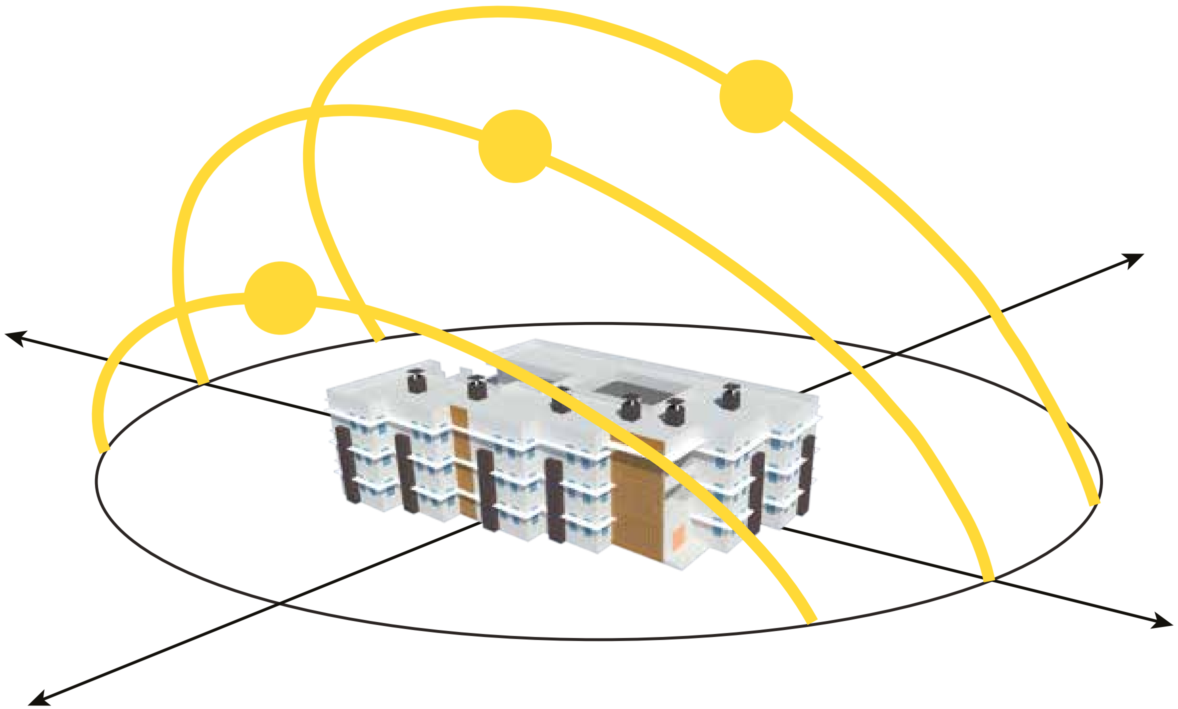
RETHINKING LOW-COST SCHOOLS IN PAKISTAN

SCHOOLS AS A MODEL FOR SUSTAINABLE DEVELOPMENT

ERIKA ALATALO



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Rethinking Low-cost Schools in Pakistan
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Master of Science Thesis in the Master's Programme Design for Sustainable Development

Erika Alatalo

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Examiner: Inger Lise Syversen
Supervisor: Catarina Östlund

Department of Architecture
Chalmers University of Technology
SE-412 96 Gothenburg, Sweden
Telephone +46 (0) 31-7721000

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ABSTRACT

The need to mitigate climate change and environmental degradation is forcing the building industry to rethink the way buildings are designed and built. At the same time there is a need to improve people's lives by reducing poverty and improving equality, and a key element of this development is education. In this context schools can be catalysts that not only educate in the usual sense but also promote sustainable building.

This thesis studies the design of schools buildings in Pakistan and aims to find ways in which they could be made more sustainable. The analysis is based on schools of The Citizens Foundation (TCF), a Pakistani non-profit organization. The aim is to make education more accessible while reducing negative environmental impacts and keeping costs low. Moreover, the design of the schools affects development in Pakistan in a wider scale, and a positive social impact should be strived for.

This thesis is a continuation of another thesis by the same author that studied how the thermal comfort and natural ventilation of TCF schools could be improved from an engineering perspective. Both theses are based on a field study of existing TCF schools. During the field study traditional buildings and reference projects in Pakistan, Bangladesh and Iran were also studied.

The analysis focuses on four themes that have been identified as the design strategies that can make the greatest impact: passive design, building materials, water management and community involvement. The main result is design guidelines that TCF's architects can use when designing new schools, and the results can be used as a reference for other projects as well. A revised design of a TCF school is also made to demonstrate the guidelines, but the aim is not to design a school for a specific location but instead to inspire and to generate further discussion.

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1 INTRODUCTION

This section introduces the background and aims of the thesis. This section also explains how the work has been done and how this report is structured.

BACKGROUND

This thesis has been done in collaboration with The Citizens Foundation (commonly abbreviated as TCF), a non-profit organization that builds and runs primary and secondary schools in Pakistan. The project started with a proposal of collaboration made to TCF. This proposal was developed by the author and a Pakistani doctor who had contacts with TCF, and it consisted of a proposal to design an energy efficient school for TCF. In January 2015 a field study was made to Pakistan in order to meet with TCF and to visit existing school.

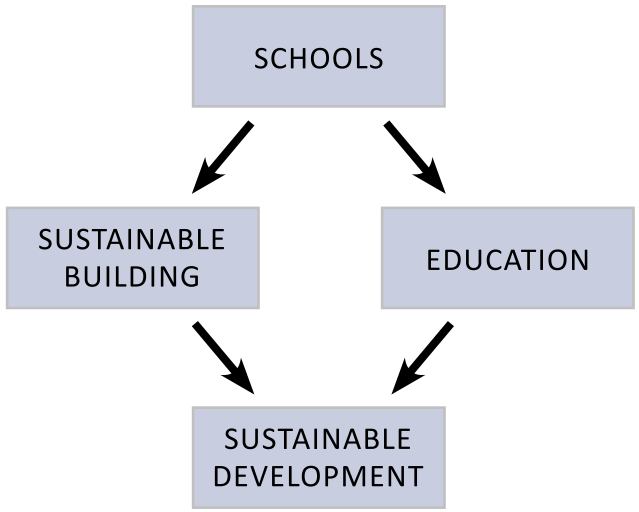
During the field study the focus of the thesis changed when the context was better understood. Problems were identified with the existing school designs, but the designs also had a lot of positive sides and energy efficiency and climatic factors had clearly been considered. Instead of designing a completely new school with a focus on energy efficiency, the task became rethinking the original designs from a wider perspective - studying the weak points of the designs and the schools' impacts in order to find alternative solutions that would make the school buildings more sustainable while keeping costs low and promoting education in Pakistan.

This thesis is based on another master's thesis done by the same author at the Department of Civil and Environmental Engineering. The first thesis studied the thermal comfort, natural ventilation and moisture safety of existing TCF schools in order to find the design strategies best suited to the local climate. This second thesis takes the analysis further and studies the sustainability of the schools from a broader perspective.

OBJECTIVE

The aim of this thesis is to investigate how school buildings in Pakistan could be made more sustainable in order to make education more accessible. Specifically, the aim is to improve schools of The Citizens Foundation, but the results can be used as a reference for other schools in the region as well. The thesis is meant to be used by TCF's architects as a source of inspiration for alternative design strategies. Ecological, economic and social aspects of sustainability are all considered. By considering wider issues, the aim is also to see how school buildings could contribute to sustainable development in a larger scale.

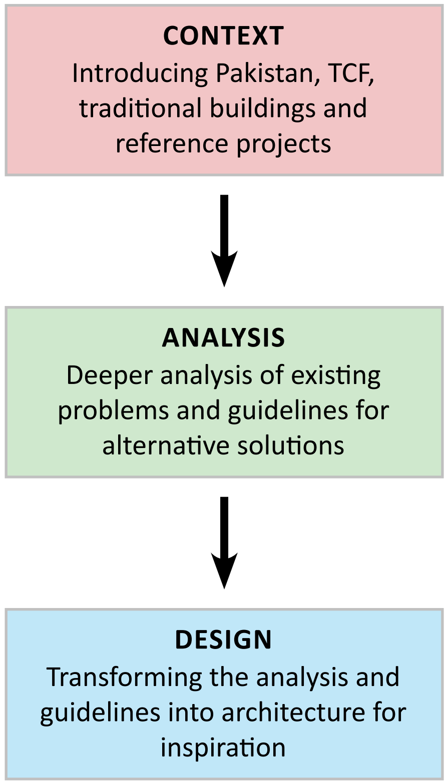
The results of the analysis have been used to develop a revised school design. The purpose is not to design a complete school for a specific location, but instead to show an example of how the theory and analysis can be transformed into architecture. The purpose of the design is also to demonstrate that working with principles of sustainable building can improve the schools without increasing costs. The design proposal aims to generate further discussion and to be an inspiration for new schools in Pakistan.

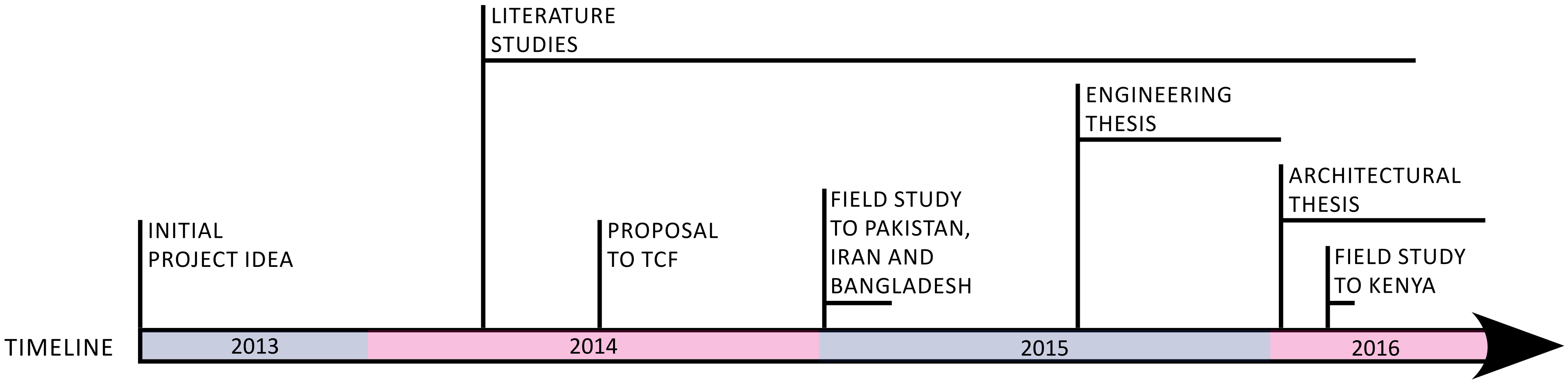


METHOD

The complete project consist of four parts: literature studies, field studies, engineering thesis and architectural thesis. Literature studies have been done to better understand the context and to find alternative solutions. The field study helped define the focus of the thesis based on existing problems and priorities of TCF schools. The engineering thesis looked at issues of thermal comfort and natural ventilation in detail in order to find the strategies best suited for schools in the local climate. The architectural thesis brings together these three parts by analysing the whole issue from a broader perspective, and transforming the results into architecture.

This report consists of three main parts: Context, Analysis and Design. The Context section introduces the background and the main issues that have been identified through literature and field studies. The Analysis section takes the issues from the Context section and studies them in more detail in order to find solutions that can have the greatest positive impact. Lastly, the Design section takes the results of the Analysis and shows an example of how the individual solutions can be turned into architecture in the form of a revised design for a TCF school.





2 CONTEXT

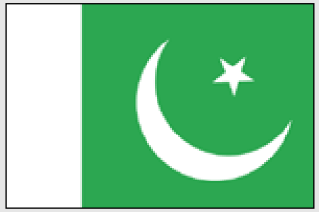
This section presents the basis upon which the analysis and design proposal are founded. In order to study the design of schools in Pakistan, it is crucial to first understand the context that is Pakistan and what challenges are faced in Pakistan, especially in terms of education. Since this thesis is done in collaboration with a non-profit organization (The Citizens Foundation or TCF), it is also important to understand how the organization functions, what are its priorities and what challenges it faces. This section also includes inspirational reference projects and traditional building techniques of the region. The research is based on literature studies and on field studies made in January-February 2015 and February-March 2016.

2.1 PAKISTAN

Pakistan, officially the Islamic Republic of Pakistan, is a country located in South Asia neighbouring India, China, Afghanistan and Iran. With a population of nearly 200 million, Pakistan is the 6th largest country in the world. Pakistan is considered a developing country, and among the challenges it faces are overpopulation, poverty, illiteracy, corruption, terrorism, political instability, environmental degradation, and vulnerability to natural disasters and climate change.

Source: Wikipedia 2016

Capital: Islamabad
Population: 199 085 847
Land area: 796 095 km^2
Population density: 250 people/km^2
Population growth rate: 1.46%
Urban population: 38.8%
Rate of urbanization: 2.81%
Human development index: 0.538
Life expectancy: 66.4 years
Literacy rate: 57.9%
Population below poverty line: 22.3%
GDP (nominal) per capita: $1400



Sources: CIA 2016, UNDP 2015

HISTORY

The area that is modern-day Pakistan has been home to a number of ancient cultures, including the Bronze Age Indus Valley Civilization (2800 to 1500 BCE) that was one of the great civilizations of the ancient world. At the peak of the Indus Valley Civilization the cities of Mohenjo-daro and Harappa were the world's most advanced urban areas in terms of urban planning.

The Indus Valley period was followed by centuries of foreign conquest. First came the Aryans who brought with them the Hindu religion and the Vedic Civilization. This was the followed by the Persian Achaemenid Empire, Alexander the Great's Empire, the Maurya Empire, the Indo-Greek Kingdom, and the spread of Buddhism.

The Arab conqueror Muhammad bin Qasim arrived in 711, bringing with him the religion of Islam. This led to a succession of Islamic Empires, the last of which was the Mughal Empire that lasted from 1526 to 1857 and left a a permanent mark on the culture and architecture of Pakistan.

4500 years ago the Indus Valley city of Mohenjo-daro was one of the world's most advanced urban areas, especially in terms of sanitation.

During the 19th century the territory of Pakistan became part of British India. Hindus and Muslims were united in British India by their mutual resistance of the British, but tensions between the two groups grew on the path to independence. The Pakistan Movement led by the All-India Muslim League resulted in the creation of Pakistan as an independent state and homeland for Muslims on August 14th, 1947. The new country consisted of the territories of West Pakistan and East Pakistan, but East Pakistan separated in 1971 to form the state of Bangladesh.

(Lonely Planet 2016) (CIA 2016)

POLITICS

Political power in Pakistan is concentrated to a small elite, and is mainly dominated by two families: the Bhuttos leading the Pakistan People's Party (PPP) and the Sharifs leading the Muslim League (PML). The military also plays an important role in politics and Pakistan has had four military rulers. (Lonely Planet 2016). Other political pressure groups include the clergy, landowners, industrialists and small merchants (CIA 2016).

Pakistan has a common law system that is influenced by Islamic law. However, the court system is largely ineffective, and tribal courts play a major role in law enforcement. Corruption is a widespread problem in the government and in the police force. (Lieven 2011)

Pakistan has spent a large part of its independent existence in political instability. Military action in neighbouring Afghanistan after the September 11th attacks has played a major role in creating instability in Pakistan. Domestic terrorism has been rising sharply in the last decade with the Pakistani Taliban being the main terrorist organization (Cordesman 2014).

Ever since Independence Pakistan has had a dispute with India over the Kashmir territory, and this dispute has led to many armed clashes between the two nations (CIA 2016). Both countries possess nuclear weapons which makes the situation even more volatile.

President: Mamnoon Hussain (since September 2013)
Prime minister: Nawaz Sharif (since June 2013)

Source: CIA 2016

Tensions between Pakistan and India have been high ever since the two countries were formed. Photo shows the daily Wagah border closing ceremony.

ECONOMY

Pakistan is a developing country, with approximately one-fifth of the population living below the international poverty line of $1.25 per day (CIA 2016). Economic growth has been slow in recent years due to political instability and other issues such as power shortages (CIA 2016). However, Pakistan is considered to be one of the so-called Next Eleven, which means it has the potential to become one of the world's largest economies during the 21st century (Grant 2011).

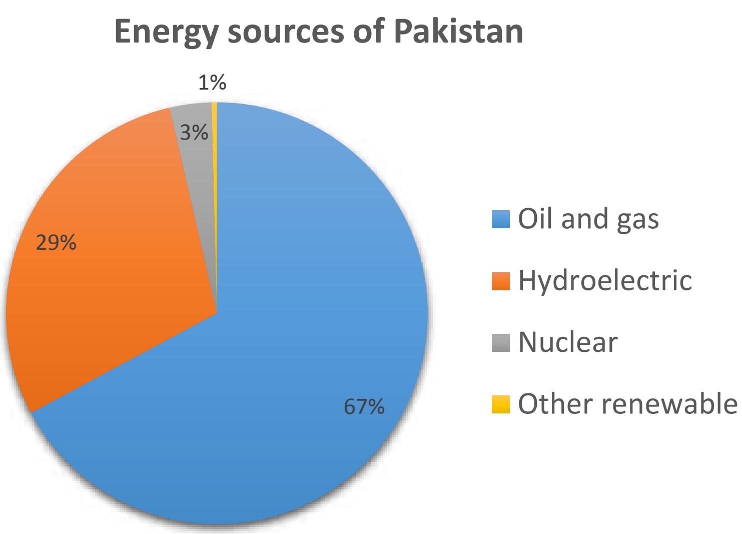
Approximately one half of the GDP is generated by the service sector, with agriculture and industry contributing one-fourth each. Textiles and apparel, food processing, pharmaceuticals, construction materials, paper products, fertilizer and shrimp are the main industries. (CIA 2016). The informal and undocumented economy plays a major role, employing as many as three-fourths of the country's labour force (Mangi 2012).

The unemployment rate is estimated at 6.5%, but substantial underemployment exists, and Pakistan exports a lot of labour force to the Middle East (CIA 2016). Child labour is commonly practiced in Pakistan, and the Human Rights Commission of Pakistan estimates the number of working children to be around 11 to 12 million, half of whom are under the age of ten (Silvers 1996). Bonded labour - a form of slavery - is also widespread, and there are an estimated 2 million slaves in Pakistan, most of whom are working in brick kilns, agriculture and carpet weaving industries (The Global Slavery Index 2016).

The brick industry employs around 4.5 million Pakistanis, but brick kilns are hotspots for bonded labour, also known as debt bondage.

ENERGY

The energy sector in Pakistan relies mainly on fossil fuels and hydropower. But even though two-thirds of the electricity comes from fossil fuels, CO_2 emissions per capita are only 0.9 metric tons, which places Pakistanis as the 139th CO_2 emitters in the world (World Bank 2016). Pakistan receives large amounts of solar radiation throughout the year, and there is great potential for solar power.



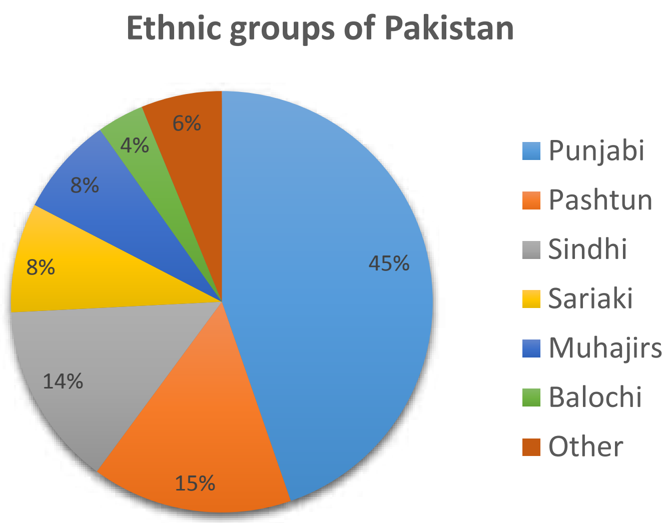
Source: CIA 2016

For years Pakistan has suffered from energy shortages, with the supply not meeting the demand. Power cuts in the form of load shedding can last up to 10 hours per day in urban and 22 hours per day in rural areas (Walsh & Masood 2013). Those who can afford it have backup generators, but for most people in Pakistan this is a luxury they can't afford. The energy crisis is slowing down economic activities and causing public unrest (Kazmi 2013).

The energy crisis is largely a political issue that is made worse by corruption, inefficient power generation and rising demand. The root cause of the problem is unpaid bills and a circular debt that cuts through the whole society and leaves power suppliers with insufficient funds. (Walsh & Masood 2013)

CULTURE

The culture of Pakistan is a mixture of influences from India, Middle East and Central Asia. The vast majority of Pakistanis (96%) are Muslim, and Islam has had an important role in shaping the culture and traditions. (Ministry of Information, Broadcasting & National Heritage 2016). Different ethnic groups have their own traditions, and tribalism plays a major role in shaping customs. The culture is largely male dominated. Different languages are spoken by different ethnic groups, but the national language Urdu is spoken in all parts of the country.



Source: CIA 2016

EDUCATION

Education in Pakistan is compulsory between ages 5 and 16, but in reality there are over 11 million children out of school (UNESCO 2016). The state is required by law to provide free education, but the amount and state of government schools in insufficient, and private schools and non-profit ogranizations play an important role in education. The national literacy rate is approximately 58%, but the literacy rate varies greatly throughout the country and is much lower in rural areas (Tahir 2014).

Women's education plays a key role in development, partly because of the social role women have in raising the family and education future generations (King & Hill 1993). In Pakistan there is a gender disparity in education with boys more likely to receive education (Tahir 2014). The situation has been made worse in recent years in areas controlled by the Taliban, since the terrorist organization has banned the education of girls and is attacking schools that educate girls (The Washington Times 2009). Between 2009 and 2012 there were at least 838 terrorist attacks on schools in Pakistan (GCPEA 2014).

The Pakistani government is unable to provide adequate education, and private schools and non-profit organizations like The Citizens Foundation are needed.

Literacy rate: total 57.9%, male 69.5%, female 45.8%
Government expenditure on education: 2.5% of GDP
Out-of school children of primary school age: 27.0%
Out-of-school children of secondary school age: 47.6%
Expected years of schooling: 7.8 years
Mean years of schooling: 4.7 years

Sources: CIA 2016, UNDP 2015, UNESCO 2016

ENVIRONMENT

The geography of Pakistan varies greatly between desert in the south and the Karakoram mountains in the north. The region is seismically active and especially the north is prone to violent earthquakes. Pakistan suffers from environmental problems such as water pollution, limited freshwater resources, access to clean drinking water, deforestation, desertification, and soil erosion (CIA 2016).

The Global Climate Risk Index (CRI) places Pakistan as one of the ten countries most affected by climate change between 1994 and 2013. Pakistan is particularly vulnerable to extreme heat waves and floods (Kreft et al. 2015). One of the worst natural disasters in recent years were the floods of 2010 that directly affected approximately 18 million people and one-fifth of Pakistan's land area (DEC 2015).

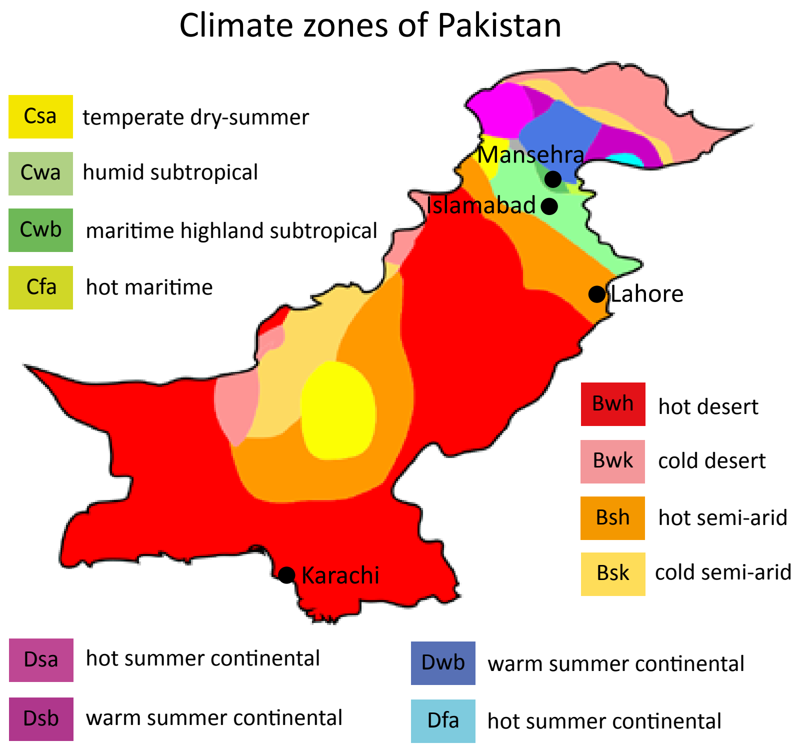
The 2010 Pakistan floods were one of the worst natural disasters the world has seen in recent decades.

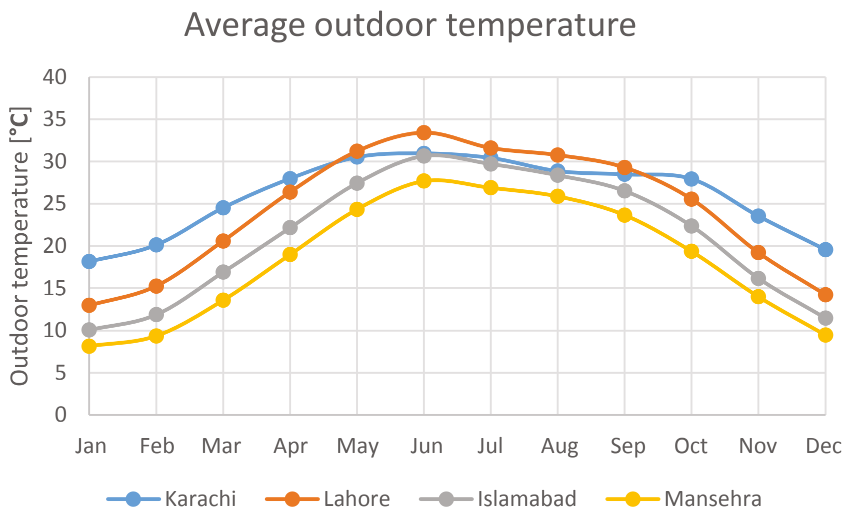
Source: Pakistan Weather Portal 2011

CLIMATE

As the geography varies throughout the Pakistan, so does the climate. The climate of Pakistan ranges from a hot and dry climate in the south to a temperate climate in the north. The main seasons are a cool and dry winter, a hot and dry spring and a hot and wet summer. During heat waves temperatures can reach 50°C (Vidal & Sethna 2013).

Most of Pakistan is subtropical arid or semi-arid and receives rainfall mostly during the monsoon season in June-September. The mountain regions in the north receive snowfall.





Sources: Peel et al. 2007, Alatalo 2016, Wikipedia 2016

2.2 THE CITIZENS FOUNDATION

The Citizens Foundation, commonly abbreviated as TCF, is a Pakistani non-profit organization that aims to improve access to basic education in Pakistan. TCF was founded in 1995 and currently has over 1000 purpose-built primary and secondary schools in over 100 cities and towns all over Pakistan and with an enrolment of 165 000 students (TCF 2016).

TCF believes that fighting illiteracy and educating the masses is the way to fight poverty in Pakistan. Their schools are located where they are needed most, i.e. urban slums and rural areas that are plagued by extreme poverty.

TCF strives for gender equality with 50% female students, and they also want to promote women's employment by hiring only female teachers and principals. In rural areas girls and boys are taught in separate classes, but in urban areas separation starts only in secondary school. Gender separation and female staff are thought to encourage parents to send their daughters to school.

"To remove barriers of class and privilege to make the citizens of Pakistan agents of positive change."
- TCF's vision

Source: TCF 2016

The classrooms and corridors of TCF schools are often filled with educational paintings and posters.

FINANCES

TCF runs on donations, and most of the donations come from Pakistanis who are religiously obliged to donate a part of their income to charity. TCF also has some offices abroad that collect donations. People donate land to TCF and if the location is deemed suitable, TCF builds a school on the land. The schools charge a symbolic fee - $0.1-0.5 per month - because a lot of people don't like accepting charity.

Because TCF both builds and runs the schools, optimal cost-effectiveness during the whole life-cycle is important. However, it is easier for TCF to raise money to build a school than for running it, because one-time donations can cover the costs of building a school.

CONTEXT

STANDARDISATION

TCF classrooms have standardised sizes that are designed to follow international standards, with 30 students in primary and 36 students in secondary school classrooms. The schools also have a library, science lab, computer lab, art room, teacher's lounge and an office for the principal.

The size of individual schools varies depending on whether the school has one or more units of primary and/or secondary school classrooms. Existing schools are sometimes expanded with new units. Some schools are only used during the morning hours, but most schools have two shifts - one in the morning and one in the afternoon - which means that twice as many students can attend the school.

TCF schools have been inspired by traditional buildings, for example schools in Lahore are inspired by the local Mughal Architecture.

Schools around Mansehra in the mountains are very different from the rest of the country because of the colder and rainier climate and earthquake risk.

REGIONAL DESIGNS

TCF has their own architectural office that designs each new school separately but using similar design elements. This makes building new schools faster and cost-efficient and creates a distinct TCF character with simple but functional designs. During the field study schools in Karachi, Lahore, Islamabad and Mansehra were visited, and in each city the schools had their own characteristics.

Locally available materials and climatic conditions are an important design parameter, and TCF's architects have researched traditional architecture for inspiration. Thicker walls and sometimes insulation are used in the north where winters are colder. Schools in the mountains around Mansehra also have a long winter break instead of a summer break because of snowfall.


Schools in Karachi are built with plastered concrete blocks. Pigment is mixed in with the plaster to eliminate future need for repainting.

BUILDING MATERIALS

TCF prefers to use locally available materials because it brings down costs. Aesthetic qualities are important for TCF and because of this the schools are maintained regularly. One of the main priorities for TCF is that the materials used should require little maintenance, because maintenance costs are more difficult to cover than building costs. Indeed, TCF is currently building less new schools than what they used to and one of the reasons is the high maintenance cost of the existing schools. TCF is currently looking into alternative materials that would require less maintenance, such as pigmented concrete and split concrete blocks that have an aesthetic value without plastering or painting.

Despite being more expensive, TCF prefers to use bricks instead of concrete blocks in areas where bricks are easily available, because bricks don't need to be plastered and painted which reduces the need for maintenance. However, during the field study it was found that brick schools around Lahore have severe moisture problems that are causing extra maintenance costs, and this problem could be due to the use of bricks that are not protected from the rain (Alatalo 2016). In Karachi in southern Pakistan concrete blocks are used because the earth is not suitable for bricks, and concrete blocks are also used in Mansehra.

Schools around Mansehra have a problem with concrete cracking due to freezing, and in Lahore there is a problem with the floor cracking as the concrete sets.


Low-maintenance materials are a high priority for TCF. Some existing schools suffer from severe moisture problems which is a major cost for TCF.

THERMAL COMFORT AND VENTILATION

Passive thermal comfort and natural ventilation have been considered in the design of the existing TCF schools, but there is room for improvement, especially in northern Pakistan (Alatalo 2016). Except for some schools in Mansehra, the schools have a high thermal mass which regulates temperatures.

Providing air flow is important both for thermal comfort and for providing fresh air, and this is especially true for crowded classrooms. TCF schools rely on cross ventilation through windows, and each classroom has some windows facing the facade and some facing a courtyard or corridor. This works well when it is hot and windy, but the ventilation has problems during varying weather conditions. In some schools the wind is blocked by neighbouring buildings. Some schools in the north have a smaller ventilator windows above the regular window, and this can provide more air flow during varying conditions.

Schools in Karachi and Lahore have shading devices that are designed to block the sun during the summer and let it in during the winter.

TCF schools rely on cross ventilation through windows, but this often doesn't work as intended.

The field studies were done in January which is the coldest time of the year. In Karachi in the south the schools were quite comfortable at this time, but in the north the schools were uncomfortably cold. The schools are designed to stay cool during the summer which makes them too cold in the winter. Schools in Mansehra in the mountains use gas heaters during the coldest months, but schools in Lahore and Islamabad don't. Because of the cold windows are often kept closed which makes the classrooms stuffy. The combination of cold surfaces and lack of ventilation can also be the cause of moisture problems (Alatalo 2016).

DAYLIGHT

Adequate lighting is important in a school so that the children can see to read properly, and natural daylight is the best kind of light. Because the schools are used only during the day, it should be possible to eliminate the use of electrical lighting.

The windows that are used for cross-ventilation are also the source of daylight. Courtyards also help provide daylight. During sunny weather glare is an issue for the seats located next to the window. On the other hand, during cloudy weather the amount of daylight is reduced. Adequate daylight is more of an issue in northern Pakistan where the sky is cloudier more often, and this is considered in the orientation of the schools.

Maximizing daylight is an important issue because the schools are only used during the day and lights might be unavailable anyway due to power cuts.

One of the design elements that the schools have taken from traditional architecture is the *jaali* lattice window that lets in air and light but blocks heat.

Daylight can be in conflict with other priorities. For example, the sun should be blocked in order to prevent heat from entering, but shading also reduces the amount of daylight. In one school some of the windows had been covered with papers, and this was done because the girls in the classroom needed more privacy.

The schools use a type of lattice window, known locally as *jaali*, that is common in traditional Islamic architecture. These lattice windows let in more diffuse daylight and less direct solar radiation, which reduces the problem with heat and glare. However, the openings would need to be quite large to provide enough light for reading. In existing schools these lattice windows are only used in corridors.

Courtyards and plants are a common feature of TCF schools, and both create a more comfortable indoor environment.

COURTYARDS AND PLANTS

Courtyards and verandahs are a common feature of traditional architecture in the region, and they are also common in TCF schools in Karachi and Lahore. Classrooms are arranged so that they have some windows facing the facade and some facing the courtyard. Verandahs are used to access the classrooms, but the courtyard space itself is not utilized for any activities.

These courtyards enhance ventilation by creating an atrium that draws air out from the classrooms (Alatalo 2016). Courtyards also provide daylight, although this works less well in schools that have more than two floors. The verandahs around the courtyard also help shade the classrooms.

The courtyards have plants, and plants are sometimes also found in corridors and outside by the facade. These plants help clean and cool the air around them. Plants are found in every school, even though watering the plants is challenging and costly in some schools. The classrooms themselves don't have plants however.

TCF schools also have a fenced yard around the school, and this yard is used during breaks and for gathering the children into class. In some schools the yard is shaded with trees but in others the yard is not shaded which makes it less usable. Trees in the yard can also help shade the school building, as well as cool down air before it enters the classrooms. Some yards have a playground. Outside school hours the yard is not used, and the boundary wall is important for safety reasons.

TCF schools have a fenced yard that is only used during the day. In some schools the yard is pleasant and well shaded but in others it is too hot.

For many TCF schools water is a major cost since the schools are often not connected to the tap water network and have to buy water in tanks.

WATER

TCF schools need water primarily for cleaning, bathrooms and watering plants, and approximately 40-60 m^3 of water is used every month. Some schools are connected to the tap water network but a lot of them are not, and these schools buy water in tanks which is a major cost. Many schools in the north in and around Lahore and Mansehra have wells that provide a more self-sufficient source of water. Waste water is treated in septic tanks.

One of the visited schools in Karachi had a different approach to water management, and the school was selling treated water to the local community.

ENERGY

TCF schools use electricity primarily for lighting and ceiling fans. However, because of the energy crisis and frequent power cuts, electricity may or may not be available when it is needed. Some schools have generators, but most schools can't afford it and suffer during power cuts.

Because the schools are only used during the day and because the activities rarely require electricity, energy use is not very high. Because of this, investing in renewable energy such as solar panels would be a major cost that would provide little cost savings later on. It is thus better to focus on passive design and optimizing daylight and passive cooling, thus eliminating the need for electrical lighting and fans.

TCF schools have ceiling fans but because of frequent power cuts the ceiling fans may or may not work when needed.

SOCIAL CHALLENGES

After building a new school, it can be challenging for TCF to get parents to send their children to the school. Uneducated parents, especially those from rural areas, often don't understand the importance of education. And even though TCF is one of Pakistan's leading non-profit organizations in the field of education and well-known in Pakistan, people are sometimes sceptical, thinking for example that the school is run by Americans. In the case of one visited school in Karachi, parents only started sending their children to the school once a local mullah (Islamic cleric) sent his children to the school.

Sometimes there are also land-use conflicts. Urban schools are built next to slums, and the school can be taking land that used to have a different meaning for the community. For safety reasons all schools have a boundary wall and a guard, but this can isolate the school from the community, and it also makes the spaces such as the yard inaccessible, even though the school only uses the spaces during a short time of the day.

TCF school buildings often stand out from their surroundings in terms of design. This is not necessarily a bad thing, and according to TCF children feel proud that they can go to school in such an important building. The design of the schools thus helps raise the status of the schools, and has the potential to both increase the acceptance of the school and to inspire other designs, if the local community are taught to understand how the school and the building function.

Safety is a priority for TCF and the schools have boundary walls and a guard, but this can isolate the schools from the community.

This school was built on a plot that had been used by the local kids to play cricket, and now the school has a problem with kids breaking windows.

2.3 TRADITIONAL BUILDINGS

The climate of Pakistan can be harsh with very high summer temperatures and little rain. And yet people have been living in Pakistan and other similar climates for thousands of years, and they have done so without electricity and mechanical cooling. Over generations of trial and error people have adapted to the climate and learned to build in a way that creates a comfortable indoor climate.

Traditional buildings can teach us a lot about building in a way that fits the local culture and climate. Traditional techniques are not perfect and don't always fit modern life, but understanding these techniques means that the techniques can be improved - facilitating development that is a continuation of traditions.

The examples in this chapter are from Pakistan and neighbouring Iran. In both countries, globalisation and rapid urbanisation have led to a lot of new cities and buildings being built according to Western standards. At the same time the traditional techniques are being forgotten and there is not enough knowledge on adapting these techniques into modern buildings. (Manzoor 1989)

> *"An architect is in a unique position to revive people's faith in their own culture."*
> - Hassan Fathy

Source: Fathy 1986

The houses in Kharanaq, Iran are clustered together to provide protection from dusty winds and to minimize the area exposed to solar radiation.

The traditional town Kharanaq in Iran, for example, was abandoned because electricity couldn't be provided into the houses, and the old town is now falling apart next to the new development. The original Kharanaq was built as a cluster where street were covered and buildings protected each other from the heat and from sand storms.

A more thorough explanation of the different techniques can be found in the author's first thesis at the Department of Civil and Environmental Engineering (Alatalo 2016).

Courtyards were the center of activities in traditional Persian houses, and rooms open towards the courtyard for ventilation.

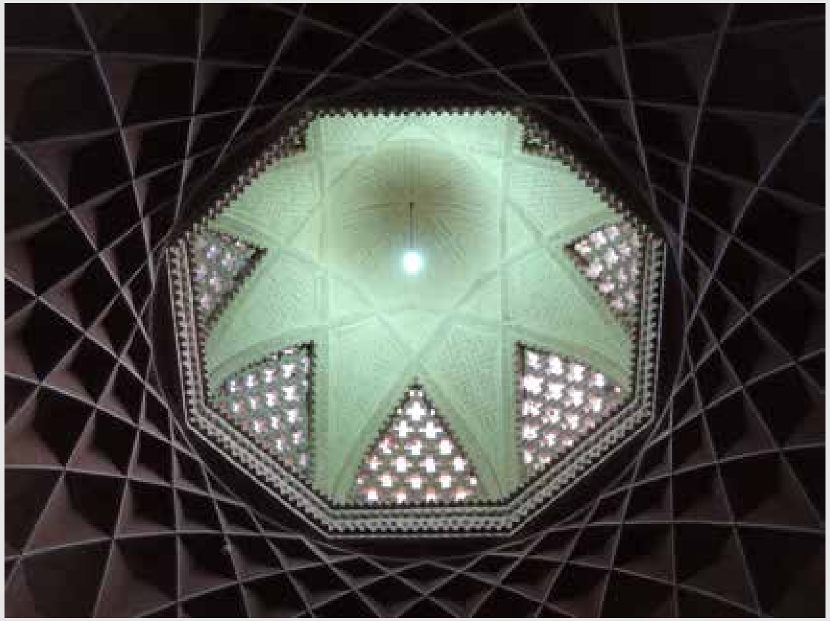
PERSIAN ARCHITECTURE

Traditional houses of Iran are a mixture of techniques that provide thermal comfort and privacy. The houses were often used differently in summer and winter, with some rooms designed to stay cooler than others. The houses were traditionally built with mud or mud bricks with thick walls. (Manzoor 1989). Because there is a large variation in day and night temperatures in the dry climate, thick walls with a high thermal mass regulate temperatures by absorbing heat during day and releasing it during the night.

