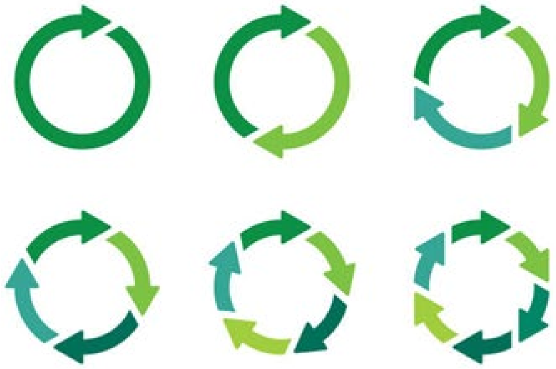

Cycle of
Education and Life

Cycle of Education and Life

Design a secondary school and optimization of water and waste management in Benga, Malawi, Africa

Professor: Enrico Sergio Mazzucchelli

Master thesis of: Parisa Raeesi

Academic year 2020 – 2021

Abstract

The thesis is a competition of designing a secondary school in Benga, Malawi. Benga is in east of Malawi near the Malawi lake. Through the analysis of climatic conditions, vernacular architecture, and social habits, it introduces a secondary school, with concentration on water management, waste management and passive strategies.

Likewise, it identifies natural and available local resources as potentials for the development of a sustainable model of building. The project proposes a multilayered envelope solution for roof and walls using local materials, an optimal window to wall ratio that guarantees internal natural lightning while minimizing solar gains and a designed ventilation system to achieve maximum internal comfort.

Considering lack of portable water and lack of cooking gas, the project proposes water management and waste management systems by using natural resources.

The thesis document explains step by step the research, modeling, and processing of the results to obtain measurable data that can help identifying an enhancement in the use of resources and comfort for inhabitants.

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Introduction

This thesis is based on a competition which is about a secondary school in Benga, Malawi, Africa.

In this thesis, the goal is to design the high-performance secondary school building through climate-responsive strategies and nZeb technologies for 200 students in total, which can popularize in many African countries. The aim of this project is to provide a better education to the youngest citizens of the country and gender equality by giving them the opportunity to access a decent secondary school infrastructure. The school will not be a simple school with classrooms it would be a place mix of academic education and skill workshops and helps families also to earn money by technologies which will be apply. We want to use local materials, easy constructive systems (low tech buildings) and energetic technologies to make proposals as efficient as possible.

The school must be designed to accommodate four academic years. At first only one classroom per academic year will be constructed, but participants will have to consider that the school could be extended in the future to three classrooms per academic year, which means twelve classrooms could be built at some point.

chapter 1

Introduction of project

1-1 Introduction

This thesis is based on a competition which is about a secondary school in Benga, Malawi, Africa.

In this thesis, the goal is to design the high-performance secondary school building through climate-responsive strategies and nZeb technologies for 200 students in total, which can popularize in many African countries. The aim of this project is to provide a better education to the youngest citizens of the country and gender equality by giving them the opportunity to access a decent secondary school infrastructure. The school will not be a simple school with classrooms it would be a place mix of academic education and skill workshops and helps families also to earn money by technologies which will be apply. We want to use local materials, easy constructive systems (low tech buildings) and energetic technologies to make proposals as efficient as possible.

The school must be designed to accommodate four academic years. At first only one classroom per academic year will be constructed, but participants will have to consider that the school could be extended in the future to three classrooms per academic year, which means twelve classrooms could be built at some point.

1-2 Why Africa

Africa, the second largest and second most-populous continent, is also home to the youngest population in the world. These young men and women are the future of Africa, but their future is also uncertain. Due to major limitations in education and other mitigating factors, the students of Africa fight an uphill battle to obtain their education.

School, a school desk, a notebook, or a teacher are still only a dream for more than 38 million children in Africa. By not being able to experience the empowerment that comes with education, they lose the chance to reach their potential, escape poverty and build a better future for themselves, their family and community.

Globally there are still 67 million children out of school, 43% of whom live in Africa. In 2010, there were still approximately 9 million children of primary school age unable to attend schools in Africa due to various reasons.

Girls, nomadic peoples, orphans, children with disabilities, children affected by HIV/AIDS, children affected by armed conflict and children affected by natural disasters are at a particular risk of missing out on education. Young girls are in significant danger due to the threat of bodily injury and sexual abuse while traveling to and from school. For every two children who attend school in Africa, one will drop out before graduating.

Approximately 8 of the 10 countries with the lowest primary enrollment rates are in Sub-Saharan Africa. Additionally, 33 million primary school-aged children in Africa do not go to school.

Many schools are located far away from children's homes. Only 7 in 10 children who live in rural areas will ever set foot in a school. Secondary schools can only accommodate 36% of students of age and qualification.

Regional primary enrollment rates now stand at 89% for boys and 86% for girls.

Rates for secondary school enrollment are significantly lower than primary schools. Regional enrollment averages 32% for boys and 29% for girls and many do not actually attend school. Approximately 28% of both boys and girls will attend secondary schools in Africa.

Enrollment in percent education programs is expanding throughout Africa. It nearly doubled between 1999 and 2012.

Primary school attendance has more than doubled between 1999 and 2012. Enrollment rose from 62 million to 149 million during this time.

Parents often cannot afford the cost of education, including books, uniforms, and tuition fees for their children to attend schools in Africa. In response, 15 countries have abolished school fees since 2000, enabling more children to attend primary school.

There are a multitude of reasons to explain why these children are not in schools – lack of facilities, culture, the need to be in employment and so on, but sometimes simple measures can make a huge difference. A Save the Children initiative in South Sudan increased school attendance considerably by building permanent classrooms with sanitary facilities. Children understandably preferred this environment to learning 'under the tree'.

1-3 Why school

Getting an education is not just a fundamental human right. It is pivotal to increasing employment and income opportunities. It is fundamental to breaking the cycle of poverty. Education is the key to unlocking the golden door of freedom for all in Africa. It is the bedrock of social and economic development. Education is crucial as it is an investment in human capital. This yields tremendous benefits at many levels and spheres. It benefits the individual, family community, and nation. Education is a sustainable means to alleviate poverty and bring lasting change. Consequently, to effect permanent change, any effort to bring lasting change must include education, in one way or the other.

Providing quality education to children reflects the fact that every child is entitled to fundamental human rights and should be treated with dignity. Where children lack access to education, this results in poverty, violence, abuse, exploitation, and other undesirable results. Poverty and its related challenges contribute to high dropout rates. Therefore, one of the goals of Develop Africa is to create opportunities for promising but impoverished African children and youths.

Universal education, gender equality and empowering women are vital components of the mission in developing countries. Educating children helps reduce poverty and will give the next generation the tools to fight poverty and conquer disease. School also offers children a safe environment, with support, supervision, and socialization.

Many countries have committed themselves to more than the achievement of universal primary education. They are also looking at expanding universal education so that it includes several years of secondary school and a new basic education. The challenge of keeping children in school after primary school is great.

Education is one of the most significant investments a country can undertake in terms of its development and thus every child/citizen deserves to receive a good education that will reduce the long-term effects of poverty. There is a saying that "Education is a powerful agent for change" and with good education, health and livelihoods will substantially improve.

Help Reduce Poverty: The lack of good education is also considered the root cause of poverty and to reduce poverty, African countries and their leadership should create avenues where every child will have access to proper education. When more people are educated, the poverty rate in Africa will drop, the reason being that most of the people will have diverse knowledge and skills whereby employment and job creation become easier thus accelerating the country's development process.

Improvement in Health Service: The lack of proper education has resulted in the abysmal health sector in Africa. In Africa, certain illnesses and other treatment complications must be treated overseas in western countries. Thus, in situations where a particular patient cannot afford such high expenses of overseas medical treatment, he or she is left to die of the illness. When more people get educated, the health sector also improves. In Africa, the infant mortality rate is high. If more people receive a good education in the health domain such as nursing, pharmacy, pediatrics, and others, infant mortality rates will drop drastically.

Reduction in Crime Rate: Many people are living in abject poverty due to lack of education and they become vulnerable, hence they turn to illegal activities for daily survival. However, access to quality education will imbibe in them a sense of right and wrong that would deter them from carrying out criminal activities.

Reduces Child Marriage: Child marriage is prevalent in most of African countries due to absence of basic education. With access to good education, this dangerous practice will reduce or cease to exist in our society. People's awareness will expand and those advocating the practice will be aware of the importance of education which will further encourage them to send their children to school.

1-4 The main goals

The aim of this project is to provide a better education to the youngest citizens of the country by giving them the opportunity to access a decent secondary school infrastructure.

Through the project, the main goal is to:

- EDUCATE: allowing children to access school and make them understand what improvements they could reach if they work hard on learning not only history, math, or languages but also in everyday activities such as agriculture or livestock. Another fact is that many of these children live without access to proper healthcare and teaching them how they can protect their own health is crucial. Many common health issues, such as malaria, dysentery, respiratory infections, and nutrition-related illnesses are preventable by simply making small lifestyle changes.

- INVESTIGATE: study about what should their country's society do to improve socially and economically. Education is particularly important to communities that are fragile or rebuilding. Education provides stability, structure, and hope for the future, helping children and youth to overcome trauma caused by war, disaster, or conflict. Having a safe learning environment also makes children and youth less vulnerable to exploitation, kidnapping, and recruitment by militant groups or organized crime.

- CONTRIBUTE TO THE CONSERVATION OF THE ENVIRONMENT: it is a fact that people in Malawi do not worry about the deforestation. The aim is that through education, we could raise awareness of that huge problem. The deforestation in the hills is causing a major change to the landscape and to the climate. As soon as the trees are cut down, the soil is exposed to the rain and, in many places, most of the topsoil is washed away into the rivers and eventually into Lake Malawi. This is leaving the hills infertile so that trees and crops do not grow well, and the soil that is being deposited in the lake is affecting fish stocks which, together with over-fishing, is causing a dramatic reduction in the number of fish that are being caught in the lake.

Chapter 2

Introduction of site

2-1 Location

Malawi, landlocked country in southeastern Africa. Endowed with spectacular highlands and extensive lakes, it occupies a narrow, curving strip of land along the East African Rift Valley. Lake Nyasa, known in Malawi as Lake Malawi, accounts for more than one-fifth of the country's total area.

Malawi stretches about 520 miles (840 km) from north to south and varies in width from 5 to 100 miles (10 to 160 km). It is bordered by Tanzania to the north, Lake Malawi to the east, Mozambique to the east and south, and Zambia to the west.

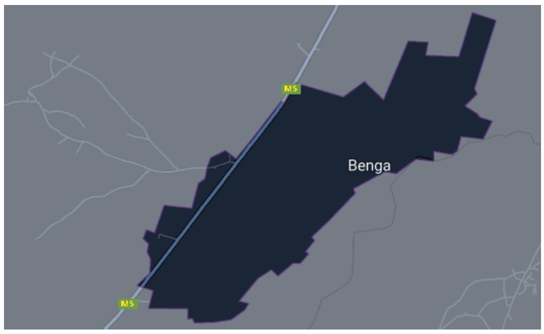


Figure 2-1 The location of Malawi in Africa Figure 2-2 The location of Benga in Malawi

Benga is located in Nkhotakota District and situated at 10 km from Lake Malawi to the east and 30 km to the Ntchisi Forest Reserve to the west. It is 60 km south of Nkhotakota Township and 50 km north of Salima Township. It is situated halfway on the tar road connecting both towns. Though the area is near Lake Malawi and Chilwa Lagoon.

The school will be located next to Benga Parish, a Missionary Community of Saint Paul the Apostle. They already have a primary school and are planning to build the secondary school in the other side of the road.

Figure 2-3 The location of site project

2-2 Weather

In Malawi there are 3 different regions: central, northern, and southern. Most regions (3) in Malawi lie in the Tropical wet and dry or savanna climate zone (Köppen: Aw). The mean average of annual temperatures ranges from a high of 24.72°C (76.5°F) in Southern Region to a low of 21.96°C (71.53°F) in Northern Region.

2-2-1 Temperature

Malawi’s regions ranking by average yearly temperature:

Figure 2-4 Malawi’s regions ranking by average yearly temperature

Benga is located in the central region and has a tropical climate. When compared with winter, the summers have much more rainfall. The climate here is classified as Aw by the Köppen-

Geiger system. The temperature here averages 24.0 °C | 75.1 °F. In a year, the rainfall is 1232 mm | 48.5 inch. The warmest month of the year is November, with an average temperature of 27.0 °C | 80.6 °F. At 20.4 °C | 68.7 °F on average, July is the coldest month of the year. The variation in annual temperature is around 6.6 °C | 11.9 °F.

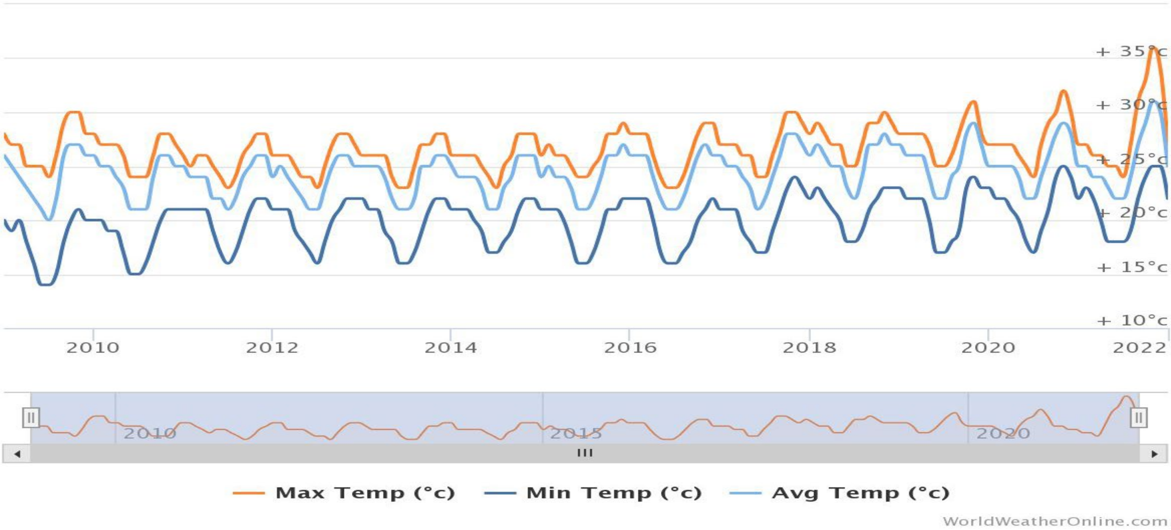


Figure 2-5 Max, Min, and average temperature in Benga

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature °C (°F)	24.7 °C (76.5) °F	24.7 °C (76.5) °F	24.5 °C (76.2) °F	23.9 °C (74.9) °F	22.7 °C (72.8) °F	21 °C (69.8) °F	20.4 °C (68.7) °F	22 °C (71.6) °F	24.5 °C (76.1) °F	26.6 °C (79.9) °F	27 °C (80.6) °F	25.4 °C (77.7) °F
Min. Temperature °C (°F)	22.4 °C (72.3) °F	22.3 °C (72.1) °F	22.1 °C (71.7) °F	21.2 °C (70.2) °F	19.5 °C (67.2) °F	17.6 °C (63.6) °F	16.7 °C (62.1) °F	17.7 °C (63.9) °F	19.7 °C (67.4) °F	22 °C (71.7) °F	23.2 °C (73.8) °F	22.7 °C (72.8) °F
Max. Temperature °C (°F)	27.6 °C (81.7) °F	27.7 °C (81.9) °F	27.6 °C (81.6) °F	27 °C (80.5) °F	26.4 °C (79.5) °F	25 °C (76.9) °F	24.6 °C (76.2) °F	26.8 °C (80.2) °F	29.5 °C (85.2) °F	31.4 °C (88.5) °F	31.2 °C (88.1) °F	28.6 °C (83.5) °F
Precipitation / Rainfall mm (in)	348 (13.7)	281 (11.1)	188 (7.4)	56 (2.2)	9 (0.4)	4 (0.2)	3 (0.1)	2 (0.1)	2 (0.1)	15 (0.6)	72 (2.8)	252 (9.9)
Humidity(%)	86%	85%	83%	76%	67%	64%	62%	57%	54%	55%	64%	80%
Rainy days (d)	21	18	18	9	2	1	1	0	0	2	8	18
avg. Sun hours (hours)	8.0	7.9	7.6	8.0	8.9	9.0	9.0	9.8	10.3	10.4	10.1	8.3

Figure 2-6 Monthly Max, Min, and average temperature in Benga

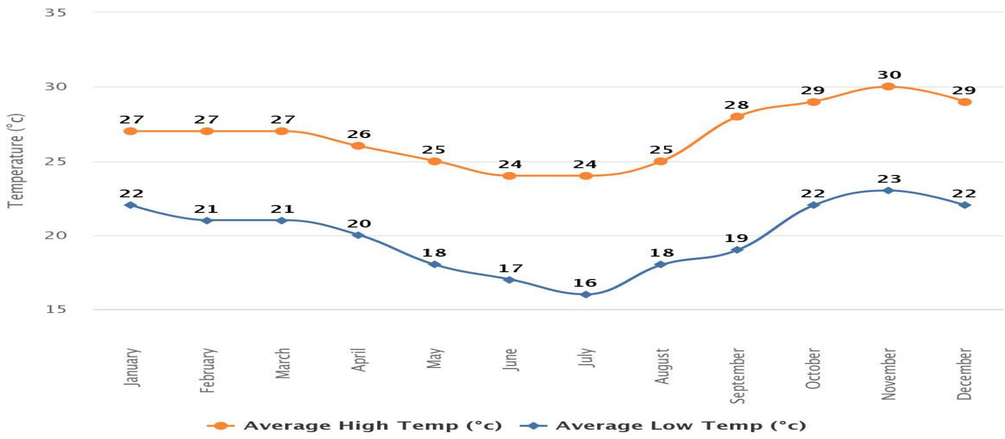


Figure 2-7 Monthly average high-temperature and low-temperature in Benga

Dew point	Max	Average	Min
Dew point	20.0°C	18.11°C	15.0°C

Table 2-1 Max, Min, and average of dew point in Benga

2-2-2 Precipitation

The difference in precipitation between the driest month and the wettest month is 346 mm | 14 inches.

Month	Day	Night	Rain Days
January	27°c	22°c	30
February	27°c	21°c	27
March	27°c	21°c	28
April	26°c	20°c	23
May	25°c	18°c	13
June	24°c	17°c	7
July	24°c	16°c	8
August	25°c	18°c	4
September	28°c	19°c	3
October	29°c	22°c	8
November	30°c	23°c	17
December	29°c	22°c	26

Table 2-2 The difference in precipitation

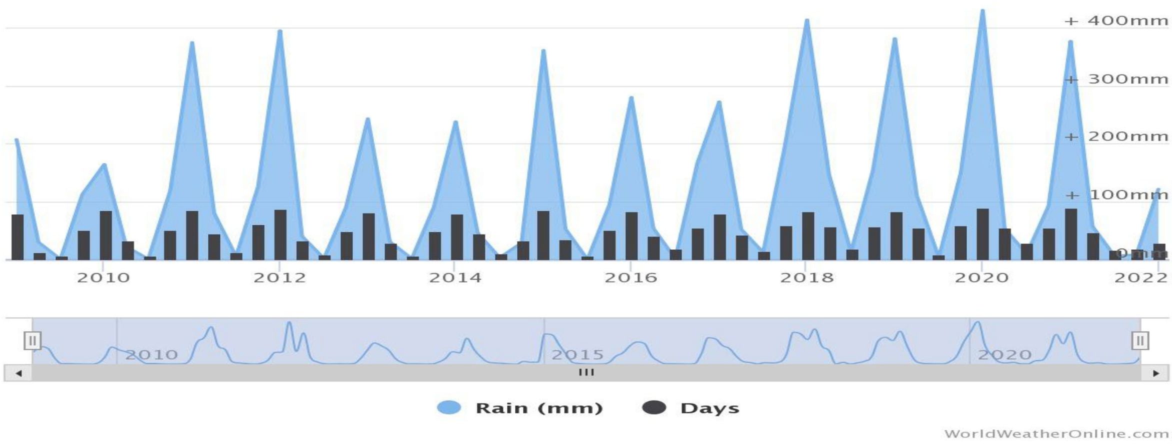


Figure 2-8 Rainfall and rain days

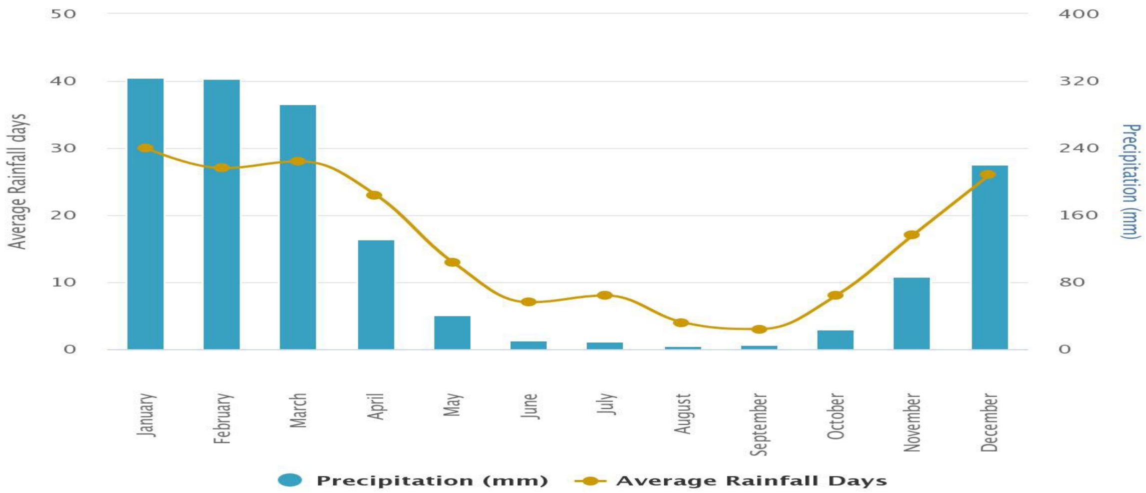


Figure 2-9 Monthly average rainfall

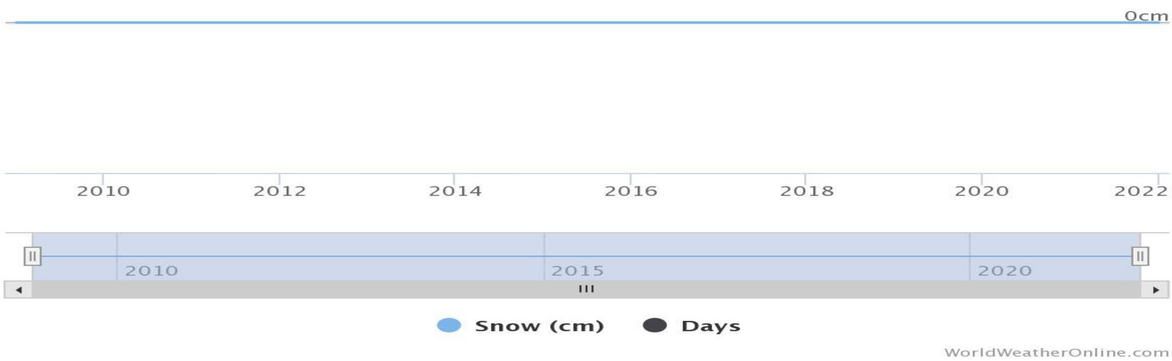


Figure 2-10 Snowfall and snow days

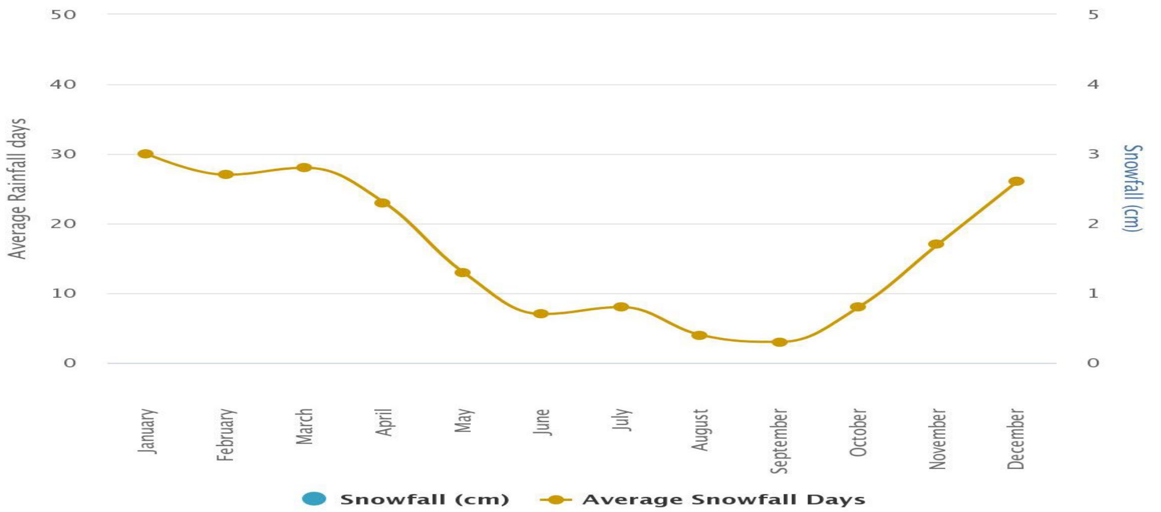


Figure 2-11 Monthly average snowfall

2-2-3 Wind

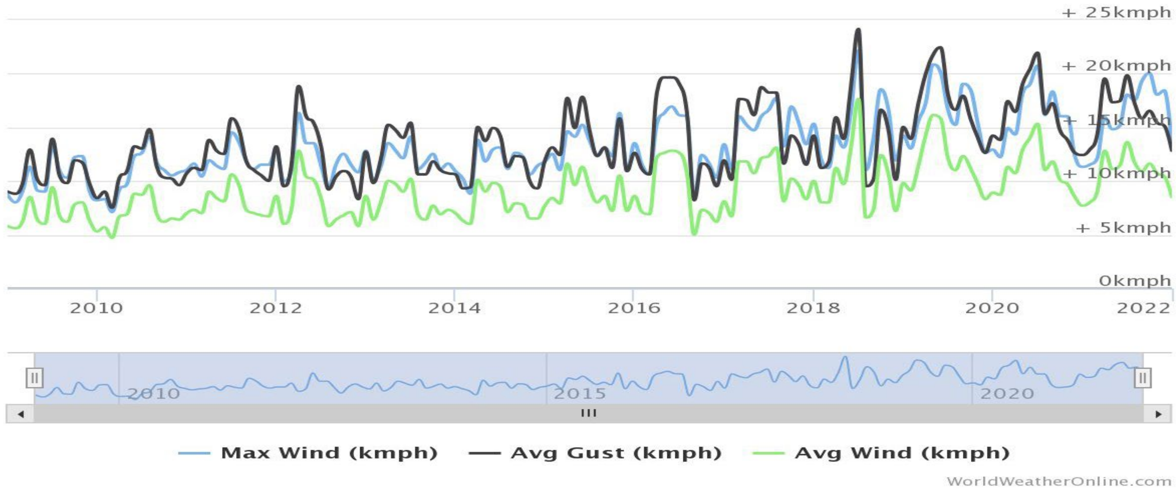


Figure 2-12 Max and average wind speed and wind gust

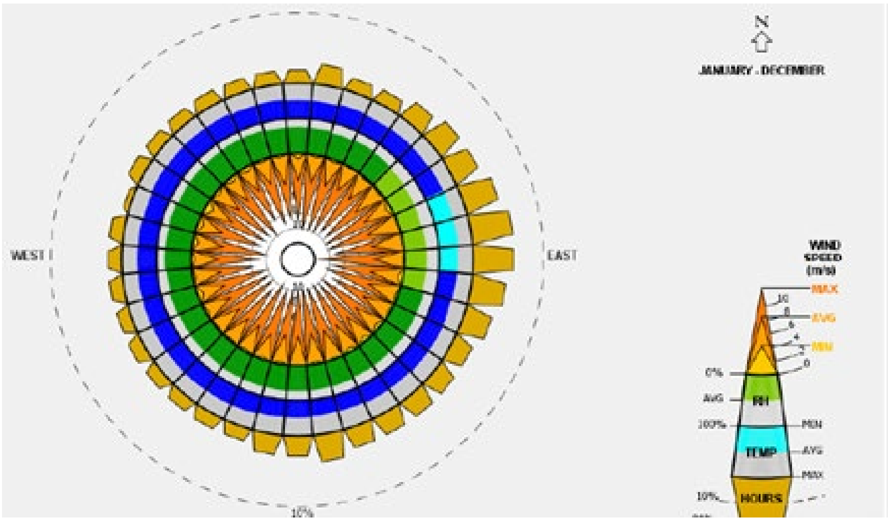


Figure 2-13 Direction of wind

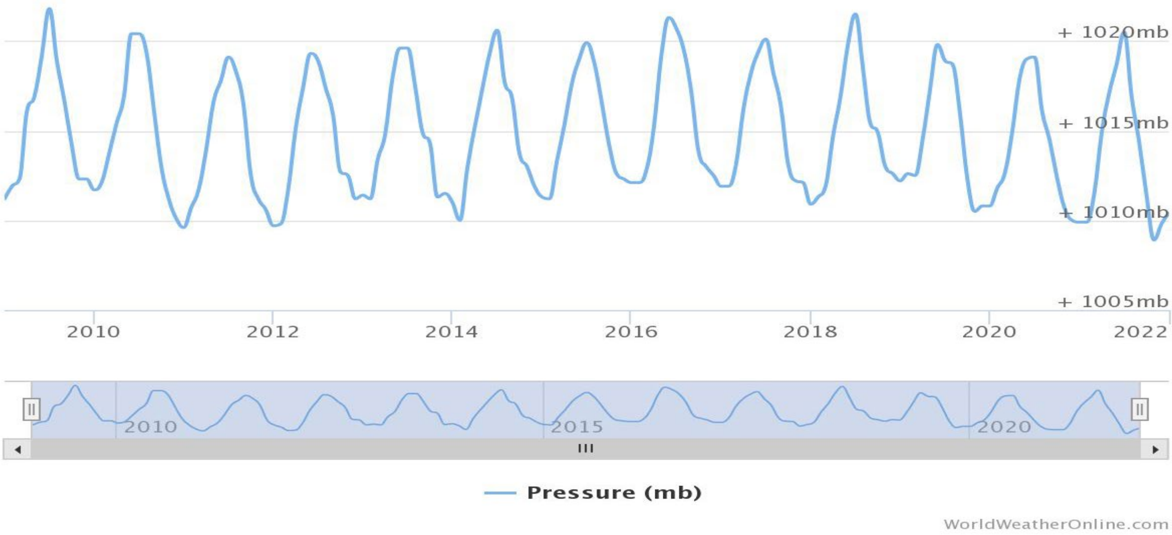


Figure 2-14 Average pressure

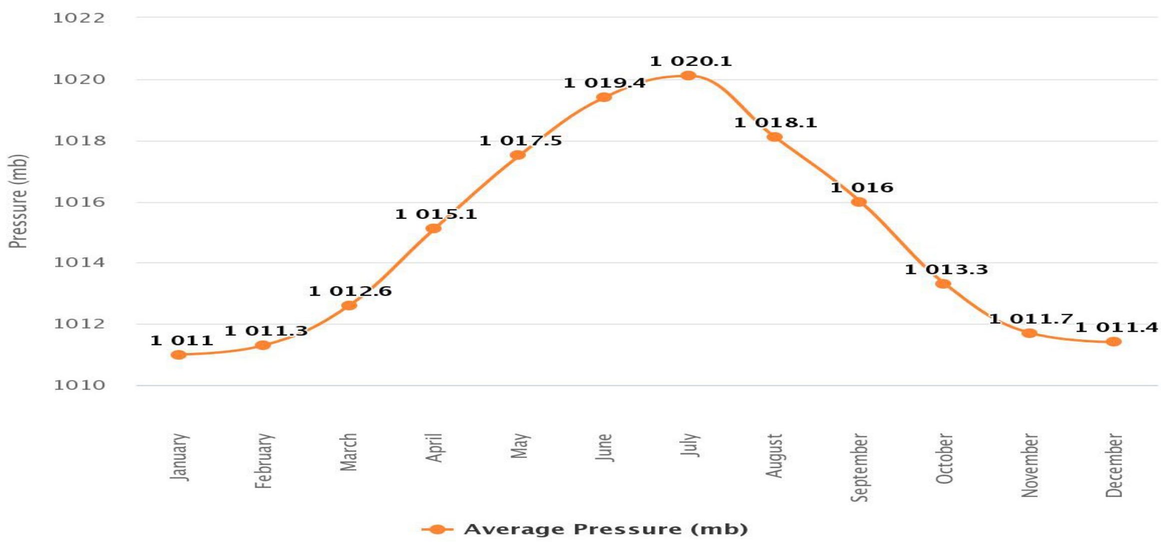


Figure 2-15 Monthly average pressure

2-2-4 Air humidity

The month with the highest relative humidity is January (85.97 %). The month with the lowest relative humidity is September (53.62 %).

