KIT SE
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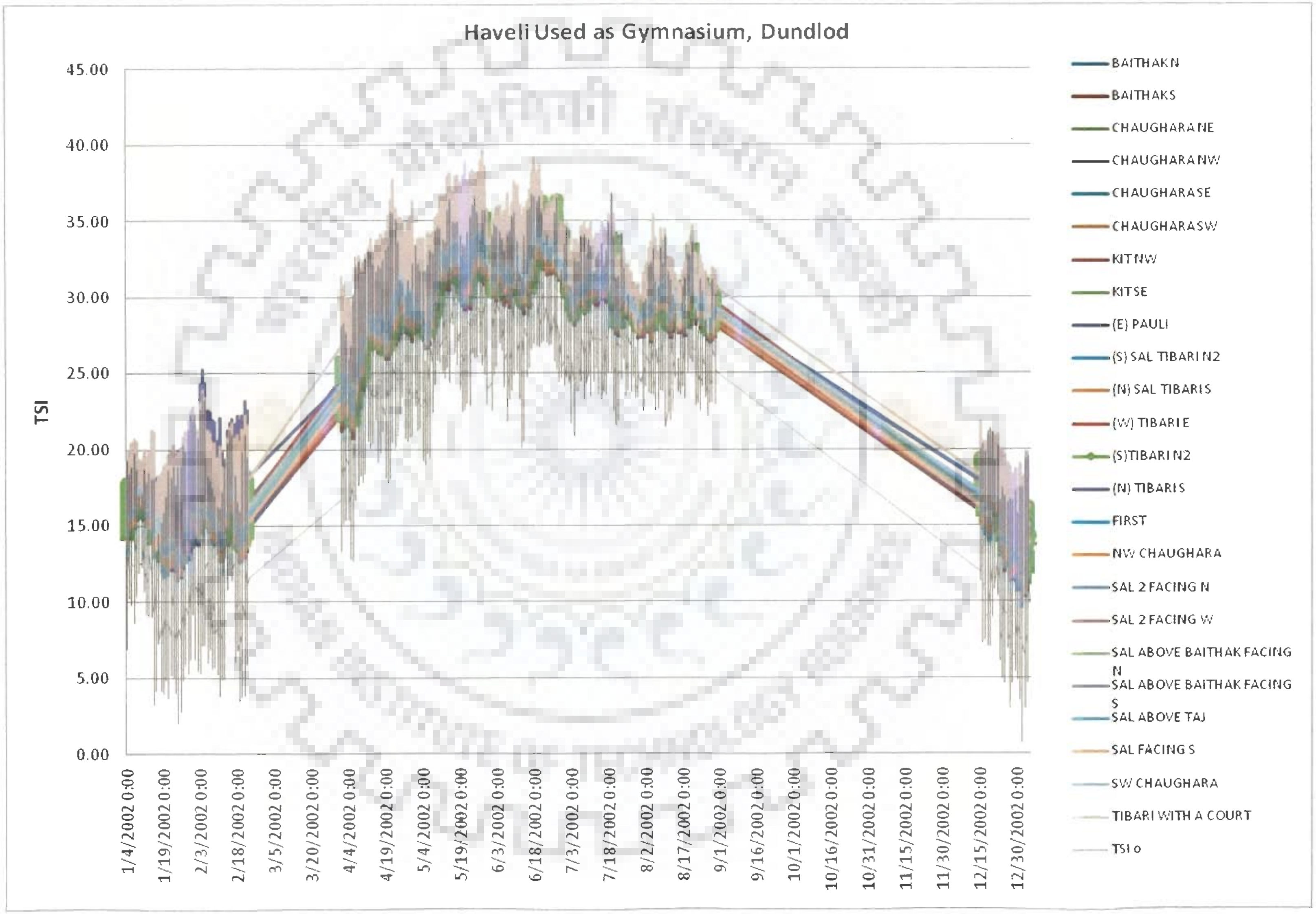
TSI o