Most houses had courtyards with verandahs, and the courtyard was the center of activities. Rooms opened towards the courtyard and the street-side was more closed and private. The courtyard thus provided air and light into the houses. Courtyards usually had plants and water elements such as fountains which provided cooling through evaporation. (Manzoor 1989)

Roofs were traditionally either flat or domed. Flat roofs were used for sleeping during summer nights. Domed roofs on the other hand were structurally more efficient and didn't require wooden beams in an area where wood was scarce (Bahadori 1978). Domes also have the benefit of raising the ceiling height, which provides space for hot air above the height where people are.

Some domed roofs had air vents, which are openings that create air flow as the hot air escapes from the top. Wind enhances this effect and pulls air out from the room below, and the shape of domes increases wind speed. (Bahadori 1978)



Domes are a common feature of Persian architecture, and having gaps in the dome enhances ventilation and daylight and adds aesthetic value.

Iranian windcatchers usually have several vertical shafts with openings in different directions.

Possibly the most elegant passive cooling device in traditional Persian architecture is the windcatcher or *badgir*. Persian windcatchers can work in many different ways depending on the design and the weather. Most windcatchers have several shafts facing different directions, and by opening or closing different shafts depending on the wind direction, the windcatcher can either be an air intake (windward side) or an exhaust (leeward side) or both. During calm weather the windcatcher works as solar chimneys that ventilates out hot air. (Alatalo 2016)

Combining windcatchers with water elements provided additional cooling. Iranian desert cities get water through a system of underground aqueducts, known as *qanats*, and some houses are directly connected to these aqueducts. The *qanat* is accessed from the basement and the basement remains cool thanks to the water, the thermal mass of the ground, and the lack of solar radiation. When hot air exits the house through the windcatcher, cool air is drawn into the house from the basement. Windcatchers that work as air intakes can also have a fountain under the windcatcher to provide cooling.

Another advanced passive technique is the Persian ice house. Even though temperatures rarely dropped below 0°C even during winter nights, the Persians managed to make ice in the desert using a phenomenon known as night sky radiation. During winter nights water was placed in a shallow pool that had been kept cool during the day with the help of shading walls. The night sky has a much lower temperature than the air, and because of this heat from the water would radiate to the sky, and as a result the temperature of the water would drop below freezing. (Bahadori 1978)

This fountain is located under a windcatcher, and the water cools down the incoming air through evaporative cooling.

The ice was then stored in an ice house where it lasted until summer when it was used for cooling ice drinks. The ice was stored in alternating layers of ice and insulating hay, and the thick walls of the ice house helped keep the ice from melting. (Bahadori 1978)

The ice house had a domed roof thanks to which the hottest air would remain at the top, far from the ice. At the top there was a hole that was covered with a piece of marble. Because the hole was covered the cool air didn't escape, but because of the marble light could enter the ice house which meant that people entering the ice house didn't have to bring candles that would have heated the space. (Alatalo 2016)

This pool outside an ice house is kept shaded during the day so that it stays as cool as possible. During winter nights water is placed in it to make ice.

The skyline of Hyderabad in the beginning of the 20th century was completely dominated by windcatchers, showing how effective they were.

Source: Insideflows 2015

WINDCATCHERS OF HYDERABAD

Hyderabad is a city in southern Pakistan that used to be known as the city of windcatchers. Photos from the early 20th century show how the city's skyline was completely dominated by these simple ventilation devices that funnelled air into houses. These devices are simpler than Persian windcatchers, but very effective in the local climate.

The windcatchers were traditionally wooden but over time they were eaten by termites (Hyderabad Development Authority 2015). Most people simply stopped using the windcatcher then, favouring air conditioning at a time when electricity was cheap. Because of this windcatchers are rare today.

Hyderabad has a dominant wind from the southwest, and these windcatchers are oriented towards southwest in order to catch this wind. During the rainy season the wind direction changes which means that rain doesn't come in through the windcatcher. The windcatchers were traditionally kept open during the night in summer and during the day in winter, which provided cooling and heating respectively. (Hyderabad Development Authority 2015)

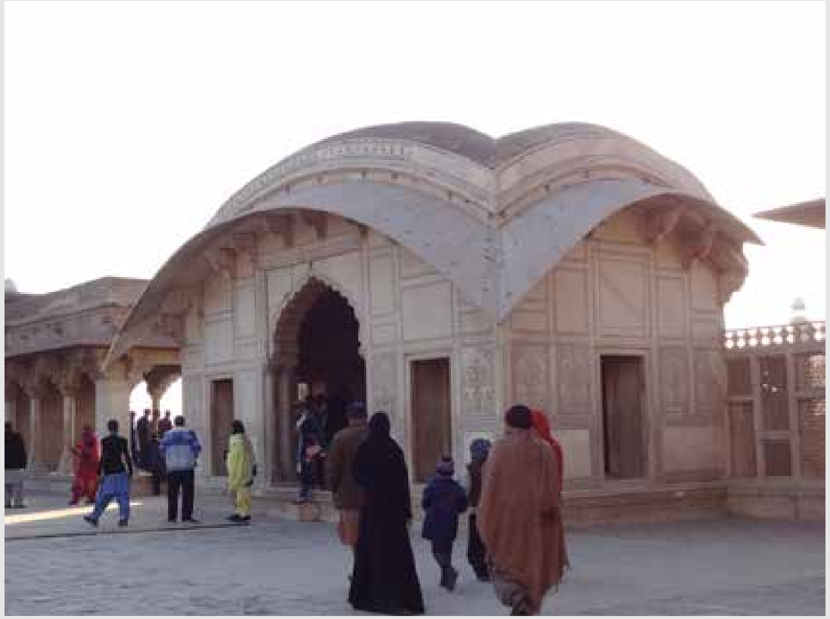
Some people have built new windcatchers out of more permanent materials such as concrete or brick. A visit to the home of a family that still uses their windcatcher showed that windcatchers are not only still in use, but they are also effective and the family was very pleased with how it worked. The house had a ceiling fan but according to the family it wasn't needed. The family hadn't built a permanent windcatcher and instead used just the shaft.

Hyderabad disctrict administartion's office is one of a few modern buildings in Hyderabad that have windcatchers, but they are only decorative.

This decorative modern windcatcher shows that windcatchers can also let in diffuse daylight.

Hyderabad Development Authority has researched the windcatchers but they see them as a part of cultural heritage, not as a technical device that could be used today. There are a few modern buildings in Hyderabad that have windcatchers, but they are only decorative and air conditioning devices can be seen right outside the windcatcher.

Yet bringing back the windcatchers could make buildings much more comfortable, especially now during Pakistan's energy crisis. Using aesthetically pleasing and functional windcatchers in modern buildings could help raise the status of the device and inspire people to start building windcatchers again.



Mughal architecture often includes roof overhangs, which protects the walls from rain and also shades the walls.

MUGHAL ARCHITECTURE

Mughal's ruled the northern part of the Indian subcontinent between the 16th and 19th centuries, and Lahore in Pakistan was one of their most important cities. Mughal architecture is very similar to traditional Persian architecture but with a mix of Indian influences. Some of the techniques used by the Mughals include courtyards, thick walls and latticed screen windows (Ali 2013).

One of the finest examples of Mughal architecture in Lahore is the Shalimar Gardens. The gardens are especially characterized by the use of water and plants to provide evaporative cooling. When water evaporates, it cools the air around it, and plants also have the same effect. Fountains are particularly effective as it speeds up the evaporation process. At Shalimar Gardens there is a water tank outside the garden, and with the help of gravity this water slowly flows through the whole garden.

Water creates comfort in Mughal architecture, and at Shalimar Gardens the king's seat was the place that was surrounded by water from all sides.

2.4 REFERENCE PROJECTS

These reference projects are presented as a source of inspiration for rethinking low-cost schools in Pakistan. In all of these projects design is used as a tool to improve people's lives. These projects show that design based on local traditions and conditions is more sustainable and can empower the locals.

This heritage house was designed by Yasmeen Lari and built to demonstrate to the locals how they could use traditional materials and techniques today.

Yasmeen Lari has promoted the use of traditional materials such as earth and bamboo as a sustainable and low-cost solution to disaster relief.

Source: Al Jazeera 2014

YASMEEN LARI AND THE HERITAGE FOUNDATION

Yasmeen Lari is one of Pakistan's most well-known architects and she was the country's first female architect. In 1980 she co-founded the Heritage Foundation of Pakistan that among other things promotes vernacular building techniques such as earth and bamboo. In recent years she has been active in disaster relief, helping victims of natural disasters such as floods and earthquakes build new homes using vernacular techniques. These houses have a small environmental footprint and they are cheap and easy for people to build themselves, thus providing housing quickly after natural disasters. Using local knowledge and labour also creates employment opportunities for the local people. (Al Jazeera 2014) (Heritage Foundation of Pakistan 2016)

Through knowlwedge sharing and participation, a group of local unskilled labourers became a team with independent projects and goals.

A COMMON TOMORROW

A Common Tomorrow is a ongoing project in Kisumu, Kenya that started as student project for the course Reality Studio at Chalmers University of Technology. The project is located in the village of Kajulu on the outskirts of Kisumu on a plot owned by Make Me Smile, a local non-profit organization that mainly works with children. The project shows how community involvement can benefit both the community and the NGO.

The initial stage of the project was to turn the project site into a site that promotes permaculture, organic farming and sustainable construction. A group of local men were hired to help with the labour, and through sharing of knowledge and ideas, the men started taking more responsibility and eventually they took ownership of the project. After the initial stage, the men formed a group, Team Rarudi, that could continue the project and further employ themselves. The group received a microcredit from Make Me Smile and with it they have started new projects on the site, aiming to become independent. The group has also grown with female members.

The long-term plan of Make Me Smile is to turn the site into a rescue center for street children. By involving the community in the development of the land, the NGO has gained the respect of the community and this will make the site safer for vulnerable children. The idea is to continue the involvement of the community in the construction of the rescue center, which will also reduce costs. In this way community involvement in the project is benefitting the NGO.

One of the projects Team Rarudi has started on the site with the microcredit is beekeeping, and they are waiting for the bees to start producing honey.

METI Handmade School revived the local villagers' interest in earth buildings by using the traditional material in a new and improved way.

METI HANDMADE SCHOOL

METI Handmade School in Rudrapur, Bangladesh was also visited during the field studies. METI is a rural school that was built in 2004 and is often considered a good example of sustainable development and building in South Asia. The school is run by a non-profit organization called Dipshikha that has several educational programs, one of which is METI (Modern Education and Training Institute). The Dipshikha campus in Rudrapur also has a second earth school building, known as the DESI (Dipshikha Electrical Skill Improvement) school.

METI and DESI are built with earth, straw and bamboo, and they revived the local people's interest in traditional building materials that were before seen as backward. Bangladesh has a tradition of earth building but the traditional earth buildings have short lifespans. In this project the traditional materials were used in a new and improved way, raising the status of the material and creating spaces that couldn't be made with other materials such as playful caves in the preschool classrooms. (Lepik 2010)

The schools were built with the help of local labour and the students themselves, and METI was finished in just four months. The students are also responsible for cleaning and maintaining the buildings. (Dipshikha 2015). After building METI the architects also did a project with the villagers showing how they could improve their own earth houses, in particular by building a second floor which is important in densely populated Bangladesh (Heringer 2014).

DESI is a later earth school in Rudrapur that took the concept even further and created and even more unusual building out of earth.

Earth buildings have a problem with erosion caused by rainwater and in this case the buildings are made more durable by mixing straw with the earth, forming cob (Lepik 2010). The DESI building has pieces of bamboo sticking out from the walls and these slow down rainwater runoff which also slows down the erosion of the wall. The buildings also have a brick foundation and there is a plastic moisture barrier between the bricks and the earth walls (Lepik 2010).

The windows of the upper floor classrooms have shades made of bamboo. When the shades are closed, air still flows in and out through the shade but solar radiation is mostly blocked. Daylight enters through gaps in the shades in a beautiful way, and even when most of the shades are closed there is enough daylight coming into the classroom.

In DESI school the budget was higher but instead of investing in more expensive materials, more money was put into craftsmanship and the local labour.

Bamboo shades and colorful saris add aesthetic value to the otherwise simple classrooms, and they also help ventilate the space.

Traditional earth houses in Bangladesh have hay on the roof which insulates the house from solar radiation but let's air flow through. However, newer earth houses in Bangladesh often have steel roofs, and if this roof is not properly ventilated, the house can become very uncomfortable when the heat from the steel radiates onto the people.

In METI Handmade School the roof is made of steel but in the interior ceiling there are hanging sari fabrics. The saris not only make the space more colourful but also block the heat from the steel from radiating into the room. The space between the steel and the fabrics becomes very hot, which creates pressure differences and air flow with the hot air exiting, and thus the classroom underneath is ventilated.

3 ANALYSIS

This section goes deeper into analyzing the issues introduced in the previous section. A systems mapping illustrates the connection between the different issues previously identified. From this system analysis four focus areas have been identified as the design components that can have the greatest impact. These focus areas are passive design, materials, water management and community involvement, and each is studied in detail, including the basic concepts, the existing challenges and possible alternatives. These four themes are also linked in many ways. The analysis is meant to be used as a reference when designing new TCF schools, and it can be used as a reference for other projects as well.

3.1 SYSTEMS ANALYSIS

Design choices affect what impact buildings have on the environment and on the society. The impact of TCF schools has been assessed through a systems analysis that includes the main environmental and societal elements that the schools impact and vice versa. A change in one element creates changes in the rest, and the most important elements are explained below. The right design can create positive change in the system and contribute to sustainable development.

CLIMATE CHANGE

Even though Pakistan's own contribution to climate change is very small, Pakistan is very vulnerable to the effects of climate change. Climate change affects many parts of the wider system negatively, and thus mitigating climate change should have high priority.

RESOURCE DEPLETION

Another major environmental problem is the depletion of natural resources on a limited planet. Buildings use resources directly as building materials but a lot of resources are also used indirectly, such as firewood. One of the most important resources in most danger is water.

INDOOR ENVIRONMENT

Indoor environment is a measure of how comfortable indoor spaces are in terms of temperature, air flow, lighting and acoustics. A good indoor environment is healthy, improves concentration and productivity, and makes indoor spaces more enjoyable.

RESILIENCE

Resilience relates to climate change adaptation and measures the system's ability to respond to changes. A resilient society can function even during extreme events such as floods and heat waves. In the same way buildings need to be resilient to such changes.

BASIC NEEDS

Basic needs refer to elements that are fundamental for human survival, such as food and shelter. If basic needs are not fulfilled, other needs such as education can become neglected.

POVERTY

Poverty is closely related to basic needs, and poverty can be defined as the level below which basic needs cannot be met. Poverty reduces access to basic needs, and it forces people to go to desperate means in order to fulfil those needs.

EDUCATION

Education increases awareness of other issues which has a positive effect on the whole system. Education also creates skills that can be used to find employment which reduces poverty and improves access to basic needs.

COST OF SCHOOLS

The cost of schools includes the construction costs, running costs such as electricity and maintenance costs such as painting. The cheaper the schools are to build and run, the more schools can be built and more children will have access to education.

LEGEND

RED TEXT Negative element

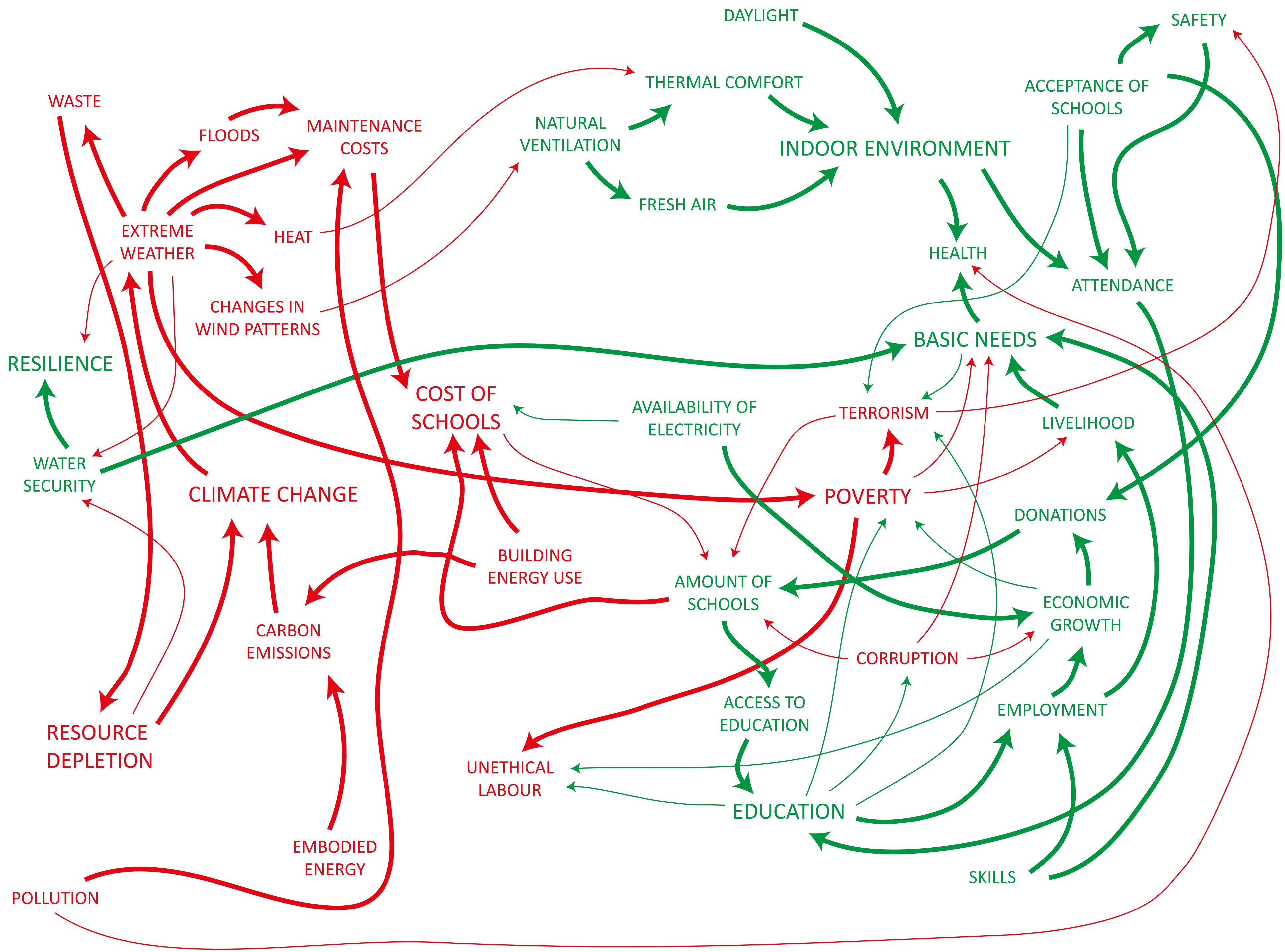
GREEN TEXT Positive element

Desired increase

Desired decrease

Undesired increase

Undesired decrease



IMPACT OF DESIGN

SUSTAINABLE DESIGN

The goal of sustainable design is to create positive change in the system. Some design solutions contribute to sustainable design while others don't, and the key to finding the most appropriate solutions is understanding how design solutions affect the system.

MECHANICAL COOLING

Mechanical cooling and ventilation improve comfort and the indoor environment, but because they require energy they increase carbon emissions, electricity costs and equipment costs. Mechanical devices are also unreliable due to power cuts.

PASSIVE DESIGN

Passive design also creates comfort, but it reduces energy use which lowers costs and carbon emission and leaves more energy available for things that need it more. Passive design also improves resilience by forcing people to adapt to variations in indoor climate.

RENEWABLE ENERGY

Renewable energy improves resilience and mitigates climate change and it can also save costs. However, since passive design is cheaper and the schools use very little energy otherwise, investing in renewable energy and the required equipment is less profitable in this case.

WATER MANAGEMENT

Water is one of the most important natural resources required for human survival, and climate change and environmental degradation are threatening water security. Water management strategies can improve water security and also reduce the need to buy water.

INDUSTRIAL MATERIALS

Industrial production of materials requires a lot of energy, which creates carbon emission and pollution. Industrial materials usually also use more resources like water. In some cases industries also use unethical labour like slaves or child labour.

LOCAL MATERIALS & CONSTRUCTION

Using local materials and construction reduces material costs but increases labour costs which means the money goes more directly to the people. This reduces the environmental impact and can give the local people new skills and employment.

DURABLE MATERIALS

Using durable materials reduces the need for maintenance which reduces costs, even if the material is initially more expensive. Using durable materials also reduces the amount of waste. Climate change makes durable materials more essential due to damage by natural disasters.

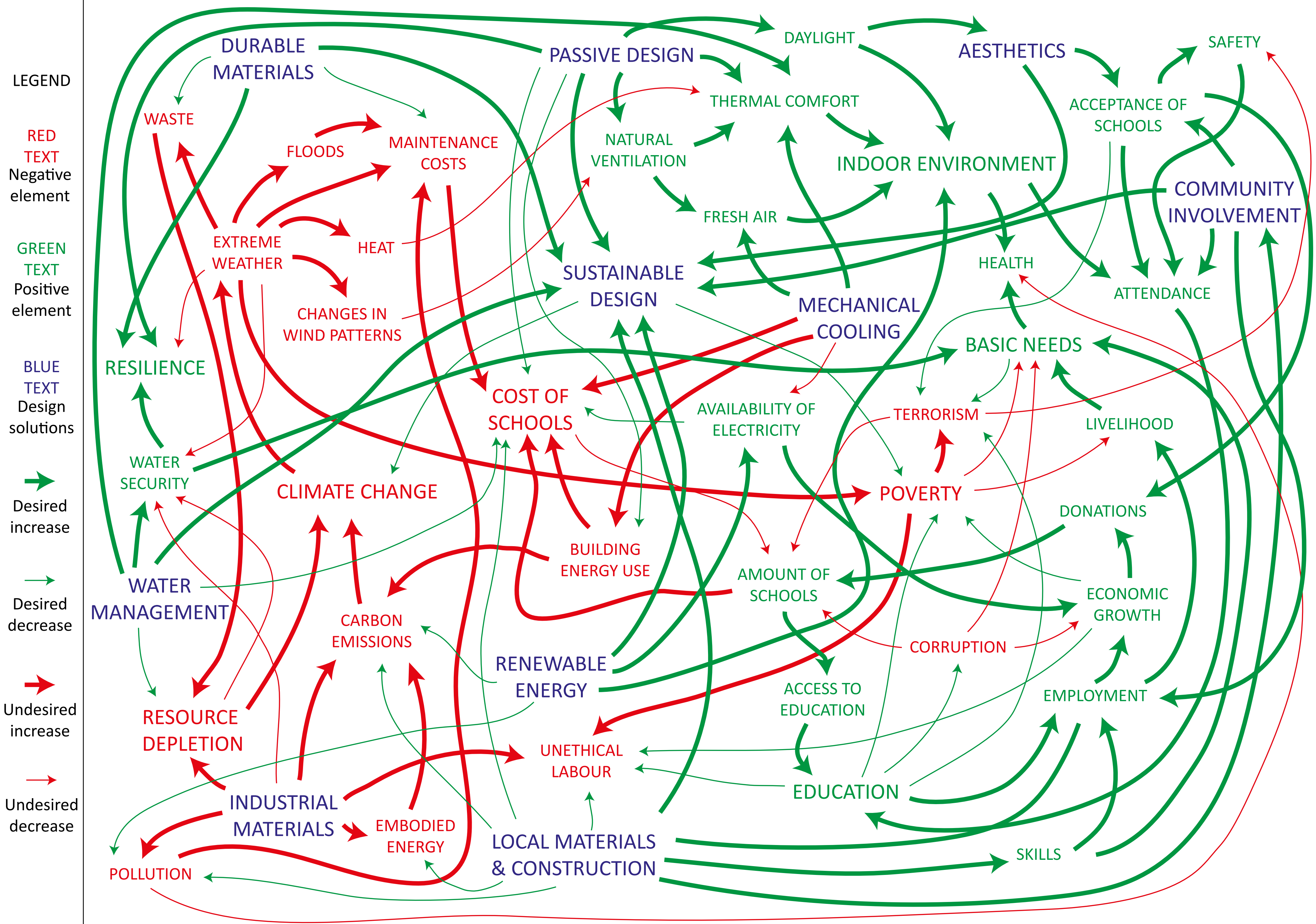
COMMUNITY INVOLVEMENT

If the local community is involved in the school project in different ways - such as through participatory design or use of local labour - it can not only benefit the community, but it can also improve the acceptance of the schools and of education.

AESTHETICS

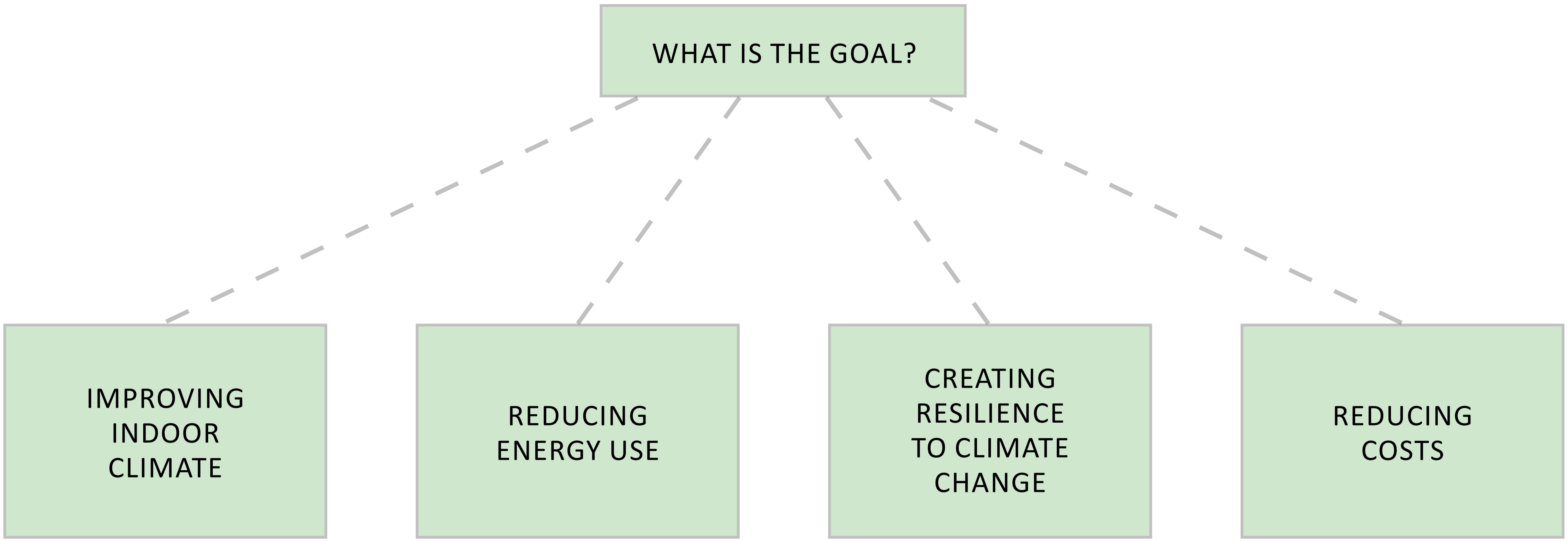
Beautiful design can raise the status of the schools among the local people, and can make kids proud about going to school. Aesthetics can also promote sustainable building techniques and traditional materials and techniques that are seen as backward.

→ Focus areas for maximum positive impact: **PASSIVE DESIGN, MATERIALS, WATER MANAGEMENT & COMMUNITY INVOLVEMENT**


LEGEND
RED TEXT Negative element
GREEN TEXT Positive element
BLUE TEXT Design solutions
Desired increase
Desired decrease
Undesired increase
Undesired decrease
DURABLE MATERIALS
PASSIVE DESIGN
DAYLIGHT
AESTHETICS
SAFETY
WASTE
FLOODS
MAINTENANCE COSTS
THERMAL COMFORT
NATURAL VENTILATION
ACCEPTANCE OF SCHOOLS
INDOOR ENVIRONMENT
COMMUNITY INVOLVEMENT
EXTREME WEATHER
HEAT
FRESH AIR
HEALTH
SUSTAINABLE DESIGN
ATTENDANCE
CHANGES IN WIND PATTERNS
MECHANICAL COOLING
RESILIENCE
BASIC NEEDS
COST OF SCHOOLS
AVAILABILITY OF ELECTRICITY
TERRORISM
LIVELIHOOD
WATER SECURITY
CLIMATE CHANGE
POVERTY
DONATIONS
BUILDING ENERGY USE
WATER MANAGEMENT
AMOUNT OF SCHOOLS
ECONOMIC GROWTH
CARBON EMISSIONS
RENEWABLE ENERGY
CORRUPTION
ACCESS TO EDUCATION
EMPLOYMENT
RESOURCE DEPLETION
UNETHICAL LABOUR
INDUSTRIAL MATERIALS
EDUCATION
EMBODIED ENERGY
LOCAL MATERIALS & CONSTRUCTION
SKILLS
POLLUTION

3.2 PASSIVE DESIGN

Passive design refers to building in a way that creates a comfortable indoor climate without needing to use mechanical cooling, heating, ventilation and lighting. This section presents basics of passive cooling in hot-dry climates, and ways in which the passive design of TCF schools could be improved. The thermal comfort and ventilation analysis is largely based on the author's previous thesis at the Department of Civil and Environmental Engineering.

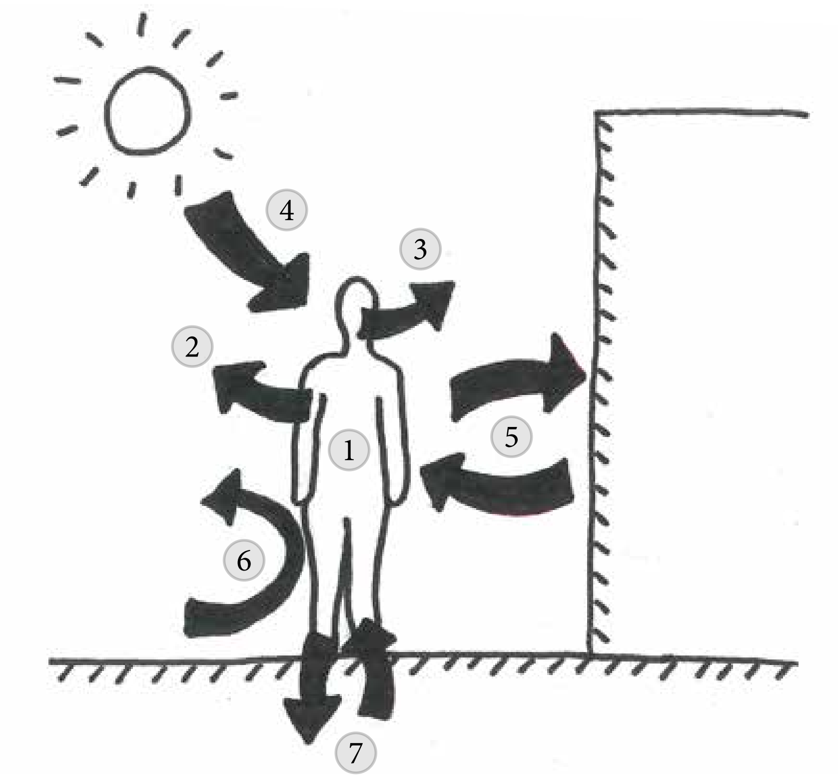


THERMAL COMFORT

1 The human body is constantly generating heat due to metabolic activities. In order to stay comfortable, this heat needs to be dissipated to the surrounding environment. Comfort is determined by a combination of air temperature, air flow, surrounding surface temperatures, clothing and activity rate. As the temperature difference between the body and the surroundings becomes smaller, less heat is dissipated by the body and the person feels more uncomfortable.

2 Evaporation of sweat requires energy which thus has a cooling effect, and sweating is one way the human body dissipates heat. In a humid climate, the rate of evaporation is slower, which causes more discomfort at the same air temperature.

3 The body also loses heat through perspiration, when hot air is exhaled and cooler air is inhaled.



4 People gain heat from the sun directly through solar radiation. In hot-dry climates the sky is usually clear, and this makes solar radiation very strong during the day.

5 The temperature of surrounding surfaces affects comfort through long-wave heat radiation. Hot surfaces radiate heat unto people, while people lose heat by radiating heat onto cooler surfaces.

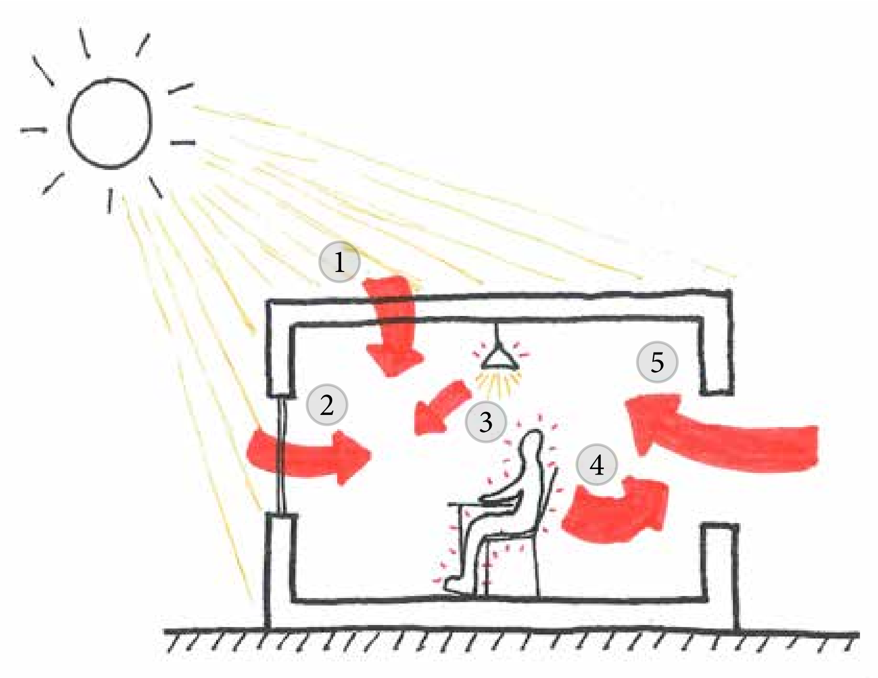
6 Air flow increases the rate of evaporation of sweat by removing humid air from the skin. Air flow also removes heat from the skin through convection. Because of this, air flow improves comfort in hot climates, especially if the air is humid.

7 People also lose and gain heat through conduction to and from the ground and other surfaces people are in direct contact with. People gain heat from hotter objects and lose heat to cooler objects.

HEAT SOURCES

(1) Heat enters buildings through the walls and roof when the exterior surface is hotter than the interior. The amount of heat that enters this way depends on more than just the air temperature. If the external surface is receiving direct sunlight, it will become very hot and more heat will enter the building. On the other hand, if the weather is windy and there is a lot of air flow by the external surface, this will reduce the surface temperature and the subsequent heat gain.

(2) Direct and diffuse solar radiation enters buildings through windows as solar heat gain. However, not all the solar heat energy that hits a window passes through the window and some of it is reflected. Windows with a low g-value or solar heat gain coefficient reflect more solar energy and reduce heat gains through windows.



(3) Heat is generated indoors by electrical equipment such as lighting. Using energy efficient equipment reduces these internal heat gains.

(4) As described before, people are constantly generating heat due to metabolic activities, and this heat needs to be dissipated from the body, which will result in heating the indoor environment.

(5) Ventilation creates heat flow by moving hot air from one place to another. If the outdoor air is hotter than the indoor air, ventilation brings heat into the building. However, ventilation can still improve comfort by creating air flow.

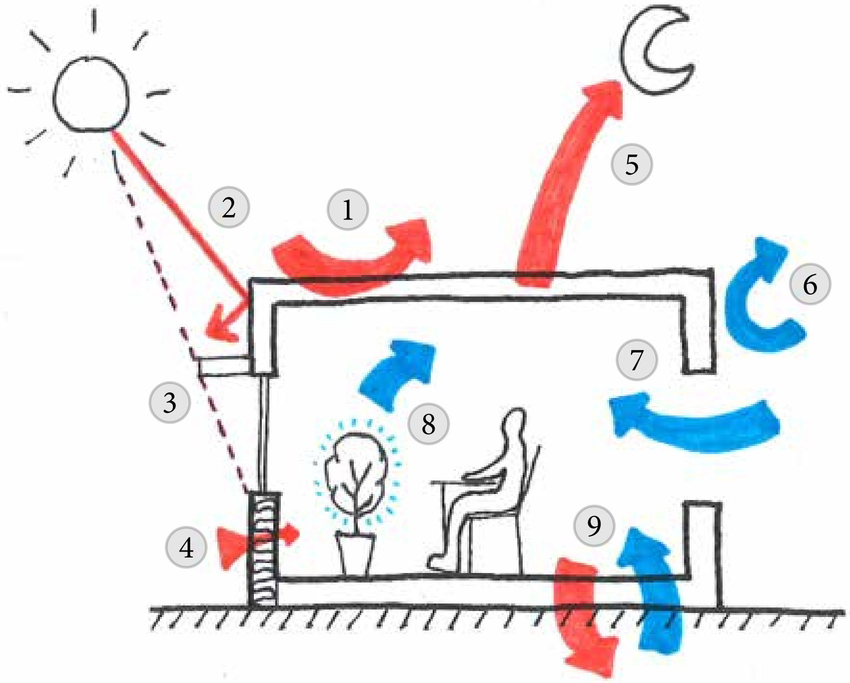
HEAT REGULATORS

(1) Materials with a high thermal mass can absorb a lot of heat energy before their temperature rises. These materials absorb heat during the day and release heat during the night. There has to be a significant temperature difference between day and night in the climate, and the achieved indoor temperature is close to the daily average outdoor temperature.

(2) Light colors reflect direct solar radiation more than dark colors. Light colors on exterior surfaces reduce the amount of heat entering through the building envelope by reducing the surface temperature. The effect is particularly noticeable on the roof, because the roof receives the most solar radiation.

(3) Shading blocks solar radiation from entering through windows and other openings. Shading elements can be designed so that they block the sun during the hot summer months, but allow the sun to penetrate during the winter months when the sun is lower.

(4) Insulating materials block heat from entering and leaving through the building envelope by slowing down convection of heat.



(5) During the night buildings lose heat when the outdoor temperature is cooler than the indoor temperature. Especially the roof loses a lot of heat due to heat radiating to the night sky which has a much lower temperature than the air.

(6) Exterior surfaces get very hot in the sun, and wind cools buildings by removing heat from surfaces through convection.

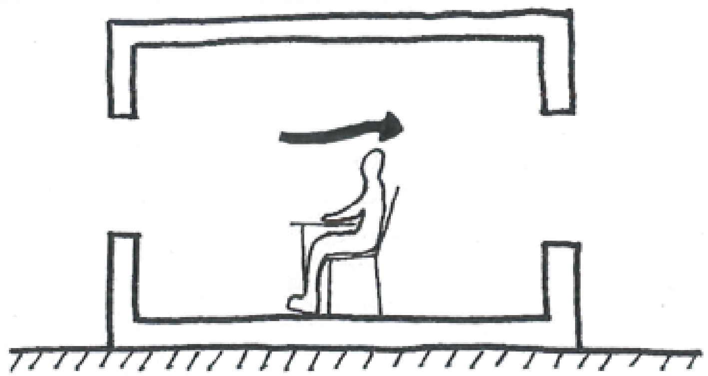
(7) Heat can be either gained or lost through ventilation, depending on the temperature difference between outdoor and indoor air.