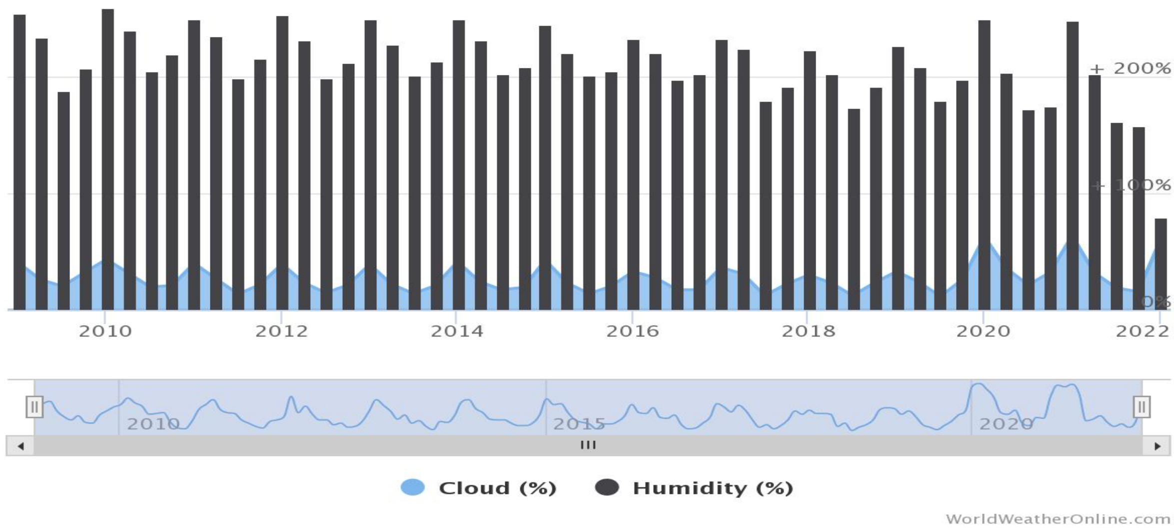


Figure 2-16 Cloud and humidity percentage

2-2-5 Solar radiation

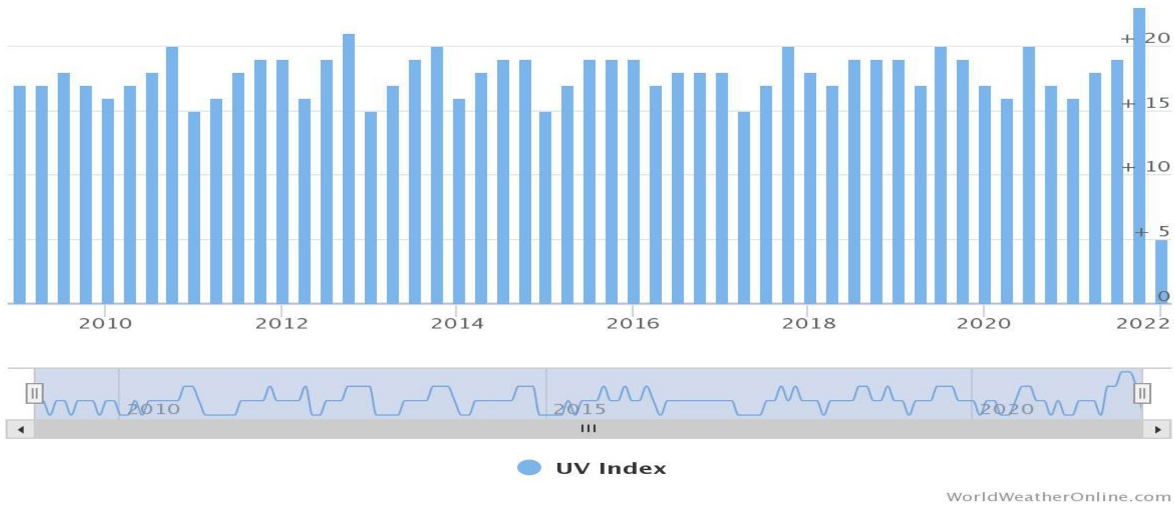


Figure 2-17 UV Index

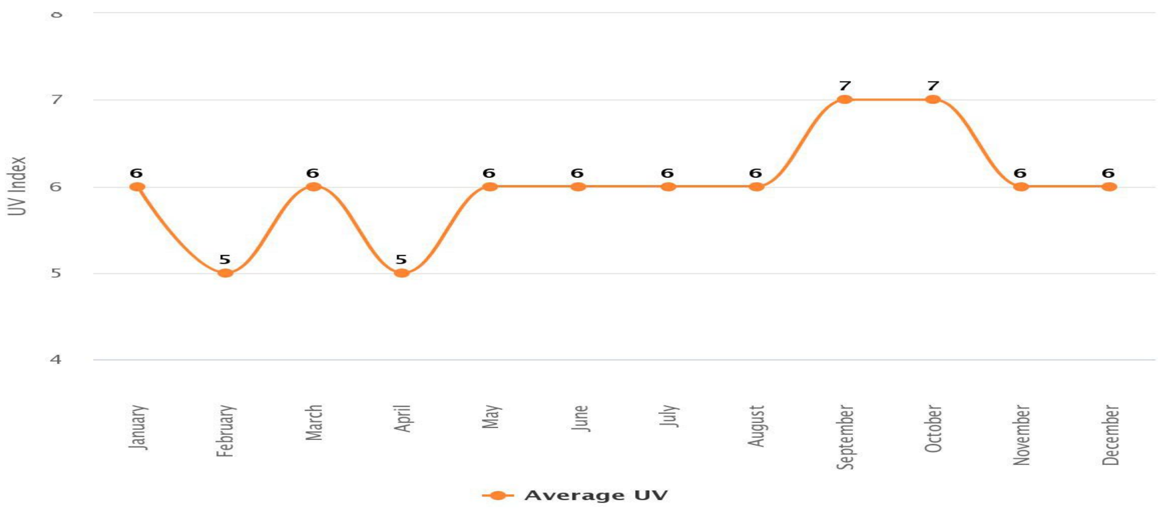


Figure 2-18 Monthly average UV

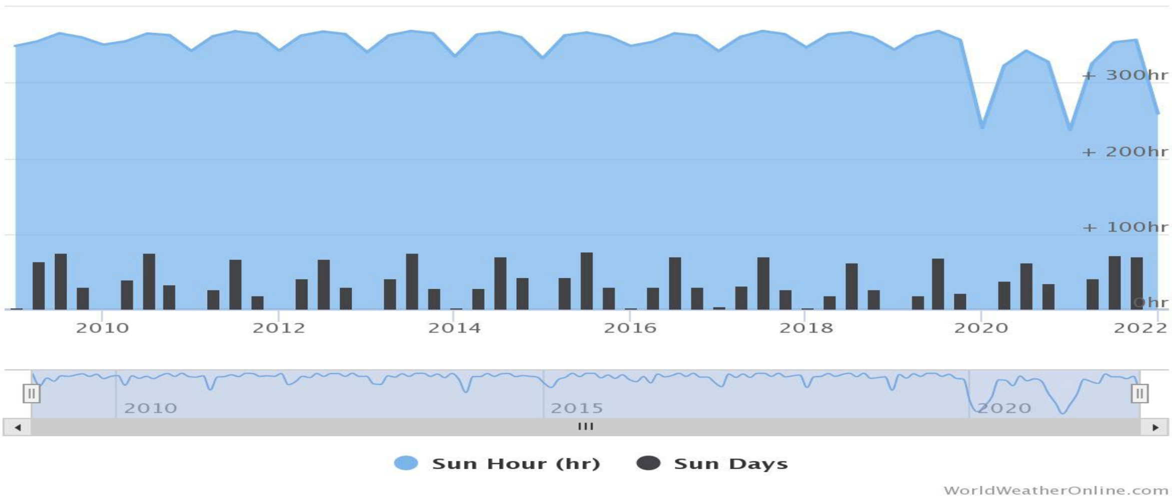


Figure 2-19 Sun hours and sun days

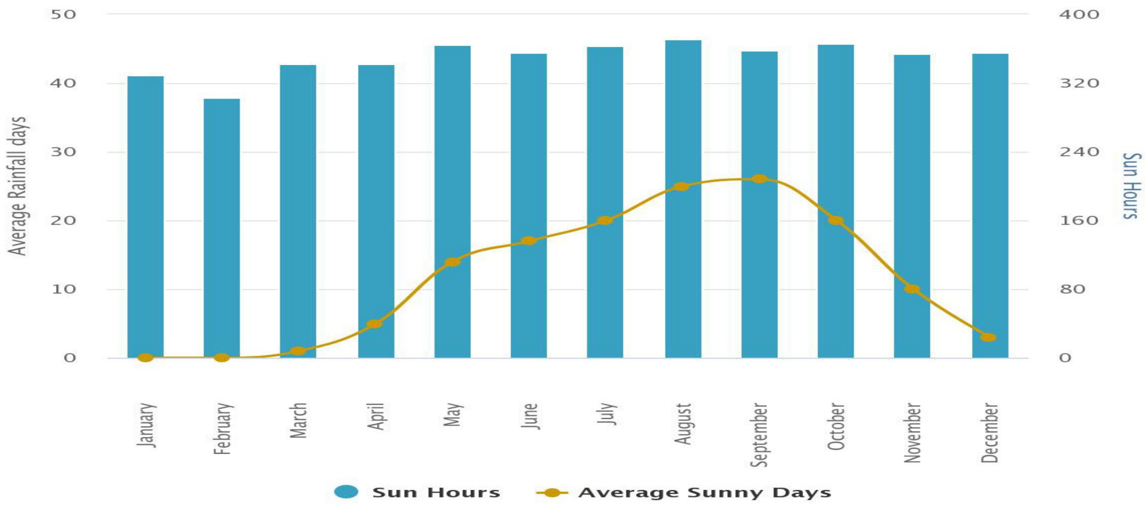


Figure 2-20 Monthly average sun hours and sun days

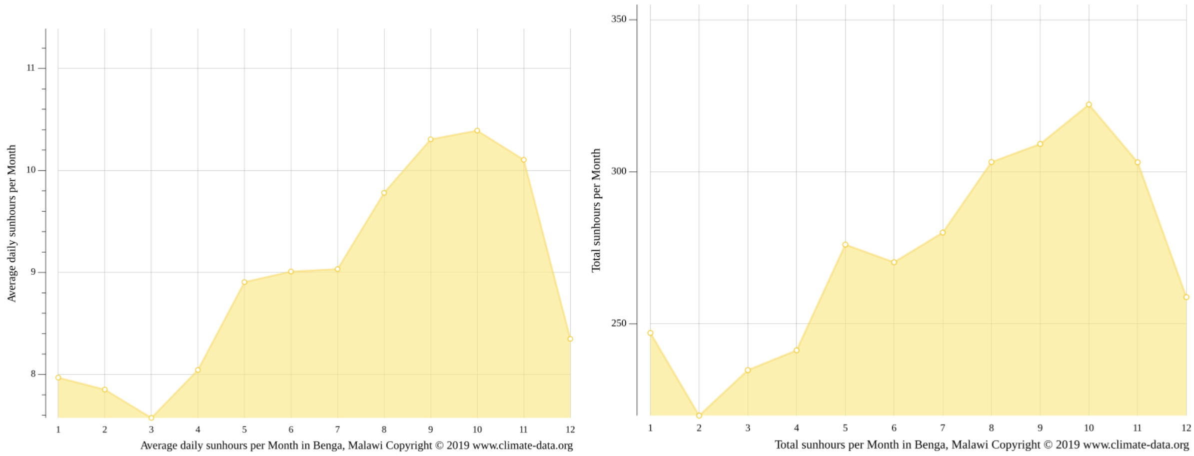


Figure 2-21 Hours of sunshine in Benga

In Benga, the month with the most daily hours of sunshine is October with an average of 10.39 hours of sunshine. In total there are 322.12 hours of sunshine throughout October.

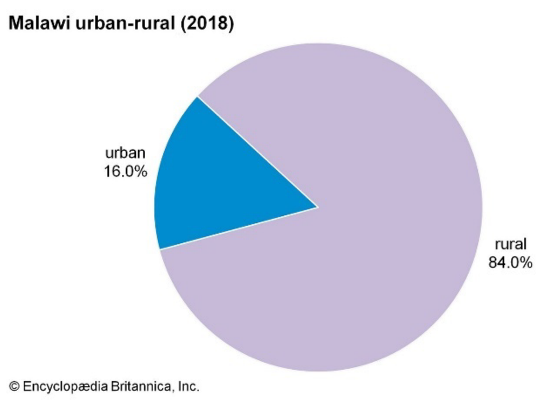
The month with the fewest daily hours of sunshine in Benga is January with an average of 8.35 hours of sunshine a day. In total there are 258.81 hours of sunshine in January.

Around 3265.76 hours of sunshine are counted in Benga throughout the year. On average there are 107.32 hours of sunshine per month.

2-3 Papulation

Malawi is a country with a population of 16 million people, where more than a million are orphans. It is one of the most densely populated countries in sub-Saharan Africa, and one of the least developed and poorest countries in the world.

It is also one of the least urbanized, with more than four-fifths of its people living in rural locations. It is urbanizing at a very rapid rate, however, with movement toward urban areas taking place at a pace far swifter than either the African or global averages.



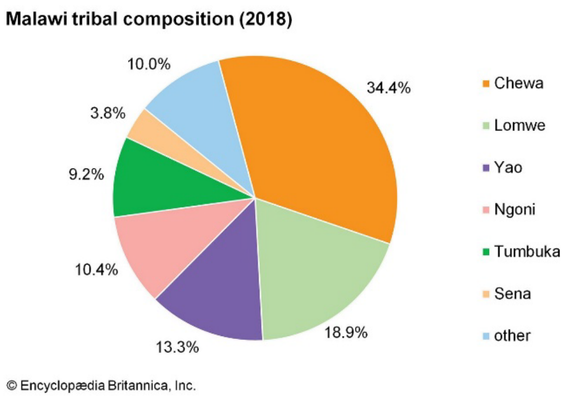


Figure 2-22 Malawi urban-rural Figure 2-23 Malawi tribal composition

the Chewa, Nyanja, Lomwe, Yao, Tumbuka, Sena, Tonga, Ngoni, Ngonde, and the Lambya/Nyiha. All the African languages spoken are Bantu languages. From 1968 to

1994, Chewa was the only national language; it is now one of the numerous languages used in print and broadcast media and is spoken by most of the population.

In 1996 government policy indicated that education in grades 1–4 would be provided in the students’ mother tongue or vernacular language; from grade 5, the medium of instruction would be English, which, though understood by less than one-fifth of the population at independence in 1964, continues to be used widely in business, administrative and judicial matters, higher education, and elsewhere. Other major languages include Lomwe, Yao, and Tumbuka.

The population is growing at a rate above average for sub-Saharan Africa. The birth rate is among the highest on the continent, but the death rate is also high, and life expectancy for both genders is significantly lower than the average for sub-Saharan Africa, primarily because of the incidence of HIV/AIDS. Nearly half the population is younger than age 15, and about three-fourths of the population is 29 or younger.

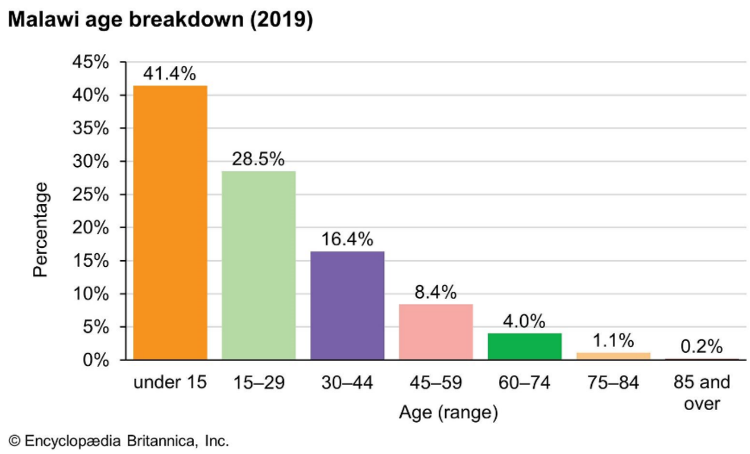


Figure 2-24 Malawi age breakdown

2-4 Economy

The backbone of the Malawi economy is agriculture, which in the 2000s employed more than four-fifths of the working population and accounted for about one-third of the gross domestic product (GDP) and most export earnings. Tobacco, the most important export crop, accounts for a major portion of the country’s trade income; tea, sugar, and cotton—all mostly grown in the estate sector—are also important.

Since the mid-1960s the government has sought to strengthen the agricultural sector by encouraging integrated land use, higher crop yields, and irrigation schemes. In pursuit of these goals, several large-scale integrated rural-development programs, covering one-fifth of the country’s land area, have been put into operation. These projects include extension services; credit and marketing facilities; physical infrastructure such as roads, buildings, and water supplies; health centers; afforestation units; and crop storage and protection facilities. Outside the main program areas, advisory services and educational programs are available. However, these schemes have brought little benefit to the smallholders, real growth instead being largely concentrated within the estate sector, which has been favored by the government. Many smallholders have remained poor and indebted, and smallholder production has generally not increased enough to meet the demands of the rapidly growing population.

2-4-1 Agriculture, forestry, and fishing

Agricultural products constitute a large proportion of Malawian export revenue; the most important of these are tobacco, sugar, tea, and cotton. Tea is grown on plantations on the Shire Highlands; coffee is produced mostly in the Shire Highlands and in northern Malawi, especially in the northeastern Viphya Mountains, and near Rumphi and Misuku. Tobacco, by far the most important export, is raised largely on the central plateau on large estates and by smallholders in various parts of the country. With the rise of worldwide campaigns against smoking, however, farmers have been increasingly encouraged to diversify so as not to be wholly dependent on tobacco.

Corn (maize) is the principal food crop and is typically grown with beans, peas, and peanuts (groundnuts) throughout the country by virtually all smallholders. Other important food crops include cassava (manioc), bananas, pulses, sweet potatoes, and rice; chickens, cattle, pigs, sheep, and goats are raised.

Although the major share of commercial crop production is on large estates, most farms are small, with the majority less than 2.5 acres (1 hectare) in size. Until the early 1990s, smallholder cash crops were purchased and marketed solely by the Agricultural Development and Marketing Corporation (ADMARC), which also dominated the fertilizer business. Because ADMARC kept a high proportion of the profits, this arrangement was to the disadvantage of smallholders, whose conditions improved little. In 1987 the ADMARC monopoly over smallholder produce was ended. Through schemes such as the United States Agency for International Development (USAID) Agricultural Sector Assistance Program, the government liberalized the production and marketing of smallholder tobacco. With greater control of their crop, growers' income from tobacco sales was significantly increased.

Beginning in the early 1970s, the government sponsored the development of several large timber and pulpwood plantations aimed at making the country self-sufficient in construction grades of timber; pine and eucalyptus have also been planted extensively in the northern Viphya Mountains to supply a large pulp and paper project in the region. Despite this, forest plantations account for only a fraction of the total Malawian forest cover.

The rapid rate at which wooded areas have been disappearing in Malawi is a source of grave concern. Between the early 1970s and the early '90s, more than half of Malawi's forested area was depleted, and, although the deforestation rate modestly decreased in the following decade, it nevertheless remained extremely high by relative standards. The use of wood as fuel is one major factor in the depletion of the country's woodlands. In rural areas, wood has always been used to provide fuel for cooking, and, as the population grows, more of it is used; in the urban areas, charcoal is the main source of energy, adding more pressure on woodlands. The heavily dominant tobacco industry has resulted in further denudation of forests, as trees have been regularly felled both as timber for the construction of sheds to dry or cure the crop and to fuel the curing process itself. Another source of the problem is brick making, which relies heavily on firewood to fire the kilns. The reduction of casual labour and the number of civil service positions at the behest of the International Monetary Fund (IMF) and the World Bank has meant forest reserves no longer have personnel to guard them from abuse.

Fishing is practiced for subsistence as well as by artisanal and commercial fisheries. The lakes and rivers of Malawi provide a diverse catch. Lake Malawi in particular is a rich source of fish within easy access for most of the country's population and accounts for some three-fourths of the country's catch. Other important sources include Lakes Chilwa, Malombe, and Chiuta and the Shire River. Although aquaculture is practiced, much of the country's total catch is obtained by capture, with artisanal fisheries accounting for the greatest proportion of that take. Some fish are exported to neighbouring countries. Since the late 20th century, the fish population has dwindled because of overfishing, the use of nets with a mesh size smaller than those recommended by fisheries experts, and the disregard of the ban on fishing in the breeding season. In response, natural resources committees have been formed in lakeshore communities to participate in the management of fisheries and the enforcement of fishing regulations.

2-4-2 Resources and power

Most of Malawi's mineral deposits are neither extensive enough for commercial exploitation nor easily accessible. Some small-scale mining of coal takes place at Livingstonia and Rumphi in the north and quarrying of limestone for cement production is also an important activity. Precious and semiprecious stones are mined on a small scale; these include agate, aquamarine, amethyst, garnet, corundum, rubies, and sapphires. Exploration and assessment studies continue on other minerals such as apatite, located south of Lake Chilwa; bauxite, on the Mulanje massif; kyanite, on the Dedza-Kirk range; vermiculite, south of Lake Malawi near Ntcheu; and rare-earth minerals, at Mount Kangankunde northwest of Zomba. Deposits of asbestos, uranium, and graphite are known to exist as well. Also under investigation are base metals, gold rutile, and ilmenite sands.

Arable land is considered one of Malawi's most significant natural resources, although it is strained by both the country's high population density and its agriculture-based economy. Forests and woodlands cover about one-third of the country, and almost 4,000 square miles (10,300 square km) are in state-controlled forest reserves.

Malawi's water resources are plentiful, although some rural areas are inadequately supplied. Treated water for the major cities of Blantyre and Lilongwe is supplied by the Walker's Ferry Scheme and the Kamuzu Dam, respectively. Most of the rivers are seasonal, but a few large ones, particularly the Shire River along its middle course, have considerable potential for irrigation and electricity generation. Power demands are met by hydroelectric schemes, including those at Nkula Falls, Kapichira, and Tedzani Falls, and by diesel plants. Major consumers of electric power include the industrial areas of the south near Blantyre, where electricity consumption has steadily multiplied, and the industrial area of Lilongwe; the vast sugar estates at Nchalo and Dwangwa also consume much electricity. By contrast, only a fraction of Malawians themselves have electrical access, and almost all domestic energy needs are met by firewood.

Power availability has been hindered by different factors. The drying of rivers due to deforestation near their sources and along their courses has resulted in a reduction of water flow into Lake Malawi, which in turn has adversely affected the currents of the Shire, on which the Nkula and Tedzani hydroelectric plants are located. The devaluation of the Malawi kwacha has also had some effect on electricity supply in the country, as spare parts can be expensive and difficult to obtain. These factors have at times led to load shedding of electricity and therefore an irregular availability of power.

2-4-3 Trade

More than two-fifths of Malawi's foreign-exchange earnings are derived from exports of tobacco, of which Malawi is a leading producer. Sugar, tea, and cotton are also major exports. Principal imports include chemicals and chemical products, petroleum products, consumer goods, machinery and transport equipment, and food. South Africa is Malawi's most significant trading partner. Other trading partners include China, the United States, India, and neighboring African countries.

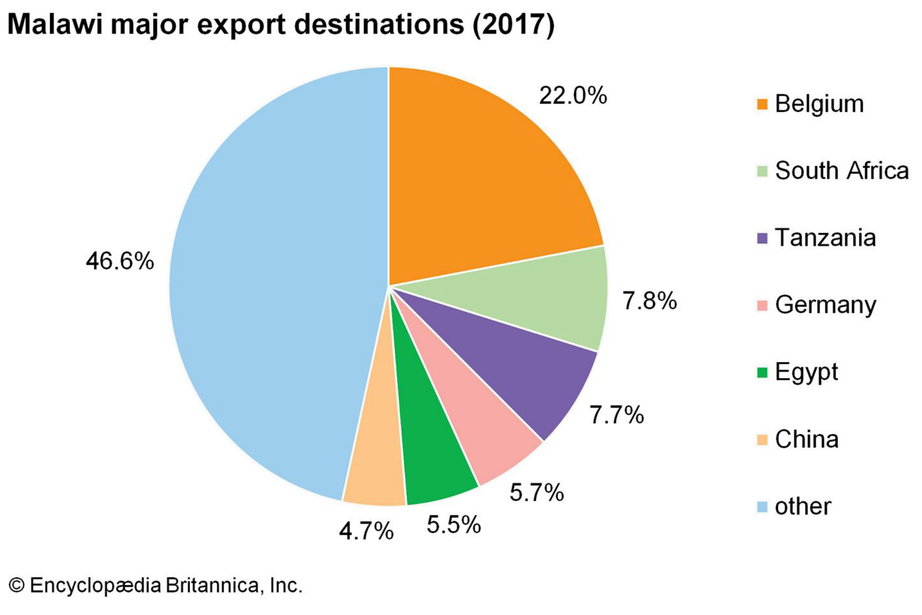


Figure 2-25 Malawi major export destinations

2-5 Culture

2-5-1 Daily life and social customs

Many Malawians observe holidays celebrated by Christian societies throughout the world, including Easter and Christmas. Holidays celebrated by the Muslim community—including ʿĪd al-Fiṭr, which marks the end of Ramadan, and ʿĪd al-Aḍḥā, which marks the culmination of the hajj—are governed by the lunar calendar. In addition to these, other holidays include John Chilembwe Day on January 15, in honour of the missionary who was a forerunner of Malawian nationalism; Martyrs' Day on March 3, commemorating those who lost their lives in a 1959 uprising against the British colonial administration; Freedom Day on June 14, in honour of the many Malawians who struggled for the country's transition to a multiparty democracy during the early 1990s; Republic Day on July 6, commemorating Malawian independence; Labour Day on May 1; and Mother's Day, which is celebrated in October.

2-5-2 The arts

Various traditional arts and crafts, including sculpture in wood and ivory, form part of Malawi's material and aesthetic culture. A variety of musical forms, both local and international, are also important. One of the most distinctive features of Malawian culture is the enormous variety of traditional songs and dances that feature the drum as the major musical instrument. Among the most notable of these dances are ingoma and gule wa mkulu, performed by men, and chimtali and visekese, performed by women.

Through domestic broadcasts and international broadcasts received by way of shortwave radio, Malawians—especially those of the younger generations—have always been part of world pop culture and enjoy many international musical artists. Western popular music forms a major repertoire on local radio. It is associated with the more modern urban nightclubs, and most town-based local artists play it rather than music with a strictly African-sounding beat. African styles of pop music are also very popular among all ages in Malawi, however, and, because of strong historical ties with South Africa, township music such as mbaqanga has always occupied a significant place in the Malawian musical culture. Equally notable is the popularity of Congolese music (a mixture of traditional African rhythms and instruments and those borrowed from other cultures), which, along with mbaqanga, tends to be played in both villages and bars in the urban centers.

2-6 Problems

Development of human capital contributes to the full participation of the socio-economic and political development of the country. Malawi has recognized that it has poor social indicators, especially in the areas of health and education. This is evidenced by the high child and maternal mortality rates, child and maternal malnutrition, low life expectancy, poor access to water and health facilities, and low education quality.

In Malawi, the male-female ratio in schools, universities, and higher positions in public service and industry generally favors the male gender. In the past, parents assumed that the destiny of daughters was to get married, have children, and serve their husbands and society. Although such attitudes are changing rapidly, they partly explain why the gender imbalance exists. Matters concerning family planning were considered to be too sensitive to most Malawians, and government was reluctant to intervene in spite of the growing population. Women, many of whom not only raised children but also tended food crops to support their families—in some cases without the assistance of their husbands—often bore the greater burden.

2-6-1 Agriculture

Current situation and major challenges of the sector:

The economy of Malawi is predominantly agriculture based. Agriculture accounts for 30 percent of Gross Domestic Product and generates over 80 percent of national export earnings. The agriculture sector employs 64 percent of the country's workforce and contributes to food and nutrition security1. Although there is potential for better production and productivity, the agriculture sector operates below its capacity. As a result, the country continuously faces food shortages at national and household levels. Malawi has also been hit by fall army worm attack in recent past and this has significantly affected production of maize. Some of the challenges the sector faces include vulnerability to weather shocks; poor management of land, water, and soils; low adoption of agricultural technologies; low access to finance and farm inputs; low mechanization and technical labor skills; a limited irrigation system and weak linkages to markets.

In recent years, Malawi has made efforts to develop agricultural markets. These include increased liberalization, development of rural marketing infrastructure and agricultural market information systems, and the establishment of commodity exchanges. Despite these efforts, agricultural marketing systems in Malawi are still rudimentary, and in some cases, missing markets persist, especially in rural areas. Most farmers continue to have limited information on prevailing market prices. As a result, traders take advantage of this and purchase from the farmers at a lower price far much below the set farm gate prices by the government.

2-6-2 Education

Current situation and major challenges of the sector:

The Malawi education system is classified into basic, secondary and tertiary levels which follows an 8-4-4 system. Primary education takes 8 years, secondary 4 years and tertiary ranges from 2 years for a certificate to 4 or 5 years for a first degree. Basic education comprises of early childhood development, out of school youth, adult literacy and primary education. Early Childhood Development caters for children aged zero to eight. ECD is under Ministry of Gender, Children Development and Social Welfare. Entry age to primary is 6 years. Reinforcement of this policy has been a daunting challenge leading to entry of underage children who overcrowd the schools and classrooms which are already direly resourced with teachers and teaching and learning materials causing effective teaching and learning challenging. Currently, overall enrolment for 2020 is at 5.4 million registering an annual increase of 3 percent from enrolment of 5.1 million in 2019 (MoE 2020). High enrolments are experienced at primary with 91% percent net enrolment rate but as low as 55 percent completion rate and 38 percent transition rate to secondary education. Higher education is over restrictive less than 1 percent gross rate of eligible candidates attending higher education. Double shifting, open learning and distance learning have been some of the solutions to increase access. However, quality of these services has been a challenge and many students shun away from these education modes.

2-6-3 Water

Current situation and major challenges of the sector:

In Malawi, there is a growing national demand on water resources and concern on its availability due to national population growth and dwindling water sources, particularly during the dry season hence there is need for better management of the water resources. The government has placed a high priority on irrigation and water resources management in order to ensure food and water security at household level through among other things enhancing water-harvesting technologies, promoting catchment protection and management including disaster risk reduction measures.

Overall, 88.3% of the national population has access to improved water source. A household is considered to have access to improved drinking water source if it is piped into the dwelling, piped into the yard or plot, collected from a communal standpipe, a protected well in yard or plot, protected public well, borehole, tanker truck or bowser and bottled water, according to the Fifth Integrated Household Survey (IHSS) 2020 Report. This is a higher access as compared to 85% in 2018/2019 financial year which was lower than in 2017-18, the decline was attributed to damage caused by floods and drought which casted some doubt if Malawi is to achieve the SDG's.

Currently water resources development accompanying rapid water demand in urban and peri-urban areas due to rapid population growth is a serious problem in Malawi. A total Malawian population increased by 35% between 2008 and 2018 representing an intercensal growth rate of 2.9% per annum and for Lilongwe city, it is 3.8% and Blantyre city 2.0% according to National Statistics Office (NSO), 2018.

According to Water, Sanitation and Hygiene (WASH) sector Joint Review Meeting Report (2019) the sector faces daunting challenges in meeting its objectives, and key among them are: (a) poor revenue collection efficiency for the water boards due to huge government unpaid bills. (b) there is an increase in non-functionality rate of rural Water Supply Systems due to the occurrence of the Cyclone Idai which damaged most of rural water supply infrastructures. (c) inadequate allocation of finances to the water department by the GoM; (d) limited capacity in the water and sanitation sector at the Ministry and in the districts with a vacancy rate of 62.2%, there are few local NGOs active in WASH sector; (e) deforestation and environmental degradation of catchment areas for water supply which is rendering quantity of water insufficient and quality of water bad, dwindling water sources; (f) high levels of non-revenue water for water utility companies which are estimated to be around 35% due to ageing infrastructures; (g) vandalism of water supply facilities and water monitoring equipment (h) inadequate evidence based formative research to support policy formulation, and (i) inadequate coverage due to increasing water demand as a result of population growth especially in urban areas and in peri-urban areas.

2-6-4 Transportation

Current situation and major challenges of the sector:

Malawi has a very limited transport system, and it is one of the lowest in the Southern African Development Community (SADC) region. As a result of all these problems, the country faces high transport costs (average cost in the region of US$7 per ton per km and Malawi with a cost of US$7 to US$10) rendering economic and social development difficult. However, there is an attempt to invest in aviation; rejuvenation of the rail subsector is also a target of the Government of Malawi as well as continued expansion of the road's subsector. The COVID-19 Pandemic is also severely affecting the sector. Many experts from development partners have had to return to their country of origin and the import of crucial materials especially for construction has proved to be more challenging as the movement of goods from country to country has slowed down.

Malawi's transport sector comprises of the following sub-sectors:

a) Road sub-sector: According to the Ministry of Transport Joint Sector Review (2018) The main method of transportation is by road with 90% of goods and 70 % of passengers using this method of transportation for local and international destinations respectively. Classified road network comprises 15,451 km of which only 26% (2,317.7 km) is paved.

b) Inland water transport extends from the northern to the southern region passing through the centre. Main ship ports are Monkey Bay in the south, which is also a ship assembling dock, Chipoka and Nkhota-kota in the central region, Nkhata Bay, and Chilumba in the northern region. There is no adequate private sector participation in this sub-sector. This led to slow development of the sub-sector over the years.

c) Rail sub-sector: In the early years of Malawi's independence, the main method of transporting goods was by rail. However, a lack of maintenance and investment into the rail sub-sector has led to a collapse of a lot of the infrastructure that had been there before. However, in 2017 Vale and Mitsui developed Nacala railway line from Moatize in Mozambique to Nacala passing through Malawi. This has led to the rehabilitation of old railway lines, which has made train movements easier. Currently, the section between Nkaya and Mchinji is undergoing rehabilitation with works expected to be completed by 2021. Once completed, a spur will connect to Chipata in Zambia thereby easing the movement of goods and passengers.

d) Civil Aviation sub-sector is very important for Malawi due to its landlocked nature but is still not well developed. There are only two international airports: Chileka in Blantyre and Kamuzu in Lilongwe. There are about 31 other airfields scattered across the country.

2-6-5 Environment

Current situation and major challenges of the sector:

The environment and natural resources play a very significant role in influencing social and economic development at both household and national levels. Environment and natural resources form a bedrock of Malawi's agro-based economy. However, the degradation of the environment and natural resources in Malawi is due to many factors including deforestation, decreasing soil fertility and increasing erosion, water depletion, loss of biodiversity, increasing pollution and increased vulnerability to climate change. The degradation of the environment and natural resources continue to be a major threat to the social and economic development of Malawi. The success of many important sectors of the economy relies on environment and natural resources to enhance their productivity. It is estimated that Malawi is losing about $190 million annually due to unstainable use of natural resources. Therefore, it is important to address the factors that lead to environmental degradation and work to conserve and restore the environment.

Environment and natural resources comprise of many components. This paper mainly focuses on forest conservation, with emphasis on soil and water conservation. The main drivers of forest degradation in Malawi are charcoal production, firewood production, infrastructure development, timber production and agricultural expansion. Forests provide essential services that are critical to preventing land degradation and climate change as well as conserve wetlands and freshwater systems, which are a foundation of rich biodiversity. The soil and water conservation play an important role in supporting sustainable livelihoods and reducing environmental degradation. Malawi continues to lose soil and water due to unstainable use of these natural resources. Improved land management practices like soil and water conservation have been suggested as a key strategy to reduce land degradation and sustain soil quality. The loss of soil and water cause the decline in the productivity of these resources capacity to perform their functions. This among others, affects the generation of electricity due to low water levels and silt deposits in Shire River. Improved land management practices like soil and water conservation have been suggested as a key strategy to reduce land degradation and sustain soil quality.