Haveli Used as Gymnasium, Dundlod
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CHAUGHARA SE
CHAUGHARA SW
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KIT SE
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(N) SAL TIBARI S
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(S)TIBARI N2
(N) TIBARI S
FIRST
NW CHAUGHARA
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SAL 2 FACING W
SAL ABOVE BAITHAK FACING N
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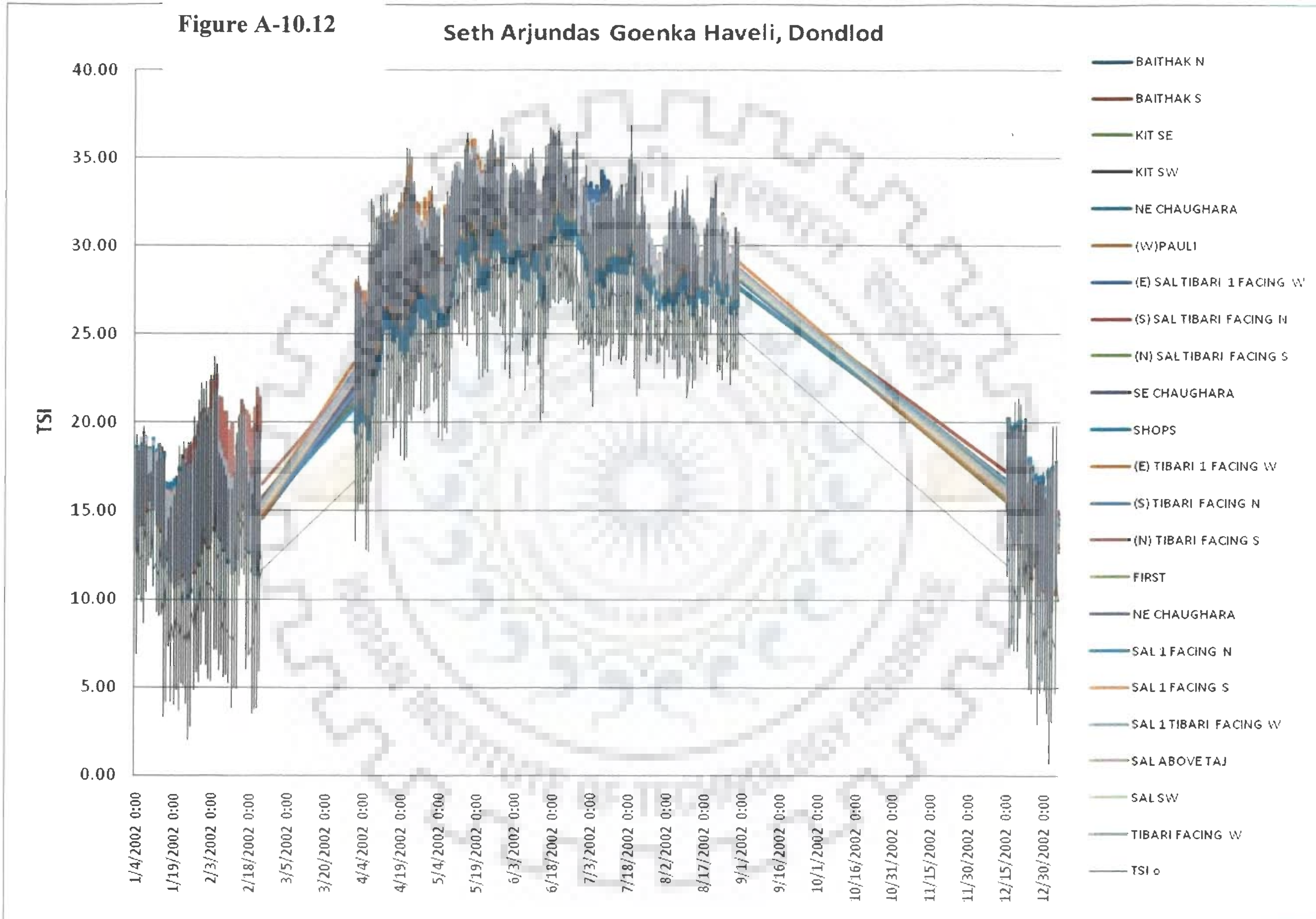
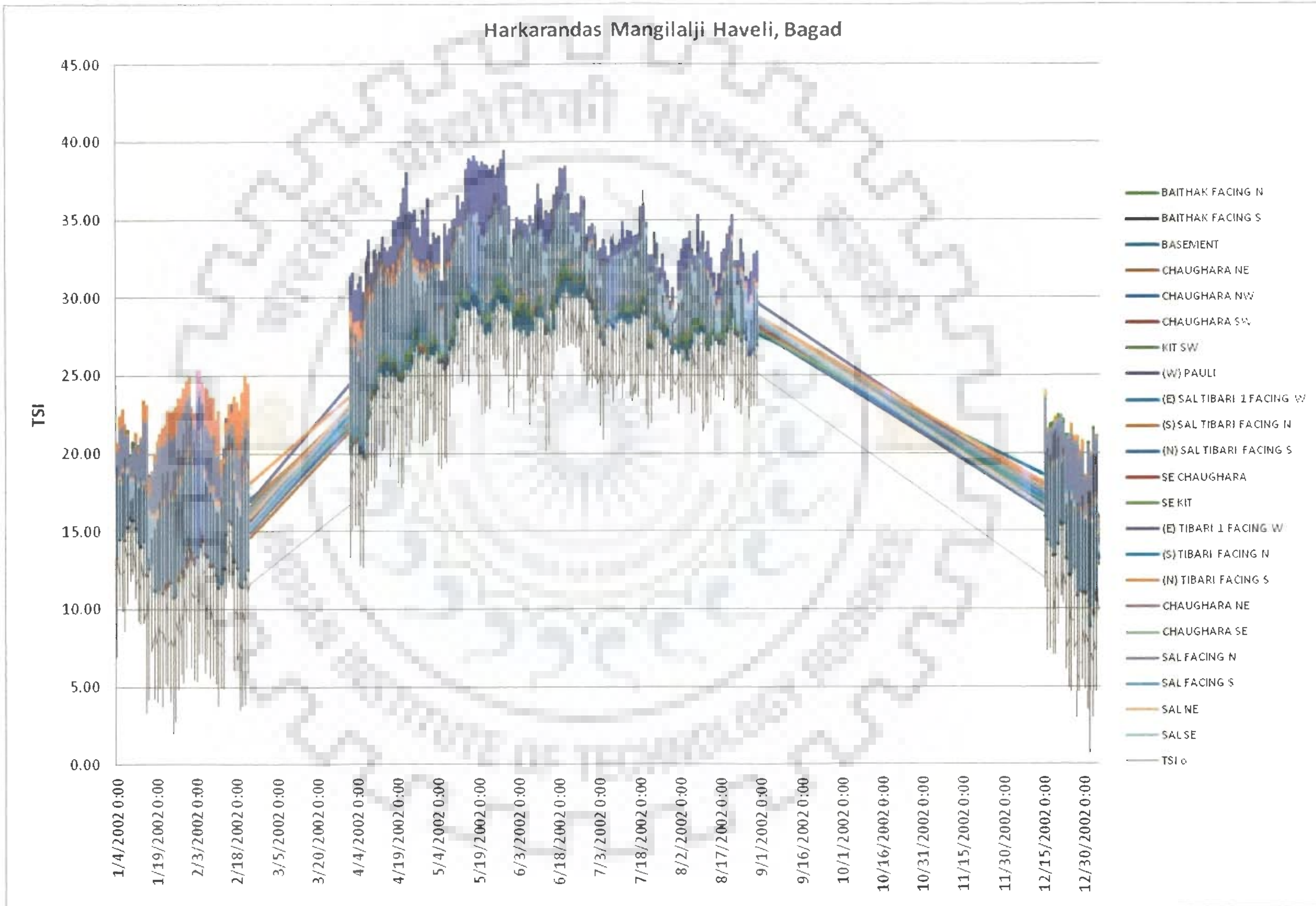
SAL ABOVE TAJ
SAL FACING S
SW CHAUGHARA
TIBARI WITH A COURT
TSI o

Figure A-10.12





Harkarandas Mangilalji Haveli, Bagad
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BAITHAK FACING S
BASEMENT
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CHAUGHARA NW
CHAUGHARA SW
KIT SW
(W) PAULI
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(S) SAL TIBARI FACING N
(N) SAL TIBARI FACING S
SE CHAUGHARA
SE KIT
(E) TIBARI 1 FACING W
(S) TIBARI FACING N
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SAL FACING S
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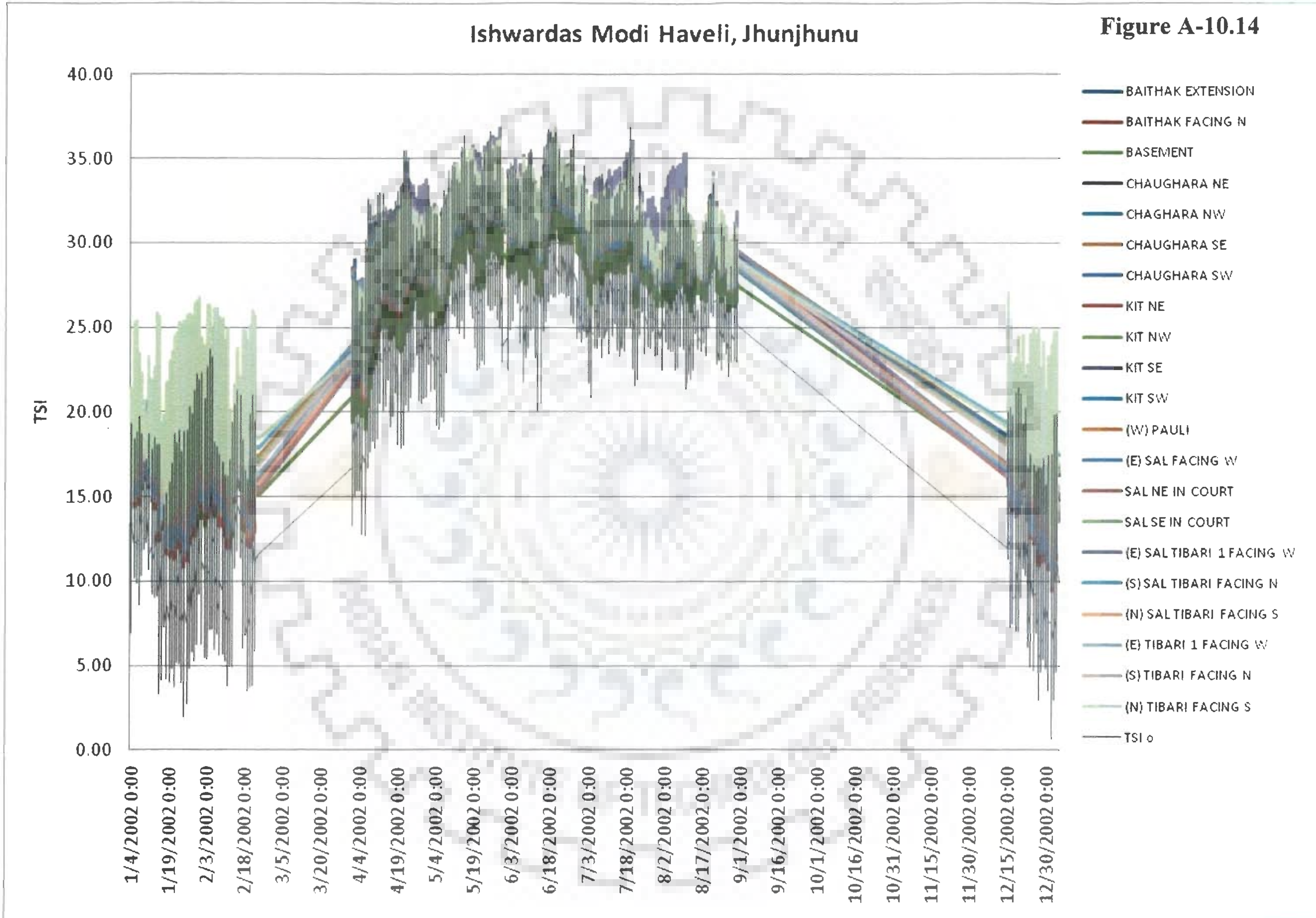
SAL SE
TSI o



