ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

FAKULTA STAVEBNÍ

KATEDRA KONSTRUKCÍ POZEMNÍCH STAVEB

STUDIJNÍ OBOR BUDOVY A PROSTŘEDÍ

Design of the Kashitu high school

Návrh střední školy v Kashitu

Master thesis

Diplomová práce

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Prague, January 2019

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Studijní program: Budovy a prostředí

Studijní obor: Budovy a prostředí

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce: Návrh vnitřního prostředí střední školy Kashitu v Zambii

Název diplomové práce anglicky: Design of inner building environment of Kashitu high school, Zambia

Pokyny pro vypracování:
At the diploma work, the student will use project documentation from another subject and finish it in suficient scale and details. The goal of the work is to complete design of all expected buildings and key components, that was not done by previous subject and optimize original project documentation of Kasihitu highschool and create more efficient ways to solve thermal-technical requirements, humidity hazard and visual comfort in the school buildings. Next step is designing of building service systems: sanitation, water supply, ventilation and if necessary, electric components like small photovoltaic system. All the systems should be simple, energy efficient and made with the use of local materials or materials, that are not hard to obtain in a current location. Considering the location of the building, all key components should be suitable for current environment, local people with their needs and risks. The idea of building a school was initiated by a non-profit organization from Czech Republic and the final work should provide them with reasonable results, that can lead to a realization of the school.

Seznam doporučené literatury:

Jméno vedoucího diplomové práce: Ing. Jan Tilinger Ph.D.

Datum zadání diplomové práce: 01-10-2018 Termín odevzdání diplomové práce: 16-01-2019

Údaj uveďte v souladu s datem v časovém plánu příslušného ak. roku

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Podpis vedoucího práce

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10-10-2018

Datum převzetí zadání

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I hereby confirm that my thesis entitled Design of the Kashitu high school is the result of my own work. I did not receive any help or support from commercial consultants. All sources and materials applied are listed and specified in the thesis.

Furthermore, I confirm that this thesis has not yet been submitted as part of another examination process neither in identical nor in similar form.

In Guimarães 16.01. 2019 ……………………………

Place, Date signature

ACKNOWLEDGEMENTS:

I would like to express my appreciation to thesis supervisors from University of Minho, Ing. Ricardo Mateus, Ph.D. and Ing. Sandra Silva, Ph.D. for their guidance and support throughout the work on this master thesis. They provided needed expert opinions and helped me develop my ideas in the process of the work. I really appreciate they personal approach and time they were able to give me. I want to thank Ing. Jan Tilinger, Ph.D. for being my supervisor in Czech Republic and finally, I am expressing my gratitude to my friends and family for their vast support not only during work on this thesis, but also for all years of my study.

Design of the Kashitu high school

Návrh střední školy v Kashitu

Abstract:

This work is dealing with design of the high school in Kashitu region, located in Zambia. The master thesis is developing all major design component, important for the specific climate and comfort of school occupants. The project is solving selection of ideal material by using sustainability assessment and developing construction system from chosen material. By using passive design principles, the building shape was optimized by adding beneficial elements. For comfortable inner built environment, condition in daylight, acoustic, ventilation and thermal comfort were examined. An appropriate building service system was introduced to improve occupants' comfort and ensure satisfying their needs in school operation. The main goal of the work is designing a sustainable solution for the need of high school in African rural area, that can be fulfilled by the non-governmental organization Friends of New Renato, to which this thesis is dedicated to.

Keywords: *Sustainability, natural materials, developing countries, energy efficiency, high school, material optimization, inner built environment*

Anotace:

Tato práce se zabývá návrhem střední školy v region Kashitu, který se nachází v Zambii. Magisterská práce rozvíjí všechny hlavní součásti návrhu, které jsou důležité pro dané specifické klima a pro komfort uživatelů školy. Projekt řeší výběr ideálního materiálu pomocí hodnocení udržitelnosti a vytvoření konstrukčního systému z tohoto materiálu. Užitím principů pasivního návrhu byl optimalizován tvar budov a přidány zlepšující prvky. Podmínky denního osvětlení, akustiky větrání a tepelný komfortu byly řešeny pro příjemné vnitřní prostředí v budovách. Pro zajištění potřeb při školním provozu, byly představeny odpovídající systémy technických zařízení budov. Hlavním cílem práce byl návrh udržitelného řešení pro potřebu střední školy v africké venkovské oblasti, který může být naplněn neziskovou organizací Přátelé New Renáto, které je tato práce věnována.

Klíčová slova: *Udržitelnost, přírodní materiály, rozvojové země, energetická účinnost, střední škola, materiálová optimalizace, vnitřní prostředí budov*

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List of used abbreviations and acronyms

AP	Acid Potential
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BREEM	Building Research Establishment Environmental Assessment Method
CAD	Computer Aided Drawing
CEB	Compressed Earth Blocks
CFD	Computational Fluid Dynamics
ČSN	Česká Státní Norma
CZK	Czech Koruna
EP	Eutrophication Potential
GWP	Global Warming Potential
HIV	Human Immunodeficiency Virus
HVAC	Heating, Ventilation, and Air Conditioning
ICEB	Interlocking Compressed Earth Block
LCIA	Life Cycle Impact Assessment
LEED	Leadership in Energy and Environmental Design
MARS	Methodology for the Relative Sustainability Assessment of Residential Buildings
NMEC	The National Malaria Elimination Centre
NRCS	New Renato Community Society
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
SAP	Structural Adjustment Programme
SB TOOL	Sustainability Tool
UMINHO	University of Minho
UNHABITAT	The United Nations Human Settlements Programme
UNICEF	United Nations International Children's Emergency Fund.
UTC	Coordinated Universal Time
ZMK	Zambian Kwacha

1 Introduction

1.1 Introduction of the master thesis

Third world countries and their development are one of the most important problems that we are facing in our globalized world. There are many problems, that people in these countries are facing. One of the most important one is a lack of quality education. Education is the key part in every human development, which we can observe in the past as in the present world. Education provides better conditions for all people regardless of religion, tribe, social status or wealth. That's why encouraging all forms of education should be the primary goal of every developing plan, where people wish to gain better conditions for them and generations to come.

Zambia is a country that is not facing wars or political insecurity. It is one of very few countries in Africa that has experienced a time of peace since its independence and aims at self-sufficiency and productivity. In the newest National Development Plan we can find that people gathered in civil society organizations submitted as follows: "education was a key driver to higher productivity which is a prerequisite for national development" and "[we] saw the need to increase investment in educational infrastructure with the view to improve the quality of education, especially in rural areas." (Seventh National Development Plan 2017-2021, 2017). Not only civil societies but also Zambian government have had major interest in promoting education in their past and present development plans.

The story of the aim of building a school in Kashitu is long and complicated. To introduce it, I mention only brief important information. The New Renato Community Society (NRCS) was found in 1987 in the rural area of Kashitu region by local people. The focus of their work is to improve quality of live in the locality by providing guidance and knowledge in the field of agriculture, education, health and youth development. To support these activities, the non-governmental organization Friends of New Renato was developed. Thanks to their help, several small scale projects were performed. A new floor in the primary school buildings, bringing eyeglasses or providing financial resources in realizing local projects are examples of the organization's activities. (Friends of New Renato, 2019)

The ultimate goal of NRCS is to build a high school that can provide needed secondary education, which this region truly misses. Primary education in Zambia is free and mandatory, provided mainly by government schools and community schools. Children learn in them basic skills and knowledge in the official language (English). Secondary schools are not compulsory and for their operation students needs to pay tuition. Therefore, secondary schools are not common, especially in rural areas and they are usually not accessible for ordinary families due to the school fees. Graduating from high schools makes the difference in developing the region. People without secondary education cannot find a job in conventional companies no matter the field of their skills. Secondary schools also create qualified labour and job opportunities in the region. To sum up, secondary education is elevating regions they are presented in and it is especially important in less developed and poor rural areas.

In Kashitu region, there are several primary schools that are operating in poor conditions, but they are providing needed education. In one school, it is not exceptional to have one thousand students in one small school. Potential that is created by primary schools is not embraced in secondary education due the lack of secondary and high schools in the area. The closest school is located 10 km from Kashitu and is only an extension of some subjects of primary education. Other schools are available only in bigger cities. In Kapiri Mposhi, at distance of 30 km and Ndola and Kabwe, distant from Kashitu by 90 km each. It is clear that Kashitu region, like most of the rural regions, need secondary education for developing the area and solving poverty and unemployment problems.

1.2 Objectives and goals of the thesis

This work has no goal of answering the big problems of third world countries on a broad level. The main objective of the thesis is a proper design of the high school in Kashitu region, corresponding to the given climate and school occupants' comfort. The work should include all major components of the design to provide enough answers to complex problems usually interlinked to one another. The focus will be on cost effective and efficient solutions that are not difficult to use by local people. They also should have easy maintenance and renewal to serve their needs most effectively. The best result to achieve would be a project that can be easily understood and replicated with no additional guidance by local people themselves.

This master thesis will be following important topics in design in the following way. The first point would be the analysis of the climate and conditions in the locality. In addition, there should be taken notice to important laws and regulation that has to be considered in the project. After finding all central boundary conditions, work deals with choosing materials for design that have a limited availability in the targeted area. Sustainability principles are used for finding ideal material for a construction system of the buildings, by developing a sustainability assessment. The design continues by using passive design principles to reduce unintended build environment conditions and thus use climate and weather on our side. The build environment is examined by acoustics, daylight, ventilation and thermal comfort. All those parts of design are crucial for comfortable and joyful occupancy of the school and good performance of the students and staff. Lastly, building service systems are added to the project to fulfil the needs of the school occupants and improve their study conditions.

The focus of the design is on the building technologies that allow the realization of the project by unskilled local people with certain guidance, using local building materials mostly from existing natural resources. Natural hazards and weather conditions also have to be considered. In conclusion, the design of the school and building technologies used in the planned realization should be effective, intuitive and sustainable in order to give certain guidance, but not to create alien ways that would be not useful for Kashitu people.

1.3 Methodology

To develop sufficient ways for creating this thesis, proper guidelines and standards are necessary. To fill schools in Zambian based location, Zambian laws and regulation have to be adhered to. There are not many specialized guidelines and standards concerning the design of high schools, but what I was able to obtain I consider in the design process. Targeted comfort and conditions were discussed with NRCS and the ideal solution was found in using European standards and guidelines that I tried to follow in current conditions with some modifications. This seems to be right for the Zambian environment. From the African context, most helpful were sources of information from South Africa, that is not that much distant from Zambian climate and situation concerning administration and state policies.

All used guidance is always mentioned in the current topics. There are special guidelines used in the thesis that are specially targeted to developing countries and the African context. These materials were especially appreciated, and they provide valuable inside for shaping the design methods and results. Calculations were mostly made in a way to allow readers to understand the procedure of intended solutions. More advanced software was primarily used for complex calculations, generally in designing inner build environment. Drawings in the final part of the thesis were created in CAD software. The architecture design was developed by friend of mine, ing. arch. Jan Rosík, which is member of Friend of New Renato. The architectonic work was developed with my assistance, but I didn’t take any credit for it in this work. The drawings are part of annexes.

1.4 Structure of the thesis

Thesis is divided to chapters, following process of the design. Second chapter introduce all important design condition, that are connected to the task of the project. Following chapters contain brief introduction and then approach of design is explained. All major figures and results are presented and final part is the conclusion of the chapter. In the chapter eight is final conclusion of the work. And in last chapters, are presented annexed and references. Annexes should show all important procedures of the calculation, graphs or other information. Drawing present final design solution. References should give reader sources of information, used in the thesis and also give him possibility to find more information about mentioned topics.

2 Initial important information

2.1 Country profile

2.1.1 General information:

Pic. 1: Zambia location and map; Source: (Google maps, 2019); (Zambia Location, 2014)

Capital city: Lusaka
Number of provinces and districts: 10
Time zone: UTC +2
Official language: English
Government type: Presidential republic
Total area: 752 614 km²
Population: 16,445,079 (July 2018 est.)
Currency: Zambian kwacha (ZMK) (1CZK is 22 kwacha)
Climate: Tropical with hot, dry and rain season
Mean elevation: 1,138 m
Population growth rate: 2.91% (2018 est.)
Population below poverty rate: 54.4% (2015 est.)
Urbanization: 43.5% of total population (2018)
Population density: 23 people/ km²
Place on the list of the poorest countries: 46

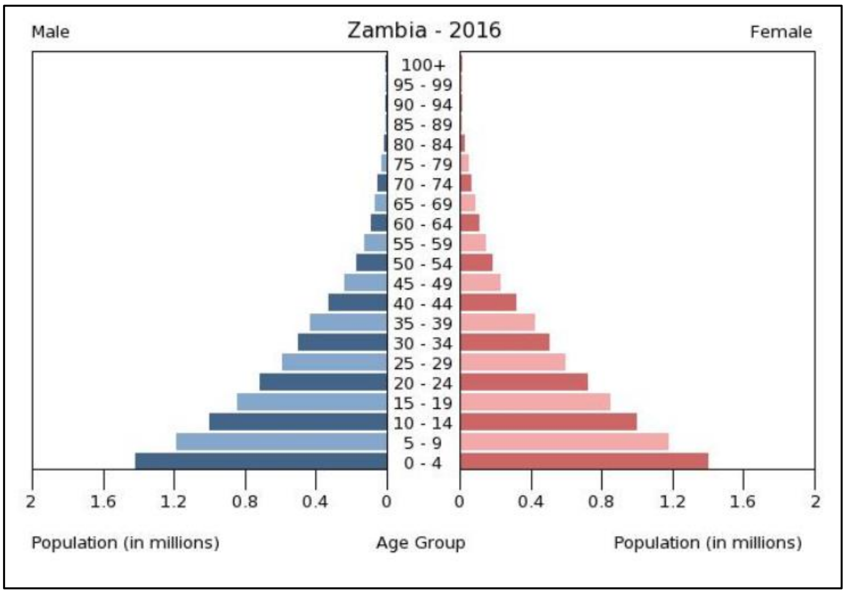
2.1.2 Geography:

Zambia is a sub-saharan African country, in the centre of the continent. It shares borders with Tanzania, Zimbabwe, Malawi, Mozambique, Angola, Namibia Democratic Republic of Congo. Most of the country is situated on high plateau with an elevation of 1100 m and more. The lowest area is located by Zambezi river. The country is rich in natural resources such as copper, cobalt and zinc. Also gold and silver are presented in some locations. The land is mostly unoccupied. More than 30 % of the land is used for agriculture purposes and several vast areas of national parks are protecting the original state of nature. There are some significant water sources, mainly river Zambezi and lake Kariba.

2.1.3 Political situation, population and society:

Zambia was a former British territory named Northern Rhodesia. The country gained independence in 1964 and became a presidential republic. Since the time of independence, there has been no war conflict in Zambia. Approximately half of the population is living in the urban areas and half is present in the rural areas. Zambia has one of the biggest urbanization rates, where most of the urban areas can be found in the cities of Lusaka, Ndola, Kitwe, Chipata and

Chingola. There are more than 70 ethnical groups with language and cultural differences. The major ones are Bemba 33.4%, Nyanja 14.7%, Tonga 11.4%, Lozi 5.5%, Chewa 4.5%, Nsenga 2.9%, Tumbuka 2.5%. Native languages are also presented in a vast amount of forms, due to ethnical groups of the speakers. The majority of them belongs to the Bantu family. The most common religion is Christianity. Zambia has a high population growth rate of 2,91%. That is 10th place in the world's comparison. On average 5.58 children are born from one woman. The population has a very low median age of 16.8 years, signifying a down-based age structure that can be seen on picture 2. Authorities are still struggling with the high infant and maternal mortality rate. Life expectancy continually increases to the current number of 53 years (2018 est.).



Pic. 2: Age structure of population in Zambia; Source: (The World Factbook: Zambia, 2018)

2.1.4 Health and hazards:

HIV is a big problem in Zambia by costing the lives of a vast number of people. There are 16 000 deaths annually and approximately 1.1 million people are infected. Another deadly disease is Malaria, caused by infected Anopheles mosquito. The government organization NMEC reports a significant decrease of death numbers in the past 10 years, still 2,000 people are killed by it annually. (NMEC, 2017). Natural hazards are periodic drought in the dry season, tropical storms in the wet season and venomous animals in open landscape. Zambia is currently dealing with polluted air condition in the mine cities, soil erosion in the agriculture areas and desertification. Health problems are caused by lack of adequate water treatment and sanitary service. 65.40 % of the people have drinking water access from data of the year 2015.

2.1.5 Economy, education and poverty:

The Zambian economy is heavily dependent on natural resources, in particularly on the copper industry. The Zambian currency rate rises and falls with changing copper prices. These problems have had the Zambian government worried from the beginning of the republic and in 1991, the new government introduced the Structural Adjustment Program (SAP). This program has involved liberalization and privatization of the economy to make it more stable. However, the rapid implementation of the SAP has caused a destructive impact on the social sectors (Zambia - History & Background, 2019). Despite that, the country's economy is one of the fastest growing economies, with a real GDP growth rate of 3.4% (2017 est.). Most of the country development is done by foreign companies. China is the most significant investor that is building Zambian infrastructure. Schools, roads, railroads and airports are built by Chinese workers with the aid of Chinese loans. In March of this year, Zambia debt rose to $9.3 billion, thanks to Chinese supported projects (Business Daily, 2018). Main country problems regarding economy lie at the extreme level of poverty in the rural areas with high unemployment rates. Also education is very challenging. In rural areas, schools are far away from each other and in most cases, students are unable to study in the secondary schools because of their high tuition fees. In the cities, there are very large quantities of potential students, but schools are struggling with their acceptance.

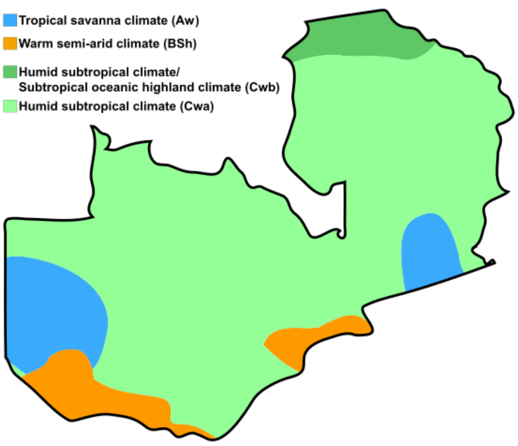
References and sources, if they were not mentioned otherwise, come from:

- (The World Factbook: Zambia, 2018)
- (Zambia - World Bank Open Data, 2018)

2.2 Climate

2.2.1 Seasons during the year

The climate can be described as tropical or sub-tropical (Zambia climate, 2019). The country is in the middle of the continent and has three seasons. The first main difference we can see is in the precipitation amount during the year. We can identify a warm wet period, lasting from November to April, when temperatures are at medium values and the land gets a major part of yearly rainfall. The cool dry period starts in May and lasts till August. Temperatures change substantially during the day and the coldest temperature is in July. This is a period with almost no precipitation. The last period lasts form September till October and can be characterized by

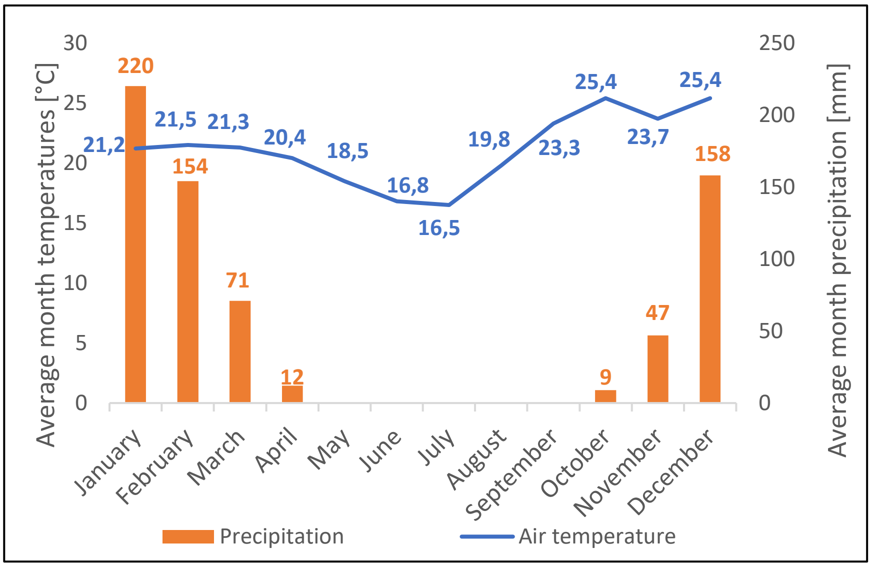


Pic. 3: The Köppen climate classification; Source: (Climate of Zambia, 2018)

a fast increase in temperature. The hottest month is usually October, when the humidity gathers in the air and there are air dust particles in big quantities. In October, the dry period ends and rainfall returns to the weather conditions.

2.2.2 Sun conditions

The country is located near the equator, which creates an almost constant day duration throughout the year. From obtained data, that was generated by Metheonorm software, we know that the hottest month is October and the highest mean daily temperature is on 11th of October with a value of 29,9°C. The coldest month is July with the coldest day on 15th of July and a temperature of 11,19°C. The difference of mean month temperatures is 8,9°C during the year but the difference between day and night temperature can be up to 22°C.



Pic. 4: Air temperature and precipitation in the locality; Source: Meteonorm data

2.2.3 Wind conditions

The prevailing wind direction is from the East. Most of the rain clouds come from that direction and the east distance to the sea is the closest one. The annual average wind force is 2,9 m/s. The wind changes its force during the year only slightly, which gives us the possibility to use it.

2.3 School system in Zambia

There are four stages of education in Zambia (Zambia - Educational System—overview, 2019): preschool, primary school, secondary school and university. Preschool is a type of education that is not compulsory and its main goal is to teach English, an official language used in the following education. Preschools are usually available only in bigger cities or they are run by communities in villages. The next level is primary education. The duration of study is seven years and it is compulsory. The entrance year for acceptance is seven years. The Government and sometimes communities run primary schools, providing this type of education without school tuition fees. The money is spent only for needed school equipment. The primary education covers almost all school aged children. The following secondary education has five years of study period. Students are accepted to this stage only by achieving enough points in national examination that takes place in the final year of primary education. Secondary schools require school tuition fees. Also materials, clothing and in many cases boarding expenses increase the cost to a not affordable level for many people. The last stage of the education system is universities, where the normal study period to achieve an undergraduate diploma is four years. Universities are present only in the biggest, mostly provincial cities. There are only seven public universities in Zambia, others are private (2018 Zambian University Ranking, 2018). This level of education is for the vast majority of people inaccessible due to the study expenses.

Statistics show (EDUCATIONAL STATISTICAL BULLETIN 2016, 2016) that 90.4% of children were enrolled at primary education, but only 25.4 % have access to secondary education. The gender parity in primary education is exactly 1, in secondary it is 0.86 in favour of male students. There are almost 60 000 classrooms and 96 000 teachers for 4 million students.

2.4 Traditional building materials and techniques

Local materials have been used by local people for centuries. They create important design factors that we can use in the project. A combination of well-known building techniques and experience can help with developing better design solutions. In the following pages, I will introduce building techniques that were presented to me by local people in Kashitu.

2.4.1 Traditional local based materials

2.4.1.1 Unburn bricks

The traditional building technique in Kashitu area is unburned clay bricks. They are manufactured by hand mould of a manual presser. A mixture of earth that was soaked with water in an ideal amount is placed to the mould or presser. When the brick gets shape, it is placed in a ventilated place, covered against sunlight to dry. They are used in the majority of buildings for wall structures. Usually, plaster covers the wall structure from both sides.

Advantages: Easy to create, cheap, well-known solution

Disadvantages: Hard labour, less strength of bricks

2.4.1.2 Burn bricks

Burn bricks are usually produced from unburned ones by burning process in the brick clamp. When the unburn bricks are produced, they are formed into the clamp. In the place between the brick firewood is placed and the whole clamp is covered by earth with clay. Fire is lit and after some time, bricks become burned. That gives them more durability and strength. For burning, a vast quantity of wood is needed that is gained from forests. This is the big issue in the rural areas, where forests are disappearing due to the charcoal production and burning bricks. Bricks are not burned perfectly in the first time, so in many cases, more than half of them must be burned again.

Pic. 5: Brick clamp; Photo by author in 2018

Advantages: More durable, more strength

Disadvantages: Large wood quantities, bricks are not burned equally

2.4.1.3 Timber, straw and reed

The location is based in the landscape, created by vast savannas. There are also some forests, where trees with small diameter grow. In this case, timber obtained in the closer surroundings can be used only for minor purposes, without rectangle shape modifications. In most cases, we cannot use this timber for structural elements. Reed and straw are traditional materials for roof covering.

Advantages: Cheap, available, easy to obtain

Disadvantages: Small size, not for structures

2.4.1.4 Stones

Stones are mainly used for foundations. In some cases, some walls of the houses are built with them, but labour connected to this activity is enormous. Stone is a very durable material with substantial strength.

Advantages: Available, durable

Disadvantages: Hard labour, more difficult to build with

2.4.2 Traditional buildings in rural area

Traditional buildings are connected with the way of life in the rural area and climatic condition in the locality. A typical family in rural area owns a piece of land to grow crops and vegetables for a whole year. Houses are rather small, dedicated to the specific purpose. One family has two houses for sleeping, one house for cooking, a dry toilet and sometimes houses for domestic animals.

Pic. 6: Building for sleeping; Photo by author in 2018

Houses for sleeping are rectangular shaped, with small windows or even without any windows. They are used only in the night for sleeping. These houses are the most developed and most cared for of all. Walls are made from fired or unburned bricks with clay plasters. The roof can be made from reed or by using metal sheet. A House for cooking, also called Insaka, is a semi-open building, with a fireplace in the centre. Insaka is usually built in circular shape, made by unburn bricks and timber in circular profiles. The roof is simple, mostly made from reed. This building is also used as a gathering place for the family, a meeting place for visits or for shelter in in the rain season.

Houses for animals are also more simple structures. Walls are made from unburn bricks and the roof is usually made from reed and timber.

Pic. 7: Insaka – building for cooking; Photo by author in 2018

2.5 Project locality

Kashitu is a small village at the borders of Central Province and Copperbelt, located in the Masaiti district (KASHITU, 2019). The Total area is 237 km² with a population of 7520 people (2010 est.). The density of population is 31.71 people/km², which is little higher than the national average (23 people/km²). In Kashitu, there is access to the main road and a train station. The closest bigger cities are Kapiri Mposi (30 km), Ndola (90 km), Kabwe (90 km) and the capital of Lusaka at a distance of 230 km.

Pic. 8: Location of Kashitu; Source: modified (Google maps, 2019)

2.5.1 New Renato community

People in the rural area are gathered in communities. This community of volunteers from Kashitu village also works as the non-governmental organization New Renato Community Society (NRCS). They operate a local nursery and an elementary school. They also run the New Renato community centre, where self-developing workshops take place. The nursery has around 70 children in care, the New Renato community primary school has about one hundred students.

Pic. 9: Kashitu nursery, Photo by author in 2018

Pic. 10: New Renato elementary school, Photo by author in 2018

2.6 Overview of the project design

2.6.1 Idea of the project:

Building a high school in Kashitu has the main goal for fulfilling the need of having enough secondary education facilities in the locality. The school will be run by NRCS and will be developed as a community school. The school must have a boarding area, where students from more distant places can be accommodated. Also, it should be self-sufficient and depend only on income, which will be raised by school operation and supporting facilities. These are gardens and fields near the school, where food for the school´s kitchen can be produced. That raises the question of school tuition fees. The idea of NRCS is to provide a quality level of education in the region by using volunteers from Europe as teachers. This solution can attract students from other bigger cities, where the money is much easier to obtain. By providing education to the students in the cities, they will pay extra money to support students from rural areas whocould not afford this education. The task to develop a system for evaluation of the students with low income is not easy and must be transparent and fair. But only in this way, without support from another organization or company, can the access to the secondary education be achieved for local students from low income families and have enough money for running the school.

2.6.2 Task of the project:

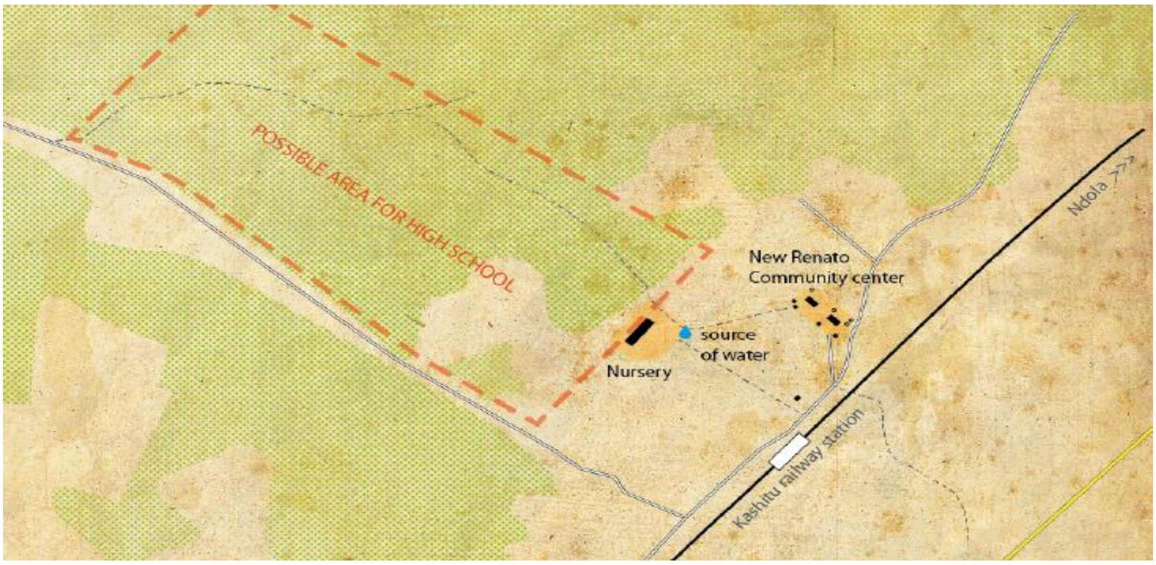
Building a high school in a rural part of Zambia is not an evident task to perform. Buildings and also education are regulated by the Zambian government. All projects have to be consistent with laws and regulations of the country. For high schools, we have a regulation on how many buildings it should have, how many students should be in one classroom and how many teachers will be present in school operation. I will not mention all laws and regulations that must be fulfilled. These are the main documents that play a significant role in design and realization of the school project:

- The town and the country planning act
- The national council of construction act
- Zambia institute of architects act
- Public health act

For the school development, the most important document is Education standards and evaluation.