2-6-6 Energy

Current situation and major challenges of the sector:

Malawi has a very low national electrification rate estimated at 12.0 percent - the lowest in the Southern Africa Development Community (SADC) region. It trails Madagascar and Mozambique which are at 23% and 24% respectively. Rural and urban electrification rates are estimated at 3.9% and 48.7%, respectively1. Installed generation capacity (as of October 2017 was 367.3 MW (350.8 MW being hydro and 16.57 MW thermal diesel generators run by the Electricity Generation Company (EGENCO) Limited against a peak demand of over 470 megawatts2. The main source of electricity is hydropower which generates about 95% of the power in this country. In order to meet the fast-growing demand for energy, EGENCO has projected to increase generation capacity to 521.5 MW by 2024 to 1,256.5 MW by 2029 and to 1,631 MW by 2034. Three of the four hydropower generating stations are situated along the Shire River in the southern region of the country.

Apart from the low energy generation capacity, there is also a problem of insufficient transmission and distribution facilities. As a result, of all these problems, the country faces frequent power outages rendering economic and social development difficult.

Two natural challenges have emerged in the sector, namely: (i) effects of climate change which are leading to less rainfall and therefore less water available for generating power; and (ii) environmental degradation. One of the causes of this environmental degradation is deforestation which is leading to siltation of water intakes at hydropower stations.

Considering the challenges and future projections, the following actions need to be taken in the energy sector.

· Firstly, the government needs to increase the rate of electrification for economic and social development.

· Secondly, in order to increase access to electricity so that the set target is met, it is necessary to produce sufficient power.

· Thirdly, the government needs to increase and strengthen transmission and distribution facilities.

2-6-7 Disaster

Current situation and major challenges of the sector:

Disasters are distinguished in terms of their nature and extent of impacts. Globally, disasters continue to increase in many countries, affect the economy of the affected countries and attack vulnerable areas where it affects those in lower income brackets. The report by Economics of Climate Adaptation Working Group (2009) on 'Economics of Climate Adaptation, shaping climate-resilient development', projected that the global average for annual economic losses resulting from natural disaster is expected to increase from US$340 billion in 2009 to US$415 billion by 2030 for urban infrastructure alone. These disasters are considered to be caused due to climate change, increasing urbanization and environmental degradation. The United Nations International Strategy for Disaster Reduction, in its 2015 report on "The Future of Disaster Risk Management, Global Assessment Report on Disaster Risk Reduction" projected that globally, on average, about 218 million people are affected by disasters each year.

Malawi is highly vulnerable to the impacts of disasters given its location along the great African Rift Valley, rapid population growth, unsustainable urbanization, poor settlement patterns, weak buildings/infrastructure, lack of access to information and knowledge, climate variability and environmental degradation. The most common weather-related shocks affecting Malawi include floods, drought, stormy rains, and hailstorms. Climate change further exacerbates the frequency and severity of disasters in the country. These disasters cause damage to infrastructure, food insecurity and increase poverty, loss of lives and property, decline in health status, poor environmental conditions, and a decline in the quality of education of affected populations.

Although there are many types of disasters, this paper mainly focuses on flood related disasters. The reason is that Malawi has experienced more floods than any other natural disasters. According to the 2019 Post Disaster Needs Assessment (PDNA) report, over the past five decades, Malawi has experienced more than 19 major floods and 7 droughts. Furthermore, the report from the National Disaster Risk Management Communication Strategy (NDRMCS) 2020 -2023, mentioned that about 15 out of 28 districts (which represent 54% of the districts) in Malawi are considered flood prone.

The main challenges this sector face include: (i) Insufficient levels of implementation for each planned activity due to inadequate financial resources. (ii) Poor coordination among stakeholders and lack of information sharing, including with respect to risk assessment, monitoring and evaluation, early warning, disaster response and other Disaster Risk Management (DRM) activities.

Chapter 3

Case studies

3-1 Lycée schorge

Lycée schorge

Architect: Diébédo Francis Kéré

Typologies: school and high school education

Date: 2014 - 2016

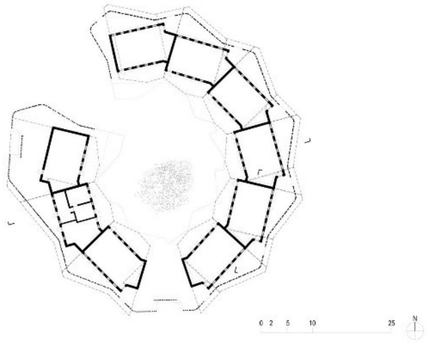
Location: Koudougou, Burkina faso

Located on the outskirts of Koudougou, the third most populated city of Burkina Faso, the new Lycée Schorge building draws inspiration from traditional settlements in this part of West Africa, offering reinterpretations of vernacular building materials and systems on a contemporary note.

From a typological point of view, the secondary school is formed like a 'village' that closes in on itself.

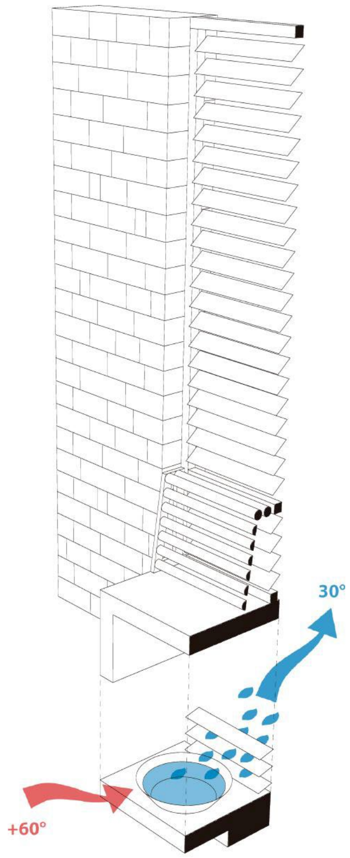
Creating a sort of autonomous ‘village’ condition, the radial layout of classroom modules wraps around a central public courtyard. This configuration not only creates privacy from the main public domain, but it also shelters and protects the inner courtyard from wind and dust. An amphitheater-like condition at the center of the courtyard will accommodate informal gatherings as well as formal assemblies and celebrations for the school and community.

The classrooms, protected by a perimetral lattice, are arranged around a space that acts as a communal and representative central court. This whole layout resonates with the materials and construction methods used.

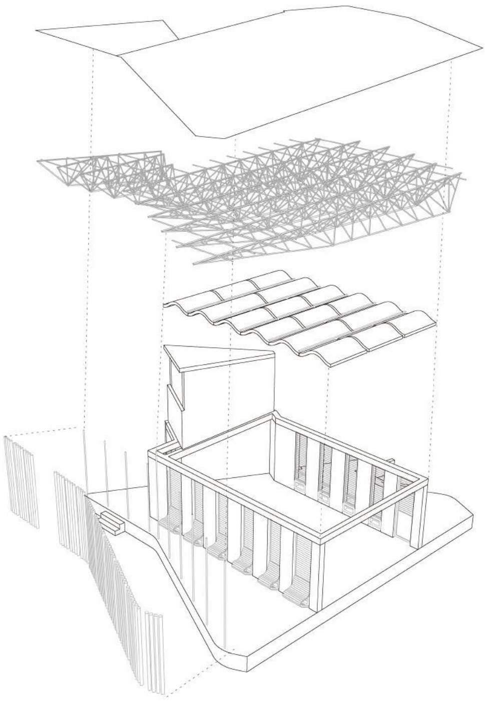


The walls of these modules are made from locally harvested laterite stone, which, when first extracted from the earth, can be easily cut, and shaped into bricks. When the stone is left exposed to the atmosphere above ground, it begins to harden. The material functions well as a wall system for the classrooms because of its thermal mass capabilities. This, in combination with the unique wind-catching towers and overhanging roofs, lowers the temperature of the interior spaces exponentially.

Wrapping around these classrooms like a transparent fabric is a system of wooden screens. This secondary façade is made from a local fast-growing wood and acts as a shading element for the spaces immediately surrounding the classrooms. The screens not only function to protect the earthen classrooms from corroding dust and winds, but they also help to create a series of secondary informal gathering spaces for the students as they wait to attend their classes.

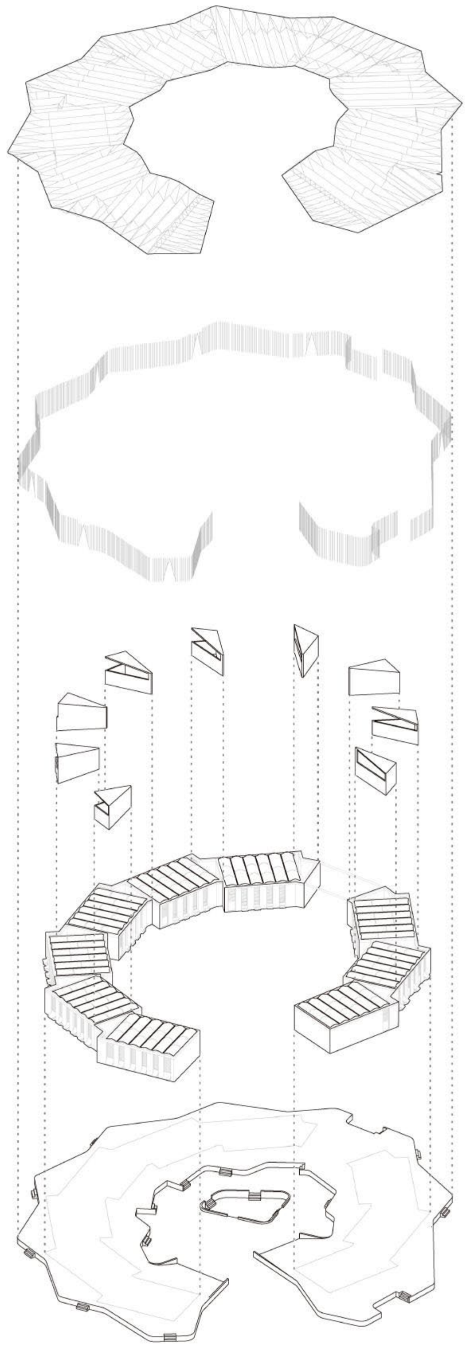


Another major factor that helps to naturally ventilate and illuminate the interiors is a massive undulating ceiling. The wave-like pattern of plaster and concrete components are slightly offset from each other, allowing the interior space to breathe and expel hot stagnant air. The off-white color of the ceiling serves to diffuse and spread around indirect daylight, providing ample illumination during the day while keeping the interior learning space protected from direct solar heat gain.



In order to maximize the material transported to the site, the school furniture inside the classrooms is made from local hardwoods and leftover elements from the main building construction such as steel scraps from the roof. In this way, the economy of the building is extended by reducing waste adding additional value to the cost of construction.

Overall, one of the most important goals of the design is to serve as a catalyst for inspiration for the students, teaching staff, and surrounding community members. The architecture not only functions as a marker in the landscape, but it is also a testament to how local materials, in combination with creativity and teamwork, can be transformed into something significant with profound lasting effects.



3-2 Legson Kayira

Architect: Architecture for a Change

Typologies: Community Center and Primary School

Date: 2014

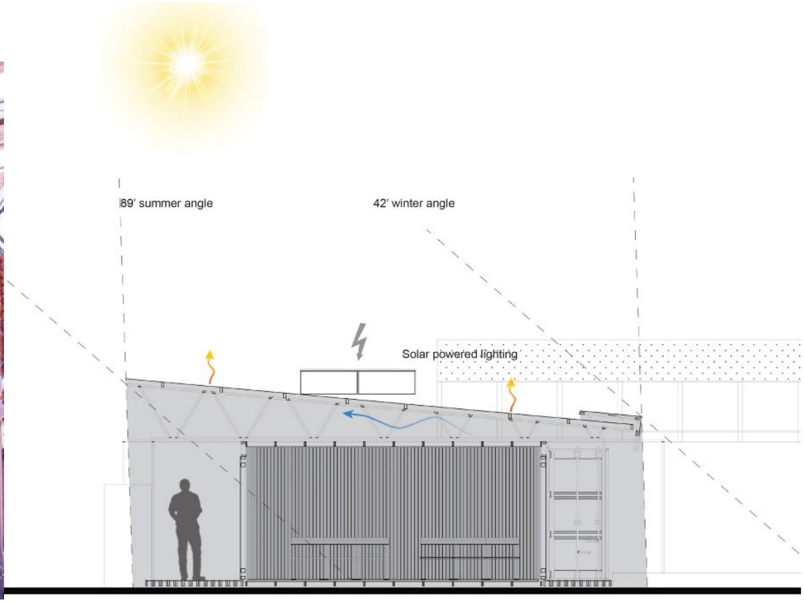
Location: Chimpamba, Malawi

This building explores the possibility of the school as a covered canopy. It offers a larger covered area that provides shade, open, well-lit, and well-ventilated spaces. The structure becomes very efficient in terms of material vs. covered square meterage and becomes itself a visual icon.

Shade netting, lightweight steel, local masonry, and corrugated iron form the architectural language of the building. Local masonry is used to create vertical louvers on the exterior of the classrooms to act as shading devices and structural support for the roof. The roofs have a slight fall to drain water into the gutters which feed the water tanks.

Furthermore, the building includes the use of refurbished shipping containers as these are structurally sound elements that have duality of function. Firstly, as a transportable element, and secondly, as a shell and anchor for a new structure.

One side of the container is removed, locally manufactured bricks and pavers will be incorporated into the structure. By utilizing locally manufactured materials, it provides the people with a sense of ownership and softens the container as a foreign contextual element. The over-all feel of the building is light yet permanent and with the outer facade adjustable, provides the user with freedom in terms of spatial layout and climatic comfort.

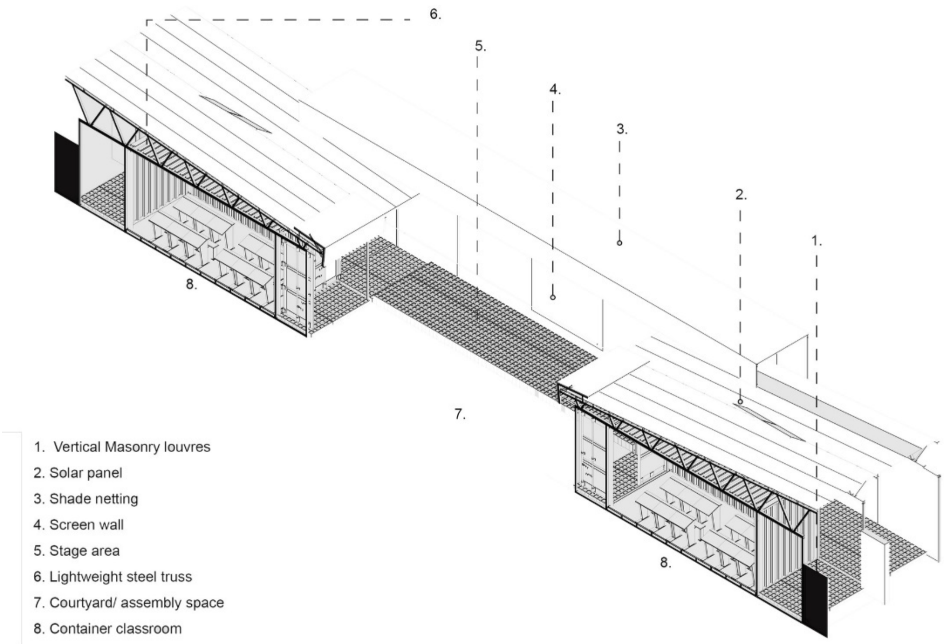



The addition of more containers makes the possibilities endless. The function of the building is not limited to a school but can double as a community building or marketplace. These schools will act as beacons within the community, providing hope through learning, shelter through built infrastructure and nourishment through harvested rainwater to sustain subsistence farming initiatives.

Each classroom has open-able partition Louvre walls covered with shade-netting. These side louvers can either be in a vertical or horizontal position. When in a vertical position, the space becomes more private and sheltered but still allows for cross-ventilation. The horizontal positions provide more shaded area and extends the space beyond the buildings boundaries and allows more natural light into the spaces.

A digital projector is stored in the container and mounted when needed at night. The courtyard/ assembly space then becomes the seating/ viewing space for movies or soccer games. The projector and laptop are powered by solar energy stored during the day.

Sectional Axo



The school was pre-manufactured in the Architecture for a Change workshop in South-Africa. The whole school structure was packed into 46m containers and delivered to site in Malawi. This was mostly done for quality control, availability of materials and due to expensive material cost in Malawi. The school was then assembled in 8 weeks.

The site architect (John Saaiman) trained a local team on site with valuable skills and employed the local community during the construction process. The local bricks that were used have been laying on site for many years as the local community made them in hope that someone would fund a school.

The main structure consists of light-weight steel framing and concrete footings. The school is completely of the grid and harvests rainwater.

3-3 Burckhardt Partner's Vaulted Brick School

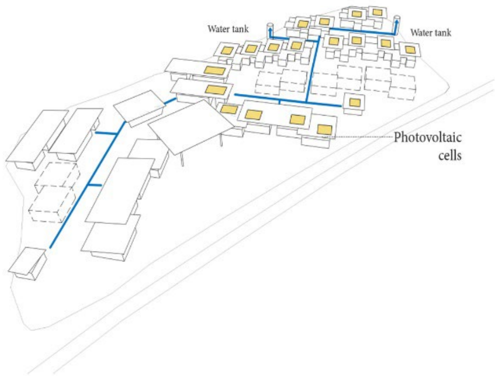
Location: Chimpamba, Malawi

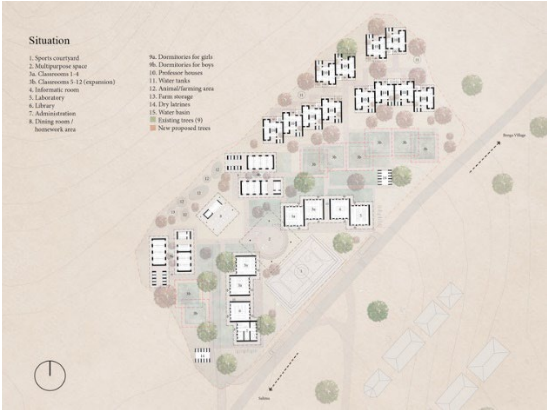
Burckhardt + Partner has released details of their proposed secondary school in Malawi. Finalists in a competition for the school's design, the Burckhardt + Partner scheme embodies the old African proverb that it takes a community to educate a child, rather than simply the walls, roofs, and books of a school. The St. Paul's new secondary school therefore embraces its community, inviting the adjacent parish and primary school to grow together as a village.

The "village" is an agglomeration of different uses, such as classrooms, dormitories, and houses. Though the program varies, all parts are built in the same way: variations or combinations of one single constructive unity respecting local resources and traditions.

The school's walls are built from compressed clay bricks made by the local community. The bricks are 20x40x20cm, forming dramatic modular vaults covered by a light metal truss and tin metal roof. As well as ensuring water and heat protection, and rainwater harvesting, the tin roof also allows the implementation of solar panels. Terracotta floors are made from compressed soil according to local traditions and techniques.

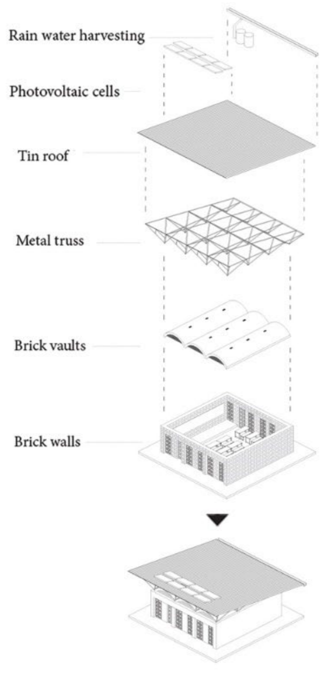
Resources Strategie



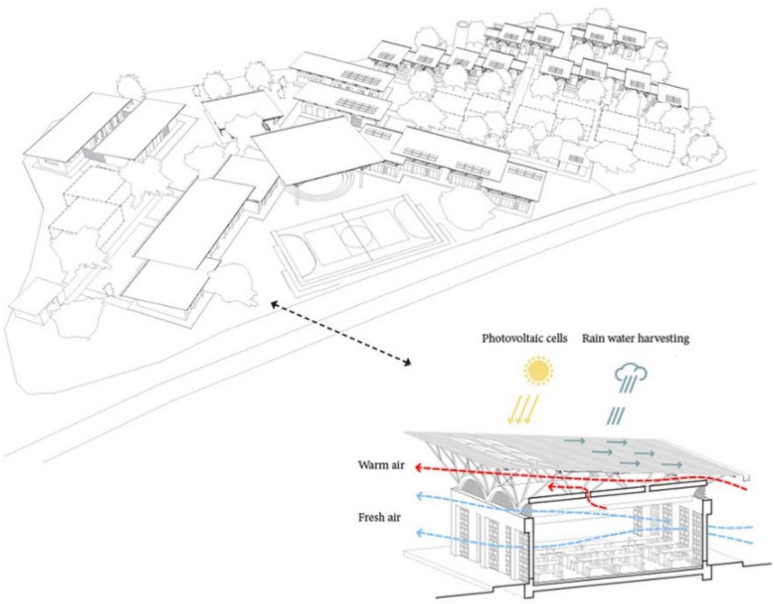


The aim of the material palette is to profit from local resources and techniques, enhanced by technological thinking. A radial settlement concept plays a big role, allowing occupants to build gradually, when necessary, in a well-orchestrated sequence. The radial organization of the program also follows the existing topography, allowing the heart of the plot to open up to the wider community. The inner "heart zone" contains a sports courtyard serving the entire community and an open multipurpose space for gatherings and performances. Classrooms and complementary programs of the school are evenly distributed at either side of the scheme, promoting dialogue, exchange, and constant use of the central courtyard.

The Unity



Concept



3-4 Green School

Architect: GASS Architecture Studios

Typologies: Educational architecture, School

Date: 2021

Location: South Africa

Green School South Africa, is an eight-hectare sustainable schooling campus located in the low-lying Paarl Valley in the Western Cape, spatially defined by the Paarl Berg to the north, Drakenstein Mountains to the east and south, and Simons Berg towards the southwest. The spatial arrangement at a macro level is what inspired the space making, but also down to the individual buildings and spaces between them.

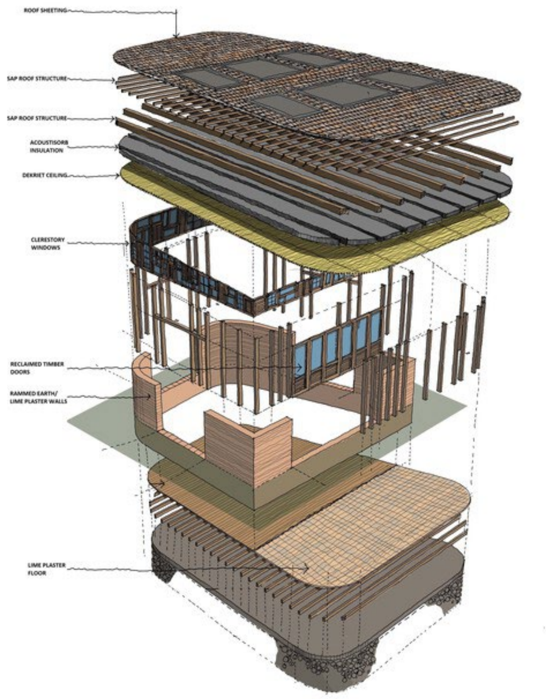
The reoccurrence of multiples at incremental scales is an idea that defines the behavior of most natural systems. The architecture of the individual buildings is defined by organic tectonic shapes originating from the mountains that contain the valley but also more directly from the Paarl Berg Boulders. These solid shapes are arranged to accommodate the programmatic need of each of the individual buildings.

The first phase of the campus was completed in February 2021. Which constitutes various clusters of buildings nestled amidst orchards, vegetable gardens, walkways, landscaped terraces, and spill-out spaces. These buildings include 16 classroom facilities for children ranging from kindergarten to Gr 8, the Sangkep (Balinese term for a multipurpose space), an Administrative Building and the Heart of the School. The individual clusters of buildings are weaved together by landscaping and a series of organic shaped 'werf' walls to create a coherent whole, and a world of passageways and spaces for students to discover.


Upon arriving at the school, a landscaped gabion wall leads the visitor to the Administrative Building that sits on the main axial circulation spine of the campus, linking the more public buildings together. These buildings include the Sangkep, tree-lined Market Area, Deli, Co-Working Space and Heart of the School. The Heart of the School is the center of the precinct where all the paths converge. The building is defined by three boulder-like shapes defining the path leading from the arrival plaza. One side of the building contains the Dining Hall, Life Lab, and Kitchen, and the other a Library, Art and Music Studio and Ablution Facilities.

The main circulation spine branches off into carefully considered meandering routes, to create moments of excitement, wonderment, and discovery. These secondary routes lead to the Primary School and Kindergarten where both spill out in landscaped courtyards. The Kindergarten Cluster is sheltered and hidden by landscaped berms, and the walkway is covered with a hand-woven sapling growing tunnel.

The positions of the different zones and buildings have been carefully considered, considering passive design principles, feng shui and the seven petals provided by the Living Building Challenge. The result is harmonious spaces where humankind and nature can reconnect. To further enhance this idea, the building walls are kept to a minimum to allow for big expansive openings ensuring the visual connection between inside and outside.



The visual connectedness of the buildings is not the only aspect that links architecture with nature. All buildings are constructed from naturally and locally sourced materials, such as dek-riet ceilings, clay and soil harvested from the site to create rammed earth walls and lime plaster walls and floors, the pebbles retrieved from the site used to construct gabion walls, and reclaimed tique doors from the larger Drakenstein region. This is all to better integrate the architecture within its surroundings and celebrate the materials and workmanship from the local area.

These organic-shaped stereotomic buildings with large oversailing leaf-like roof structures for rainwater collection, punched openings to frame vistas, bay windows, thick rammed earth or clay brick walls, clerestory windows for filtered natural light and ventilation, textured screening elements, all create enticing and playful spaces. This multi-layered development where architecture and landscape coincide creates enticing and playful spaces where children can engage, explore, and learn.

3-5 Gangouroubouro Primary School

Architect: LEVS architecten

Typologies: School

Date: 2013

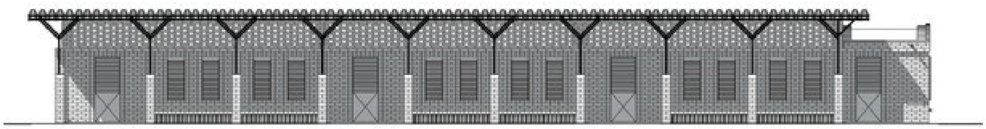
Location: South Africa

The architecture of the school reflects a connection to the local building traditions, culture, and function. Compared with the rich architectural areas near the rocky walls in the Dogon area, particularly at this location the plain offers the possibility of a different architectural appearance.

The ensemble consists of a school, blocks with sanitary facilities and a communal outdoor space. The structure of the school building consists of an enlarged front porch of more than 3 meters parallel to the three classrooms.

The walls are constructed with newly developed and locally produced hydraulic compressed earth blocks (HCEB) in alternating strips. They determine the rhythm of the facades and provide a cool inside climate. The porch, which is equipped with stone benches on both sides, forms the large terrace of the school.

The roof is constructed of overlapping steel plates, each hanging 1 meter over and creating extra shade spaces. By means of thin steel shaft profiles, the mass of the roof is being transferred to the buttresses. The Poligny rafters stretch across the classrooms and create a free floor surface.



Wind forces are prevented from pushing up the roof by a wide stroke of semi-open masonry for ventilation and using several openings of long and narrow windows. The openings in the facade with its tilt window frames are painted in an ochre yellow color. The office and the storage facility have been built with curved roofs and on a smaller scale, corresponding to the function of the space.

3-6 Advantages taken from case studies

3-6-1 Lycée schorge

From a typological point of view, the secondary school is formed like a 'village' that closes in on itself.

Creating a sort of autonomous 'village' condition, the radial layout of classroom modules wraps around a central public courtyard. This configuration not only creates privacy from the main public domain, but it also shelters and protects the inner courtyard from wind and dust.

Overhanging roofs and lowers help to prevent to overheat.

Wrapping around these classrooms like a transparent fabric is a system of wooden screens. This secondary façade is made from a local fast-growing wood and acts as a shading element for the spaces immediately surrounding the classrooms. The screens not only function to protect the earthen classrooms from corroding dust and winds, but they also help to create a series of secondary informal gathering spaces for the students as they wait to attend their classes.

Another major factor that helps to naturally ventilate and illuminate the interiors is a massive undulating ceiling. The wave-like pattern of plaster and concrete components are slightly offset from each other, allowing the interior space to breathe and expel hot stagnant air. The off-white color of the ceiling serves to diffuse and spread around indirect daylight, providing ample illumination during the day while keeping the interior learning space protected from direct solar heat gain.

3-6-2 Legson Kayira

It offers a larger covered area that provides shade, open, well-lit and well-ventilated spaces.

Shade netting, lightweight steel, local masonry and corrugated iron form the architectural language of the building. Local masonry is used to create vertical louvers on the exterior of the classrooms to act as shading devices and structural support for the roof. The roofs have a slight fall to drain water into the gutters which feed the water tanks.

The over-all feel of the building is light yet permanent and with the outer facade adjustable, provides the user with freedom in terms of spatial layout and climatic comfort.

Each classroom has open-able partition Louvre walls covered with shade-netting. These side louvers can either be in a vertical or horizontal position. When in a vertical position, the space becomes more private and sheltered but still allows for cross-ventilation. The horizontal positions provide more shaded area and extends the space beyond the buildings boundaries and allows more natural light into the spaces.

3-6-3 Burckhardt + Partner's Vaulted Brick School

The “village” is an agglomeration of different uses, such as classrooms, dormitories, and houses. Though the program varies, all parts are built in the same way: variations or combinations of one single constructive unity respecting local resources and traditions.

The school’s walls are covered by a light metal truss and tin metal roof. As well as ensuring water and heat protection, and rainwater harvesting, the tin roof also allows the implementation of solar panels.

A radial settlement concept plays a big role, allowing occupants to build gradually, when necessary, in a well-orchestrated sequence. The radial organization of the program also follows the existing topography, allowing the heart of the plot to open up to the wider community.

3-6-4 Green School

The spatial arrangement at a macro level is what inspired the space making, but also down to the individual buildings and spaces between them.

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3-6-5 Gangouroubouro Primary School

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Chapter 4

Architectural design

4-1 The main goals

Through the projects, the main goal is to:

- EDUCATE: allowing children to access school and make them understand what improvements they could reach if they work hard on learning not only history, math's, or languages but also in everyday activities such as agriculture or livestock. Another fact is that many of these children live without access to proper healthcare and teaching them how they can protect their own health is crucial. Many common health issues, such as malaria, dysentery, respiratory infections, and nutrition-related illnesses are preventable by simply making small lifestyle changes.

- INVESTIGATE: study about what should their country's society do to improve socially and economically. Education is particularly important to communities that are fragile or rebuilding. Education provides stability, structure, and hope for the future, helping children and youth to overcome trauma caused by war, disaster, or conflict. Having a safe learning environment also makes children and youth less vulnerable to exploitation, kidnapping, and recruitment by militant groups or organized crime.

- CONTRIBUTE TO THE CONSERVATION OF THE ENVIRONMENT: it is a fact that people in Malawi don't worry about the deforestation. The aim is that through education, we could raise awareness of that huge problem. The deforestation in the hills is causing a major change to the landscape and to the climate. As soon as the trees are cut down, the soil is exposed to the rain and, in many places, most of the topsoil is washed away into the rivers and eventually into Lake Malawi. This is leaving the hills infertile so that trees and crops do not grow well, and the soil that is being deposited in the lake is affecting fish stocks which, together with over-fishing, is causing a dramatic reduction in the number of fish that are being caught in the lake.

4-2 Concept

Derived from the Greek word "Triskeles" meaning "three legs", the Triskele or Triple Spiral is a complex ancient Celtic symbol. Often referred to by many as a Triskelion, its earliest creation dates to the Neolithic era, as it can be seen at the entrance of Newgrange, Ireland. The Triskele gained popularity in its use within the Celtic culture from 500BC onwards. This archaic symbol is one of the most convoluted to decipher as symbolists believe it is reflective of many areas of culture from the time.

Firstly, the triskele can be thought to represent motion as all three arms are positioned to make it appear as if it is moving outwards from its center. Movement, or motion, is believed to signify energies, within this Celtic Symbol the motion of action, cycles, progress, revolution, and competition.

Secondly, and the more challenging area for symbolists, is the exact symbolic significance of the three arms of the triskele. This can differ dependent on the era, culture, mythology, and history, which is why there are so many variations as to what these three extensions in the triple spiral symbol mean.

Some of these connotations include life-death-rebirth, spirit-mind-body, mother-father-child, past-present-future, power-intellect-love, and creation-preservation-destruction to name but a few.

It is thought that through the combination of these two areas we gain one meaning of the Celtic triskele. It is believed to represent a tale of forward motion to reach understanding. However, this is thought not to be the only meaning, as it is also believed to represent three Celtic worlds; the spiritual world, the present world, and the celestial world. Like the ancient Trinity knot, the number 3 holds a special symbolism within the triskele.

The meaning of the triskele is diverse, varied and has many possibilities. This Celtic symbol is far more complex than others and has much prominence in modern day Celtic jewelry. Most notably as Celtic pendants, earrings, Irish charms, or Celtic brooches.

Tchopa is a performing art practised among Lhomwe communities in southern Malawi. The dance is usually performed during celebrations after good harvests and successful hunting trips and during offerings to ancestral spirits after calamities such as droughts and outbreaks of disease. Tchopa entails knowledge of particular dancing skills and singing and employs three different sizes of drums. Twenty to thirty dancers perform in a circle while criss-crossing each other. Some dancers carry packs on their backs holding farming tools, animal skins, puppets, hunting gear and old kitchen utensils. Each village headman has a small group of Tchopa dancers. Although primarily performed by older Lhomwe men and women, who function as the bearers and practitioners and principal custodians, Tchopa is now also increasingly performed by children. Knowledge and skills for the dance are transmitted during practice sessions and occasional performances. Other key roles among the group include the makers of dancing costumes and drums, drummers, whistlers, and dancers. Tchopa dance strengthens social cohesion among Lhomwe communities with members providing mutual support in times of need, such as during ill health and bereavement, and coming to the assistance of overburdened practitioners by providing communal labour in the field.