Ishwardas Modi Haveli, Jhunjhunu
Figure A-10.14
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CHAGHARA NW
CHAUGHARA SE
CHAUGHARA SW
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KIT NW
KIT SE
KIT SW
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SAL NE IN COURT
SAL SE IN COURT
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(S) SAL TIBARI FACING N
(N) SAL TIBARI FACING S
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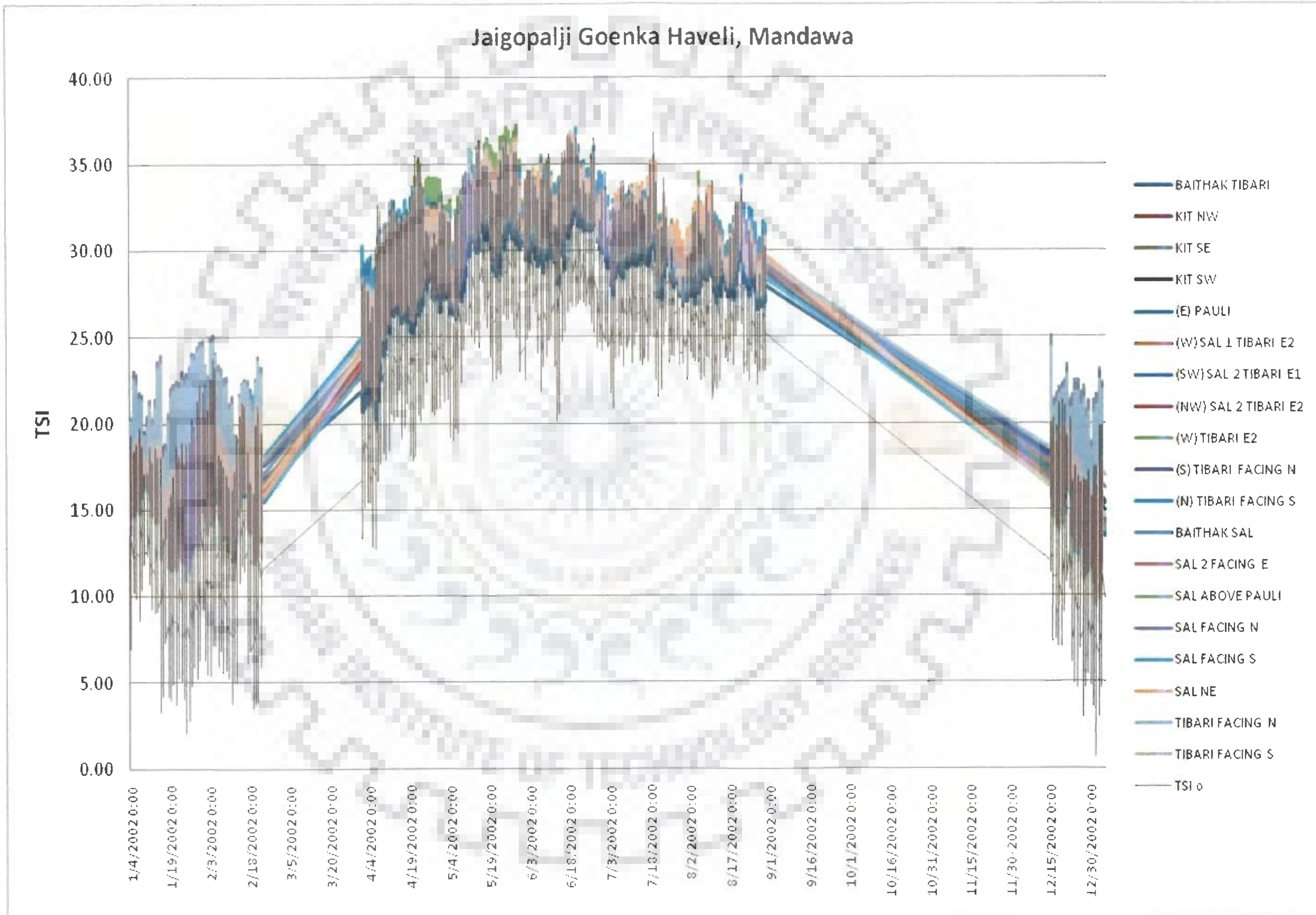
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(SW) SAL 2 TIBARI E1
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(W) TIBARI E2
(S) TIBARI FACING N
(N) TIBARI FACING S
BAITHAK SAL
SAL 2 FACING E
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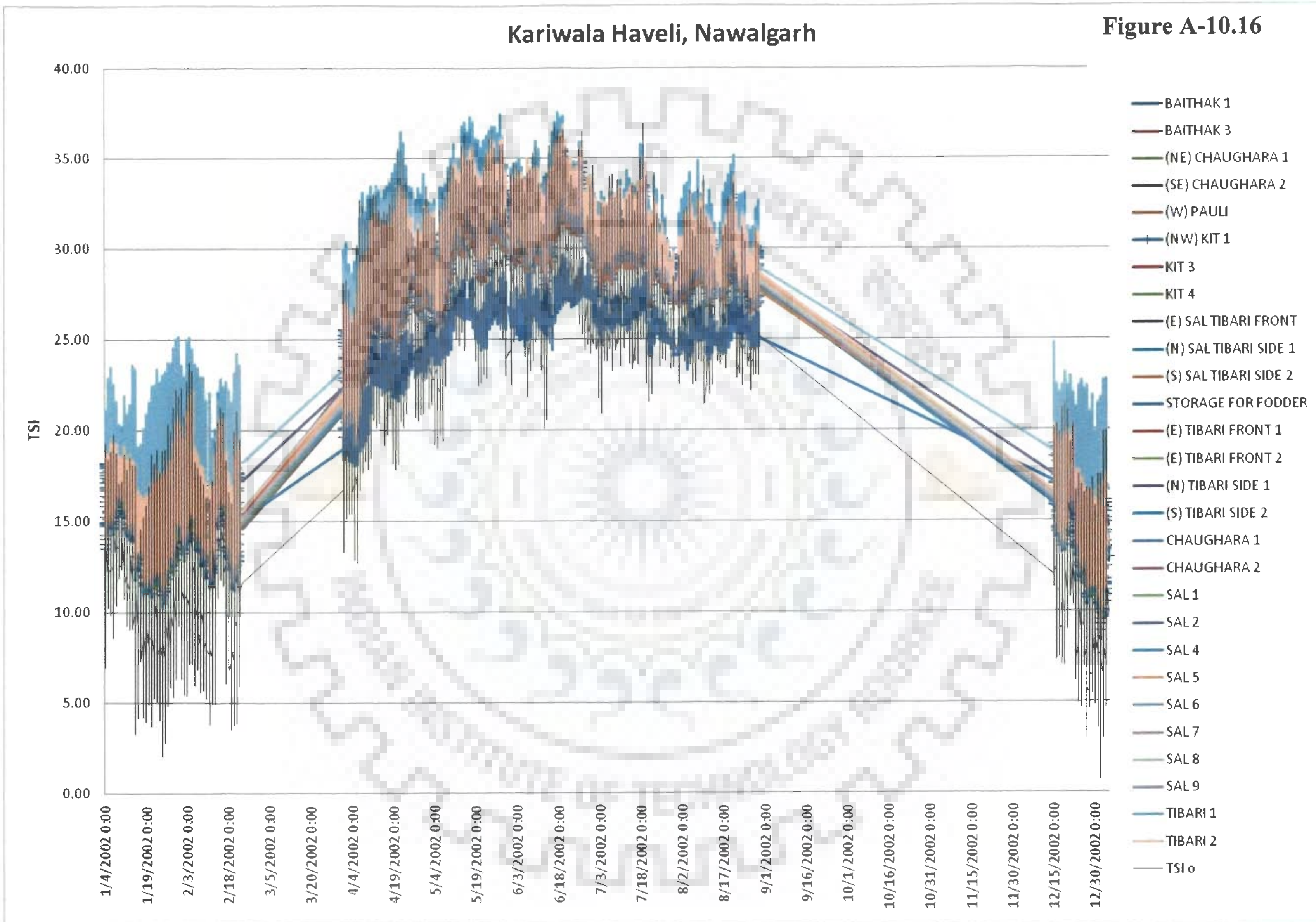
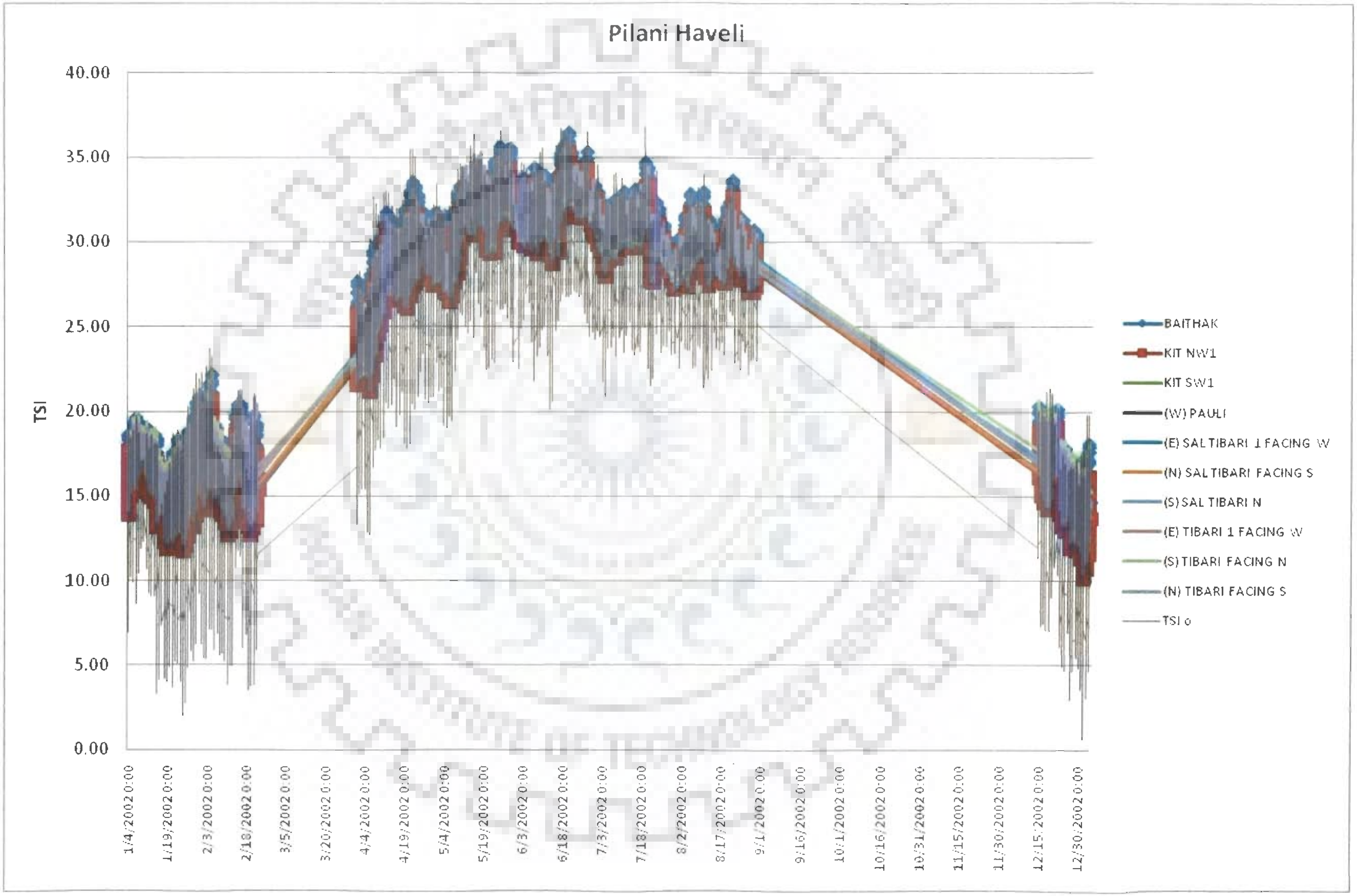
SAL NE
TIBARI FACING N
TIBARI FACING S
TSI o