From the mentioned documents a school overview was developed:

- A school for 250 students in a five-year study period
- A boarding school with students accommodation in the school property with a maximum capacity for all presumed students. Boys and girls will be accommodated separately
- 14 teachers with required houses for their families
- 8 presumed volunteers from Europe



Pic. 11: Area for high school in Kashitu

Also needed buildings were determined. The school will be developed in two stages. Stage one will ensure all necessary function for the beginning of the school's operation. Stage two will ensure full functioning of the school.

2.6.3 Schools buildings

Stage one:

- 3 classrooms
- Teachers office
- 2 laboratories
- Utility blocks
- Kitchen and dining room
- Accommodation for 100 students
- Teachers houses for 4 teacher families
- Sick bay
- Fence and Gate house

Stage two:

- 2 classrooms
- Accommodation for 150 students
- Teachers houses for 7 teacher families
- Volunteers houses for 8 people
- 3 workshops
- More utility blocks
- Chapel

When the boundary conditions of the project are set, we can start developing the design of the high school. Architectonic design drawings are a part of the annexes.

3 Building material options

In the beginning of the design the key factor to consider is building materials and their use in the project. Every material has different characteristics that determine its use. In the Kashitu project building materials are limited due to their availability. This part of the thesis is dealing with the problem of selecting needed materials and their performance. This data will be used for next step in designing the project – a construction system assessment.

The main goal of this part is to present the building materials that can be used in the project as well as the performance of these materials in order to choose the best solution for the specific parts of the buildings design, such as walls, roofing, foundation etc.

3.1 Building materials in the locality

From the sustainability point of view, the good material for the construction of the building is the one that exists in the locality, because local materials:

- Do not create any pollution from transportation and are easy to obtain,
- Save money for the transportation and in some cases from complicated manufacturing procedure
- And local people in rural context know how to work with them

Not every material that we will need for the high school is presented in the locality. Therefore, we will use on a maximum scale local material and for the specific purpose we will add other materials that are necessary to be transported to the site.

Building material presented on the locality are:

- Earth
- Sand
- Gravel
- Stone
- Timber (small circular profiles)
- Reed and bamboo

Earth and its products like adobe bricks or burnt bricks on plasters are materials frequently used in rural areas. Reed is traditional material for roof covering and it is also not hard to obtain in the closer surroundings of the Kashitu region. Soil, that is not used for agricultural purposes and is covered with savanna trees, which can supply the building site with the small profile timber. It can also be used as a fuel for burning bricks. At the distance of 6 km from the site is a stone mine that can provide stones, gravel and sand. The mine is accessible for everyone without any payment.

Pic. 12: Stone mine; Photo by author in 2018 Pic. 13: Trees in the locality; Photo by author in 2018

3.2 Materials from the nearby cities:

Bigger cities near Kashitu offer more building materials in the local markets or in hardware shops. Also, near the roads are small companies offering solid blocks of steel frames for windows. Transportation from those cities is mostly done by trucks. There are also cities that are using railway transportation.

3.4.1 Kapiri Mposhi

30 km from Kashitu is Kapiri Mposi, the nearest bigger town around Kashitu. There are some hardware stores, concrete block making companies and craftsmen. Building materials and the prices from this place can be found in Annex 1 - Cost of building materials

3.4.2 Ndola and Kabwe

Ndola and Kabwe are provincial cities, both with a distance of 90 km to Kashitu. Ndola is the industrial center of the Copperbelt province, with the mines of the limestone for copper and its cement plant and tree plantation program. The city has bigger hardware stores and some building companies with specific services like Boreholes construction. Kabwe is a main city in the Central province. It is also known for its mining industry, but at the moment agriculture and electrical production is more important. In both cities we can find bigger building companies and services, and both are connected to the railways.

3.4.3 Lusaka

Lusaka is the capital of Zambia. It is located 230 km between Lusaka and Kashitu. The capital provides the most complex services and in the city, you can find the biggest construction supply stores in the country. Materials and prices of the materials from this location are available in Annex 1 - Cost of building materials

Pic. 14: Map of the nearby cities of Kashitu region; Source: [2]

3.3 Building material for each part of the building:

3.3.1 Foundations**:**

Materials:

- Stone
- Concrete

We will take advantage of the mine nearby the location and we will use stone for the foundation combined with concrete. The main foundation will be made from stone. Concrete parts will be in places that are special because of increased stress or that are influenced by other elements.

3.3.2 Walls:

Materials:

- Stone
- Concrete
- Earth
- Burnt bricks
- Walls with steel and concrete elements

For determining witch material is best for using in the construction, we need to know how the material behaves in the climate of the locality. The following measurements done by the software DesignBuilder will show how the air temperature and relative humidity changes during the year.

3.3.3 Roof:

3.3.3.1 Construction material for the roof

Materials:

- Steel beams
- Timber beams
- Concrete beams
- Brick vault

Choices of material for constructing the roof of the buildings are steel or timber. We can also use vaults made from bricks. Materials for the roof are not much different in load-bearing capacity, because the buildings in the design are one storey high. Maximum sponge is not bigger then 9 m, so determining the material is not about performance of the material but using right method to create a construction system.

3.3.3.2 Covering material for the roof:

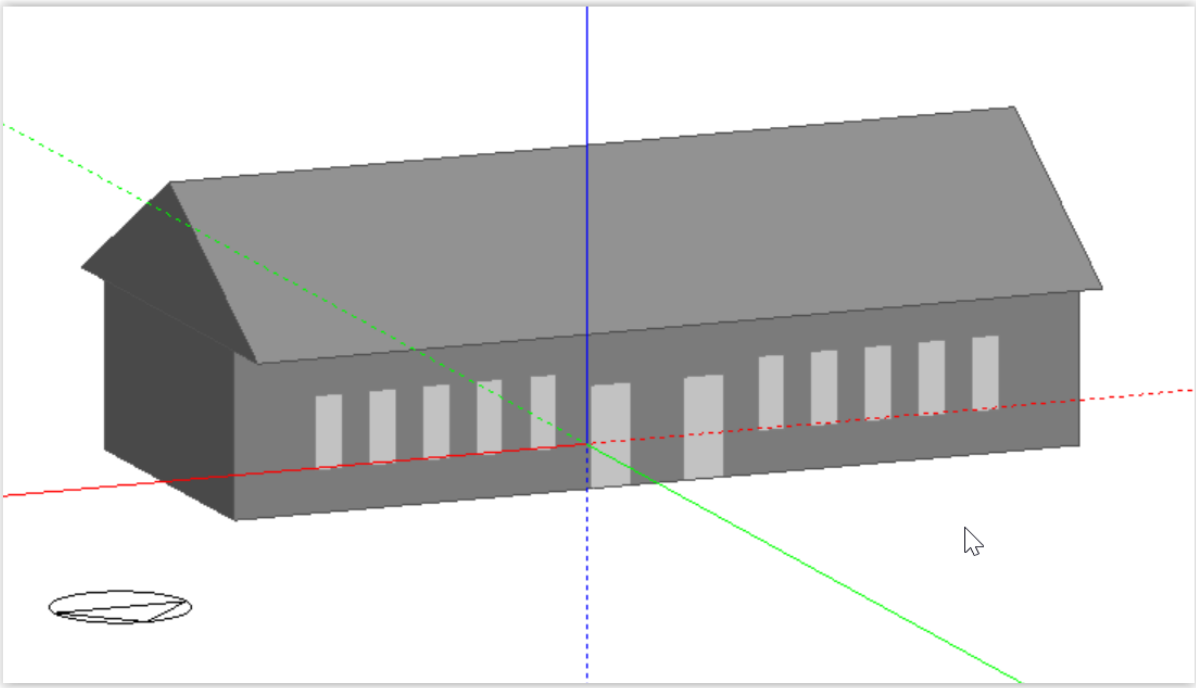
Materials:

- Reed
- Metal sheet
- Ceramic tiles

For the covering material in the roof the most used material in this condition is metal sheet. Other materials are less durable or they are much heavier. The choice about roof covering will be determined also in creating the right construction system, which must correspond to the design of the inner build environment and plausibly building service systems.

3.4 Wall materials comparison measurement by DesignBuilder

For measurements we pick an example building. The building will be used for three different purposes - workshop, classroom and laboratory. The dimensions of the building are for all three cases equal; the difference is in the operation and requirements for those types of using the building.



Pic. 15: Printscreen of the model in DesignBuilder

3.4.1 Description of different types of using the building

Workshop:

The building is used for practical education. Ventilation is provided only by windows. There is no lighting and no HVAC system.

Classroom:

The building is used for theoretical education. There is a system of natural ventilation providing the exchange of the air inside the building by ration 1/h. The lighting system is based on the example school schedule and there is no system of mechanical ventilation.

Laboratory:

The building is used for practical education. Ventilation is provided by a mechanical system with the exchange of the air inside the building by ration 6/h because of the chemical pollutants. The lighting is at the same schedule as the classroom.

3.4.2 Materials used in the comparison measurement:

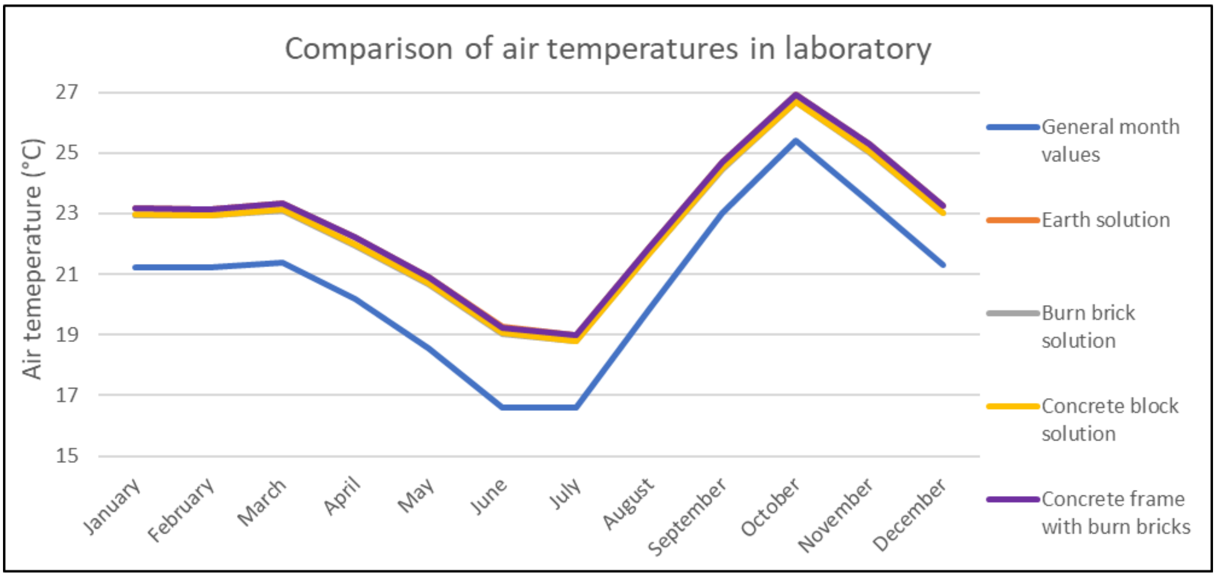
- Adobe wall with thickness of 300 mm
- Burnt brick wall with thickness of 110 mm
- Concrete block wall with thickness of 140 mm
- Concrete frame wall with unburnt brick with thickness of 140 mm

Weather data:

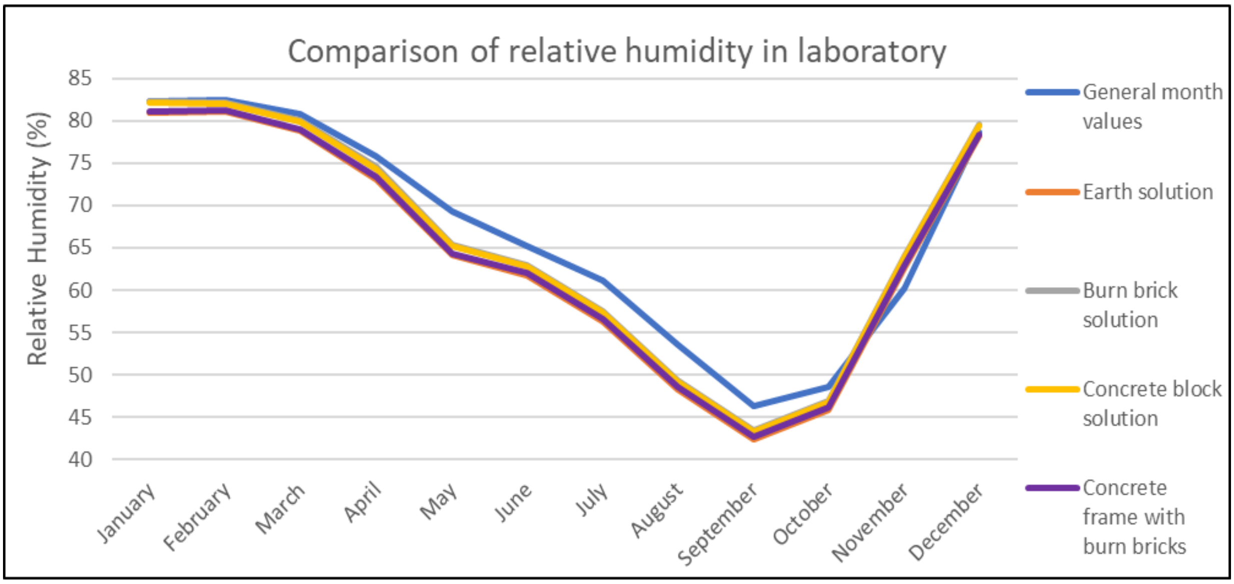
Weather data used in the study was obtained by the program Meteonorm for the locality of Lusaka.

3.4.3 Conclusion of calculation:

As we can see from the graphs, there are almost no differences between different material performances. All materials are heavy and their differences in the other characteristics are not causing any distinction. Even for different uses of the building, air temperature and humidity has no variety of figures among the measured materials. Therefore, from a performance point of view, there is almost no difference between monitored materials. Detailed calculations are presented in Annex 2. For showing the results, graphs of air temperature and relative humidity for the laboratory were chosen.



Pic. 16: Comparison of air temperatures in laboratory



Pic. 17: Comparison of relative humidity in laboratory

3.5 Conclusion

Material options were selected to create the construction system of the buildings. Foundation structures will be done by stone with components from concrete. A different wall solution was examined and no major difference between their performances was found. Choosing the right option will be done in the next part of the thesis concerning sustainability assessment. Roof materials were chosen and will be used in developing the construction system of the building.

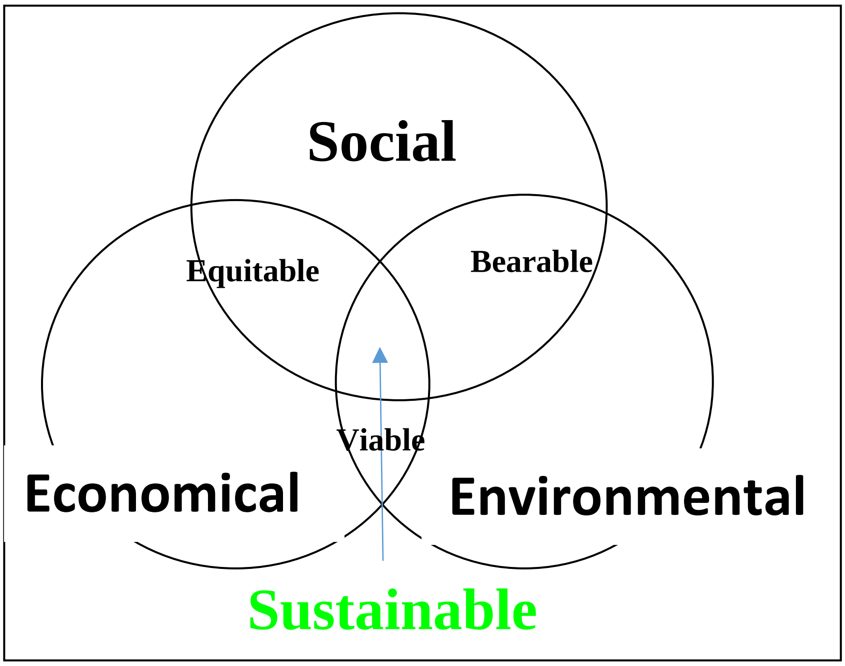
4 Sustainable building design

4.1 What is sustainability?

Buildings are not objects of their own. They can be seen as a commodity on the market, as a dominant in the landscape or as a masterpiece of art. They are connected to their environment, to the climate and the weather condition, they are present in and to the people, who use them. To see a building holistically, we cannot just focus on the engineering, financial or any other part of the industry. To see a whole picture, we have to apply a principle that unites all the important factors across the fields of human study.

Sustainability is a term that gives this overall look. The definition of sustainability comes from defining a sustainable development. According to Brundtland Commission's 1987 definition, Sustainable development is: "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (Our common future, 1987)

Now how to transform this sustainability principle to the context of architecture and buildings? The document (Aghimien, 2016) states that a "construction can be said to be sustainable, when it encourages the preservation of natural habitat, promotes social well-being of its occupants and provides reasonable economic stands for its investors". From this perspective we can see that a building should not only fill the functional goal to serve the user or to be an economical commodity on the market or to be just an object that is creating a mark in the land. Sustainable construction combines all those three components to create a complete framework. These three perspectives we can call three pillars of sustainability (Henry Clune, 2018).



Pic. 18: Three pillars of sustainability; Source: (Camarinha-Matos, 2012)

4.2 Sustainability building design

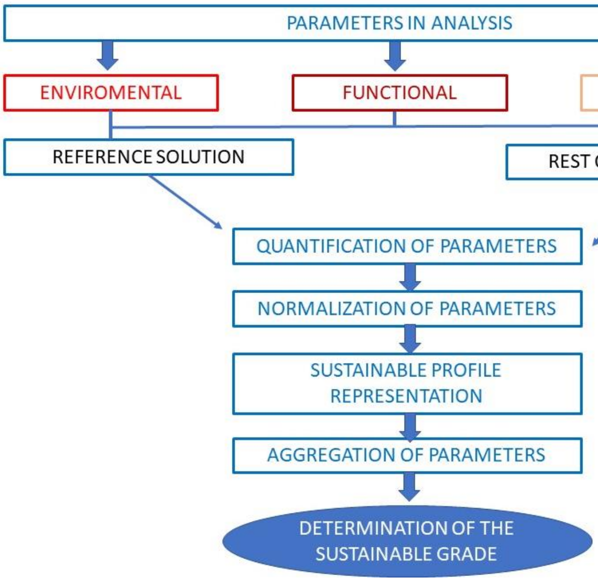
In the building design we must focus on those three components of sustainability. Every component has a special role to play, but they all must work together. To develop a sustainable framework, we need to be more specific about every pillar in the case of building design. The framework of sustainability is presented in several sustainability assessments of the building. This assessment has its own methodology and parameters that determine the building in some phases of the construction design or life. To name a few we can mention LEED, BREEM, and SBTooL. SBTooL has some versions depending on the country which uses it. The Czech Republic and also Portugal have their own versions to use. Examples of using sustainable tools in African context can be found at (Omwoma, 2017). In this thesis, I am not using any existing sustainability tools. I developed my own tool using MARS methodology.

4.3 MARS methodology

MARS is a Portuguese acronym for Methodology for the Relative Sustainability Assessment of Residential Buildings (Bragança, 2010). It is a sustainable evaluation methodology (Bragança, 2018). The main premise of this methodology is to create a procedure of evaluating parameters of three different sustainability pillars to one total score. The result of one scenario can be compared with the other possible solutions and compared with one another.

At first, parameters of each pillar have to be selected to give important information in decision-making. To each parameter we can assign the weight it has in the overall context of the assessment. Parameters have different weight value which is determined by studying the field and opinions of the field experts. Then those parameters are normalized. That means obtaining the value without units and gives us information in the scale of 0 to 1. This adjustment shows how the parameter performs compared to the other solution. 0 is the worst solution and 1 is the best solution. Afterwards we can aggregate those parameters for every pillar to get the performance of individual pillars. At last, there is the final score by selecting weights to every pillar of sustainability and computing the total sustainable grade.

Every parameter in the assessment represents a topic that is important for developing the sustainability of the project. Those parameters after normalization can be compared and weak spots can be found. Picture 19 shows the whole overview of MARS methodology.



Pic. 19: Schematic representation of MARS; Source: (Bragança, 2018)

4.3.1 Environmental parameters:

Those parameters examine buildings in relation to the nature, landscape, pollution and reusing and recycling of materials. From this point of view, we try to reduce the amount of pollution and the impact on the environment that the building industry produces by its operation. The Building process should also use local materials which, afterwards, can be reused or recycled in order to save natural resources.

4.3.2 Social parameters:

Social parameters or, in other words, functional parameters aim to describe how building affects users. In this category we can find performance in building environment, such as thermal, acoustic or visual comfort or use of the building to its purpose. We can also evaluate impact on human health by building material or providing accessibility to the building for the users. Another important aspect is health and safety of the occupants and air quality inside the building.

4.3.3 Economical parameters:

Affordability and life cycle cost are also important pieces of information for the investors. Construction cost affects the whole design of the building and by reducing maintenance cost we can save a lot of energy for using it in another way. By including the local and circular economy, houses do not have to be only consumers of money, but also their producers.

4.4 Sustainability building assessment

In the following pages the developed sustainability assessment tool for determining which solution of construction systems is the best for using in this project will be presented. The framework of the tool is based on sustainable principles and the MARS methodology.

4.4.1 Construction systems

From the building material available in the locality these construction systems of building outside walls were selected that will be compered by the sustainability assessment tool.

Construction systems are the following:

Outside wall	Description	Thickness [mm]
Solution 1	Rammed earth wall	300
Solution 2	Compressed earth block wall	330
Solution 3	Burnt brick wall	160
Solution 4	Concrete block wall	190
Solution 5	Concrete frame + compressed earth block wall	190

Tab. 1: Solution of the outside walls

4.4.2 Characteristics of the construction systems:

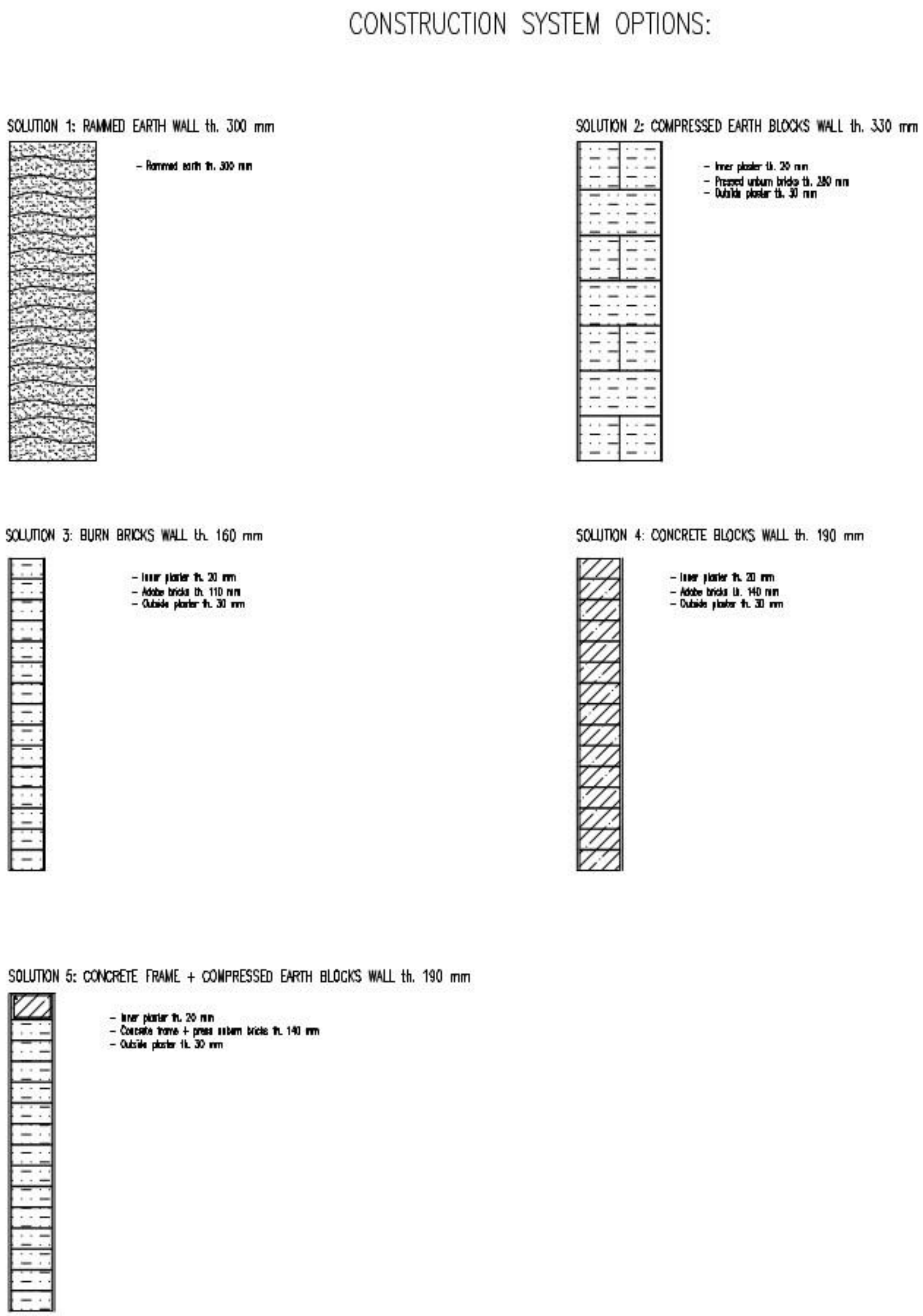
Rammed earth: Soil for the construction will be extracted by diesel machinery. The mixture will consist of sand, clay and water without stabilization of cement material. Compression will be provided with diesel generator.

Compressed earth blocks: These blocks have 90 % of soil and 10% stabilization of Portland cement. Extraction of soil, separation and pressing is done by diesel machinery. After forming, bricks are cured and left on site for 4 or 5 days.

Burnt brick wall: Bricks are done by soil extraction in the site. Brick are manufactured by press. After pressing they are formed to create brick clamp. Fuel for the burning of bricks is firewood from the surrounding area.

Cement blocks: Cement blocks are of medium density and hollow. Blocks are made of cement, expanded clay, water and sand. They were manufactured by machine not by hand mould.

Concrete frame with compressed earth block: The wall is combining concrete reinforced frame structure with 20% of the total volume with 80% of compressed earth block. The concrete frame has 2% of reinforcement in the total volume of concrete structure. Information about compressed earth block in this solution is identical to the second solution.



Pic. 20: Construction system solutions

4.4.3 Developed sustainability assessment parameters

In this part of the work individual parameters presented in the assessment will be introduced. Each parameter will be described and explained why it is important for the comparison. The assessment will be comparing five different solutions of the wall construction. The size of the wall will be 1 m^2.

4.4.3.1 Environmental performance:

GWP (Global Warming Potential):

Measuring the contribution of the material to the greenhouse effect. The typical value is carbon dioxide. Other substances, e.g. methane, are transferred to the CO_2 equivalent, which shows the impact of the gas in comparison to the CO_2.

Units: kg CO_2-equivalents

AP (Acid Potential):

Measuring the contribution of the material to the acidification of the land. The typical value is sulphur dioxide. Other substances are transferred to the SO_2 equivalent, which shows the impact of the gas in comparison with the SO_2.

Units: kg SO_2-equivalents

EP (Eutrophication Potential):

Measuring the contribution of the material to excessive biomass grown in the soil and eutrophication in the water.

Units: kg PO4-equivalents

ODP (Ozone Depletion Potential):

Measuring the contribution of the material to damaging the ozone layer in the stratosphere.

Units: kg CFC-11 equivalents

POCP (Photochemical Ozone Creation Potential):

Measuring the contribution of the material to creating the photochemical oxidation also known as a summer smog.

Units: kg ethylene equivalents

Embodied energy:

Represents the total primary energy demand from renewable and non-renewable resources.