4-2-1 What is sacred geometry

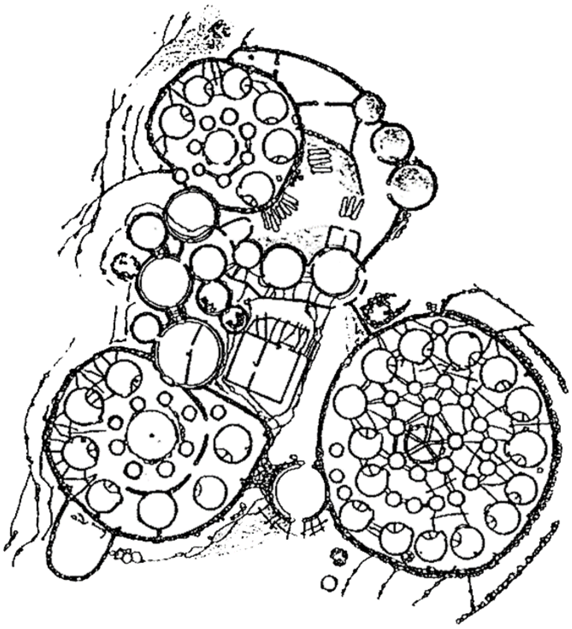
Sacred geometry is essentially the study of the spiritual meaning of various shapes. It can be applied to the forms, numbers, and patterns seen throughout the natural world.

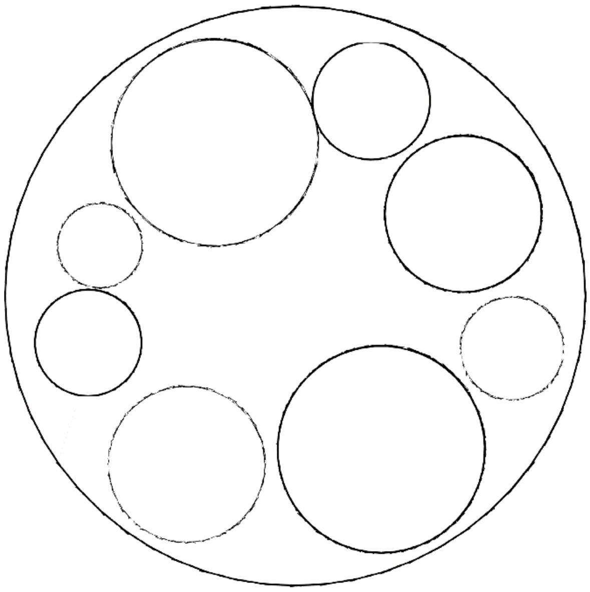
The spiral of a snail's shell, the captivating pattern of a single snowflake, and the branches of a tree can all be examples of sacred geometry. Sacred geometry is also thought to exist beyond the naked eye, both on a cellular level and in the stars and orbiting planets.

The idea that the universe follows an intricate equation dates as far back as ancient Egyptian and Mesopotamian cultures. It received more attention centuries later in ancient Greece, popularized by philosophers like Pythagoras and Plato.

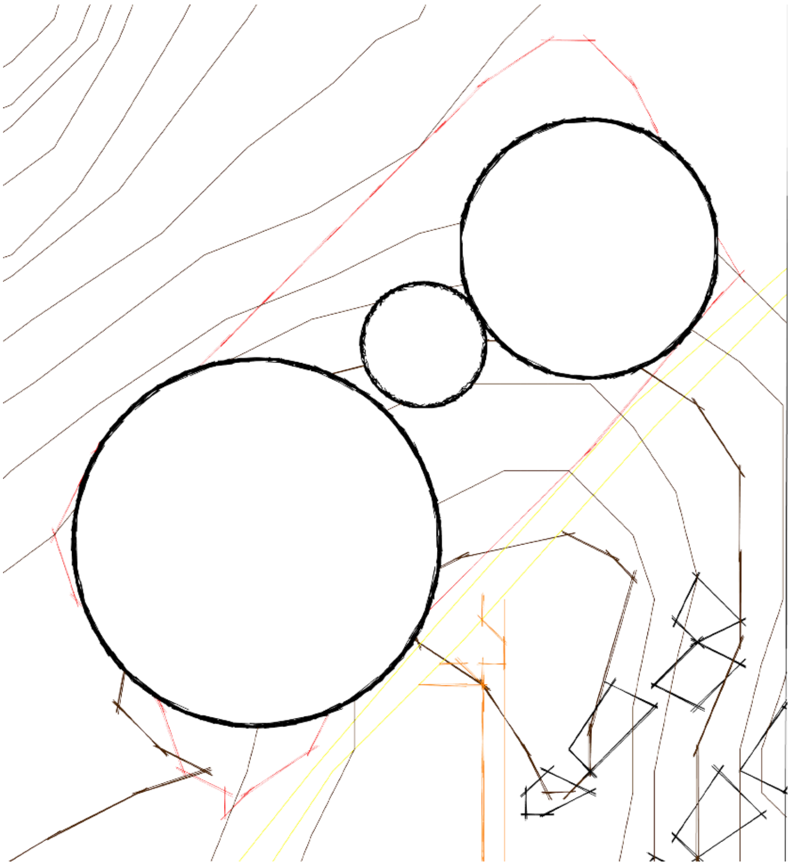
4-3 Design process

Usually in Africa the houses are around each other for safety reasons and social connection. The spiral shape of buildings is inspired from African vernacular architecture.

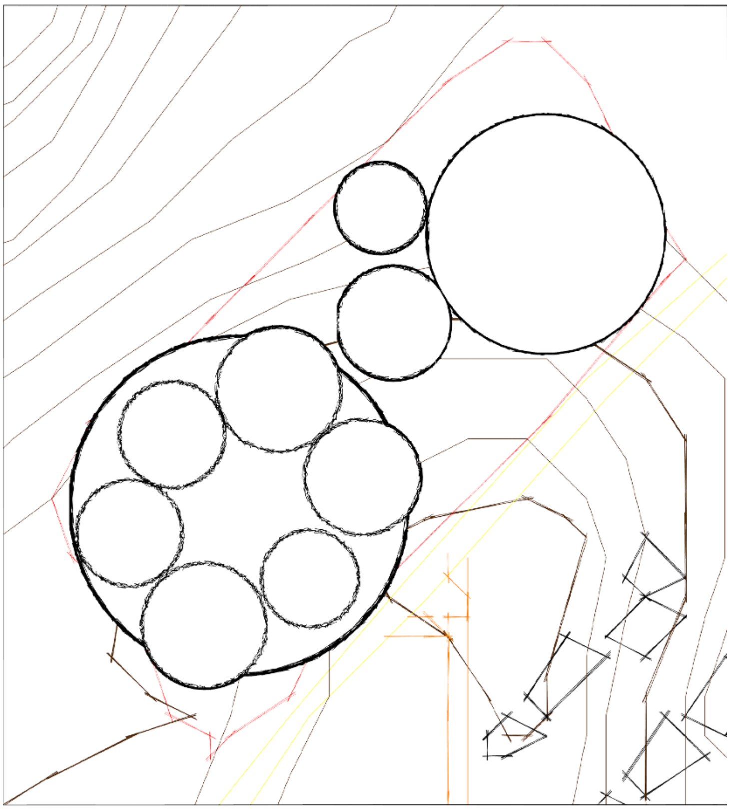




The distinct size of buildings is inspired from a special African music instrument.

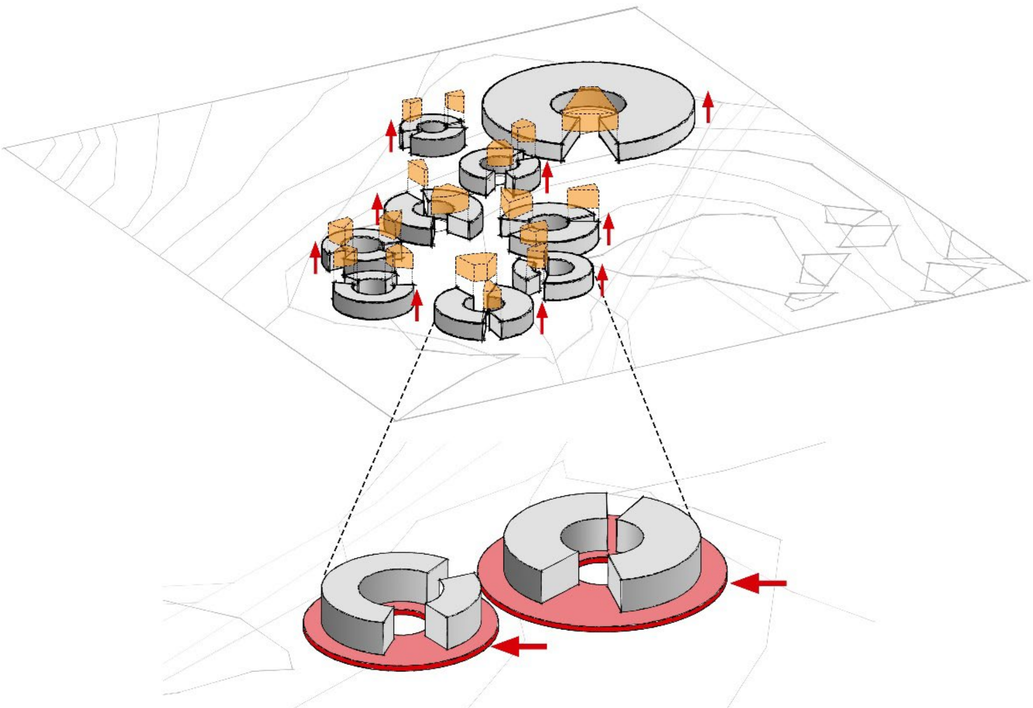


The final arrangement is achieved by combining these two steps.

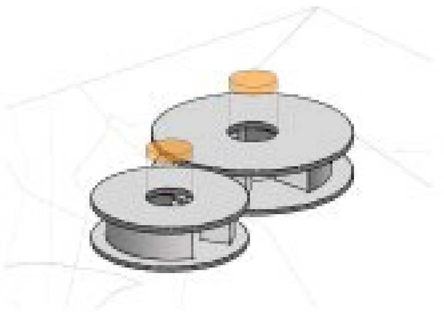


In the next step, it is shown the extrusion of volume and the openings for creating a connection between buildings.

For technical reasons the slabs are extruded.



Creating the openings in the roof for increasing natural light during the day and ventilation.



Chapter 5

Technologies

5-1 Wall construction and material

Rammed earth construction is the process of ramming a mixture of aggregates, like gravel, sand, silt, and clay into a formwork to create walls. When the earth is dry the formwork is removed to reveal solid monolithic walls.

Rammed earth is an ancient form of construction, generally seen in drier hotter parts of the world. Although many rammed earth structures exist in this basic form, a new 'stabilized' rammed earth variant has been developed which adds a small amount of cement (5-10%) to the mixture to ensure strength and durability.

Traditionally, a wooden pole is used to ram the earth into the formwork, but modern methods now use a mechanical ram.

The process is labor intensive but is considered to have a low environmental impact depending on materials used (cement content) and source of those materials. While some elements of the rammed earth wall will have a low embodied energy, cementitious products do not.

The appearance of rammed earth will depend on the earth and aggregate used, in terms of color and texture. However, rammed earth has a horizontal layered appearance which demonstrate the process used to construct the walls. Some like this feature of rammed earth, however it is possible to control it so that the layers are not visible. Rammed earth is often seen in a red/orange tone color – a simple google image search will demonstrate this.

Rammed earth structures can be considered relatively basic and of simple form, or for eco enthusiasts. However, many architects are now developing designs to use the process in contemporary projects, to spectacular effect. Check out some of the examples at the end of this post.

Figure 5-1 Rammed earth wall

Structure

Rammed earth is strong in compression and suitable for load bearing construction. It is possible to introduce reinforcement to the walls like concrete, however this must be carefully designed due to possibility of cracking and difficulty ramming around the reinforcement bars.

Insulation

A feature often exploited with rammed earth structures is thermal mass. The thermal mass slows the movement of heat through the walls, then releases the heat when the surrounding temperature drops (at night). Thermal mass structures can even out temperature variations, creating a comfortable internal environment.

Insulating a rammed earth structure can require careful thought. Often designers would like to keep the external face of the rammed earth exposed for aesthetic reasons. Insulating the structure in the inside of the building will lose all thermal mass benefits. It is more beneficial to insulate the structure on the outside of the building which will protect the rammed earth but also allow the building to benefit from thermal mass.

Positioning and requirement of insulation will depend on location and climate, but it is worth noting that rammed earth is hygroscopic, meaning the walls must be able to breath, and allow evaporation. Any finishes must be vapor permeable to ensure condensation does not build up within the assembly.

Durability

Rammed earth construction is suited to warmer drier climates, there are relatively few rammed earth examples in the UK for this reason. It is a popular method of construction in Australia.

Walls should be protected from the weather as best as possible. Raised foundations should lift the wall at least 225mm above ground level, while roof overhangs should protect the walls from rain. All water should be drained away from the walls and moisture should be allowed to evaporate easily.

Some additives have been developed that are water repellent, these are added to the mix to allow the walls to be constructed in more exposed environments.

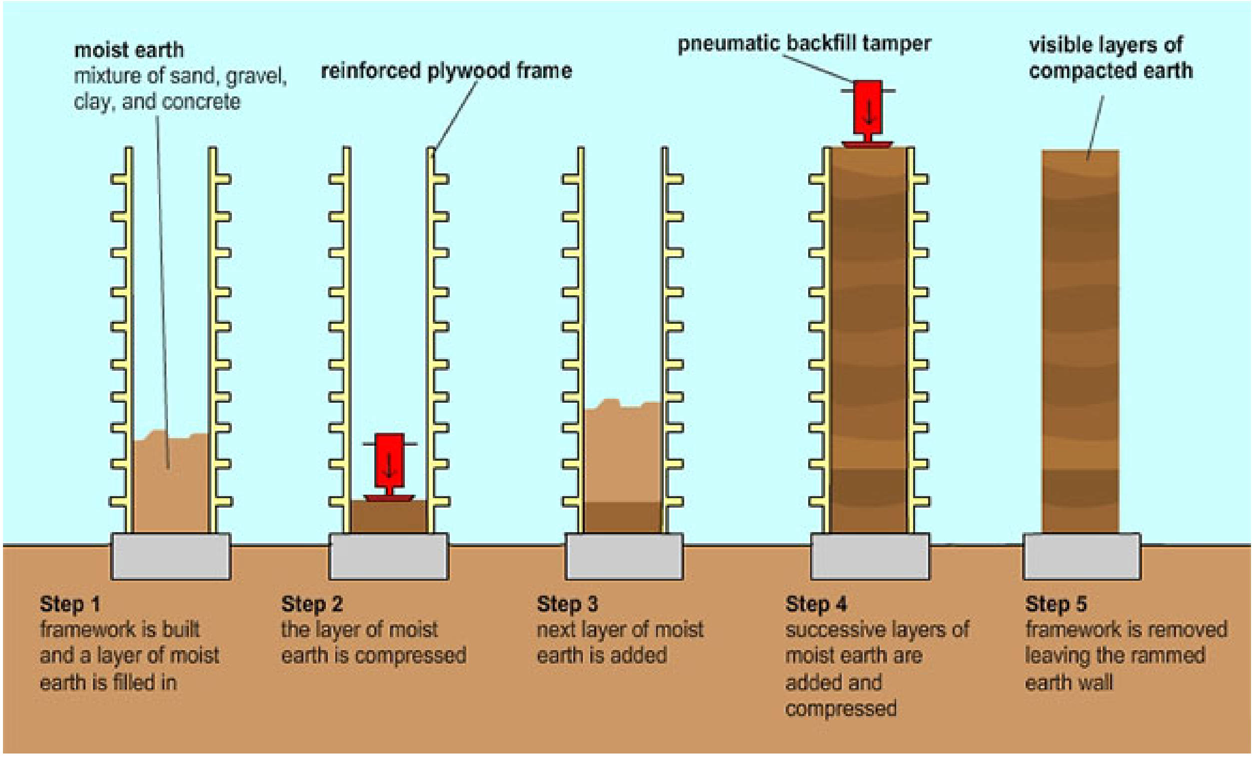


Figure 5-2 construction process of rammed earth wall

Advantages:

Distinct appearance

Natural and readily available

Low embodied energy (a lever like break veneer construction)

Unestablished earth is reusable post-demolition

High moisture mass, hygroscopic-helps regulate humidity

Use of local soils supports sustainability practices

High thermal mass (though work is still underway to quantify its extent)

Airtight construction achievable

Traditional form of construction

Many of the shortcomings associated with the durability of rammed earth (primarily external surface protection, water resistance, shrinkage and strength) can be averted by the addition of a stabilizer. This has become general practice in Australia where it perceived to reduce uncertainty and risk. Though other forms have been used, the most common stabilizer is cement, which when added typically makes up between 6 or 7% (by volume) of the mix.

The addition of cement (high embodied energy), however, is seen by many to compromise the environmental credentials of rammed earth – though this might be balanced out when additional protection and maintenance of non-stabilized rammed earth is built into the equation.

Building Regulations

For walls constructed from stabilized rammed earth (SRE):

Part A – Structure

• Rammed earth has proved to be suitable for loadbearing and non-loadbearing construction.

• Compressive strength is a maximum of 1MPa for unsterilized rammed earth and approximately 10MPa for stabilized rammed earth.

Part B – Fire Safety

• Rammed earth can be classed as non-combustible material.

• A 300mm wall can provide fire resistance of at least 90 minutes.

Part C – Resistance of moisture

• Rising damp is prevented by DPCs.

• Penetrating moisture is limited through absorption and subsequent evaporation.

• Weather erosion is reduced / prevented through appropriate detailing e.g., extended eaves, raised plinths, rainscreens etc.

Part E – Resistance to the passage of sound

• Rammed earth walls provide effective acoustic separation

• Where floors are supported by separating (party) rammed earth walls, design detailing should follow the norm for other solid masonry walls, but with the additional requirement to accommodate moisture movement.

Part L – Conservation of fuel and power

• U-value of 300mm rammed earth wall "H 1.5 – 3 W/m2K, therefore insulation needs adding in external wall applications.

Regulation 7 – Materials and Workmanship

• Fitness of rammed earth materials determined by sampling, lab testing of materials or precedence. (See below SREregcompliance.pdf)

• Adequacy of quality is measured against provision of the specification, test panels and previous works.

• For more information on Building Regs compliance, refer to 'Stabilized Rammed Earth - Physical Properties and Compliance with UK Building Regulations' published by Chesterfield

Borough Council. The main source of reference is Hall & Djerbib's 2004 study 'Rammed Earth Sample Production: Context, Recommendations and Consistency'.

Design issues

Insulation

• There are few examples of rammed earth walls combining insulation in the UK. Most contemporary walls remain un-clad. The following suggested solutions have yet to be thoroughly tested.

• Because of rammed earth's poor thermal performance, extra insulation will be required.

• Rammed earth is hygroscopic. Wherever walls are clad externally, cladding systems and finishes must be vapor-permeable to allow evaporation. This is important for unsterilized walls, but less-so for stabilized walls where the stabilizing agent will impair breathing. Non-the-less, it might be wise to consider vapor permeable solutions for both instances to reduce the chance of condensation build-up on the inside face of insulation.

• Vapor permeability is less of a concern when specifying internally applied insulation - when moisture is encouraged to evaporate externally. Internally, insulation specification is a lot more flexible, though its application directly to the face of the wall should be avoided.

The strategic decision to be made is where to locate it - inside or outside - both have advantages and disadvantages:

External insulation

+ Wall is protected from weathering

+ Exposed thermal mass internally

- loss of characteristic appearance externally

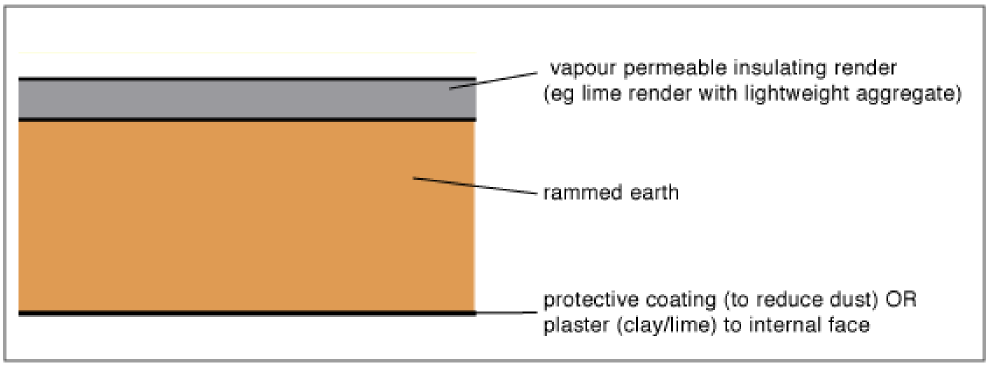


Figure 5-3 Rammed earth wall detail

Materials: hemp Lime, proprietary renders, mineral-based renders and hygroscopic insulation

Insulation board and render

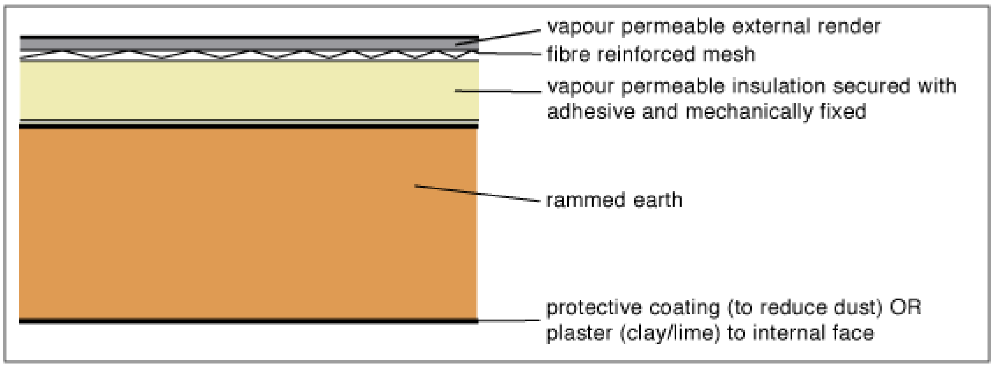


Figure 5-4 Rammed earth wall detail

Insulation materials**:** breathing insulation: cellulose slab, composite wood wool board (not cement-based), wood fiber board, cork, hemp, hemp-lime.

Rainscreen cladding

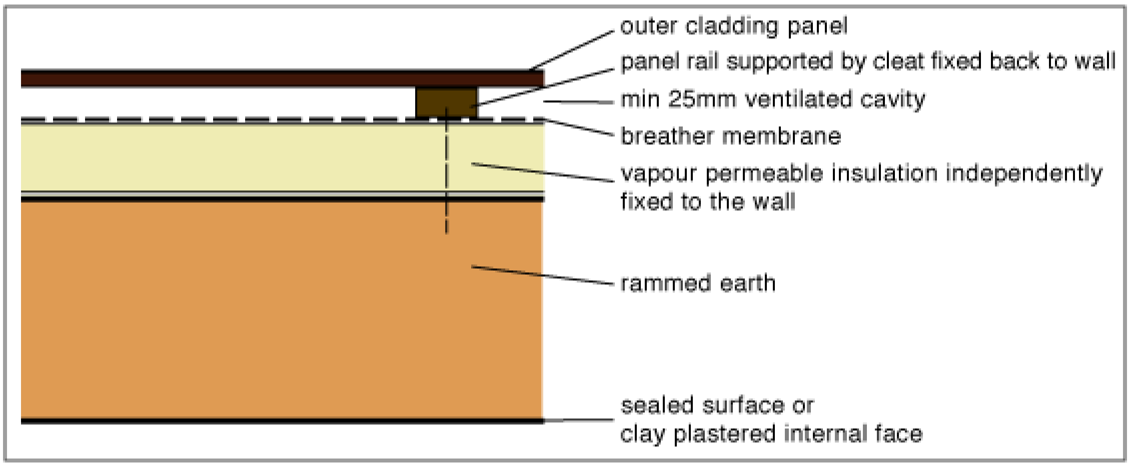


Figure 5-5 Rammed earth wall detail

Insulation materials: breathing insulation: cellulose slab, composite wood wool board (not cement-based), wood fiber board, cork, sheep's wool, hemp, hemp-lime

Cladding: wood, tiles, slate, board and polymer-based render, proprietary cladding systems

Internal insulation

+ External appearance maintained

- Loss of available thermal mass

Free-standing studwork with infill insulation

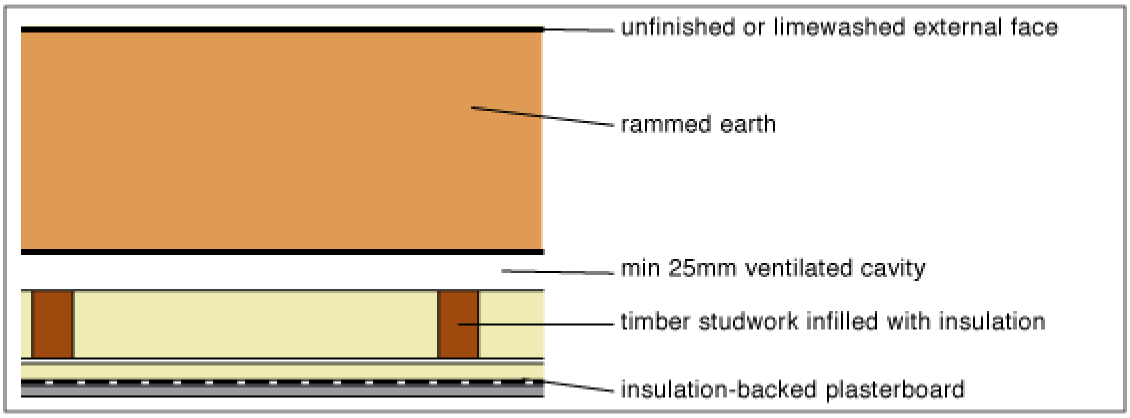


Figure 5-6 Rammed earth wall detail

Insulation materials: Cellular glass, Mineral wool slab, Expanded polystyrene, Phenolic foam, Polyisocyanurate (PIR), Polyurethane (PUR).

Weather protection

•All water should drain away from the walls

• Walls should be constructed upon raised footings

• Avoid sites that are liable to flood

• Protect the wall where possible from rain using adjoining elements such as projecting roofs

• Allow excess moisture means to evaporate from walls

• On exposed sites, consider rainscreen cladding or render

• Water sealant protective coatings are not recommended

Protection given by the roof

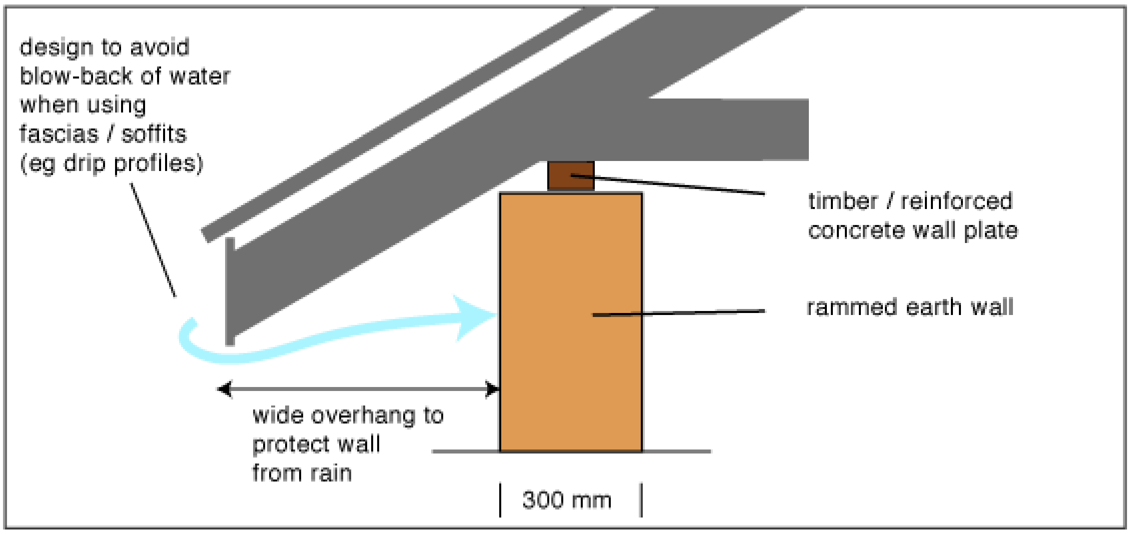


Figure 5-7 Rammed earth wall detail

The eaves provide protection from rain. An emerging rule-of-thumb states that the overhang should be equivalent to a third of the overall wall height.

Footings and base

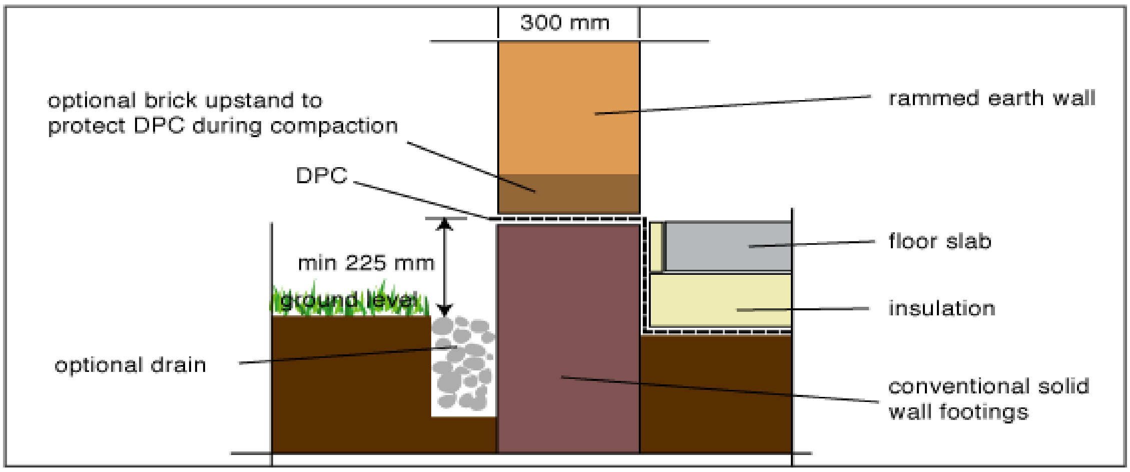


Figure 5-8 Rammed earth wall detail

- The DPC should be finished flush with the wall surface to avoid splash.
- Blue engineering brick might be considered as an alternative to the DPC membrane.
- A filter drain will also reduce the height of splash by means of Radom splash effect.
- As with all solid walls, ensure careful detailing to avoid cold bridging.