(8) When water evaporates it cools down the air around it. This can be used to cool buildings and is called evaporative cooling. Plants have the same cooling effect due to the process of evapotranspiration.

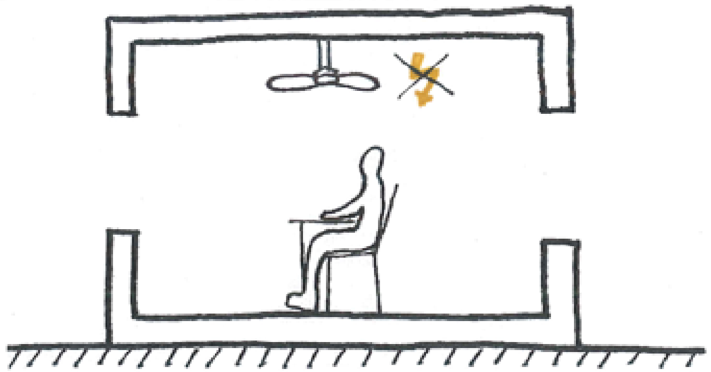
(9) The ground acts like a large thermal mass that can absorb heat during the summer and release it during the winter. The temperature of the ground is close to the average yearly outdoor air temperature.

EXISTING SITUATION

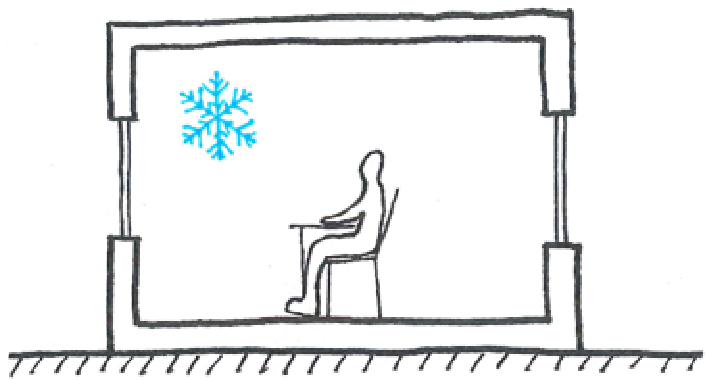
Unless the weather is very windy, natural ventilation is rarely strong enough to create enough air flow to have a cooling effect.

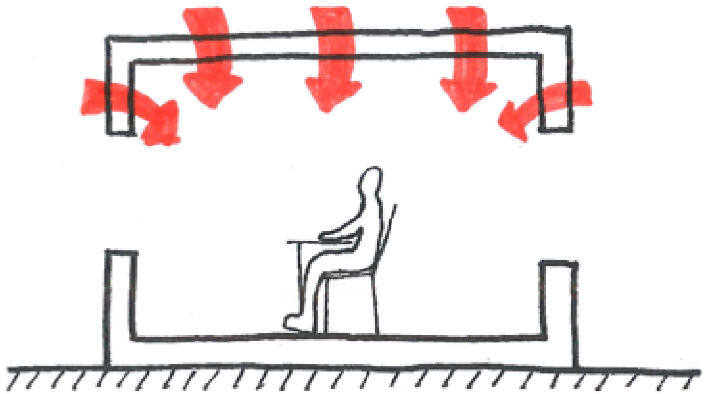


TCF classrooms have ceiling fans, but since they rely on electricity, the ceiling fans don't work during power cuts.

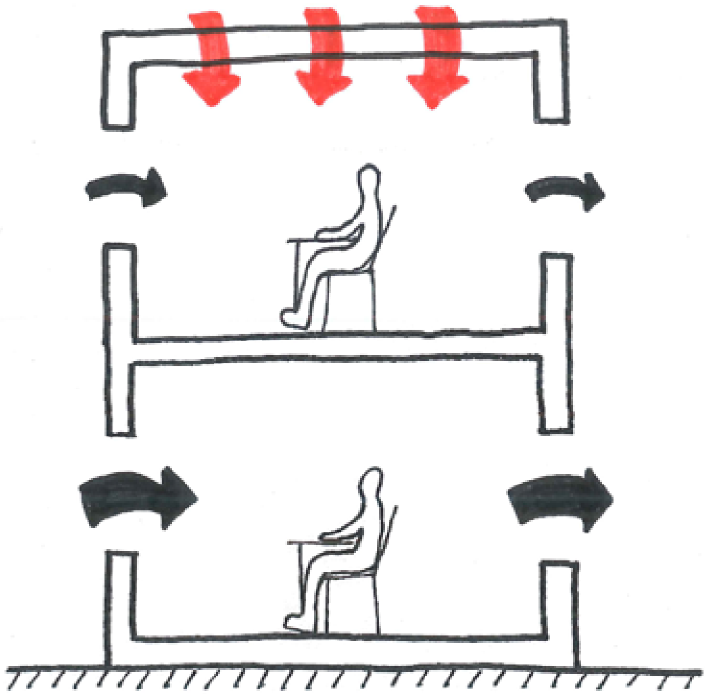


Schools in northern Pakistan are very cold during the winter months, especially in the mornings.





The sun is very strong and surfaces that are not shaded get very hot during the day. Because of this a lot of heat enters the building through the walls and especially roof, even though most schools have relatively light colors.



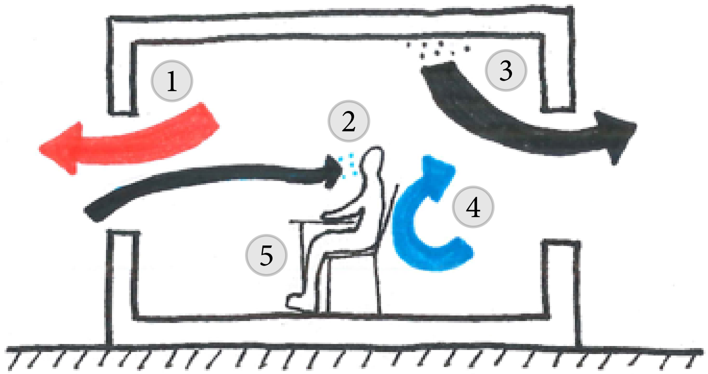
The second floor is hotter than the first floor. This is because the second floor receives heat through the roof. In schools that have courtyards, the air flow is also lower on the second floor, which reduces heat losses.

VENTILATION

(1) Ventilation is needed to remove heat that would otherwise accumulate indoors, such as heat created by people.

(2) Ventilation provides fresh air and oxygen while removing carbon dioxide and moisture created by perspiration.

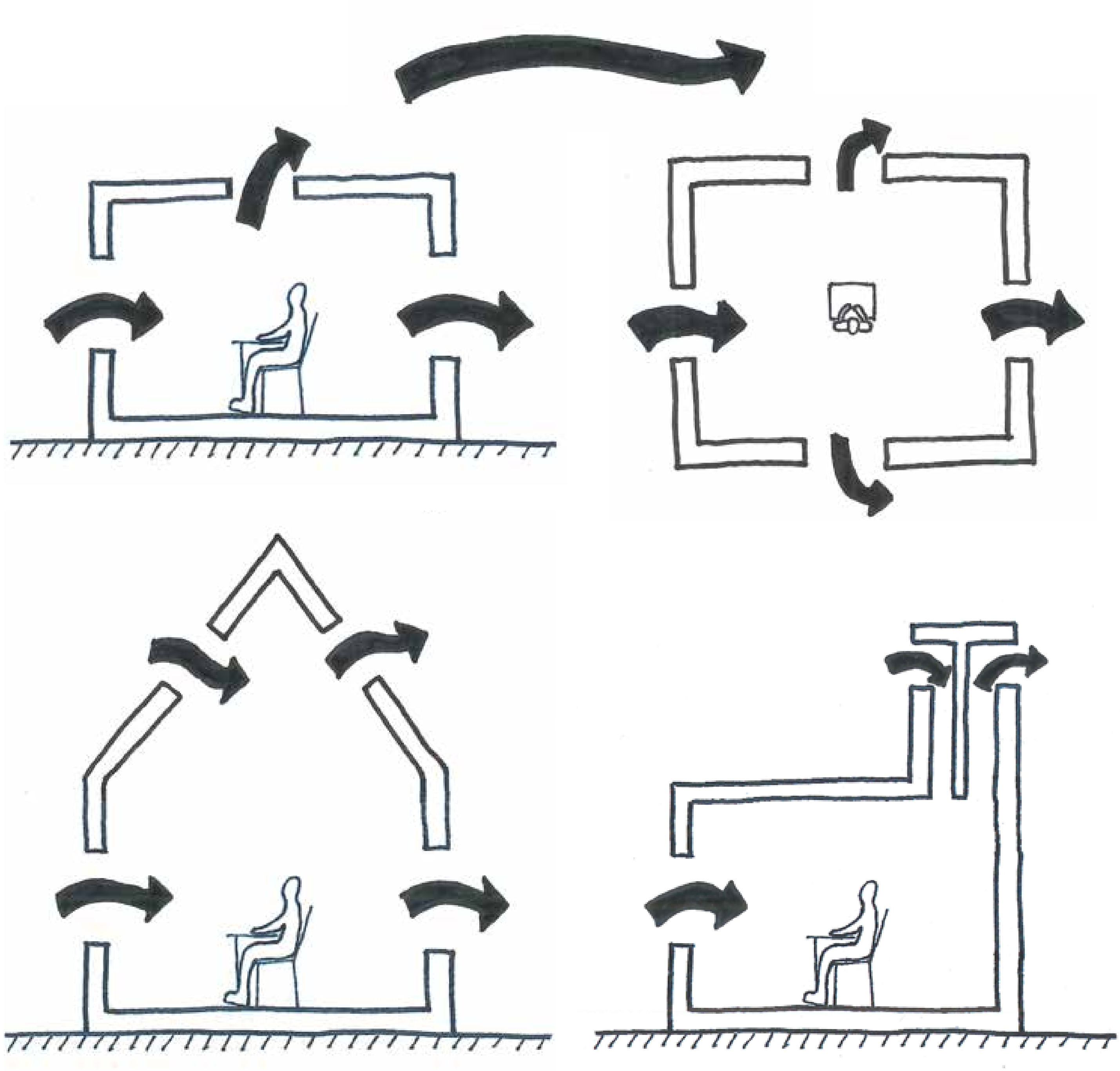
(3) Ventilation removes harmful substances that are emitted indoors from building materials, furniture and people.



(4) Ventilation creates air flow, which increases comfort in hot climates.

(5) The desired ventilation rate is determined by the size of the room and how many people are using the room. Adequate ventilation is thus especially important in schools, because classrooms are small spaces used by many people at the same time.

NATURAL VENTILATION: WIND



Wind creates pressure differences around the building. This pressure difference creates air flow through the building, by drawing air in from one side and out from another.

On the windward side a positive pressure is created and this pushes air into the building. On the leeward side a negative pressure is created that pulls air out of the building. On flat roofs a negative pressure is created, but on a sloped roof the windward side has a positive pressure and the leeward side a negative pressure.

Windcatchers can act as either an air intake or an exhaust, depending on whether the opening is facing the windward or leeward side. Windcatchers that have several shafts can act as both the exhaust and intake simultaneously, but this is not desirable because much of the air that enters through the windward shaft will immediately exit through the leeward shaft without passing through the room. It is better to have a control system so that shafts can be opened and closed, depending on the wind direction and the desired air flow.

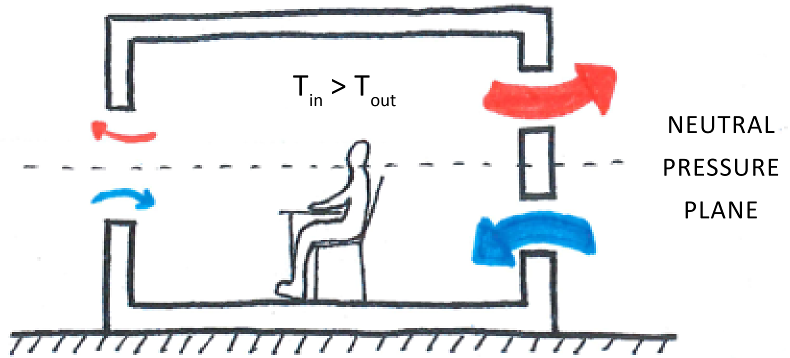
NATURAL VENTILATION: STACK EFFECT

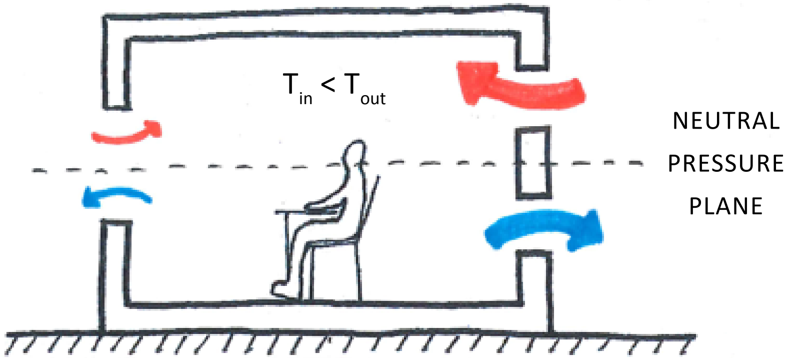
Hot air is lighter than cold air which causes hot air to rise. This phenomenon - known as stack effect - can be used to ventilate buildings in the absence of wind when there is a temperature difference between indoor and outdoor air.

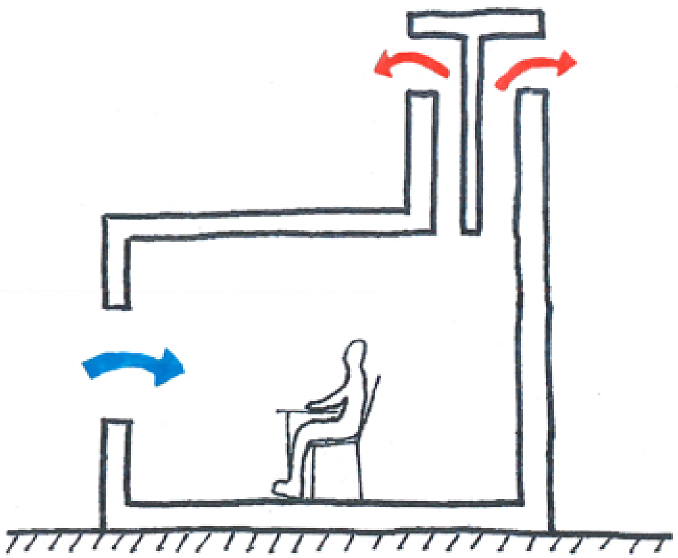
When the indoor air is warmer than the outdoor air, cold outdoor air will enter through lower openings and hot air will exit through higher openings. When the outdoor air is warmer, the reverse is true.

At the height of the neutral pressure plane there is no air flow. In order for the stack effect to be useful, there needs to be openings at different heights, some above and some below the neutral pressure plane. The further an opening is from the neutral pressure plane, the greater the air flow is. If all openings are located at the same height, the neutral pressure plane will also be at that height and there will be very little air flow.

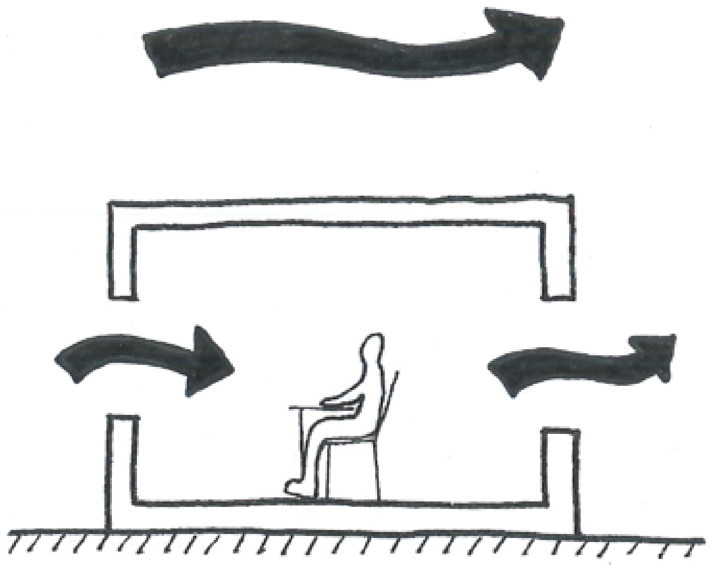
Windcatchers also ventilate using the stack effect by acting as solar chimneys. The tower is exposed to a lot of solar radiation which raises its temperature, and this causes air to flow up the tower while cooler air enters through lower openings.



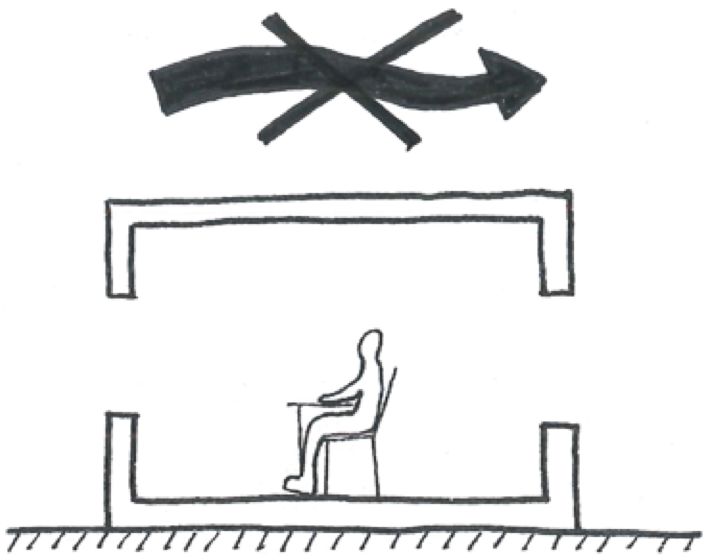




EXISTING SITUATION

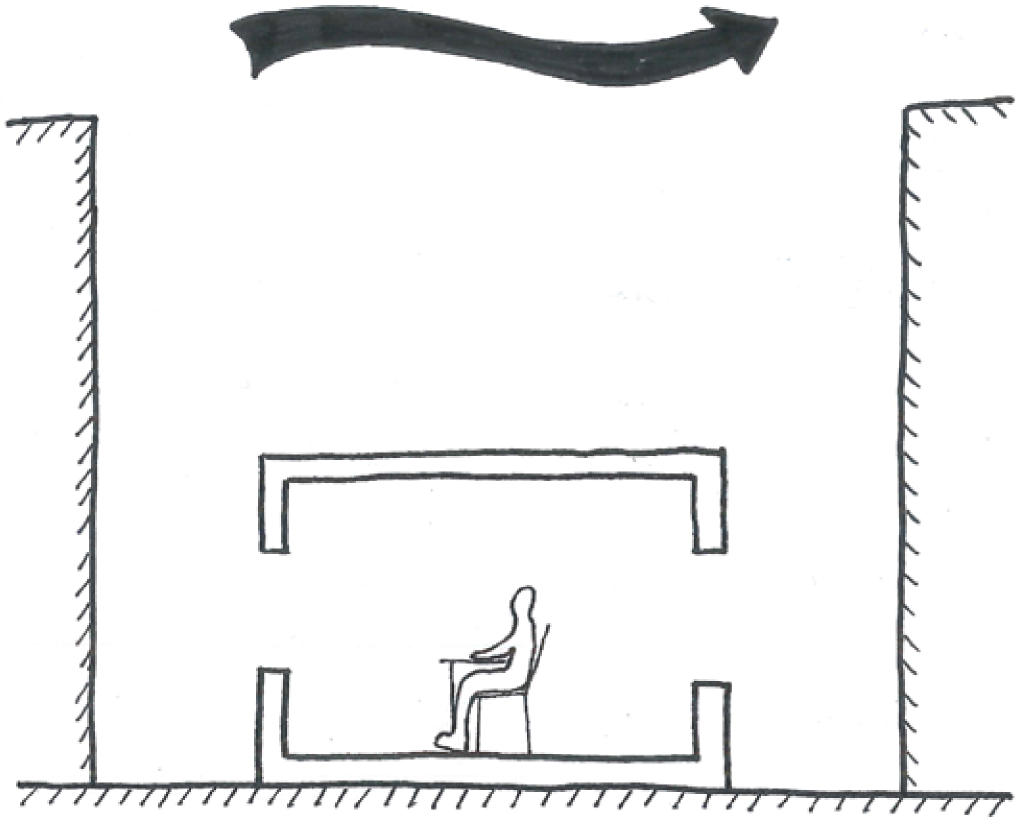


Existing TCF schools rely on wind driven cross ventilation through windows. Windows are placed on two sides of the classroom and the school is oriented to catch as much of the dominant wind as possible. This strategy works well when there is a fairly constant wind but is more challenging when the conditions vary.

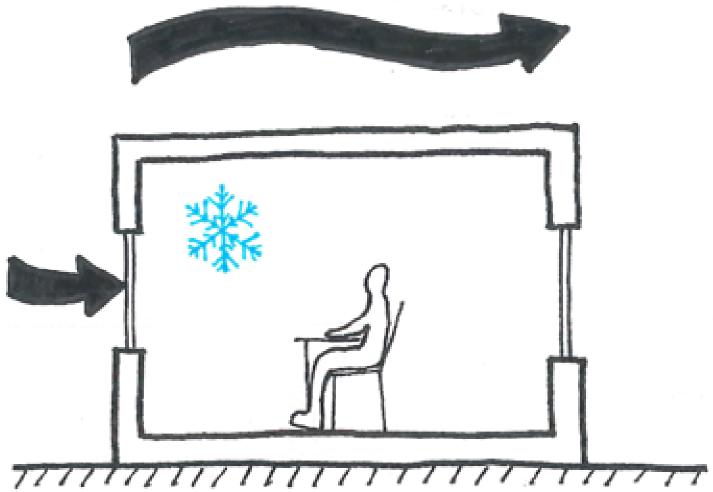


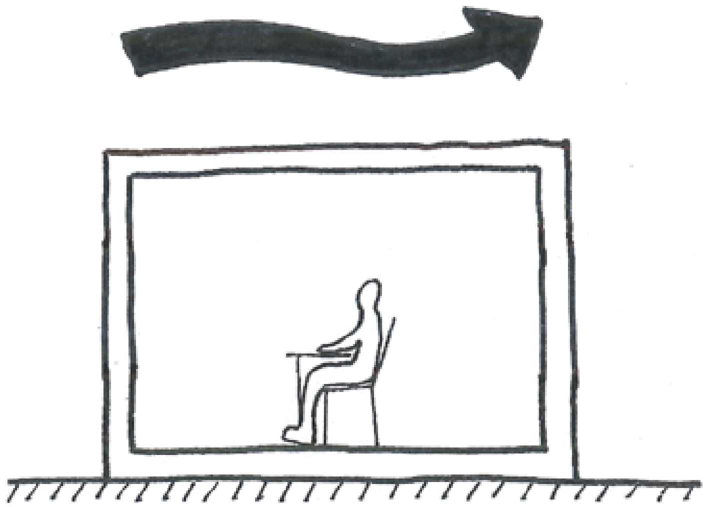
Because the design relies on wind, the amount of ventilation reduces considerably during lower wind speeds and calm weather. If the windows are all located at the same height, the neutral pressure plane is located in the center of the windows and there is virtually no air flow. Some existing schools have higher ventilator windows above the regular windows and these provide some air flow during calm weather.

In urban areas wind speeds are reduced by surrounding buildings. If a large neighbouring building is located close to the school, it can block the wind. Some parts of the school can also block the wind from entering other parts, depending on the design of the school.

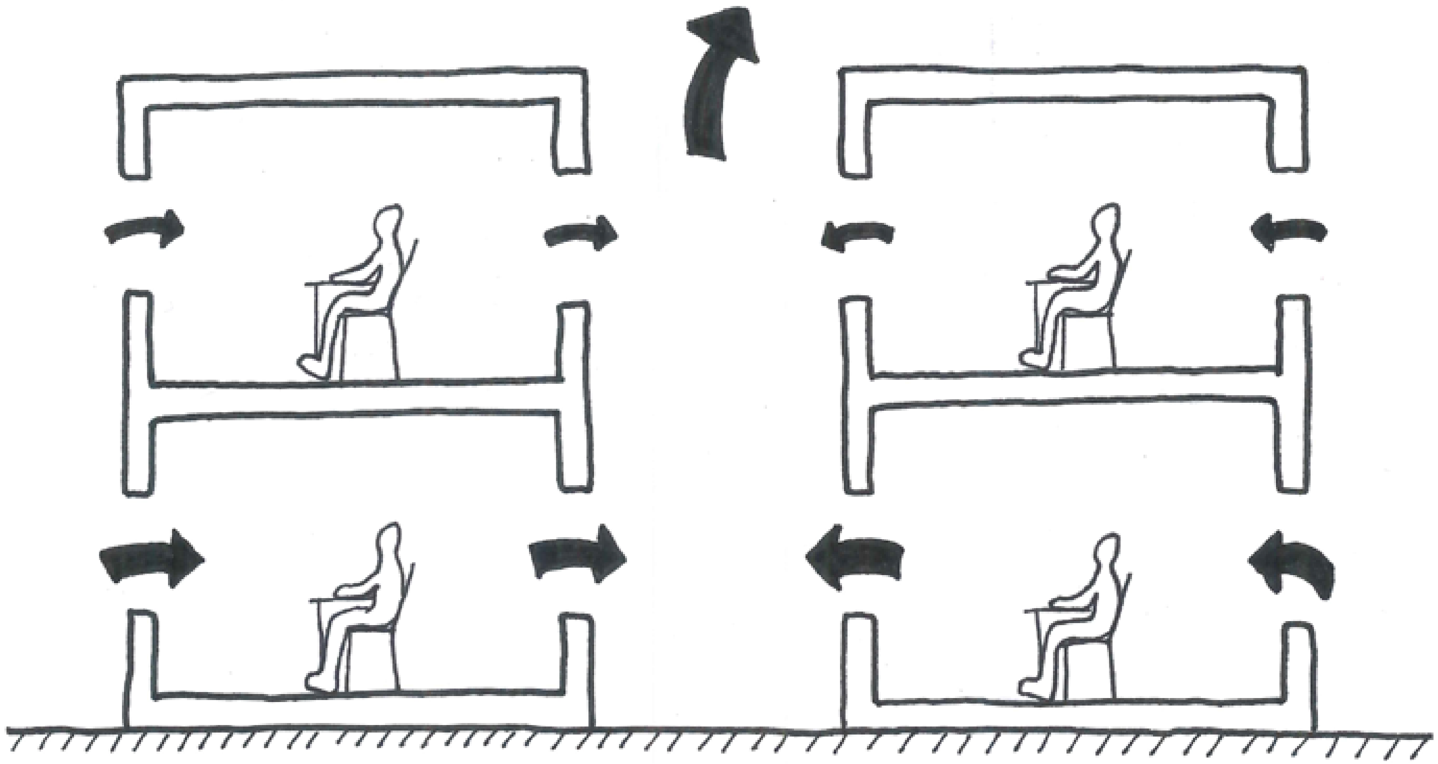


During cold weather windows are often kept closed in order to keep the classroom warmer. This is a problem because the lack of fresh air affects the students' health and concentration. It can also cause moisture problems because the extra humidity created by the people is not removed.





The amount of ventilation in existing schools relies a lot on the direction of wind. If the wind is parallel to the windows, there will be no air flow. This is particularly challenging in areas where the wind direction varies more. Even if the wind direction is reliable, sometimes the size and shape of the available plot forces the windows to be oriented differently.



During calm weather the courtyard helps ventilate the schools with the help of stack effect. The courtyard acts like an atrium that raises the neutral pressure plane and ventilates out hot air. However, the effect is less significant on the second floor, because the windows there are located close to the neutral pressure plane.

DAYLIGHT

1 Direct sunlight should be avoided because it causes glare and heat gains.

2 Diffuse daylight filtered through clouds is less strong but better for working and reading.

3 Diffuse background light from the sky is very good. Generally, the more sky can be seen from inside a room, the better the daylight conditions.

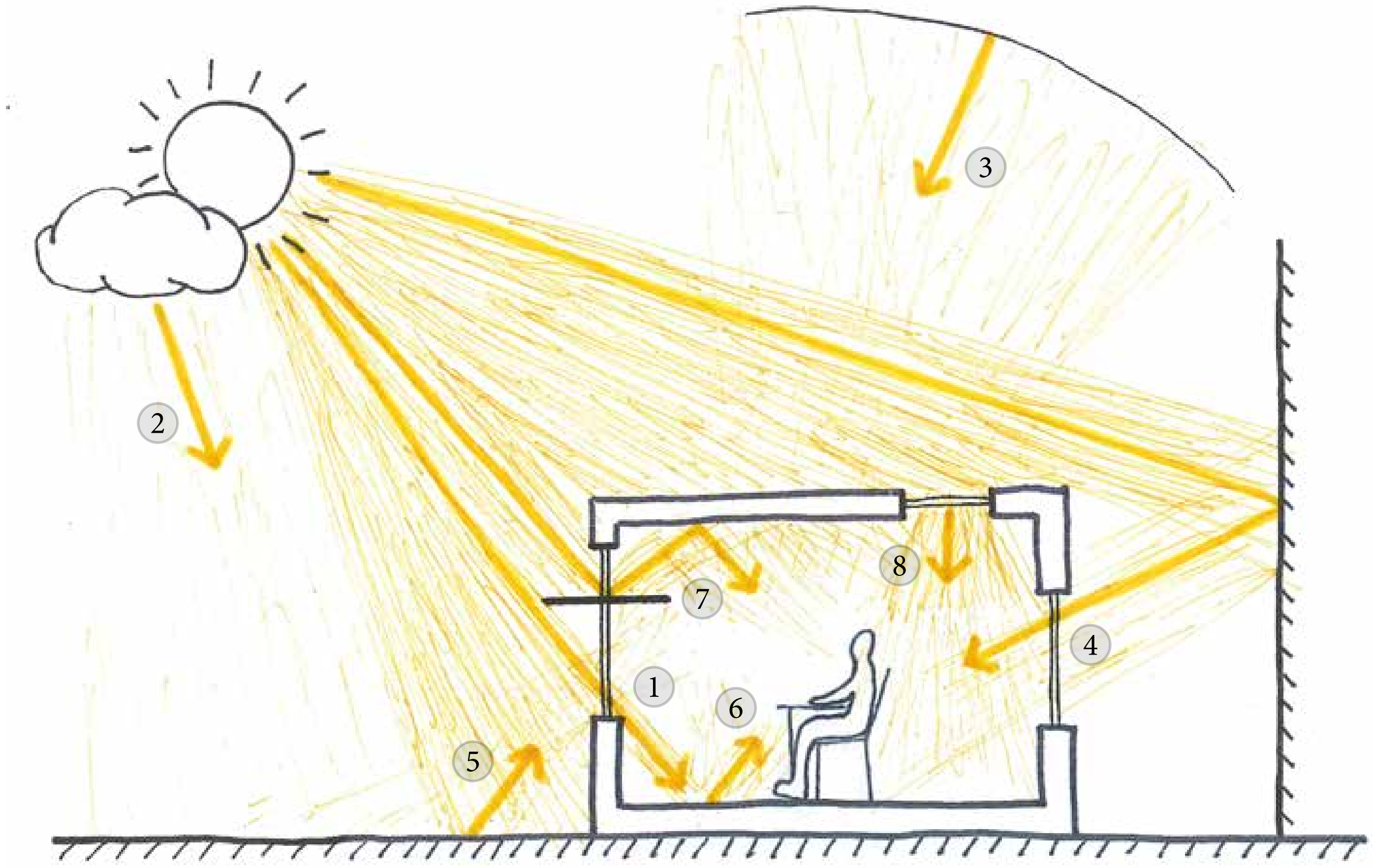
4 Surrounding buildings and other natural and man-made objects reflect daylight.

5 The ground also reflects daylight.

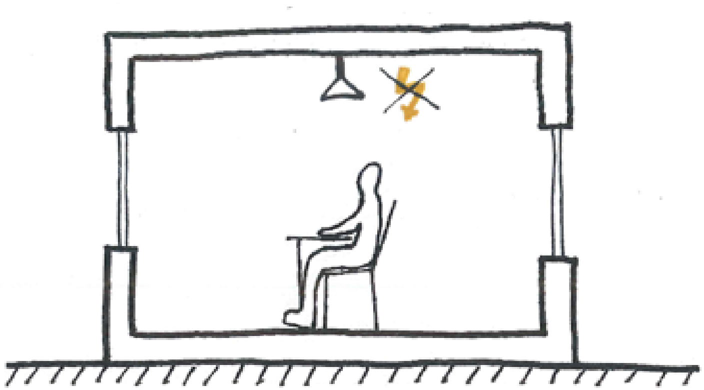
6 Internal reflections spread daylight inside rooms. White surfaces reflect light more, but they can also cause glare.

7 Light shelves block direct sunlight, but through reflections on the light shelf and in the ceiling, they can provide a more even distribution of daylight than regular windows.

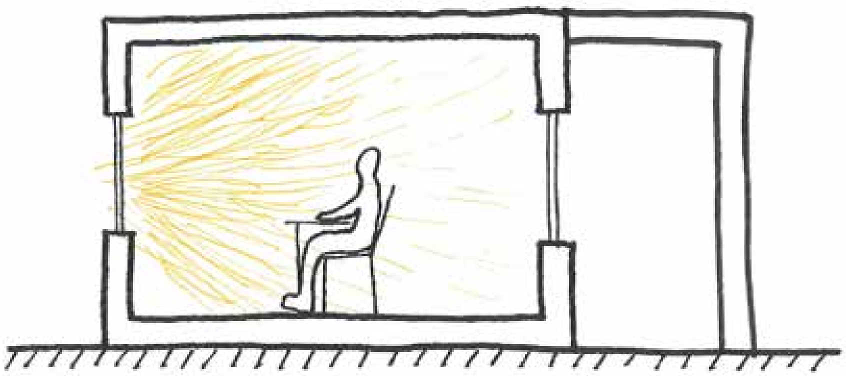
8 Skylights provide a lot of daylight because they face the sky.



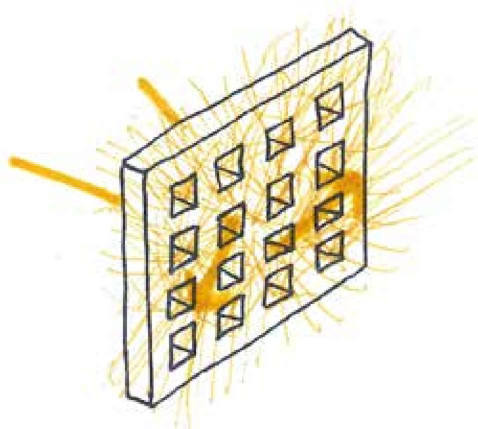
EXISTING SITUATION



Adequate daylight in the classrooms is made more necessary by the unreliable electricity supply. All classrooms have electrical lighting, but relying on electrical lighting is difficult because of frequent power cuts. This is particularly a problem during the late afternoon and during cloudy weather.

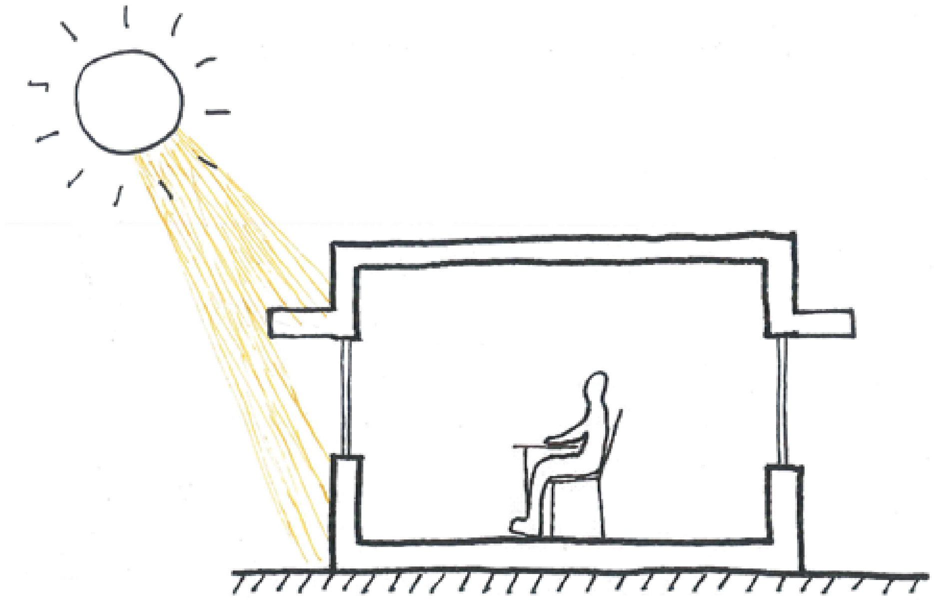


All classrooms have windows on two walls which increases the amount of daylight. However, if the other side is facing a dark corridor, the benefit is significantly reduced, and the seats by the corridor can be too dark.

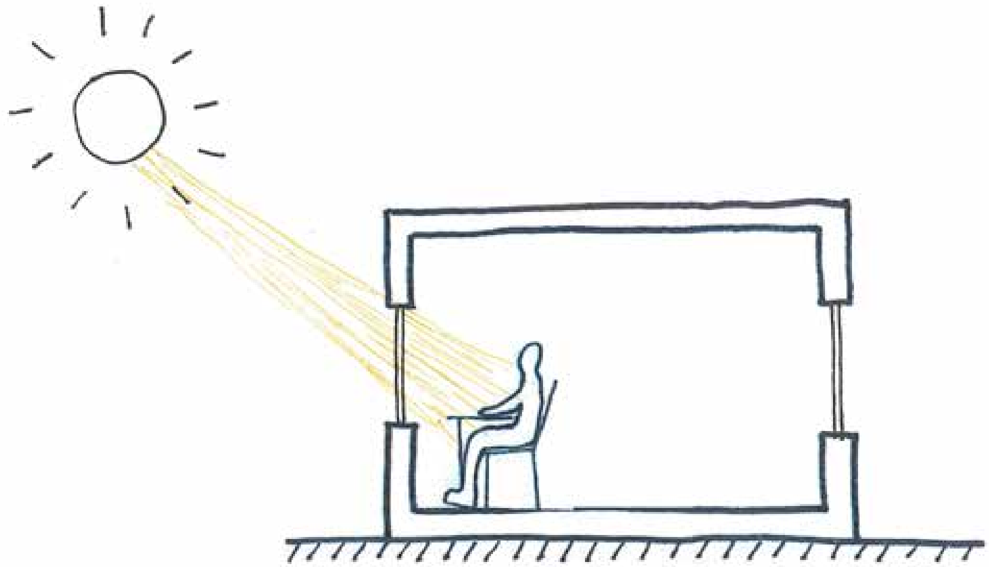


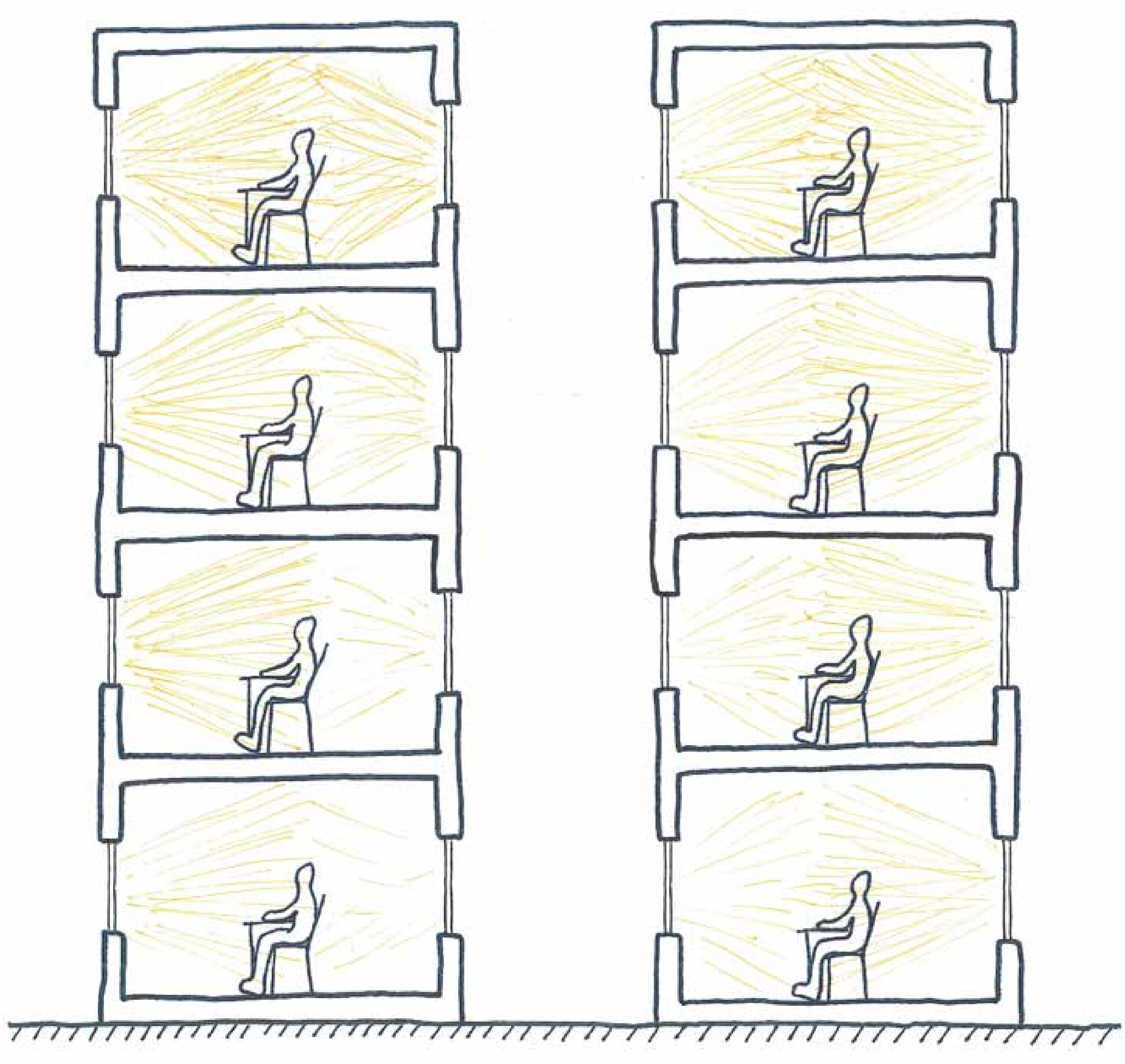
The *jaali* lattice windows in existing schools have angular edges which helps reflect light into the interior. However, the *jaali* are generally grey, and if they were white they would reflect more daylight.