Units: Megajoules [MJ]

These parameters are basic characteristics for an environmental sustainable assessment and they are used in many sustainability tools. They show the impact on the nature environment and energy use of the materials. All figures for these parameters are present in the database: (India Construction Materials Database, 2017)

References and detailed definitions: (LCIA Recommended Indicators, 2015)

Two more parameters extended the environment scale because of the special conditions of this project.

Amount of the material used in the locality:

To promote local material and determine the effect of transportation this parameter will show materials used in solution in the context of their local use.

Units: km * kg

Use and degradation of the land:

This parameter was developed to show how much land is needed to extract and produce desired building materials.

Units: kg/m^2

4.4.3.2 Economic performance:

Construction cost:

Total cost of 1 m^2 wall construction. The cost will include all materials that the wall is composed of. The price for the worker salary is not included. The currency is the Zambian Kwacha. All prices will be used from the market examination, done in summer of 2018. In Annex 1 prices from different shops and warehouses are gathered. Used price is the average. Working hours were obtained from the site (Gerador de preços para construção civil, 2013), that works as a database for all the procedures needed to build every solution

Units: ZMW

Note: Exchange rate to this date (5. 11. 2018)

- 1 EURO is 13.55 Zambian Kwacha
- 1 USD is 11.91 Zambian Kwacha
- 1 CZK is 0,52 Zambian Kwacha

Working hours:

Working hours to build 1 m^2 wall construction. Working hours include extraction of soil, pressing and erecting the wall with all the components.

Units: /hours

Note: To promote local economy, a solution with more working hours was considered better than a faster solution. Reference: (Gerador de preços para construção civil, 2013).

Working hours include:

- Rammed earth - soil extraction by hand, formwork, ramming by compressor.
- Compressed burnt bricks - soil extraction by hand, making the blocks, erecting the wall
- Burnt bricks - soil extraction, making the unburnt block, burning, erecting the wall
- Concrete block - making the brick on the machine, erecting the wall
- Concrete frame + compressed burnt brick - making concrete in situ, formwork for the frame, soil extraction, making the blocks, erecting the wall

4.4.3.3 Functional performance:

To the functional performance we will include all the parameters whose performance in the building is different in every solution. The Annex 2 shows that outside wall material solutions have almost no difference in performance on air temperature and relative humidity. Therefore, we will not use these parameters in this assessment.

Airborne sound insulation:

Estimated airborne sound insulation of the wall from the exterior to the interior:

The higher the parameter, the higher is the insulation performance of the wall.

Units: decibels (dB)

References: (Acoustic performance of brickwork, 2019), (New Zealand concrete manual, 2019), (Daza, 2016)

Heat capacity:

The specific heat capacity of a substance is the amount of heat required to raise one gram of the substance by one degree Celsius:

The lower this parameter, the less energy is needed to raise its temperature.

Units: J (joules) / kg °C

Reference: DesignBuilder database

Moisture resistance:

Resistance of the material to the water is presented by water absorption capacity coefficient.

The higher the value, the better is the absorption of the water in the material.

Units: $kg/m^2\sqrt{t}$

Reference: (Mužíková, 2017)

Lifespan:

Lifespan is the expected life period of the material.

Units: years

Reference: (Typical Life Expectancy Table for common building materials systems, b.r.) (FAQs about Rammed Earth, 2019)

Experience by local people:

Some techniques for making the wall are more familiar to the local people than others. The value of this parameter is from the 0 to 1 according to the experience with current construction system.

Values were established by dialog with the people from the locality, who will be the workers in the future building site.

Units: None

4.4.4 Developing of the weight system

Every parameter has a specific weight in all parameters of the assessment. Weights are implemented in the tool in every sustainability pillar before normalization of the parameters. Estimation of the weights figures was done by using the similar weight system in the class of sustainable build overview in University of Minho. Weights of total sustainable score are corresponding with weights of other sustainability tools, e.g. SBTool.

Environmental performance:

Indicators	GWP	AP	POCP	EP	ODP	PEI	Local materials	Use of the land
Weights [%]	16	5	6	5	5	5	20	38

Tab. 2: Weights of the environmental parameters

Economic performance:

Indicators	Construction cost	Working hours
Weights [%]	60	40

Tab. 3: Weights of the economical parameters

Functional performance:

Indicators	Sound insulation	Heat capacity	Moisture resistance	Lifespan	Experience by local people
Weights [%]	20	10	20	25	25

Tab. 4: Weights of the functional parameters

Weights of total sustainable score:

Sustainable profiles	Functional	Environmental	Economical
Weights [%]	50	20	30

Tab. 5: Weights of sustainable profiles

4.4.5 Calculation results

Environmental Performance									
Solution	GWP	AP	POCP	EP	ODP	FFDP	Transport	Use	IA(Normalization)
Rammed earth	1,00	0,96	0,07	0,00	0,67	0,07	1,00	0,99	0,83
CEB	0,51	1,00	0,98	1,00	0,79	0,71	1,00	0,99	0,89
Burnt bricks	0,00	0,00	0,00	0,57	1,00	0,00	1,00	0,00	0,28
Concrete blocks	0,48	0,77	0,99	0,97	0,00	0,59	0,00	1,00	0,63
Concrete frame + CEB	0,94	1,00	1,00	1,00	0,78	1,00	0,56	1,00	0,89

Tab. 6: Normalized environmental performance (red = worst solution, green = best solution)

Economic performance			
Solution	Construction cost	Working hours	IF (Normalization)
Rammed earth	0,00	0,00	0,00
CEB	0,89	0,62	0,78
Burnt bricks	1,00	0,25	0,70
Concrete blocks	0,99	0,16	0,66
Concrete frame + CEB	0,58	1,00	0,75

Tab. 7: Normalized economic performance (red = worst solution, green = best solution)

Functional performance						
Solution	Airborne sound insulation	Heat capacity	Moisture resistance	Lifespan	Experience by local people	IA(Normalization)
Rammed earth	1,00	1,00	0,96	0,00	0,00	0,49
CEB	1,00	0,91	0,96	0,81	0,80	0,88
Burnt bricks	0,00	0,00	0,00	0,81	1,00	0,45
Concrete blocks	0,17	0,10	1,00	1,00	1,00	0,74
Concrete frame + CEB	0,00	0,32	0,96	0,81	0,70	0,60

Tab. 8: Normalized functional performance (red = worst solution, green = best solution)

Total environmental score:

Sustainable score	Functional	Environmental	Economic	NS
Weights (%)	50	20	30	
Rammed earth	0,49	0,83	0,00	0,41
CEB	0,88	0,89	0,78	0,86
Burnt bricks	0,45	0,28	0,70	0,49
Concrete blocks	0,74	0,63	0,66	0,70
Concrete frame + CEB	0,60	0,89	0,75	0,70

Tab. 9: Total environmental score (red = worst solution, green = best solution)

4.4.6 Conclusion of calculation

From the calculation results we can see that the CEB solution achieved the highest rate in every sustainability pillar. Its total score is logically the best option for the construction system. Other solutions have diverse grades in different sustainability pillar scores and are not that much suitable as a CEB option. There is no major problem that would be critical for not selecting the CEB solution as the main one. That is why I will use this solution in the following work on the project. Detailed calculation can be found at Annex 3.

4.5 Conclusion

The sustainability assessment tool was developed by using sustainability principles and the Mars methodology framework. By introducing parameters influencing the scores in every sustainability pillar we can comprehend all factors that we consider to be important for this assessment. The final score was given and the CEB solution was found most suitable for developing a construction system.

5 Construction system of buildings

After finding the suitable material by the sustainability assessment tool, we have to choose a specific construction system. By using the same system in multiple buildings, we can speed up the building process and reduce effort for training the workers.

This chapter will be handling the development of the right construction system according to the results of sustainability assessment. This construction system should be introducing all main features of the design, accomplishing needed requirements of the inner build environment and satisfy needs of school users.

5.1 Construction system for the vertical structures

From the sustainable building assessment we discovered the best solution for the vertical structures, which is compressed earth blocks (CEB). For a better understanding of the system we will present the main information about the system of compressed earth blocks.

5.1.1 CEB (Compressed earth block)

Compressed earth blocks are building elements that are created from the earth materials by manual or mechanized presser technology. They are representing the next step from adobe technology that uses an earth mixture and creates bricks without any compression. Compressed earth bricks are more compact and more durable. They can be stabilized by use of cement or lime or they can be without any stabilisation. Stabilisation increases compressive strength.

Characterization of the technology: (Dwell Earth, 2016)

- Main amount of material needed for creating blocks is at most cases present in the building site
- Technology is simple for understanding and intuitive for building
- Integrity of the brick is accomplished by compressing the earth mixture, not by burning.
- Material absorbs moisture and heat, loads and stores them in its own mass and they are realised when the environment conditions change.
- By using local materials, the environmental footprint is reduced to a minimum
- The energy for manufacturing the block element can be reduced to a minimum by manual compression.
- Earth blocks are easier to recycle than burning cement-based blocks.

5.1.2 ICEB (interlocking compressed earth block)

CEBs are a good start for designing load bearing structures, but there is always way to improve their concept. Interlocking is used between bricks, creating one major advantage – the dry stacked construction method. The method of block laying can be entirely without mortar or with a maximum reduce of its amount in the construction method. This type of construction is faster and more precise (Irwan, 2016). Interlocking also creates a construction that is more durable and stable. Some of those building elements are used in the location with earthquake hazard (Moreira, 2015). Blocks that are not connected by mortar can be reused in another project. There are more ways to interlock the bricks between each other. ICEBs are a major improvement in a faster construction method and in reusing the building elements. That is why I will use them in my project.

5.1.3 Selected solution:

During my study I came across some interesting construction systems that can be suitable for the project of the High school in Kashitu. I want to introduce two of them.

5.1.3.1 Interlocking Stabilised Soil Blocks (UNHABITAT)

Pic. 21: Stabilized soil block by UNHABITAT; Source: (Pérez-Peña, 2009)

One solution that I found appropriate was developed in a project of UNHABITAT. These stabilized soil blocks with interlocking features were designed to be an improvement of the most common used material in rural areas of Uganda, which is adobe brick. The earth constructions are the most applied type of structures in Africa (Pérez-Peña, 2009). The idea is not to change this material for something else, but to improve the technology in a way that the homes of the people will be nice and decent places to live in. To transform the usual African mud hut into a solid earth-based family house.

This solution presents the way of making earth bricks with stabilisation elements done by human force. The bricks are precise in the interlocking shape and helpful to be more effective in creating constructions. Earth is excavated from the ground by removing the upper levels of the soil. Then the soil is sieved and gathered for the mixing with the stabilisation element, most likely cement or lime. In the mixing period, water must be added to the mixture to activate the chemical process of stabilisation of the blocks. After that, the soil is ready for manufacturing in the pressing machine (manual or fuel based). When the blocks are removed from the machine, they must be stored in the proper area and protected from direct sunlight. The curing period comes next, normal time is 28 days. After that block are check for the quality inadequacies and are good to be used for construction purposes (Pérez-Peña, 2009).

This solution has a good potential to build houses fast and smooth. Buildings can be built in rectangle or round shape. The training of the workers does not have to be complicated and the production of the building material is fast. The only inconvenience is that you must have a precise pressing machine with a specific mould, that can be done only by an expert company of individual professionals.

5.1.3.2 Compressed earth block by UMinho

Pic. 22: CEB by UMINHO; Source: (Moreira, 2015)

The HiLoTec project is a construction technology developed by the University of Minho, Portugal, and Mota-Engil S.A. Construction Group. The objective is to create a sustainable construction system for developing countries from traditional building materials. It is also aimed for places with seismic hazard like Malawi, which was chosen for the case study of this project.

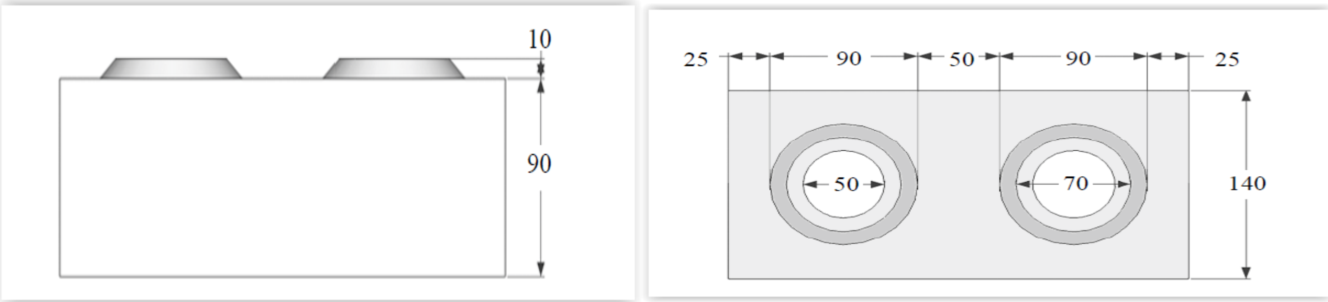
CEB blocks are made from soil with cement stabilisation. Soil should be collected from the down layer of earth, after removing the upper layer with organic materials. Then it is sieved by a net of 0,5 mm. Mixing the soil with cement can be done manually or by a mixing machine, the volume of the cement in the mixture is about 5%. When the mixture of soil is ready, we can put the mixture to the pressing machine and manufacture the blocks. The blocks are then stored. They must be covered against direct sunlight and cured in the period of 28 days. Then they are ready for using it as a construction element (Moreira, 2015).

This system is more suitable for the condition of the Kashitu project. Malawi is a neighbouring country of Zambia and the purpose for which the HiLoTec project was developed is very close to my objectives of the work. Thanks to the fact that the project was developed in cooperation with university of Minho, I had obtained more detailed information that can be used in the specific design parts of the school. Therefore, I chose this system for the construction of the vertical structures.

5.1.3.3 More information about construction system:

Mechanical properties:

The mechanical properties of the material are depending on the properties of the soil. Values presented in this thesis originate from the doctoral thesis of Thomas Moreira (Moreira, 2015). In Kashitu, the parameters of the soil will be different. But if we will be guided in the procedure of making the block by the HiLoTec project, the mechanical properties of our blocks will be most likely similar.



Pic. 23: Dimensions of the HiLoTec block; Source: (Moreira, 2015)

<u>Experimental characterisation of the material properties:</u>

Material properties that should serve as a reference of the expected value. In the doctoral thesis they are presented by the name PL soil.

Set up	Characteristic	Unit	Average value for PL soil	COV for PL soil
Blocks	F_b	MPa	2,34	24 %
	E	MPa	163	30%
	F_r	MPa	0,21	19%
	$G_{F_t}^I$	Nm/m2	18,1	41%
Prisms	F_p	MPa	0,95	24%
	E	MPa	129	19%
	$E_{33\%}$	MPa	72	35%
	$G_{F_t}^I$	Nm/m2	2380	31%
Wallets	f_m	Mpa	0,53	-
	E	Mpa	102	-
	ν	-	0,23	-

Tab. 10: Experimental characterisation of the material properties

Parameter	Value	Units
Gross area	392	cm2
Net area	353	cm2
Area of holes	10.0	%
Net volume	3175	cm3
Weight of the block	5,6-6,4	kg

Tab. 11: Mechanical properties of the HiLoTec block

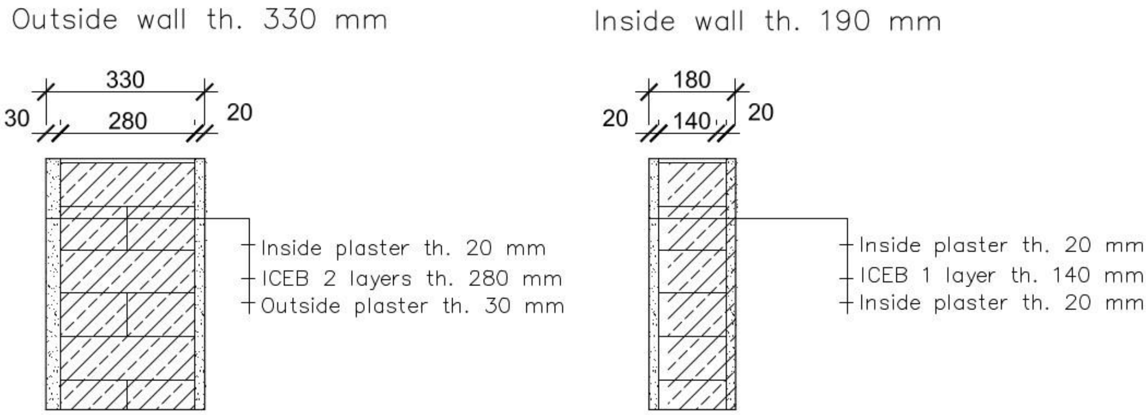
Productivity of the block manufacture process by manual press machine:

20 ICEB/hr

5.1.4 Use of the solution in the project

From the CEB that we selected we have to compose wall structures and module system. Walls should take advantage of the interlocking technology and respect the dimensions of the blocks. An effective module system helps with the effective realisation of the project and saves time, when no blocks are modified.

5.1.4.1 Components of the vertical constructions:

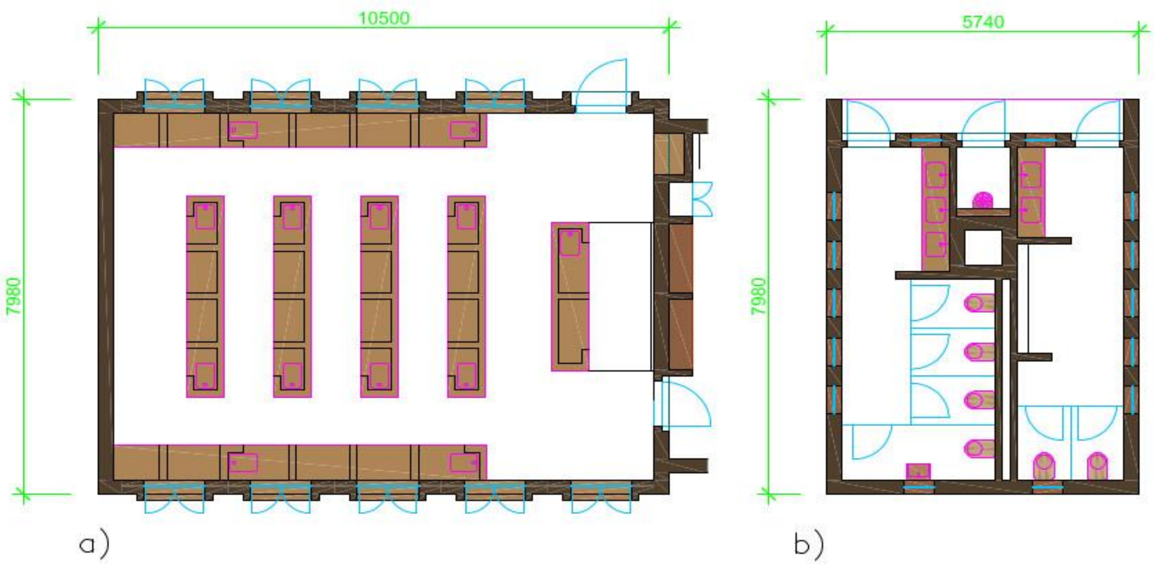


Pic. 24: Walls structure

The outside wall is composed of two layers of ICEB and outside and inside the wall. It is complemented by outside and inside plaster. Plaster from the outside is with lime component. The inside consists of a natural clay plaster finish. The inside wall is usually composed of one layer of ICEB and plastering from each side. In the need of better acoustic performance, there will be two layers of ICEB.

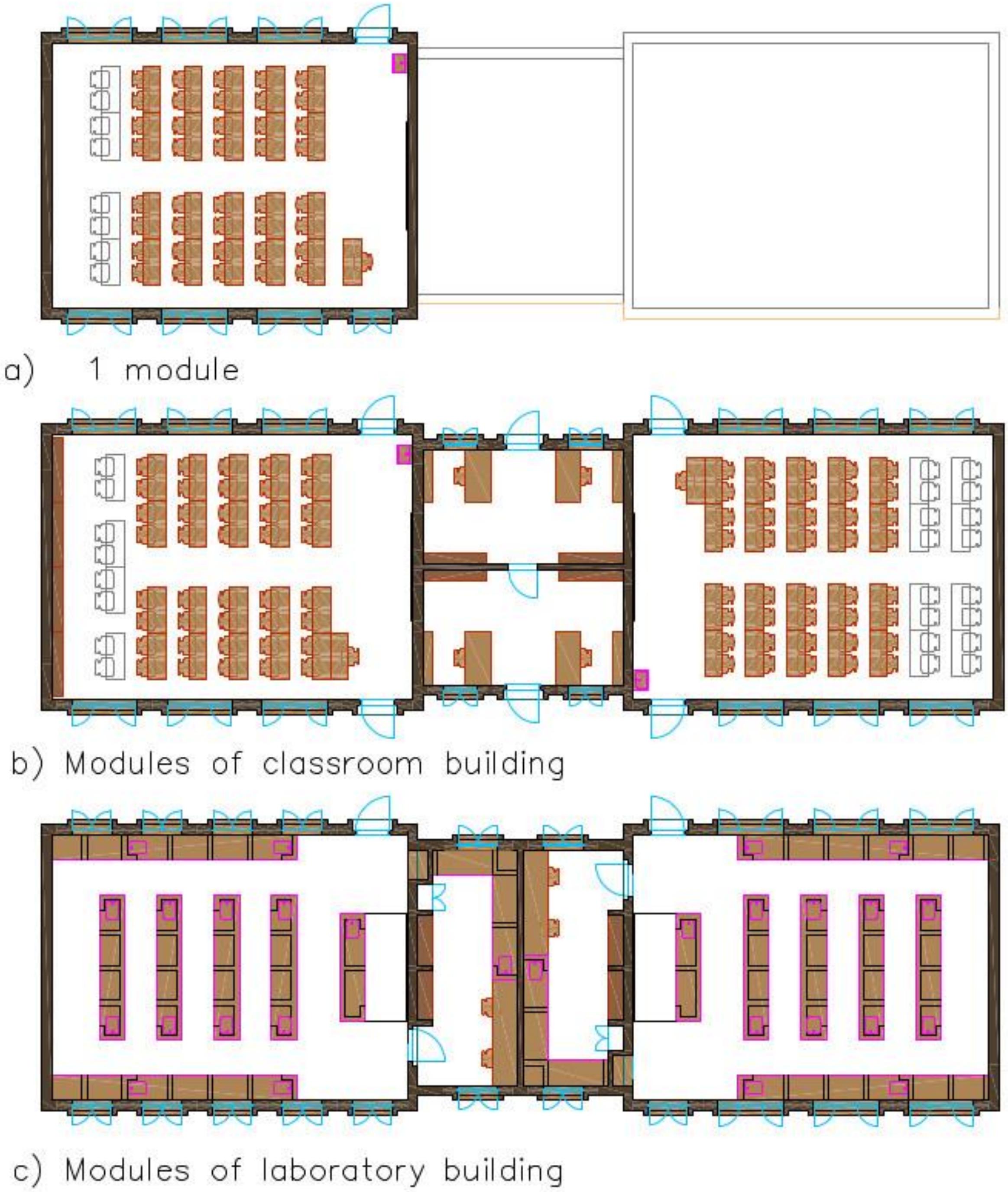
5.1.4.2 Building modules:

The dimensions of the block are 280x140 mm. That gives us guidance to create a module system for the building that will be a more effective way in the construction process. The basic module of the certain area is developed by requirements according to the design building standards. To fulfil all requirements in the classroom and laboratory spaces, the basic module has the dimensions 10,5 m x 7,98 m. With that information we can calculate a brick row of 37,5 resp. 28,6 blocks. The utility block building has the same width but different length, because it is neighbouring those spaces.



Pic. 25: Basic module of buildings. a) laboratory and classroom module, b) Toilets module

The whole buildings are composed from these module spaces. Smaller space is added between two main module spaces. In the case of the classroom building, there are teachers' offices in the middle. In the case of laboratory, in the middle we can find preparation rooms.

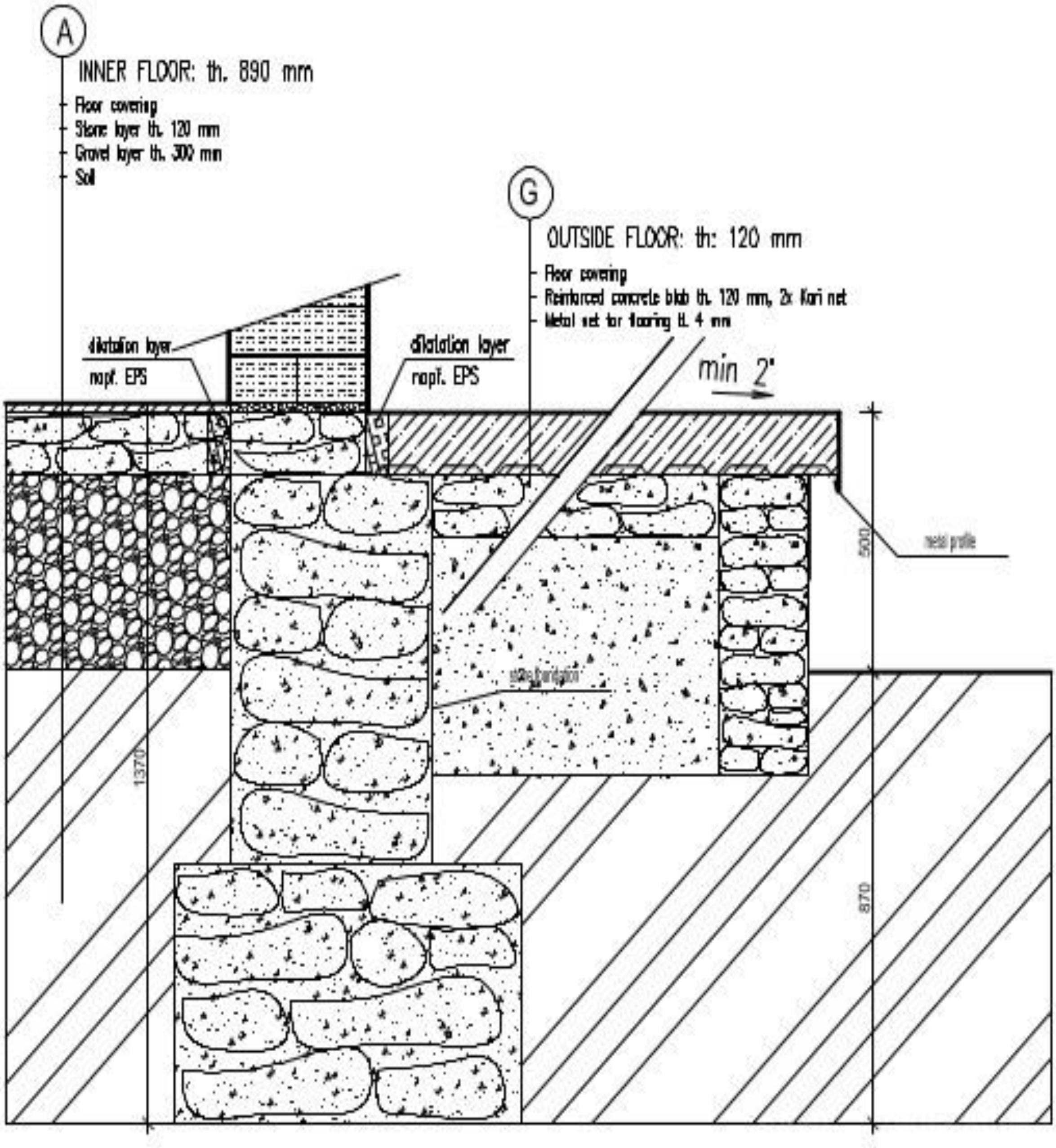


Pic. 26: Development of the single module space to the complete buildings

5.2 Foundations structure:

Foundations are a key component of the structure for the building itself. As I mentioned in chapter three, the foundations will be created mostly by stones from the nearby stone quarry. Only the foundation base slab will be made of concrete.

The foundations must be designed for all impacts of the elements that affect the foundation structure and the building itself. Mainly the loads from above structures have to be transferred to the soil underlay. Exterior rendering creates a barrier that protects the wall construction from the outside water, caused by rain or present in the soil next to the structure. The hydrophobic layer prevents water transportation through the constructions.