5-2 Technical details

5-2-1 Wall

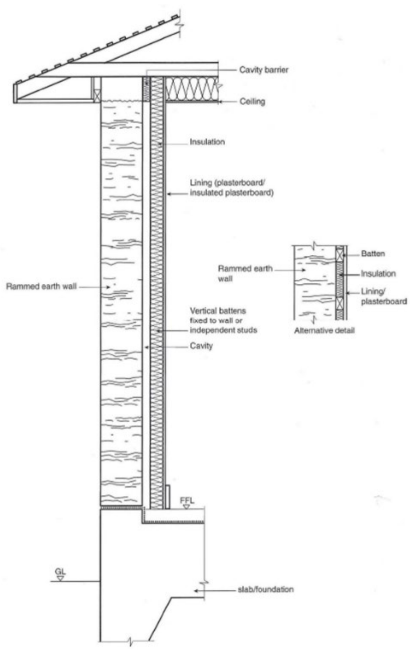


Figure 5-9 Rammed earth wall detail

5-2-2 Roof

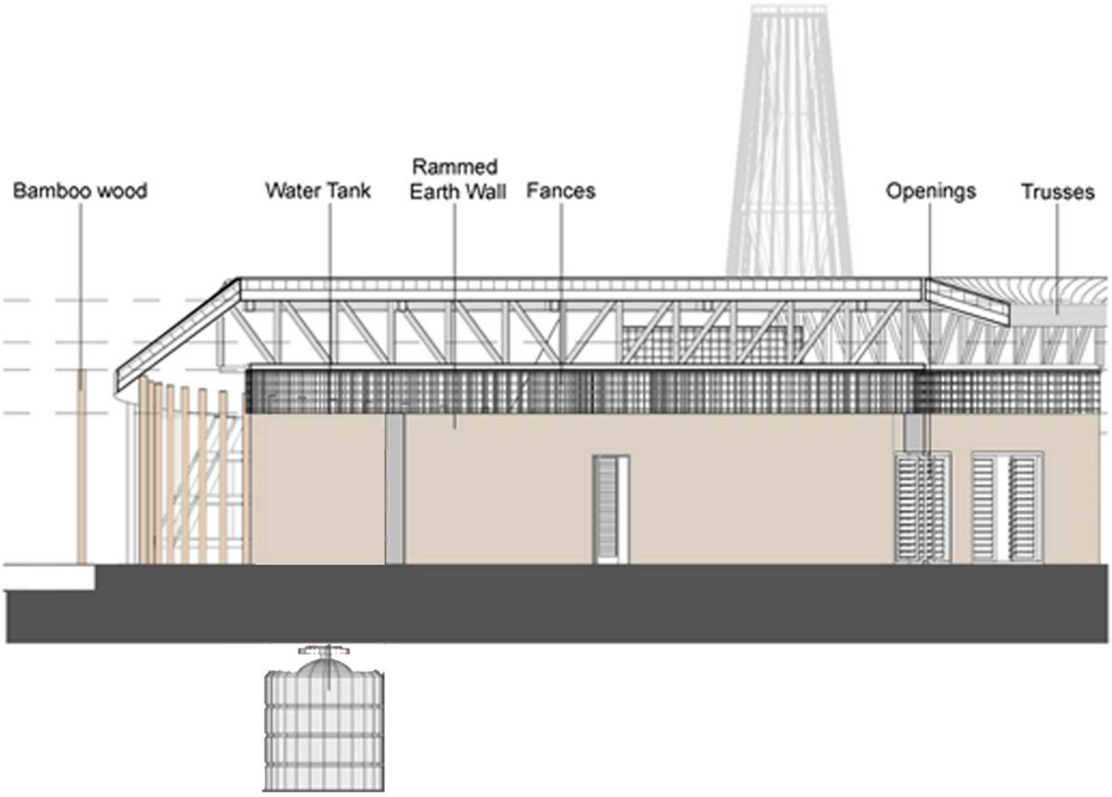


Figure 5-10 Roof section

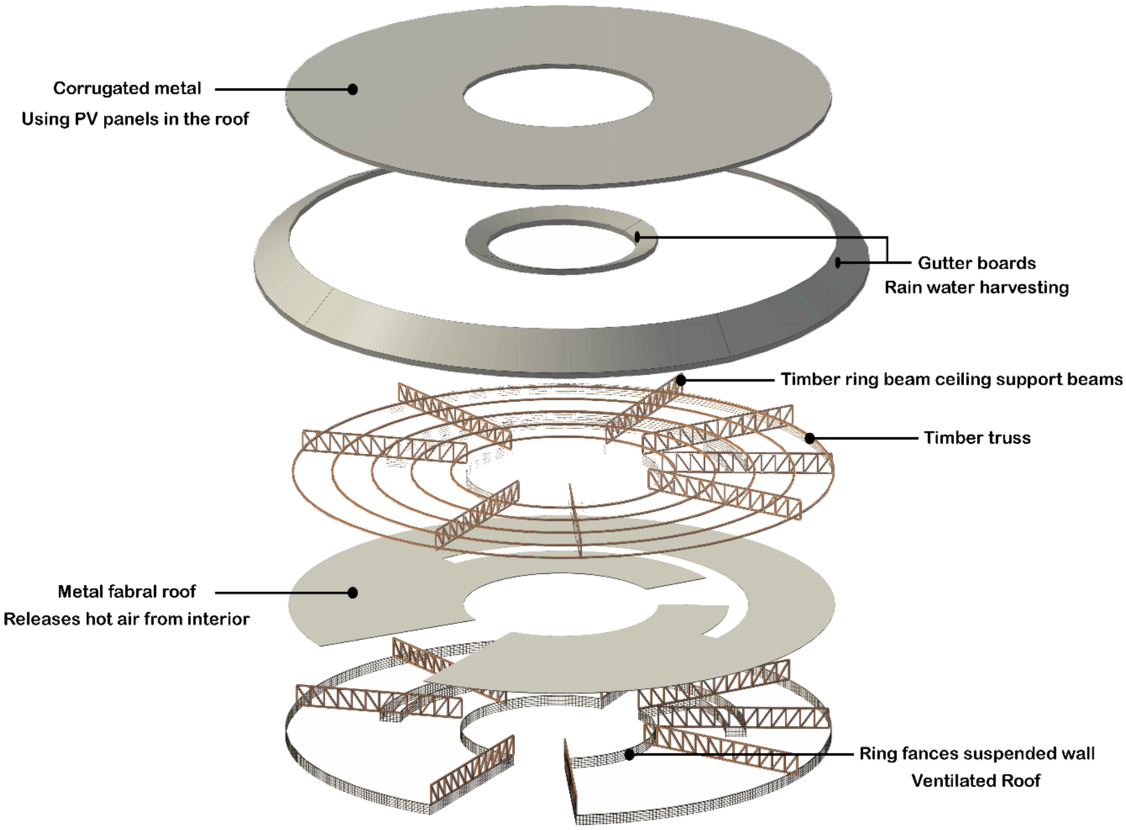


Figure 5-11 Roof detail

5-2-3 Opening

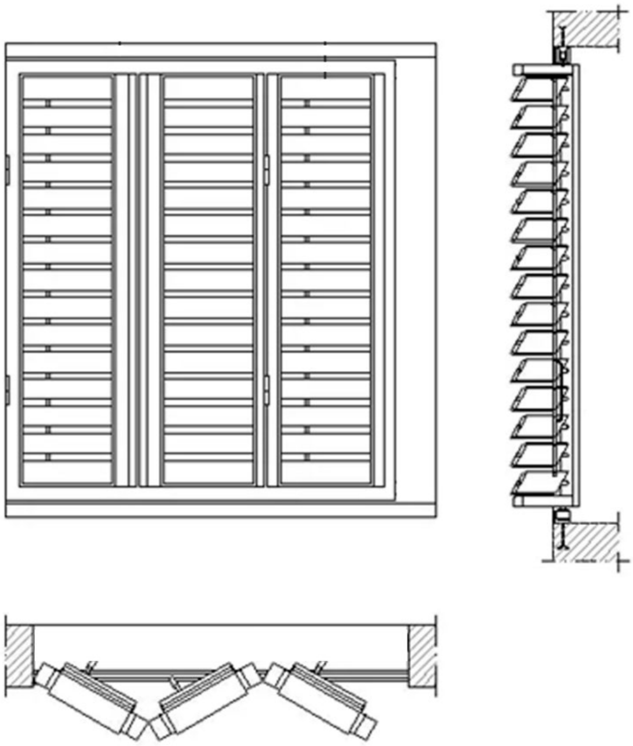


Figure 5-12 Opening detail

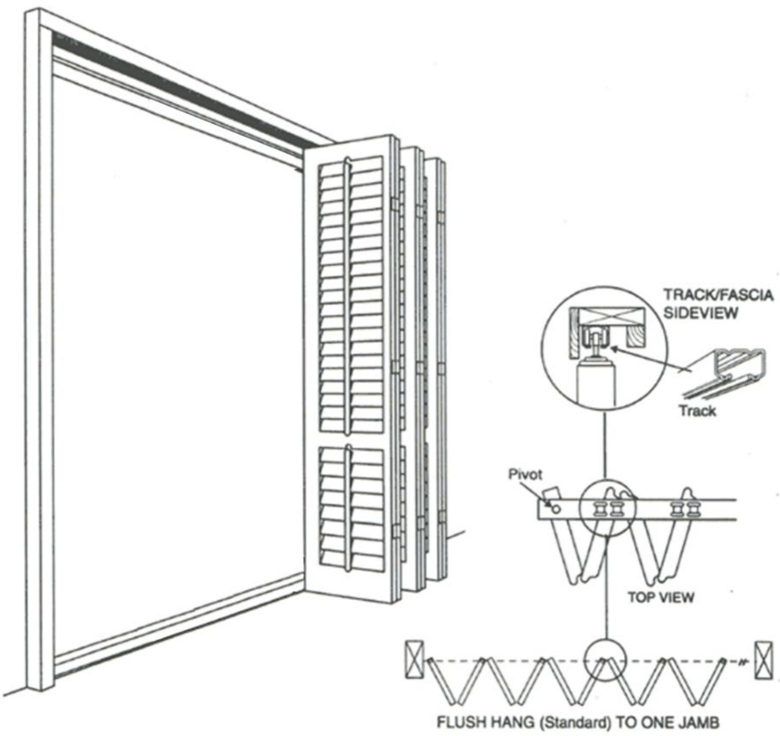


Figure 5-13 Opening detail

Chapter 6

Water management

6-1 Basic water requirement for human activity

Different sectors of society use water for different purposes: drinking, removing, or diluting wastes, producing manufactured goods, growing food, producing, and using energy, and so on. The water required for each of these activities varies with climatic conditions, lifestyle, culture, tradition, diet, technology, and wealth.

The type of access to water alone is an important determinant in total water use. The following tables show that the level of domestic water use varies with distance from the water source and with the climate.

Source of water	Water use (liters per person per day
Public standpipe further than 1 kilometer	Less than 10
Public standpipe closer than 1 kilometer	20
House connection, simple plumping, pour, flash toilet	60 – 100
House connection, urban, with gardens	150 – 400

Table 6-1 Domestic water uses by distance to source

Climate zone	Public standpost Liters/cpita/day	House connection Liters/capita/day
Humid	10 to 20	20 to 40
Average	20 to 30	40 to 60
Dry	30 to 40	60 to 80

Table 6-2 Rural household water uses by climate and source

6-1-1 Minimum drinking water

An absolute "minimum water requirement" for humans, independent of lifestyle and culture, can be defined only for maintaining human survival. To maintain the water balance in a living human, the amount of water lost through normal activities must be regularly restored. While the amount of water required to maintain survival depends on surrounding environmental conditions and personal physiological characteristics, the overall variability of needs is quite small. Routes for water loss include evaporation from the skin, excretion losses, and insensible loss from the respiratory tract. Humans may feel thirst after a fluid loss of only I per cent of bodily fluid and be in danger of death when fluid loss nears 10 per cent.

Prior physiological studies have generated "reference values" for a daily human water requirement. Table 3 summarizes several estimates of total daily water requirements for a "reference" human. Minimum water requirements for fluid replacement have been estimated at about three liters per day under average temperate climate conditions. When climate and levels of activity are changed, these daily minimum water requirements can increase. In a hot climate, a 70-kilogram human will sweat between four and six liters per day without a comparable change in food intake or activity.

The National Research Council of the National Academy of Sciences in the U.S.A. separately estimated minimum human water requirements by correlating them with energy intake in food. They recommend a minimum water intake of between one and one-and-a-half milliliters of water per calorie of food (1 - 1.5 ml/kcal). Note that a food calorie is equivalent to a kcal of energy. In this article, the energy content of food will be represented by kcals. This does not include the water required to grow the food consumed, which is discussed later. With recommended daily diets ranging from 2,000 to 3,000 kcals, minimum water requirements are between 2,000 and 4,500 milliliters, or 2 to 4.5 liters per day - comparable with the data presented in the following table.

Source	Average daily water intake in liters per capita per day
Vinograd, Roth	2.5
World health organization	2.5
White et al.	1.8 to 3.0
U.S. Environmental Protection Agency	2.0
National Academy of Sciences	2.0
Saunders and Warford	5

Table 6-3 Average daily water intake

Using these data, a minimum water requirement for human survival under typical temperate climates with normal activity can be set at three liters per day. Given that substantial populations live in tropical and subtropical climates, it is necessary to increase this minimum slightly, to about five J/p/d, or just under two cubic meters per person per year. A further fundamental requirement not usually noted in the physiological literature is that this water should be of sufficient quality to prevent water related diseases.

6-1-2 Basic water requirements for sanitation

There are many technologies for improving access to adequate sanitation services, with widely varying water requirements. In regions where absolute water quantity is a major problem, alternatives that require no water are available. The following table lists those technologies that require no water except for minimal washing. Where historical circumstances led to the use of wasteful, high-volume flush toilets, as much as 75 liters per capita per day, or more, have been used.

Sanitation technologies that require no water
Ventilated improved pits (VIP)
Reed Odorless Earth Closets (ROEC)
Ventilated Improved Double-Pit Latrines
Double-Vault Composting Toilets (DVC)
Continuous Composting

Table 6-4 Sanitation technologies

The following table lists the wide range of sanitation technologies that require water. The choice of sanitation technology will ultimately depend on the developmental goals of a country or region, the water available, the economic choice of the alternatives, and powerful regulatory, cultural, and social factors.

Because alternatives are available that require no water, it is technically feasible to set a minimum at zero. Two factors argue against doing this: additional health benefits are identifiable when up to 20 liters per capita per day of clean water are provided; and where economic factors are not a constraint, cultural and social preferences strongly lean toward water-based systems.

Sanitation Technology	Water Requirement	Minimum Water
Pit latrine	Water near toilet	l to 2 liters/flush
Pour/Flush (PF) toilets	Water near toilet	6 to 10 liters/person/day
Vault toilets and cartage	Water near toilet	3 to 6 liters/person/day
Sewered PF toilets/septic tanks	Water piped to toilet	7.5 liters/person/day
Small-bore sewerage	Water piped to toilet	>50 liters/person/day
Inefficient conventional sewerage	Water piped to toilet	>75 liters/person/day

Table 6-5 sanitation technologies requirements

Access to some water for sanitation, together with concurrent education about water use, decreases the incidence of diseases, increases the frequency of hygienic food preparation and washing, and reduces the consumption of contaminated food products. Accordingly, while effective disposal of human wastes can be accomplished with little or no water when necessary, a minimum of 20 liters per person per day is recommended here to account for the maximum benefits of combining waste disposal and related hygiene, and to permit for cultural and societal preferences. This level can be met with a wide range of technological choices.

6-1-3 Basic water requirements for bathing

On top of these direct sanitation requirements, additional domestic water is used for showering or bathing. A review of a range of studies in North America and Europe (Table 6) suggests average (not minimum) water use in industrialized nations for bathing to be about 70 liters per person per day, with a range from 45 to I00 J/p/d. Data on water used for bathing in developing countries or in regions with no piped water are not widely available. Some studies suggest that minimum water needed for adequate bathing is on the order of 5 to I 5 If p/d and that required for showering is 15 to 25 J/p/day. A basic level of service of 15 J/p/d for bathing is recommended here.

6-1-4 Basic water requirements for food preparation

The final component of a domestic basic water requirement is the water required for the preparation of food. While most detailed surveys of residential water use in industrialized countries do not provide separate estimates of water used for cooking, brooks and peters estimate that water use for food preparation in wealthy regions ranges from 10 to 50 liters per person per day, with a mean of 30 liters per person per day. In a study done of the water provided for 1.2 million people in northern California, an average of 11.5 liters per person per day was used for cooking, with an additional 15 liters used for dishwashing. Other studies in both developed and developing countries suggest that an average of 10 to 20 liters per person per day appears to satisfy most regional standards and that 10 l/p/d will meet basic needs.

6-1-5 Basic water requirements for agriculture

In the absence of any measured climatic data, it is often adequate to use estimates of water requirements for common crops.

Crop	Crop water need (mm/total growing period)
Beans	300 - 500
Citrus	900 - 1200
Cotton	700 - 1300
Groundnut	500 - 700
Maize	500 - 800
Sorghum/millet	450 - 650
Soybean	450 - 700
Sunflower	600 - 1000

Table 6-6 water requirements for common crops

6-1-5-1 Factors influencing crop water requirements

6-1-5-1-1 Influence of climate

A certain crop grown in a sunny and hot climate needs more water per day than the same crop grown in a cloudy and cooler climate. There are, however, apart from sunshine and temperature, other climatic factors which influence the crop water need. These factors are humidity and wind speed. When it is dry, the crop water needs are higher than when it is humid. In windy climates, the crops will use more water than in calm climates.

The highest crop water needs are thus found in areas which are hot, dry, windy, and sunny. The lowest values are found when it is cool, humid, and cloudy with little or no wind.

From the above, the crop grown in different climatic zones will have different water needs. For example, a certain maize variety grown in a cool climate will need less water per day than the same maize variety grown in a hotter climate.

It is therefore useful to take a certain standard crop or reference crop and determine how much water this crop needs per day in the various climatic regions. As a standard crop (or reference crop) grass has been chosen.

The following table indicates the average daily water needs of this reference grass crop. The daily water needs of the grass depend on the climatic zone (rainfall regime) and daily temperatures.

climatic zone	Mean daily temperature		
	low (< 15°C)	medium (15-25°C)	high (> 25°C)
Desert/arid	4-6	7-8	9-10
Semi-arid	4-5	6-7	8-9

Table 6-7 Average daily water needs of standard grass during irrigation season (mm)

For the various field crops it is possible to determine how much water they need compared to the standard grass. Several crops need less water than grass, several crops need more water than grass and other crops need the same amount of water as grass. Understanding of this relationship is extremely important for the selection of crops to be grown in a water harvesting scheme.

-30%	-10%	same as standard grass	+10%	+20%
Citrus Olives	Squash	Crucifers Groundnuts Melons Onions Peppers Grass Clean cultivated nuts & fruit trees	Barley Beans Maize Cotton Lentils Millet Safflower Sorghum Soybeans Sunflower Wheat	Nuts & fruit trees with cover crop

Table 6-8 Water requirement of crops

6-1-5-1-2 Influence of crop type on crop water needs

The influence of the crop type on the crop water need is important in two ways.

a. The crop type has an influence on the daily water needs of a fully grown crop, i.e., the peak daily water needs of a fully developed maize crop will need more water per day than a fully developed crop of onions.

b. The crop type has an influence on the duration of the total growing season of the crop. There are short duration crops, e.g., peas, with a duration of the total growing season of 90-100 days and longer duration crops, e.g., melons, with a duration of the total growing season of 120-160 days. There are, of course, also perennial crops that are in the field for many years, such as fruit trees.

While, for example, the daily water need of melons may be less than the daily water needs of beans, the seasonal water need of melons will be higher than that of beans because the duration of the total growing season of melons is much longer.

Data on the duration of the total growing season of the various crops grown in an area can best be obtained locally. These data may be obtained from, for example, the seed supplier, the Extension Service, the Irrigation Department or Ministry of Agriculture.

The following table gives some indicative values or approximate values for the duration of the total growing season for the various field crops. It should, however, be noted that the values are only rough approximations, and it is much better to obtain the values locally.

Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100-365	Melon	120-160
Barley/Oats/ Wheat	120-150	Millet	105-140
Bean, green	75-90	Onion, green	70-95
dry	95-110	dry	150-210
Citrus	240-365	Pepper	120-210
Cotton	180-195	Rice	90-150
Grain/small	150-165	Sorghum	120-130
Lentil	150-170	Soybean	135-150
Maize, sweet	80-110	Squash	95-120
grain	125-180	Sunflower	125-130

Table 6-9 values for the duration of the total growing season for the various field crops

It is obvious that there is a large variation of values not only between crops, but also within one crop type. In general, it can be assumed that the growing period for a certain crop is longer when the climate is cool and shorter when the climate is warm.

6-2 Water resources of Malawi

6-2-1 Surface water resources

Malawi has a distinct climate with high plateau, rugged relief and one fifth of the country is composed of Lake Malawi. The country experiences good rainfall from November to April. The mean annual rainfall is 1,037mm.

Lake Malawi stores the bulk of the renewable surface water resources, with an average of 90 km3 of live storage. This lake, which is the third largest in Africa, has a surface area of 28,760 km2 and an estimated total volume of water of 7,725 x 109m3 with a mean level of 474 meters above sea level. The annual surface water resources yield on land is about 13 Km3 and predominately drains into Lake Malawi and the Shire River. However, more than 90 percent of this runoff occurs in rainy season, particularly from December to April, every year.

Other important surface water resources include Lake Chilwa with a surface area of 683 km2, Lake Malombe with an area of 303 km2, and Lake Chiuta with a surface area of 60 km2 while small lakes, lagoons and marshes include Lake Kazuni, Chia Lagoon, Chiwondo lagoon, Elephant Marsh, Ndindi Marsh and Vwaza Marsh.

The country has an extensive network of river systems. The drainage system has been divided into 17 Water Resources Areas (following figure) and each WRA represents one basin. The WRAs are sub-divided into 78 Water Resources Units.

Major rivers are the Shire, Bua, Linthipe, Songwe, North Rukuru, South Rukuru, Dwangwa and Ruo. Shire is the largest river and the only outlet of Lake Malawi while all other major rivers drain into Lake Malawi or Shire River. The mean annual runoff over the land area of the whole country is 196mm (i.e., an equivalent of 588 m3/s) and this constitutes 19 percent of the mean annual rainfall. The mean annual outflow in the Shire River at the Lake outlet upstream Mangochi is 395m3/s.

The major rivers are perennial, but due to the seasonal rainfall most of the smaller rivers have ephemeral flow.

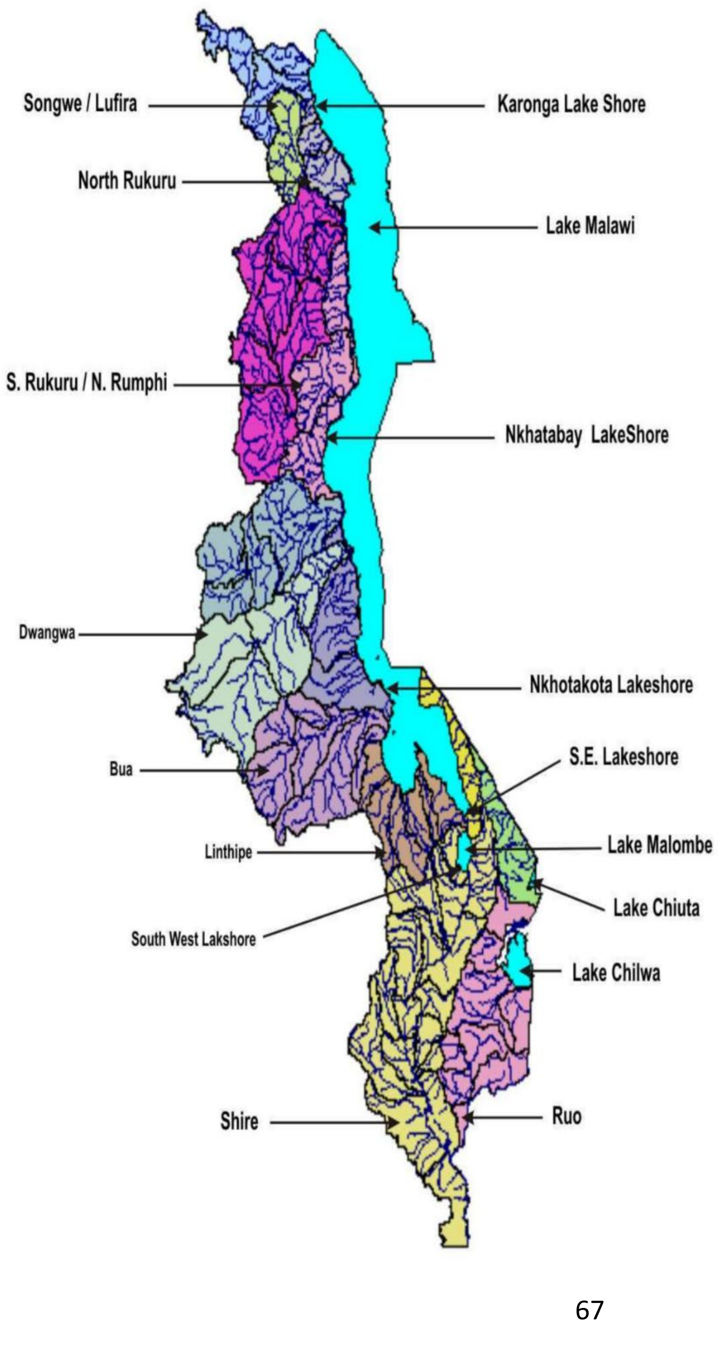


Figure 6-1 Water resources of Malawi

6-2-2 Ground water resources

There are basically two main aquifer types in Malawi. The first type is the extensive, but relatively low-yielding, weathered basement aquifer. The second type of aquifer is the high – yielding alluvial aquifer which occurs along the lakeshore plains and the Shire valley (following figure).

Ground water exploitable resources are limited. The existing aquifers are disjointed with characteristic relatively low yields and in most cases these aquifers are highly localized. Aquifer yields range from 4 liters per second to 0.15 liters per second.

Groundwater resources have been primarily exploited for drinking water supply for both rural and urban areas.

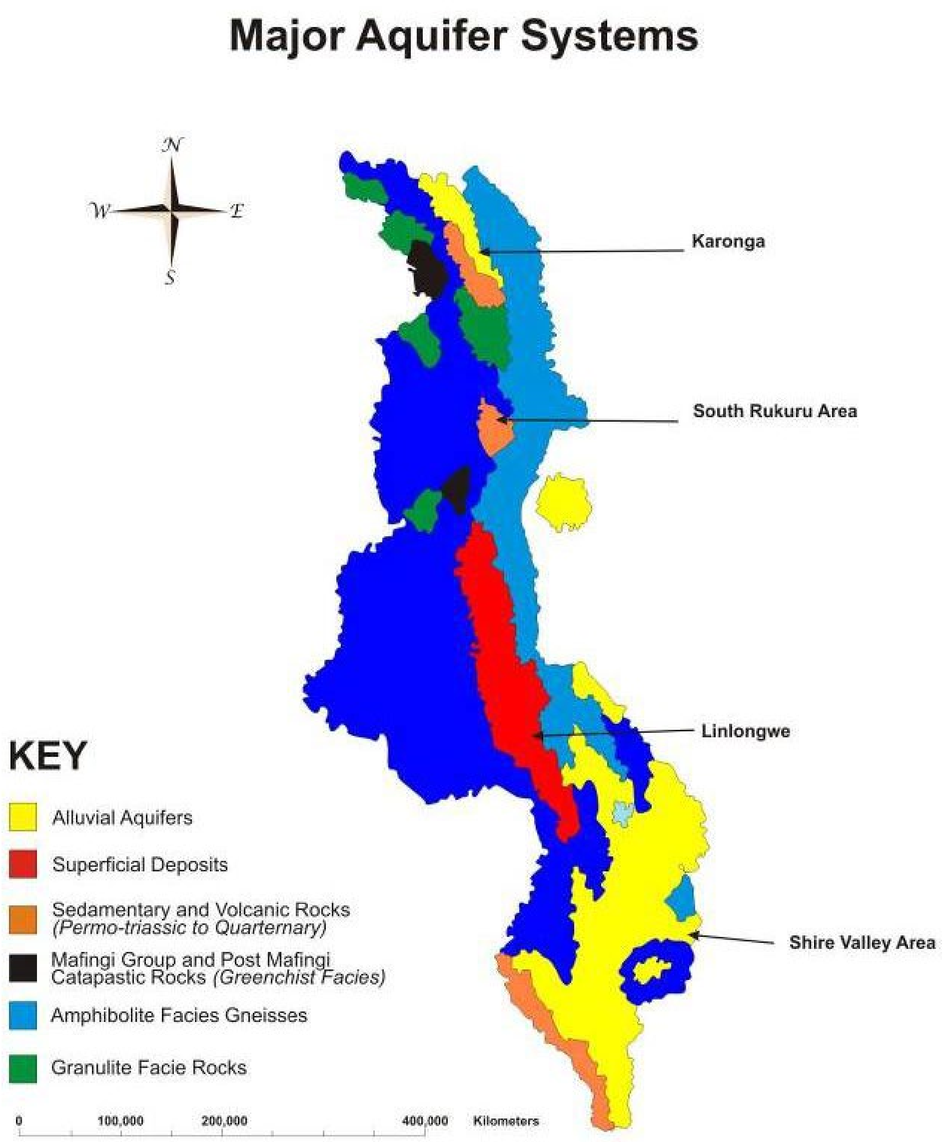


Figure 6-2 Groundwater resources of Malawi

6-3 Rainwater harvesting

6-3-1 Above ground tanks

Above ground tanks for domestic application have been the most popular technique for rainwater harvesting in Malawi. The reasons for their popularity include ease of colleting water from them; the water is usually of good quality; and the impacts they have on reducing drudgery of water collection over long distances. The first tanks were normally constructed using bricks and mortar. However, the last three years has seen the proliferation of ferrocement tanks and the use of plastic tanks.

Figure 6-3 Above ground tank – brick Figure 6-4 Above ground tank - plastic

To upscale rooftop harvesting, low-cost methods for water harvesting using the Calabash Cistern which cost about 300USD for a 5000-liter tank are being explored.

Figure 6-5 Above ground tank Figure 6-6 Above ground tank

6-3-2 Lined underground tanks

Concrete lined underground tanks have mostly been built to collect runoff from ground surfaces e.g., school grounds, hill sides and road runoff. The water from underground tanks is mostly used for cleaning, watering livestock and tree nurseries for afforestation.

Underground tanks have been popular in Malawi since they are able to collect huge volumes of water compared with the above ground tanks. The water is cooler making it suitable for irrigation. Their disadvantages include the large amount of sediment that is collected in the tank, and since the water is stored under the ground, withdrawing water cannot be done using gravity.

Figure 6-7 Lined underground tank

Figure 6-8 Lined underground tank

6-3-3 Dams

The colonial government constructed small dams as a conservation strategy and, as a source of water for the urban populace as well as for livestock Njoloma (2011). Irrigation around small dams was an 'informal trend' that progressively developed either downstream or upstream of the dams.

Figure 6-9 Dam

Figure 6-10 Dam

The dams were used for irrigation farming, but some also supported livestock production and other activities. Due to land degradation, most of these dams are no longer functional as a result of siltation and lack of maintenance. Of late, there have been several projects that have constructed run off detention weirs for retaining surface run off. However, siltation remains a major challenge for these structures requiring farmers to routinely de-silt them.

Figure 6-11 Dam

6-3-4 In-situ or soil storage rainwater harvesting

Farmers in Malawi are fully aware of the changes in climatic conditions evidenced by erratic rainfall and frequent dry spells. To address the situation, farmers practice rainwater harvesting in their fields in order so that they can harness any water that is available. Farmers have implemented a number of low costs in-situ water harvesting measures including swales, infiltration pits, percolation pond, conservation agriculture, box ridges, marker ridges, mulching and crop residue management, compost manure making and application, and the planting of grass strips/hedge-grows along the contours.

Figure 6-12 Infiltration pits

Figure 6-13 Percolation pond

Figure 6-14 Check-dams

In Liwonde Village, Neno District, rainwater stored in the ponds and hand dug wells is used productively in watering vegetables and fruit trees. Farmers are growing different vegetables (Chinese lettuce, mustard, and tomatoes) in their fields that are recharged using in-situ techniques. The vegetables are growing well and can be used as a source income for the households. The success of in-situ techniques is attributed to the fact that they are cheap and easy to implement. The structures are continually monitored so that some minor maintenance is done by individual landowners. Implementation of in-situ techniques is achieved in clusters formed by the farmers. Choice of sites for in-situ technologies is based on sites that have serious land degradation and can show the best results within a short time.

6-4 Atmospheric water harvesting

This step is to review different types of sustainable water harvesting methods from the atmospheric fogs and dew. In this paper, we report upon the water collection performance of various fog collectors around the world. We also review technical aspects of fog collector feasibility studies and the efficiency improvements. Modern fog harvesting innovations are often bioinspired technology. Fog harvesting technology is obviously limited by global fog occurrence. In contrast, dew water harvester is available everywhere but requires a cooled condensing surface. In this review, the dew water collection systems are divided into three categories: i) dew water harvesting using radiative cooling surface, ii) solar regenerated desiccant system and iii) active condensation technology. The key target in all these approaches is the development of an atmospheric water collector that can produce water regardless of the humidity level, geographical location, low in cost and can be made using local materials.

This figure shows how atmospheric water harvesting technologies may be classified.

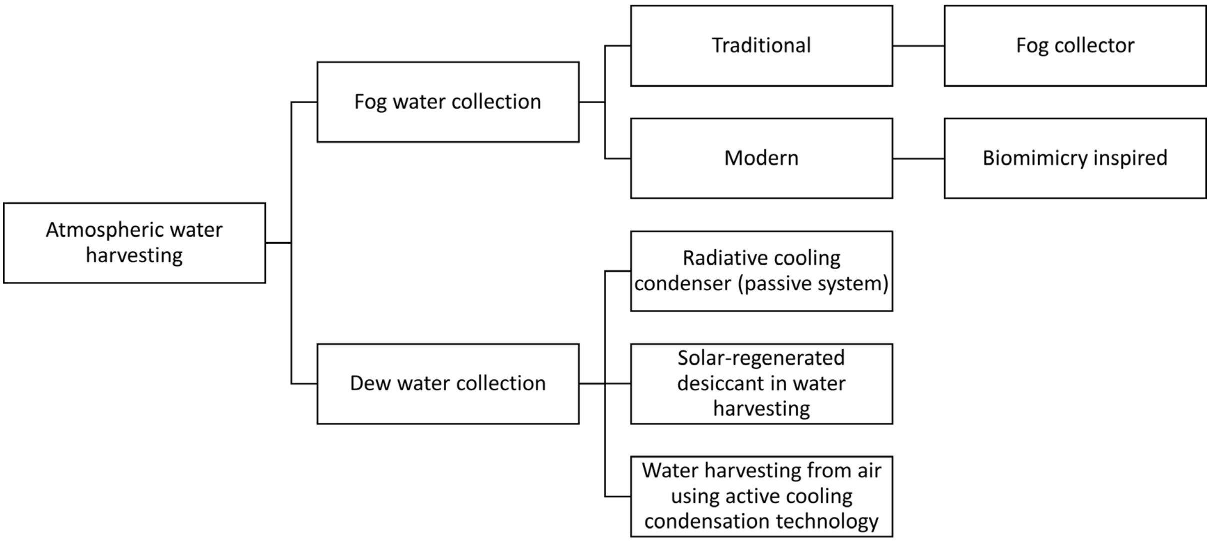


Figure 6-15 atmospheric water harvesting technologies classification

The first category is harvesting water from fog, i.e., a visible cloud water droplets or ice crystals that are suspended in the air at or near the Earth's surface. It normally occurs due to added moisture in the air or falling ambient air temperature. Methods may be usefully divided into 'traditional' and 'modern'.

The second collection category is the collection of water vapor. While fog is visible to our naked eyes, water vapor is invisible and is generated by the evaporation of liquid water or the sublimation of ice. When water vapor condenses on a surface cooled temperature below the dew point temperature of the atmospheric water vapor, 'dew water' will be formed.

While fog water harvesting system are more related to traditional concept using a mesh like structure, there are various technologies related to dew water harvesting technique. The early studies involved passive systems using radiative condenser, but their low efficiencies resulted in, researchers introducing solar-regenerated desiccant methods to enhance the moisture sorption and desorption, however, still has not proved on its own to be sufficient. Thus, research in dew water harvesting also covers integration with active cooling condenser technology that covers the use of typical vapor compression air conditioning system and most recently, thermoelectric cooler. Due to the high in efficiency of active cooling condenser systems, at the end of this paper, readers will be presented with selected commercially available technology on water harvesting technology involving active cooling condensing system.

6-4-1 Fog collector inspired by traditional

concept Illustrated in following figure, the traditional fog collecting method is very simple, comprising a mesh exposed to the atmosphere over which the fog is driven by the wind. Two posts on guy wires are used to support the mesh and cables to suspend the mesh. Water droplets trapped by the mesh accumulate and drain under gravity into the channels of the water collection system. Collectors can be usefully classified as standard fog collectors (SFCs) and large fog collectors (LFCs). SFCs are typically used in a small-scale exploratory study to evaluate the amount of water that can be collected for a specific condition. The collector has a typical size of (1 × 1) m2 surface with a base of 2 m above the ground. LFCs, typically 12mlong and 6mhigh has mesh covers the upper 4 m of the collector giving ∼48 m2 of water collection area. They are mainly used for actual harvesting installation. For maximum efficiency, fog collectors should be positioned perpendicularly to the prevailing wind. Typically, LFSs produce 150 l to 750 l of water a day depending on the site. Reported in 2011, the cost for a unit of 48 m2 fog collectors is US$400 meanwhile, the 1 m2 SFCs cost from US$100 to US$200 to build depending on the country and the materials.

Commercially available, Raschel-weave high-density polyethylene mesh, commonly used for shading crops in hot climates, has been a popular collector material, although other weaves such as aluminet shade net have subsequently been investigated.