There exists a conflict between daylight and thermal comfort. Windows need to be shaded in order to prevent solar heat from entering, but these shades also decrease the amount of daylight. On the other hand, shading elements do help prevent glare.



Glare can be a problem for seats that are by the facade, especially in the winter and during early morning and late afternoon when the sun is lower. White indoor surfaces can also cause glare, but it is less strong and white surfaces have the benefit of spreading daylight inside the classroom.

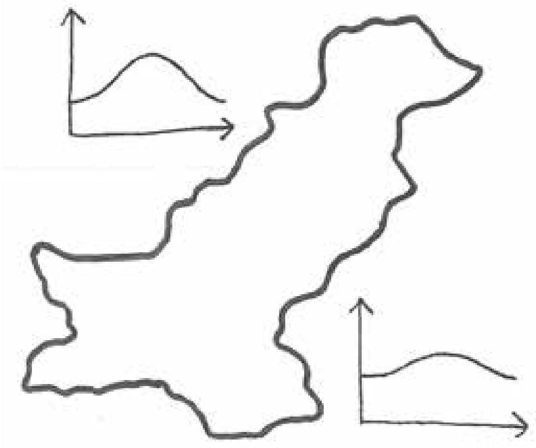




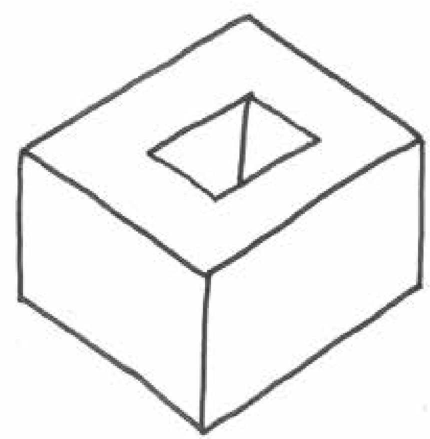
Courtyards increase the amount of daylight in classrooms that have windows facing the courtyard. However, the effect decreases further down, and in schools with more than two floors the lower floors don't always have enough daylight. Verandahs by the courtyard also decrease the amount of daylight, although their shading effect helps with passive cooling.

ENGINEERING RECOMMENDATIONS

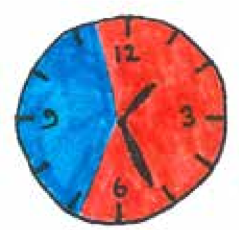
Schools in southern Pakistan perform better in terms of thermal comfort and ventilation. In the south the outdoor temperature varies less during the year and the wind speed is higher and more reliable, which makes it easier to rely on passive design than in northern Pakistan. In northern Pakistan summers are very hot and winters cold, which means the schools need to be able to provide both passive cooling and heating.

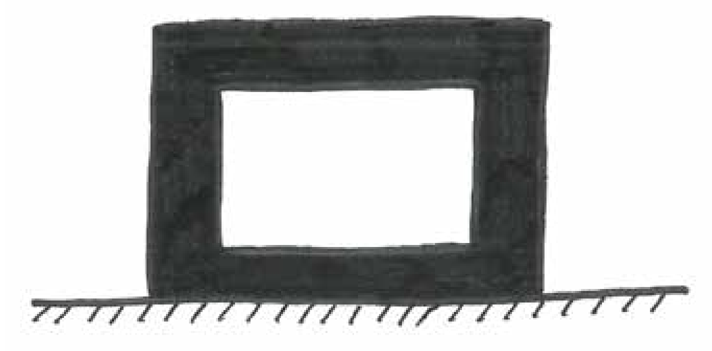


Existing TCF schools generally have courtyards though not in all regions. Courtyards improve ventilation and thermal comfort and their use should be encouraged. Air exits the schools through the courtyard and smaller courtyards can enhance the effect. Courtyards also provide daylight.

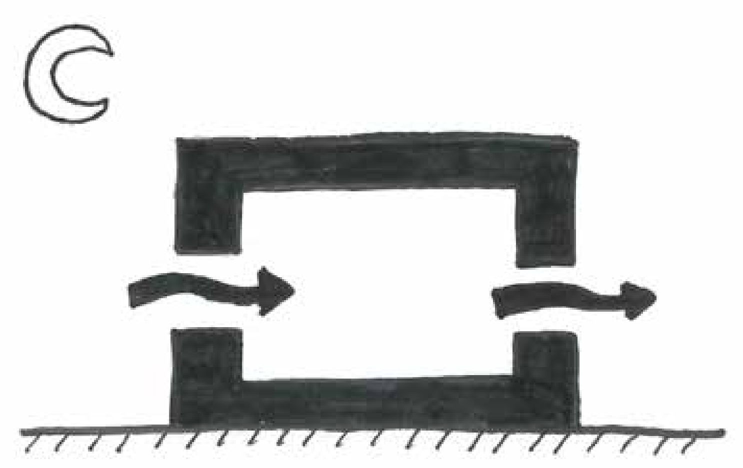


In the summer afternoons are very hot, and in the winter mornings are very cold. Schools that only have one shift could consider having the morning shift in the summer and afternoon shift in the winter.

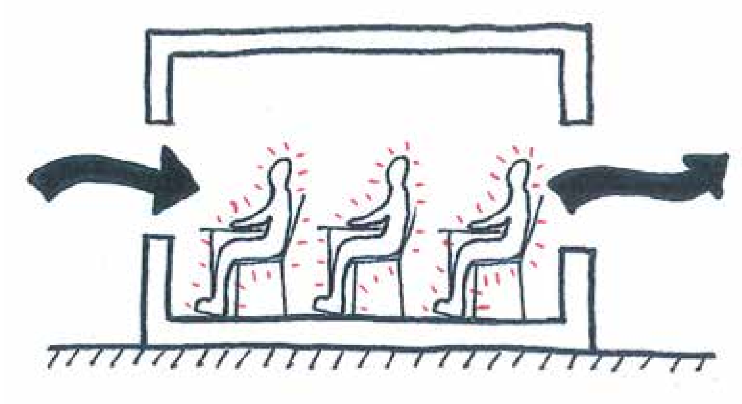




Thermal mass is beneficial in both southern and northern Pakistan and in both summer and winter. In Mansehra some schools have thermal mass while others don't, and the schools that have thermal mass are more comfortable in both summer and winter.

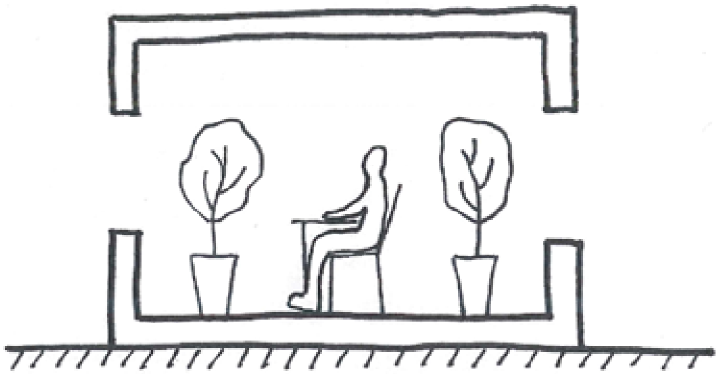


Thermal mass coupled with night ventilation is particularly effective. Night ventilation should be started immediately after school, because in the afternoon the schools are generally hotter than the outdoor air. Night ventilation should only be done during the hot months of the year and not during winter.

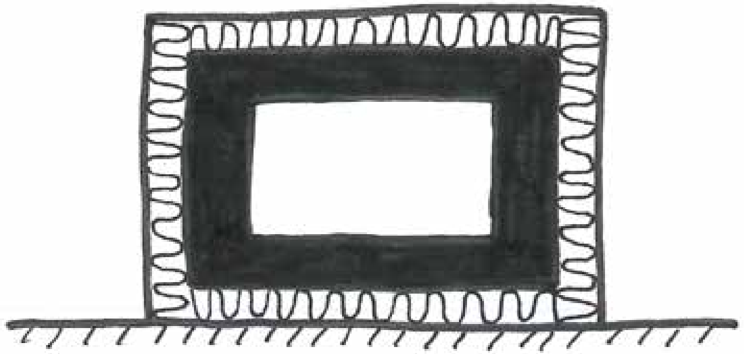


Traditionally in hot-dry climates ventilation during the day is minimized in order to prevent hot air from entering. However, in this case it shouldn't be done, because the large amount of people in each classroom means that ventilation is needed to remove the heat produced by the people.

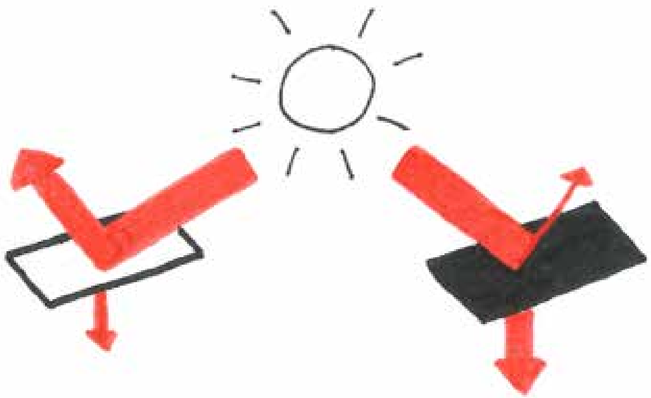
Plants create shade, clean the air, and have a cooling effect. Existing TCF schools have plants and these should be kept. In existing schools plants are located in courtyards and corridors, but having plants inside classrooms would be more beneficial. The school yard should have more trees for shading and for cooling the air since ventilation air enters from the exterior, not from the courtyard.

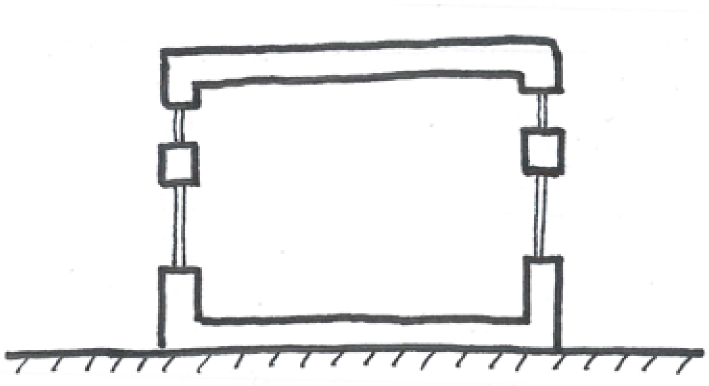


Insulating buildings in northern Pakistan would improve thermal comfort in both winter and summer by blocking heat from leaving and entering, respectively. However, insulation reduces favourable heat losses during summer nights. Insulation should be located on the exterior side of the thermal mass.

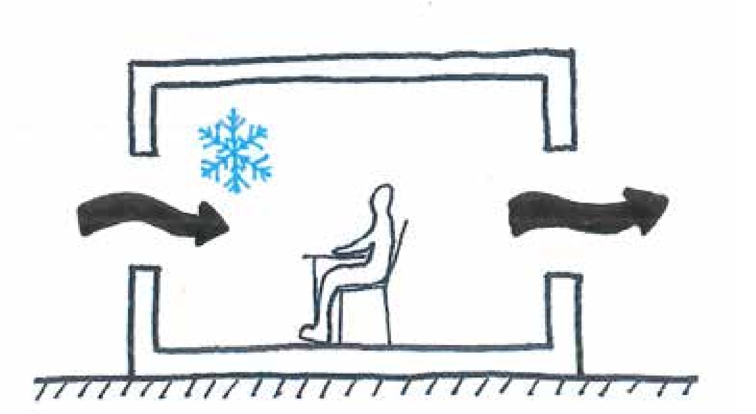


Favouring light colors is an effective way to reduce indoor temperatures, because light colors reflect solar radiation more than dark colors. Especially heat gains through the roof can be reduced with a white roof. Unlike insulation, light colors don't block heat losses during the night. However, light colors have no benefit in the winter when the heat of the sun would be favourable.

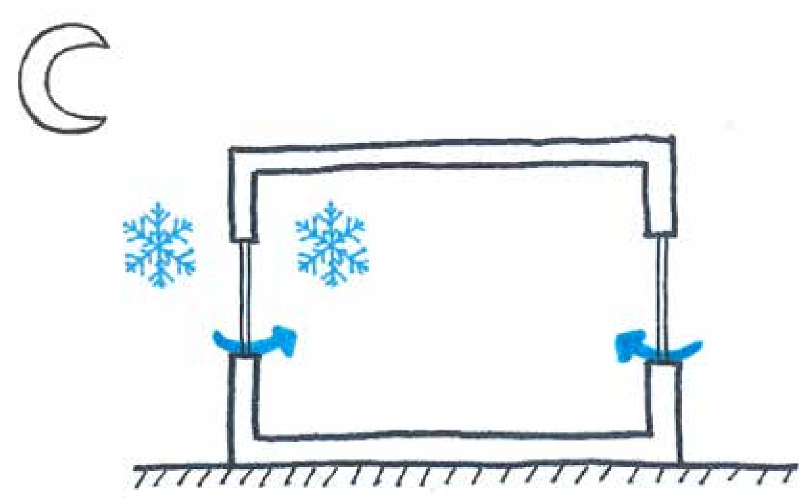




In northern Pakistan wind speeds are commonly so low that windows located at the equal heights are not enough to create adequate air flow. Alternative openings at different heights are needed. Some schools already have small ventilator windows above regular windows and this solution is encouraged. Windcatchers could increase the air flow even more.



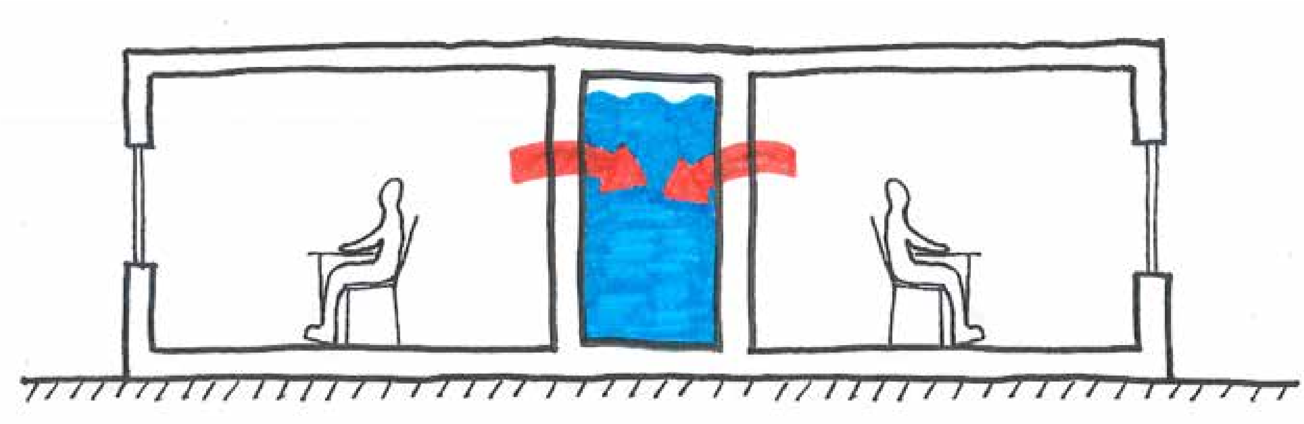
Adequate ventilation even in winter is important to provide fresh air and to remove indoor moisture. Inadequate ventilation leads to tiredness and moisture problems. Ventilator windows are better for winter ventilation because they are located higher up and cause less draft at seating level.



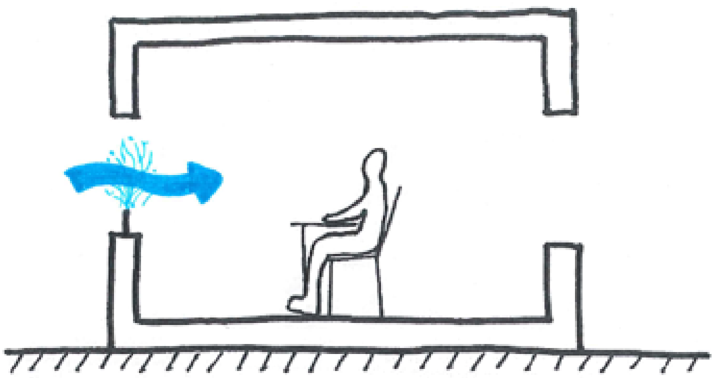
It is important that all openings can be properly closed during the night in the winter. Air leakages in the night lead to colder surfaces, and when there is not enough ventilation during the day, high indoor air humidity will lead to condensation on these cold surfaces. Colder surfaces also create discomfort. Airtight windows should thus be favoured.

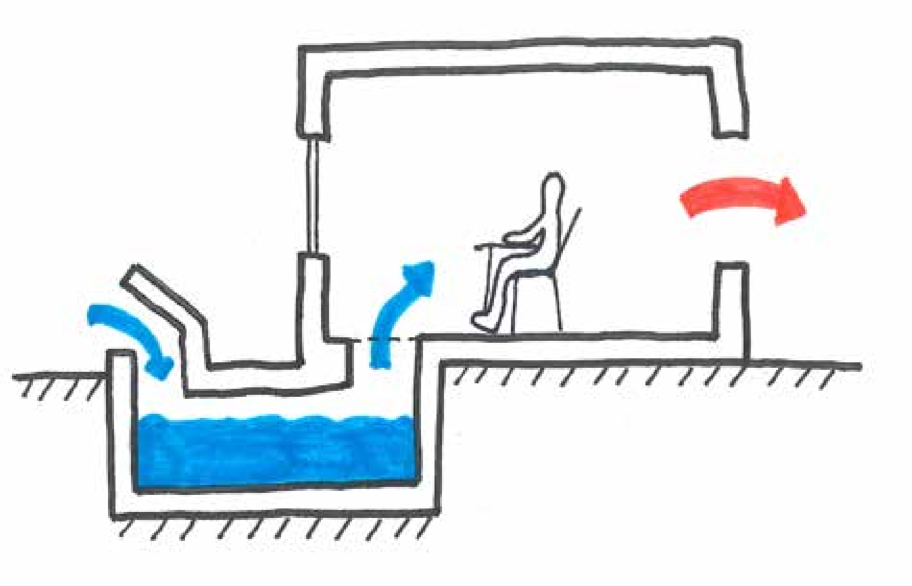
WATER AND THERMAL COMFORT

Water has a very high thermal mass, and this thermal mass can be used to keep indoor temperatures more stable as the outdoor air temperature varies during the day. A large body of water can even store heat from one season to another.

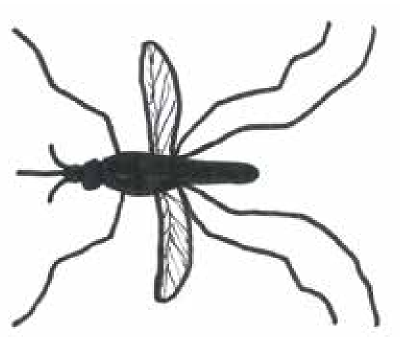


Evaporation of water has a cooling effect. All water evaporates, but sprayed water evaporates much faster, which means it provides more cooling. Spraying water also increases air humidity which creates comfort in a dry climate.





If ventilation air can pass over water before entering the building, the air will be cooler than the outdoor air. The cooling effect happens thanks to evaporative cooling although the effect is less strong than with sprayed water.



In still water elements such as ponds there is a risk of mosquito breeding, and this should be considered in torpical climates. Mosquitoes can be prevented with fish, a deep pond or chemical treatment.

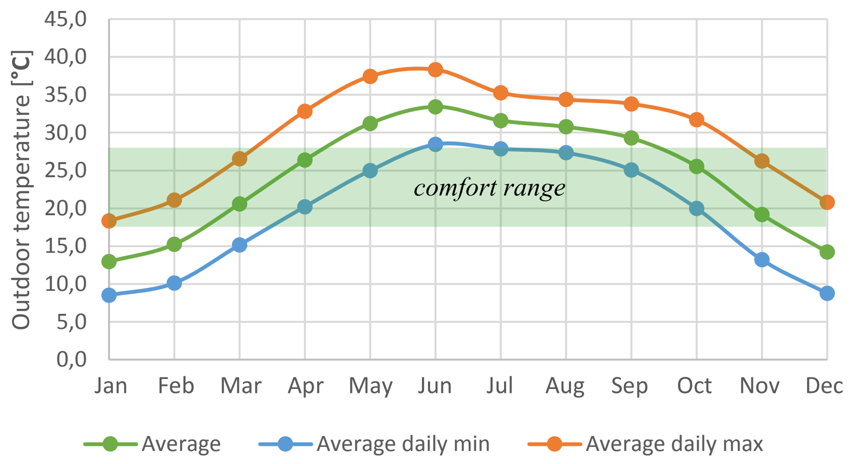
Schools in northern Pakistan are uncomfortably cold during the winter, and passive heating strategies should be developed to improve comfort. One way to passively heat the schools is to use the heat of the sun. During the winter the sun is lower and this makes it possible to design shading elements that block the summer sun but allow winter sun to penetrate. This study is done to see when the sun should be avoided and when it should be allowed to enter the building.

Even though low inter sun is favourable, the sun is also low during early morning and late afternoon in the summer, and this sun should be avoided. The sun rises and sets further north in the summer, so the problem can be solved by shading low northwest and northeast sun while allowing low southwest and southeast sun to penetrate. Mornings are especially cold in the winter so allowing for eastern and southeastern sun to penetrate is especially important. Likewise, afternoons are especially hot in the summer so western and northwestern sun should be blocked.

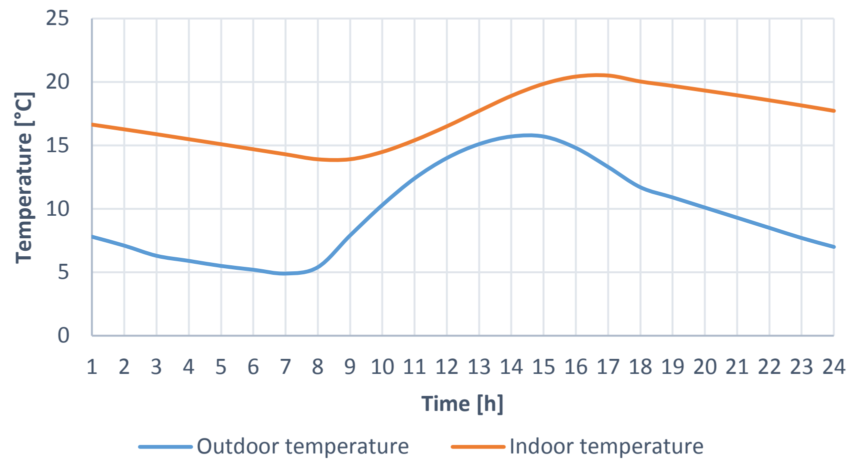
The analysis is done for Lahore and is based on data from Meteonorm software and the author's previous thesis.

SOLAR STUDIES

MONTHLY OUTDOOR TEMPERATURES

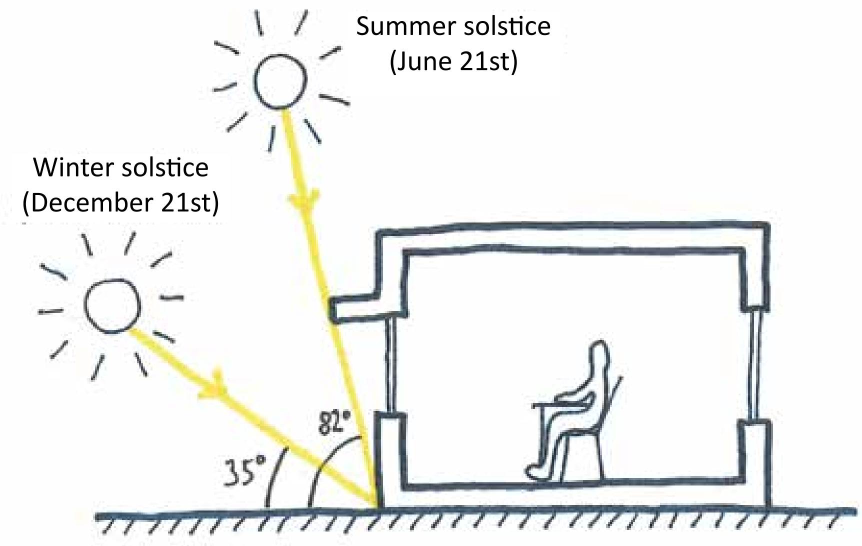


TEMPERATURE ON JANUARY 15TH

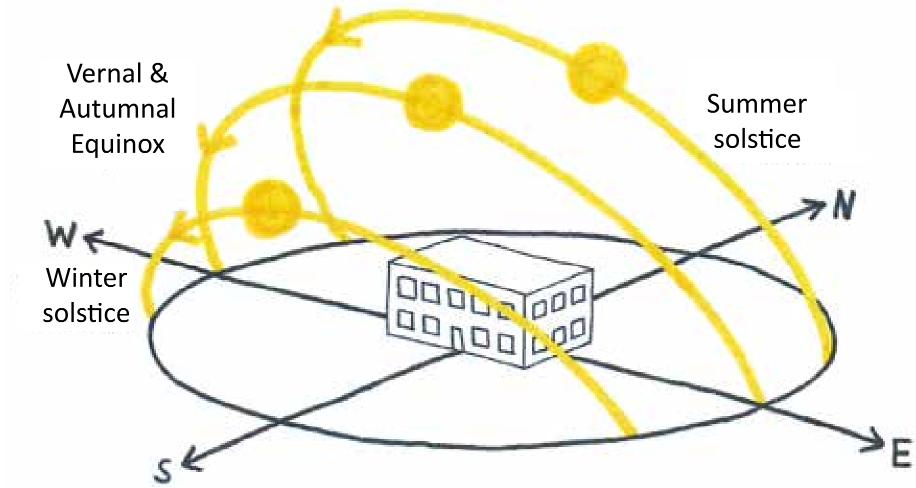


Source: Alatalo 2016

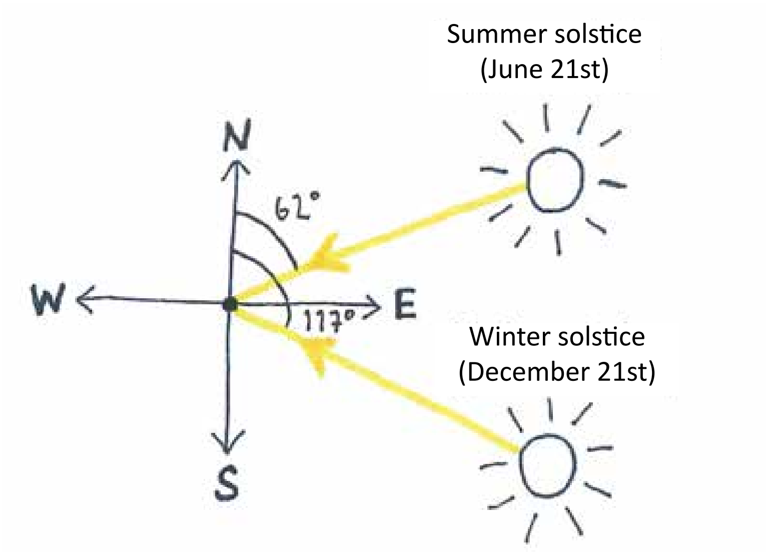
HEIGHT OF SUN AT NOON



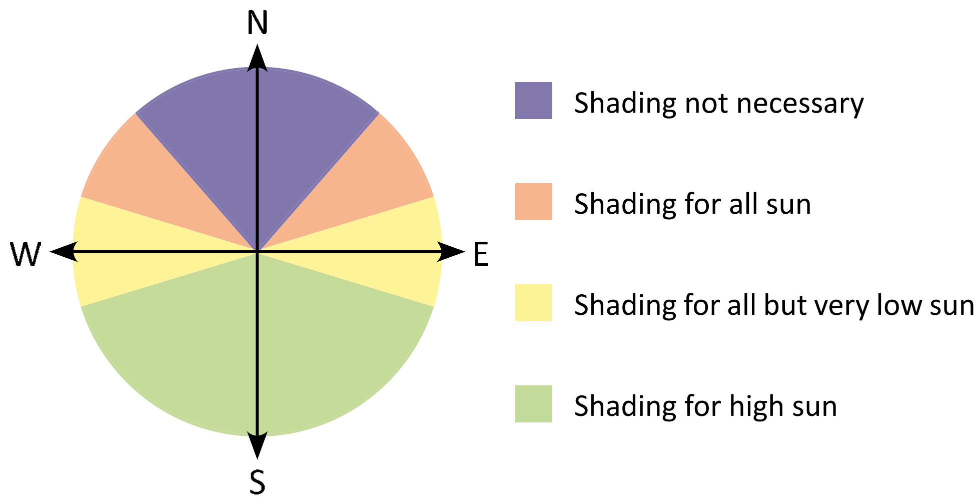
SUN PATHS



SUNRISE DIRECTION

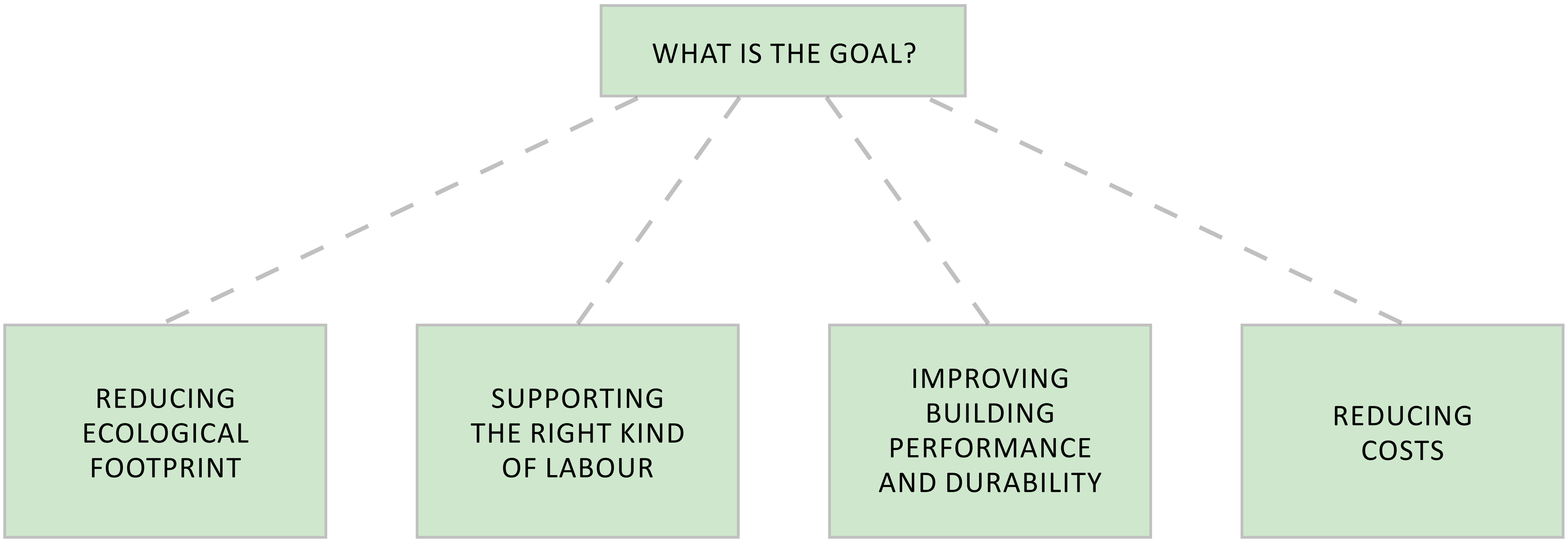


RECOMMENDED SHADING



3.3 MATERIALS

The choice of building material is often driven by cost, but the choice affects how well the building performs in terms of thermal comfort and durability. Durability is often related to moisture safety and moisture damages. Material choices also have an impact on a wider scale, for example on employment and resource depletion. The impact during the whole life-cycle should be understood. The environmental impact is often expressed in term of embodied energy, which is the energy used by the material during its whole life-cycle.

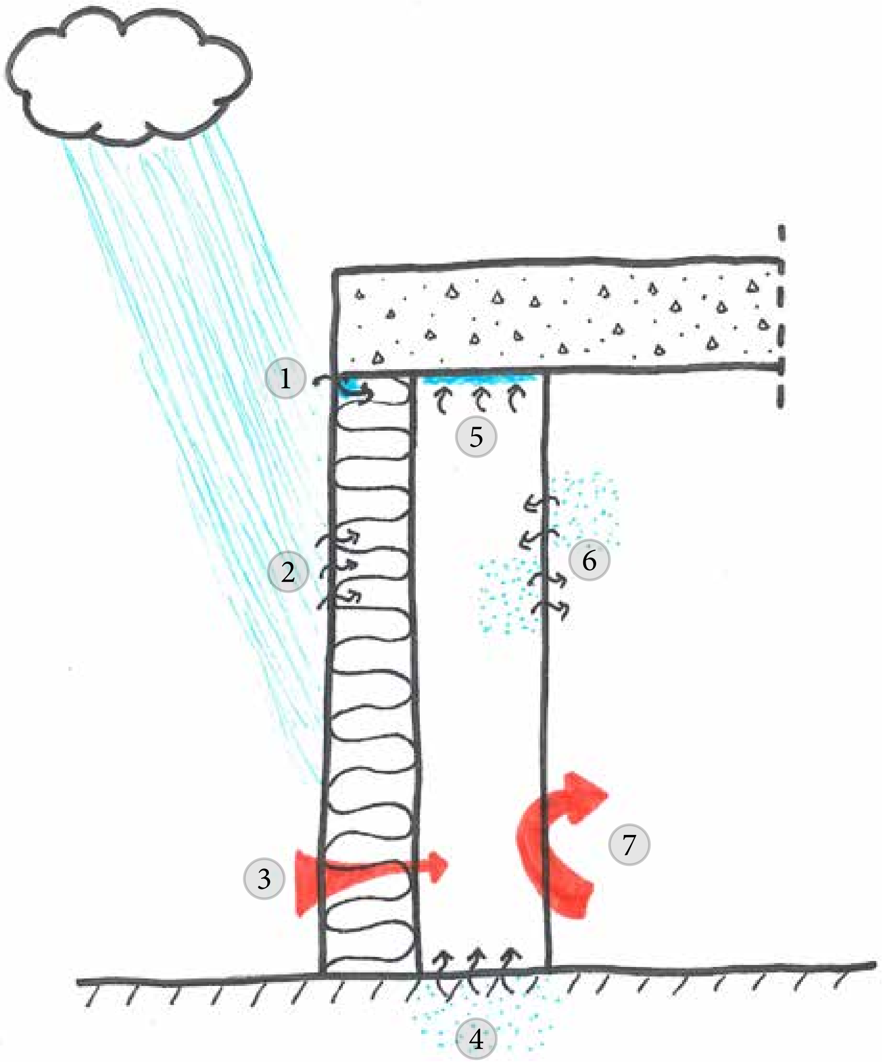


1 If construction details are badly designed and built, there can be leakages, especially in joints. Leakages can cause severe damage to building materials.

2 Exterior materials come in contact with rainwater. Porous materials absorb more water and they can transport the moisture further into the construction.

3 Insulating materials slow down heat transfer between exterior and interior. These materials generally have a low density. If insulating materials become wet, their insulation capacity decreases.

4 Materials that absorb moisture easily need to be protected from ground moisture with a damp proof course. Materials transport moisture from the ground through capillary action.

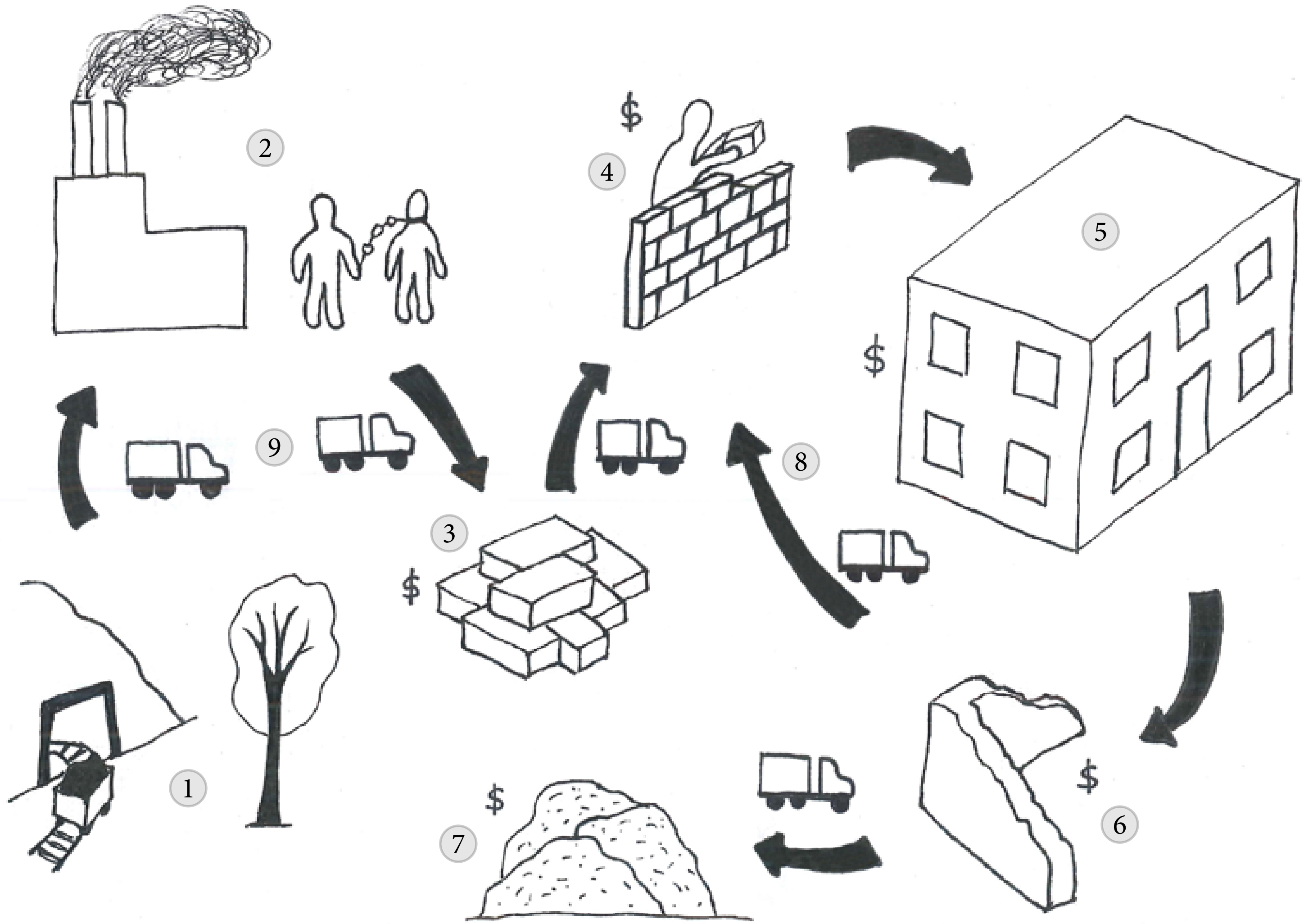


5 Some materials transport and absorb moisture better than others. When two materials meet, there can be an accumulation of moisture and this can lead to mould problem and deterioration of materials.