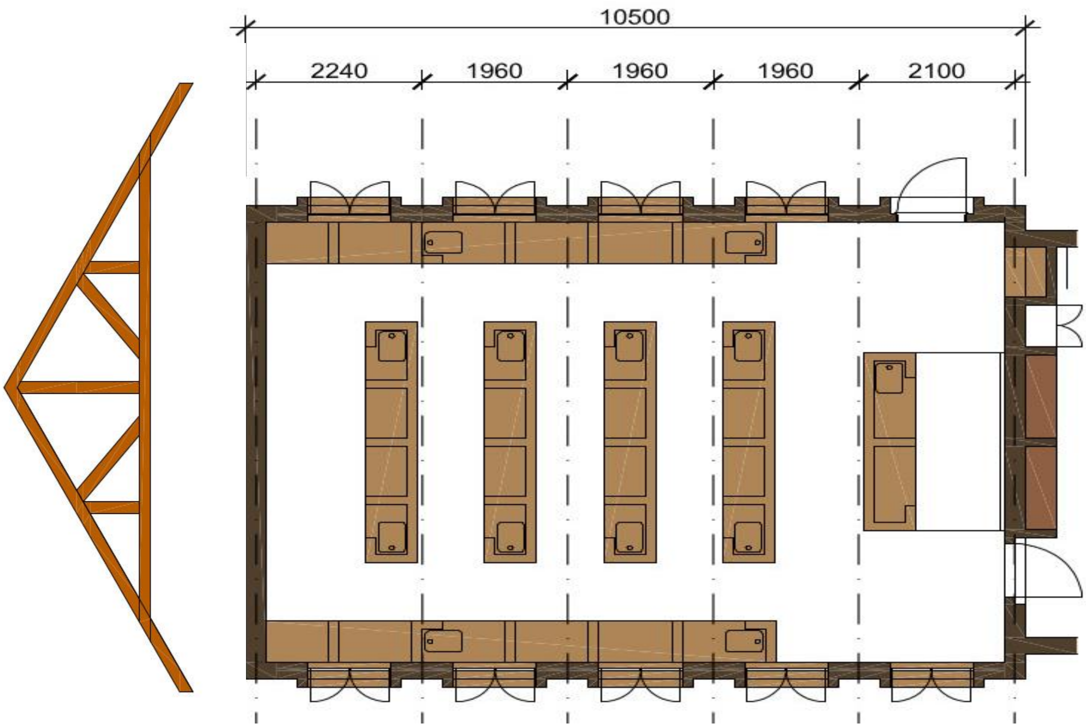


Pic. 27: Foundation drawing

5.3 Roof structure:

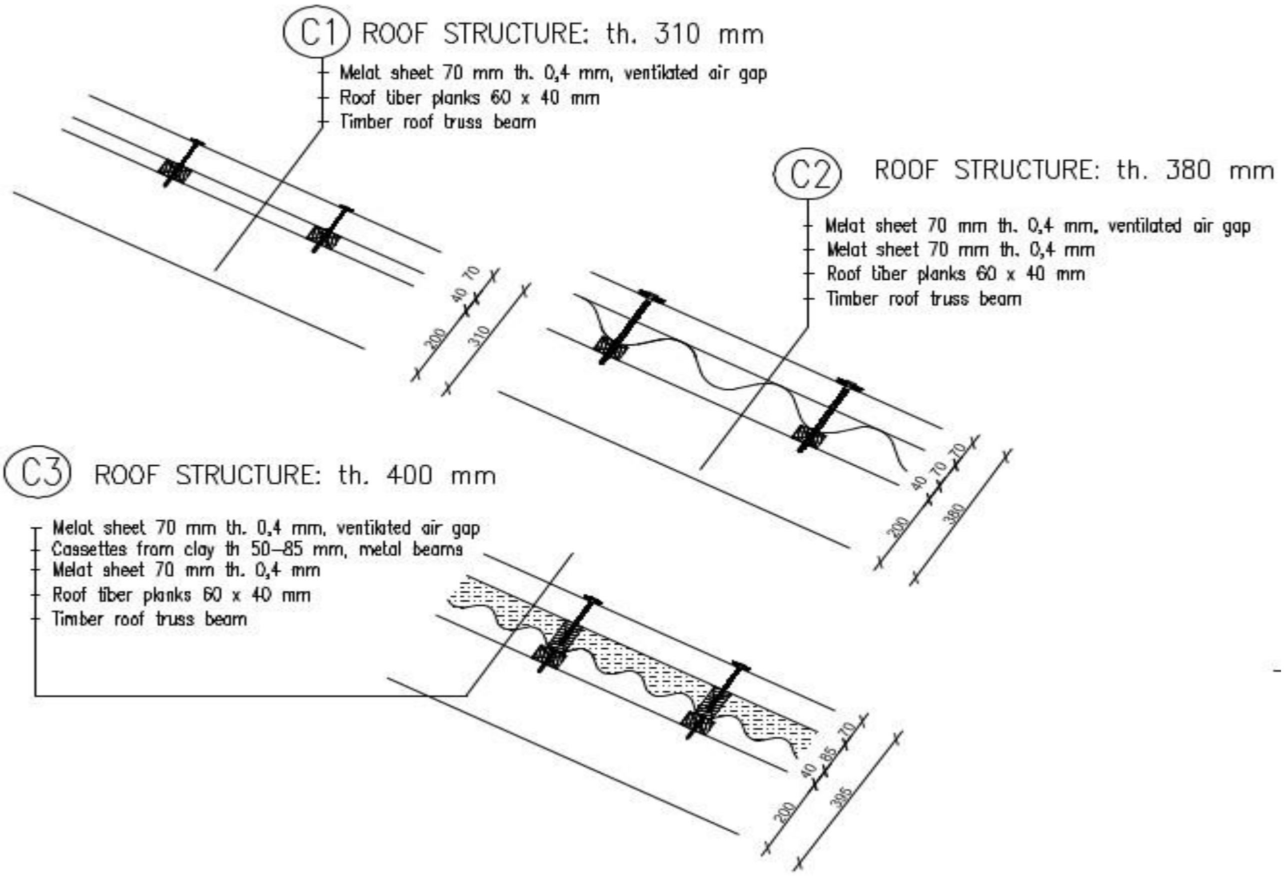
The roof structure is also critical for the right design of the building. For the roof cover we can use metal sheets or reed. The Climate has a big role to play in the design. The rain season prevails in five months of the year and in this time, we want to use rainwater for the accumulation and to increase acoustic comfort, which can be, in this period, reduced significantly.

A major component of the roof will be timber, because it is a more environmentally friendly material and it is available in the locality. For the roof covering, we will use metal sheet that serves as a very good rainwater harvesting surface. The load bearing construction will be timber truss beams with the distance of 2 m from each other, with the biggest distance at 2,24 m. To prevent acoustic discomfort, we must develop a solution, that would deal with the noise caused by rain.



Pic. 28: Distance and position of the truss beams in the roof construction

Truss beams will be constructed from construction timber profiles. Timber creating truss beam will be connected by nail joints. Manufactured beams will be attached with each other by timber profiles, which will ensure stability and create space for earth cassettes. To increase thermal comfort and improve acoustic insulation performance, earth cassettes will be placed in the roof composition. The earth component increases thermal capacity of the roof construction and improves night cooling in the hot season. And by full area support of the metal sheet roof cover, we will reduce noise from the rain in the rain season.



Pic. 29: Scheme of the roof structure

Option 1:

Frequency (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
Rain intensity Li_A (dB)	**47**	**49**	**51**	**52**	**55**	**57**	**58**	**59**	**63**	**59**	**58**	**57**	**54**	**53**	**53**
Summary value of rain intensity (dB)	**64**														

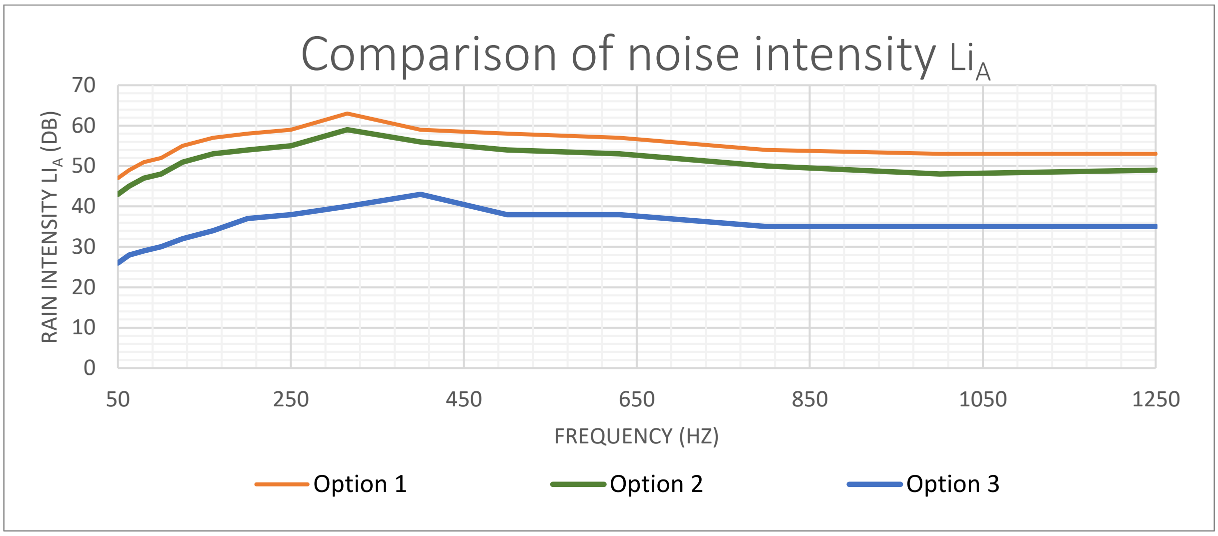
Option 2:

Frequency (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
Rain intensity Li_A (dB)	**43**	**45**	**47**	**48**	**51**	**53**	**54**	**55**	**59**	**56**	**54**	**53**	**50**	**48**	**49**
Summary value of rain intensity (dB)	**60**														

Option 3:

Frequency (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
Rain intensity Li_A (dB)	**26**	**28**	**29**	**30**	**32**	**34**	**37**	**38**	**40**	**43**	**38**	**38**	**35**	**35**	**35**
Summary value of rain intensity (dB)	**45**														

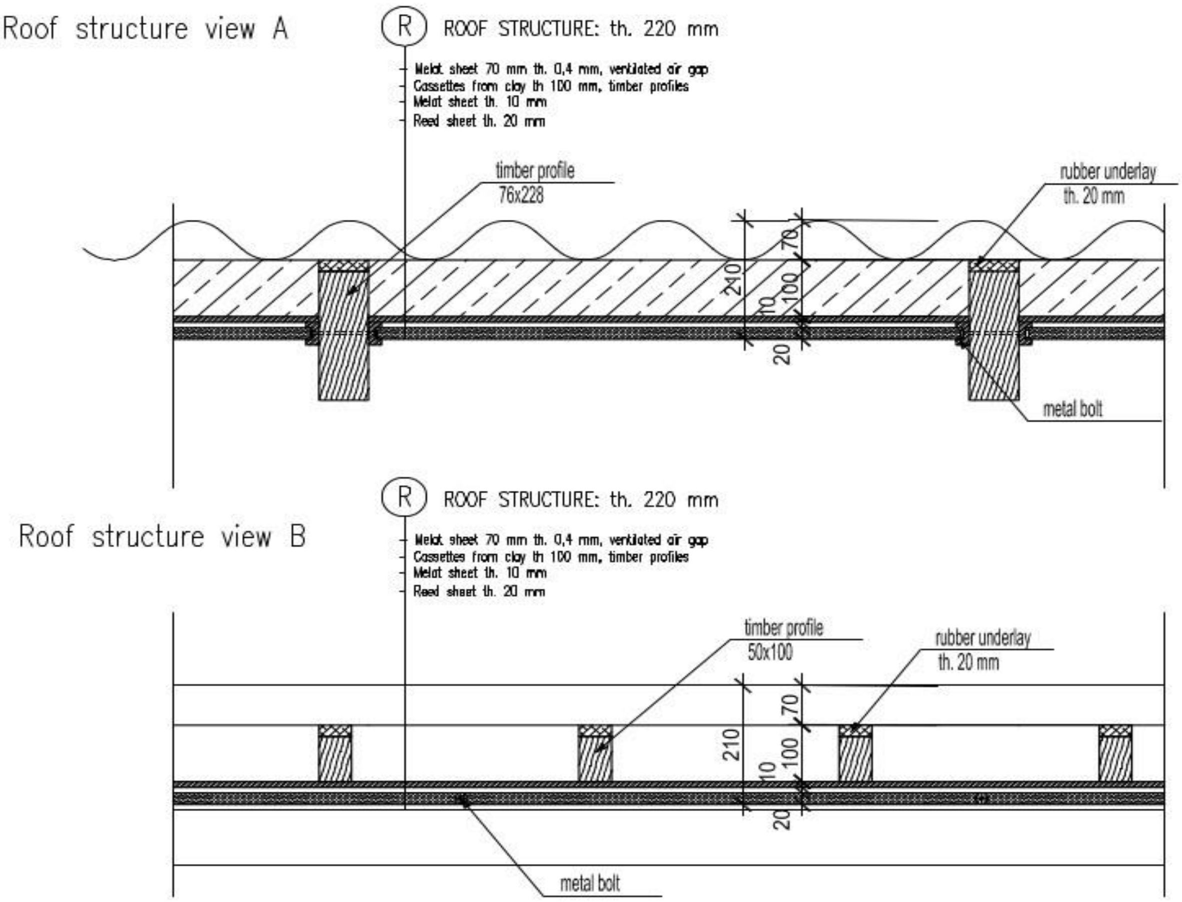
Tab. 12: Rain intensity calculation



Pic. 30: Comparison of noise intensity of assessed options

With the following values we can see that the option with clay cassettes can reduce rain noise from 64 dB in case of simple metal sheet covering to 45 dB. This noise reduction is significant and with implementing adjustments we have a roof with a good thermal and acoustic performance.

The roof construction with all adjustments is as follows:



Pic. 31: Scheme of the roof structure

5.4 Conclusion on the chapter:

Compressed earth blocks were introduced as a building component and a suitable type of ICEB was found for developing the construction system. The wall construction is composed of the UMINHO ICEBs. The buildings are shaped according to the module system, respecting dimensions of the blocks for more a effective construction process. A foundation structure was introduced and stone was found to be the ideal solution. The roof structure was developed with special attention on acoustic performance and rainwater harvesting. A solution was found and acoustic calculations are show good noise reduction from the noise caused by rain.

6 Built environment design

In our project we have multiple buildings that have different types of use. For all these building uses, for example a classroom for studying, a canteen for preparing meals or a workshop for practical study, we have to develop the right condition by creating a comfortable environment for school purposes. Every aspect of the building environment is important, rooms should have enough daylight and fresh air, they must provide thermal and acoustics comfort.

6.1 Daylight

Daylight is the key component in designing a school. Students must have the perfect visual condition in study areas to help their performance in learning activities and to feel comfortable.

6.1.1 Methodology and design standards:

Daylight design will be developed according to the European standards with some specification used in the Czech standards. These are the documents considered in the design:

Laws and regulations:

- EN 12464-1:2011: Light and lighting. Lighting of work places. Indoor work places
- EN 15251:2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
- ČSN 73 0580-1: Denní osvětlení budov. Část 1: Základní požadavky (1994)
- ČSN 730580-3: Denní osvětlení budov. Část 1: Denní osvětlení škol (1994)

Design guidelines:

- (Designing Quality Learning Spaces: Lighting, 2017)
- (The Lighting Handbook, 2018)

6.1.2 Construction principles of daylight design

The design of the school rooms do not have to start with complicated calculations. There are some construction principles that are necessary for designing the buildings and they do not depend on the calculations. From the studied documents I highlighted those construction principles that will be used in the daylight design.

1) The design of the buildings should provide the interior with enough natural daylight, which is the main source of the lighting.

2) The amount of light should be even in every part of the room
3) The windows should have sufficient space for providing daylight, but not overglazing the building causing high thermal gains
4) There should be no direct sunlight in the work places that would glare users
5) Light reflection can help get more light to the building exterior
6) The colour of the room surfaces should not have a big contrast.
7) The view from the windows should provide users with awareness of the changing time and enable the eyes of the students to modify to longer distance to maintain their health.
8) Users should have control of the amount of daylight coming to the interior.
9) Transmittance of the windows is changing in time. Windows should be regularly cleaned to achieve the desired amount of daylight.

6.1.3 Numeral requirements and calculation methods for daylight design

Building standards and guidelines provide designers with reference number requirements to achieve a good level of daylight. Important information from studied document is:

EN 12464-1:2011: Light and lighting. Lighting of work places

A) Ranges of useful reflectance of the room surfaces:

— ceiling: 0,6- 0,9

— walls: 0,3 - 0,8

— working planes: 0,2 - 0,6

— floor: 0,1 - 0,5

B) Illimunance level, UGR limits, colour rendering indices

Room	Em	UGR	Ra
Classroom	300	19	80
Laboratory	500	19	80
Workshop	500	19	80
Reading area	500	19	80
Teachers room	300	19	80
School canteens	200	22	80
Kitchen	500	22	80
Toilet	200	25	80

Tab. 13: Numeral requirements according to EN 12464-1:2011

ČSN 73 0580-1: Denní osvětlení budov

This standard is used to assess the daylight condition in residential houses and has also some requirements for school buildings.

A) General requirements

A room is insulated if:

—the smallest dimension of the window is at least 900 mm, window in the roof with dimension at least 700 mm.

—direct sunlight comes to the building by window areas, where the sum of their areas is bigger than 1/10 of the floor area of the room.

—Insulated rooms have at least 8 m^2 of floor area, kitchen at least 12 m^2

Windows oriented to the north (in our case to the south, because our locality is at the southern hemisphere) or oriented within the angle of 25 degrees are not considered for the calculation, because sunlight in these conditions is not enough in the measured space.

B) School requirements

—The work plane is at the height of 850 mm from the floor.

—Trees and other vegetation must not reduce the level of daylight in the building. The distance of those elements have to be at least the same at their expected maximal height.

—Distance of shading obstacles: ratio of height between edge of shading obstacle and axis of the window in the right angle is 1.3

—Exterior surfaces should not be shiny, with reflectance of 0,3-0,6

—Interior surfaces should not be shiny, with reflectance of 0,3-0,6

More especially:

- ceiling: 0,7
- walls: 0,5
- window walls 0,7
- floor: 0,3

—Daylight factor:

Room	Minimal daylight factor	Average daylight factor
Classroom, reading room, laboratory, kitchen	1,5	5
Dining room, workshop	1	3
Toilet, bathroom, changing room	0,5	2

Tab. 14: Numeral requirements according to EN 12464-1:2011

6.1.4 Calculations in classroom building

Daylight in the classrooms is one of the most needed aspects of designing a school. Students must have quality conditions that guarantee top performance of the students and visual comfort in the build environment. Therefore, daylight design of the classroom was particularly taken into consideration. Options for daylight strategy were developed and then calculated.

Option	Proposed modifications
Reference design	No modifications
Modified geometry of the building	Angle of the roof=from 30° to 20° Overhang on one side= from 1,2 to 0,7
Using vertical windows in the roof	3 x window 0,8 x 2m
Using transparent roof sheet	4 x transparent sheet 1x1,5 m

Tab. 15: Description of daylight option of classroom

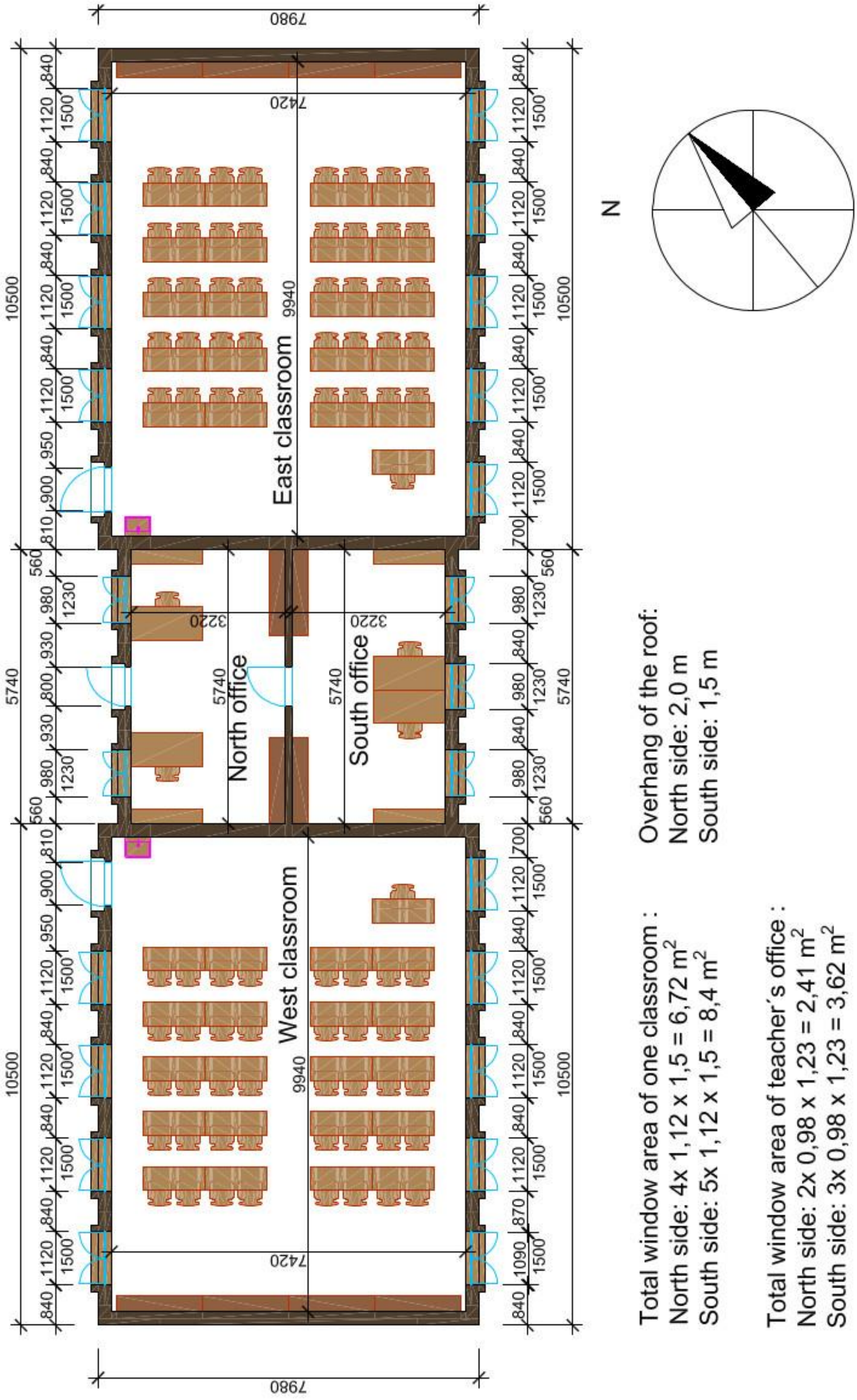
Calculation was done by software DIALux evo. This software provides a calculation of the Illimunance level and Daylight factor. The sky type can be calculated as overcast sky, average sky and clear sky. Standards used for calculation are all European ones and German DIN V 18599:2007. Figures presented here will be average Illuminance and average Daylight factor.

<u>Results of calculation using DIALux evo:</u>

Results of daylight calculation for overcast sky								
Option	East classroom		North office		South office		West classroom	
	Daylight factor [%]	Iluminance level [lx]	Daylight factor [%]	Iluminance level [lx]	Daylight factor [%]	Iluminance level [lx]	Daylight factor [%]	Iluminance level [lx]
Reference design	0,805	166	0,356	75,4	0,744	146	0,746	148
Modified geometry of the building	1,049	242	0,351	74,7	1,191	238	0,969	219
Using vertical windows in the roof	1,214	299	0,517	122	1,491	312	1,365	316
Using transparent roof sheet	3,252	586	2,138	360	2,161	377	3,035	533

Tab. 16: Results of classroom daylight calculation

Reference design:



Pic. 32: Reference design of classroom

6.1.5 Conclusion:

From the calculation for classrooms we can see that the solution with transparent roof sheets provides enough daylight for occupants' comfort. This solution will be used also in workshops, laboratory buildings, teachers' office building and sick bay. Report from software can be found at Annex 4.

6.2 Acoustics

To achieve a good study condition it is necessary to secure acoustic comfort in study areas and other important places. Rooms should have a low ambient noise level to ensure clear listening settings and enough insulation performance by inside walls to repel noise from other rooms' activities. Clear communication between students and the teacher is also an important aspect in the design.

6.2.1 Methodology and design standards:

Design method and calculations were developed using these documents.

Laws and regulations:

- EN ISO 717-1:2013; Acoustics -- Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation
- EN 12354-1:2000; Building acoustics. Estimation of acoustic performance in buildings from the performance of elements. Airborne sound insulation between rooms
- BS EN 12354-6:2003; Building acoustics. Estimation of acoustic performance of buildings from the performance of elements. Sound absorption in enclosed spaces
- EN 15251:2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
- ČSN 73 0532; Akustika - Ochrana proti hluku v budovách a posuzování akustických vlastností stavebních výrobků - Požadavky
- ČSN 73 0527; Akustika - Projektování v oboru prostorové akustiky - Prostory pro kulturní účely - Prostory ve školách - Prostory pro veřejné účely
- Regulamento Geral do Ruído; Decreto-Lei n.º 9/2007 (Portugal)

Design guidelines:

- (Acoustics of Schools: a design guide, 2015)

6.2.2 Design principles for acoustic comfort:

Airborne sound insulation:

Characteristics of the construction are how much they can reduce noises between two spaces. This value can be computed by calculation presented in the standard or measured in the acoustic laboratory.

Sound impact insulation:

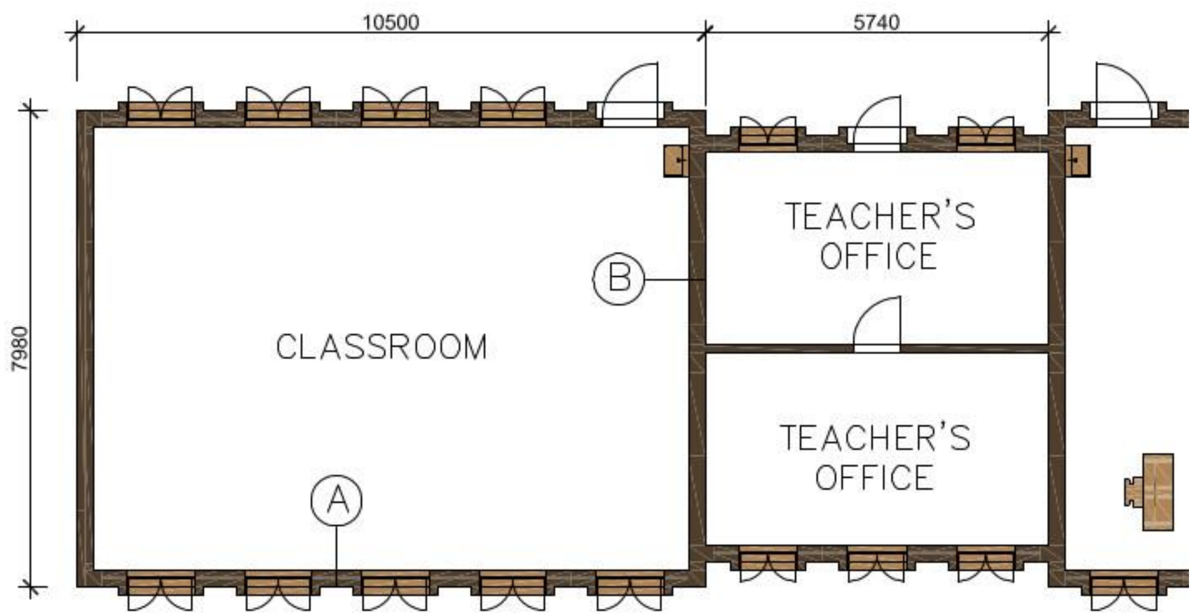
Considering the fact that all project buildings are one storey high, sound impact on insulation was not considered in the project. Reduction of noise level produced by rain is calculated in the part of this work dealing with the roof structure.

Room acoustic: acoustic of enclosed spaces:

A clear listening state for the students is main condition goal in classrooms. For the purpose of establishing a good speech condition for the teachers and of ensuring good listening for the students, reverberation time was computed for the classroom space.

6.2.3 Calculations:

Acoustic comfort in classrooms is one of the most important aspects of designing a school. Classrooms should be places where students are not disturbed by the outside environment and by activities from other rooms. Geometry of the rooms should be also considered to ensure that the spoken word will be easy to understand.



Pic. 33: Scheme of classroom building for acoustic calculation

6.2.3.1 Calculation of Airborne sound insulation:

Acoustic performance for the used construction material (ICEB) was computed in this publication (Simões, 2015) for a single layer wall of ICEB in the thickness of 140 mm. The mean value of $D_{nT,w}$ was measured on average at 26 dB. In our project we have walls made by double layer of ICEBs. In this case we must compute values for two constructions. One is the outside wall (sign A) and the other is the inside wall between two rooms with different activities (sign B). The following calculations are developed from Mass Law method from Mathias Meisser research done by António Thadeu and Diogo Mateus, from University of Coimbra. The final phase of the calculation was done by software Acoubat. More detailed information and results of the calculations can be found in Annex 5.

We can compare those values with the requirements of the legislation. For Zambia, I did find any specific requirements. Implementation of the European legislation in Portugal and in Czech we can see on the following table.

Type of structure	Airbourne sound insulation (dB)		
	Obtained value	Czech legislation	Portugal legislation
Outside wall	40	30	33
		Approve	Approve
Inside wall classroom house	50	47	49
		Approve	Approve

Tab. 17: Airborne sound insulation of structures in classroom

6.2.3.2 Calculation of Reverberation time

With this value we can measure the absorbing sound characteristic of the room. When the room is empty and surfaces are smooth, the time of reverberation gets higher and that causes communication discomfort in the buildings. For this calculation we are using methodology of Czech standard ČSN 73 0527, that is using both the Sabine and Eyring formula. The right value is determined by the ratio of reverberation time that must fit in the required ratio. The fime is measured for each frequency band (in our case one octave) and all values have to fulfil the requirements.