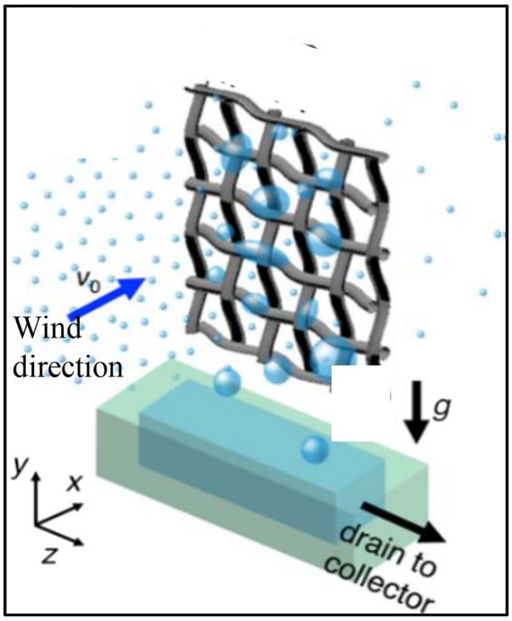


Figure 6-16 The basic concept of fog collector. Adapted with permission

Illustrated in following figure, the standard Raschel mesh is black in color, with treated UV-resistance and has 35% shade coefficient S. Shade coefficient S is the portion of the fog collector’s area that is capable of capturing fog droplets and can be expressed using the following equation:

$S = 1 - f$,

where f is defined as the ratio of mesh openings area to the total screen area.

Along the longitudinal direction, the mesh filament is tied up continuously, meanwhile transversely, we can see that the filaments are not continuous but knotted to the longitudinal one.

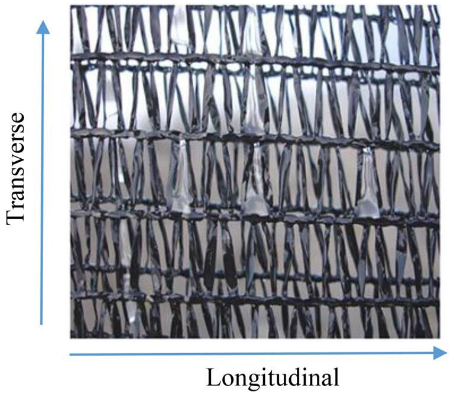


Figure 6-17 Mesh

6-4-1-1 Fog collector design

A unique design of fog collector called cloud harvester has been designed by Choiniere-Shields, see following figure. The concept of cloud harvester is based on a fog catcher that turn the condense fog into water droplet. In comparison to the current model available on the market, the unique part of in the design of cloud harvester is that it uses stainless steel mesh instead of the polypropylene nets with an extra sheet under the net for the water collection. The cloud harvester is expected to have a better condensing efficiency and much smaller than the similar products that are currently on the market. The cloud harvester has a potential water harvesting output of 1 l of fresh water per hour for each 10 square feet of mesh.

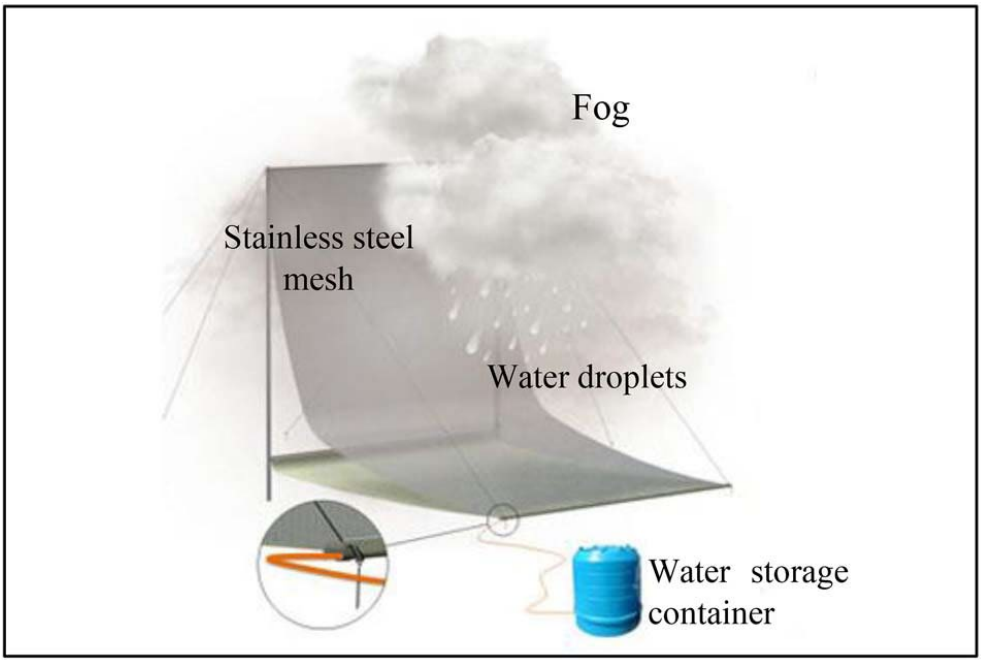


Figure 6-18 The concept of the cloud harvester

The concept of the cloud harvester. The harvester is designed to catch and condense fog into water droplets that in turn run down on a stainless-steel mesh into a gutter type of extrusion leading to a water storage container.

6-4-1-2 Warka water

Aiming to harvest water from the atmosphere to supply fresh drinking water to the community in the developing world, a unique wooden atmospheric water harvesting project called Warka Water has been founded by Arturo Vittori. The project won the World Design Impact Prize 2015–16 at World Design Capital(R) Taipei 2016 Gala. Arturo and his team have developed 12 different prototypes since 2012. Following figure shows an example of the prototype and its working principle. The team's target is to develop a prototype that is lightweight (about 80 kg), easy and quick to build using local materials without using scaffolding and power tools. They intend to use bamboo for the frame structure, while the water catchment system will be made from biodegradable mesh 100% recyclable materials. Fog and dew, and rainwater, will be collected when they strike the mesh and then trickle down a funnel into a reservoir at the base. To prevent water evaporation, a fabric canopy will be used to cover the lower section of the water collector. There is no indication of the amount of water that can be produced by the prototype since the project is still in the exploratory phase. However, the aim of the project is to produce water from fog or highly humid places between 50 to 100 l per day.

Figure 6-19 Warka water

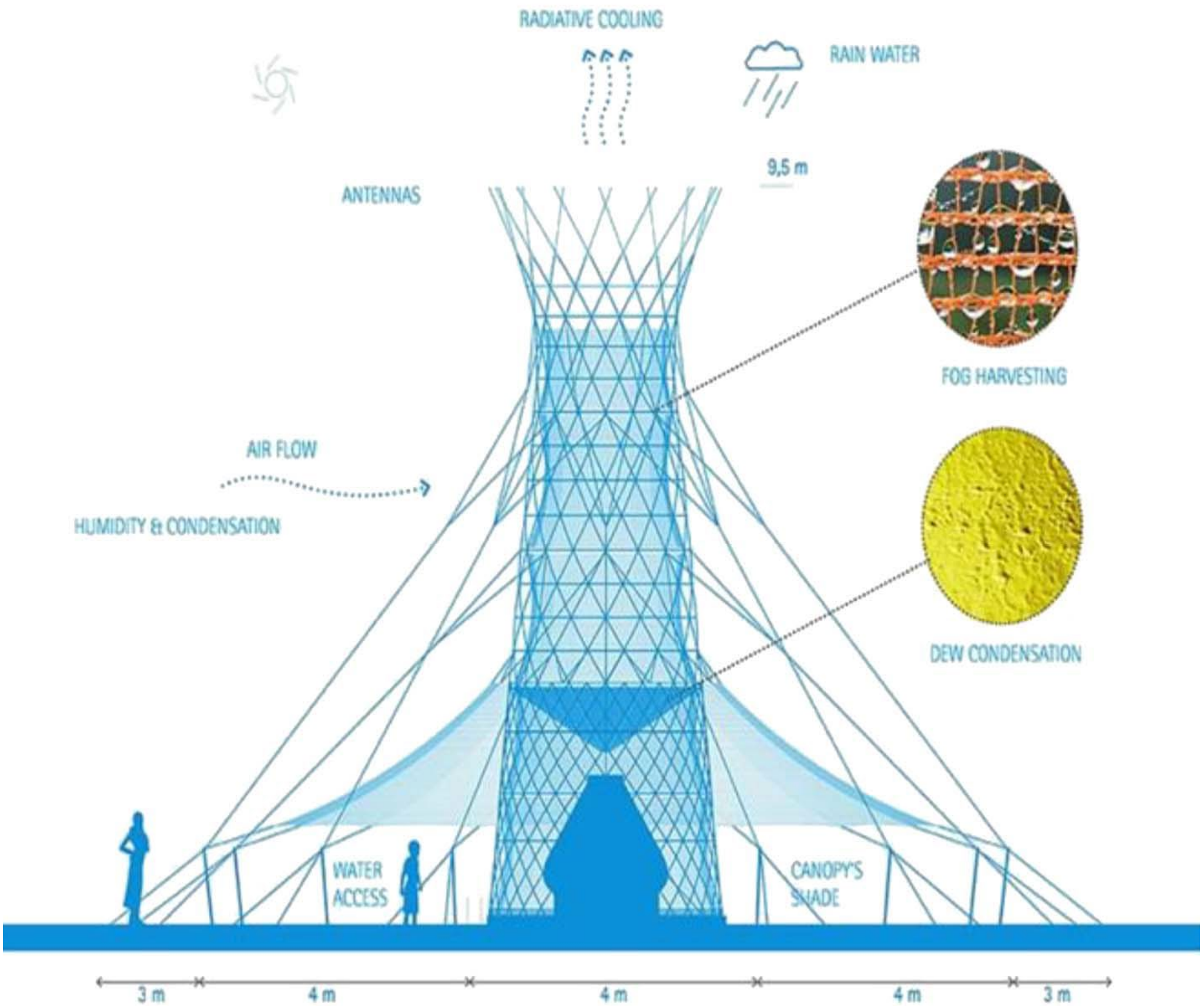


Figure 6-20 Warka water

6-4-1-3 Fog collector efficiency and feasibility studies

A fog water collector would act as the barrier to the wind-driven fog. However, a portion of the fog is unperturbed by the fog water collector. Although there is a collision with the fog collector, it cannot capture all the liquid water contained in the fog. There are losses due to:

(i) Fog passing around the fog water collector.

(ii) Fog passing through the openings of the mesh.

(iii) Droplets bouncing back into the airflow.

For the fraction of the fog that is captured by the fog water collector, we call this fraction as fog interception efficiency. The captured water droplet merged, move to the lower part of fog collector, reached the water gutter, and transported to the water tank. However, at water gutter, there is a potential of re-entrainment or water can return to the air flow or some water from the mesh slack, wrinkles, and folds, may be entering the gutter and collected at the water tank.

The basics calculation for the fog water collection has been discussed in Rivera. To discuss the collector efficiency, there are four important factors that determine the efficiency of the fog collection, and they are wind velocity, fog liquid water content, droplet size distribution and mesh characteristics. The water collector efficiency ηcoll of a fog collector can be computed using the following equation.

$\eta_{coll} = \dot{W}''_{coll} / v_o.LWC$

Where $\dot{W}''_{coll}$ (kg/sm2) is the water flow rate collected in the gutter per unit screen area, vo (m/s) is the unperturbed wind velocity of the incoming fog/air flow and LWC (Kg/m3) is the liquid water content of the incoming fog/air flow.

Additionally, Rivera reported that we can also express the collection efficiency by considering the following conditions:

i. The aerodynamic collection efficiency ηAC, calculated based on the amount of unperturbed fog droplets that would collide with the fog's mesh.

ii. The capture efficiency ηcapt, to account for the fraction of the intercepted droplets that are captured by the mesh wire.

iii. The draining efficiency ηdr, to account for the fraction of the water captured by the mesh that is collected by the gutter since some of the water can spill or re-enter the air flow.

Therefore, the fog water collector can also be expressed using the following equation:

$\eta_{coll}=\eta_{capt}.\eta_{dr}.\eta_{AC}$

Clearly, before installing a fog collector, its practicality must first be assessed. A group of Iranian researchers have discussed the feasibility of implementing fog collectors as a mean to harvest water in their country. Their research has included analysis on the data collected from 10 representative stations located facing the Persian Gulf and Oman Sea. Among the important parameters recorded were 'hourly dry and wet temperature, relative humidity, wind direction and velocity and the dew point temperature'. The values were then used to calculate 'the atmosphere water vapor pressure, saturated vapor pressure and the absolute humidity of the atmosphere' and the feasibility of fog harvesting system predicted by using the equation:

For $RH \geq 69\%$, $WH3 = (3 \times Mt \times Uz \times \eta coll \times 3.6)$.

If $RH < 69\%$, → $WH3 = 0$

Where RH is relative humidity measured by weather station, WH is the potential water harvested (liters per square meter per day) and the subscript 3 represents for every 3 hours, an input value chosen because data at the representative stations was recorded 3 hourlies, and they assumed stable conditions were achieved after this period is achieved. U2 is the wind velocity at 2 m height above the ground, Mtis the absolute humidity that is defined as the humidity in grams per cubic meter of air in a specific temperature (g/cm3). The values of wind speed for eight different wind directions were then investigated. Their analysis has shown promising results for water collection at Abadan and Chahabar station with the amount of potential collected water is 6.7 l/m2/day and 156.3 l/m2/day, respectively.

6-4-1-4 Study on mesh typology

To improve fog collector performance, understanding the effects of fog collector topology is a key as defined especially by the mesh radius and mesh diameter. Collectors can be categorized based on their fiber radius R and the half spacing of the fibers D, values that are important in the calculation of Stokes coefficient that is related to the collector efficiency. Stokes number typically determines the inertia of the moist air and its migration across the streamline and thus indicates the effectiveness of the fog collector design, thus a large Stokes number implies a higher rate of water droplet collection. However, this paper will not further elaborate the equation used for the calculation of Stoke coefficient. As previously discussed, Rivera investigated aerodynamic collection efficiency (ACE). Rivera considered that two important characteristics of the mesh were the shade coefficient and the characteristics of the fibers used to weave or knit the mesh. He also discussed a simple superposition model in analyzing the influence of these parameters to Regalado and Ritter the ACE of the fog water collectors. Rivera concluded that the ACE value can be increased by introducing concave shape to the fog water collector and improving the aerodynamics of the mesh fibers. Regalado and Ritter have performed a theoretical analysis on wind catchers in the form of cylindrical structures equipped with several screens of staggered filaments to determine their efficiency. Like Rivera, these researchers also assessed the aerodynamic effects of the water/fog impacting on the mesh.

6-4-1-6 Studies on surface wettability of a fog harvester

Park et al. have investigated the influence of surface wettability characteristics, length scale and weave density on the fog harvesting capability of woven meshes. In their research, Park et al. have developed a model that combined the hydrodynamic and surface wettability characteristics of a fog water collector in predicting the overall fog collection efficiency. From their modelling, later validated against experimental results and depicted in following figure, there are two limiting factors that will affect fog harvesting and reducing the collection efficiency; first is the re-entrainment of collected droplets into the prevalent wind, and second one is the blockage of the mesh opening.

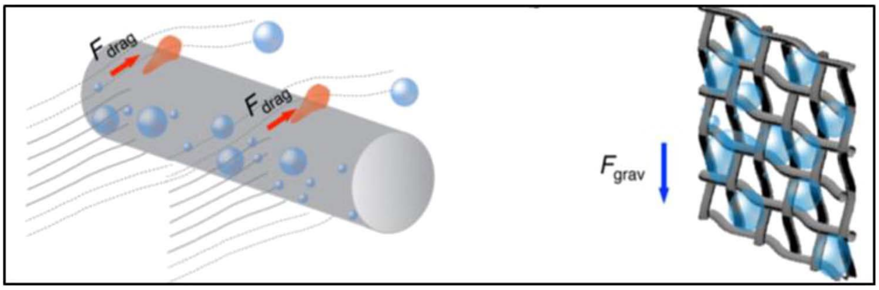


Figure 6-21 Wettability

Factors affecting fog harvesting and reducing the collection efficiency are (a) the re-entrainment of collected droplets in the wind and (b) blockage of the mesh.

However, they have concluded appropriate tuning of the wetting characteristics of the surfaces, reducing the radius of the wire and optimizing the wire spacing will lead to more efficient fog collection. Additionally, they have introduced family of coated meshes that have demonstrated enhancement in the fog collecting efficiency as high as five times of the conventional polyolefin mesh.

To coat the mesh 'a 1.7 wt.% 1H,1H,2H,2Hheptadecafluorodecyl polyhedral oligomeric silsesquioxane (fluorodecyl POSS) 98.3 wt.% poly (ethyl methacrylate) (PEMA, MW = 515 kDa, Sigma Aldrich) solution in a volatile hydrochlorofluorocarbon solvent (Asahiklin AK-225, Asahi Glass Company) at a concentration of 10mg/m' was used by the researchers.

They first dipped the mesh in the solution for 5 minutes and then air dried to evaporate the solution. To check the uniformity of the coating, they have used scanning electron microscopic method and by contact angle measurements at several locations on the coated surface. The aim of the coating is to decrease the contact-angle hysteresis of the mesh wires that allows small droplets to easily slide down into the collecting gutter when they were captured by the mesh wires. Even in a mild fog with a droplet radius of 3 µm, wind speed of 2 m/s and liquid water content of 0.1 g/m3, the use of optimal dip-coated mesh surface can collect ∼2 l of water over an area of 1 m2 in a day.

Seo et al. have investigated the effects of surface wettability for both fog and dew harvesting. Their approach to fog harvesting involves different test surfaces. A commercially available copper was used in various wetting characteristics, see following figure.

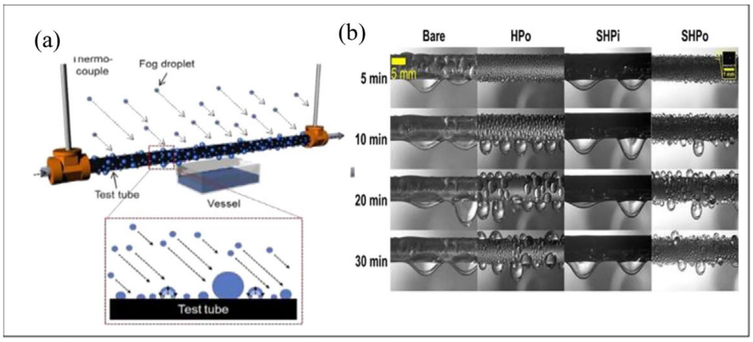


Figure 6-22 copper

(a) The schematics of the experimental arrangement and (b) the photos of different materials used to the test surface wettability in fog harvesting with the water droplets.

The wettability of surface is determined by the contact angle of the liquid on the surface where the liquid-vapor meets the surface. When a droplet is flowing, the contact angle (following figure) can be classified as advancing or receding. The researchers showed that the moisture harvesting performance was determined by the combination of the moisture capture at the surface and the removal of the captured water from the surface. In their study, they found out that a large receding contact angle is a determining factor in performance. Among all the surfaces tested, the oil-infused surfaces with their large receding contact angle at a high supersaturation condition exhibit the best fog harvesting performance.

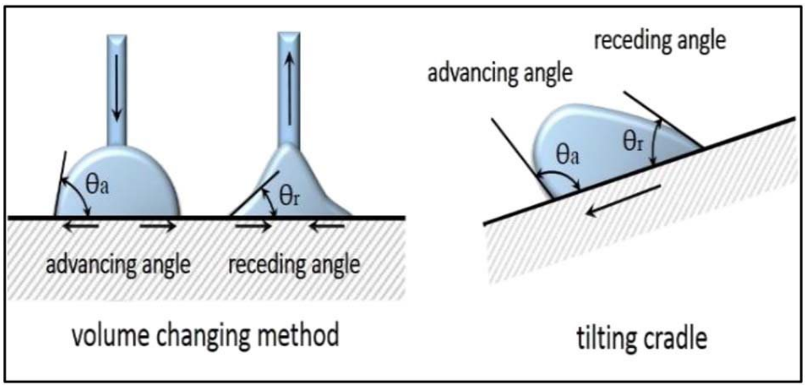


Figure 6-23 Wettability

Azad et al. compared the fog collection performance of three different categories of mesh sample for fog collection performance:

i. Surfaces with fine microstructures and different coatings can have markedly different wetting behaviors than smooth surfaces. Therefore, in their research, they have investigated smooth and micro grooved copper wire with a diameter of 1.2 mm. They created the microgroove surface using a sandpaper. Then, microgrooves were implemented on the wire surface using Korn 80 sandpaper that contains particles with the diameter of 190–265 µm. Illustrated in following figure, the copper wires (10 of them, with smooth and micro grooved structure) were soldered electrically on a wire stick.

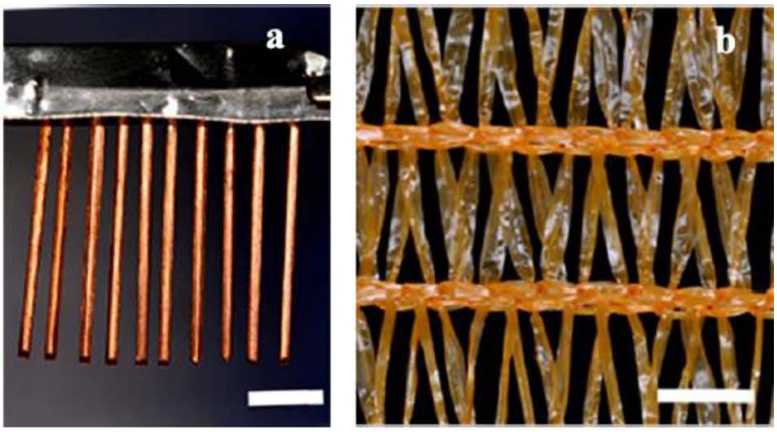


Figure 6-24 Surfaces with fine microstructures and different coatings

ii. Polyolefin mesh samples that comes in three types, hydrophilic mesh (attract water), super hydrophilic mesh that was dip coated with an aqueous TiO2 solution and dried at room temperature for 48 hours and 'hydrophobic mesh' (repel water) that were prepared by dip coating the polyolefin mesh with a hydrophilizing agent and dried at room temperature for 48 hours.

iii. Epoxy replication (replica) to replicate surface microstructures of Gunnera and Dendrocalamus under leaf surfaces and a smooth glass (microscope slide). The glass replica had a smooth surface, the Gunnera replica had a convex shape microstructure and random channels with hairs inside of the channel and the Dendrocalamus replica had microgroove surface.

It was found that the amount of collected water by super hydrophilic mesh was five times higher than the hydrophilic polyolefin mesh. Whereas water collection by hydrophobic mesh was 2.5 times higher than the hydrophilic mesh. In the micro structured replica, water dripped 2–3 times higher than unstructured replica and smooth surface. In addition, the water was collected more quickly for the micro-grooved copper wire than smooth wires.

Rajaram et al. studied ways to improve the capacity of fog water collection by modifying the surface and geometrical shapes of Raschel mesh structure as shown in following figure. The surface modification includes coating the mesh using superhydrophobic coating such as Teflon, ZnOnanowires, Never Wet and hydrobead. In general, when compared with the uncoated Raschel mesh, the use of the coatings gives about 50% enhancement in the collection efficiency given by equation. Meanwhile, in terms of the modification to the geometrical shapes, they have increased the shade coefficient of the Raschel mesh by developing a new manufacturing method via a punching process. That has resulted in reduction in the pore size and the increase in the distance between two inclined filaments. The change in the geometrical shape leads to another 50% of enhancement. In general, both methods have collected water about two times that of a typical Raschel mesh.

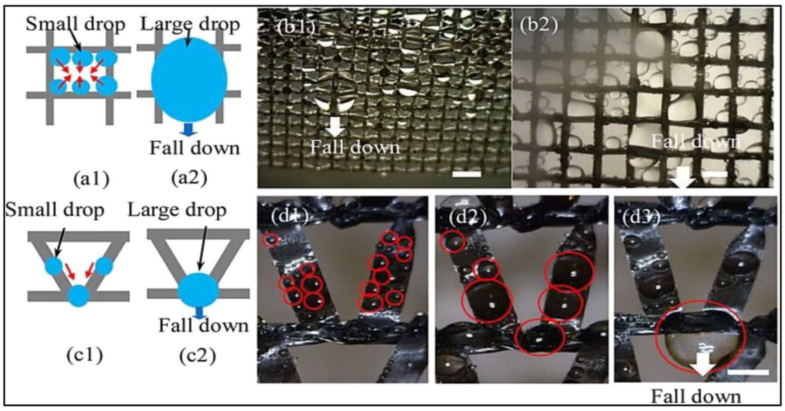


Figure 6-25 Illustration and experimental results of mist flow (optical images) on two rectangular Rachel meshes with cylindrical fibers (real images)

6-4-2 Dew water harvesting

In fog water harvesting, the collection of water will occur when the fog droplets impact and intercept with the collection surfaces. However, the main limiting factor of harvesting water from the fog droplets is the global fog occurrence that is highly dependent on the geographical and metrological factors or conditions. Only limited number of places experience environmental conditions whereby the temperature of moist air could naturally drop below its saturation temperature thus form fog. Not surprisingly therefore, on a global scale, fog is reported to be even less accessible than seawater as an alternative source of freshwater. Water vapor is ubiquitous in the atmosphere, so, if condensed by cooling, freshwater can be harvested at many locations. Nevertheless, the condensation process is more thermodynamically complicated than fog harvesting and as reported in Gido et al., the process involves a significant release of heat. Water droplets that are formed due to the condensation of water vapor on a surface at temperature below its dew point temperature are called dew water.

dew water harvesting processes are divided into three categories: i) passive (radiative) cooling condenser, ii) solar-regenerated desiccant and iii) water harvesting from air using active cooling condensation technology. This review includes dew water collection under both high and low humid air conditions.

6-4-2-1 Water harvesting using radiative cooling condenser (passive)

The principle of radiative cooling condenser is very simple. Inspired from dew formation on plants in the morning, the formation of dew is driven by radiation phenomena of the surface of the materials. The formation of the dew is physical and determined by the surface cooling without additional energy, and the most important element being the power gradient between the condenser outgoing radiative power and the sky radiative power P which is presented by the Stefan–Boltzmann law presented in equation:

$P = \varepsilon\sigma(T)4$

The radiative power per unit area P (W/m2) also depends on the local surface temperature T (K). In equation (5), σ is the Stefan–Boltzmann constant (W/m2K4), and ε is the emissivity of the surface. Thus, to optimize the dew formation, as reported in cited in, one could:

(i) maximize the infrared wavelength emitting properties of the surface to allow surface cooling at night.

(ii) increase the reflectivity of the condensing surface to ensure that the surface will not trap heat that will warm the condenser and resulting in evaporation during the day.

(iii) reduce the wind effect to the condenser by tilting the condenser surface.

(iv) increase the hydrophilic property of the surface, and this can be achieved by applying hydrophilic coating to the surface and lastly.

(v) reduce the heat inertia of the condensing surface to promote change in temperature difference and to avoid heat transfer from the ground.

Studies on passive cooling system include investigation on materials with low emissivity surfaces. Early study on the influence of condensing surface materials to the dew formation has been investigated for Bahrain climatic condition. Three materials: aluminum, glass and polyethylene foils were investigated as the condensation surfaces. From their study, aluminum surfaces were reported to have the highest amount of average dew collected at 3 kg/m2 per hour, followed by glass and polyethylene foils at 0.8 and 0.3 kg/m2 per hour, respectively. Three different types of condensing surface namely: i) galvanized iron (GI) sheet with emissivity 0.23 and thickness 1.5 mm, ii) commercial aluminum sheet with emissivity of 0.09 and thickness 1.5 mm and iii) PETB film (polyethylene mixed with 5% TiO_2 and 2% $BaSO_4$)

UV stabilized with emissivity 0.83 and thickness 0.3 mm have been investigated, see following figure.

The condensing surfaces were tested as a radiative condenser at 1 m × 1 m in size installed at the village of Kothara (23◦ 14 N, 68◦ 45 E, 21 m a.s.l.) that is a part of the semi-arid coastal region of northwest India. The aim of the project was to use the water harvesting system as a solution to drinking water problem in that region that is well known with poor groundwater quality.

From the daily data collected over 2-year period in 2004 and 2005, the quantity of water collected on most (60%) nights varied uniformly between 0.05 and 0.25 mm and there were two peaks.

Figure 6-26 Radiative cooling condense

The peaks that one of them centered over March–April (summer) and the other over October (fall) shows water collection of 0.55 mm. From all the three surfaces being tested, the highest collection was in the PETB units (19.4 mm) followed by GI (15.6 mm) and aluminum (9 mm). Kothara village in the Kutch region now has India's first potable large-scale water production plant designed to harvest atmospheric moisture and process it into drinking water. The condensers were made of planar panels using high emissivity plastic film insulated underneath that promotes cooling. In addition to dew water harvesting, the condenser is also capable to collect rainwater. It was reported that the expected cost of 1 l of bottled water is 0.5 rupee with the expected yield of filtered, treated potable water from the plant is 150000 liters a year.

Another important surface parameter that influences the performance of the passive system is the shape of the radiative condenser. As reported in Khalil et al., among the early researchers who investigated various shapes of these passive condenser surfaces were Jacobs et al. who investigated an inverted pyramid shape. Investigated at the grassland of the Netherlands, the authors concluded that their collector collected water 20% more that the planar shape at angle 30◦. Researchers have performed a CFD simulation Computational Fluid Dynamics using PHOENIXS to simulate the innovative designs proposed in their study.

In a passive system, natural convection between the condenser surface and the air flow is not favored since it will reduce the condensing efficiency of the condenser system. Thus, a condenser in a hollow form such as a funnel will reduce the free convection along the surface since the heavier cold air will remain at the bottom of the funnel due to gravity regardless of the wind direction. The researchers have performed both simulation and field studies. From their simulations, cone angle ≈ 60◦ give the best condenser cooling efficiency. Based on experimental work and field testing, a repetitive pattern of hollow shapes to pave a planar or weakly curved roof surface, have been considered, providing pleasing aesthetics and construction cost advantages. The egg-box and origami types were specifically investigated. The prototypes were fabricated and installed at Les Grands Ateliers (Villefontaine - France) during the 'Chaleurs urbaines' project (ENSA de Grenoble - Metro).

6-4-2-2 Solar regenerated desiccant in water harvesting (passive)

Low yield is a key issue for the passive, radiative condenser system because of its dependency on certain parameters, notably the sky emissivity, the amount of water vapor in the air (relative humidity), wind speed and topographic cover. Desiccant materials such as silica gel, zeolites and CaCl2 are hygroscopic and can absorb moisture through adsorption and absorption process thus increasing the amount of the dew water collected. As a result, desiccant beds are now commonly being used in atmospheric water harvesting applications.

Following figure presents the generic process of atmospheric water harvesting using desiccant. The process may be explained as follows: the first stage is water absorption stage at night where the desiccant bed will absorb moisture from humid air. The second stage is water desorption during the day by heating the bed with solar radiation, which will regenerate the desiccant by driving out water vapor. In the third and final stage, the evaporated water will then condense into water droplets and collected in a tank.

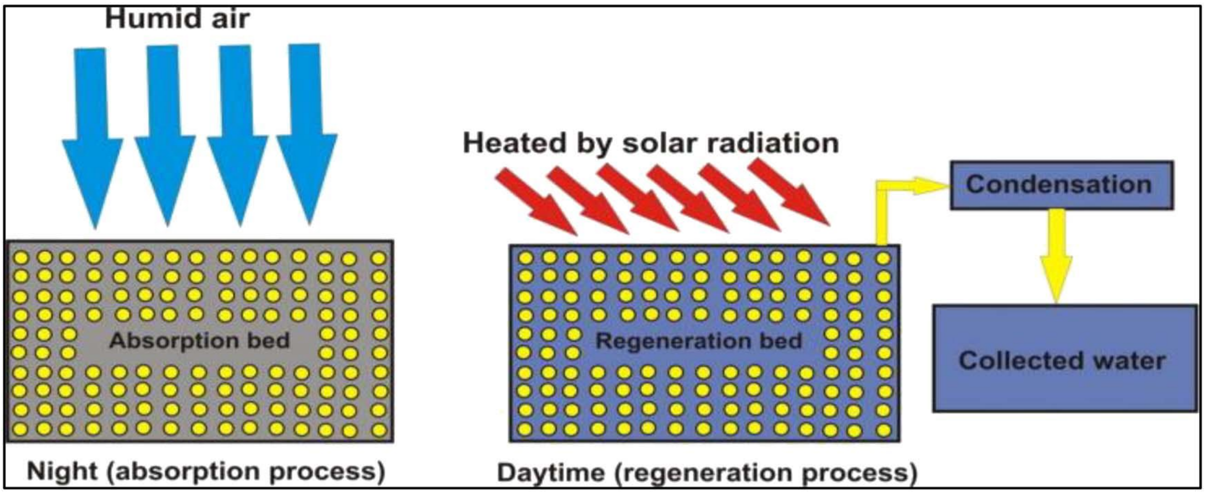


Figure 6-27 Wet desiccant technique for water production from atmospheric air

The advantages of a desiccant system over radiative condensers include the hygroscopic capacity of the desiccant that enables more efficient water collection, achieving low dew points without the risk of freezing thus reducing operational cost. Early studies on solar regenerated systems involve desiccants such as saw dust, silica gel and recycled newspaper. In a patent, Ackerman claimed a spiral water harvester containing hydrophilic particles such as silica gel and tilted at an angle that optimized water collection.

6-4-2-2-1 Glass pyramid collector

Kabeel described a glass pyramid collector (following figure) comprising: i) desiccant beds on shelves, ii) a slanting wall cover, iii) a collection cone and iv) a condenser section mounted on top of the pyramid, shading it from solar radiation.