6 Materials also absorb moisture from the air. At a particular relative humidity, each material can hold a certain amount of moisture. Materials that can hold a lot of moisture can buffer air moisture by absorbing moisture when the air is humid and releasing it when the air is dry.

7 Materials with a high thermal mass buffer heat by absorbing it during the day and releasing it during the night. These materials generally have a high density.

MATERIAL LIFE-CYCLE



1 The first stage in a material's life-cycle is the extraction of raw materials. Some natural resources are used directly for the desired materials, while others are used more indirectly, such as water and firewood.

2 During manufacturing raw materials are turned into a desired product. Depending on the material, this stage can be very energy intensive and polluting. Material industries employ people, but money goes less directly to the labourers and more to companies, and in some cases the company can use unethical labour practices.

3 The finished material is sold to be used in construction. Buying materials supports the industries and companies that produced the materials.

4 During construction materials are used to create a building. Money is needed for equipment and for labour. Construction is a chance to create employment that supports people more directly than industries. The chosen material and the design determine how complicated the construction is and how much money is needed.

5 When the building is built and in use, the building and the materials require maintenance. The amount of maintenance required depends on the durability of the materials.

6 Each building has a limited lifetime, and at the end of this lifetime the building is demolished. Material choice and method of construction affects how long the lifetime of the building is and how easily the building can be demolished. Design for disassembly is a strategy that aims to preserve materials by making it possible to demolish a building in a way that doesn't harm the materials and allows for them to be used again.

7 After demolition, materials become waste and need to be disposed of. The amount of waste should be minimized in any way possible.

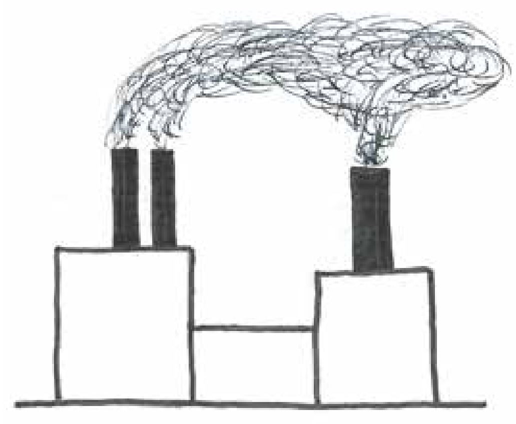
8 Instead of disposal, some materials can be recycled and used again which reduces the amount of waste. Recycling can also save costs by eliminating the need to buy new materials.

9 Whenever materials are transported from one place to another, the embodied energy increases due to energy required for transportation. Favouring locally available materials reduces the need for transport and thus also the embodied energy.

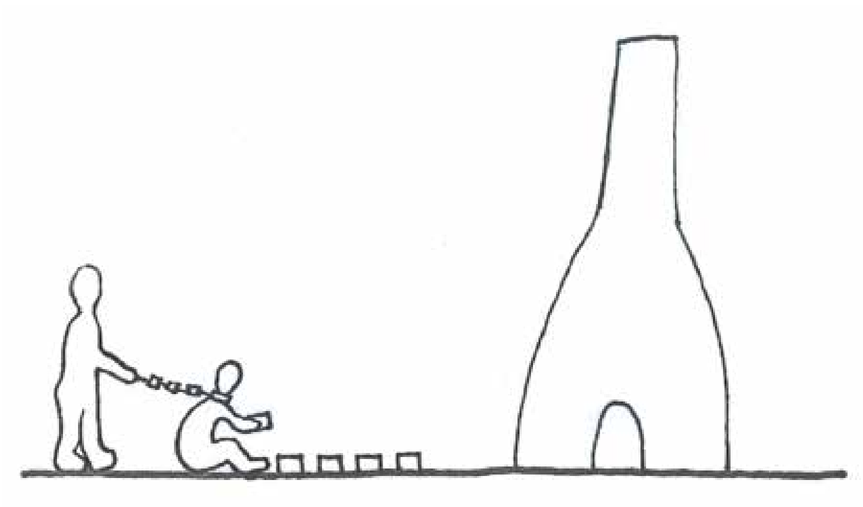
EXISTING SITUATION

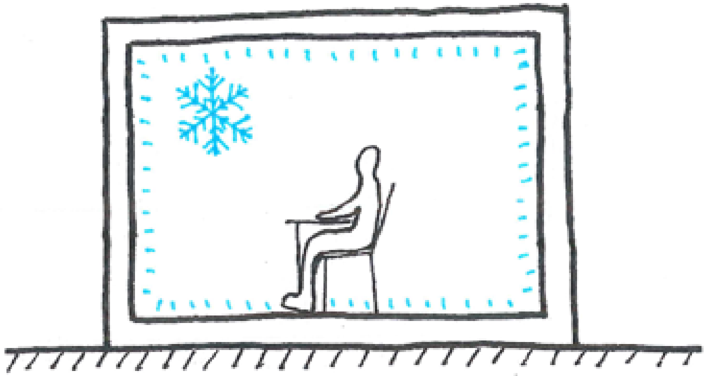
When selecting materials, the main priority for TCF is saving costs. Because of this TCF favours locally available and low-maintenance materials.

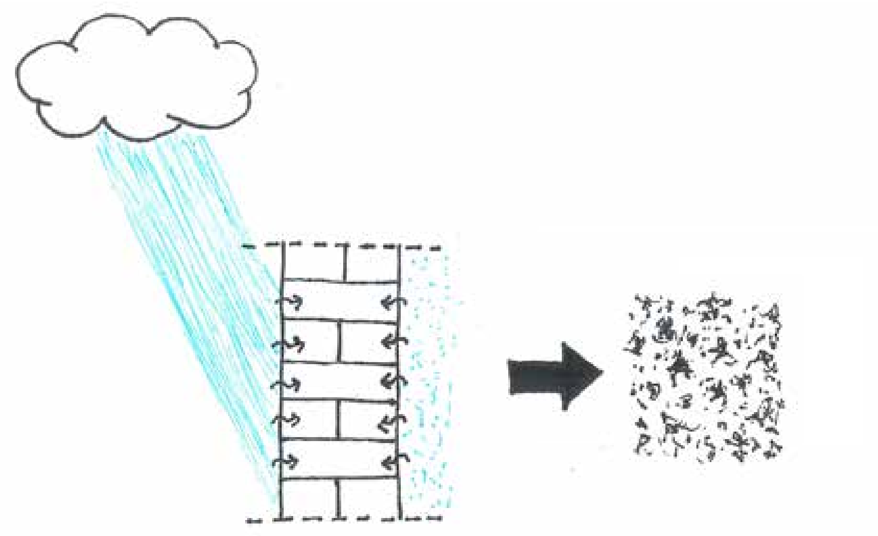
Favouring locally available materials reduces transport distances and thereby also the embodied energy. However, industrial materials like concrete blocks and bricks still have a high embodied energy because of the production method, even if they are locally produced.

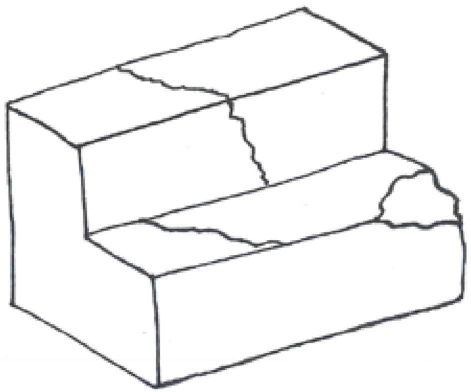


In Pakistan, unethical labour practices like child labour and slavery are still common. The brick industry for example is a hotspot for bonded labour. Buying products made by these industries supports unethical labour practices.







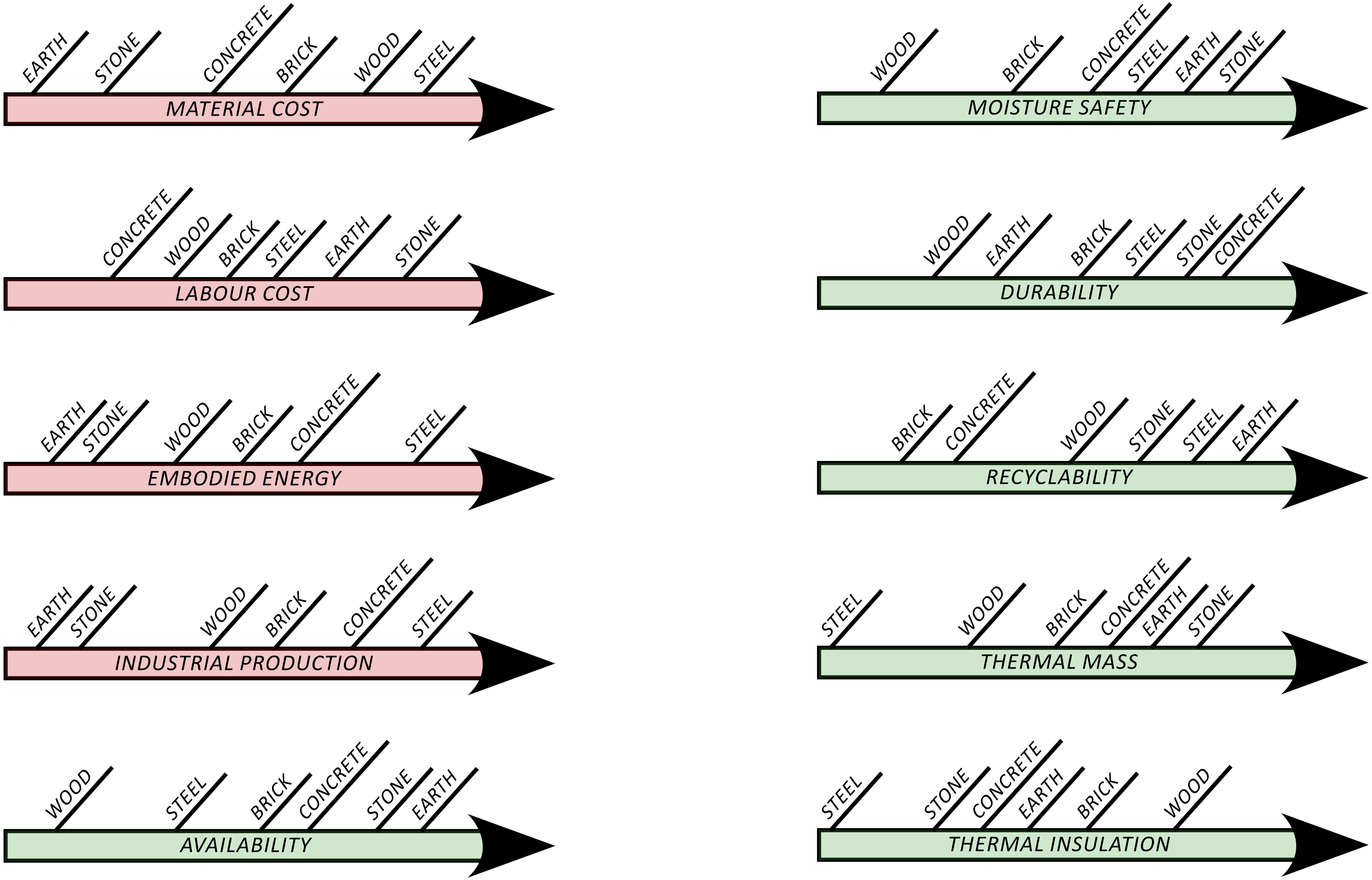


Materials with a high thermal mass - such as concrete blocks and bricks - keep the schools cool during the summer months, but during the winter these materials create discomfort. Combining thermal mass and insulation would lead to better comfort in both summer and winter.

Existing brick schools in northern Pakistan have severe moisture problems that are causing extra maintenance cost. These problems can be caused by rain, by indoor humidity or by a combination of both. Indoor humidity is particularly a problem in the winter when the walls are cold which increases risk of condensation. The problem could be solved with a moisture buffering construction that has the capacity to absorb and release moisture as the air humidity varies.

Concrete features such as floors and stairs have a problem with cracking during the setting of the concrete. In Mansehra outdoor concrete features also have problems with damages caused by freezing.

MATERIAL ASSESSMENT



EARTH is a traditional material in the region, and different techniques exists. Earth has a very low embodied energy. Material cost is also very low, but construction is labour intensive. Earth needs to be protected from rain, but it buffers air humidity which increases moisture safety.

STEEL is a strong but expensive material. Production is energy intensive but steel is easy to recycle. Steel has no usable thermal mass or insulation value and needs to be combined with other materials. Steel can rust but otherwise it is moisture safe.

CONCRETE is a strong and durable construction material. Concrete blocks are relatively inexpensive and easily available, but they have a high embodied energy. Concrete is waterproof, but combining concrete with other materials can lead to moisture problems.

WOOD is biodegradable and renewable, but it is sensitive to moisture damages. Wood is quite expensive in Pakistan and overuse leads to deforestation. A lot of wood is needed to achieve a high thermal mass Wood has a higher insulating value than other structural materials.

BRICKS are easily available, but they are more expensive than concrete blocks. Embodied energy is high and the brick industry in Pakistan employs slave labour. Bricks have more aesthetic value than concrete blocks and require less surface treatment.

STONE is easily available, but harvesting and quarries affect the landscape and cause erosion. Stone construction techniques usually require skilled labour which can be expensive. Local stones should be used, otherwise the required transport leads to high costs and emissions.

EARTH CONSTRUCTION

Earth is one of mankind's oldest construction materials, and even today over one third of the world's population lives in earth houses (Minke 2009). Earth buildings have a low environmental impact, and the characteristics of earth help create healthy and comfortable buildings that buffer both heat and moisture.

Many different earth construction techniques exist but the basic materials needed are clay, sand, silt and water. The earth can often be obtained on site for no added costs, for example when excavating the foundation or a basement. Different additives, such as straw or lime, can be added depending on the desired outcome.

In industrial countries, the drawback with earth construction is the high labour costs, and more efficient construction methods are needed. In developing countries labour is cheaper, and the challenge that earth buildings face is one of image, as earth is often seen as a backward material. Raising the status of earth construction is important as the middle classes grow and more people want to upgrade their houses. (Hall et al. 2012)

STAGES

ANALYSIS OF EARTH

↓

CHOICE OF TECHNIQUE

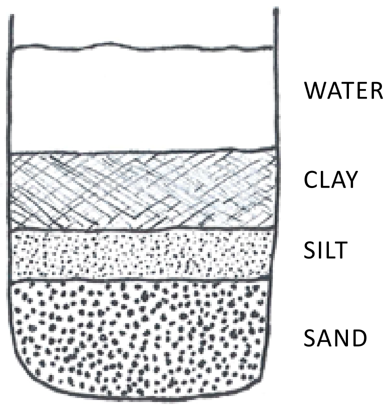
↓

CHOICE OF ADDITIVES

↓

CONSTRUCTION

MIXTURE



TECHNIQUES

1 WET LOAM

Wet loam refers to earth construction where a relatively wet mixture of earth is directly shaped and put in place by hand. Many different techniques exist and some are very labour intensive. In some cases the earth is placed into a skeleton structure that can be made for example of bamboo.

2 RAMMED EARTH

Rammed earth is a technique where moist earth is poured into a formwork and then compacted with a manual or mechanical rammer. The earth is rammed in layers and the formwork is moved as the wall is built up. Moving the formwork can take a lot of time if it is not optimized, and the formwork can also be expensive.

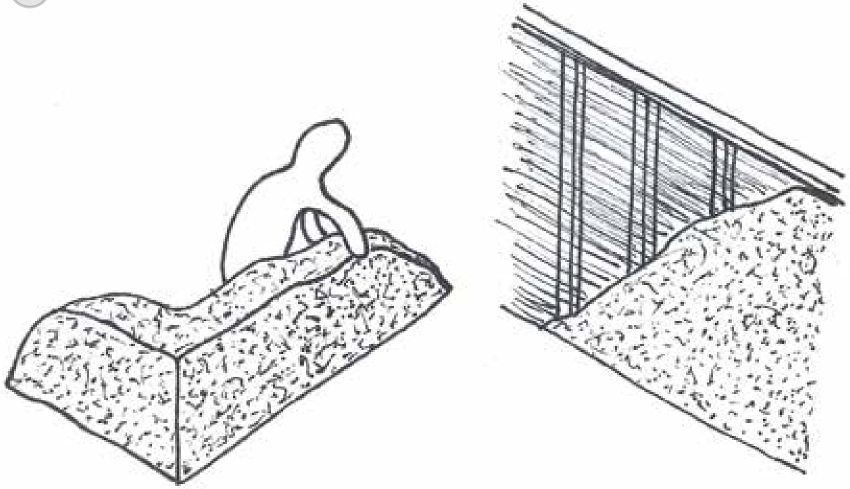
3 ADOBE

Adobe - also called mud bricks or sun dried bricks - is made by placing or throwing wet earth into a formwork that produces blocks. Throwing creates stronger blocks because it compressed the earth. These blocks are then left to dry before assembled into place. One person can produce approximately 300 adobe blocks per day.

4 COMPRESSED BLOCKS

Compressed earth blocks are made by compacting earth into blocks with a manual or powered press. They require less clay and less water than adobe. Less blocks per person can be produced manually than with adobe, but the blocks can be assembled into place immediately. Interlocking blocks require little or no mortar.

1



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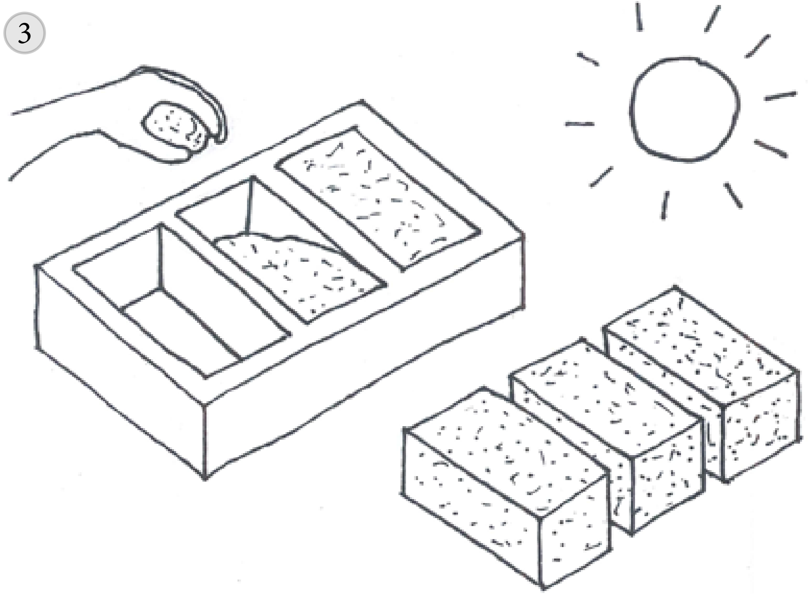

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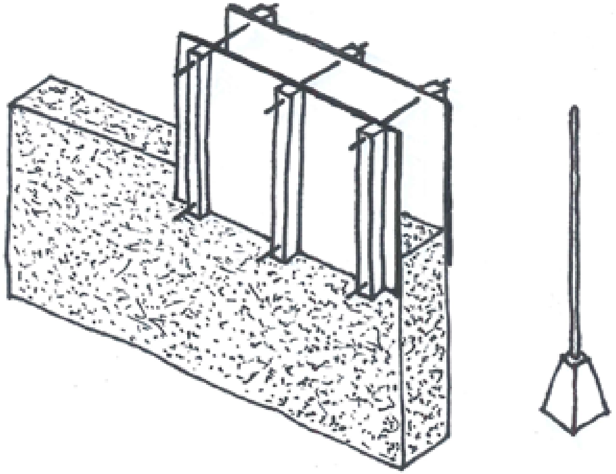

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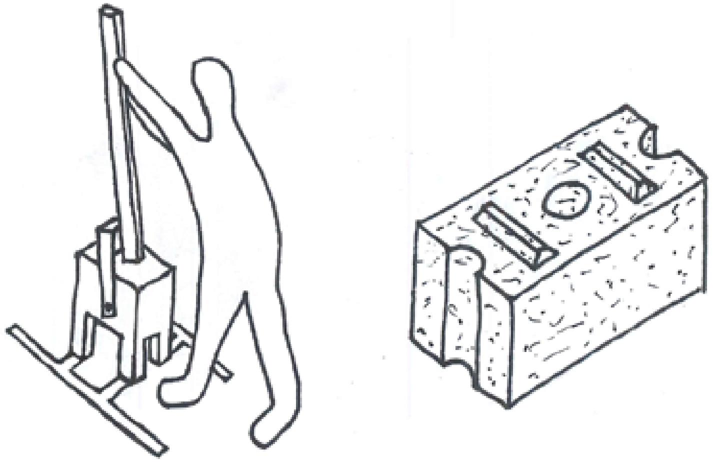
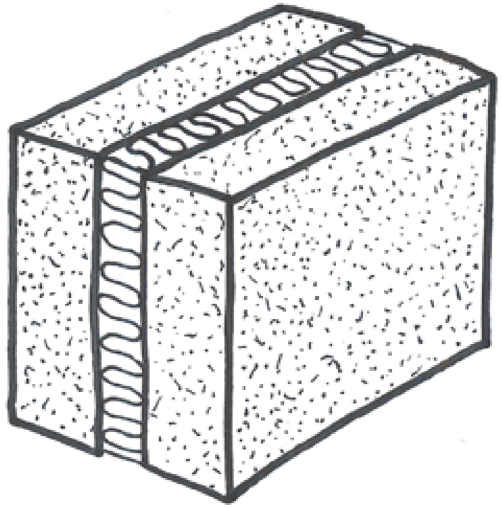


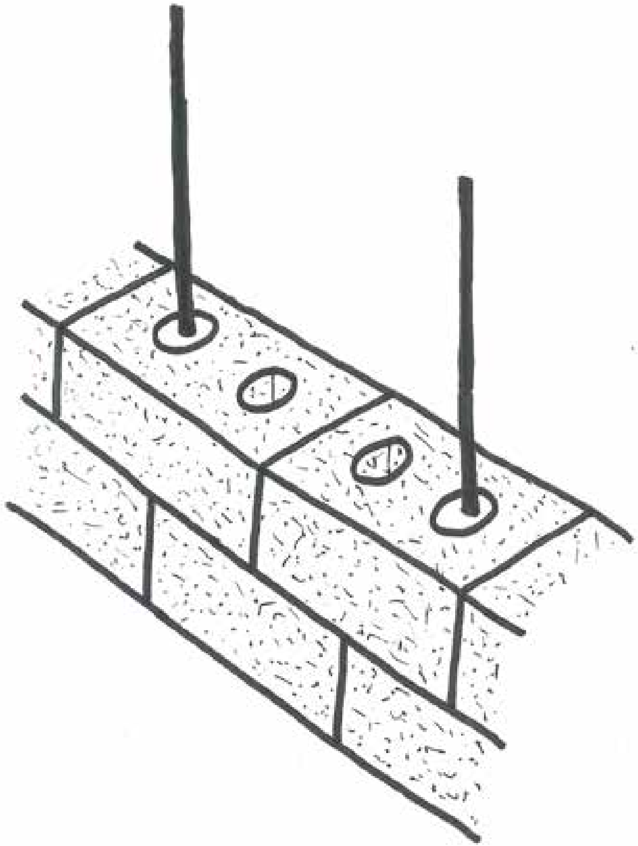
THERMAL INSULATION

Even though earth walls are generally thick, earth as a material has little insulating value and plain earth walls are not suited for cold climates. In northern Pakistan adding insulation to earth walls should be considered.

Thermal insulation can be improved with the addition of porous substances that decrease the density of the earth. Some possible additives are straw, reeds, cork, or porous mineral materials such as expanded clay, perlite, lave and foamed glass - depending on the availability of such materials. If organic material is used, it is important that the final density of the wall is at least 600 kg/m^3 so that the organic material is completely covered by the earth. (Minke 2009)

Thermal insulation can also be achieved by adding an insulating layer of a different material with a high insulating value, for example expanded polystyrene that is used in TCF schools in the northern mountain areas. The insulating layer should be either inside the wall (cavity wall) or on the exterior side. If the insulating layer is placed on the interior side of the wall, the heat and moisture buffering capacity of the earth is lost.





IMPROVING STRENGTH

The strenght of earth buildings varies depending on the type of technique used. In general, block construction is weaker than rammed earth construction because of the joints between blocks. Rammed earth and compressed blocks require less water than wet loam or adobe, and this means there is less shrinkage on one hand, but on the other hand there is also less binding of clay.

One reason earth is sometimes seen as an inferior material is because it is not resistant to water and erodes, and earth walls should be protected from rain with an overhang. Earth walls should also have a damp proof course to protect them from moisture from the ground.

The lifetime of earth construction can be extended by stabilising the earth with a small amount (approximately 5%) of cement or lime. In general, cement should be used for stabilising soils with a lot of sand and lime for soils with a lot of clay. (Auroville Earth Institute 2016) Cement interferes with the binding forces of the clay and if the earth has a lot of clay, more cement is needed to produce the same stabilising effect (Minke 2009). Cement stabilised earth blocks should be cured for four weeks before use (Auroville Earth Institute 2016).

Pakistan is prone to earthquakes and it is important that buildings are designed accordingly. Hollow concrete blocks can be reinforced by filling the holes with steel and poured concrete, and the same can be done with hollow earth construction to improve resistance to earthquakes (Auroville Earth Institute 2016).

SURFACE TREATMENT

Surface treatment of earth walls is not necessarily needed, especially for rammed earth construction where the surface is homogeneous. If plaster is used, the three main choices of binder for the plaster are clay, cement and lime. The choice of surface treatment determines whether the moisture buffering capacity of the earth can be used. The surface should be wetted before applying the plaster.

CLAY PLASTER

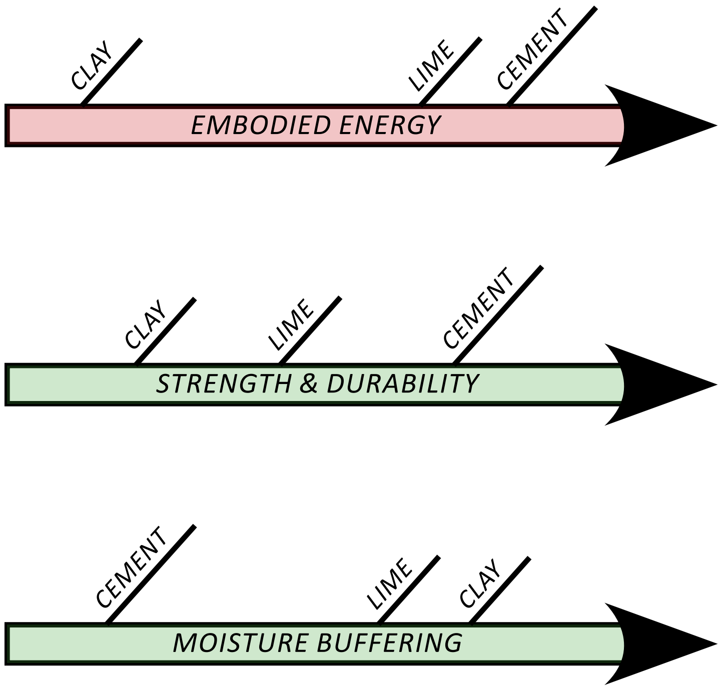
Clay plaster is made of sand, silt and clay, and it retains the moisture buffering capacity of the earth wall. With adobe and compressed earth block walls clay plaster can be used to create a monotonous surface for aesthetic reasons, but for rammed earth construction plastering with clay plaster has little or no benefits. Clay plaster is less strong than other plasters which means it can crack easily and requires more maintenance.

CEMENT PLASTER

Cement plaster is strong and requires little maintenance, but cement has a high embodied energy. Cement plaster is waterproof which protects exterior walls from rain, but it is not breathable so if moisture enters the wall (for example through cracks) then it can't leave the wall and will accumulate. This can lead to mould growth and/or plaster falling off, which is the case in existing TCF schools around Lahore.

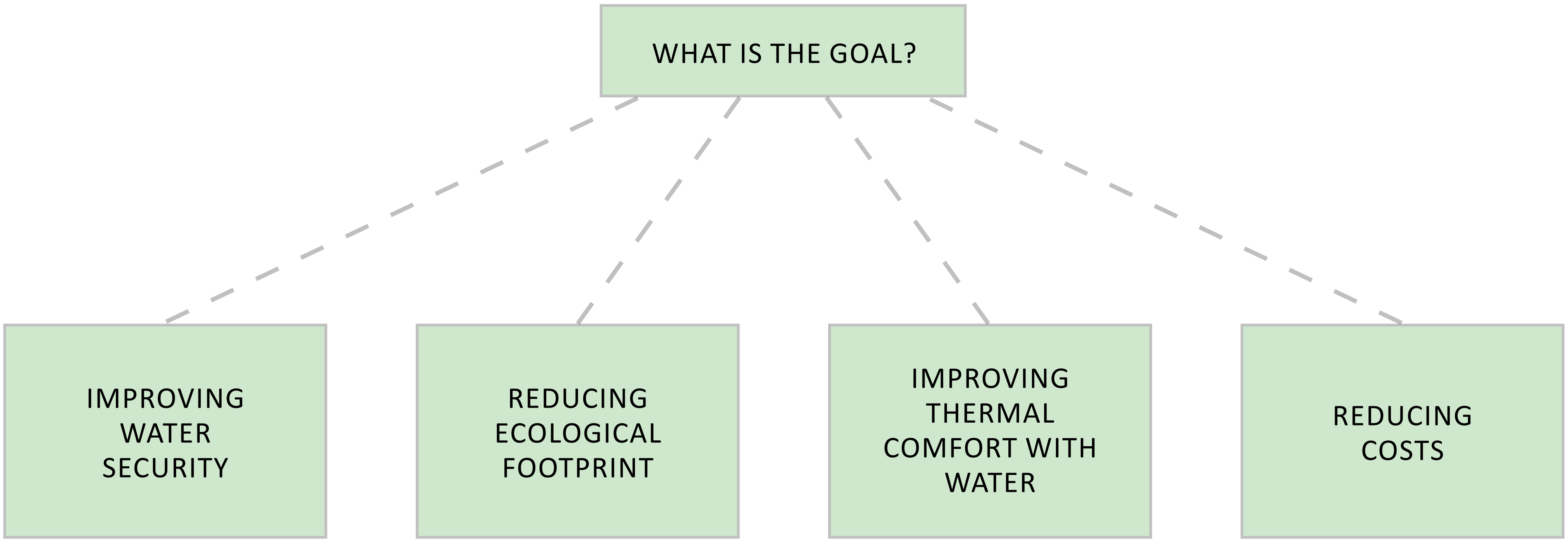
LIME PLASTER

Lime plaster can absorb and release moisture just like clay plaster, but it is more durable and requires less maintenance. Lime is produced by burning limestone and even though production is energy intensive, during its lifetime the lime absorbs CO_2 from the air which neutralizes the carbon emission during its lifetime. Lime cures slower than cement which reduces risk of cracking.



3.4 WATER MANAGEMENT

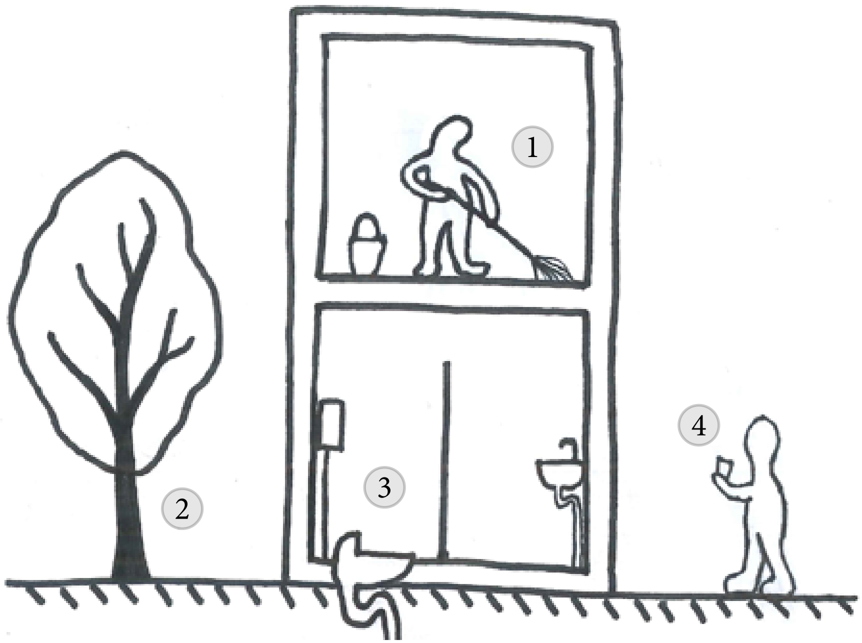
Access to clean water is an issue for many in Pakistan and the water available per person is dropping quickly. TCF schools often have no access to tap water and buying water is a major cost. Diversifying water management with different sources of water can reduce costs and increase water security and resilience. Water can also help provide thermal comfort as described on pages 56 and 57.



WATER NEED

(1) Cleaning is one activity that requires water in TCF schools.

(2) There are always plants in TCF schools and they need watering. Local plants that are adapted to the climate require less watering.



(3) The schools also have bathrooms that require water, but they are not used a lot and don't use as much water as cleaning and watering plants.

(4) People also need water for consumption. Drinking water is not the responsibility of schools, but the schools' water management affects water security on a wider scale.

STRATEGIES

1 Digging wells is a self-sufficient way to access and use groundwater on site. Wells however can easily lead to overuse of groundwater, which is not sustainable and eventually leads to the well drying up.

2 Existing TCF schools don't have concrete yards, but as Pakistan develops, the amount of asphalt and concrete paving in cities increases. When the paving doesn't allow water to penetrate, groundwater reserves are not replenished, and the risk of flooding increases. Because of this, natural ground cover, or permeable pavement is favourable.

3 Rainwater in cities usually leaves the city through stormwater drains, but collecting rainwater provides a free source of water. Rainwater is generally harvested from roofs. However, the amount of water that can be harvested varies greatly depending on the weather, and this makes it less reliable, especially in climates like Pakistan where there are rainy and dry seasons.

4 Recycling of water improves water security because it doesn't depend on the weather. Recycling can be done either with chemicals or with natural methods such as plants. However not all water used is recyclable, such as water used to clean floors or to water plants, and in TCF schools there is little recyclable water.

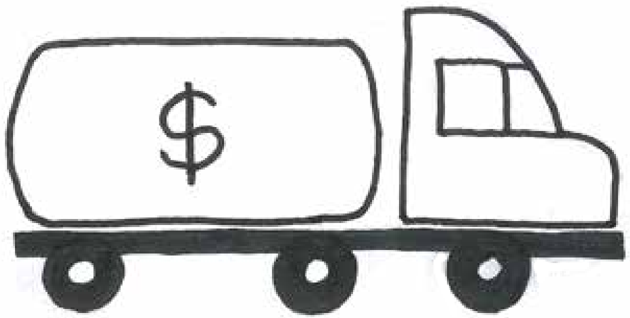
5 Water can be used in many ways to improve thermal comfort. Water has a high thermal mass, and for example a roof pond can keep a building cool by absorbing the heat that would otherwise enter the building through the roof.

6 Fountains are another way to use water for thermal comfort. When water evaporates, it cools down the air around it and fountains increase the rate of evaporation because the water is sprayed. Fountains also add aesthetic value.

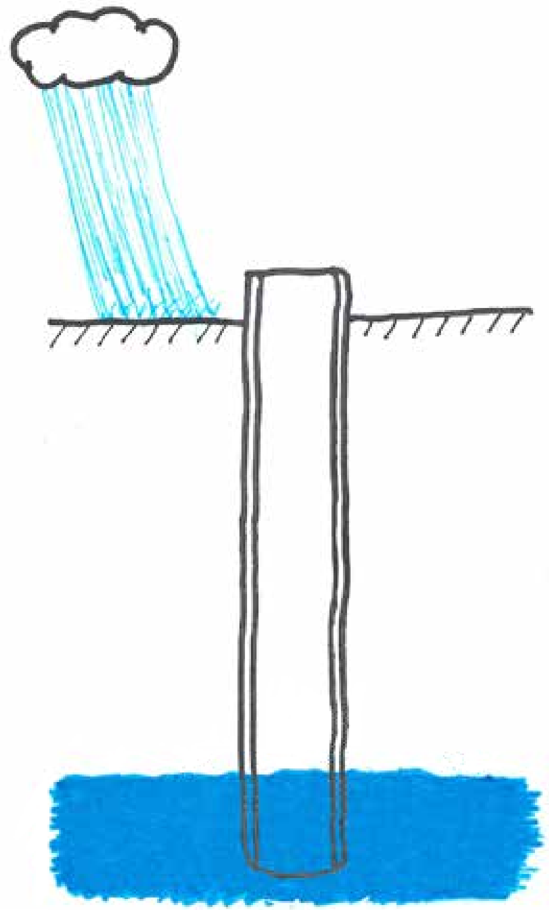
7 With improved water management there is more water available, and this allows for more plants, that in turn create more pleasing and comfortable spaces.

EXISTING SITUATION

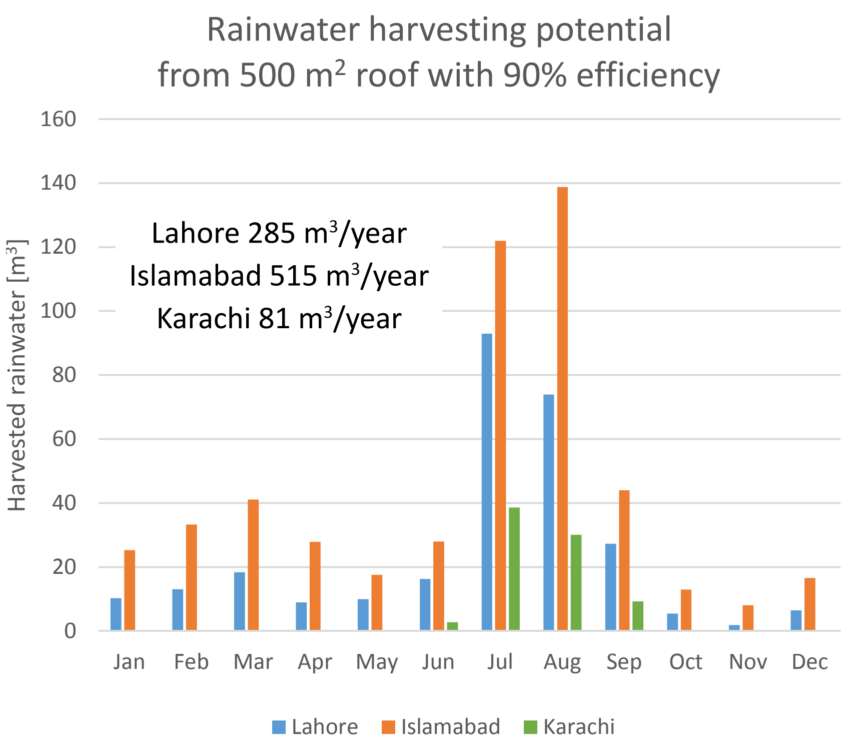
Many existing TCF school have to buy water in tankers which can be very expensive. For example, one of the visited schools in Karachi buys water for $150 every month.