Calculation by:		f (Hz)					
		125	**250**	**500**	**1000**	**2000**	**4000**
Sabina	TS (s)	1,24	1,28	1,14	1,09	0,93	0,83
Eyring	TE (s)	**1,12**	**1,16**	**1,02**	**0,97**	**0,81**	**0,71**
	T0 (s)	**0,646749568**					
	TE/T0	**1,74**	**1,80**	**1,58**	**1,51**	**1,25**	**1,10**
$T_{limit, down}$ (s)		0,65	0,8	0,8	0,8	0,8	0,65
$T_{limit, upper}$ (s)		1,2	1,2	1,2	1,2	1,2	1,2
		NOT OK	NOT OK	NOT OK	NOT OK	NOT OK	OK
Resolution		**NOT APPROVED**					

Tab. 18: First calculation of reverberation time in classroom

The first calculation did not fulfil requirements done by standard. The reverberation time has too high values and it is not in the right ratio.

To improve acoustic performance, we must include some material that has a better absorption coefficient α. In conventional buildings there are special wall absorbers that can be placed on the ceiling of the walls to increase absorption of the sound. In our case, the selected material should be something that is available in our conditions. In my research, I came across a study concerning the use of reed as an absorption element. (Jiménez-Espada, 2010)

The absorption performance of reed is according to the following study:

Material with thickness:	Absorption coefficient in octave bands α (-)					
	Absorption coefficient in octave bands f (Hz)					
	125	**250**	**500**	**1000**	**2000**	**4000**
Reed 50 mm	0,25	0,43	0,92	0,66	0,65	0,69
Reed 100 mm	0,35	0,75	0,72	0,75	0,77	0,75

Tab. 19: First calculation of reverberation time in classroom

Results of the calculation with use of reed in thickness of 50 mm as an absorber in the ceiling in the 40 % area.

Sabina	TS (s)	0,87	0,88	0,68	0,75	0,68	0,62
Eyring	TE (s)	**0,75**	**0,76**	**0,56**	**0,63**	**0,56**	**0,50**
	T0 (s)	**0,65**					
	TE/T0	**1,16**	**1,17**	**0,86**	**0,97**	**0,87**	**0,77**
$T_{limit, down}$ (s)		0,65	0,8	0,8	0,8	0,8	0,65
$T_{limit, upper}$ (s)		1,2	1,2	1,2	1,2	1,2	1,2
		OK	OK	OK	OK	OK	OK
Resolution		**APPROVED**					

Tab. 20: Second calculation of reverberation time in classroom

The second calculation gives us results that are consistent with Czech standards. If we use reed to cover the whole area of the ceiling, we will reduce reverberation time, but put it out of range of standard demanded figures. More details are presented at Annex 5.

6.2.4 Conclusion:

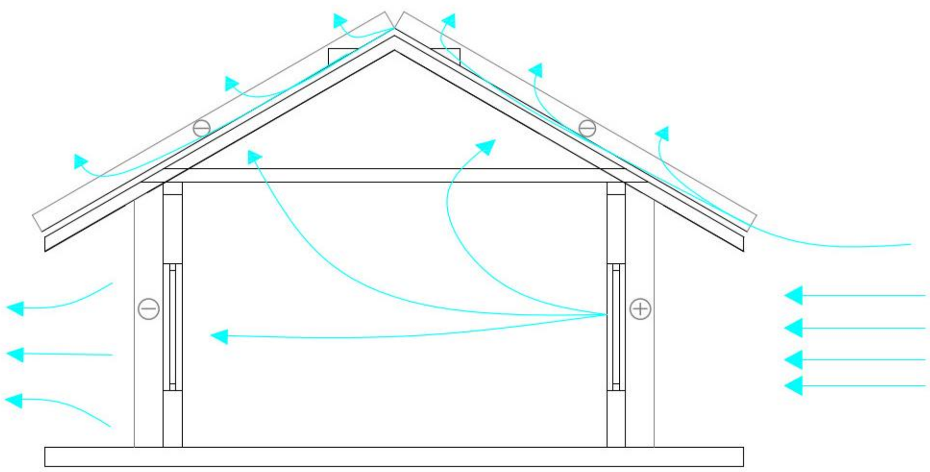
All main acoustic calculations were done to ensure acoustic comfort in the school buildings. The classroom was chosen to be the building for computing all characteristics. Airborne insulation of the inside and outside walls is sufficient. Reverberation time in the classroom is also consistent with standard according to which calculations were done.

6.3 Natural ventilation system

Ventilation provides a fresh air and changes temperature in the building. In the project we use two principles of natural ventilation.

6.3.1 Cross ventilation:

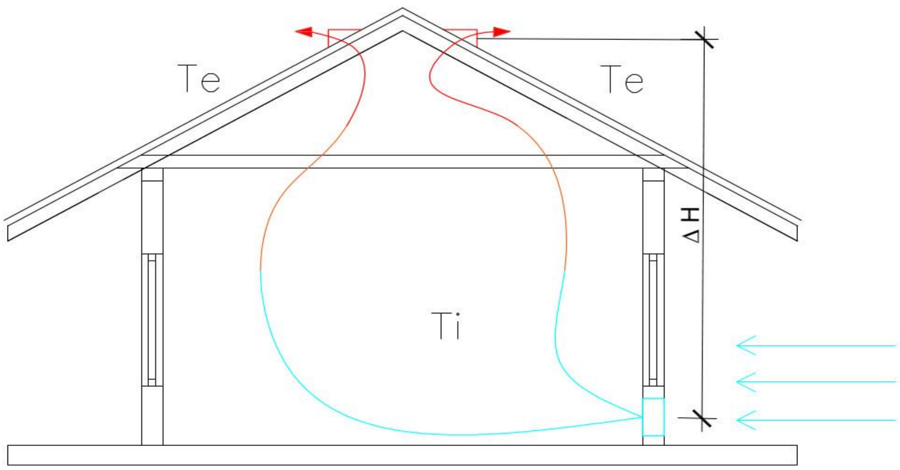
Cross ventilation is driven mainly by the wind, flowing through the building envelope and its openings. Wind flow creates a positive pressure on the windward side and negative pressure on the leeward side of the building. Difference of the pressure level creates air flow from the inlet opening to the outlet opening. The principle is demonstrated on pictu re 34.



Pic. 34: Cross ventilation diagram

6.3.2 Stack effect:

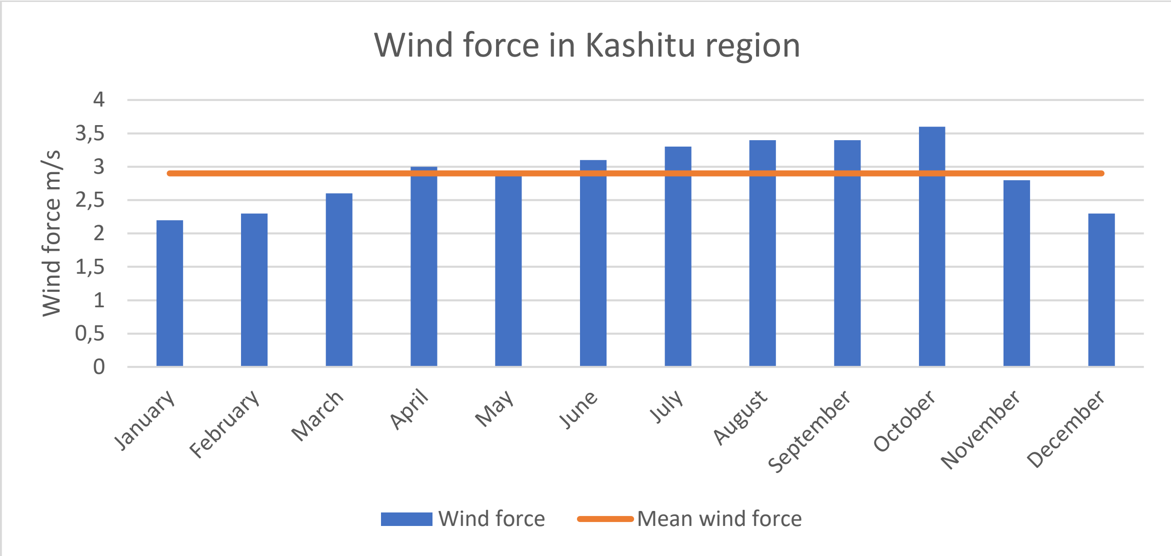
The stack effect uses a different height of the openings in the envelope and the difference of temperatures. When the inside temperature is higher (Ti) and the outside temperature is lower (Te), cold air goes to the interior from the lower placed openings and it goes to the outside environment from the upper placed openings. The efficiency is greater when the difference between temperatures and the height difference (ΔH) are larger. The principle is demonstrated on picture 35



Pic. 35: Stack effect diagram

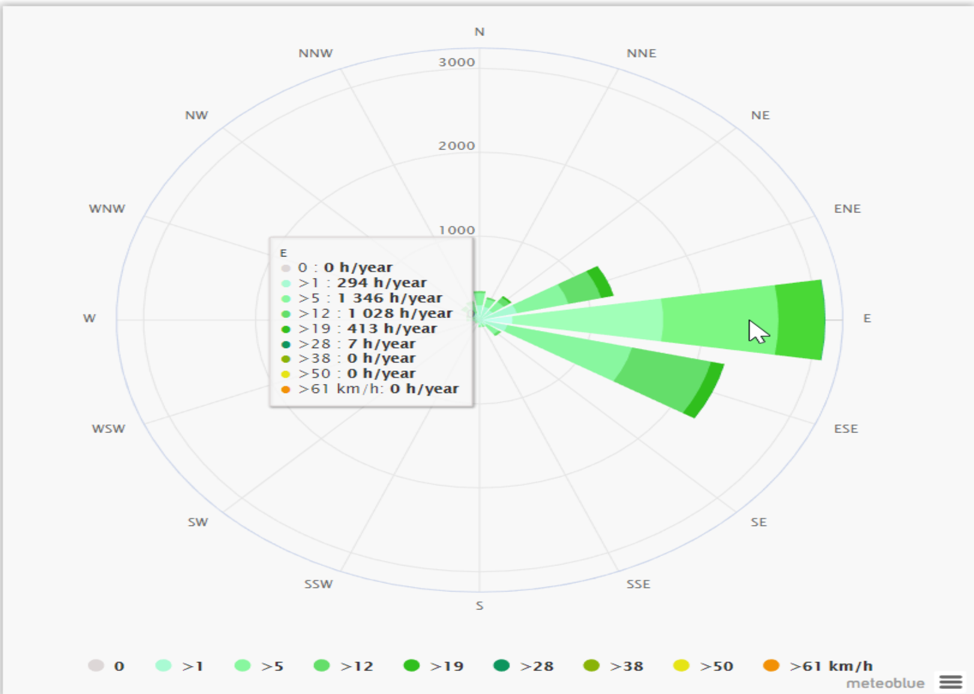
6.3.3 Wind force and direction:

When we want to use the environment of the locality, the wind is an important factor for the design. The wind can be used as a driving force for ventilation and for creating energy. Zambia and Kashitu locality are places that have good conditions for using wind as a driving force. Average month values of the wind speed are presented in the picture 36. The mean wind force for a year period is 2,9 m/s



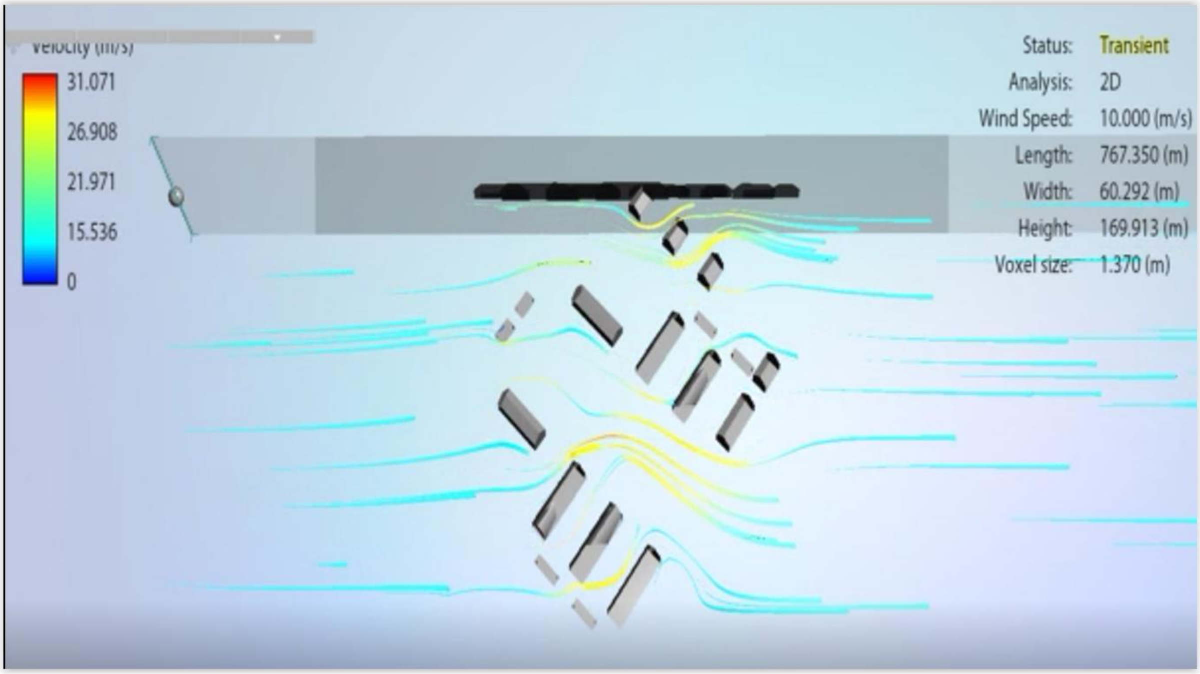
Pic. 36: Wind force values in Kashitu; Source Meteonorm data

Another important information is the direction of the wind. This information we can find at energy plus data from the meteorological station near our locality. In the case of Kashitu, we have a prevailing wind direction from the east and south-east. Picture 37 provides needed information about wind direction.

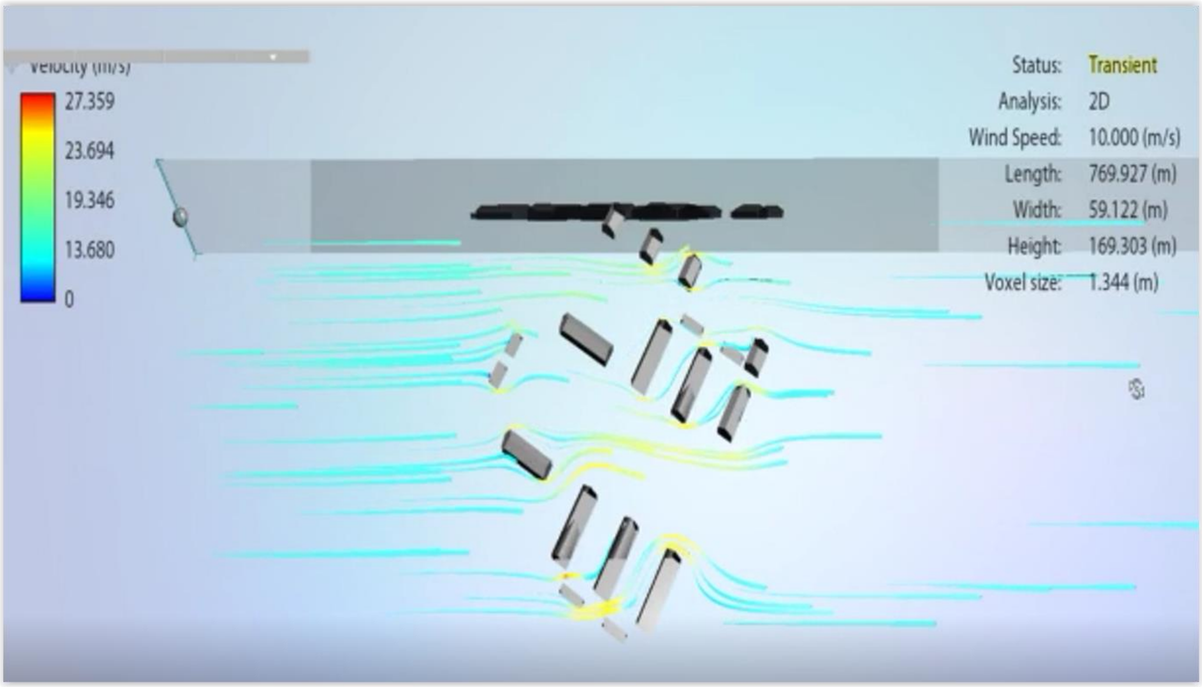


Pic. 37: Wind rose for Kashitu locality; Source: (Climate Kashitu, 2019)

When we know the prevailing wind direction, we can simulate how the buildings at the locality will be influenced by wind. The wind can improve our driving force of natural ventilation in the buildings. Therefore, we have to decide which side of the building is windward. For the simulation, Autodesk Flow Design software was used. On the picture 38 and picture 39 the reader can see the influence of the wind on the building on the east direction, resp. south-east direction.



Pic. 38: Influence of the wind in the east direction in Autodesk Flow Design



Pic. 39: Influence of the wind in the south-east direction in Autodesk Flow Design

6.3.4 Natural ventilation for indoor air quality:

Natural ventilation has one major function, which is to provide fresh air for a building's occupants. Especially for the residential building and buildings intended for education of the students, we have to take away all the pollutants that are decreasing comfort of the indoor environment. The pollutant that we must focus on the most is CO_2. According to all ventilation guidelines, we must keep the CO_2 concentration in certain limits during the day. An average day concentration limit is based on the following standards:

- According to the EN15251 is 1500 ppm.
- According to the ASHRAE standard 62.1.2010 is 1200 ppm.

The needed airflow rate for classroom was calculated in Annex 6.

There are other pollutants that needed to be taken care of. In the case of laboratories and the kitchen, simple HVAC system providing needed fresh air change will be installed according to the standard regulations. More about this topic can be seen in this document targeted to the education buildings. (Khatami, 2016)

The heating and cooling effect have their function according to the climate of the locality. On the graph of the mean month temperatures we can see that the main difference of the temperatures is at day-night period, not during the year period. That creates a possibility to use the ventilation also for cooling purposes. But for heating, natural ventilation is not an option, providing reasonable results. This matter will be described more thoroughly in the chapter about thermal comfort.

6.3.5 Conclusion

With the analysis of the wind condition in the locality, two systems of natural ventilation were designed. Also a limit of CO_2 was determined. By using the CFD software, the location of buildings in the locality was assessed to ensure wind access to the majority of them.

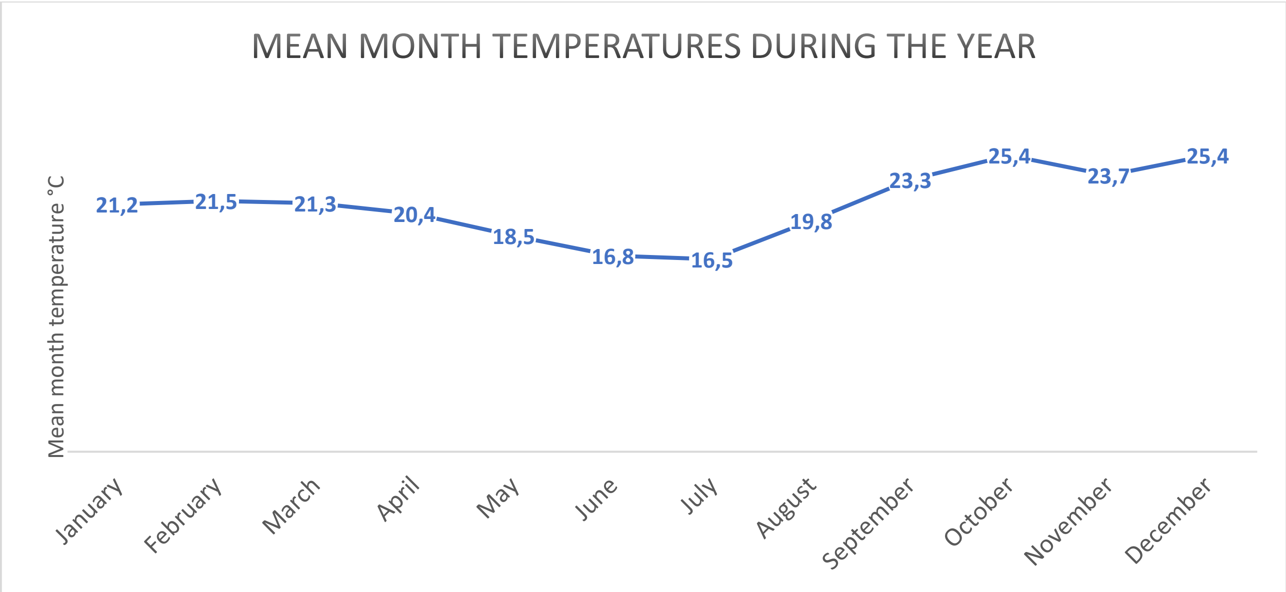
6.4 Thermal comfort

The last criterion of the inner build environment is thermal comfort. The buildings have to be prepared for thermal gains in the hot season and for the cold outside temperatures in the dry season. Temperatures should be stable during the school schedule and not disturb students, lowering their comfort and study performance.

For the evaluation of thermal comfort, we will follow ANSI/ASHRAE standard 55-2010: Thermal environmental conditions for human occupancy with assistance of EN 15251 standard. Each standard offers an evaluation method for the determination of a thermal comfort level. Considering the fact that in the building we use primarily natural ventilation, we will use the adaptive method of ASHRAE 55 with a prevailing mean outdoor temperature.

6.4.1 Determination of the critical period during the year.

For assessing the thermal comfort in the building we need to look at the temperature values during the year and the school schedule with its holidays. On the picture 40 we can see temperature values. The highest mean month temperature is in October and the lowest mean month temperature is in July.

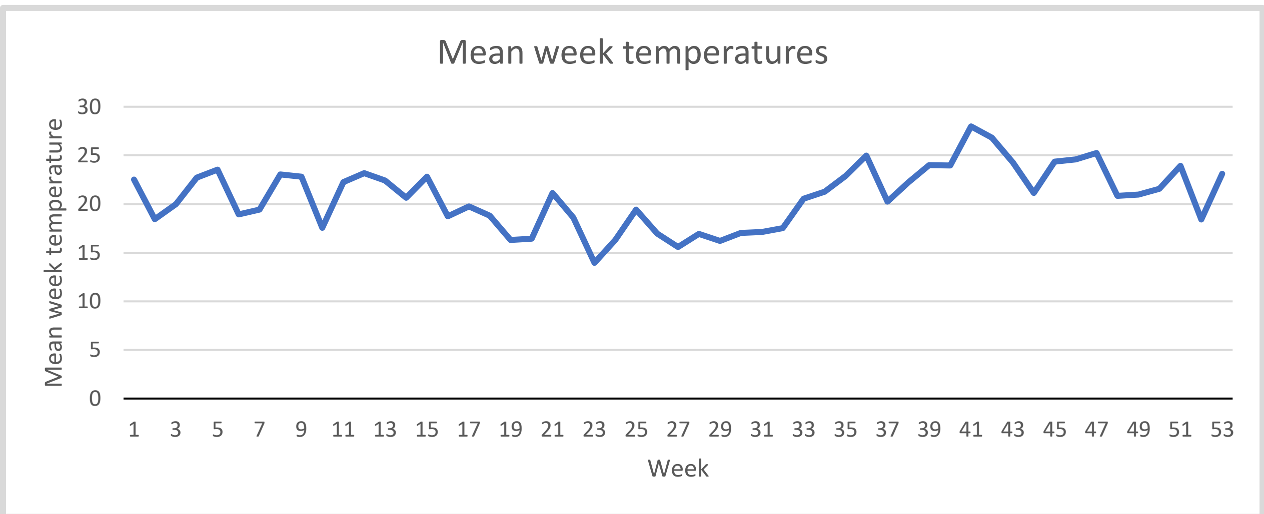


Pic. 40: Mean month temperatures; Source: Meteonorm data

For the following the methodology used in the standard ASHRAE 55, we have to estimate the prevailing mean outdoor temperature. The standard describes this value as:

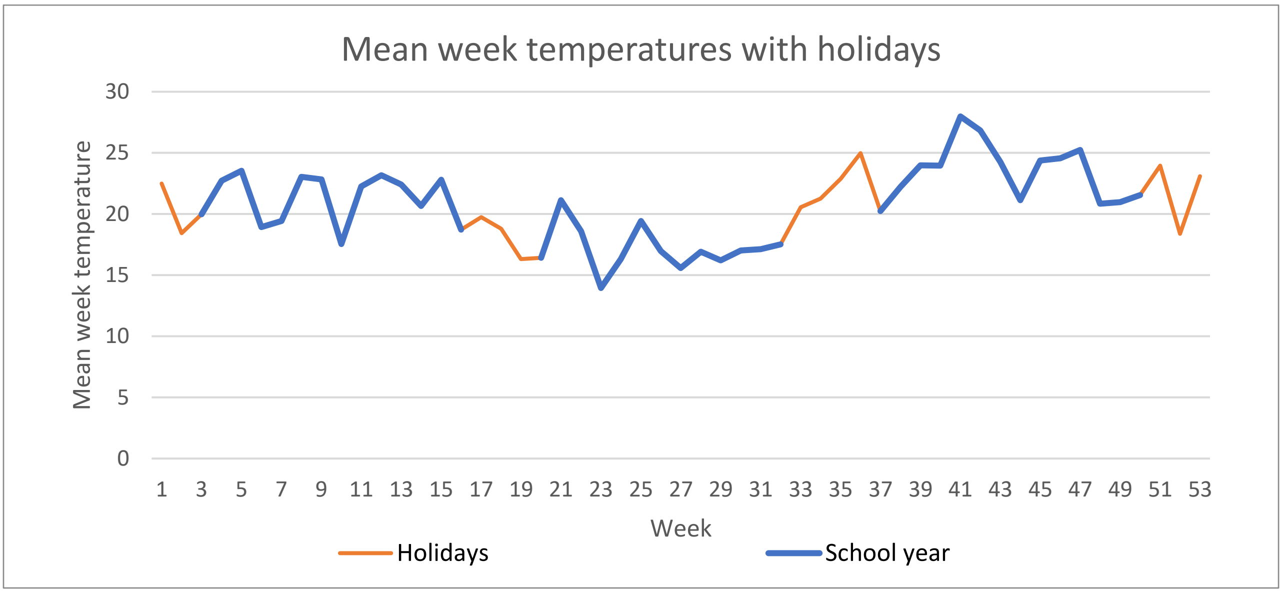
" the arithmetic average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question" (ASHRAE, 2010)

In our case, these values will be calculated for every week of the year. The results are shown on picture 41.



Pic. 41: Mean week temperatures; Source: Meteonorm data

This graph shows that values for the prevailing mean outside temperatures are significantly different from the month values. The minimum is at week 23 (3.6. – 9. 6) and the maximum is at week 41 (7-13. 10.). We can apply the school schedule and eliminate all weeks that are during the holiday period.



Pic. 42: Mean week temperatures with holidays; Source: Meteonorm data

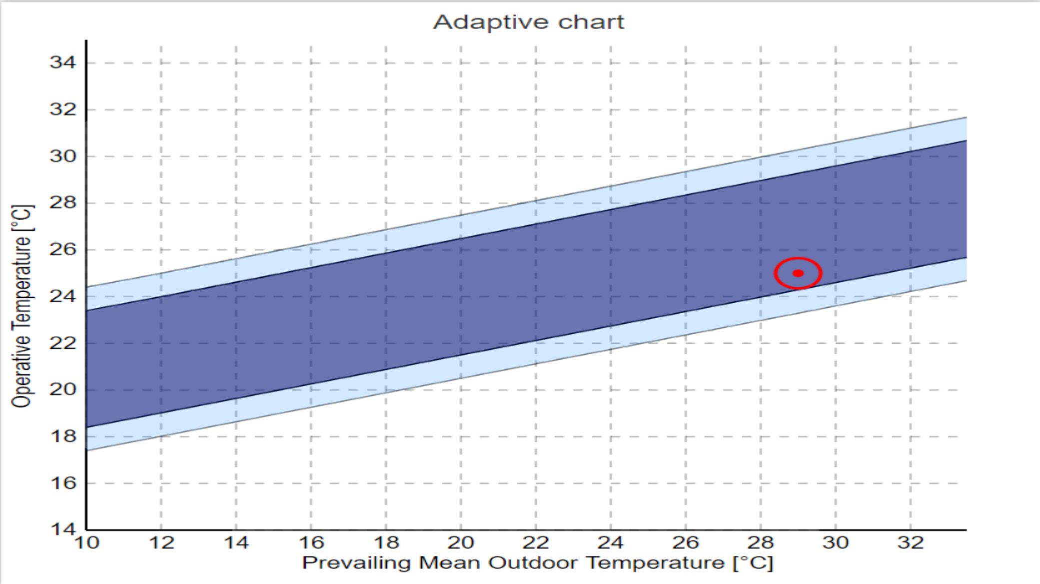
Holyday periods are not the period that has the maximum or minimum values of the temperature, so we can indicate critical weeks that we will be studying for the detailed thermal comfort assessment.

For the cold period it will be the 23. week with prevailing mean temperature of 13,95°C

For the hot period it will be the 41. week with prevailing mean temperature of 27,98°C

6.4.2 Detailed thermal comfort assessment

For the values defining comfortable values of indoor temperatures, we will use the adaptive method of ASHRAE 55. Graphical interpretation of the tool is shown on picture 43.



Pic. 43: Chart of the Adaptive method of ASHRAE 55 standard; Source: (Hoyt, 2017)

The dark blue area of the chart shows values of the temperature for 90 % of acceptability. The light blue is an area for 80% of acceptability for occupants comfort.