Figure A-10.16





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(W) PAULI
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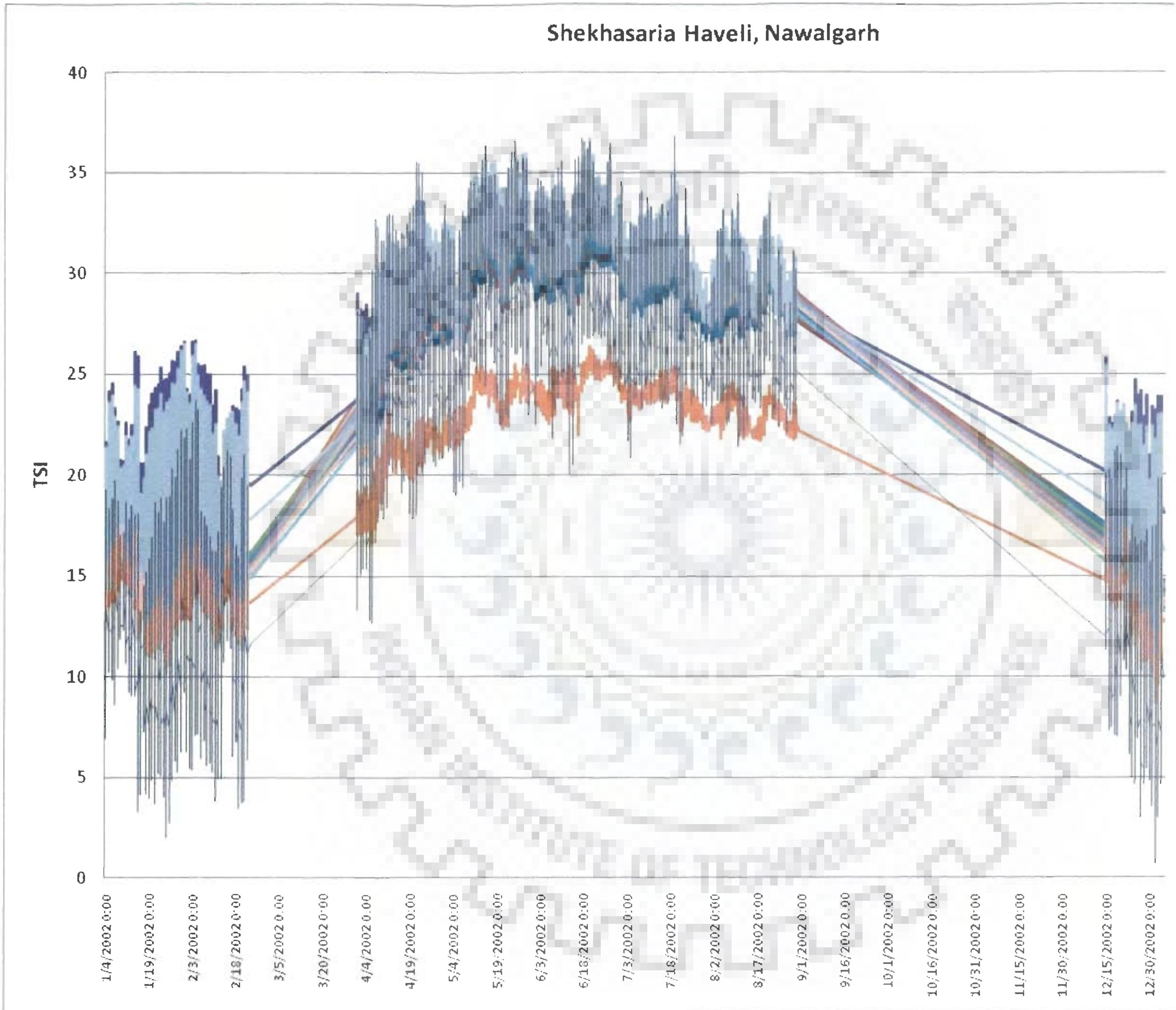