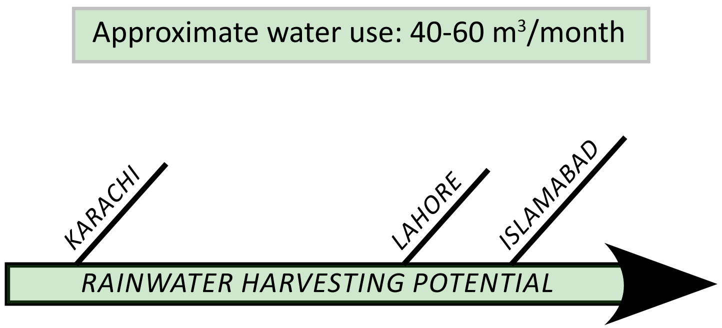


Some schools in northern Pakistan have wells, and wells are a more self-sufficient solution. However, the water table in cities like Lahore is dropping because of overuse of groundwater (Adnan 2015). At the same time rainwater in cities is not allowed to penetrate the ground due to asphalt and concrete, and this means the groundwater reserves are not replenished.



RAINWATER HARVESTING





Even though Pakistan has a long dry season with little rain, rainwater harvesting could increase water security, especially in urban areas. Neighbouring India has made rainwater harvesting compulsory for new buildings in 18 of 28 states (Walton 2010).

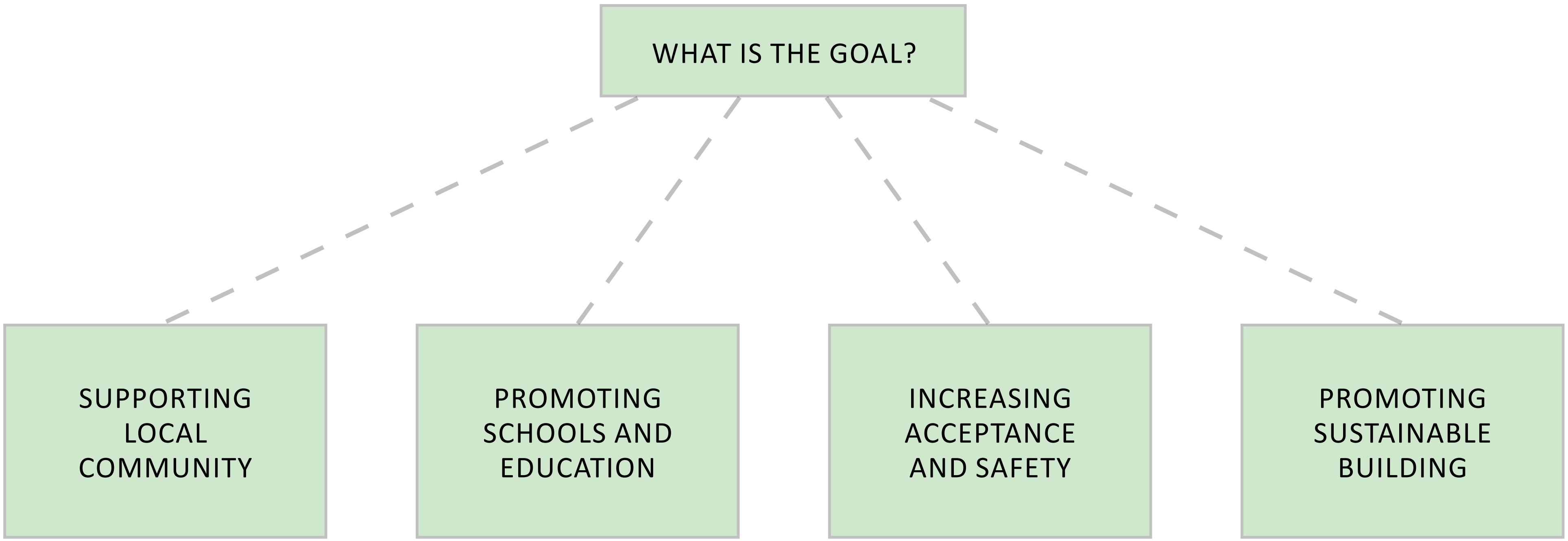
From the figure to the left it can be seen that in Karachi in southern Pakistan there is too little rain to make rainwater harvesting feasible, especially since most rain falls during the school holidays in July and August.

In northern Pakistan there is more rain throughout the year, and the figure shows that in Islamabad and Lahore rainwater harvesting could be feasible. Schools in Lahore have wells, but schools visited in Islamabad bought water, and rainwater harvesting could lower costs considerably.

However, because of large seasonal differences, a large reservoir would be needed to store the water from the rainy season. Storing still water for a long time makes it less suitable for human consumption, but since the schools only use water for cleaning, toilets and plants, this wouldn't be a problem.

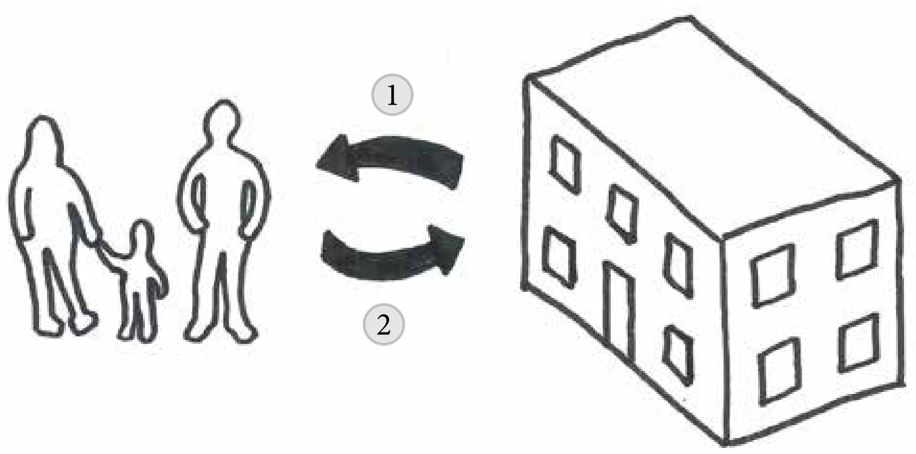
3.5 COMMUNITY INVOLVEMENT

It has already been established that the schools have wider effects that just providing education for children. Involving the community more in the design, construction and running of the school can provide the community with employment, skills, and better access to basic needs. Furthermore, through community involvement the acceptance of the schools and education can increase, and it can also create interest in sustainable building techniques.



SOCIAL IMPACT

1 A new school provides the community with education for the children, but it can provide more. Construction is an opportunity for employment and also for learning new skills. The school building can be also an inspiration buildings that teaches sustainable ways of building and using resources.

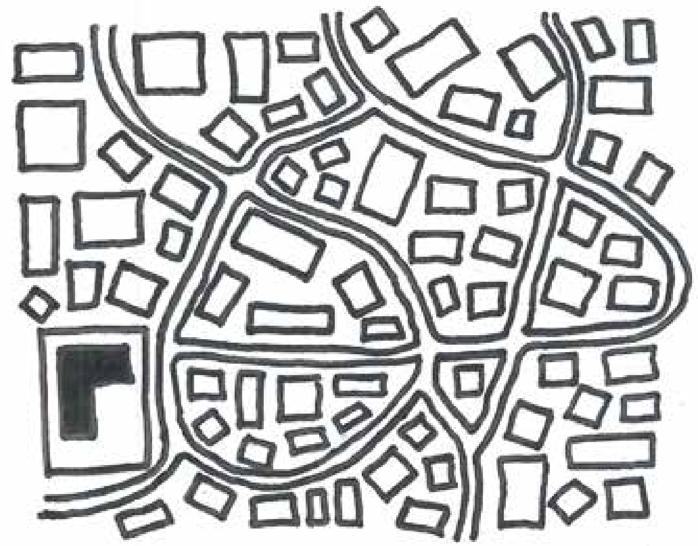


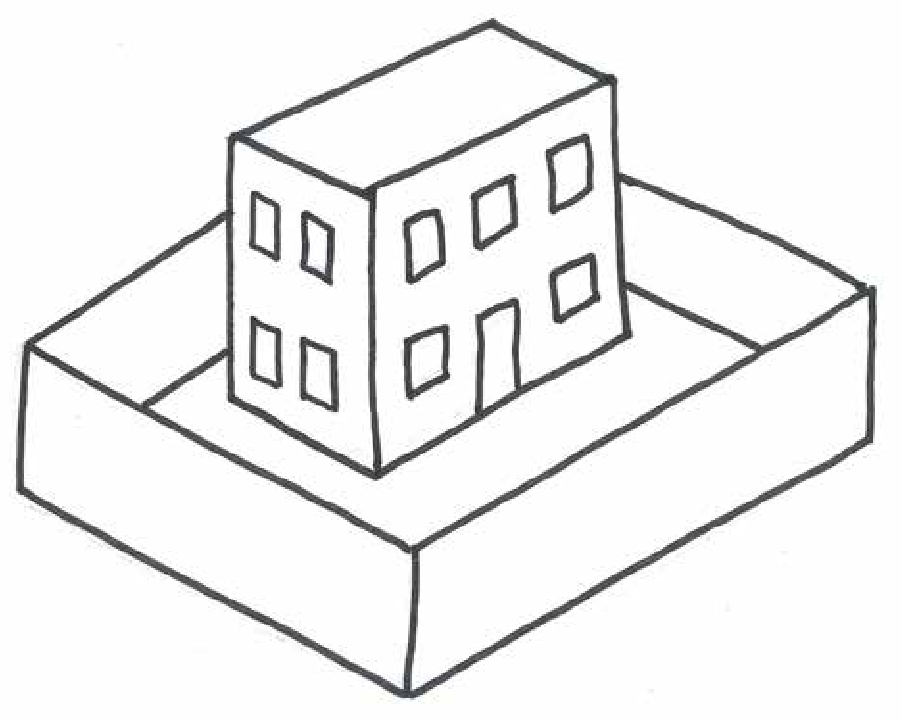
2 The schools can also gain from involving the community. Parents decide whether to send their children to the school, and if the community is more involved, the acceptance of the school can increase. Better acceptance can also improve safety. Using local labour can be a way to save money by using inexpensive but labour intensive materials such as earth.

EXISTING SITUATION

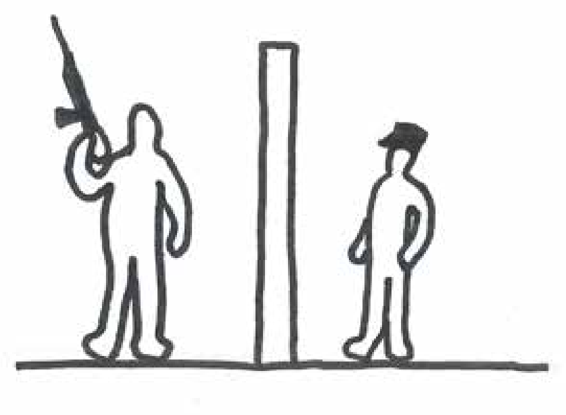
After building a new school, it can be challenging to get parents to send their children to the school. These parents are skeptical about who runs the school, or don't understand the value of education. Because of cultural reasons it is especially difficult to get parents to send their girls to school.

In dense urban areas there can be land-use conflicts when space is scarce. TCF builds schools on donated land, but if this land was previously not used by the owner and was instead a communal space, the community loses a space it used to have. The school spaces are also unused outside school hours.





All TCF schools have boundary walls for safety reasons, but this can isolate the schools from the community. Especially in slum areas TCF schools stand out because of their design and size and this also separates them from the community. On the other hand, children also feel proud about going to school in a building that stands out.

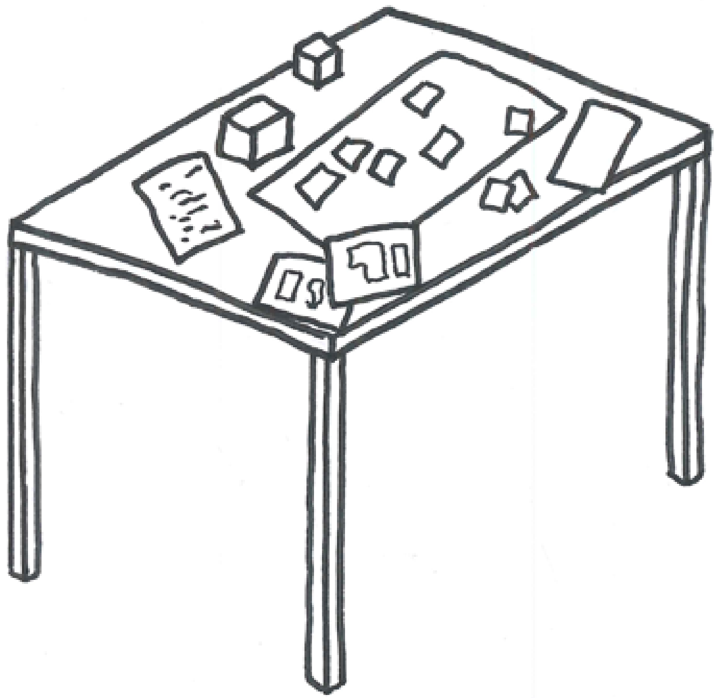


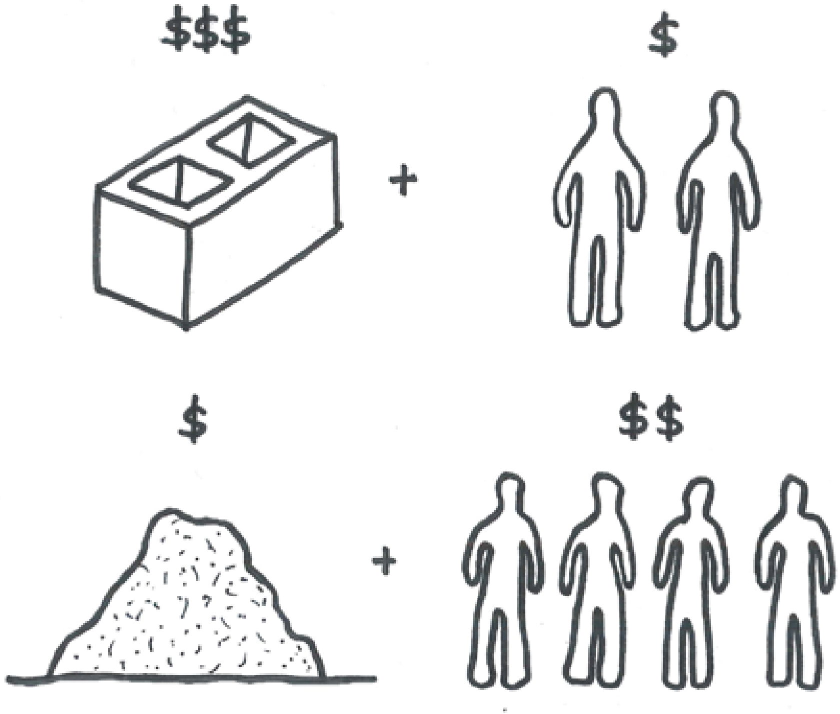
Safety is a high priority for TCF and all schools have a boundary wall and a guard. Safety is undoubtedly important - especially now that there is a high risk of terrorist attacks on schools in Pakistan - but in order to deal with it efficiently it is important to see where the threat is coming from and whether it is local or external.

BEYOND EDUCATION

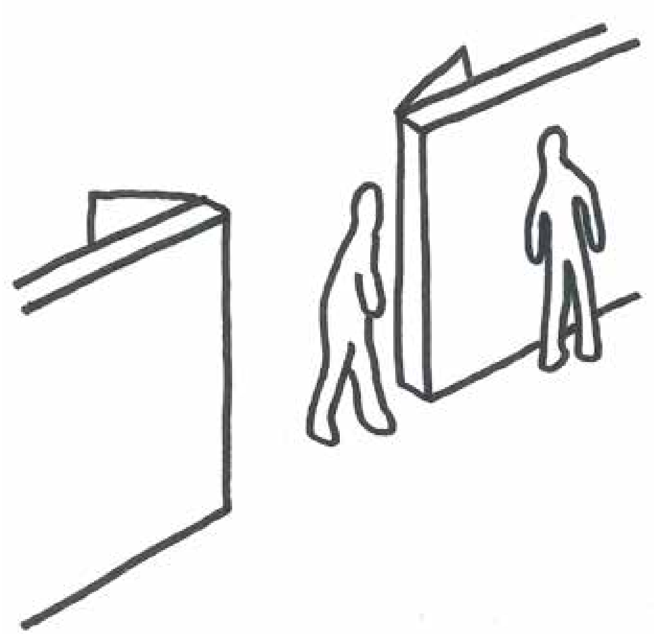
TCF schools are located in areas of extreme poverty and the people in these areas are in need of more than just education. People need to fulfil their basic needs first, and the schools can help provide these needs in different ways. A good example of this is one visited TCF school in Karachi that sells treated water to the locals, thus improving access to safe drinking water.

In existing schools, TCF reaches out to the community after the school has been built, but it could be beneficial to involve people earlier. The earlier people are involved, the better they understand why and how the school is built. Involving the community in the design process through participatory design could make the schools fit the community better. It can also be a way to promote sustainable building and improve the image of techniques such as earth. However, it can be difficult to get people involved and people need an incentive.





Involving the locals in construction can provide them with employment and new skills. The acquired skills can then be used to find further employment and/or to improve their own houses. Choosing low-cost materials such as earth is one way to increase the amount of employment that can be created, and thus increase the positive impact on the community.



The community should also be involved in the school's activities after the school is built and in operation. This strengthens the schools position in the community. For example the school yard could be open on weekends for the children to play, or for activities with the parents.

4 DESIGN

This section presents a revised design for a TCF school. The aim is to show how the previous analysis can be turned into architecture. The design demonstrates how working with the previously defined focus areas of passive design, materials, water management, and community involvement can improve the sustainability of a TCF school. All the previously discussed solutions are not used however, and the focus is especially on solutions that link the four focus areas. The design is not meant to be a complete design for a specific location, but instead a source of inspiration for future school designs.

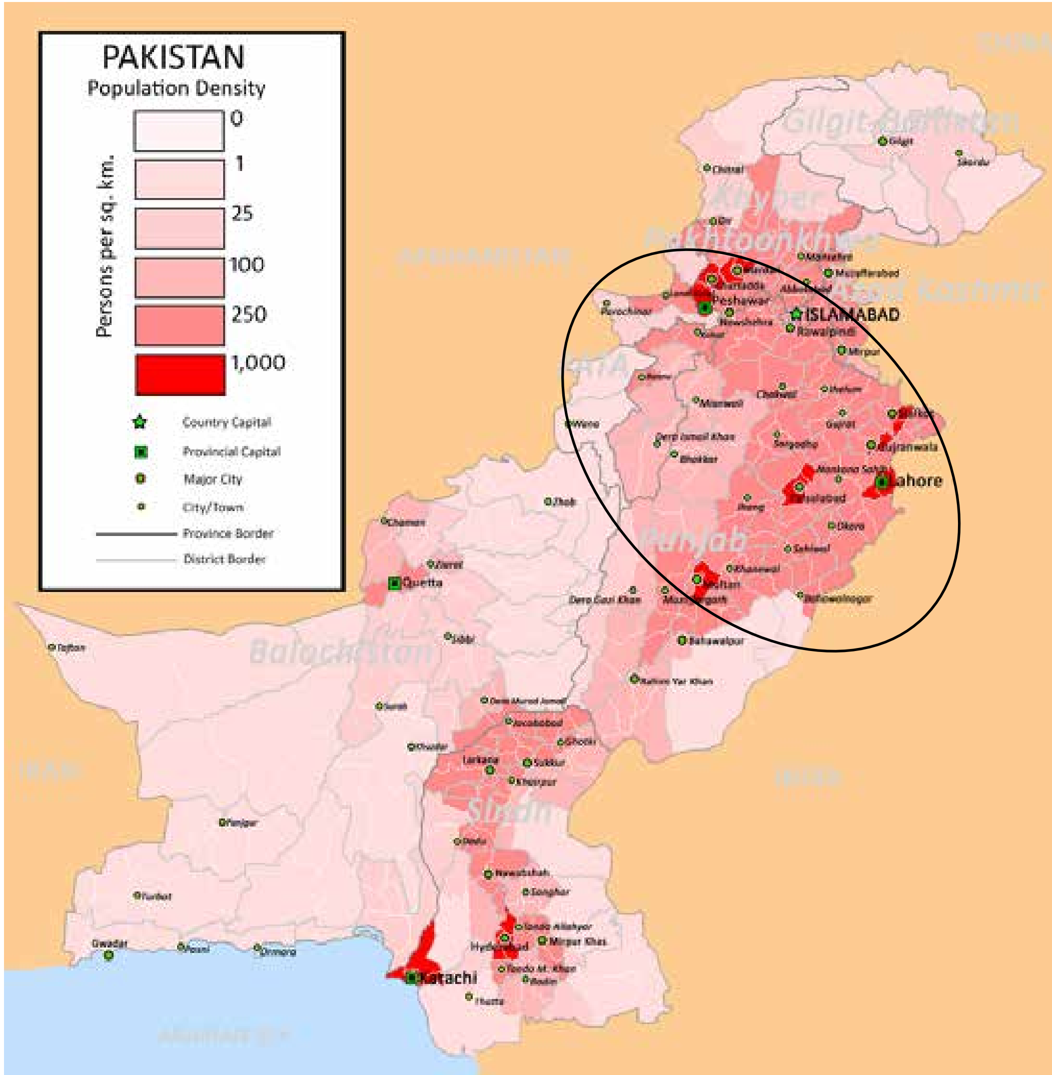
4.1 DESIGN PROGRAM

The design proposal is a hypothetical design for a TCF school in an urban area in northern Pakistan. The school has three units of primary school classes and is based on an existing TCF school. The purpose of the design is to show how working with the four focus areas of passive design, materials, water management and community involvement in a different way can result in an improved design.

Northern Pakistan is chosen because the existing schools there have more problems. The climate in northern Pakistan varies a lot and this makes it more challenging to design passive thermal comfort and natural ventilation. The summers are very hot while winters can be uncomfortably cold. Wind speeds are also lower than in southern Pakistan, and the wind speed varies more. The area receives rainfall mainly during the rainy season in July-September, but there is rain throughout the year.

The design is meant for an urban area. Urban areas are densely populated and there are a lot of children needing education in a small area. There are also more land use conflicts in urban areas where land is scarce. It can also be more challenging to work with the community than in rural areas. 7 of Pakistan's 10 largest cities are located in the considered area.

The design focuses on the four focus areas and other factors are given less consideration. TCF schools have a distinct character and the design should not differ a lot aesthetically from existing TCF schools in order to fit TCF's image. Unnecessary changes should be avoided to save costs.



Population density of Pakistan and approximate area for the design proposal
Source: Wikipedia 2016

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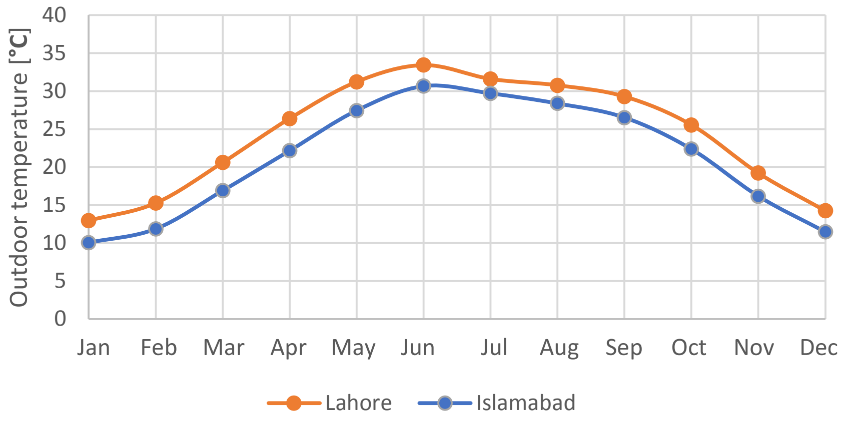
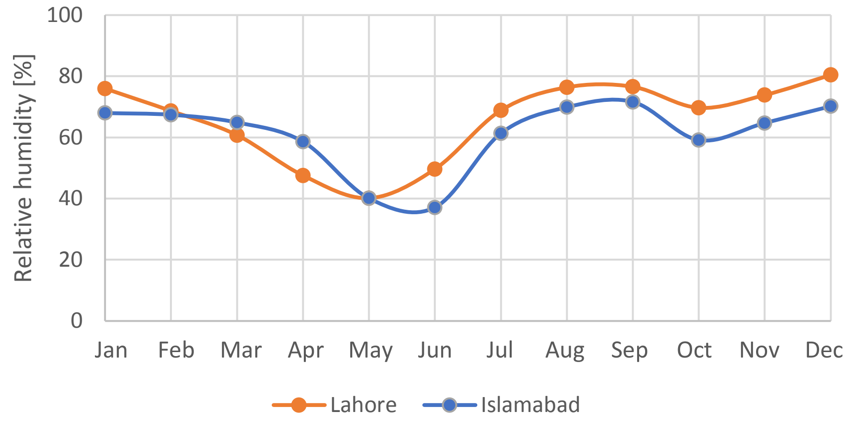
CLIMATE

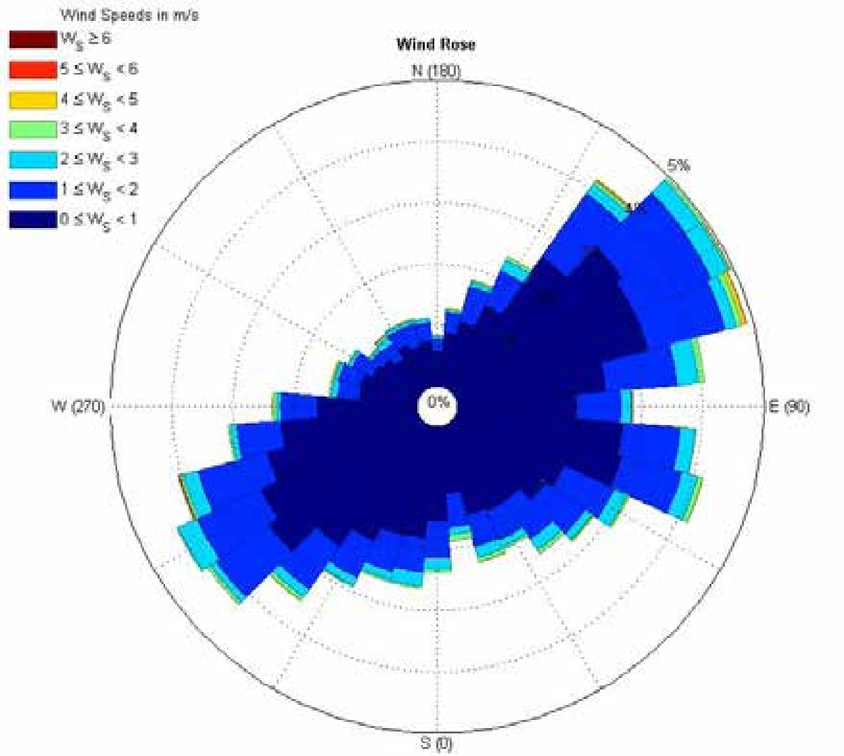
AVERAGE OUTDOOR TEMPERATURE



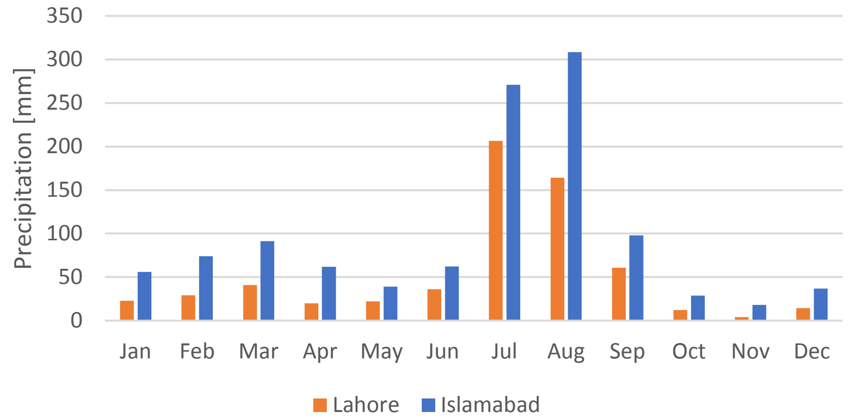
AVERAGE RELATIVE HUMIDITY



WIND ROSE FOR LAHORE



MONTHLY PRECIPITATION



DESIGN

DESIGN CRITERIA

Minimize COSTS
- construction costs
- maintenance costs
- running costs

Minimize ENVIRONMENTAL IMPACT
- building energy use
- embodied energy
- embodied carbon

Minimize USE OF SCARCE RESOURCES
- construction materials
- water

Maximize INDOOR ENVIRONMENTAL QUALITY
- thermal comfort
- ventilation
- daylight

Maximize POSITIVE SOCIAL IMPACT
- education
- employment
- acceptance

Maximize AESTHETICS

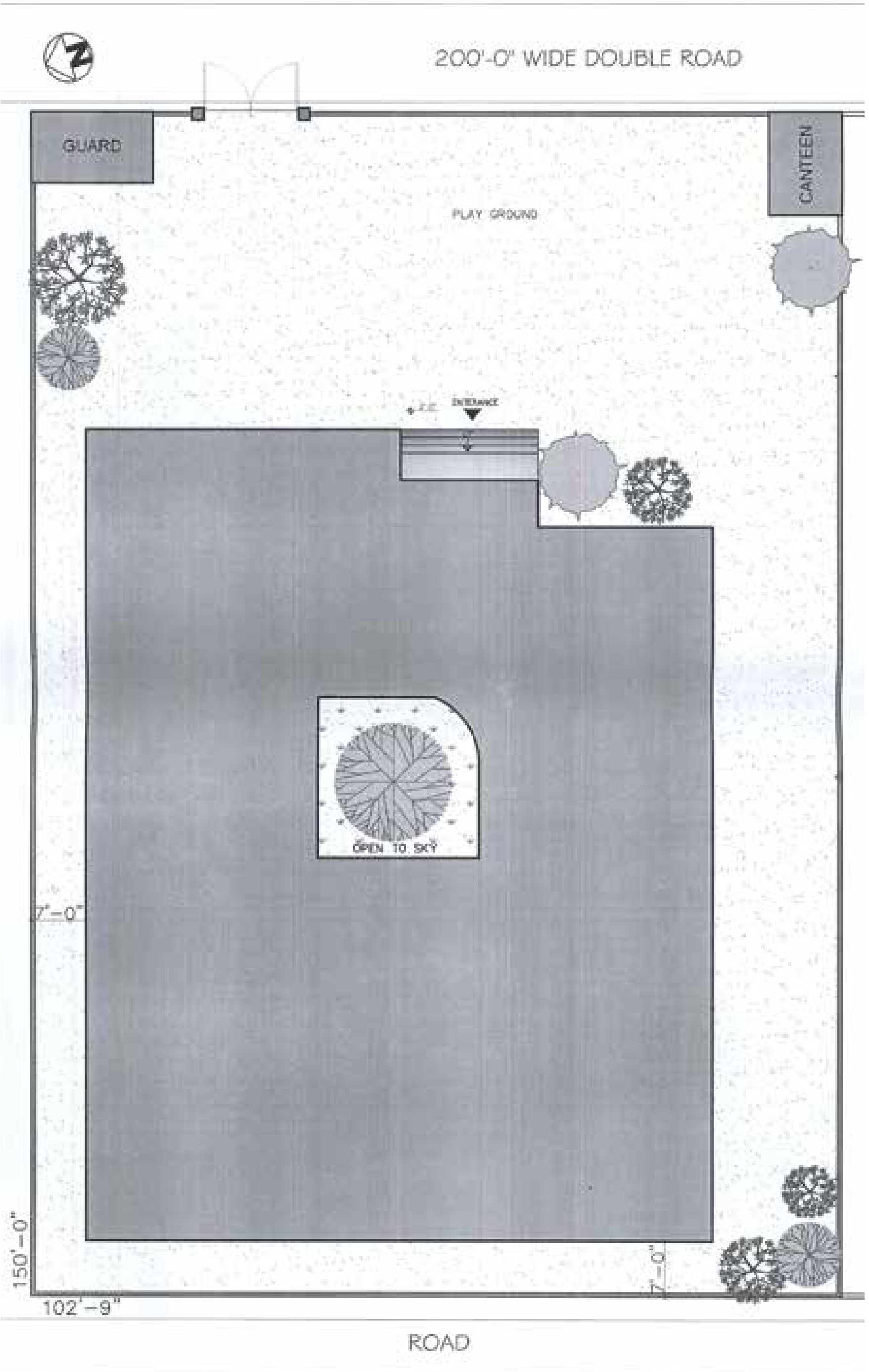
REFERENCE SCHOOL

The design proposal is based on drawings for TCF Burhanuddin Campus in Karachi. The design proposal has the same rooms as the reference school, and their sizes are kept approximately the same. The reference school is located in southern Pakistan, but the reference is mainly used to determine which rooms are needed and this is very similar between different regions.

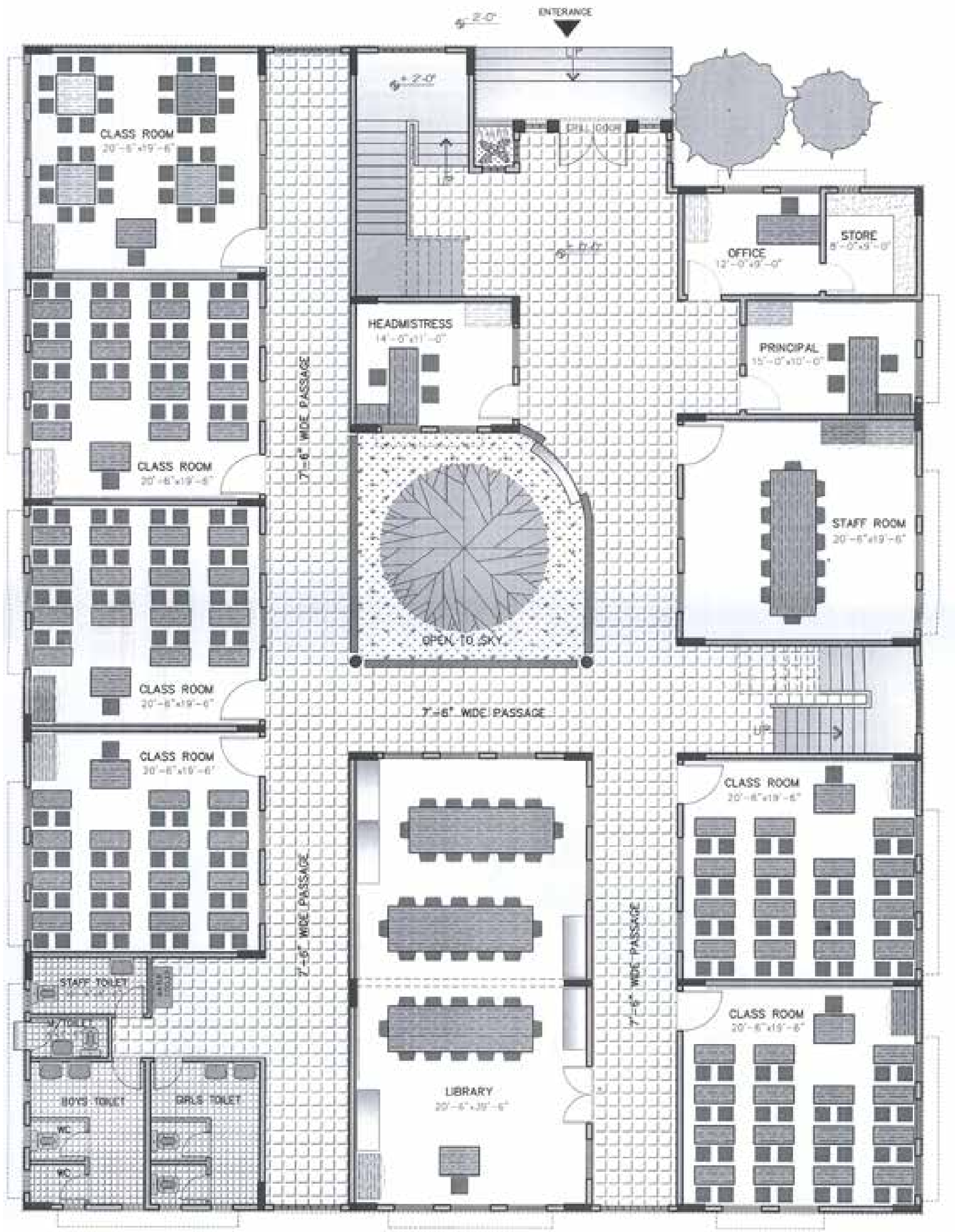
The reference school has the following rooms:

18 classrooms, 37.1 m^2 each
art room, 37.1 m^2
library, 75.3 m^2
2 staff rooms, 37.1 m^2 each
principal's office, 13.9 m^2
headmistress's office, 14.3 m^2
office with storage, 16.7 m^2
storage and pantry, 7 m^2 each
3 staff bathrooms, 4.9 m^2 each
janitor's room 1.6 m^2
3 boy's and 3 girl's bathrooms, 13.3 m^2 each

Complete drawings for the reference school are found in the appendix.



Siteplan of reference school



Ground floor plan of reference school

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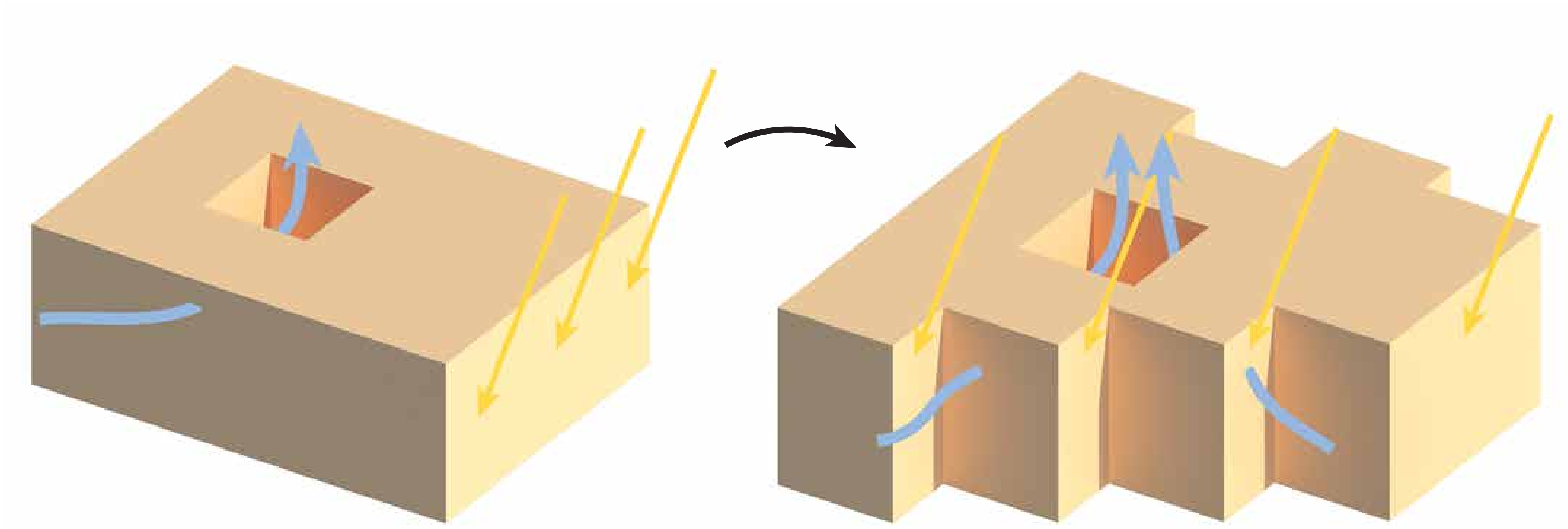
4.2 DESIGN PROPOSAL

CONCEPT



UNIFORMITY OUT OF VARIATION

- More variety in form creates a more even indoor climate
- Resilience to changes in wind direction
- Less variation in sun and air between classrooms

OVERVIEW

PASSIVE DESIGN

- The focus is on optimizing comfort in classrooms since other rooms are used less often and/or by less people.
- All classrooms have windows facing south and east so they receive more sun in the winter, especially during the morning hours.
- All classrooms have windows in three orientations, which creates better ventilation when the wind direction varies.
- There are two courtyards so that all rooms have better access to a courtyard, which improves daylight and ventilation.
- Bathrooms are located in the northwest corner since it is the most challenging location because it receives low western sun in summer but very little sun in winter.
- Classrooms have two ventilation shafts, one provides passive cooling during summer and the other provides passive heating during winter.
- Top floor classrooms have windcatchers that work as air exhausts, using both wind and stack effect. The windcatchers are designed so that wind passes through from any direction, which makes the wind direction irrelevant. The windcatchers are black which enhances the stack effect.
- Other rooms have higher ventilator windows for enhanced ventilation.
- Heat gains through the roof are reduced with a hollow ceiling.
- Overhangs shade windows and work as light shelves.