Values of operative temperature can be in hourly values or for slightly longer periods of time (morning, afternoon). In our case we will use hour values obtained from the DesignBuilder software. Values will be for the following day of the week that we calculated as the prevailing mean outdoor temperature.

For the cold period: 23. week (3-9. 6.) = critical day will be 10.6.

For the hot period: 41. week (7-13. 10.) = critical day will be 14.10.

For these days there will be a table with an inside temperature for the hour period, with the effect of all systems designed to the buildings. These are:

- Thermal gain by openings
- Shading
- Ventilation
- Heat capacity
- HVAC system

The building will improve standards, if the values of temperature in the scheduled time of the school operation will be in the limits of 80% of acceptability. The ASHRAE 55 standard allows operation temperatures to be outside limits for short period of time.

6.4.3 Calculation for classroom

Calculation for hot period, critical day 14.10. prevailing mean outdoor temperature 28,54 °C											
Time	**Outside temperature**	**Inside temperature**	**Wind speed**	**Window coefficient**	**Airflow rate cross ventilation**	**Openings control**	**Airflow rate stack effect**	**Total airflow rate**	**Indoor operative temperature**	**Thermal comfort**	
t [h]	*Te* [°C]	*Ti* [°C]	w [m/s]	ξ [-]	*n* [1/h]	ψ [-]	*n* [1/h]	*n* [1/h]	*To* [°C]	Limits for 90% acceptability	Limits for 80% acceptability
1	25,93	27,37	3,6	0,75	5,4	1,0	1,8	5,7	27,09	TRUE	TRUE
2	24,40	26,78	3,6	0,75	5,4	1,0	2,3	5,9	26,67	TRUE	TRUE
3	22,80	26,16	3,6	0,75	5,4	1,0	2,7	6,1	26,13	TRUE	TRUE
4	21,73	25,56	3,6	0,75	5,4	1,0	3,0	6,2	25,56	TRUE	TRUE
5	20,90	24,99	3,6	0,75	5,4	1,0	3,1	6,3	25,01	TRUE	TRUE
6	20,25	24,45	3,6	0,75	5,4	1,0	3,2	6,3	24,47	TRUE	TRUE
7	20,10	23,98	3,6	0,75	5,4	1,0	3,1	6,2	24,04	FALSE	TRUE
8	21,45	24,03	3,6	0,45	3,3	1,0	2,5	4,1	24,14	TRUE	TRUE
9	23,78	24,38	3,6	0,45	3,3	1,0	1,2	3,5	24,46	TRUE	TRUE
10	26,35	25,04	3,6	0,45	3,3	0,0	0,0	3,3	25,08	TRUE	TRUE
11	28,88	26,02	3,6	0,45	3,3	0,0	0,0	3,3	26,03	TRUE	TRUE
12	31,15	27,36	3,6	0,45	3,3	0,0	0,0	3,3	27,26	TRUE	TRUE
13	32,98	28,60	3,6	0,45	3,3	0,0	0,0	3,3	28,46	TRUE	TRUE
14	34,38	29,63	3,6	0,45	3,3	0,0	0,0	3,3	29,51	FALSE	TRUE
15	35,23	30,56	3,6	0,45	3,3	0,0	0,0	3,3	30,42	FALSE	FALSE
16	35,63	31,21	3,6	0,45	3,3	0,0	0,0	3,3	31,08	FALSE	FALSE
17	35,40	31,57	3,6	0,75	5,4	0,0	0,0	5,4	31,43	FALSE	FALSE
18	34,48	31,54	3,6	0,75	5,4	0,0	0,0	5,4	31,39	FALSE	FALSE
19	32,85	31,21	3,6	0,75	5,4	0,0	0,0	5,4	31,07	FALSE	FALSE
20	31,13	30,76	3,6	0,75	5,4	0,0	0,0	5,4	30,61	FALSE	FALSE
21	29,80	30,26	3,6	0,75	5,4	1,0	0,9	5,5	30,12	FALSE	FALSE
22	28,68	29,77	3,6	0,75	5,4	1,0	1,5	5,6	29,63	FALSE	TRUE
23	27,50	29,17	3,6	0,75	5,4	1,0	1,8	5,7	29,07	TRUE	TRUE
24	26,30	28,57	3,6	0,75	5,4	1,0	2,1	5,9	28,50	TRUE	TRUE

Tab. 21: Calculation for hot period, critical day 14.10.

The hot period is consistent with standard requirements, because the standard allowed for a small period of time had higher temperature values than required.

Calculation for cold period, critical day 10.6. prevailing mean outdoor temperature 13,94 °C											
Time	Outside temperature	Inside temperature	Wind speed	Window coefficient	Airflow rate cross ventilation	Openings control	Airflow rate stack effect	Total airflow rate	Indoor operative temperature	Thermal comfort	
t [h]	*Te* [°C]	*Ti* [°C]	w [m/s]	ξ [-]	*n* [1/h]	ψ [-]	*n* [1/h]	*n* [1/h]	*To* [°C]	Limits for 90% acceptability	Limits for 80% acceptability
1	10,25	16,14	3,1	0,00	0,0	0,0	0,0	0,0	16,26	FALSE	FALSE
2	9,40	15,56	3,1	0,00	0,0	0,0	0,0	0,0	15,69	FALSE	FALSE
3	8,53	14,98	3,1	0,00	0,0	0,0	0,0	0,0	15,14	FALSE	FALSE
4	7,63	14,40	3,1	0,00	0,0	0,0	0,0	0,0	14,55	FALSE	FALSE
5	7,10	13,83	3,1	0,00	0,0	0,0	0,0	0,0	13,98	FALSE	FALSE
6	6,63	13,30	3,1	0,00	0,0	0,0	0,0	0,0	13,45	FALSE	FALSE
7	6,28	12,82	3,1	0,00	0,0	0,0	0,0	0,0	12,97	FALSE	FALSE
8	6,20	12,41	3,1	0,50	3,1	0,0	0,0	3,1	12,57	FALSE	FALSE
9	8,15	12,36	3,1	0,50	3,1	0,0	0,0	3,1	12,50	FALSE	FALSE
10	11,05	12,77	3,1	0,50	3,1	0,0	0,0	3,1	12,89	FALSE	FALSE
11	13,98	13,65	3,1	0,50	3,1	0,0	0,0	3,1	13,71	FALSE	FALSE
12	16,58	14,80	3,1	0,50	3,1	0,0	0,0	3,1	14,77	FALSE	FALSE
13	18,78	15,77	3,1	0,50	3,1	0,0	0,0	3,1	15,77	FALSE	FALSE
14	20,35	16,85	3,1	0,50	3,1	0,0	0,0	3,1	16,86	FALSE	FALSE
15	21,30	17,90	3,1	0,50	3,1	0,0	0,0	3,1	17,92	FALSE	FALSE
16	21,65	18,85	3,1	0,50	3,1	0,0	0,0	3,1	18,88	FALSE	TRUE
17	21,25	19,57	3,1	0,00	0,0	0,0	0,0	0,0	19,55	FALSE	TRUE
18	19,98	19,52	3,1	0,00	0,0	0,0	0,0	0,0	19,50	FALSE	TRUE
19	18,03	18,92	3,1	0,00	0,0	0,0	0,0	0,0	18,92	FALSE	TRUE
20	16,75	18,43	3,1	0,00	0,0	0,0	0,0	0,0	18,49	FALSE	FALSE
21	15,75	18,08	3,1	0,00	0,0	0,0	0,0	0,0	18,14	FALSE	FALSE
22	14,68	17,67	3,1	0,00	0,0	0,0	0,0	0,0	17,75	FALSE	FALSE
23	13,65	17,24	3,1	0,00	0,0	0,0	0,0	0,0	17,33	FALSE	FALSE
24	12,65	16,78	3,1	0,00	0,0	0,0	0,0	0,0	16,88	FALSE	FALSE

Tab. 22: Calculation for cold period, critical day 10.6.

In the calculation we can see that this critical day has very low indoor temperature and can be following ASHRAE standard requirements. We will assess another week to se, how the inside temperature will change.

Calculation for cold period, critical day 8.7. prevailing mean outdoor temperature 15,59 °C											
Time	Outside temperature	Inside temperature	Wind speed	Window coefficient	Airflow rate cross ventilation	Openings control	Airflow rate stack effect	Total airflow rate	Indoor operative temperature	Thermal comfort	
t [h]	*Te* [°C]	*Ti* [°C]	w [m/s]	ξ [-]	*n* [1/h]	ψ [-]	*n* [1/h]	*n* [1/h]	*To* [°C]	Limits for 90% acceptability	Limits for 80% acceptability
1	13,68	18,14	3,1	0,00	0,0	0,0	0,0	0,0	18,22	FALSE	FALSE
2	12,73	17,58	3,1	0,00	0,0	0,0	0,0	0,0	17,68	FALSE	FALSE
3	11,75	17,05	3,1	0,00	0,0	0,0	0,0	0,0	17,16	FALSE	FALSE
4	10,75	16,48	3,1	0,00	0,0	0,0	0,0	0,0	16,61	FALSE	FALSE
5	10,13	15,93	3,1	0,00	0,0	0,0	0,0	0,0	16,07	FALSE	FALSE
6	9,63	15,40	3,1	0,00	0,0	0,0	0,0	0,0	15,55	FALSE	FALSE
7	9,20	14,89	3,1	0,00	0,0	0,0	0,0	0,0	15,04	FALSE	FALSE
8	9,18	14,44	3,1	0,50	3,1	0,0	0,0	3,1	14,59	FALSE	FALSE
9	11,08	14,33	3,1	0,50	3,1	0,0	0,0	3,1	14,47	FALSE	FALSE
10	14,10	14,73	3,1	0,50	3,1	0,0	0,0	3,1	14,86	FALSE	FALSE
11	17,23	15,59	3,1	0,50	3,1	0,0	0,0	3,1	15,67	FALSE	FALSE
12	20,10	16,79	3,1	0,50	3,1	0,0	0,0	3,1	16,76	FALSE	FALSE
13	22,45	17,96	3,1	0,50	3,1	0,0	0,0	3,1	17,89	FALSE	FALSE
14	24,20	18,98	3,1	0,50	3,1	0,0	0,0	3,1	18,97	FALSE	FALSE
15	25,35	20,09	3,1	0,50	3,1	0,0	0,0	3,1	20,09	FALSE	TRUE
16	25,90	21,13	3,1	0,50	3,1	0,0	0,0	3,1	21,13	TRUE	TRUE
17	25,63	21,98	3,1	0,00	0,0	0,0	0,0	0,0	21,93	TRUE	TRUE
18	24,45	22,15	3,1	0,00	0,0	0,0	0,0	0,0	22,06	TRUE	TRUE
19	22,38	21,67	3,1	0,00	0,0	0,0	0,0	0,0	21,58	TRUE	TRUE
20	20,98	21,24	3,1	0,00	0,0	0,0	0,0	0,0	21,22	TRUE	TRUE
21	19,88	20,93	3,1	0,00	0,0	0,0	0,0	0,0	20,90	TRUE	TRUE
22	18,78	20,54	3,1	0,00	0,0	0,0	0,0	0,0	20,53	TRUE	TRUE
23	17,75	20,12	3,1	0,00	0,0	0,0	0,0	0,0	20,13	TRUE	TRUE
24	16,68	19,62	3,1	0,00	0,0	0,0	0,0	0,0	19,67	FALSE	TRUE

Tab. 23: Calculation for cold period, critical day 8.7.

The critical day for another week also is not consistent with the ASHRAE 55 standard. We will continue with our calculation for another week.

Calculation for cold period, critical day 22.7. prevailing mean outdoor temperature 16,20 °C											
Time	Outside temperature	Inside temperature	Wind speed	Window coefficient	Airflow rate cross ventilation	Openings control	Airflow rate stack effect	Total airflow rate	Indoor operative temperature	Thermal comfort	
t [h]	*Te* [°C]	*Ti* [°C]	w [m/s]	ξ [-]	*n* [1/h]	ψ [-]	*n* [1/h]	*n* [1/h]	*To* [°C]	Limits for 90% acceptability	Limits for 80% acceptability
1	21,08	22,57	3,1	0,00	0,0	0,0	0,0	0,0	22,53	TRUE	TRUE
2	19,60	22,12	3,1	0,00	0,0	0,0	0,0	0,0	22,12	TRUE	TRUE
3	18,08	21,64	3,1	0,00	0,0	0,0	0,0	0,0	21,68	TRUE	TRUE
4	16,58	21,13	3,1	0,00	0,0	0,0	0,0	0,0	21,21	TRUE	TRUE
5	15,60	20,61	3,1	0,00	0,0	0,0	0,0	0,0	20,71	TRUE	TRUE
6	14,80	20,11	3,1	0,00	0,0	0,0	0,0	0,0	20,23	TRUE	TRUE
7	14,23	19,63	3,1	0,00	0,0	0,0	0,0	0,0	19,76	FALSE	TRUE
8	14,10	19,23	3,1	0,50	3,1	0,0	0,0	3,1	19,37	FALSE	TRUE
9	15,83	19,11	3,1	0,50	3,1	0,0	0,0	3,1	19,25	FALSE	TRUE
10	18,50	19,41	3,1	0,50	3,1	0,0	0,0	3,1	19,54	FALSE	TRUE
11	21,23	20,16	3,1	0,50	3,1	0,0	0,0	3,1	20,23	TRUE	TRUE
12	23,70	21,18	3,1	0,50	3,1	0,0	0,0	3,1	21,17	TRUE	TRUE
13	25,80	22,22	3,1	0,50	3,1	0,0	0,0	3,1	22,16	TRUE	TRUE
14	27,43	23,19	3,1	0,50	3,1	0,0	0,0	3,1	23,12	TRUE	TRUE
15	28,48	24,11	3,1	0,50	3,1	0,0	0,0	3,1	24,03	TRUE	TRUE
16	28,93	24,97	3,1	0,50	3,1	0,0	0,0	3,1	24,90	TRUE	TRUE
17	28,70	25,67	3,1	0,00	0,0	0,0	0,0	0,0	25,58	FALSE	TRUE
18	27,70	25,80	3,1	0,00	0,0	0,0	0,0	0,0	25,67	FALSE	TRUE
19	25,98	25,27	3,1	0,00	0,0	0,0	0,0	0,0	25,16	FALSE	TRUE
20	24,45	24,80	3,1	0,00	0,0	0,0	0,0	0,0	24,75	TRUE	TRUE
21	23,05	24,41	3,1	0,00	0,0	0,0	0,0	0,0	24,37	TRUE	TRUE
22	21,65	23,92	3,1	0,00	0,0	0,0	0,0	0,0	23,90	TRUE	TRUE
23	20,25	23,44	3,1	0,00	0,0	0,0	0,0	0,0	23,42	TRUE	TRUE
24	18,93	22,83	3,1	0,00	0,0	0,0	0,0	0,0	22,85	TRUE	TRUE

Tab. 24: Calculation for cold period, critical day 22.7.

6.4.4 Conclusion

The hot season results are consisting with the adaptive method. Two hours in the end of the day can be taken as a short time of discomfort. In the cold period we have two weeks of discomfort, during which temperatures are very low. Therefore, a heating system for this purpose should be found.

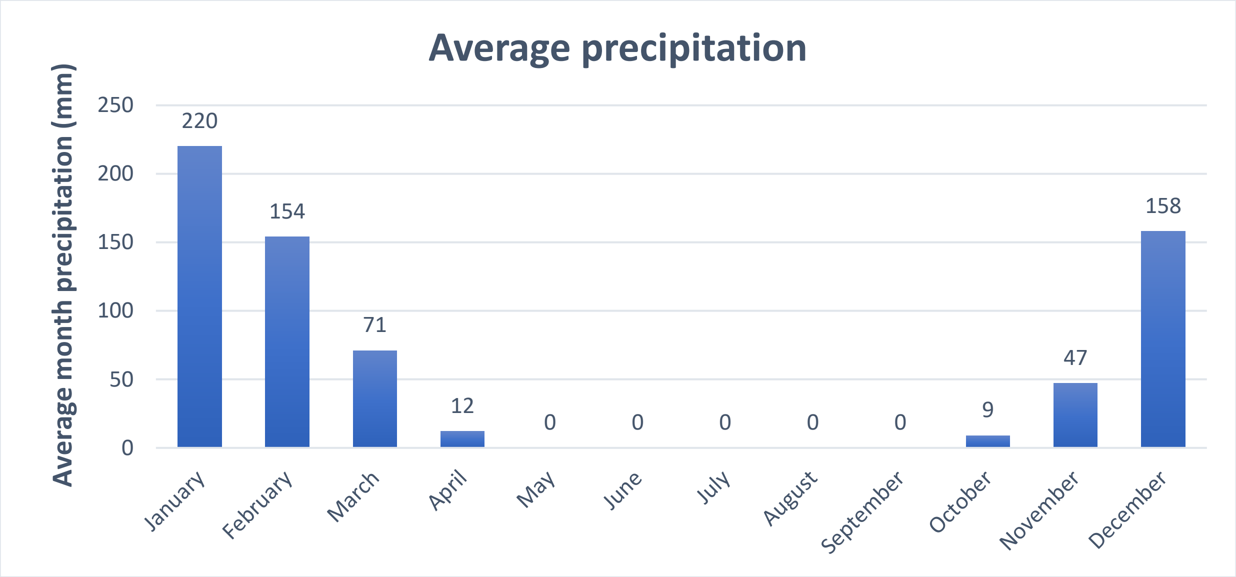
6.5 Conclusion of the chapter

The inner build environment is a key component of the design and it should not be underestimated. The daylight design was developed by initial construction rules and the detailed calculation was done by DIALux evo software. A solution with transparent roof sheets was found as ideal to ensure needed visual comfort. Acoustics calculation for the designed construction system was done and the airborne insulation of the structures and the reverberation time are consistent with European legislation of mentioned countries. Two systems of natural ventilation were developed and a critical limit of carbon dioxide was determined. Thermal comfort was examined by the adaptive method of the ASHRAE 55 standard. The condition in the classroom was found optimal in the hot season, but in the cold season, two weeks contradicted standard requirements.

7 Building service systems

7.1 Water supply system

If we look at the graph of the precipitation during the year, we can divide the year into the different weather periods.



Pic. 44: Month average precipitation; Source: Meteonorm data

For five months in the year there is almost no rainfall that would provide water to the soil. Furthermore, ground water sources are drying out in this time and obtaining water from them is more complicated. In this case it is necessary to reuse water as much as possible to safe water resources in the soil. We can also assume that we will need less water in the time of school holidays.

School holiday are:

- After 1. term 23.4. – 11.5.
- After 2. term 13.8. – 7.9.
- After 3. term 10.12. – 11.1.

Two of these holidays help us reduce the need of a water source. Especially holidays in August and September are in the time in which water is really missing in the land.

To consider all those aspects, we need a system that will combine both water sources and design them in a way that they can complement each other.

Water from land surface will be provided by boreholes, creating a reliable source of water for the school and residential buildings. Another system will be rainwater harvesting from the roof surface with accumulation tanks that will store drinking water. The last part will be the water reuse treatment of greywater, which allows returning this type of water to the water supply system.

All parts will be cooperating to ensure that all the water will be used in the most managing way for its preservation and good use.

7.1.1 Borehole wells

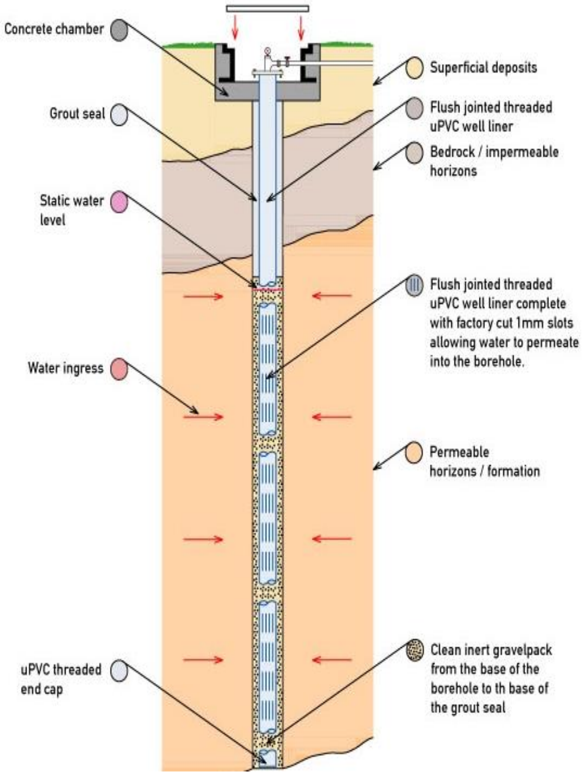
There are several ways to create a groundwater source. The simplest way is a hand well. These wells are only a few meters deep, created by hand tools or basic machinery. They are built in places with high levels of water in the soil, mostly near natural water places like rivers or the likes. The next solution are shallow wells that can be several tenths of meters deep. They are built with basic drilling machinery. The work is faster and safer. Additionally, water reserves in the holes are more stable and usually this type of wells is more reliable. (Wells in Africa, 2019)

The last common option is drilling a borehole. Boreholes need specialised machinery and staff for creating a reliable source of drinking water. The depth can be more than one hundred meters. Water comes from the aquifers in the low layers of the soil. The yield of the borehole well depends on the depth of the borehole and the reservoir volume of the aquifer in the ground. For drilling a borehole, you need a specialised design and procedure considering hydrogeological data from the locality. Wells water flow is usually powered by handpum, that is a part of the borehole construction. An example of the borehole cross section can be found on picture 45.

In Kashitu locality, more than five boreholes were drilled. In our last visit of the locality most of them were fully functional and one was being repaired. Boreholes must be properly maintained. If maintenance is regular, the lifespan is around 20 years. In South African standards and guidelines we can find that the yield should be more then 0,5 l/s, otherwise utilisation is recommended (Hobbs, 1997)

Guidelines concerning Zambia state that the minimum yield is specified to the value of 0,2 l/s (Armstrong, 2009). More information is also available in the UNICEF guidelines (UNICEF/Skat Foundation, 2016).

To the borehole is usually added a water pump, a water treatment unit and an accumulation tank. The water pump can be hand-powered or powered by diesel or an electrical engine. If the water has too many pollutants, the water must be treated in the treatment unit, mostly by using filters. Afterwards the water is collected in the water accumulation tank. Tanks are usually situated in the platform built a few dozen meters up ground level. This solution provides water pressure to use inside the buildings.



Pic. 45: Borehole cross section; Source: (Crisp, 2016)

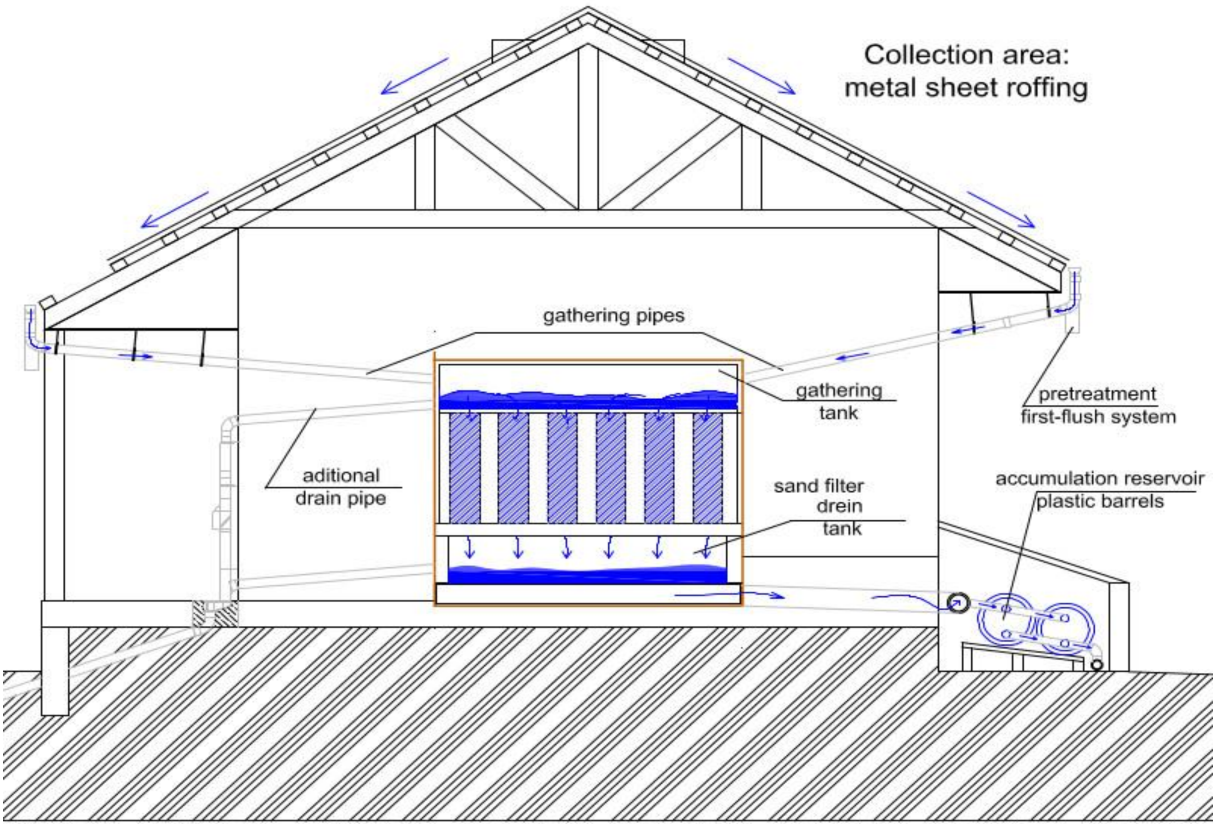
To design a borehole with full equipment, a specialised company with experience of realizing a boreholes project in the locality is needed. In Kashitu, the construction of boreholes with all components was done by the organisation Fountains of life e. v. More information can be seen on their website (Fountation of life, 2018)

7.1.2 Rainwater harvesting system

The second solution has the main goal to add another water source from the rain precipitation. Harvesting water for drinking purposes is usually quite difficult without complex mechanical or chemical treatment. Designing a system of water harvesting is very simple and a maintenance process is also not difficult to establish a targeted quality of water resource.

7.1.2.1 Overview of the system:

The Area where the falling water will be collected is metal sheet roofing on the selected buildings. Metal sheet is the ideal material for water harvesting thanks to its smooth covering and easy maintenance ability. Rainwater is collected at the eaves channel and goes through a pipeline to the mechanical pre-treatment. The first amount of collected rainwater is usually polluted by sand and other particles from the roof covering. Eaves channels can be also polluted, thus the first water amount must be led away. This is done by the first flush system based under the eaves channels. After water passes this section, it goes through gathering pipes to the gathering tank. Water is cumulated here and afterwards goes into individual units of the sand filter. If there is too much water in an accumulation tank, a safety drain pipe will take away the excess water. Separate units of the sand filter can be removed and cleaned. In the sand filter, there are several layers of the sand and gravel that clean the water from all the pollutants. From the sand filter water goes to the gathering tank and through pipes to the accumulation reservoir. Here, the water is stored in plastic barrels and it is ready to be used. Thanks to water pumps, the water comes through all the barrels and does not remain still.

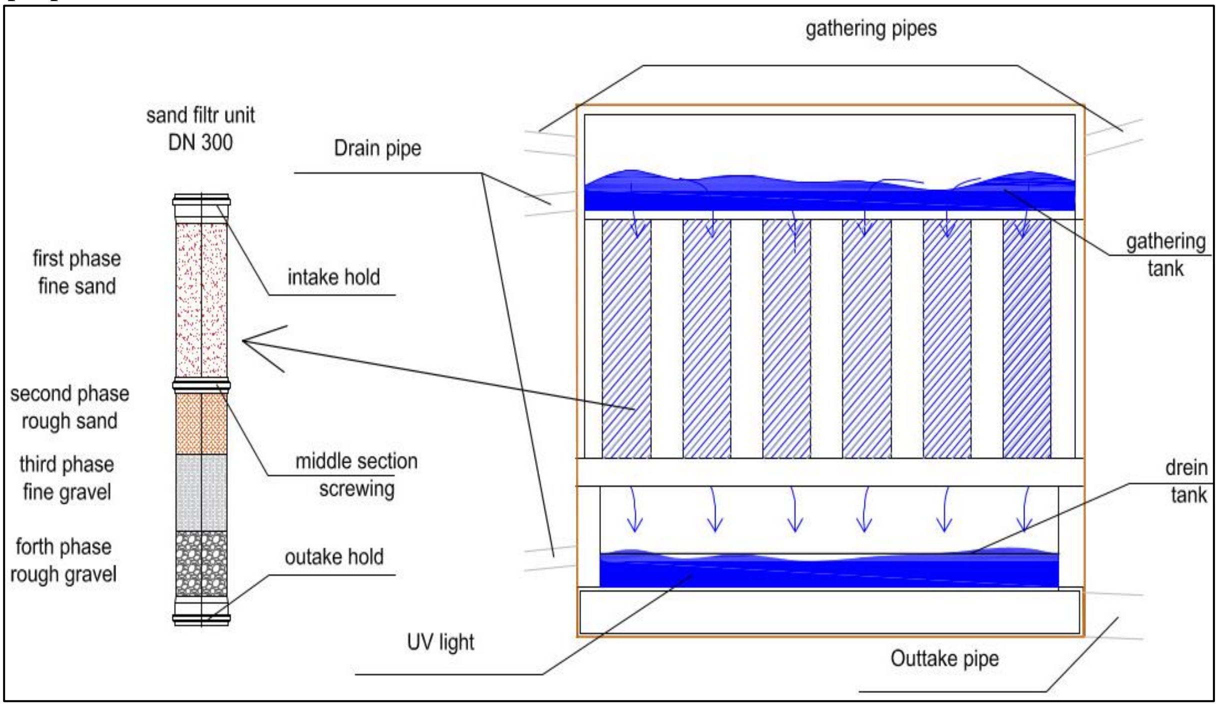


Pic. 46: Water harvesting system overview

7.1.2.2 Sand filter

The filter is composed of two tanks that collect water and sand filter units. The tanks are made of plastic and both have safety features. When the water level in the tank is so high to almost cause overflowing, additional drain pipes are designed to get out the overwhelming water. Sand filter units contain four different fractions of gravel and sand, placed in plastic pipes DN 300. The water flows through the upper layer, where the sand is finest and goes to lower layers, where the sand is rougher. After the sand follows gravel and the water leaves the unit filtrated and clean. The upper part of the unit is removable, because this part of the unit is the most clogged by pollutants. All parts of the unit can be replaced and cleaned.