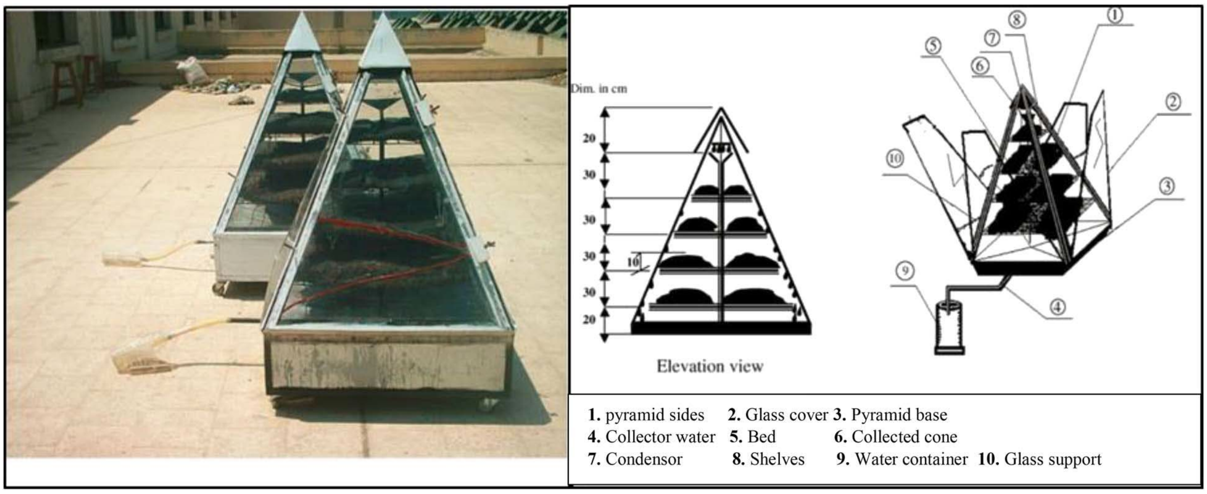
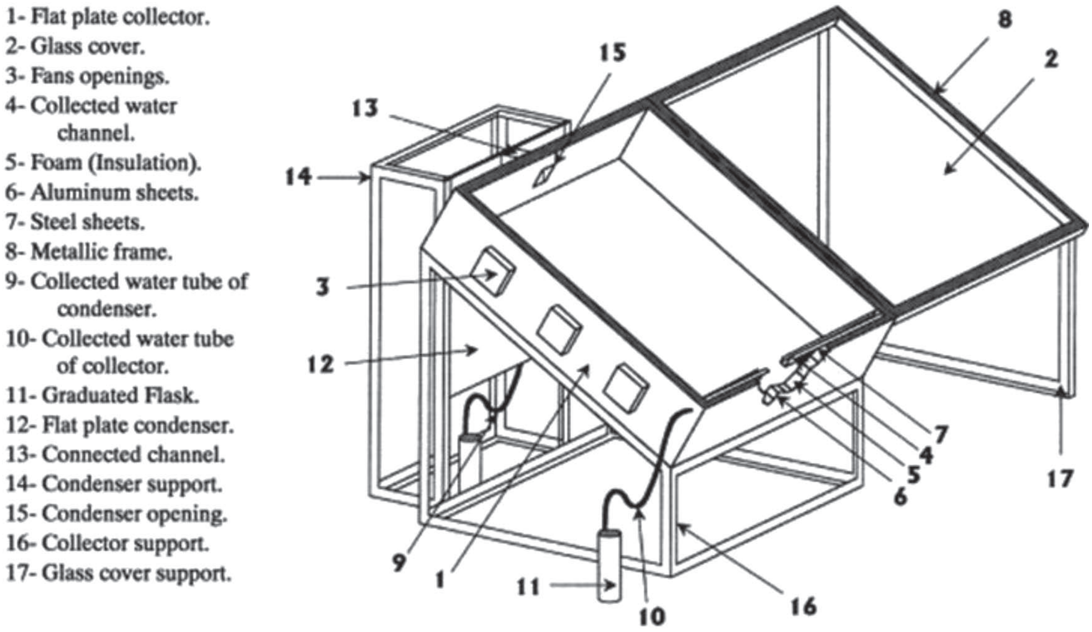


Figure 6-28 Glass pyramid collector

Sawdust and cloth, saturated with CaCl2, were investigated as the desiccants. The covers over the beds are open overnight so the desiccant can absorb water vapor from the air. During the day, the covers are closed so the beds are heated by solar radiation driving off the absorbed water, which condenses on the sides and especially at the pyramid apex water, where it is collected by a central cone and flows through a tube to an external container. The reported water yield is 2.5 l/day/m3; the cloth bed showed better performance than the sawdust bed system.

6-4-2-2-2 Corrugated surface

Based on the principle of desiccant moisture absorption at night and simultaneous desorption (regeneration using solar energy) and water vapor condensation during the day, Gad et al. introduced the use of an integrated desiccant/solar collector to harvest water from humid air. In their study, a small air circulation fan was used to force the ambient air to enter the glass-enclosed solar collector during the evening (following figure). In the collector, a thick layer of corrugated cloth was used as the desiccant bed. The use of corrugated surface was meant to increase the heat and mass transfer area during the absorption/desorption mechanism. During the day, water vapor condensation will occur on the inner surface of the glass enclosing the solar collector. According to the researchers, the solar driven system could produce 1.5 l of fresh water per square meter per day.



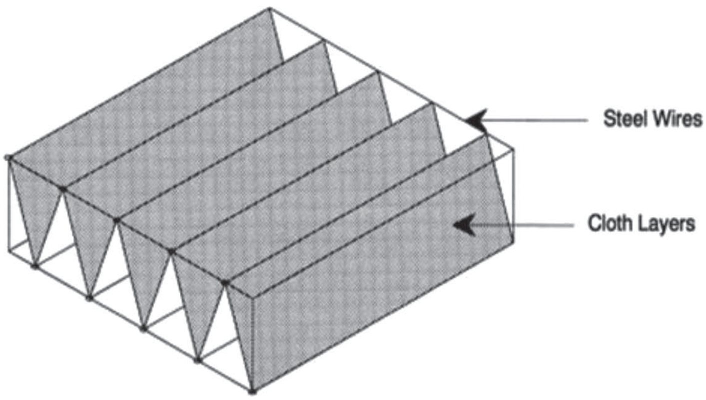
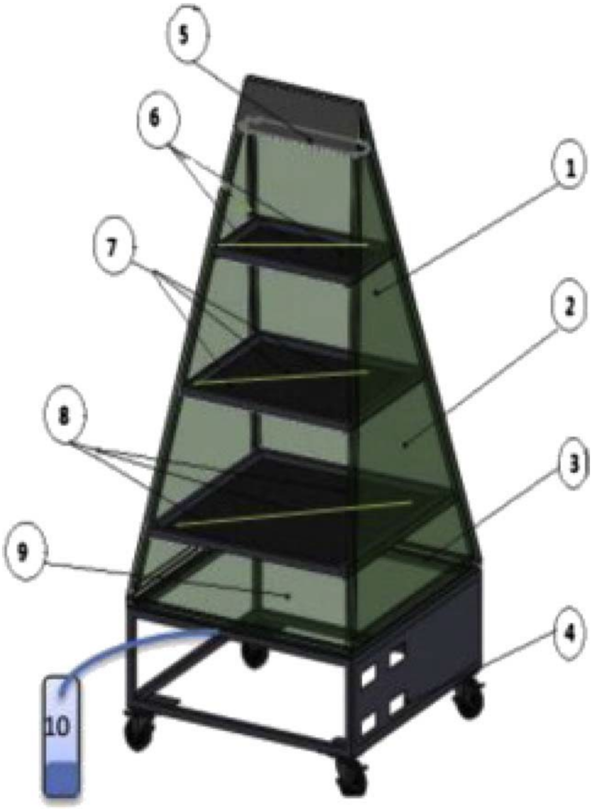


Figure 6-29 Corrugated surface

6-4-2-2-3 Trapezoidal prism

William et al. designed a trapezoidal prism with CaCl2 as the desiccant (following figure) supported on sand and on dark cloth. For the prism wall, transparent fiber glass bolted to aluminum frames was used while the top of the prism was an opaque material that acted as a condenser and to facilitate collecting the condensate water, the walls were slanting. The trapezoidal prism worked in essentially the same way as the pyramidal system described above in that moisture absorption occurred at nighttime and the solar radiation driven desorption occurred during the day with the evaporated water forming water droplets that collected in the water tank. The system efficiency was computed by considering the total heat of evaporation to the total incident solar radiation during the daytime. The recorded daily total evaporated water for cloth and sand bed achieved a maximum of 2.32 and 1.23 l perm2 at system efficiency of 29.3% and 17.76%, respectively.



No	Description
1,2,3	Temperature measuring point in each fiberglass side
4	Thermocouple selector switch position
5	Roof surface temperature measuring points
6	Top bed temperature measuring points
7	Middle bed temperature measuring points
8	Bottom bed temperature measuring points
9	Collecting surface for condensed droplets
10	Collect water tank

Figure 6-30 Trapezoidal prism

6-4-3 Wind pump

In 2007, two students from Halmstad University conducted a field study in the Mara region and found that many farmers lack clean and running water. Back in Sweden they constructed a prototype of a windmill that employs wind energy to pump water using a semi-rotary pump. The intention is that local farmers should be able to build their own windmill, and thus have running water in their household.

Important throughout the project has been to minimize cost and to only use material that local farmers can get hold of. Building and assembling of the windmill were then performed by the authors in co-operation with local workers. The windmill drives a pump that pumps water from a well to a tank for further use in irrigation.

Windmill pumps are mainly used for irrigation and watering livestock. Windmill pumps will operate once the wind speed reaches 10 kph, but they only really work satisfactorily from a wind speed of 15 to 20 kph.

6-4-3-1 Wind

Wind primarily occurs because of temperature differences in the air caused by sun radiation. When air is heated it becomes less dense and therefore rises. The pressure at ground level decreases, and because air always flows from high pressure to low pressure, thermal circulation is then developed.

One example of this thermal circulation is the sea breeze; a local wind found in coastal areas or at large lakes. It occurs on relatively clear days when the sun heats the land more than the sea, causing the air above the land to rise and flow out over the water. The air cools off, sinks, and flows back in over land. The sea breeze can occur all year round in the tropics and can reach a speed of 5-10 m/s at ground level. It is most extensive during the afternoons when the sun has heated the ground to a high temperature.

The opposite of sea breeze is land breeze. It happens during the night when the land cools off faster than the water, and the process described above is reversed. It is a lot weaker with speed at only about 1 m/s.

6-4-3-2 Pumps

6-4-3-2-1 Piston pump

A piston pump (following figure) is a simple construction. It consists of a cylinder pipe with a piston inside and two non-return valves placed opposite each other. When mechanical work is exerted on the connecting rod the piston moves up and down, sucking water into the pipe and then pumping it out. As the piston is pulled upwards, water enters the pipe through one of the valves because of the low pressure that has arisen in the pipe. When the piston is then pushed down, the water is forced out through the second valve because the first valve is closed. By repeating this movement water is transported.

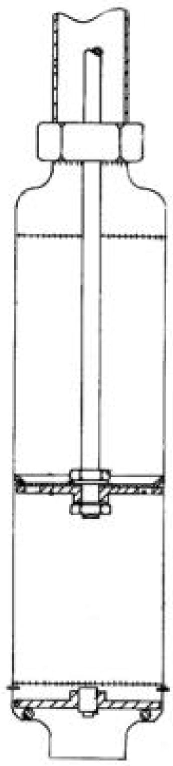


Figure 6-31 piston pump

The torque required to start a piston pump is relatively high, because it needs to overcome both the weight of the pump rod and that of the water being lifted. Once the rotor is turning, wind speed can drop to about 2/3 compared to the start speed.

The capacity of a piston pump is relatively low, and the water flow will not be constant, but it is cheap to manufacture and easy to use. A piston pump can produce large head even with low rotation speed.

6-4-3-2-2 Semi-rotary pump

A semi-rotary pump (following figure) works like a piston pump, but instead of a straight connecting rod it has a lever. The lever is rotated back and forth in a semi-circular path. The leverage means that the semi-rotary pump does not need as much force as a piston pump to perform the work of pumping liquids.

It is suitable for liquids with low viscosity, such as water or diesel, and it is generally used as a hand pump. Since it is sensitive to dirt that may come in the system it is not optimal to use this type of pump for irrigation.

Figure 6-32 Semi-rotary pump

6-4-3-3 windmill construction

Håkansson and Nilsson's original windmill construction (following figure) consists of a wooden frame, a steel axis with six steel bar wings stabilized by strings, two bicycle wheels used as bearings, and a bar and connecting rod (conrod) used for power transference. The sails should be made of a fabric that does not let too much wind through or absorb too much water. The sails are then tied to the wings with strings. There are different ways to anchor the frame in the ground. It can be dug down in the sand and hold in place with heavy stones or tied to nearby trees or stumps.

The bar is fastened on one of the bicycle wheels, so when the wheel rotates, the conrod is driven up and down in a pumping motion (following figure). A pump can be attached to lower end of the conrod, and thus the pump will be driven by the windmill when the wind blows. It will pump one stroke per rotation of the windmill.

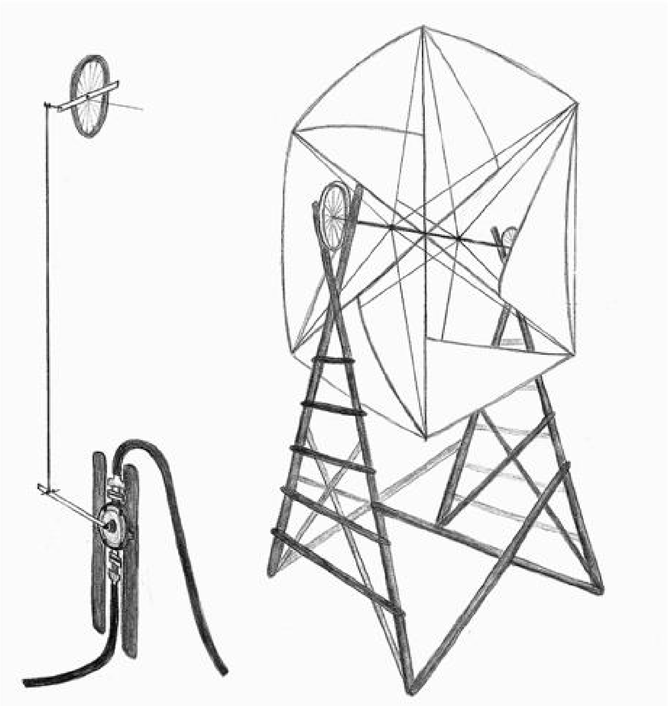


Figure 6-33 Wind pump construction

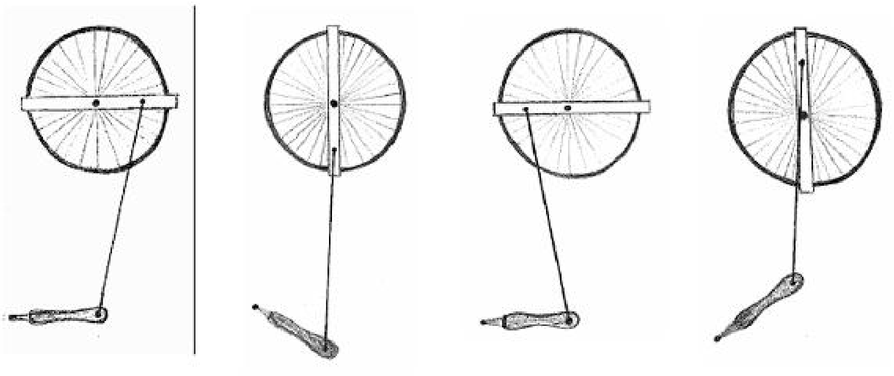


Figure 6-34 Wind pump construction

It stands on a concrete foundation and is composed of one wooden frame that holds up the wheel and axis. The pump is attached to the axis through a conrod. When the wind is captured by the six triangular sails, the wind energy is converted into kinetic energy that makes the axis rotate. The conrod is then moved up and down in a pumping motion, making the water flow through the pipes from the well to the tank.

Figure 6-35 Wind pump construction

The diameter of the wheel that holds the windmill blades (formerly sails) depends on the depth of the well and how far up the water must be pushed and on the flow rate to be achieved. The structure's height and the construction materials used are especially dependent on the maximum wind speed and any obstacles that may be located nearby (none of which must be located within a radius of at least 150 meters). The flow rate achieved by a windmill varies significantly depending on the wind and on pump characteristics. It may sometimes vary from 200 liters per hour to 6 or 7,000 liters per hour.

Figure 6-36 Wind pump construction

6-4-4 Waterless toilets - Enviro loo

Using the custom-designed ceramic toilet bowl the solid waste falls directly on to an inclined perforated drying plate. The urine passes through the plate to the tank below.


Figure 6-37 Enviro loo

By separating the liquids and solids aerobic conditions are achieved and maintained by the evaporation process. The solid waste aided by gravity moves to the collection area while being subjected to continuous ventilation from the air flow created by the forced aeration ventilation system. This encourages the formation of aerobic bacteria which kills the disease forming pathogens.

Figure 6-38 Enviro loo

Air trapped under the inspection cover is heated by the sun and this hot air rises. Air within the black polyethylene vent pipe is also heated by the sun. together with rising air and the extraction unit, negative pressure is created within the tank.

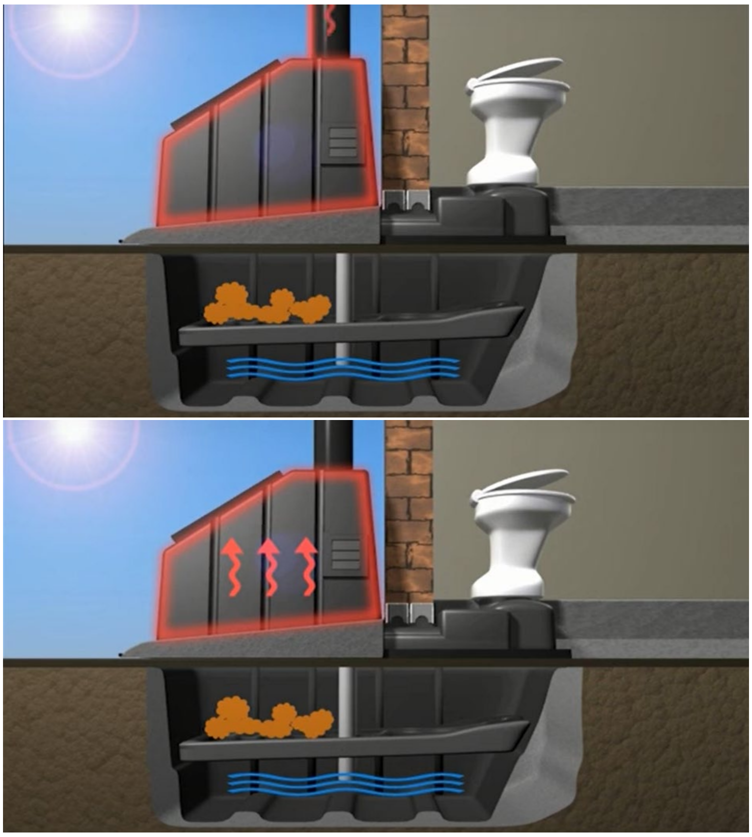


Figure 6-39 Enviro loo

Fresh air is continuously drawn into the system, via the ceramic toilet bowl and via the side inlet pipes. The air drawn in by the toilet bowl flows over the waste trapped on the drying plate.

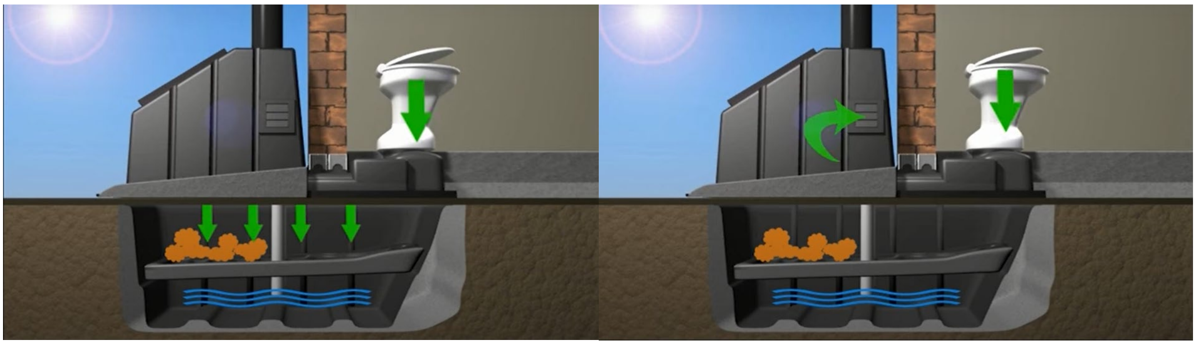


Figure 6-40 Enviro loo

The airflow passing over urine from the side inlet pipes causes it to evaporate from the unite via the vent pipe.

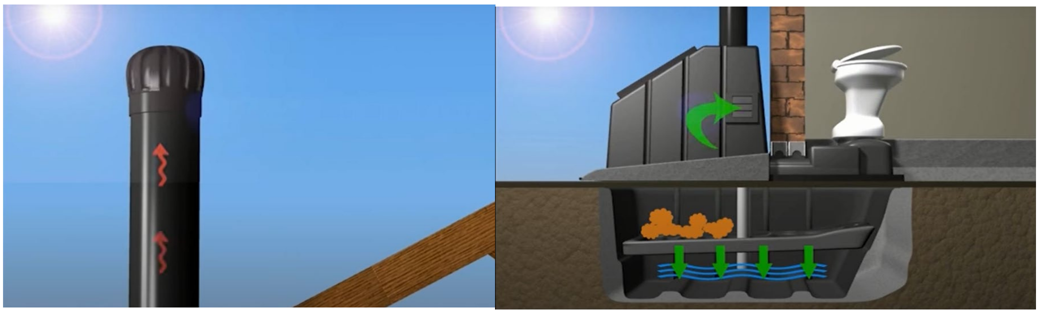


Figure 6-41 Enviro loo

The Enviro loo is a sealed unite. It does not allow leakage out of the tank nor can storm water penetrate and flood the unite. Sealed within the system the correct aerobic environment is created for prolonged stabilization of the waste through the process of dehydration and evaporation. The negative pressure created within the container prevents the scape of odors through the toilet bowl or through the air inlet pipes.

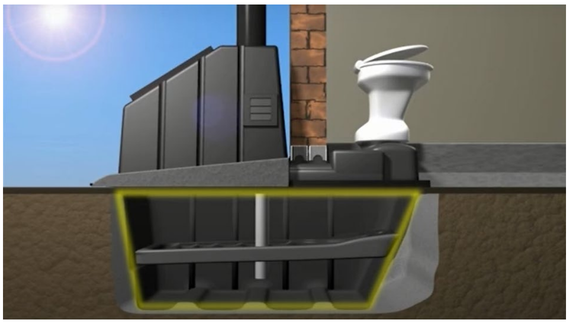


Figure 6-42 Enviro loo

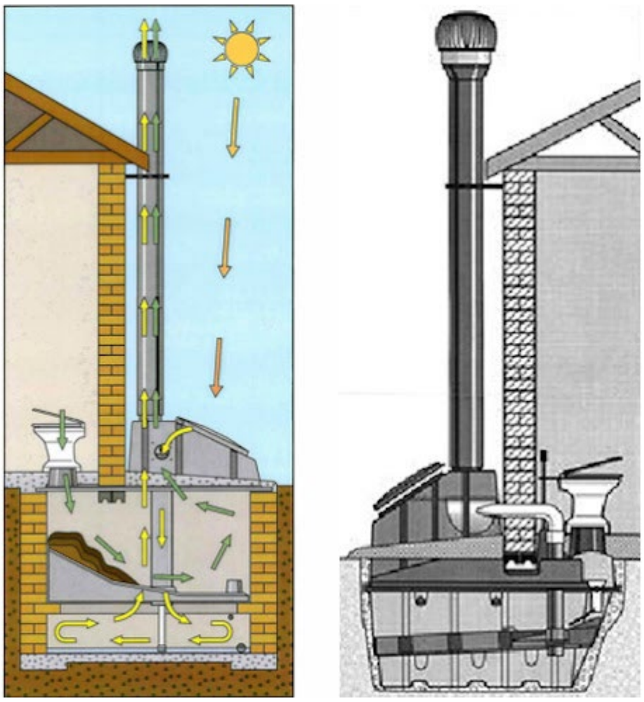


Figure 6-43 Enviro loo

Odors are vented to the atmosphere via the ventilation pip. With adequate oxygen flows, the waste decomposes into a dry stabilized material approximately 5 percent of its original volume. This stabilized waste is odorless and free of any health hazard.

Figure 6-44 Enviro loo

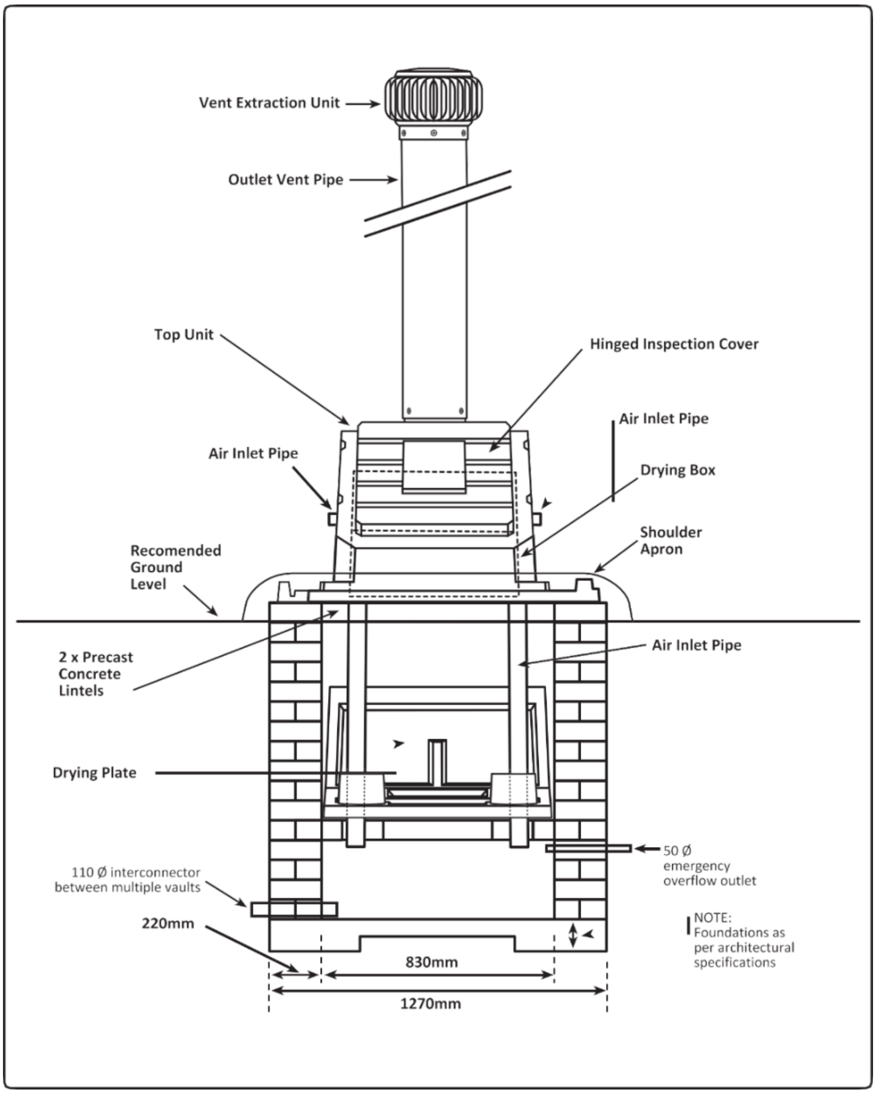


Figure 6-45 Assembly diagram

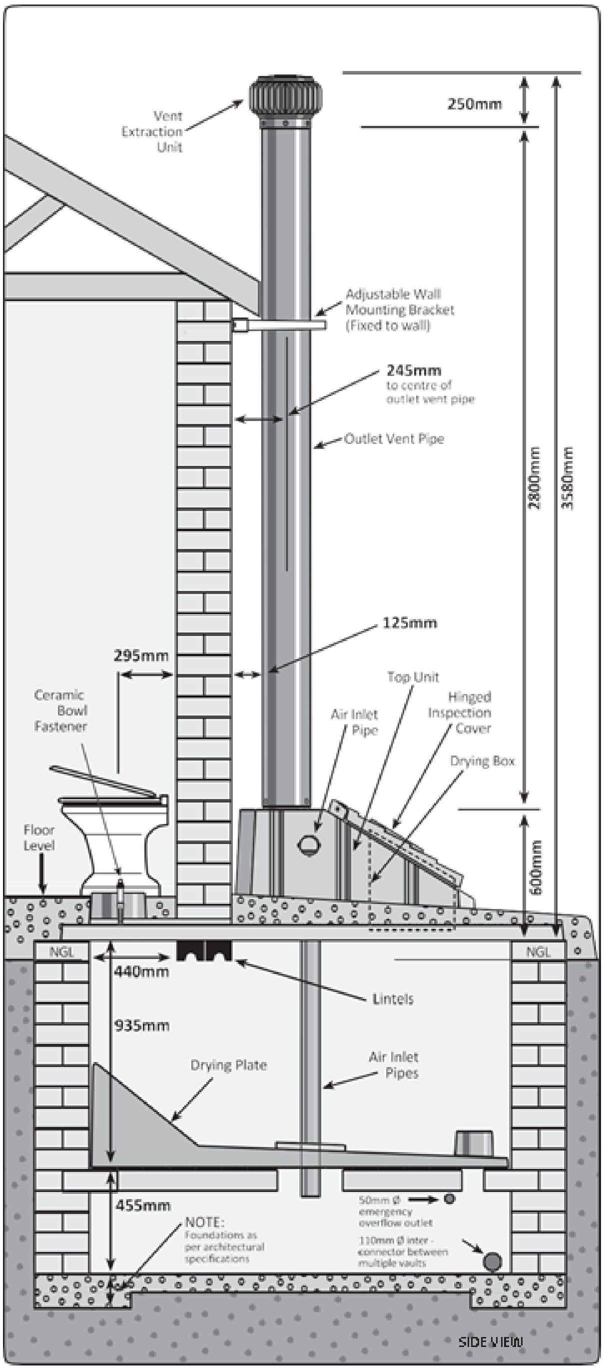


Figure 6-46 Assembly diagram

Regarding to multiple toilet installations, connect vaults with a 110 Ø pipe for even distribution of excess liquid. In addition, please install a 50 Ø pipe just under the corbelled brick level as an emergency overflow outlet which could be linked to a soak away or grey liquid waste system.