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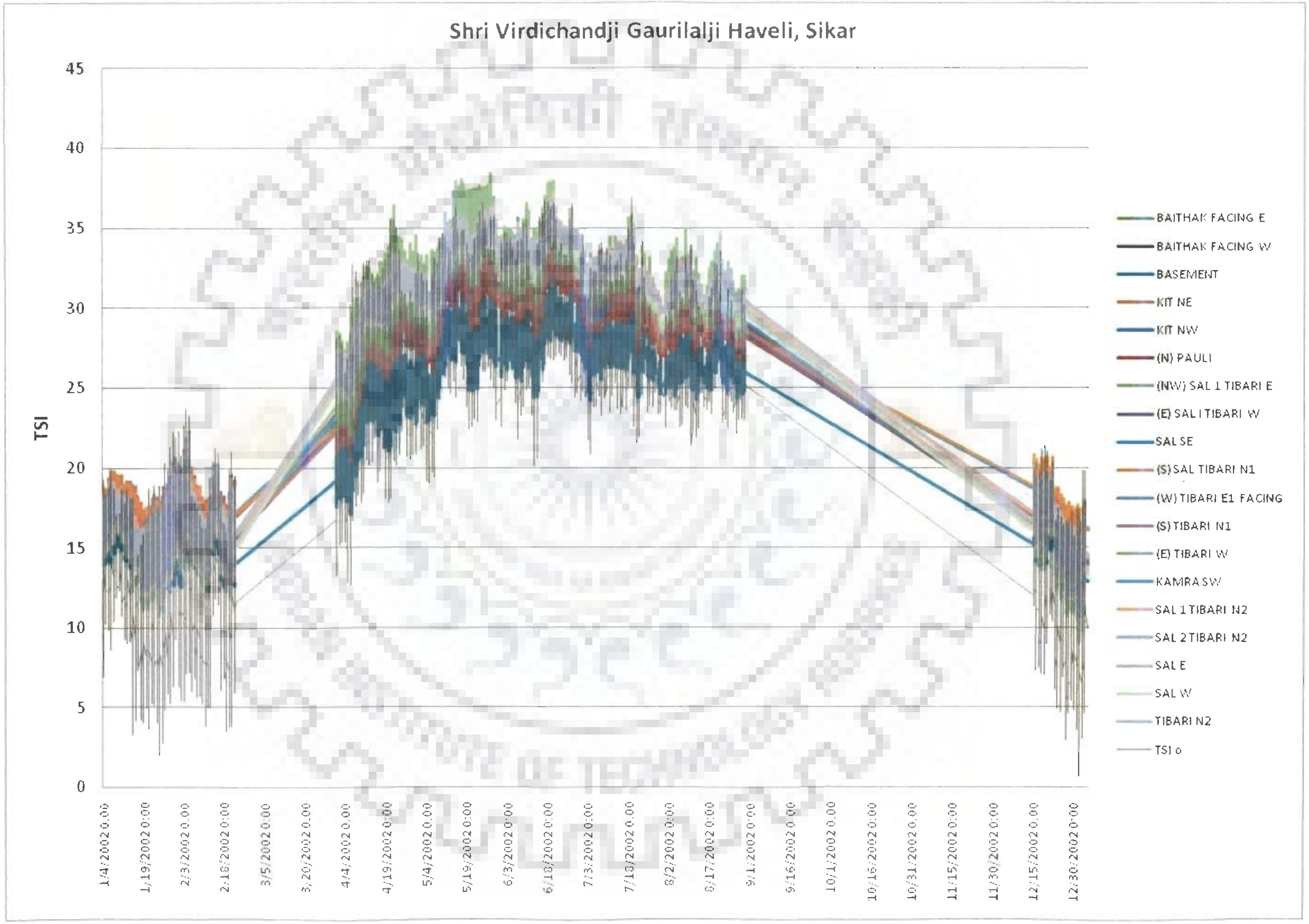