To ensure biological cleaning and destroying all organic pathogens, a UV lamp is placed in the drain tank. UV light will periodically clean the water coming inside the tank. By this procedure, all pollutants in the water are cleaned and the water can be used for drinking purposes.

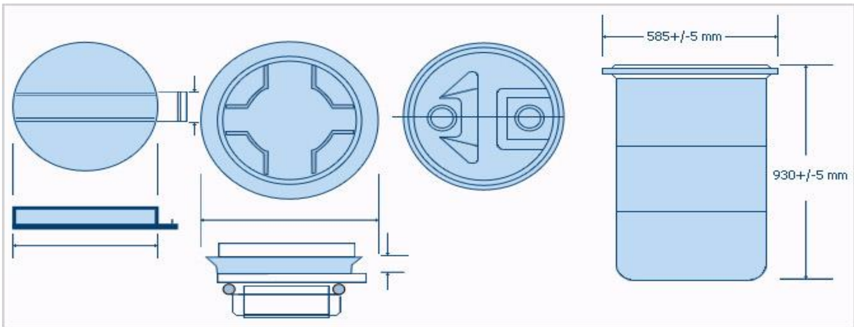


Pic. 47: Sand filter

The sand filter is set up by separate units from plastic pipes DN 300. These pipes are removable from the gathering and drain tank. Units of the filter are filled with four fractions of gravel and sand. The water flows through the first layer, where the sand is finest to the low layer, where the gravel is rough. By this procedure all pollutants in the water are taken away. Pollutants are organic substances, sand particles etc. The upper part of the unit is removable, because this part is the most clogged by pollutants.

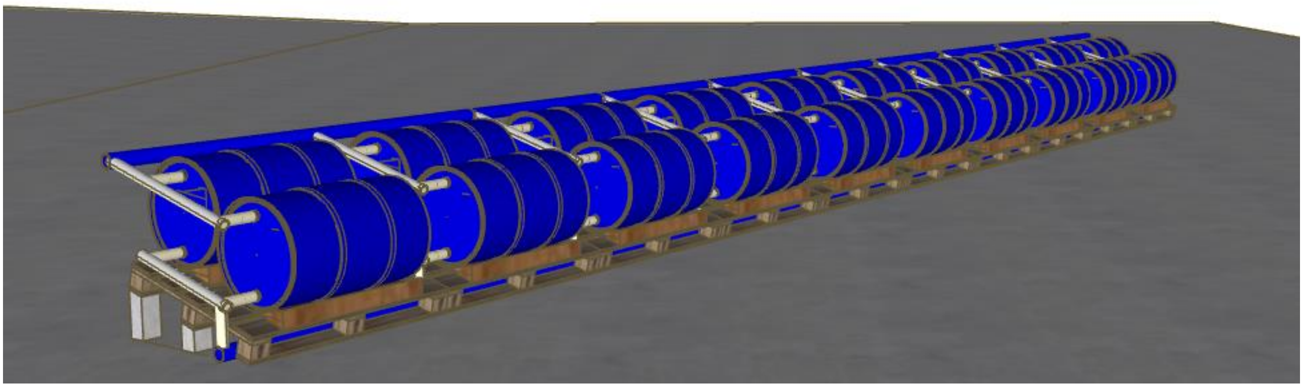
7.1.2.3 Accumulation reservoir

An important element of the design is the water reservoir. It has to be big enough to absorb the incoming amount of water in the wet season and should be good to maintain and easy to use. Other requirements suggest that the reservoir should be covered from the exterior environment because of the mosquito hazard. The water inside should be protected from direct sun radiation. The water in the reservoir has to be always in move, a still condition contributes to the corruption of the water quality.



Pic. 48: Plastic barrels dimensions; Source: (200 Litre L - Ring Drum, 2008)

The accumulation reservoir is made of 200l plastic barrels that are connected between each other by intake and outtake pipes. Clean water comes from the sand filter and fills all barrels constantly by the same amount of water. If there is a need for the water, the pump will bring water through all the barrels at the same time. Therefore, the water in the barrels is usually not still. The barrels can be disconnected from intake and outtake pipeline. Then, they can be transported, removed and cleaned. The barrels are at a shaded and ventilated place that helps the water to have better conditions and takes longer time to spoil it.



Pic. 49: Plastic barrels accumulation reservoir in SketchUp software

7.1.3 Calculation of total water consumption

To estimate the water need, we have to know how many occupants use the water supply system and how often. Then we predict the water need of every possible activity that can occur and obtain values for day and year consumption per person and the total water consumption.

7.1.3.1 Used methodology

Documents used for calculation are taken from Czech legislation and guidelines that I have most experience with. I modified them for the African context. I could not find any serious guidelines that would be created by the Zambian government of neighbouring countries. Thus, figures presented here could be different from the real ones, because the water need in the school buildings was just estimated, not supported by any African based statistic. For the day area of the school I was following instruction in Czech legislation without change. For residential parts, I assumed that the water consumption would be 30% smaller than in the Czech Republic context.

Czech legislation used:

- Spotřeba studené vody (Vyhláška č. 120/2011 Sb.)
- Specifická potřeba vody směrnice MVLH č. 9/73

7.1.3.2 Total water consumption

Calculation of total water consumption			
Water consumption	l/per person	persons	summary (l/day)
Day school area			
Students	25	250	6250
Teachers' offices	60	24	1440
Staff	60	15	900
Kitchen (per meal)	25	289	7225
Laboratory	10	100	1000
Cook workshop	25	100	2500
Sick bay	120	15	1800
Laundry house	18	250	4500
Summary day area			25615
Residential area			
Students accommodation	60	250	15000

Staff houses	87	108	9396
Summary residential area			24396
Summary (l/day)			50011
Summary (m3/day)			50,0
Average water consumption (l/per person/per day)			110
Average water consumption (m3/per person/per day)			0,11
Year average water consumption	Days	consumption/day (m3)	Consumption/year (m3)
Day part	189	25,615	4841,24
Residential area	365	24,396	8904,54
Summary			13745,8

Tab. 25: Total water consumption

<u>Check of calculation</u>

To prove that the calculation has reasonable results, I used the Czech standard - Vyhláška č. 120/2011 Sb. and computed year values. As we can see, the day area of the school has lower demand than is shown in the standard (4841 to 5220 m3/year). The residential area has a lower value too (8904 to 12530 m3/year), because the water need expected for the Czech context can go up to 180 l/day/person. In conclusion we can say that the results are reasonable. More details can be found at Annex 7.

Type of the buildings	m3/year x number of people	m^3/year
Other type of school (without boarding part)	18x290	5220
Residential units	35x358	12530

Tab. 26: Figures by Vyhláška č. 120/2011 Sb. Standard

The calculated figures of water need do not have to be final. In order to promote a sustainable approach and safe water resources, we can use some ways to reduce water demand or use a different source of drinking water.

The following pages present two ways of reducing the water need from land resource. First is rainwater harvesting system, which collects water in the rain season from the rooftop of selected buildings. Second is the greywater reuse system, which allows using utility water gained from polluted drinking water. Both systems are different for day and residential parts of the school.

7.1.3.3 Dividing water supply system to drinking and utility water

When we use a separate system, we also have to separate pipeline and drainage. Greywater can be transformed to utility water only by secondary treatment that cleans water from all critical pollutants.

7.1.3.4 Rainwater harvesting

The climate of the locality provides us with rainfall that we can use as a water source. In the wet season we can use great potential of collecting rain and not use land water source. To do it, we need a water harvesting system providing a catchment area, a water treatment and an accumulation reservoir for storing the water.

First, we need to compute the amount of water we can harvest from the rain. A key figure will be total catchment area and the volume of water obtained in the year period.

The catchment area here is computed only for the classroom and laboratory buildings with the agriculture workshop and kitchen and dining hall building. The roof area goes all the way to the utility blocks. For these conditions, we can see how much water we can accumulate.

Rainwater harvesting calculation		
Value		Unit/note
Average year precipitation	930	mm/year
Width of the building	11,34	m
Length of the building	28,14	m
Number of building	6	-
Total catchment area	1914,6456	m^2
Coefficient of water outflow	0,8	For metal sheet
Coefficient of pretreatment filter	0,9	-
Amount of accumulated water	1282,0	m^3/year

Tab. 27: Water harvesting calculation

The day values for average day precipitation are more complicated to calculate with. Thus, for these calculations average month values were used. January is the month which is the rainiest. Despite that, we have five months without rain.

This water will be used mainly for water supply of the water in the utility blocks. Now we can compute the average precipitation in the days of the months in which there is some rainfall. The following values are presented for day average.

Average precipitation					
Month	Month average (mm)	Rainfall days in the month (-)	Total month precipitation (mm)	Maximal day precipitation (mm)	Water obtained per day (m^3)
January	220	18	3960	12,2	9,8
February	154	15	2310	10,3	7,1
March	71	10	710	7,1	3,2
April	12	3	36	4,0	0,6
May	0	0	0	0,0	0,0
June	0	0	0	0,0	0,0
July	0	0	0	0,0	0,0
August	0	0	0	0,0	0,0
September	0	0	0	0,0	0,0
October	9	2	18	4,5	0,4
November	47	8	376	5,9	2,2
December	158	16	2528	9,9	7,0

Tab. 28: Water obtained per day in month period

The obtained amount of water is never more than the drinking water need for the day part of the school (9,8 m^3 < 16 m^3), so even in the wet season we cannot accumulate water to another day. Therefore, the rainwater harvesting system can be only a complementary source of drinking water.

When the amount of water is known, the next step is the calculation of the required volume of the barrel water reservoir.

Size of accumulation reservoir		
Volume of one barrel	0,2	m^3
Number of barrels in one building	14	(-)
Number of buildings	6	(-)
Total amount of barrels	16,8	m^3
Days of water stored	1,7	(-)

Tab. 29: Calculation of volume of the barrel water reservoir

For the worst-case scenario, we have 9,8 m3 of rainwater gain per day we can store in the accumulation reservoir, which has a capacity of 1,7 times of daily gain. This way, the system is also capable of solving the emergency problem with a sufficient time scale.

7.1.3.5 Water resource from boreholes

Boreholes will provide main water supply to all buildings. We will be calculating with a minimum yield of borehole mentioned earlier, which is 0,5 l/s resp. 0,2. The following table shows the water flow of the borehole in the day period for those parameters:

Scenario	needed water amount (m3)	Needed amount day area (m3)	needed amount residential area (m3)	minimal source flow (l/s)	Minute (l)	Hour (l)	Day (m3)	Boreholes needed
Yield of 0,2 l/s	29,47	15,97	13,5	0,2	12	288	6,912	5
Yield of 0,5 l/s				0,5	30	720	17,28	2

Tab. 30: Borehole day yield

We can see that the yield of the borehole is a key factor in the design. For this specific design we need a qualified hydrogeological study and a specialist's examination to design a reasonable system that could work in our conditions. Therefore, a number of boreholes and the location of the accumulation water reservoirs can be determined after the study is finished.

But from the following calculation, we can specify some requirements. The capacity of the tank will be according to the volume of 1-day supply need without reuse water, i.e. 50 m^3. Considering the vast size of the school land, we must divide it into at least two areas: one reservoir for the day area and one for the residential area of the school. The accumulation tank will be placed in the specific location due to conditions created by the building's locations and the hydrogeological study. For that purpose, the water tank will be placed on the high platform to create a water tower. The pressure, produced by hydrostatic force of water in this tower, should be in the water supply pipelines in the range of 0,1-0,6 MPa. Last but not least, the water supply should be placed above wastewater treatment and be safely done in groundwork to not interfere with the sewage system. To ensure safety of the source, a protection area should be set at a distance of 50 m from the borehole. In this zone it is forbidden to place sewage lines, do agriculture work, place toilets etc.

7.1.4 Water reuse system in the school buildings

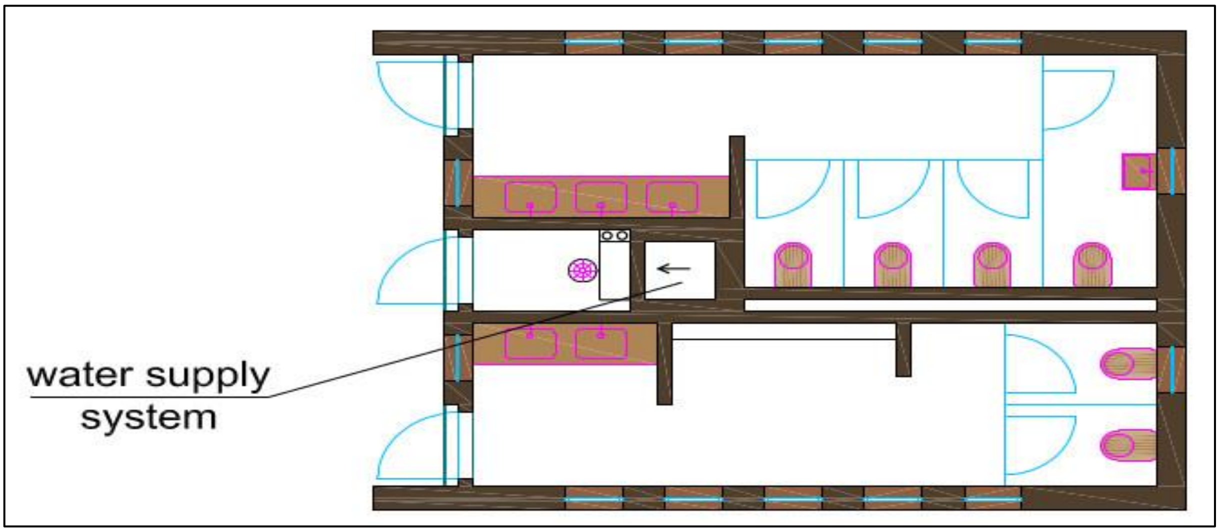
As mentioned earlier, the water reuse system has as main goal to reduce the water need. The water from basin and shower can be used again to flush toilets. We have four main types of buildings to which we can apply the water reuse system:

- Utility block
- Student accommodation
- Teachers houses
- Volunteers houses

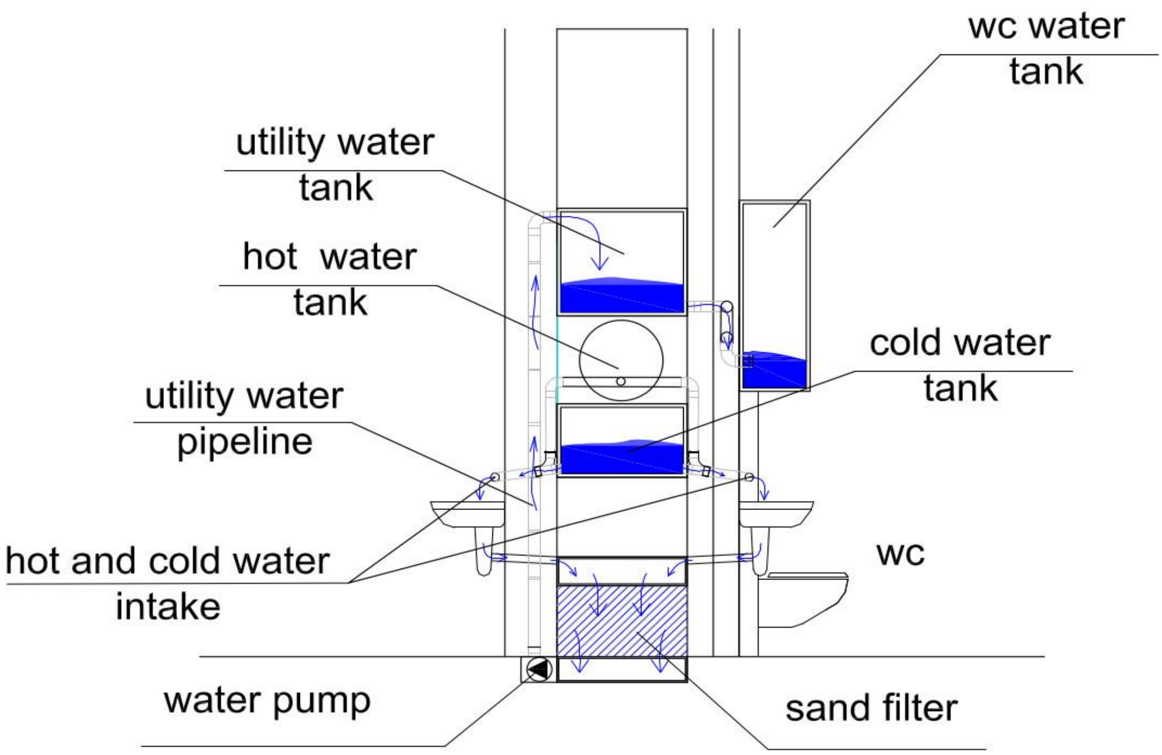
The principle of the water reuse system is similar in all scenarios, spacing and the floorplan of the houses is different.

7.1.4.1 Utility blocks

In the utility blocks we use water from washing hands as a cleaned greywater to flush toilets and rainwater from the roof area to supply the cold water tanks and also for flushing toilets. Clean water from the rainwater harvesting system is transported to the cold water tank. Hot water is stored in the hot water tank with a source of water from the water supply pipeline. Used water (greywater) from basins goes to the sand filter, where the water is cleaned. Water cumulates in the down part of the filter and when there is enough of it, it is transported by water pump to the utility water tank. In the hot season or when there is not enough grey water production, the utility water tank is filled by a water supply system. From the utility water tank the water goes to the WC water tank by gravitational force and here it is used for flushing. All components of the system are placed in the space in the middle of the floorplan. From the cleaning room the system can be checked and controlled.



Pic. 50: Location of water supply system in Utility block

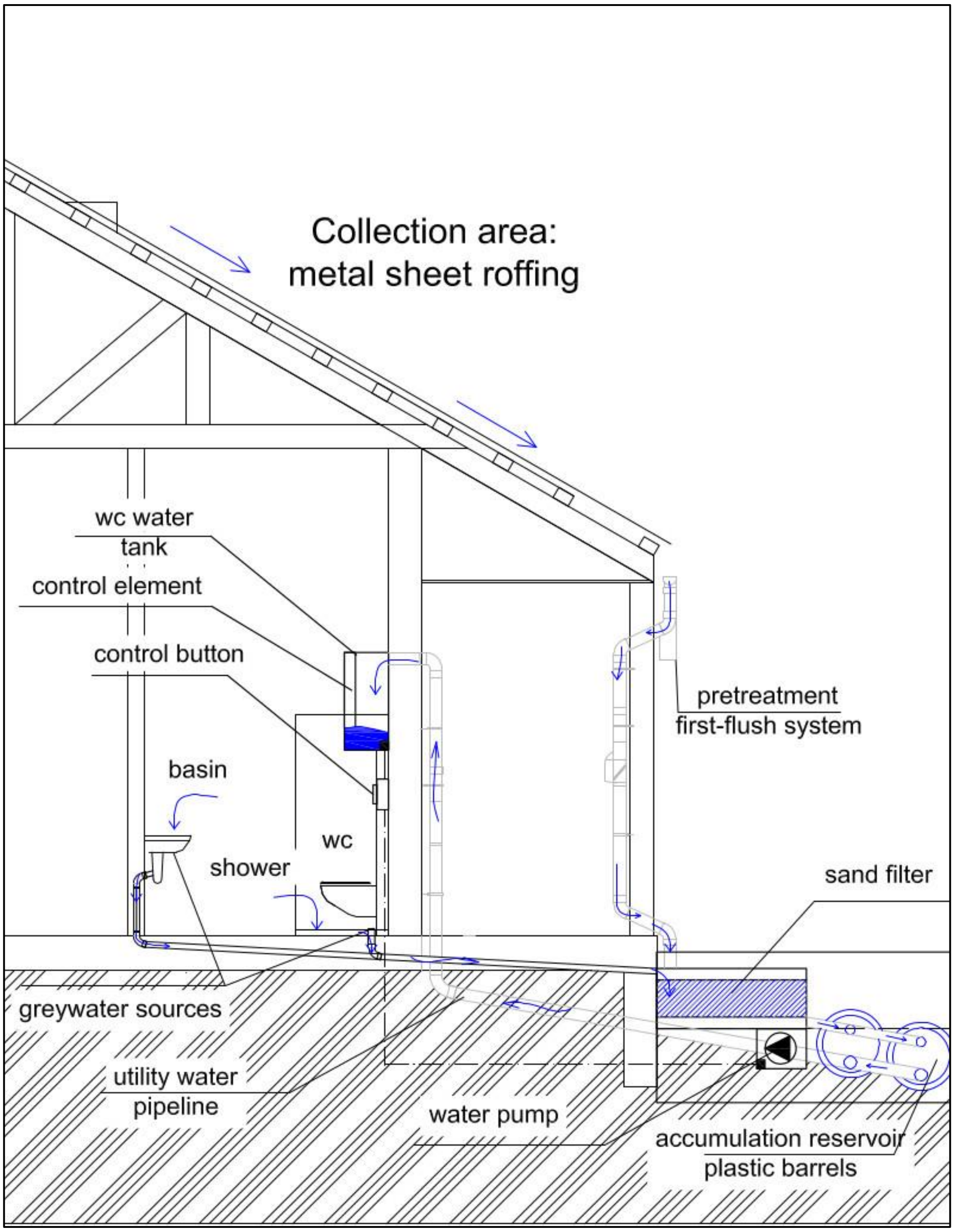


Pic. 51: Water supply system in Utility block

7.1.4.2 Residential buildings

In residential buildings the situation is similar. The water from basins and shower goes to the sand filter placed outside. Additionally, rainwater from the roof catchment area goes after the first-flush system to the filter. Cleaned water from the filter flows to the accumulation reservoir created by plastic 200 l barrels. When the occupant of the room discovers that the WC water tank is getting empty, he or she can manually press the button to fill it with the water from the barrels. The water level is visible in a control element on the WC water tank. The toilet water tank has enough capacity to provide flushing for several times. All parts of the system are visible and free to check or repair. The sand filter can be replaced with a new one and plastic barrels can be disconnected and cleaned.

This system can be modified also for utility water use in washing machines. If all conditions in the sand filter were optimal, an additional water tank would be attached to the washing machine. The water would go to the water tank in the same way as it goes to the WC water tank. The machine is then filled by the utility water by gravitational force and water from the machine goes to the sewage system. Utility water calculations are presented at Annex 7.



Pic. 52: Water supply system in residential buildings

7.1.5 Conclusion

Water supply will be provided mainly from ground source of drinking water, i.e. boreholes. The rainwater harvesting system will be the second source of water in the rain season, where water is collected from the rooftop of selected buildings, cleaned by sand filter and stored in the barrels accumulation reservoir. To reduce drinking water need, the utility water system was introduced to reuse greywater for flushing toilets. The yield of the ground water sources and location of the accumulation tower can be determined after a proper hydrogeological study.

7.2 Sewage system

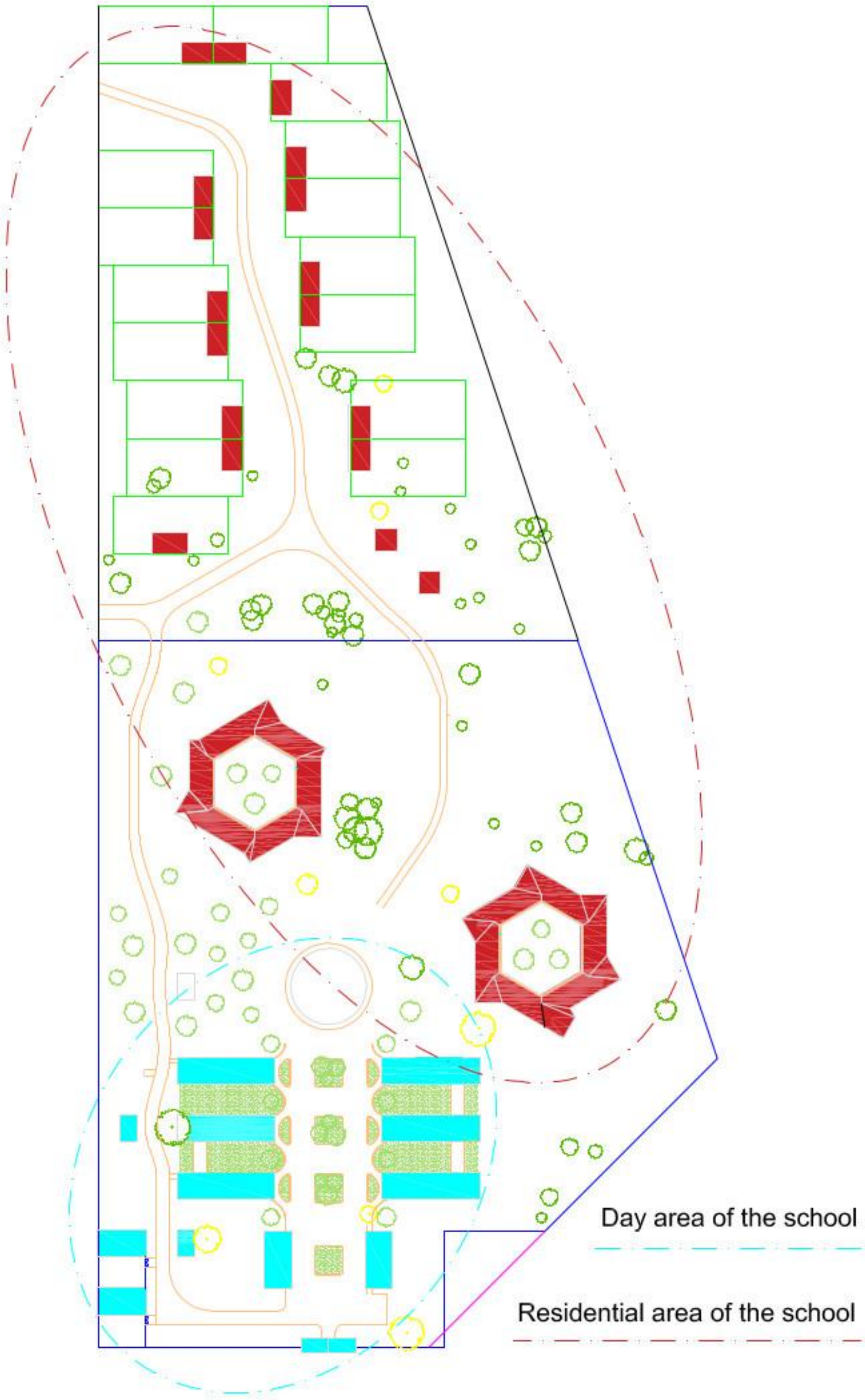
To design an effective sewage system, we have to state detailed requirements that should be accomplished. The system should be effective and reliable with an easy functional mechanism. In that case maintenance and repairs can be provided by people from the locality with non-difficult training. The locality of the school is at a rural area, where there is not a common sewer to which the school can connect. The system should not have part, that create open spaces with still water, which creates good conditions for mosquitos and thus for Malaria hazard.

The school buildings create two groups of buildings. We have school buildings that are used in the school day operation and they have a discontinuous working period due to the holidays and weekends. And we have residential buildings, located in the boarding part of the school. The accommodation buildings for the students, teachers and volunteers have requirements of residential buildings and activities in them we can consider continuously.

We also must consider different kinds of wastewater that is produced by activities in the building. We divided wastewater into two types. Blackwater is water from toilets, grey water is from bathing/washing and storm water has its origin from rain. An effective system treats those varieties of wastewater separately to embrace their reuse potential. When a separated system is used, there are more technological parts and there is more maintenance work. On the other side we reduce the volume of the waste water and needed parts in the united sewage system. When in the dry season there is no rain precipitation and water is missing in the locality, it is a good solution to reuse wastewater as much as we can.

7.2.1 Description of buildings and places connected to the sewage system

The houses of the school are divided into two zones. In one zone, there are school buildings with operation according to the school schedule. The second zone is formed by residential buildings for students, teachers and volunteers. The sewage system can be used for both zones simultaneously, or every zone can have its own treatment.
Zones are shown on picture 53.