MATERIALS

- Compressed earth blocks are the main construction material and the structural system is a composite system of earth and reinforced concrete.
- Overhangs and lime plaster protect the exterior walls from rain.
- Decorative *jaali* lattice windows made with earth blocks showcase earth by the entrance, corridors and balconies.

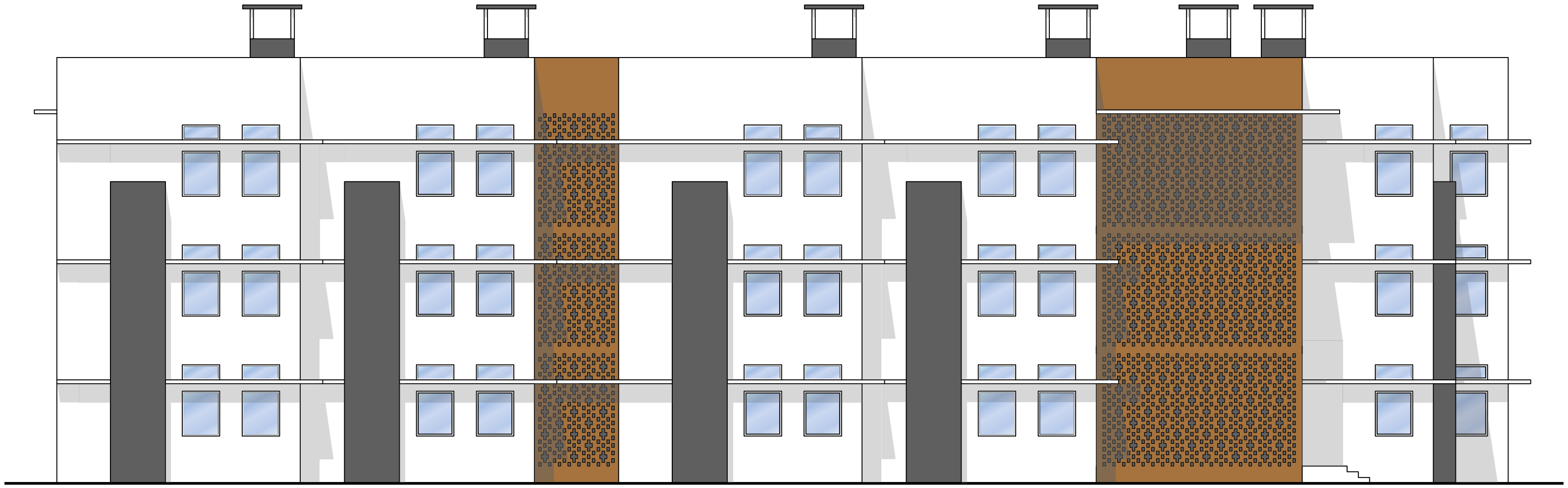
WATER MANAGEMENT

- Rainwater is harvested from the roof and a well provides back up water. Rainwater is collected first to a water tank on the second floor above the toilets and then into a larger underground reservoir.
- Underground reservoir provides water for ponds in the yard and courtyard. These ponds provide water for plants, have a cooling effect, and create a pleasant space. Water level in the ponds varies throughout the year which is symbolic for water availability.

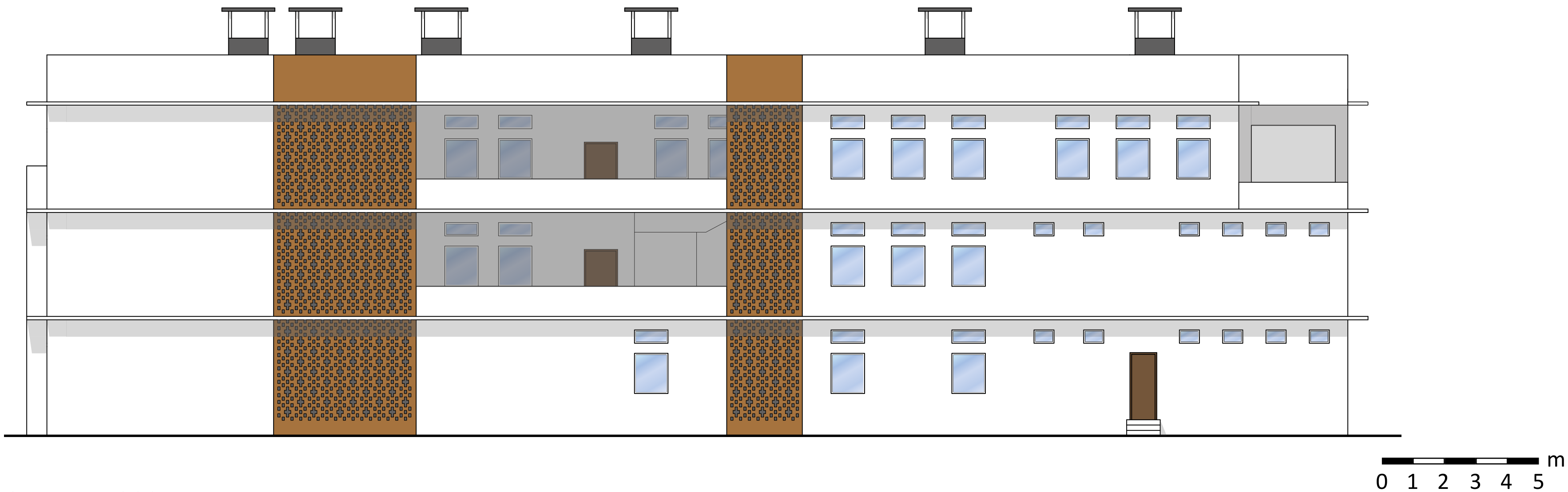
COMMUNITY INVOLVEMENT

- Local production of earth blocks employs local labour, teaches new skills and showcases a modern earth building technique.
- The yard and playground is semi-private and open to the public on weekends for activities.
- The schools activities are displayed with educational art on balconies.

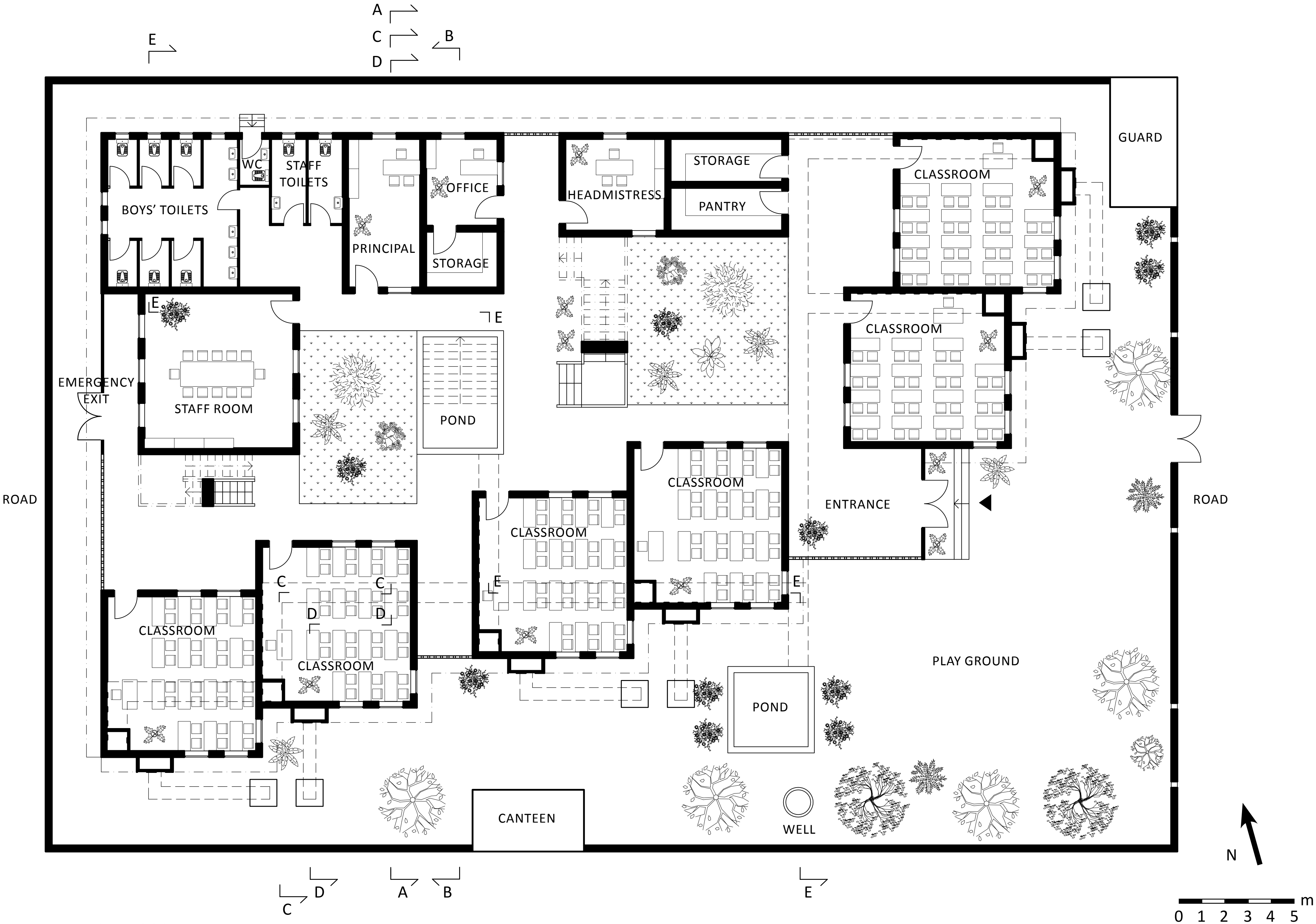
DRAWINGS



ELEVATION SOUTH - 1:200



ELEVATION NORTH - 1:200



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CLASSROOM
STAFF ROOM
EMERGENCY EXIT
POND
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PLAN 0 - 1:200

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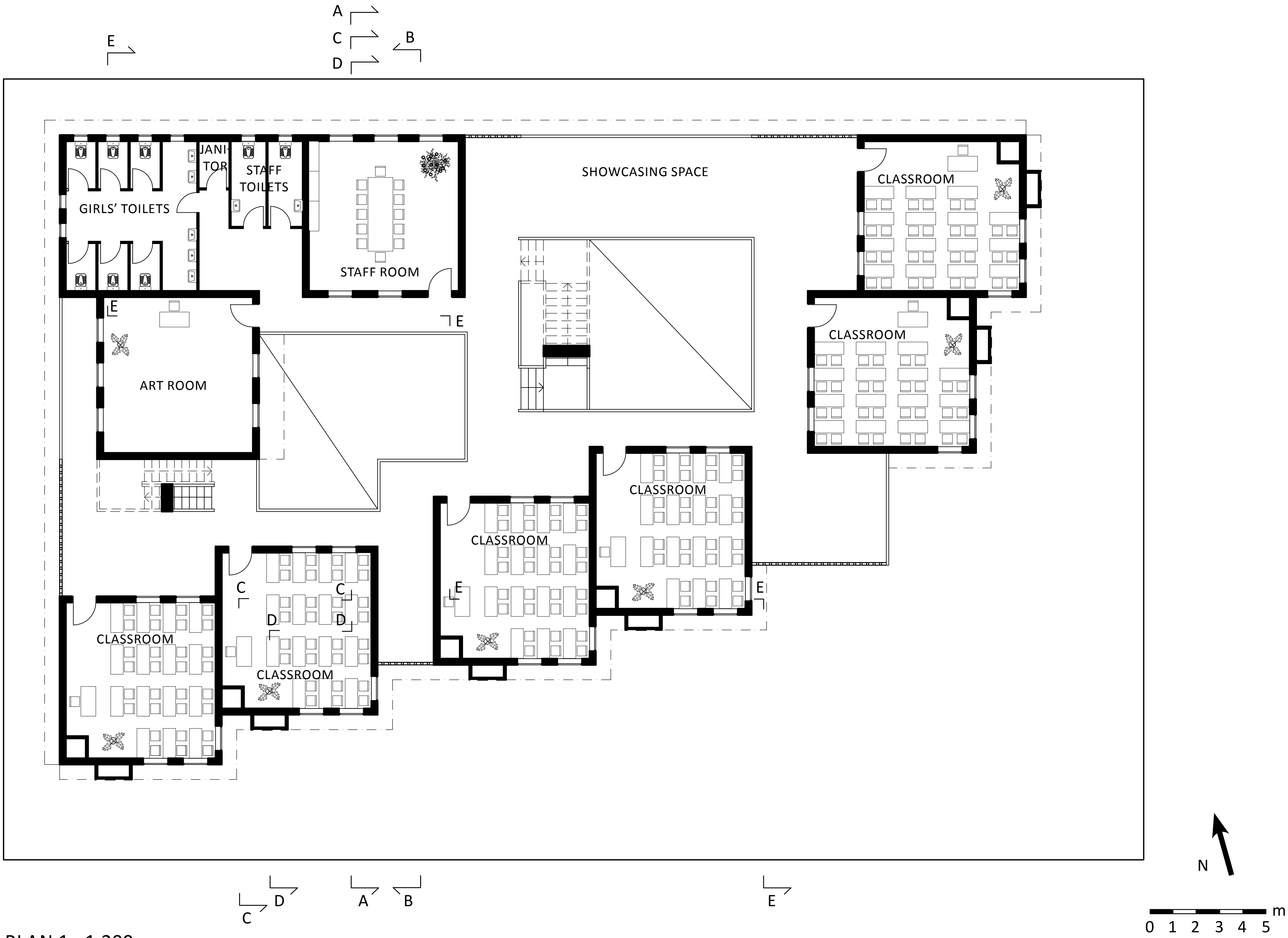
GIRLS' TOILETS
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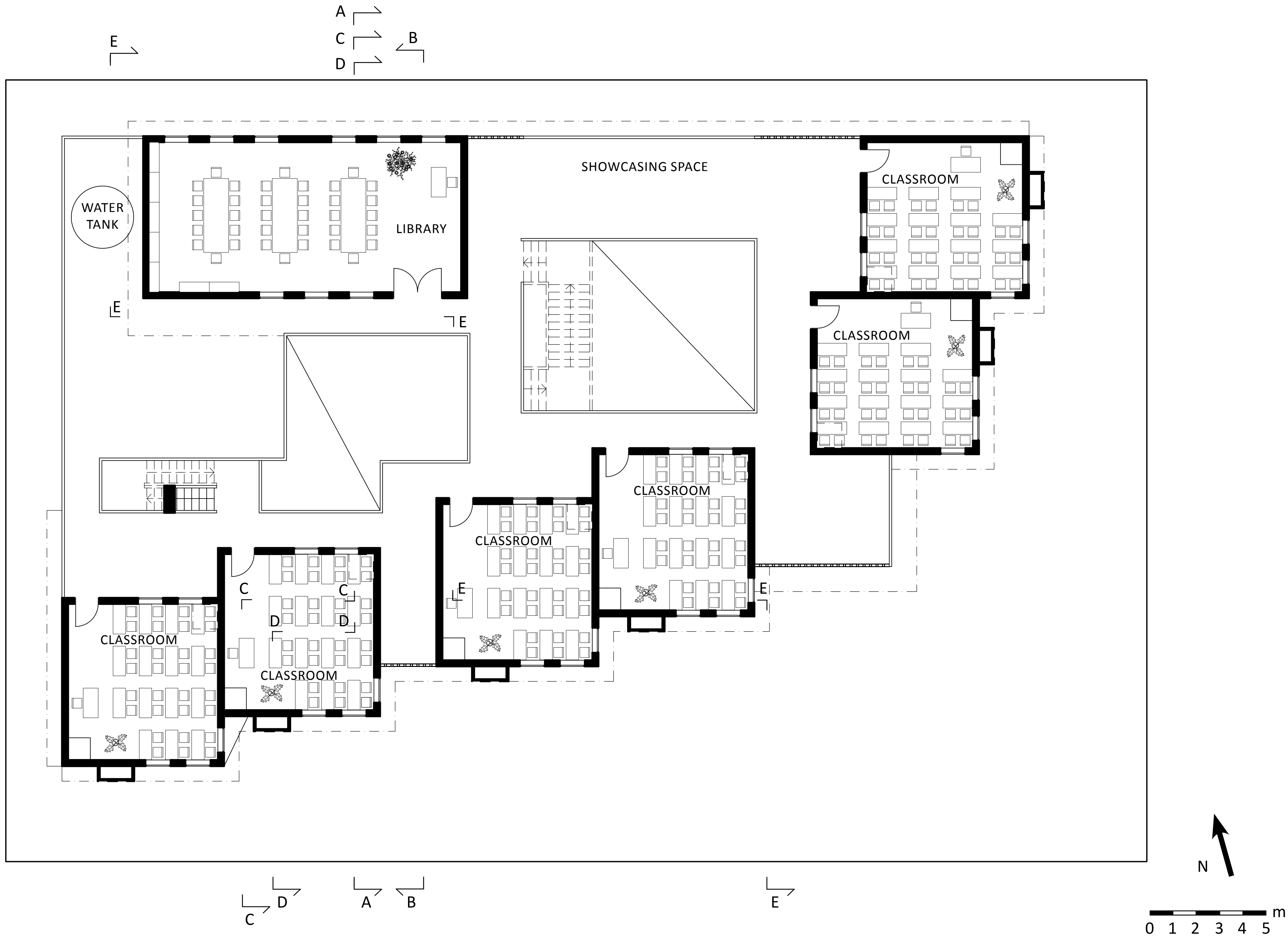
PLAN 1 - 1:200



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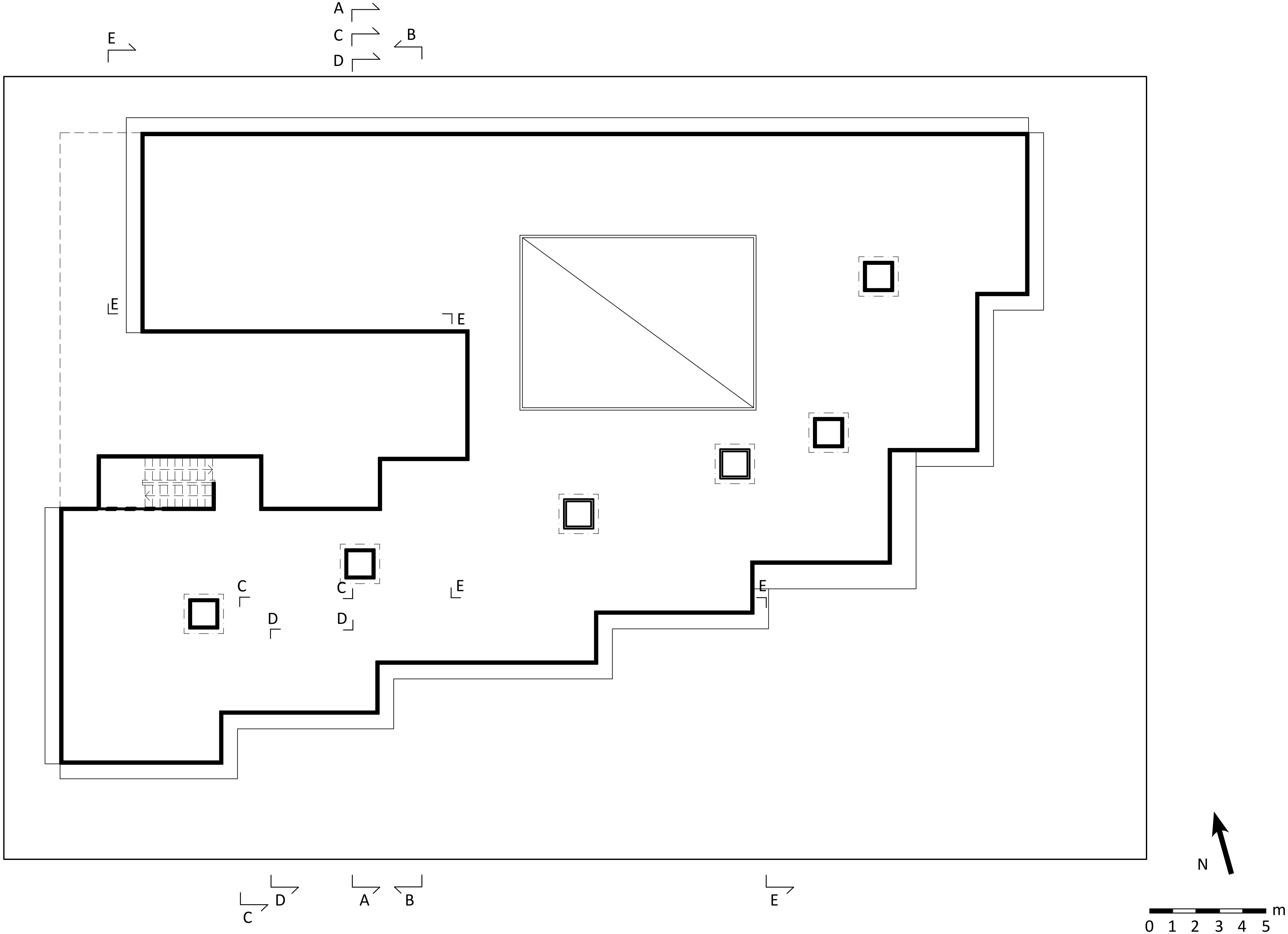
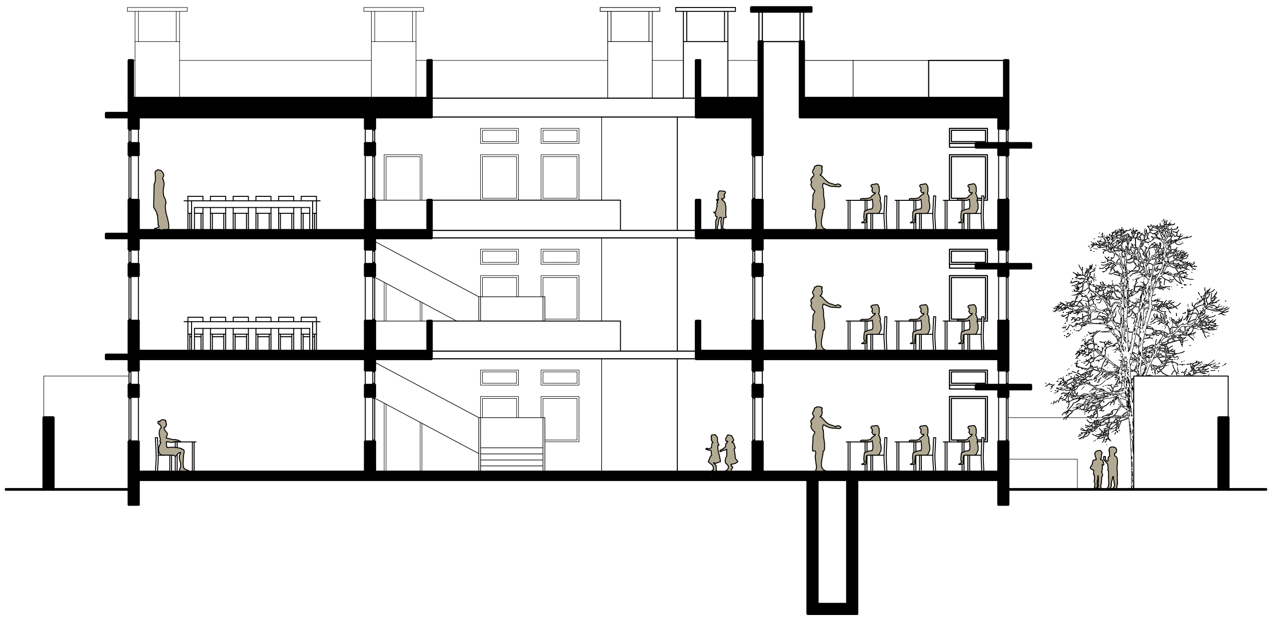
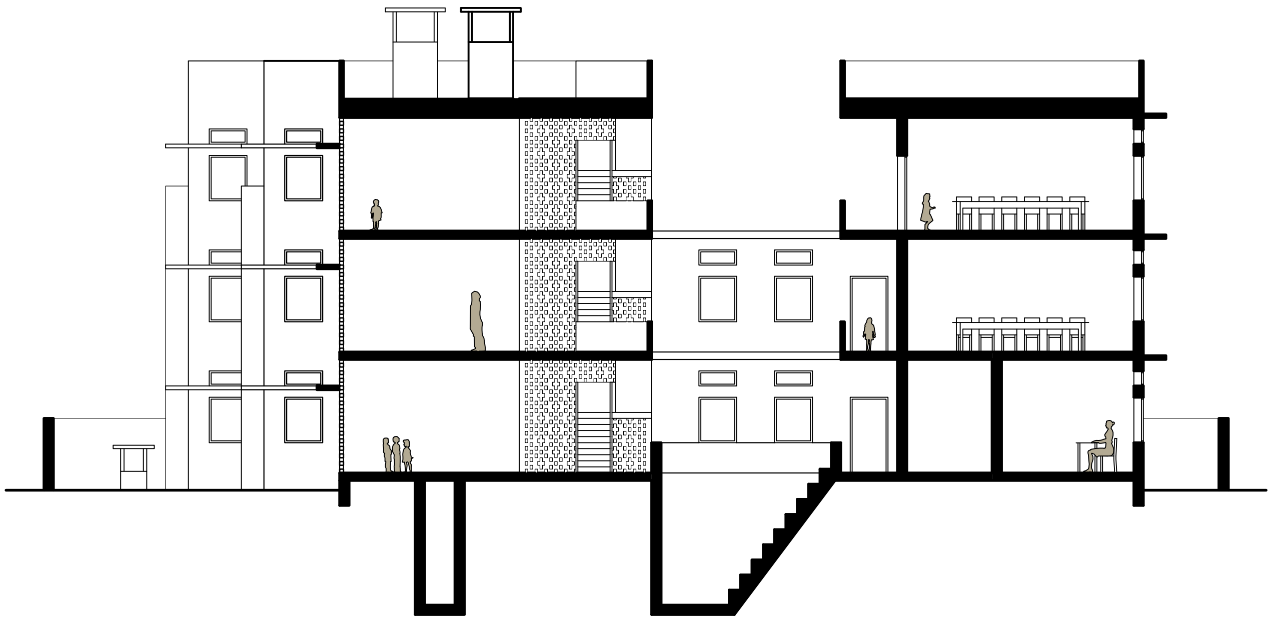
PLAN 2 - 1:200



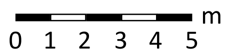
PLAN 3 - 1:200



SECTION A-A - 1:200



SECTION B-B - 1:200



SOLAR STUDIES

JUNE 21ST

12:00

8:00

16:00

During the hot summer months shading should be maximized to prevent solar heat gains through windows. When the sun is high during the day, shading elements above the windows provide shade. In the early morning and late afternoon, the sun is lower, but the shape of the building helps shade the windows. The hottest time of the day is the afternoon which makes it especially important to avoid western sun, and in the design the classrooms have no windows towards west.

DECEMBER 21ST

12:00

8:00

16:00

During the colder winter months solar heat gains should be allowed to penetrate through the windows in order to provide passive heating. The sun is lower at this time, which means the shading elements above the windows leave most of the window unshaded. Mornings are the coldest time which makes eastern sun especially valuable. In the design all classrooms have some windows facing east, while southern windows receive sun later during the day.

SUMMER

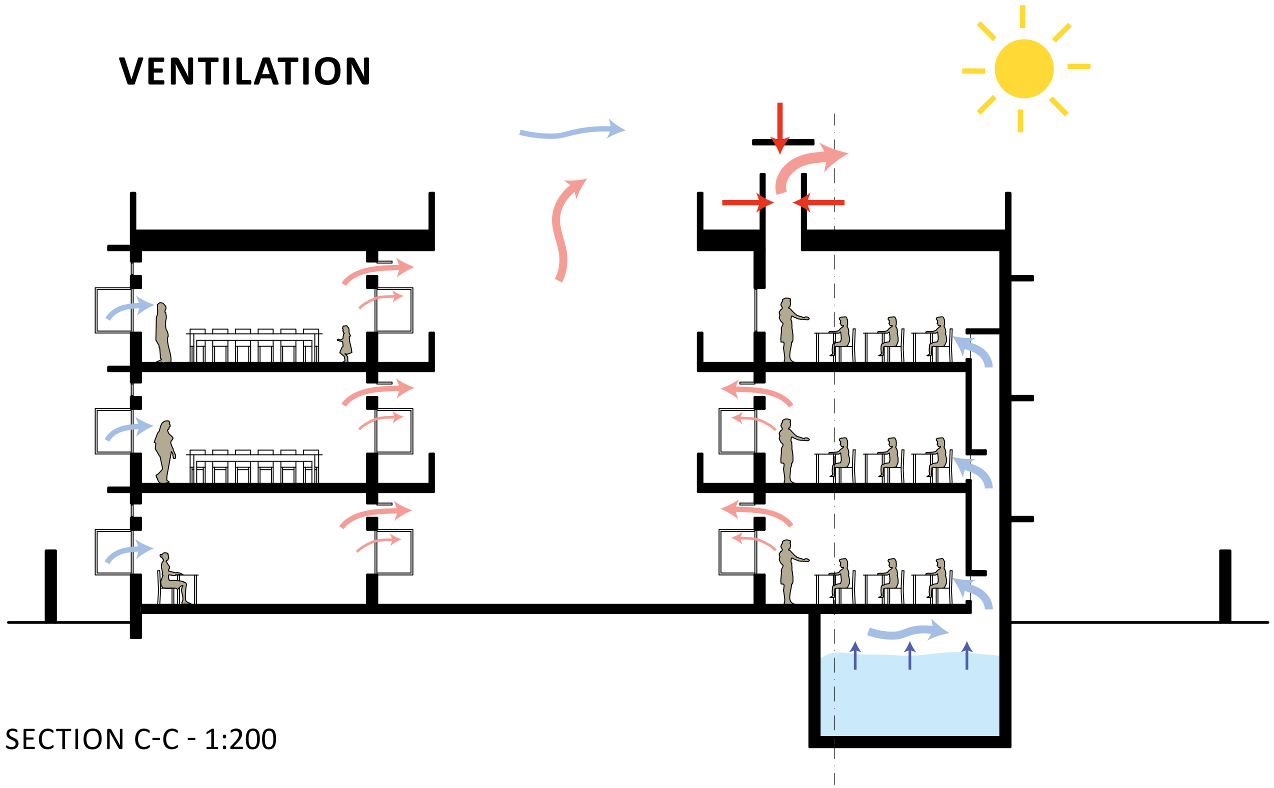
Water channels located below the school provide passively cooled air during the summer. The air is cooled by the water due to evaporative cooling, and then enters the classrooms. Since the air in the shaft is cooler and heavier, it tends to remain in the shaft and needs to be pulled out by a stronger force, and in this case the air is pulled out by the windcatcher that acts as a solar chimney. The windcatcher is black which means the air inside it will become very hot and light, causing the air to escape.

The windcatcher creates a draft in the whole shaft, but in the first two floors the hot air exits the classrooms through ventilator windows located above the regular windows.

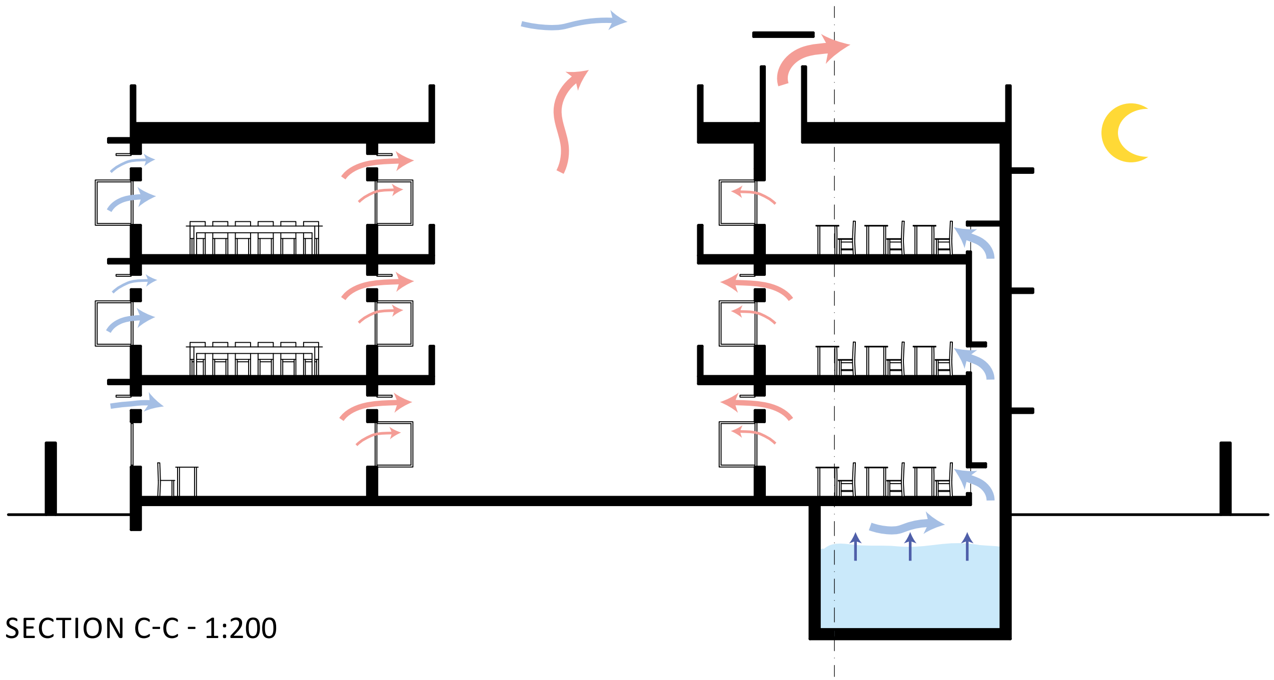
In other rooms the atrium effect of the courtyard is used to ventilate these rooms. Since the air will exit from the courtyard side, it is best to keep the higher ventilator open on this side and the lower main window on the facade side. The air will enter from the shaded north side and it will be slightly cooler because of this.

During the night it is important to cool down the structure so that heat doesn't build up in the structure and the thermal mass is used beneficially. The temperature difference between indoor and outdoor air will be higher than during the day which means there will be more air flow. On the ground floor only the ventilator windows can be opened on the facade side if this is preferable for security reasons.

VENTILATION



SECTION C-C - 1:200



SECTION C-C - 1:200

WINTER

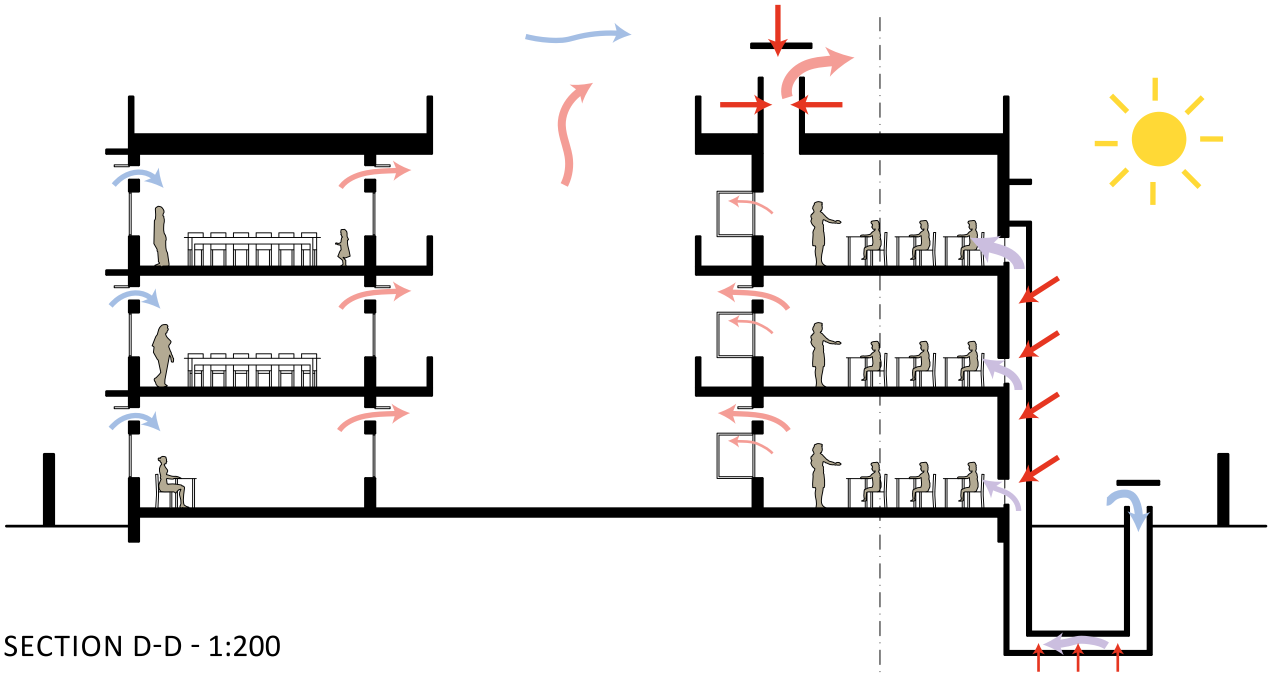
In the winter air enters the classrooms through a different shaft. This shaft is black which means it will absorb a lot of heat from the sun and this will heat the incoming air. Before entering the shaft the air passes through an underground duct, and as a result the thermal mass of the ground pre-heats the air.

When the air heats up in the shaft, it will also cause the air to rise which assures the correct direction of air flow. Windcatchers, ventilators and the courtyard pull air out of the classrooms.