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KAMRA SW
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SAL 2 TIBARI N2
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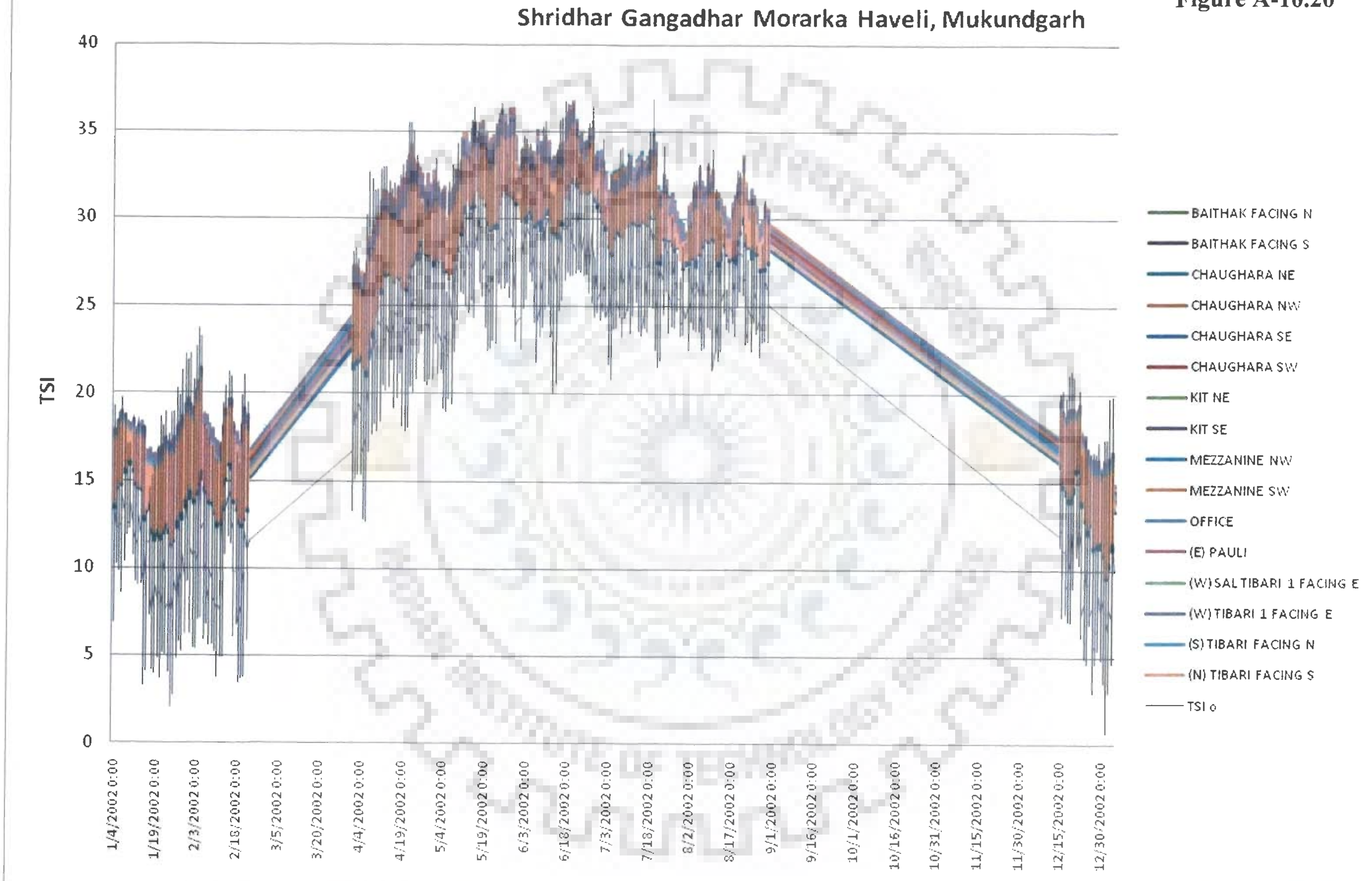
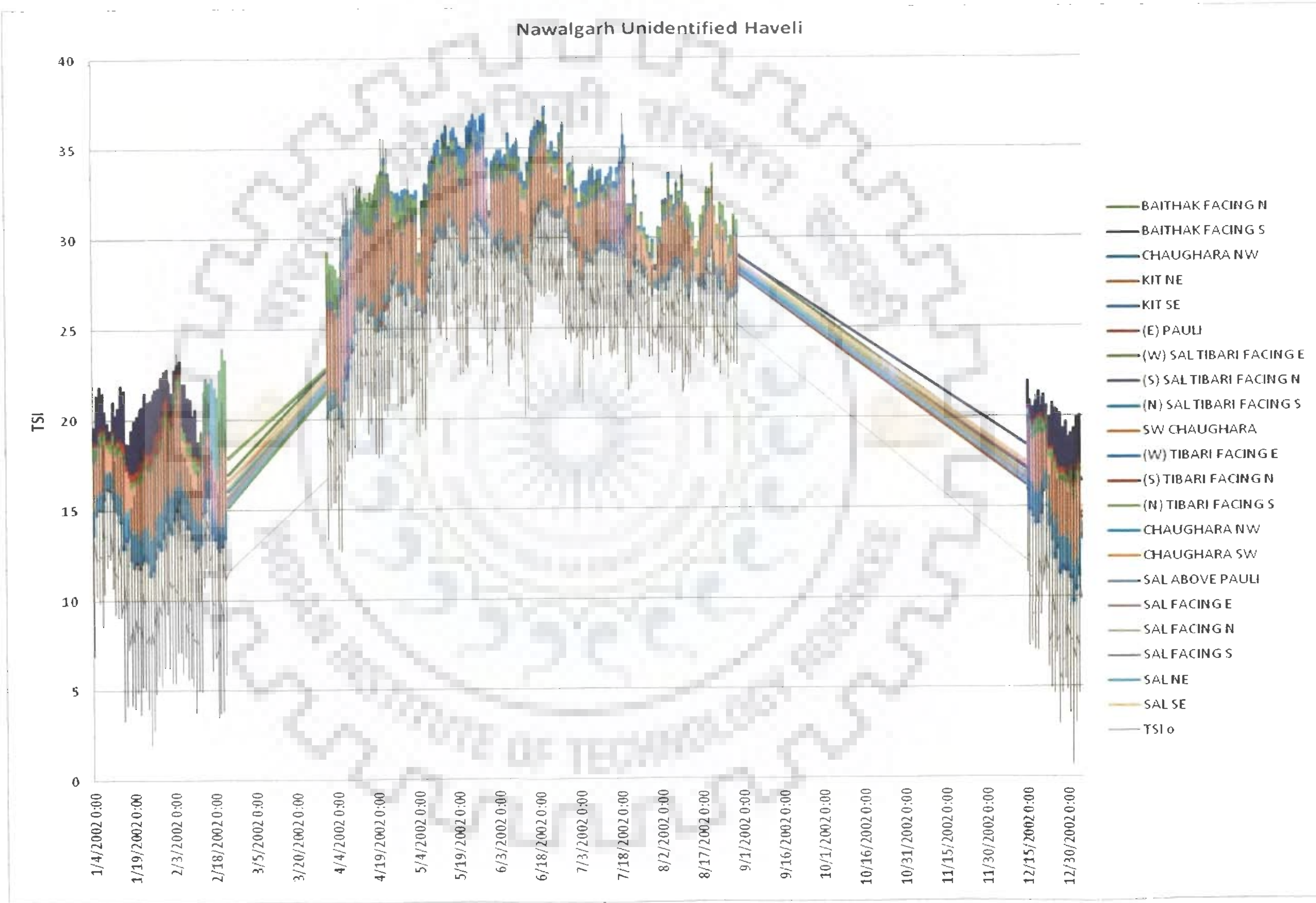
Figure A-10.20