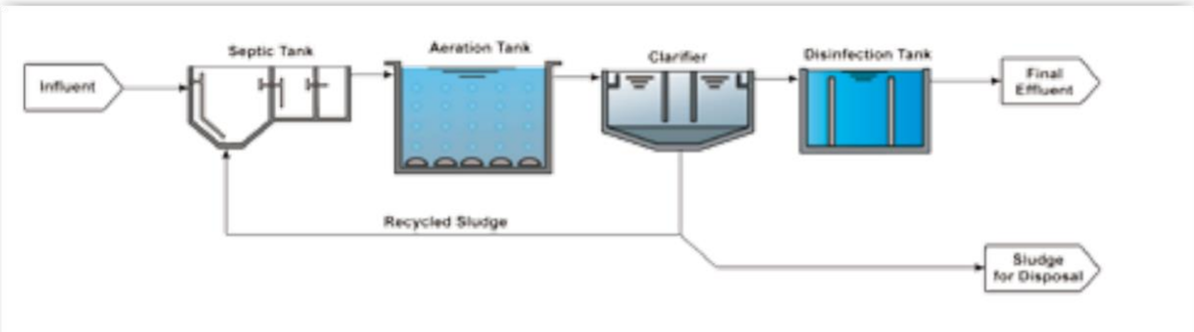
Pic. 53: Day and residential area of the school

7.2.2 Black water sanitation system

After dividing different sorts of wastewater, we have to design a right treatment that will suit our locality and all requirements. Black water has its source in the toilets. Therefore, the water contains an increased amount of sludge and other pollutants. Cleaning this water requires more than one treatment stage, normally there must be three different stages. We can use a system that is taken conventionally. There is the possible use of sludge that is aggregated in the first treatment stage and used as a fertilizer or for energy purposes. Constructed wetlands treatment is another design solution for this kind of wastewater. This solution is often considered as unconventional and unreliable.

7.2.2.1 Conventional solution for black water treatment

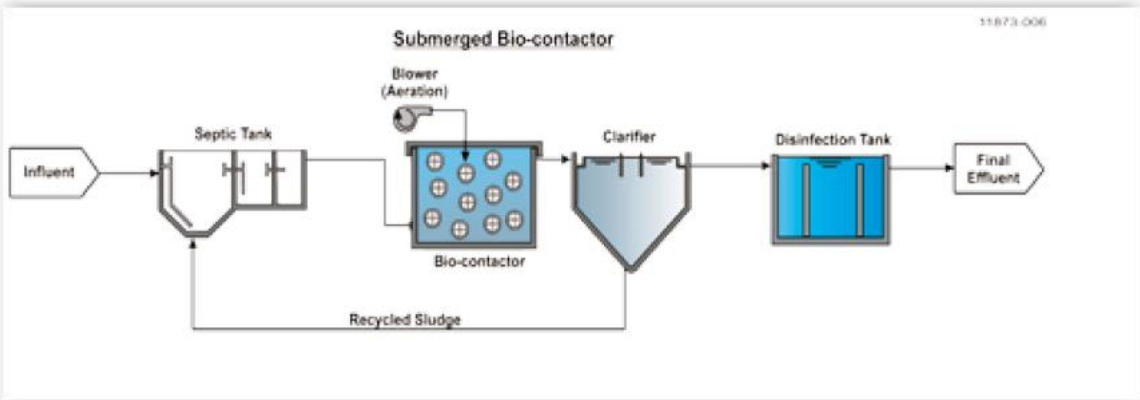
When we visited schools that were built in Zambia near our locality, all of them have a system with septic treatment. If the school is located in the city, septic is all what is required for treatment before entering to the sewer. A full treatment system has usually three parts. The primary treatment or pre-treatment has the main goal to separate bigger solid particles. Usually, septic is used for this part of the sewage system. Next is the secondary treatment that cleans the water from main pollutants. There are several options that can be used. An aerobic solution with the aeration tank is the most common one. Additionally, we can use bio-contactors, tricking filters or membranes. The third stage of treatment takes care of the cleaned water. When the water is clean enough, you can return it to the water source. There is a possibility to create an accumulation tank or pond or draining system to drain water in the ground. The basic scheme is shown on the picture 54.



Pic. 54: Scheme of aerobic wastewater treatment plant system; Source: (Van Niekerk, 2009)

Design of the wastewater plant using biological treatment:

The first part of the system is the septic tank. Septic collects most of solid sludge and lets less polluted water pass. It requires periodical removal of sludge by special equipment. Therefore, it must have enough size to make periodical maintenance in a longer time period. The next stage will be a treatment process with bio-contractors. A Better way in our conditions would be better submerged bio-contractors created from the plastic accumulation tanks. These tanks are available to buy in Lusaka and they are good for transportation too. Submerged bio-contractors create secondary treatment by bacteria-based cleaning process. The bacteria inside need an air flow that is provided by an electric blower. The last stage is a clarifier i.e. the accumulation tank, where the rest of the solid pollutants are sedimented and they return afterwards to the septic tank (Van Niekerk, 2009). Clean water can be pumped to the accumulation tank and reused for flushing toilets and irrigation. The cleaning process is visualized on picture 55.



Pic. 55: Scheme of wastewater treatment plant system with submerged Bio-contractors; Source: (Van Niekerk, 2009)

Advantages of the solution:

- Reliable and good for maintenance
- Easy to control and repair
- Compact solution

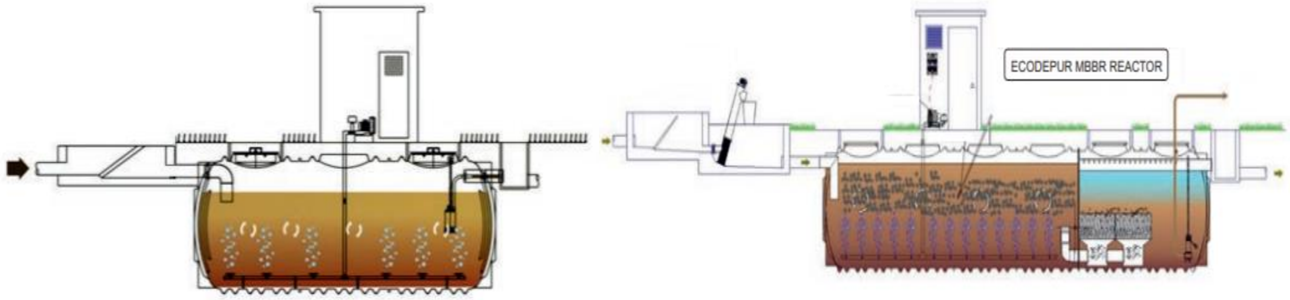
Disadvantages:

- Higher construction cost
- Need electric energy to run the blower
- Need periodic maintenance by special equipment
- Need special person to operate the plant

7.2.3 Compacted wastewater plant:

The most reliable and easy to design solution can be a compact wastewater unit. In this case, the sewer system from the school building is connected to the small unit that provides all needed treatment and leaves water clean and good for irrigation purposes. These units are provided by specialised companies. The construction cost would be higher, mostly due to the price of transportation. Also, regular periodical maintenance done by trained personnel has to be considered.

Examples of the wastewater treatment unit is shown on picture 56.



Pic. 56: Wastewater units; Source: (Ecodepur, 2019)

Advantages of the solution:

- Reliable and professional solution
- Easy to control and repair
- Compact solution

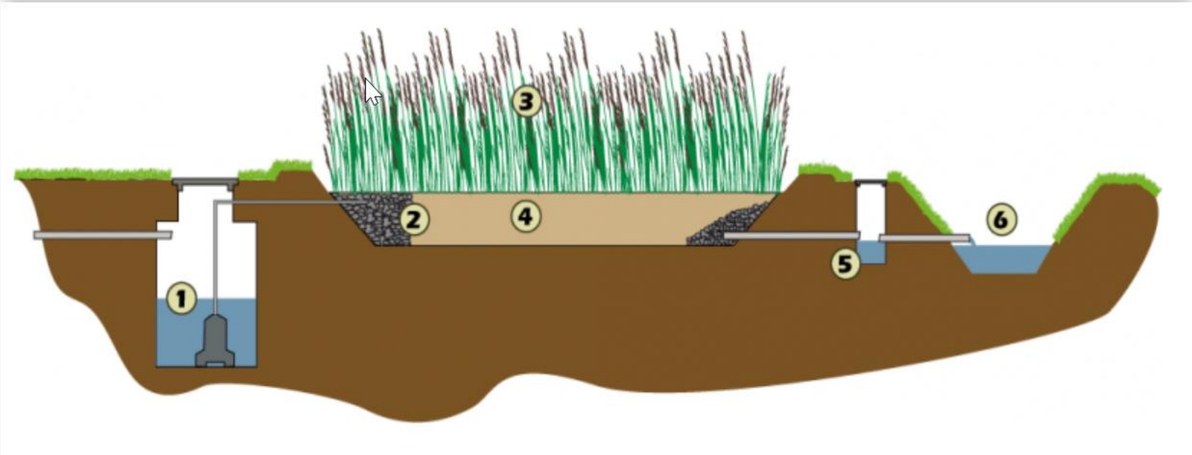
Disadvantages:

- Higher construction cost
- Need electric energy for operation
- Need periodic maintenance by special equipment
- Need special person to operate the plant

There are companies operating also in Africa (Ecodepur, 2019).

7.2.4 Constructed wetlands

Constructed wetland uses the gravitation and filtration ability of the plants like reed to clean water. The treatment process is similar to the conventional system, but a secondary treatment is created by wetlands. The primary treatment is done by a setting tank, where all solid matters are sedimented. After that by gravitational force wastewater goes to the wetland, where thanks to the filtration ability of the plants the water is cleaned. Water in the wetlands has to be brought to the roots of the plants. Filtration is done by a gravel bed of the wetland and also bacteria that are placed on the roots taken from the wastewater organic pollutants, which leaves it clean. Water is under the layer of sand and gravel, so the level of water does not rise to the edge of the wetland beds. Therefore, good conditions for mosquitos are not allowed. After wetlands beds, clean water goes to the accumulation tank, where it can be stored for reuse in irrigation or other purposes. The whole process is described on picture 57.



Pic. 57: Constructed wetlands wastewater treatment process; Source: (The Constructed Wetland Filter, b.r.)

Design of the wetland wastewater treatment plant

A critical feature in the design of constructed wetland in our conditions is to prevent to create a water level higher than the surface of the plants. In that case, we would create good conditions for mosquito existence. Wetlands need more space than a conventional secondary treatment. Usually for one inhabitant, we must use 5 m^2 of wetland area for cleaning the wastewater by Czech Republic experience (Vymazal, 2002). For a multistage system, the area for one wetland bed is 2,3 m per person equivalent (Gómez Cerezo, 2001). The treatment plants also need maintenance in the case of primary treatment by the septic tank. Wetlands beds also need maintenance. In South Africa, several constructed wetlands were built with sufficient results. In this publication detailed information can be found (Lakay, 2012)

Advantages of the solution:

- Cost effective solution
- Natural way of cleaning wastewater
- Don’t need electricity for operation

Disadvantages:

- Higher area for operating
- Need electric energy for operation
- Need periodic maintenance by special equipment

7.2.5 Wastewater calculations

First, we need to determine the amount of wastewate, that will be treated by wastewater plants. The area is divided into the day school part and residential part. We already divided wastewater into blackwater and greywater. Greywater is used for secondary reuse. Blackwater is a type of water that treatment plants must clean. The following calculation shows the production of blackwater in the selected areas.

Blackwater production			
Blackwater production	l/per person	persons	summary (l/day)
Day school area			
Students	16,7	250	4163
Teachers offices	25,0	24	599
Staff	25,0	15	375
Summary day part			5137
Residential area			
Students accommodation	25	250	6250
Staff houses	25	108	2700
Summary residential area			8950
Summary (l/day)			14086,525
Summary (m3/day)			14,1
Average blackwater production (l/per person/per day)			31
Average blackwater production (m3/per person/per day)			0,03
Year average blackwater production	Days	consumption/day (m3)	Consumption/year (m3)
Day part	189	5,136525	970,80
Residential area	365	8,95	3266,75
Summary			4237,6

Tab. 31: Blackwater production

From the calculation we can see that the production in the day area is 5,14 m^3/day. In the residential area the figure is 8,96 m^3/day.

When we choose a primary treatment by septic tank, we need to compute its size. Formulas are used from a specialised Master thesis (Dlouhá, 2016).

Septic tank calculation	Day area	Units	Residential area	Units
Number of occupants	289	persons	358	persons
Coefficient	0,33	(-)	1	(-)
Person equivalent	96	(-)	358	(-)
Blackwater production	5,14	m^3	8,95	m^3
Average blackwater production	0,054	(m3/per person/per day)	0,025	(m3/per person/per day)
Coefficient for sewage space	1,5	(-)	1,5	(-)
Time of holding up the sewage	3	days	3	days
Needed volume of septic tank	23,1	m^3	40,3	m^3

Tab. 32: Septic tank calculation

The volume of the septic tank of the residential area is almost two times larger. We can decide to divide the residential area into two treatment plans for using the water from the septic tank that is easier to obtain.

In the case of constructed wetlands, we need to know the final area of the wetland beds. With the use of previous information, the table 33 shows how much wetland area is needed for one person equivalent.

Wetland area calculation	Day area	Units	Residential area	Units
Person equivalent	96	(-)	358	(-)
Area per person by value 2,3 m2	220,8	m2	823,4	m2
Area per person by value 5 m2	480	m2	1790	m2

Tab. 33: Wetland area calculation

The last part of the treatment system is clean water and its use. All water obtained from the wastewater treatment system will be used to irrigate nearby fields. Water from the treatment plant is not cleaned to achieve standard of drinking water. Pollutants that are still in the water are beneficial for plants in the fields.

7.5.6 Conclusion

The final choice of wastewater treatment can be determined after the hydrogeological study of the school land. In that case, water resources will be located and wastewater will be designated to not interfere with them. After knowing the places of water resources from the land, we can determine the best way to clean wastewater by condition of the landscape and the building position. I would like to close this chapter with the statement that all three systems can be used in the project with careful design according to the hydrogeological study and with a consultation of a specialised person or company willing to realize the system in the locality.

7.6 Hot water heater

One feature of a water supply system is also to provide hot water in buildings. Showers and basins in the residential buildings are usual consumers of the majority of hot water. Also the kitchen needs hot water for cooking in big amounts. To heat drinking water, we will use solar collectors and storage tanks to accumulate heated water. Solar power can usually be enough to provide hot water most of the time. In some cases of unfavourable conditions, water tanks contain an electric heater that raises the temperature of the water, when the solar system is not active sufficiently.

7.6.6 Hot water supply need

First, we need to calculate how much hot water we will need. Then we can compose a specific system to provide hot water in different buildings.

Hot water need			
Hot water need	l/per person	persons	summary (l/day)
Day school area			
Students	7	250	1750
Teachers offices	12	24	288
Staff	12	15	180
Kitchen (per meal)	15	289	4335
Laboratory	5	100	500
Cook workshop	17	100	1700
Sick bay	10	150	1500
Summary day part			10253
Residential area			
Students accommodation	28	250	7000
Staff houses	40	108	4320
Summary residential area			11320
Summary (l/day)			21573
Summary (m3/day)			21,6
Average hot water need (l/per person/per day)			48
Average hot water need (m3/per person/per day)			0,05
Year average hot water need	Days	consuption/day (m3)	Consumption/year (m3)
Day part	189	10,253	1937,82
Residential area	365	11,32	4131,80
Summary			6069,6

Tab. 34: Total hot water need

7.6.7 Hot water supply system

The system consists of these elements:

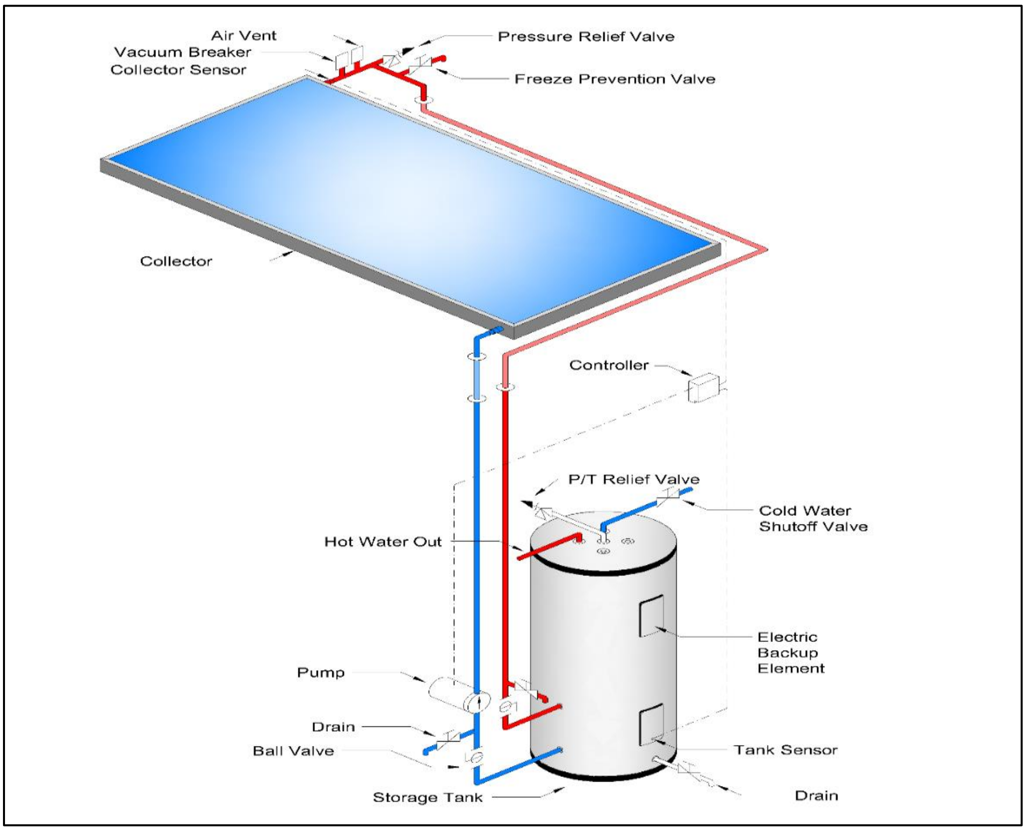
- Solar collectors
- Dual coil hot water storage tank
- Collectors loop

Overview of the systems:

We have two options for creating a hot water supply system. References and more information can be found at (Walker, 2012).

7.6.7.1 Separate system of collector and water storage tank

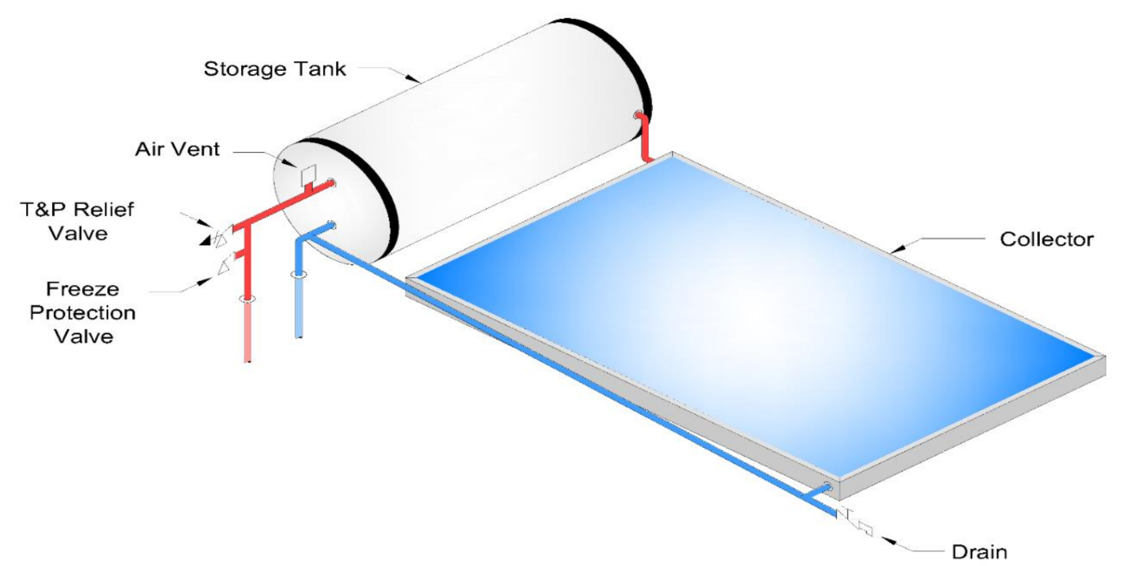
The system can be an open or closed loop. An open system means that the water goes directly to the collector and there it is heated. A closed loop is with a specific liquid that circulates between the collector and the water tank. Solar collectors will be placed on the roof with a simple supporting construction. The system will be active, which means that fluid circulating between collector and water tank will be in move by a small pump. The water tank will have auxiliary heating powered by electricity form the grid. An example diagram of this system can be found in following picture:



Pic. 58: Separate solar water heating system; Source: (Solar Water Heating Systems, 2014)

7.6.7.2 Free flow system

This system has all components in one place. The water tank is not located in the building, but is with the collectors in the roof area. The water in the collector does not need any pump to circulate. That is why this assembly is called free flow. The collector area is usually composed of only one panel, thus is suitable for a small water volume.



Pic. 59: Free flow solar water heating system; Source: (Solar Water Heating Systems, 2014)

In our project, we have several buildings that need a hot water supply system. Here is written their list with description of designed system.

Building	Description of the system
Utility block	Separate system with standard flat plate collector and auxiliary heating powered by electricity
Teachers office house	Simple free flow system
Sick bay	Continuous flow water heater
Kitchen	Continuous flow water heater
Student houses	Separate system with standard flat plate collector and auxiliary heating powered by electricity
Staff houses	Separate system with standard flat plate collector and auxiliary heating powered by electricity

Tab. 35: Description of hot water system in school buildings

For these solutions, calculation was made to estimate the needed number of collectors and the volume of water that will be needed in the building and for the size of the accumulation water tank. The location of the collectors on the roof was chosen at the side, providing more sunlight, in our case northern side at the location south of the equator. The calculation of the number of collectors and their efficiency was done by software T*SOL 2018. There is also the question of suppliers that will provide the needed equipment. The company Suntech has the needed components to offer (Suntech Zambia, 2019).

7.6.8 Calculation of solar water heating system

7.6.8.1 Water tank volume calculation

Every building requires a water tank with enough capacity to provide hot water at least for one day.

Hot water tank calculation	Utility block	Student dormitory unit	Staff house
Number of people	36	8	6
Water need per person [l]	6	28	40
Total water need [l]	216	224	240
Designed water tank [l]	300	300	300
Day capacity of tank [day]	1,4	1,3	1,25

Tab. 36: Water tank volume calculation

7.6.8.2 Collectors calculation

In the calculation of the water tank we can see that the system for all three buildings will be with very similar properties. The calculations for a free flow system are not necessary, the water need has to be confirmed by the suppliers' technical documents. Figures for collectors properties in a separate system can be found in the following table, calculated by T*SOL 2018 software. A detailed calculation can be found in Annex 10.

Characteristics	Utility block North-west orientation	Student dormitory unit North orientation	Staff house North-East orientation
Solar fraction [%]	81	82	81
System efficiency [%]	38	34	36
Collectors need [m^2]	5	5	5
Solar energy gained [kWh]	2133	2922	3024
Auxiliary energy needed [kWh]	736	627	692

Tab. 37: Collectors properties in the system of selected buildings

7.6.9 Conclusion

The water supply system will be primarily composed of the components allowing to use the sun for water heating. For every building a water supply system was designed and in specific buildings, collectors characteristics were calculated using software T*SOL 2018.

7.7 Air conditioning system and mechanical ventilation

Some buildings require specific equipment to be functional depending on the activity that is happening in them. The kitchen, the cooking workshop, laboratories, and sick bay need this special equipment that will increase the flow rate of ventilation or controls humidity in the room.

7.7.6 Kitchen

A system of air conditioning and ventilation is needed at the kitchen building. The kitchen will prepare meals for all students and teachers in the university. This creates conditions that can be controlled by natural ventilation or mechanical one. This system requires a substantial cooling potential in the hot period and humidity control in day operation of the cooking.
The air conditioning and ventilation unit will have those parts:

- Filters
- Fans
- Cooler
- Humidity control

The main exhaust will be above the cooking island, located in the centre of the kitchen room. The system should be designed by the expert to take into account all major conditions. Also, a supplier has to be found for detailed design. Dimensions of the ventilation system are too early to determine and they will come out of the advanced design of the unit.

7.7.7 Laboratory, cooking workshop, sick bay

In these buildings, we have specific pollutants that are in the inside air in larger quantities, than is usual in the other buildings. The cook workshop produces more water vapor and heat by cooking meals. The laboratory study creates pollutants from chemical experiments. In both cases, we have a source of pollution in a specific location. In this location, we can place an exhaust of a mechanical ventilation and ensure a safe level of clear air supply. For these buildings, we will place an exhaust hood above the place of the source: in the laboratories and above the working tables and in the cooking workshop above the cooking stoves. That creates underpressure ventilation, safeguarding that polluted air enters the building again. In sick bay, patients's rooms and doctor´s rooms should be ventilated mechanically to provide enough fresh air and frequent change of the air. Also in these rooms the ventilation will be underpressured. This condition will be created by a simple mechanical ventilation system with fans and air filters.

7.8 Heating system

Chapter seven ended with thermal comfort assessment, where we obtained bad results for a period of two coldest weeks. Designing a heating system just for a time period, that is this short is an uneasy solution. Temperature inside school classroom, where the lowest value is around 13°C can´t be takes as plausible in thermal comfort conditions, but also designing any conventional heating system will be very uneconomical. There is also question of reliability of Meteonorm data, that was used for the calculations.

There are some systems, that we can use. One system has the same principle as solar water heating system. We can extend the system and use collectors also for space heating. This is not very cost-effective solution, because of investment to the new solar collectors and other part of the heating system. But collectors could be used during all year, not just in the cold period. Other plausible solution is to buy electric heaters, that would provide needed comfort.

In any case, results of the calculation don't have to be true also in the reality. Need for heating system can be asses by a sample building, that will be constructed first to test all the features of the design. This building will be tested during whole year and according to these measurements, decision about heating system could be determined.

7.9 Conclusion:

The water supply system is an important part of the design. The main water source will be provided by boreholes with support of rainwater harvesting. The water will be stored in the water towers with given volume of accumulation reservoirs and rainwater is placed in barrels accumulation next to the given buildings. To reduce water consumption, we will divide wastewater to greywater and blackwater. Greywater, that has its origin in wastewater from basins and showers, will be cleaned by sand filters and used for flushing toilets. Blackwater from the toilets will be cleaned in water treatment plants. The blackwater treatment can be developed by aerobic treatment plants with submerged Bio-contractors, compacted wastewater plants or constructed wetlands. The final solution on the location of the wastewater treatment plants and location of ground water sources will be determined after a hydrogeological study. Hot water will be provided by a solar hot water supply system. It is composed of solar collectors, an accumulation tank with auxiliary electric heating system. Special ventilation and air-condition equipment will be placed in the buildings that have special conditions to deal with.

8 Conclusion of the master thesis:

The design of Kashitu high school offers a complex design overview of the most important aspects of a project development in a third world country. The main goal of the work was the design of the high school facility, corresponding to the given climate, locality and needs of the future users. To comprehend this task in a wider perspective, the design aspect was used from many different civil engineering fields. But still, final design features were developed in a simple manner to create a more effective solution and increase feasible realisation of the school.

Boundary conditions are mostly given by climate conditions, government regulations and local people’s skills, needs and desires as future builders and occupants. In a place where availability of building materials is a problem, we have to deal with choosing the right material even more. Fewer possibilities gives decision making even more importance. Materials that are locally known by the people in the building process and that are easier to use get an advantage in the selection. Sustainability is the key principle in the presented building design. With methodology based on this premise, decisions were made to create the buildings more economically, functionally and ecologically.

The construction system was developed to be consistent with the sustainability assessment and with the experience of the local people in the construction. It creates an effective way to use natural materials with basic techniques. It also provides future business opportunities in producing more blocks, when the school project will be finished. The people can use their experience and training given by the school’s realisation and build new houses and other structures by this technology. Local workers are usually not qualified by achieved education, because, in most cases, they have only a primary one. They are respected and employed by the training they have been a part of and experience is gained by their previous work projects. And from the general point of view, the best developing projects are the one, that teach local communities to continue in the region’s development by themselves, without any need of foreign help.

The conditions of the school building affects the performance of the students. Therefore, we have to ensure suitable conditions during the year by design of an inner build environment. Daylight, acoustic, ventilation and thermal comfort, all these aspects are important. Study areas especially deserve very good quality conditions. But by improving one, in many cases you are worsening the other. In our case for example, by designing more windows we improve the daylight condition, but we reduce acoustic insulation of the walls, creating more interior heat loads in the hot period of the year. To satisfy all needs in a good manner, a middle ground has to be settled and an optimal solution has to be found.

When the passive design and other design adjustments cannot help, building service systems comes into play. They not only improve thermal comfort, fresh air and humidity conditions, but are also especially needed in very polluted and thermal loaded spaces such as kitchens. Drinking water, sanitation or electricity, these are systems that we use on a daily basis and they are critical for the school's operation. The water supply system, the sewage system or the air condition have to be properly designed to be working efficiently. All those systems were developed in a simple and cost-effective way. The equipment used in the design was chosen to have very basic principles, to be easily restored or replaced. However, even in those conditions, we have some design segments that have to be done by professionals being familiar with the local context and the availability of systems and services in the locality.

A high school in Kashitu can bring to the region a missing education improvement, leading to the creation of more job opportunities, enhancing the knowledge of the people and bringing better life conditions to the region. In education truly lies the power of changing unfavourable situations. Education is the key driving element of development. There is enormous potential in the children living in every corner of the world, let us give them the chance to seize it.

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