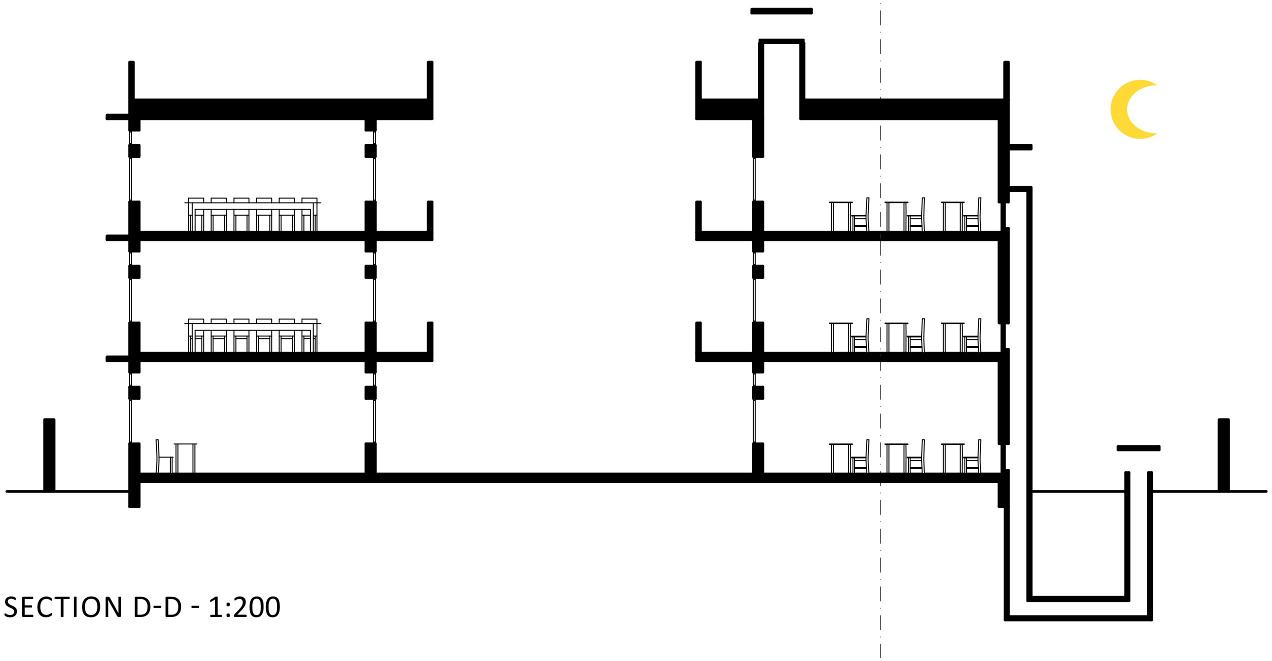
In other rooms ventilation in winter should be done with ventilators. Since these are located higher than the regular windows, there will be less draft which would cause discomfort. During calm weather air will enter from the facade side and exit from the courtyard side.

On winter nights all openings should be closed properly. Otherwise the cold night air will remove the heat that has accumulated in the structure during the day. Windows should be of good quality to minimize air leakages.

In the summer the shaft should be opened outside on the top so that air can circulate through the shaft but not enter the classrooms. Otherwise the shaft will become very hot and this will heat the building and the air entering through surrounding windows.



SECTION D-D - 1:200



SECTION D-D - 1:200

DAYLIGHT

1 All classrooms have windows facing east, south and the courtyard , and this creates more even daylight conditions throughout the day.

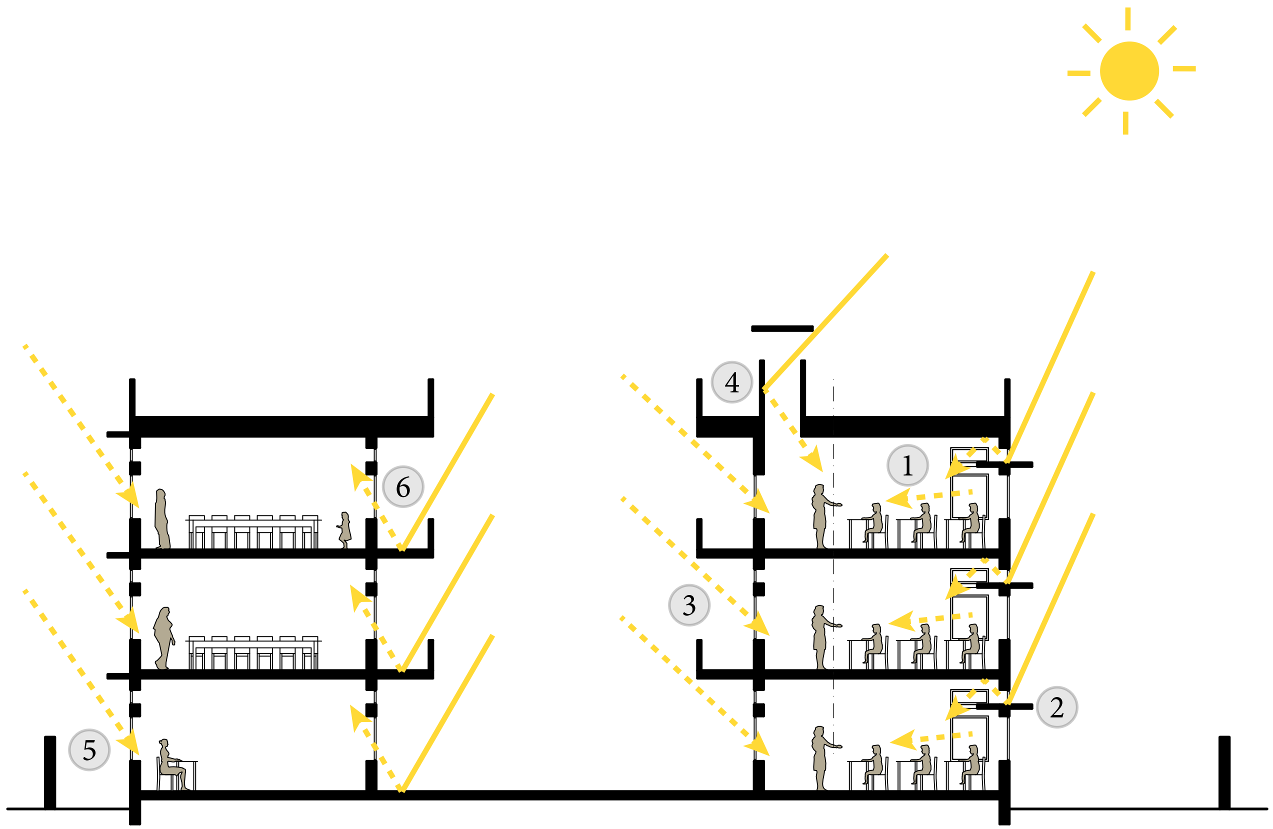
2 Classrooms have light shelves on the facade side. These reflect direct daylight into the ceiling which in turn reflects the light into the room. The ceiling should be white for the greatest effect. The light shelves also shade the main window.

3 Diffuse daylight enters from the courtyard side. The corridors are narrower than in the reference design in order to let in more daylight.

4 Daylight also enters the top floor classrooms through windcatchers.

6 White surfaces reflect daylight.

5 Offices and other rooms on the north side receive diffuse daylight. Special shading elements are not needed, but roof overhangs that protect from rainwater also provide some shading.



SECTION A-A - 1:200

MATERIALS

Earth is chosen as the main construction material due to its low environmental impact, low material cost, moisture buffering capacity and history in the region. Compressed earth blocks are used because their modern and industrial-style but still local production can raise the status of the material. Other materials are used to improve the performance of the building.

This design proposal is based mainly on earth construction technologies developed by Auroville Earth Institute in India. Their manual Auram Press 3000 can be used to make different types of blocks that can be used for walls, roofing and columns. Using hollow blocks that are reinforced with steel and concrete makes the structure earthquake safe. (Auroville Earth Institute 2016)

The earth is obtained from the excavation of the underground water reservoir. Material costs are very low, but labour costs will be higher than with brick or concrete block construction. Using local labour assures that the construction benefits the local community with employment and skills. Most of the labour would be unskilled which has been considered when selecting techniques.

Hollow interlocking block 245 x 245 x 95 mm made with Auram Press 3000
Source: Auroville Earth Institute 2016

Manual Auram Press 3000
Source: Auroville Earth Institute 2016

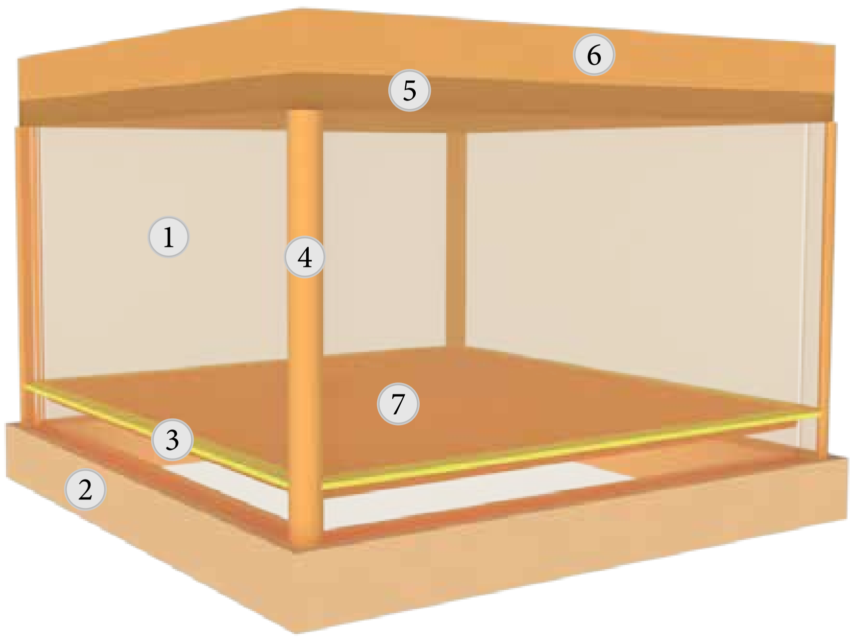
Construction of hollow roof with hourdi blocks
Source: Auroville Earth Institute 2016

Construction of composite column
Source: Auroville Earth Institute 2016

1 The wall is made with 245 mm hollow interlocking compressed earth blocks. Straw is mixed with the earth in order to increase the insulation value. At regular intervals the holes are filled with steel reinforcement and concrete to make the structure earthquake resistant. Because the blocks are interlocking they require only a small amount of mortar. The wall is plastered with white lime plaster that buffers indoor moisture, protects the wall from rain and creates a white surface that reflects light and absorbs less heat from the sun. Because the blocks are protected by the plaster and reinforced, stabilisation with lime or cement is not needed.

2 The foundation is made with stabilised rammed earth according to technology developed by Auroville Earth Institute. The soil from digging the foundation trench is sieved and mixed with sand. The mixture is then stabilised with 5% cement and rammed into place. (Auroville Earth Institute 2016)

3 The wall should have a damp proof course above ground in order to prevent moisture from the ground from rising up the wall. The damp proof course can be made with concrete, bitumen and plastic as is done in existing TCF schools.



4 The columns are composite columns, a technology developed by Auroville Earth Institute. A round stabilised earth block with holes is made with the press and the blocks are stacked to form a column. The holes are then filled with steel reinforcement and concrete. (Auroville Earth Institute 2016)

5 Because of the large span required, reinforced concrete beams are used instead of composite beams.

6 The roof is made with hollow hourdi earth blocks developed by Auroville Earth Institute. The blocks are made with the block press and placed on concrete T-beams, and the roof is then covered with concrete (Auroville Earth Institute 2016). Because the blocks are hollow, the roof has an insulating value that reduces heat gains from the sun. The ends of the roof slab should be left open to allow air to flow through the roof to remove heat. The roof surface should be white to further reduce heat gains.

7 The floor slab is made with earth and lime. Lime cures slower than cement and is more flexible, which can reduce cracking caused by the setting of the slab and the ground, which is a problem in some existing TCF schools.

WATER MANAGEMENT

1 In the design proposal rainwater is harvested from the roof. The roof area is 554 m^2, and with 90% efficiency 315 m^3 of water can be collected annually in Lahore and 571 m^3 in Islamabad.

2 The school also has a well like most existing schools in northern Pakistan. The well provides backup water during the dry season.

3 The harvested rainwater is directed first into a water tank located on the second floor. The water is first filtered and the tank is sealed which will keep the water clean. The water tank can be filled with water from the reservoir or the well if needed.

4 The water tank is located above the bathrooms in order to reduce the need for pumps, and the tank water is used primarily for toilets and washing.

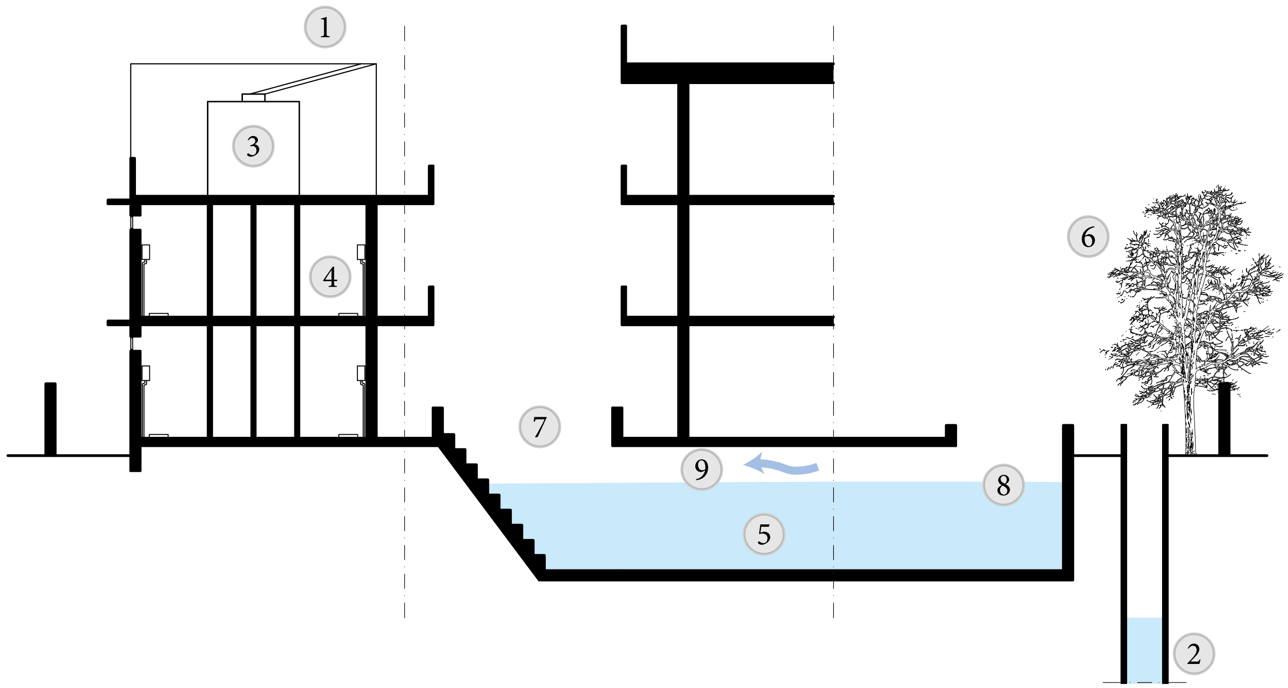
5 When the water tank is full, rainwater will instead be directed to an underground water reservoir. This water reservoir consists of two open ponds and narrow water channels. The reservoir is deep in order to prevent mosquitoes from breeding in the water, and the water should be cleaned regularly from organic matter.

6 The water from the reservoir is used mainly for plants and for cleaning.

7 The underground reservoir has one open pond in the courtyard and one in the yard. These ponds add aesthetic value to these spaces. The courtyard pond has steps so that water can be easily fetched from the pond, even when the water level is low.

8 The water level in the reservoirs and the ponds will vary throughout the year, depending on the amount of rain. This is symbolic for water availability, and serves as a reminder that water is a scarce resource.

9 The reservoir should not be completely filled so that air can pass above it in the water channels. This cooled air will enter the classrooms through the ventilation shaft described on page 102.



SECTION E-E - 1:200

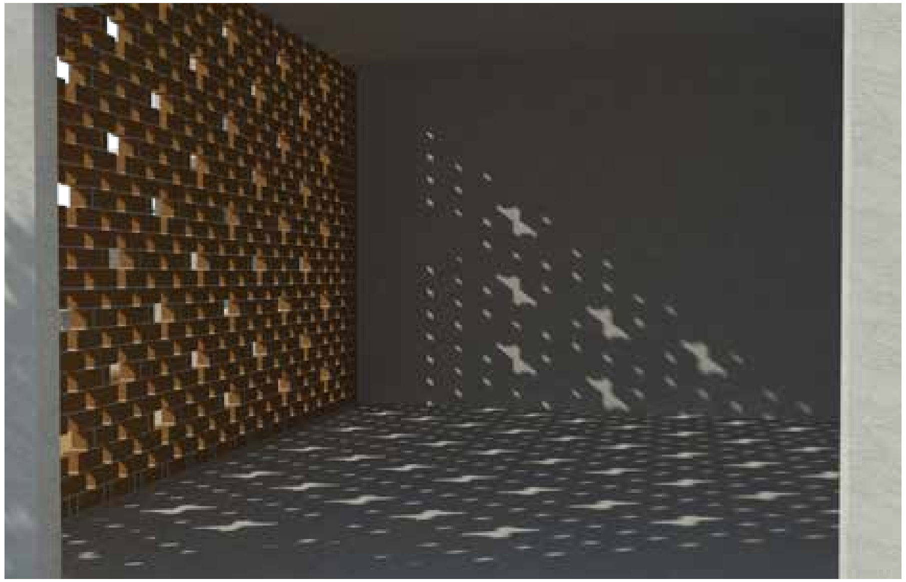
SHOWCASING

During school hours, the school is a place that provides education to children, and the gates should be kept closed for privacy and security reasons. A few gaps in the fence allow people passing by to get a glimpse of what is going on in the school while keeping the space private. But outside school hours the school should open its gates and reach out to the community in order to showcase the school's activities and in order to involve the parents in the education.

The yard can be open on weekends, so that children can use the playground. The trees and the pond create a sort of park in an area where such spaces are rare. As the water level in the pond varies throughout the year, people can understand how limited the resource is.

The school should showcase its activities to the community, so that they can better understand the importance of education. Educational paintings and examples of school work that are today found in the corridors can be made more visible to the outside by placing them on the balconies that are found over the entrance and by the west and north facades.

The building itself showcases sustainable building techniques. The windcatchers, the black ventilation shafts and the *jaali* windows are clearly visible features that can increase curiosity. When community members visit the school they can see the pond in the yard, and during special visits they can go inside and on the roof and see how the windcatchers work. When people understand better how the systems work, they can better appreciate passive techniques.



Decorative *jaali* lattice windows in corridors and by the entrace showcase earth block construction.

Student work displayed in existing TCF schools should be made more visible.

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5 CONCLUSION

This section presents a summary of the final conclusions of the thesis work and discusses how the work can be continued and used in future projects.

This thesis has studied the schools of The Citizens Foundation in an effort to find ways in which the schools could be improved through sustainable design and through rethinking the way the schools are designed and built. In order to determine the best solutions, it has been important to look at the effects of design from a broader perspective to better understand what effect design choices have and can have.

Four focus areas have been identified as the leverage points that can make the greatest impact: passive design, materials, water management and community involvement. If these four areas are given special consideration and done in a more sustainable way when designing new schools, costs and environmental impacts can be reduced while creating a positive social impact.

Some possible solutions illustrated by the design proposal include windcatchers, earth construction and rainwater harvesting. These solutions can improve passive thermal comfort, reduce the school's environmental footprint, create jobs for the local community and increase water security - all while reducing costs, which makes it possible to build more schools so that more children in Pakistan can have access to education.

Out of the four focus areas, community involvement has been studied the least, and there is room for further studies. Ideally the possible involvement of the community should be studied on site through a real-life school project. Working with the local people can be challenging, but without the acceptance of the community the schools have less impact.

With the help of design, buildings can also showcase sustainable building and promote techniques based on traditional buildings that are otherwise seen as backward. Schools in particular can play a special role in this, because of their association with education.

This thesis work is meant to be a source of inspiration for TCF's architects, and also for others designing schools in Pakistan or South Asia.

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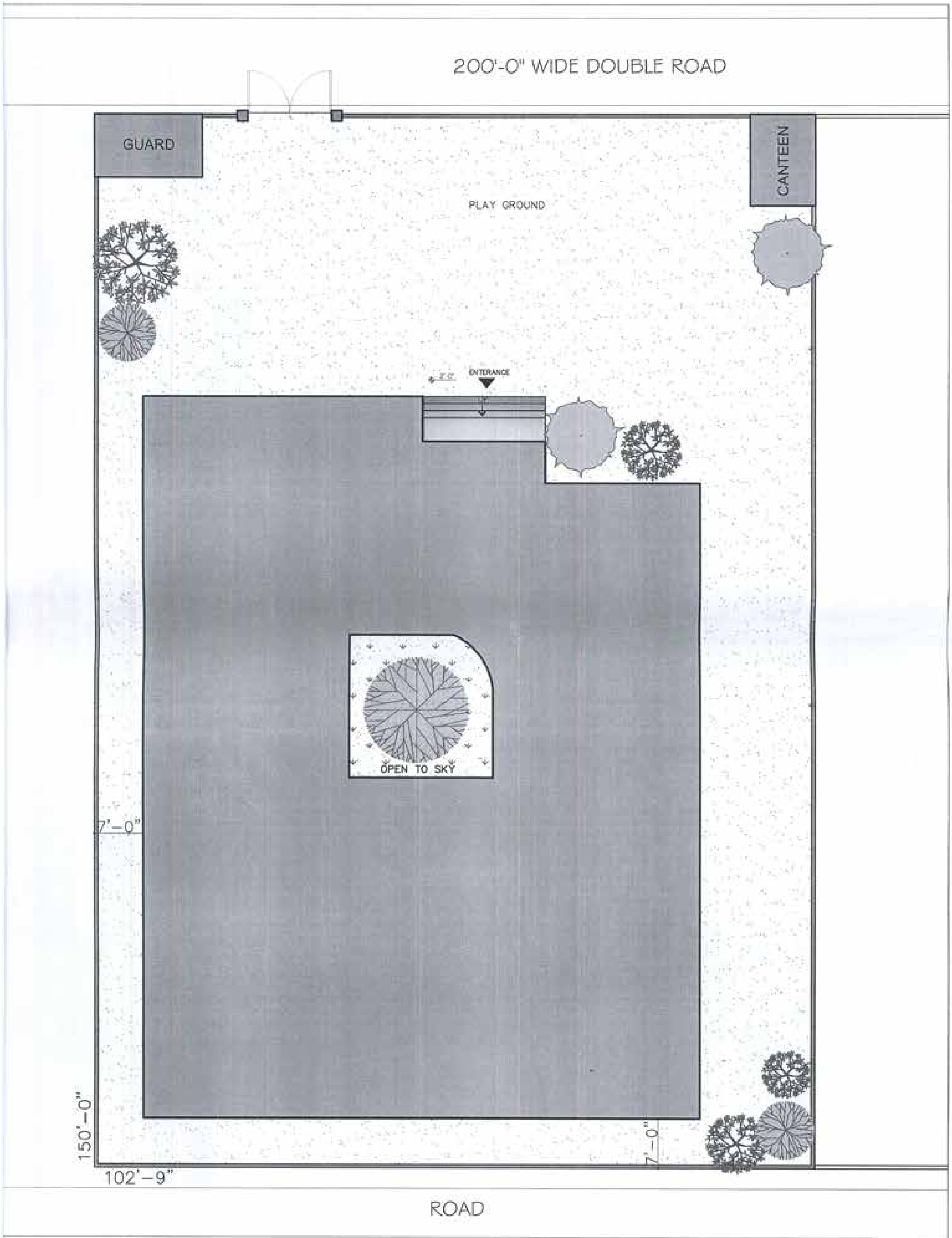
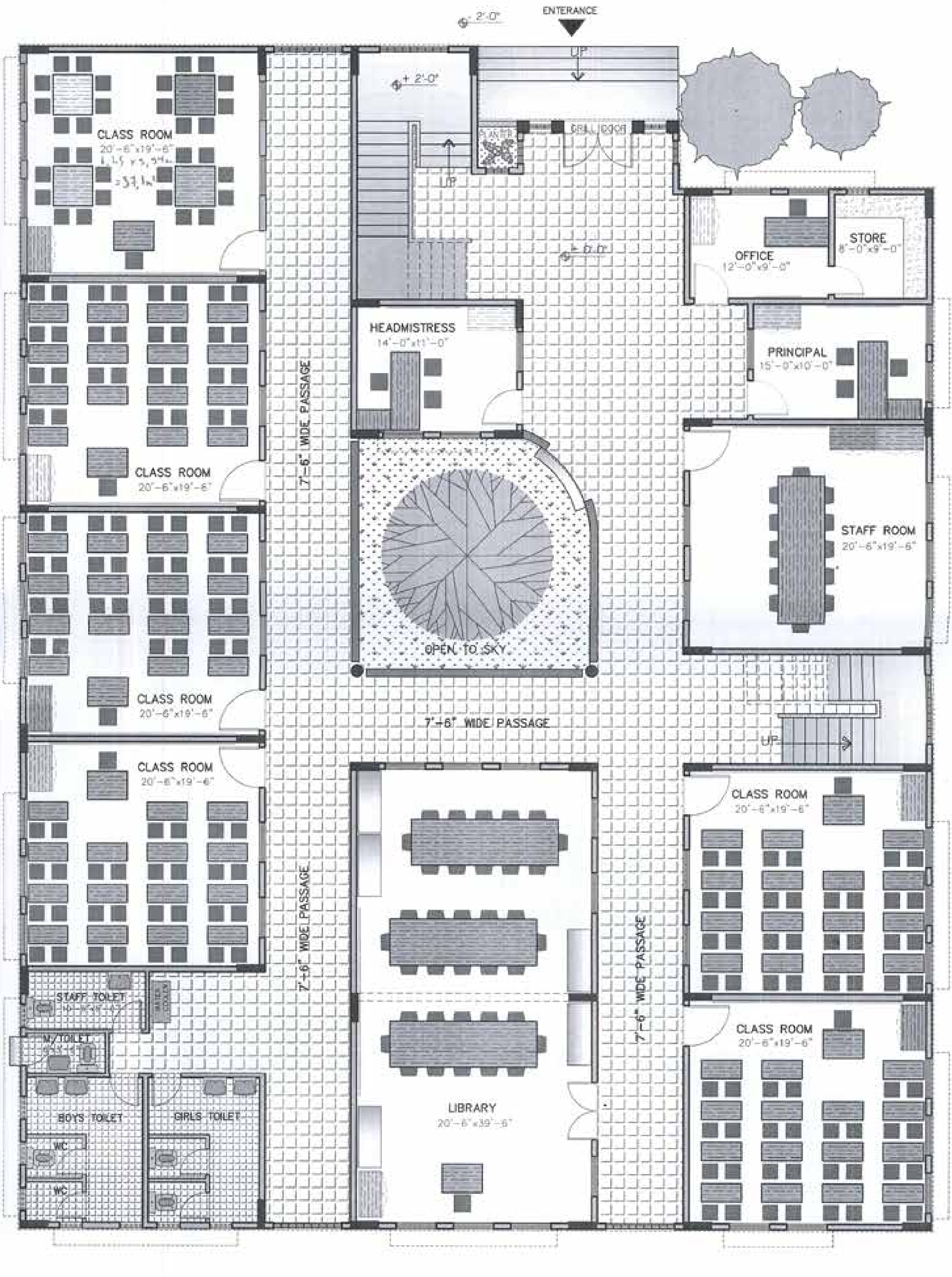
APPENDIX

This appendix contains drawings for TCF Burhanuddin Campus that were received from TCF during the field study.



THE CITIZENS FOUNDATION	Title: LAYOUT PLAN	Project: 3 UNIT TCF PRIMARY SCHOOL BURHANUDDIN CAMPUS GULSHAN-E-HADEED K.E.S.C. COLONY, KARACHI SOUTH	Drawn By:	Ala Mehmood
	North		Checked By:	A. A
			Proj. Arch:	Atif Ashraf
			Date:	10th-June-2013
			Scale:	N.T.S
			Drawing No.	A-01



THE CITIZENS FOUNDATION

Title

GROUND FLOOR PLAN

(Area: 7385.00 S.Ft.)

North

Project

3 UNIT TCF PRIMARY SCHOOL
BURHANUDDIN CAMPUS
GULSHAN-E-HADEED
K.E.S.C. COLONY, KARACHI SOUTH

Drawn By:

Checked By: A. A.

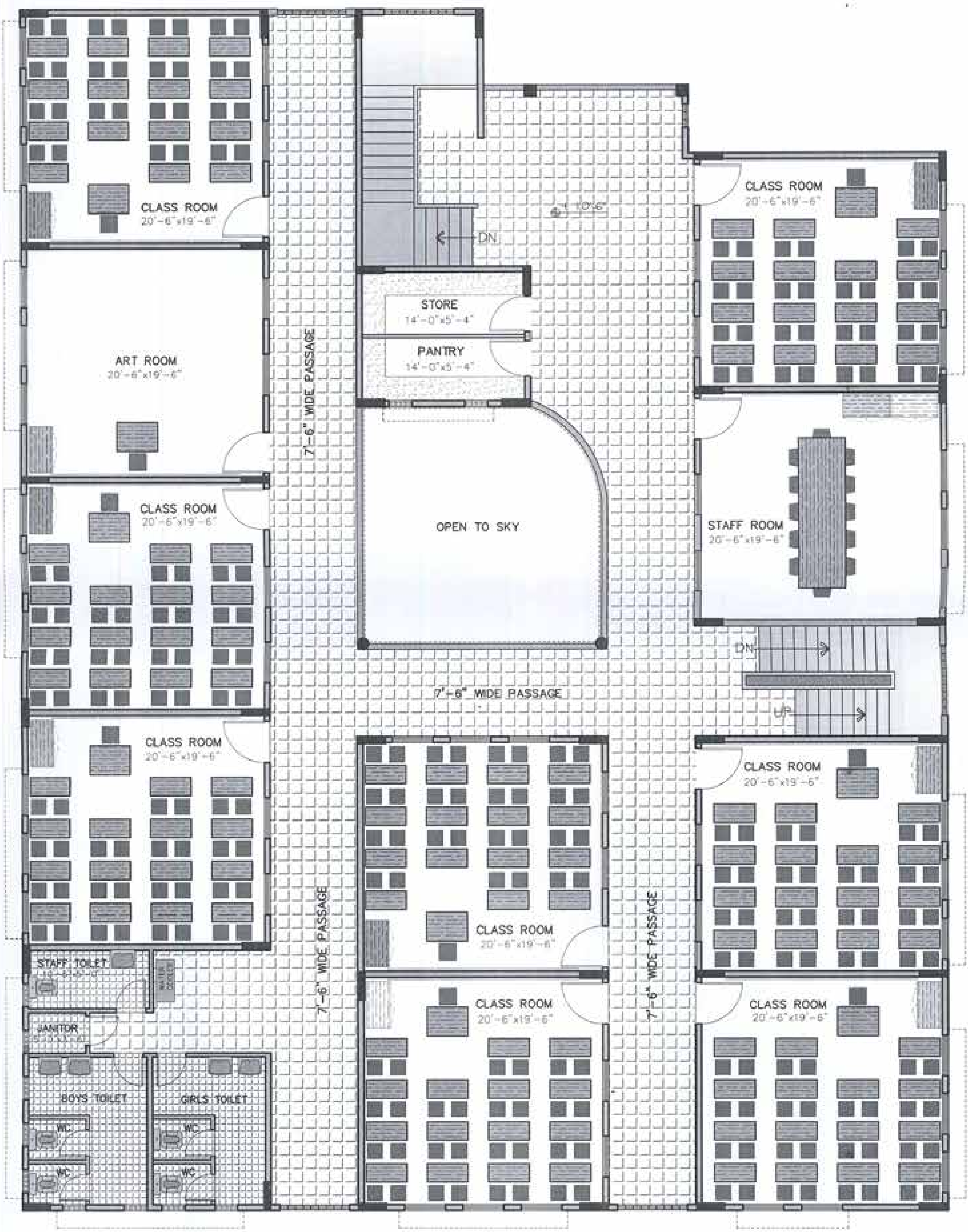
Proj. Arch.

Date:

Scale:

Drawing No.

A-02



THE CITIZENS FOUNDATION

Title

FIRST FLOOR PLAN
(Area: 7385.00 S.Ft.)

North

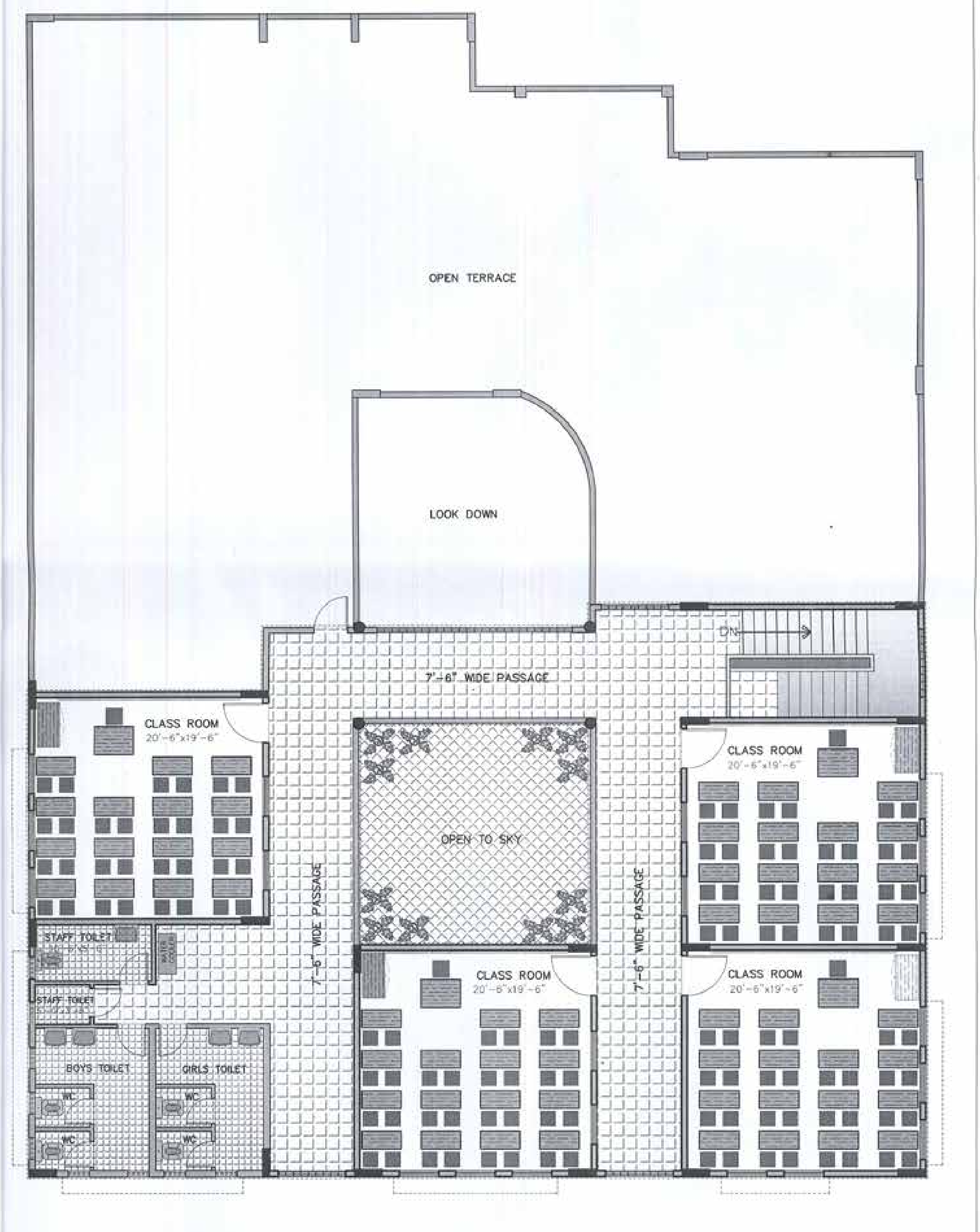
Project

FUTURE EXTENSION
3 UNIT TCF PRIMARY SCHOOL
BURHANUDDIN CAMPUS
GULSHAN-E-HADEED
K.E.S.C. COLONY, KARACHI SOUTH

Drawn By:	Alia Mehmood
Checked By:	A. A
Proj. Arch:	Atif Ashraf
Date:	10th June 2013
Scale:	N.T.S

Drawing No.

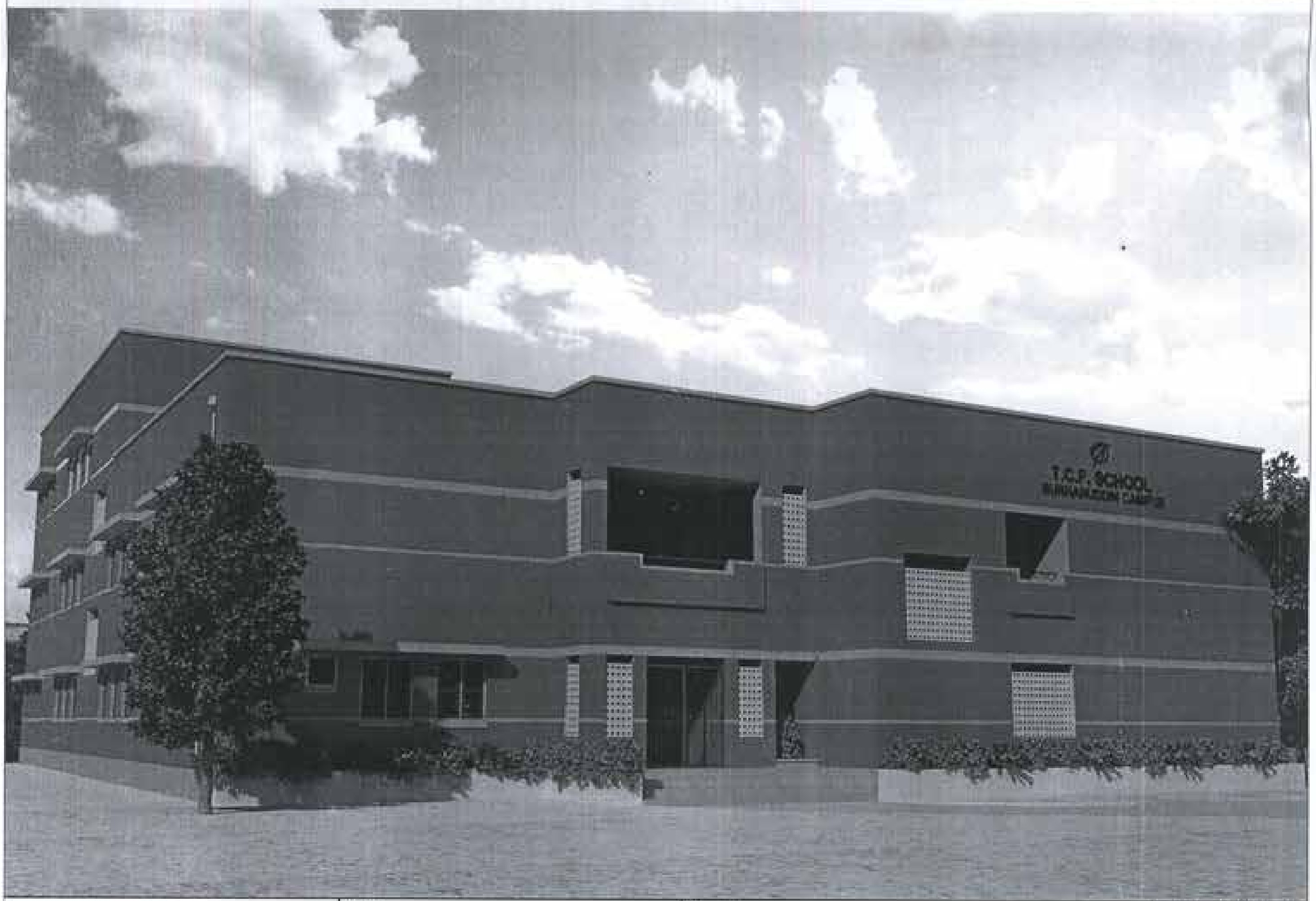
A-03



THE CITIZENS FOUNDATION

Title	SECOND FLOOR PLAN (Area: 3400.00 S.Ft.)
North	
Project	FUTURE EXTENSION 3 UNIT TCF PRIMARY SCHOOL BURHANUDDIN CAMPUS GULSHAN-E-HADEED K.E.S.C. COLONY, KARACHI SOUTH

Drawn By:	Ala Mehmood
Checked By:	A. A
Proj. Arch.	Atif Ashraf
Date:	10th June 2013
Scale	N.T.S
Drawing No.	A-04



THE CITIZENS FOUNDATION

Title: ELEVATION	Project: FUTURE EXTENSION 3 UNIT TCF PRIMARY SCHOOL BURHANUDDIN CAMPUS GULSHAN-E-HADEED K.E.S.C. COLONY, KARACHI SOUTH	Drawn By:	Ata Mehmood
North		Checked By:	A. A
		Proj. Arch.	Atif Ashraf
		Date :	10th June 2013
		Scale :	N.T.S
		Drawing No.	A-05