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(S) SAL TIBARI FACING N
(N) SAL TIBARI FACING S
SW CHAUGHARA
(W) TIBARI FACING E
(S) TIBARI FACING N
(N) TIBARI FACING S
CHAUGHARA NW
CHAUGHARA SW
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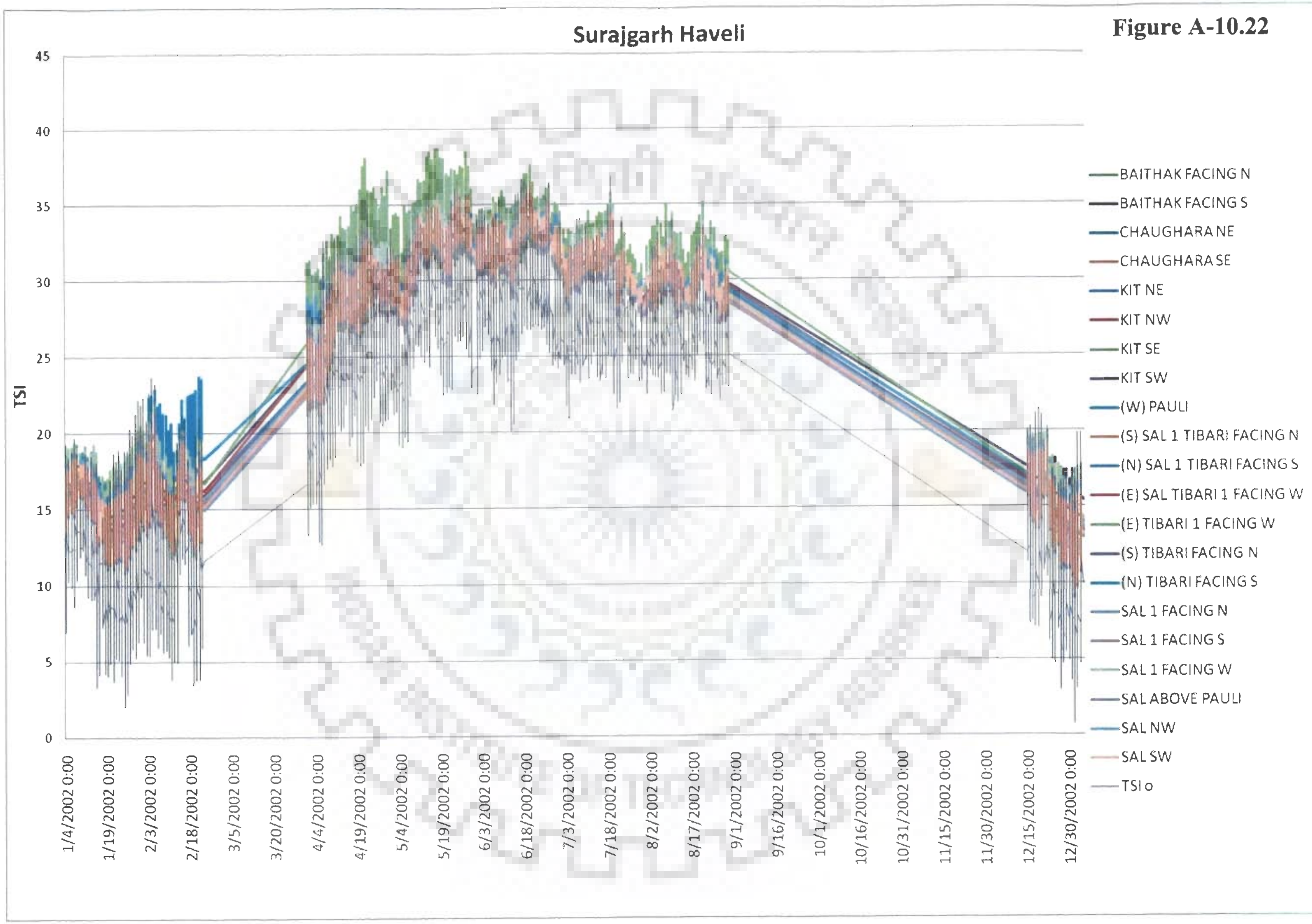
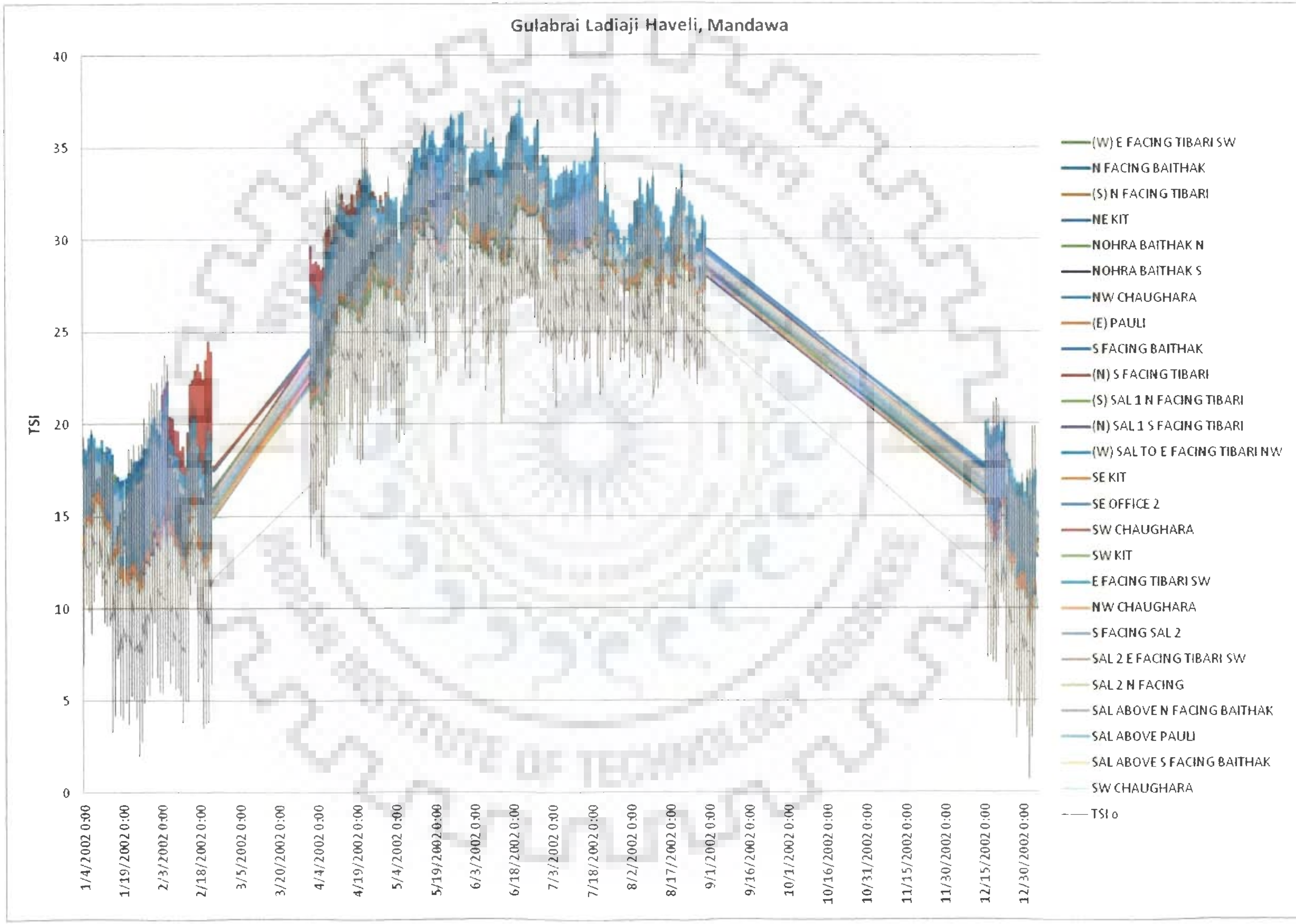
SAL FACING E
SAL FACING N
SAL FACING S
SAL NE
SAL SE
TSI o

Figure A-10.22

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(S) N FACING TIBARI
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NOHRA BAITHAK N
NOHRA BAITHAK S
NW CHAUGHARA
(E) PAULI
S FACING BAITHAK
(N) S FACING TIBARI
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(N) SAL 1 S FACING TIBARI
(W) SAL TO E FACING TIBARI NW
SE KIT
SE OFFICE 2
SW CHAUGHARA
SW KIT
E FACING TIBARI SW
NW CHAUGHARA
S FACING SAL 2
SAL 2 E FACING TIBARI SW
SAL 2 N FACING
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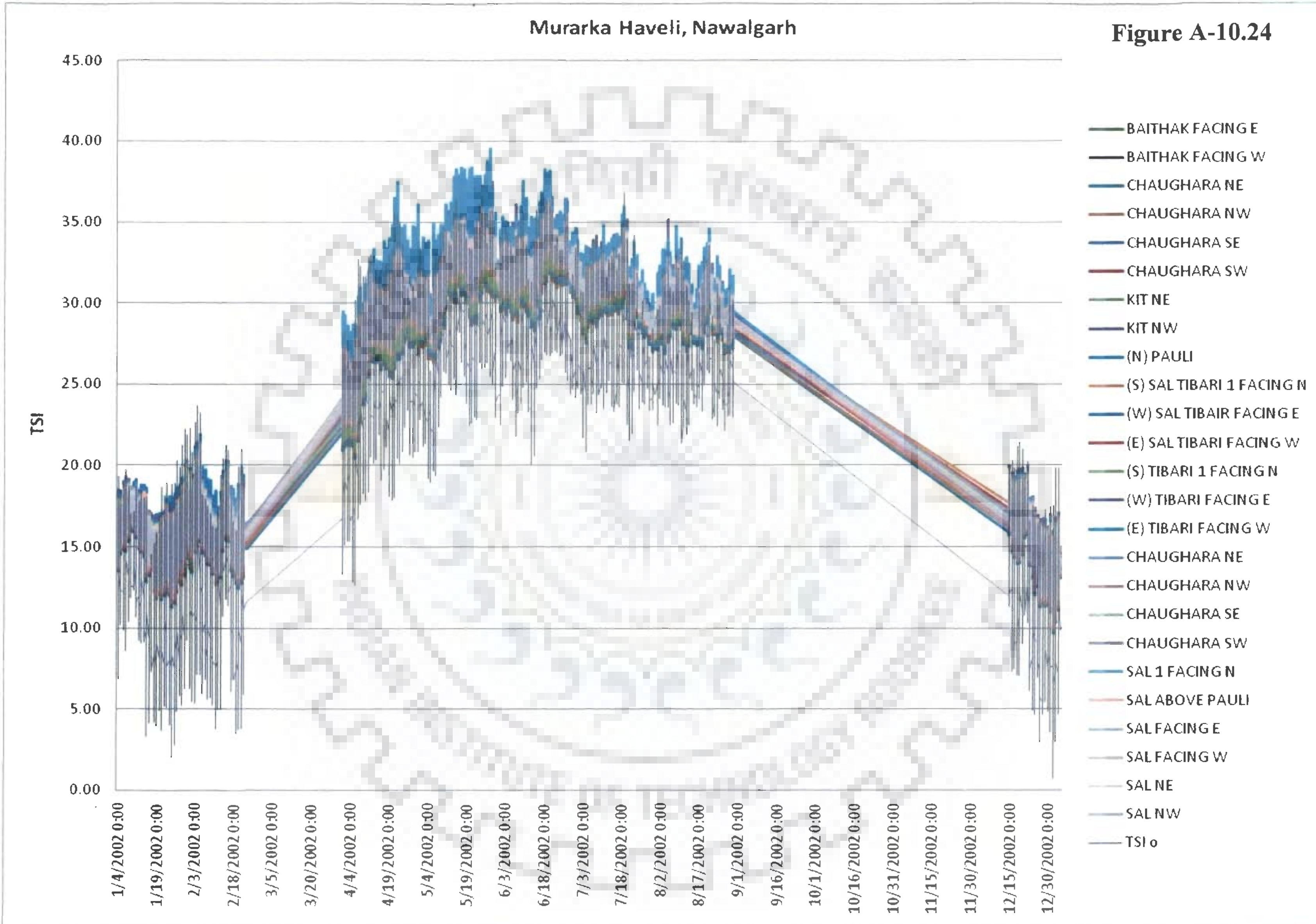
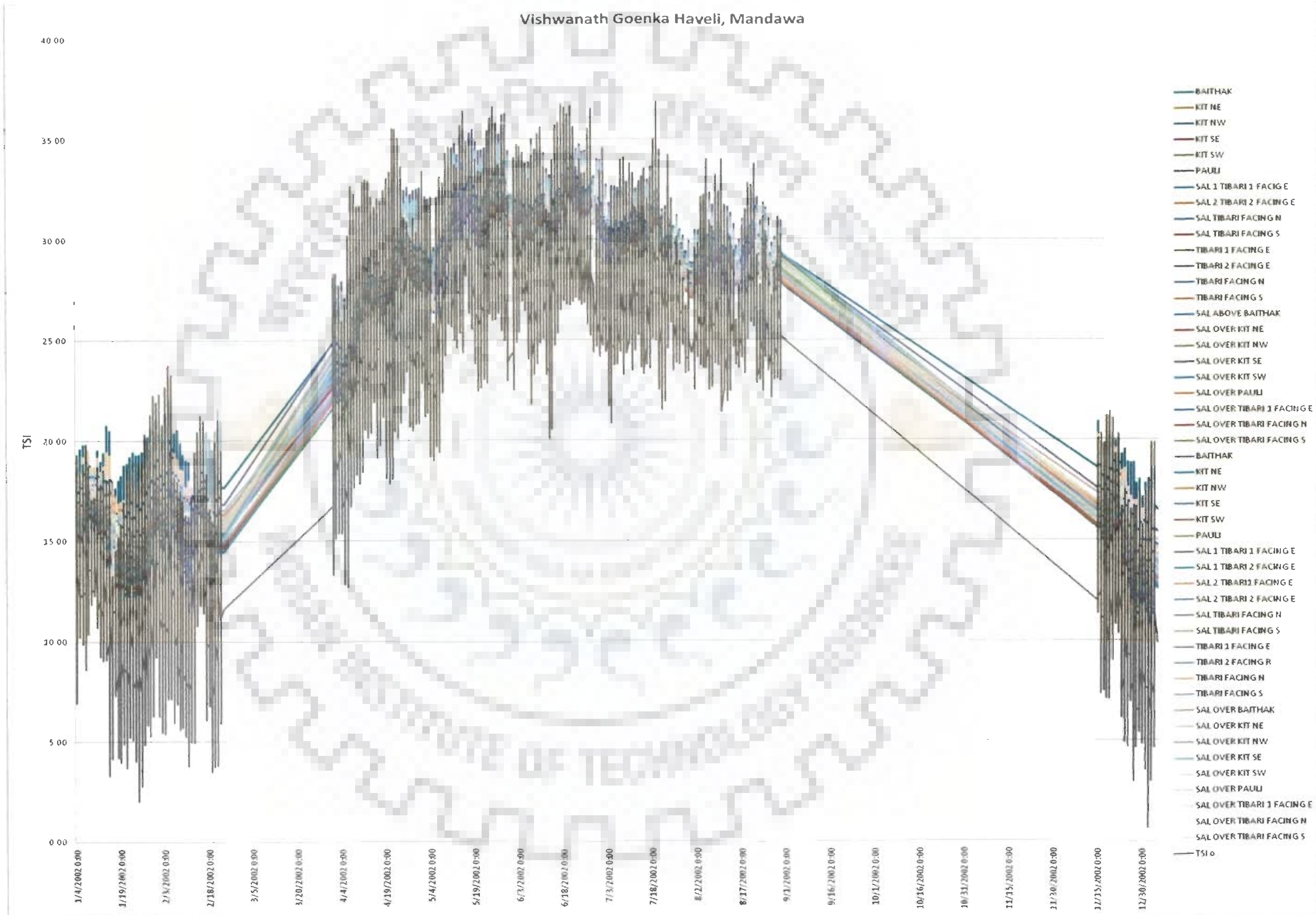
SAL ABOVE PAULI
SAL ABOVE S FACING BAITHAK
SW CHAUGHARA
TSI o

Figure A-10.24

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BAITHAK
KIT NE
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PAULI
SAL 1 TIBARI 1 FACIG E
SAL 2 TIBARI 2 FACING E
SAL TIBARI FACING N
SAL TIBARI FACING S
TIBARI 1 FACING E
TIBARI 2 FACING E
TIBARI FACING N
TIBARI FACING S
SAL ABOVE BAITHAK
SAL OVER KIT NE
SAL OVER KIT NW
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SAL OVER PAULI
SAL OVER TIBARI 1 FACING E
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BAITHAK
KIT NE
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PAULI
SAL 1 TIBARI 1 FACING E
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List of Papers Published and Presented from this Study

1. ***Shekhawati-Panorama of Haveli Architecture***, A+D, Volume 7, Issue 1, January 2007, pp 26-32.

2. ***Havelis of Shekhawati- An Analysis of Earthquake Resistance***, presented at 13th symposium on earthquake engineering at Department of Earthquake Engineering, IIT Roorkee, 18th-20th December, 2006.

3. ***Shekhawati: urbanism in the semi-desert of India- A climatic study,*** published in the proceeding of the 22nd Conference on Passive and Low Energy Architecture, 6th-8th September 2006, Geneva, Switzerland.

4. ***Analysis of Passive design Features for Hot-Dry Climate,*** presented at National level Paper presentation competition during 8th-9th January 2005, at S.V.Institute of Computer Studies, Kadi, Gujarat.

5. ***Knowldege System of Traditional Architecture of Rajasthan- A Case Study of Shekhawati***, presented during the Short Term course on Application of Traditional Architectural Knowledge in Contemporary Indian Architecture from 12th- 16th July, 2004, at IIT Roorkee.

6. ***Don't Assume- Simulate and decide logically***, published in Urjavaran, May 2009 issue.

7. ***Energy Efficient Solutions For Comfortable Indoors In Hot Climates: Lessons From Past Blended With Modern Innovation,*** Published and presented at Global Conference on Renewables and Energy Efficiency for Desert Regions, Amman Jordan, 31st march to 2nd April.