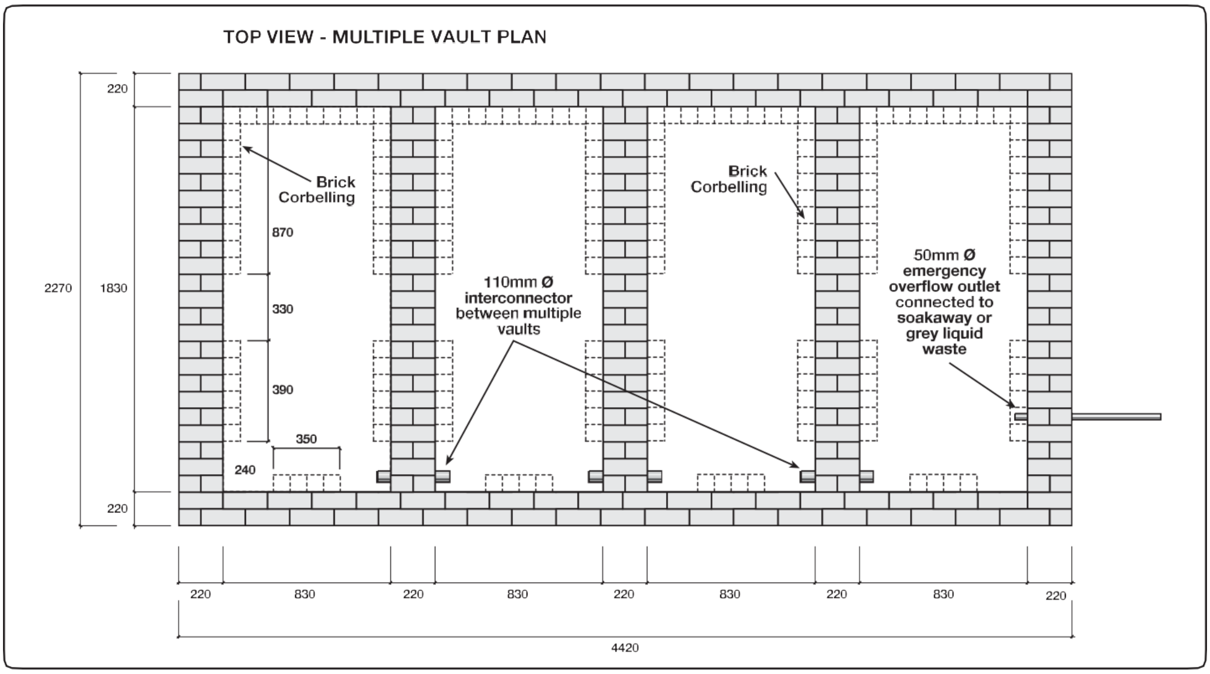


Figure 6-47 Assembly diagram

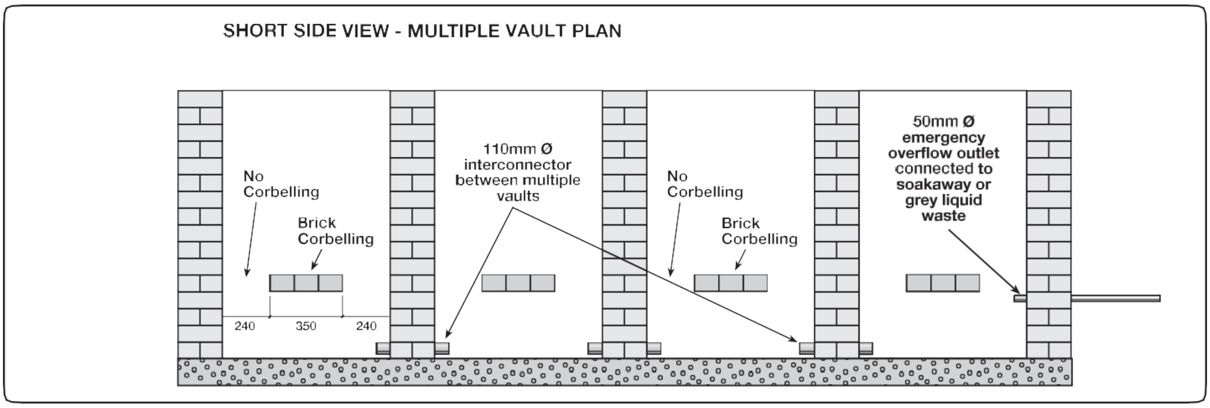


Figure 6-48 Assembly diagram

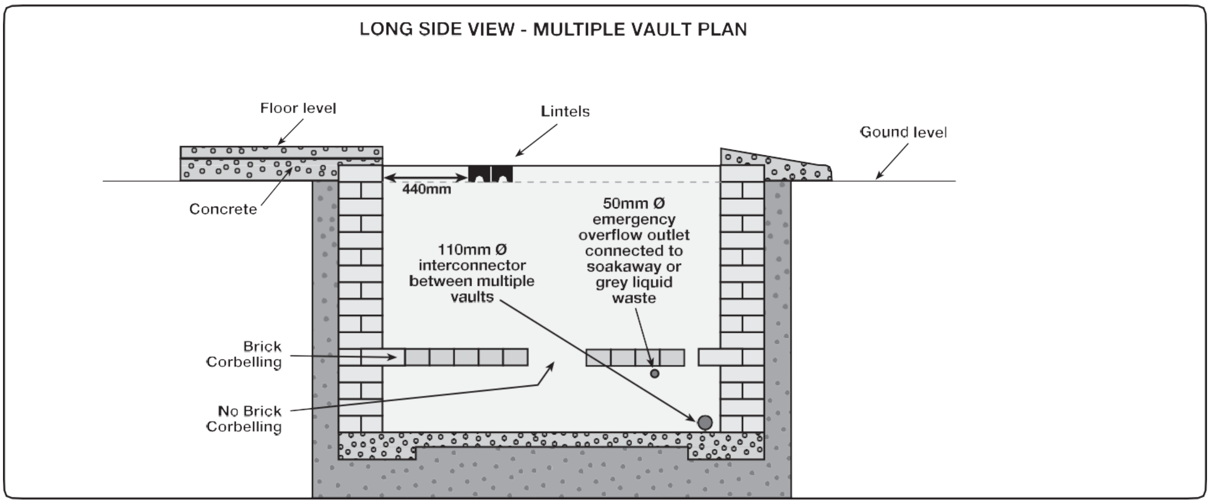


Figure 6-49 Assembly diagram

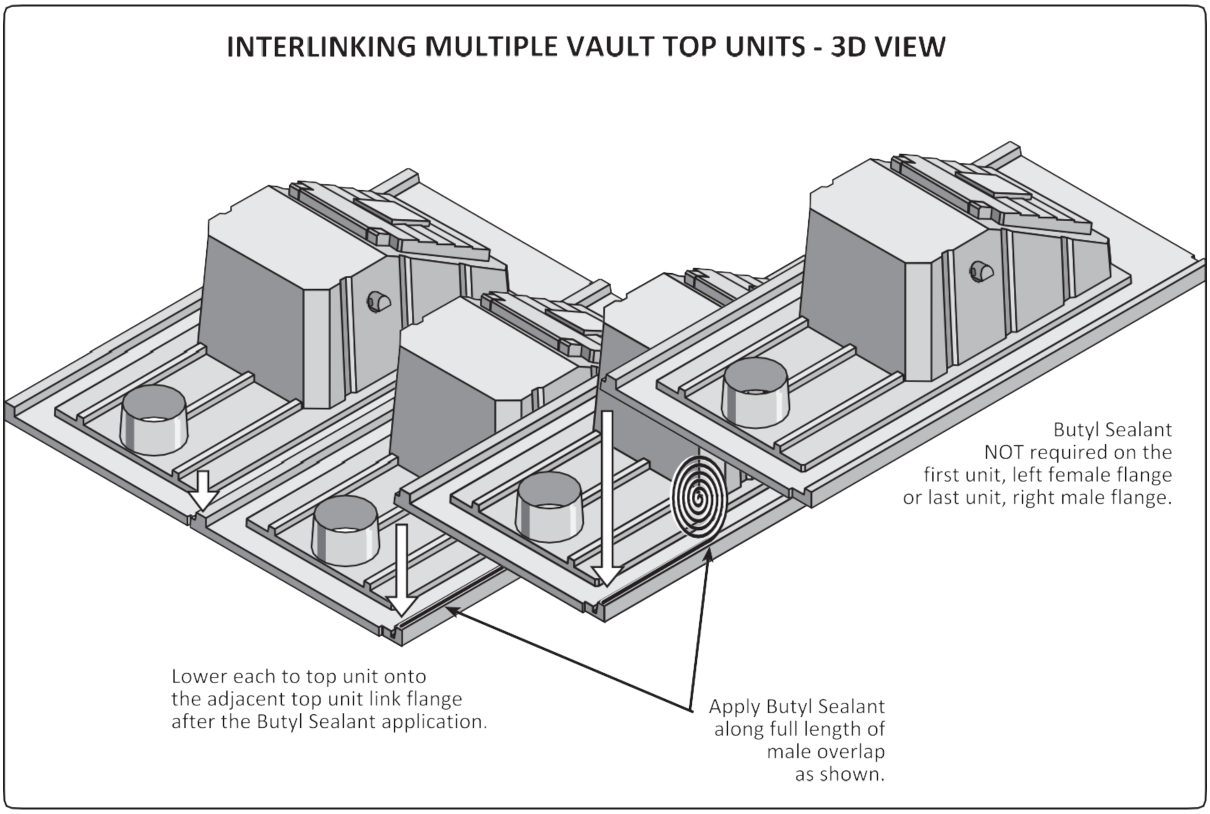


Figure 6-50 Assembly diagram

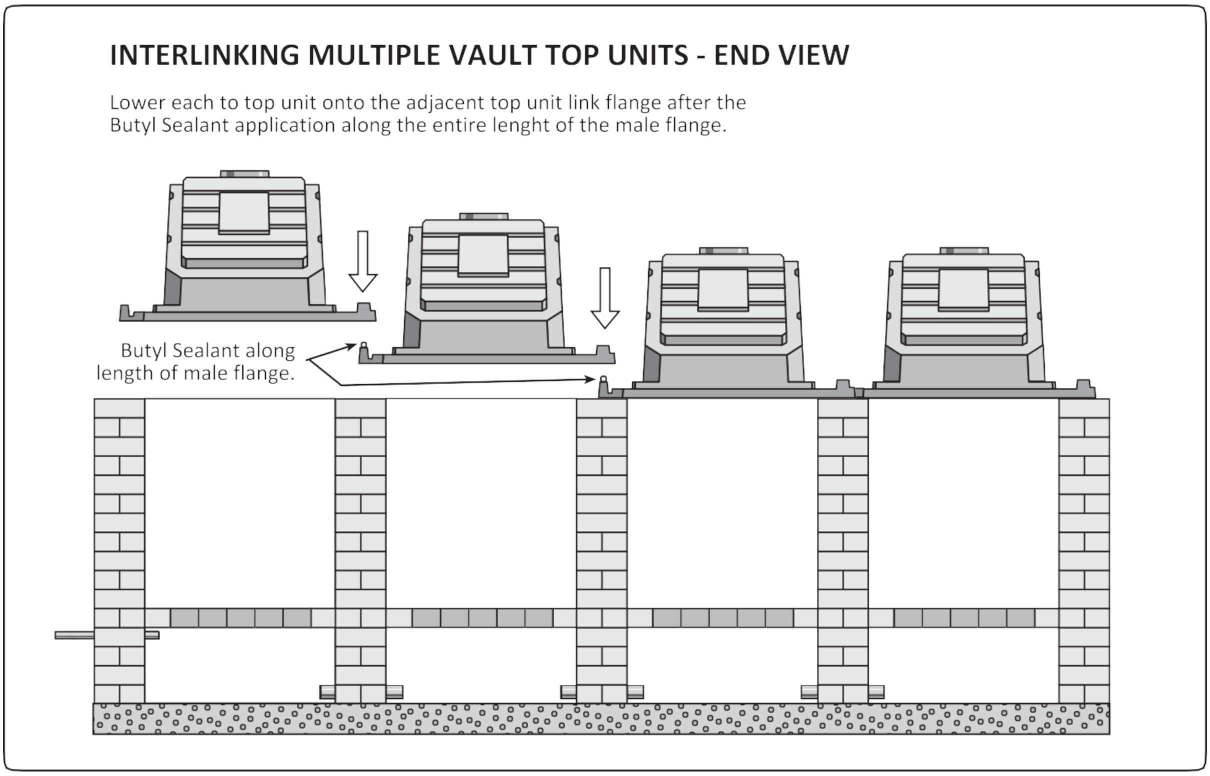


Figure 6-51 Assembly diagram

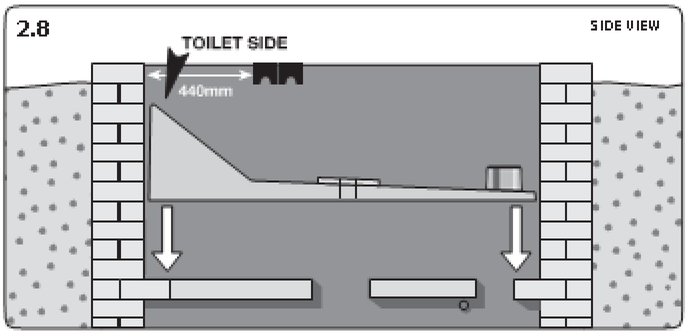


Figure 6-52 Assembly diagram

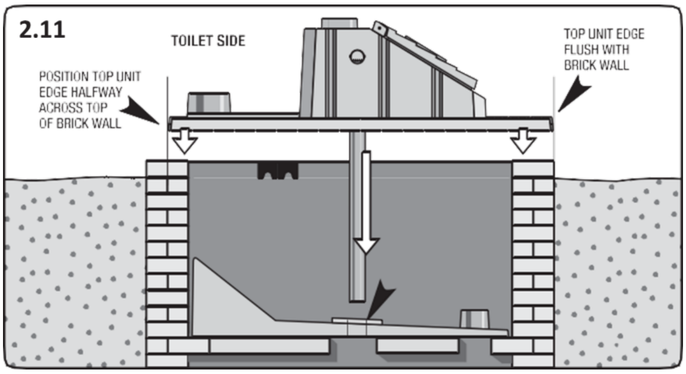


Figure 6-53 Assembly diagram

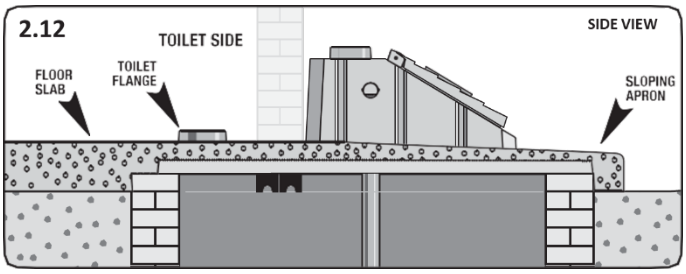


Figure 6-54 Assembly diagram

Chapter 7

Waste management

Solid waste management is an essential service in any society. Before introducing the process, however, let us start with a discussion of the material being managed—solid waste.

Solid waste refers to the range of garbage materials—arising from animal and human activities—that are discarded as unwanted and useless. Solid waste is generated from industrial, residential, and commercial activities in each area, and may be handled in a variety of ways. As such, landfills are typically classified as sanitary, municipal, construction and demolition, or industrial waste sites.

Waste can be categorized based on material, such as plastic, paper, glass, metal, and organic waste. Categorization may also be based on hazard potential, including radioactive, flammable, infectious, toxic, or non-toxic wastes. Categories may also pertain to the origin of the waste, whether industrial, domestic, commercial, institutional, or construction and demolition.

Regardless of the origin, content, or hazard potential, solid waste must be managed systematically to ensure environmental best practices. As solid waste management is a critical aspect of environmental hygiene, it must be incorporated into environmental planning.

7-1 Definitions of municipal solid waste

By OECD: municipal waste is collected and treated by, or for municipalities. It covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yard and garden, street sweepings, contents of litter containers, and market cleansing. Waste from municipal sewage networks and treatment, as well as municipal construction and demolition is excluded.

By PAHO: solid or semi-solid waste generated in population centers including domestic and commercial wastes, as well as those originated by the small-scale industries and institutions (including hospital and clinics); market street sweeping, and from public cleansing.

By IPCC: the IPCC includes the following in MSW: food waste; garden (yard) and park waste; paper and cardboard; wood; textiles; nappies (disposable diapers); rubber and leather; plastics; metal; glass (and pottery and China); and other (e.g., Ash, dirt, dust, soil, electronic waste).

7-2 Waste generation

Current global MSW generation levels are approximately 1.3 billion tons per year and are expected to increase to approximately 2.2 billion tons per year by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years. However, global averages are broad estimates only as rates vary considerably by region, country, city, and even within cities.

MSW generation rates are influenced by economic development, the degree of industrialization, public habits, and local climate. Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. Income level and urbanization are highly correlated and as disposable incomes and living standards increase, consumption of goods and services correspondingly increases, as does the amount of waste generated. Urban residents produce about twice as much waste as their rural counterparts.

Waste generation by region

Waste generation varies as a function of affluence, however, regional and country variations can be significant, as can generation rates within the same city. Waste generation in sub-Saharan Africa is approximately 62 million tons per year. Per capita waste generation is generally low in this region, but spans a wide range, from 0.09 to 3.0 kg per person per day, with an average of 0.65 kg/capita/day.

Region	Waste generation per capita (Kg/capita/day)		
	Lower boundary	Upper boundary	Average
AFR	0.09	3.0	0.65
EAP	0.44	4.3	0.95
ECA	0.29	2.1	1.1
LAC	0.11	5.5	1.1
MENA	0.16	5.7	1.1
OECD	1.10	3.7	2.2
SAR	0.12	5.1	0.45

Table 7-1 Waste generation

Current waste generation per capita by region

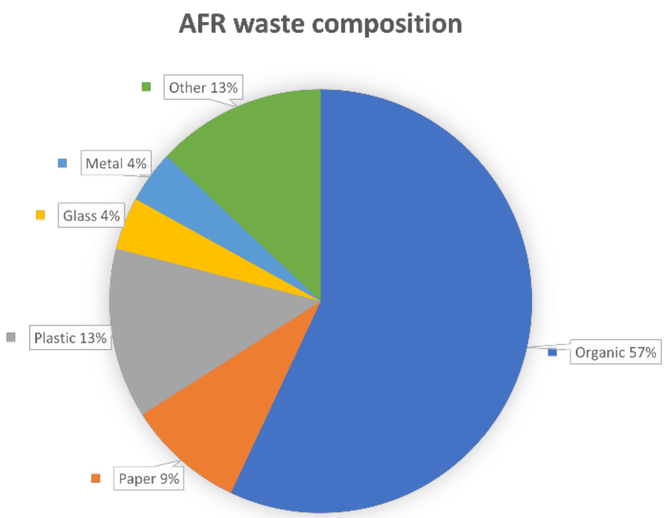


Figure 7-1 Waste composition by region

Waste production can be minimized by adopting the 3 R's principle: Reduce, Reuse, and Recycle.

a. Reduce the amount and toxicity of garbage and trash that you discard.

b. Reuse containers and try to repair things that are broken.

c. Recycle products wherever possible, which includes buying recycled products i.e., recycled paper books, paper bags etc.

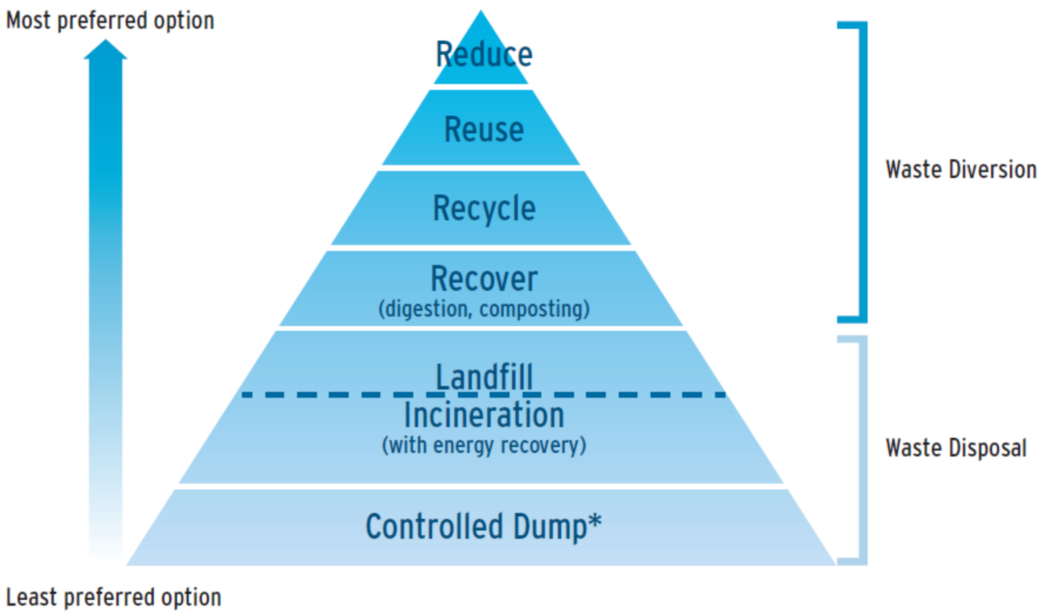


Figure 7-2 Waste cycle

Reduce (Waste Prevention):

Waste prevention, or "source reduction," means consuming and discarding less, is a successful method of reducing waste generation. Backyard composting, double sided copying of papers, purchasing durable, long- lasting environmentally friendly goods; products and packaging that are free of toxics, redesigning products to use less raw material production and transport packaging reduction by industries are the normal practices used and have yielded substantial environmental benefits.

Source reduction prevents emissions of many greenhouse gases, reduces pollutants the need saves energy, conserves resources, and reduces wastes for new landfills and combustors. It reduces the generation of waste and is generally preferred method of waste management that goes a long way toward saving the environment.

Reuse:

Reuse is the process, which involves reusing items by repairing them, donating them to charity and community groups, or selling them. Reusing products is an alternative to recycling because the item does not need to be reprocessed for its use again. Using durable glassware, steel using cloth napkins or towels, reusing bottles, reusing boxes, purchasing refillable pens and pencils are suggested.

Recycling:

The process of recycling, including composting, has diverted several million tons of material away from disposal.

Recycling prevents the emission of many greenhouse gases that affect global climate, water pollutants, saves energy, supplies valuable raw materials to industry, creates jobs, stimulates the development of greener technologies, conserves resources for our children's future, and reduces the need for new landfills and combustors.

7-2-1 Feces generation

Several medical studies have determined the fecal and urine output of human populations; however, the data are specific to distinct populations defined by geography, age, ethnicity, disease, and diet. There have so far been no attempts to summarize these data and understand the major causes of variation.

Fecal wet mass values have a median figure of 128 g/cap/day. This is from a distribution of 116 mean values from studies reporting healthy individuals, with a large minimum and maximum range of 51–796 g/cap/day.

However, as mean values for each study were recorded, individual variation within these studies is not accounted for; if all values are recorded the range extends to 15–1505 g/cap/day. The data set for mean wet fecal generation had a positive skew, hence the mean was greater than the median.

The low-income countries data set was not as skewed as the high-income countries.

As a collective group high income country had relatively small per capita wet fecal weights in comparison to low-income countries. However, between individual studies there was a large variation of 51–796 g/cap/day, despite all studies reporting healthy individuals. For low-income countries the median value of 250 g/cap/day was larger in comparison to the median value of 126 g/cap/day in high income countries.

	Wet weight (g/cap/day) High income*	Dry weight (g/cap/day) Low income*	Dry weight (g/cap/day) High income*	Dry weight (g/cap/day) Low income*
Median	126	250	28	38
n	95	17	57	8
Minimum	51	75	12	18
Maximum	796	520	81	62
Skewness	4.178	0.598	2.378	0.098
Std. error of skewness	0.248	0.550	0.327	0.752
Mean	149	243	30	39
St dev	95.0	130.2	11.7	14.1
Variance	9024	16,960	136	201

Table 7-2 Waste generation

The mean weight of children's feces (3–18 years) has been recorded between 75 and 374 g/cap/day.

Liquid generation

Human urine is a liquid that is secreted by the kidneys, collected within the bladder, and excreted through the urethra. Urine is composed of 91–96% water and the remainder can be broadly characterized into inorganic salts, urea, organic compounds, and organic ammonium salts. Liquid generation from humans is dependent on the water balance of individuals. Liquid output is in the form of urine, fecal water, from the skin through sweating, and from the lungs through respiration. A median volume of 1.4 L/cap/day urine is excreted with mean values ranging from 0.6 to 2.6 L/cap/day.

7-3 Biodigester

A biodigester is a system that biologically digests organic material, either anaerobic (without oxygen) or aerobically (with oxygen). Microbes and other bacteria break down organic materials in a biodigester. Most food, including fat, greases, and even animal manure, can be processed in a biodigester.

Biodigesters are a closed system; therefore, it gives off no odor from food waste; this will eliminate flies and rodents from the facility, increasing hygiene. Also, eliminating food waste on-site saves money by reducing hauling costs. The capacity of food a biodigester can process depends on the size; larger the digester more food it can handle. Biodigesters are a living system and do require maintenance. However, they are easy to use and maintain.

Of course, one of the great benefits of biodigesters is they are eco-friendly and will reduce a facility’s carbon footprint significantly. Food scraps and other organic materials decaying in landfills release methane and carbon dioxide contributing to climate change. Diverting food scraps and other organic materials from landfills, methane, and carbon dioxide can be captured and used efficiently.

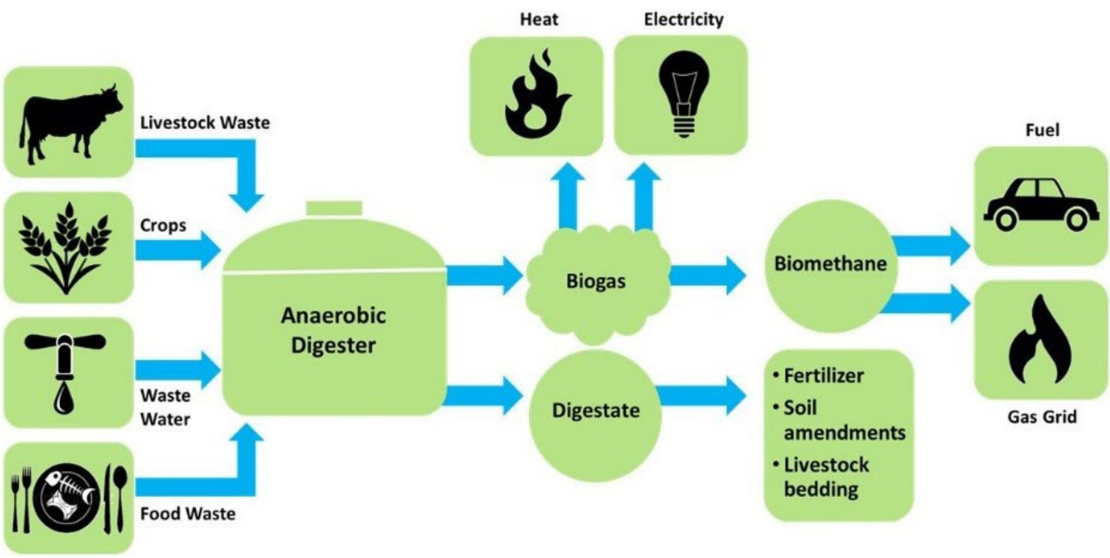


Figure 7-3 digester

7-3-1 The difference between anaerobic and aerobic biodigester

Anaerobic biodigester

An anaerobic biodigester breaks down organic materials in an environment absent of oxygen. This type of biodigester can digest food scraps, oil, grease, yard waste, and animal manure. Anaerobic biodigesters produced biogas and digestate as byproducts.

Biogas

Biogas is mainly made up of methane and produced when animal waste or food scraps decompose. Biogas can be stored and used as a sustainable energy source for electricity, cooking, and heating. Biogas is an environmentally friendly alternative to fossil fuel-derived energy. Utilizing biogas will help facilities decrease the need for energy from the grid, cutting back the electricity cost. Also, by capturing methane from animal manure and using it beneficially, farms can significantly reduce greenhouse gas emissions. The amount of biogas varies depending on the material in a digester. Production of methane can be increased by co-digestion, or combining materials from multiple sources, such as manure.

Digestate

Digestate is the material remaining after completion of anaerobic digestion. It is rich in organic nutrients, such as nitrogen and phosphorus. Farmers can use the digestate to fertilize crops, improve soil quality, or even increase revenue by selling it as fertilizer. An anaerobic biodigester is ideal for the agricultural sector.

Aerobic biodigester

Aerobic biodigester involves oxygen and is much faster, breaking down food in about 24 hours; this process does not produce biogas. Aerobic digesters break food down into gray water that can be disposed of in drainage systems or used as a fertilizer for plants. This type of biodigester can easily integrate into existing infrastructure, and it is well suited for the food industry.

Converting organic waste into biogas

It is possible to make a free cooking gas by digesting wet organic waste in a sealed chamber. Wet organic waste, such as food waste, should be placed in a sealed chamber with no air inside. As it digests, the waste will release a gas which can be captured and used for cooking. The system needs to be airtight and the temperature close to 35˚C.

A biogas plant needs some methane-producing bacteria to get it started. This is found in animal dung, so a small amount is used to start the process even if it is not the main feedstock. Once the system is producing biogas the bacteria reproduce and keep the process going.

Waste materials

Plant waste that is starchy, sugary, or fibrous; fatty substances including animal fat or oil cake from oil seeds; flour swept from the floor of a flour mill; leftover and stale food; damaged or over-ripe fruits; insect damaged grain; non-edible rhizomes of banana or cane; tea leaves; animal dung, abattoir waste, and human excreta. If necessary, the feedstock must be pulped or ground and mixed with water, so it is like a soup.

Product

After 14-21 days, the process will produce biogas and a nutrient-rich soil conditioner called digestate. About 1-1.5kg starchy material typically yields enough gas to cook the meals of 4-5 people. If the digester is working properly, the digestate will have little smell.

Benefits

Making biogas from organic material is a good way to manage potentially harmful organic wastes. Cooking with biogas does not produce smoke so it is ideal for the home, and it reduces the need to cut down trees for firewood. The digested slurry can be used wet or dry as a valuable soil conditioner, reducing the need for chemical fertilizers.

Biogas essentials

- A large container to hold the mixture of decomposing organic matter and water (digester)
- A container to collect the biogas (gas holder)
- A way to add more organic matter (inlet)
- A way to move the gas to where it will be used (gas outlet)
- A way to remove the residue (slurry outlet)
- A way to insulate the container and keep it warm, unless the container is already in a tropical country with a temperature around 35˚C.

7-4 Types of biogas digesters and plants

7-4-1 Fixed-dome Plants

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes. The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise, plants may not be gas-tight (porosity and cracks).

Size

Fixed-dome plants must be covered with earth up to the top of the gas-filled space to counteract the internal pressure (up to 0,15 bar). The earth cover insulation and the option for internal heating makes them suitable for colder climates. Due to economic parameters, the recommended minimum size of a fixed-dome plant is 5 m3. Digester volumes up to 200 m3 are known and possible.

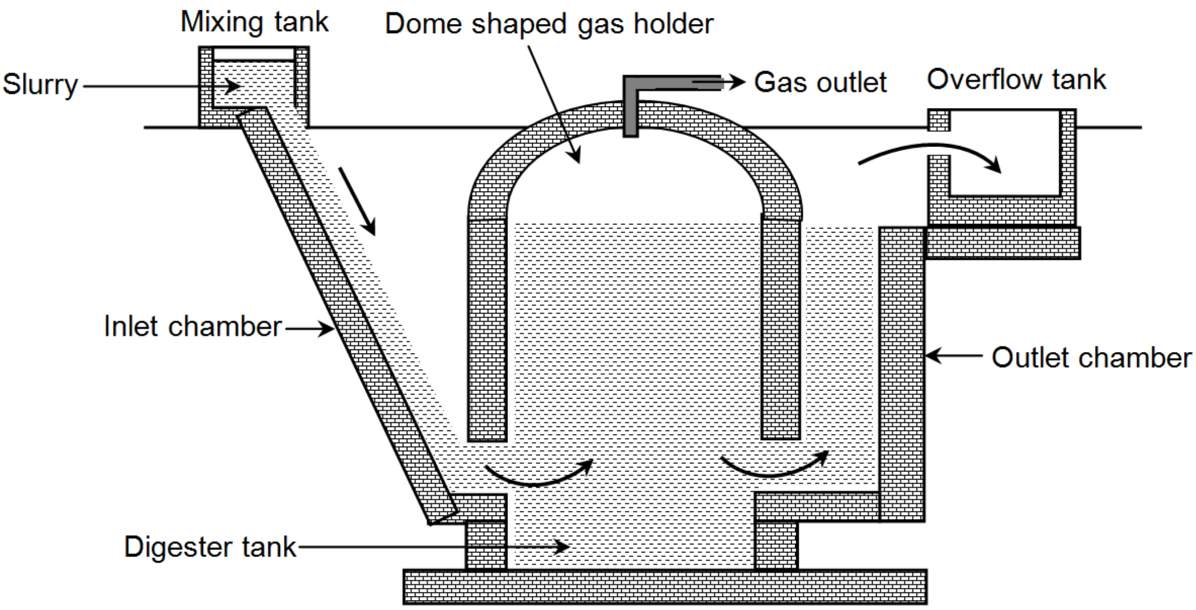


Figure 7-4 Fixed-dome Plants

The basic elements of a fixed dome plant (here the Nicarao Design) are shown in the figure below. Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap. 2.Digester. 3.Compensation and removal tank. 4.Gasholder. 5.Gaspipe. 6.Entry hatch, with gastight seal. 7.Accumulation of thick sludge. 8.Outlet pipe. 9.Reference level. 10.Supernatant scum, broken up by varying level.

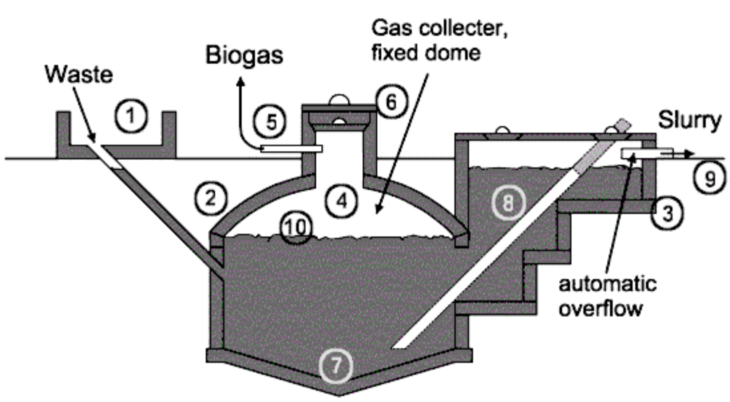


Figure 7-5 Fixed-dome Plants

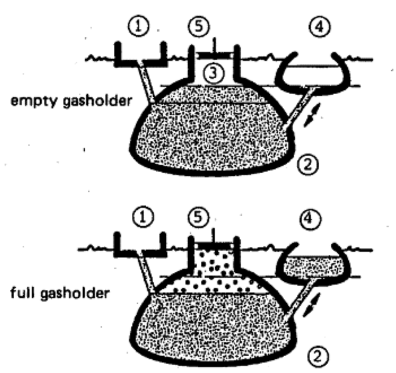


Figure 7-6 Fixed-dome Plants

Basic function of a fixed-dome biogas plant: 1. Mixing pit, 2. Digester, 3. Gasholder, 4. Displacement pit, 5. Gas pipe

A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gasholder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e., with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low.

Digester

- The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are:
- Technical suitability (stability, gas- and liquid tightness).
- cost-effectiveness.
- availability in the region and transport costs.
- availability of local skills for working with the building material.

Fixed dome plants produce just as much gas as floating-drum plants if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gasholder is necessary.

Fixed-dome Gasholders

A fixed-dome gasholder can be either the upper part of a hemispherical digester (CAMARTEC design) or a conical top of a cylindrical digester (e.g., Chinese fixed-dome plant). In a fixed-dome plant the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry.

The following aspects must be considered regarding to design and operation:

- An overflow into and out of the compensation tank must be provided to avoid over-filling of the plant.
- The gas outlet must be located about 10 cm higher than the overflow level to avoid plugging up of the gas pipe.
- A gas pressure of 1 m WC or more can develop inside the gas space. Consequently, the plant must be covered sufficiently with soil to provide an adequate counter-pressure.
- Special care must be taken to properly close the manhole, which may require to weigh down the lid with 100 kg or more. The safest method is to secure the lid with clamps.

The following structural measures are recommended to avoid cracks in the gasholder:

- The foot of the dome (gasholder) should be stabilized by letting the foundation slab project out enough to allow for an outer ring of mortar.
- A rated break/pivot ring should be provided at a point located between 1/2 and 2/3 of the minimum slurry level. This to limit the occurrence or propagation of cracks in the vicinity of the dome foot and to displace forces through its stiffening/articulating effect such that tensile forces are reduced around the gas space. Alternatively, the lowest point of the gasholder should be reinforced by a steel ring or the whole gasholder be reinforced with chicken mesh wire.

Normally, masonry, mortar and concrete are not gas-tight, with or without mortar additives. Gas-tightness can only be achieved through good, careful workmanship and special coatings. The main precondition is that masonry and plaster are strong and free of cracks. Cracked and sandy rendering must be removed. In most cases, a plant with cracked masonry must be dismantled, because not even the best seal coating can render cracks permanently gas tight. Some tried and proven seal coats and plasters:

- multi-layer bitumen, applied cold (hot application poses the danger of injury by burns and smoke-poisoning; solvents cause dangerous/explosive vapors). Two to four thick coats required.
- bitumen with aluminum foil, thin sheets of overlapping aluminum foil applied to the still-sticky bitumen, followed by the next coat of bitumen.
- plastics, e.g., epoxy resin or acrylic paint; very good but expensive.
- paraffin, diluted with 2-5% kerosene, heated up to 100°C and applied to the preheated masonry, thus providing an effective (deep) seal. Use kerosene/gas torch to heat masonry.
- multi-layer cement plaster with water-proof elements

Advantages: Low initial costs and long useful lifespan; no moving or rusting parts involved; basic design is compact, saves space and is well insulated; construction creates local employment. Advantages are the relatively low construction costs, the absence of moving parts and rusting steel parts. If well-constructed, fixed dome plants have a long-life span. The underground construction saves space and protects the digester from temperature changes. The construction provides opportunities for skilled local employment.

Disadvantages: Masonry gasholders require special sealants and high technical skills for gas tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, plant operation not readily understandable; fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock. Disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas). Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians. The gas pressure fluctuates substantially depending on the volume of the stored gas. Even though the underground construction buffers temperature extremes, digester temperatures are generally low. Fixed dome plants can be recommended only where construction can be supervised by experienced biogas technicians.

7-4-2 Floating Drum Biogas Plants

Om 1956, Jashu Bhai J Patel from India designed the first floating drum biogas plant, popularly called Gobar gas plant. Floating-drum plants consist of an underground digester (cylindrical or dome-shaped) and a moving gasholder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. When biogas is produced, the drum moves up and when it is consumed, the drum goes down.

If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content. After the introduction of cheap Fixed-dome Chinese model, the floating drum plants became obsolete as they have high investment and maintenance cost along with other design weakness.

Size

In the past, floating-drum plants were mainly built in India. They are chiefly used for digesting animal and human feces on a continuous-feed mode of operation, i.e., with daily input. They are used most frequently by small to middle-sized farms (digester size: 5-15m3) or in institutions and larger agro-industrial estates (digester size: 20-100m3).

Water-jacket plant with external guide frame: 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 5 Gas pipe

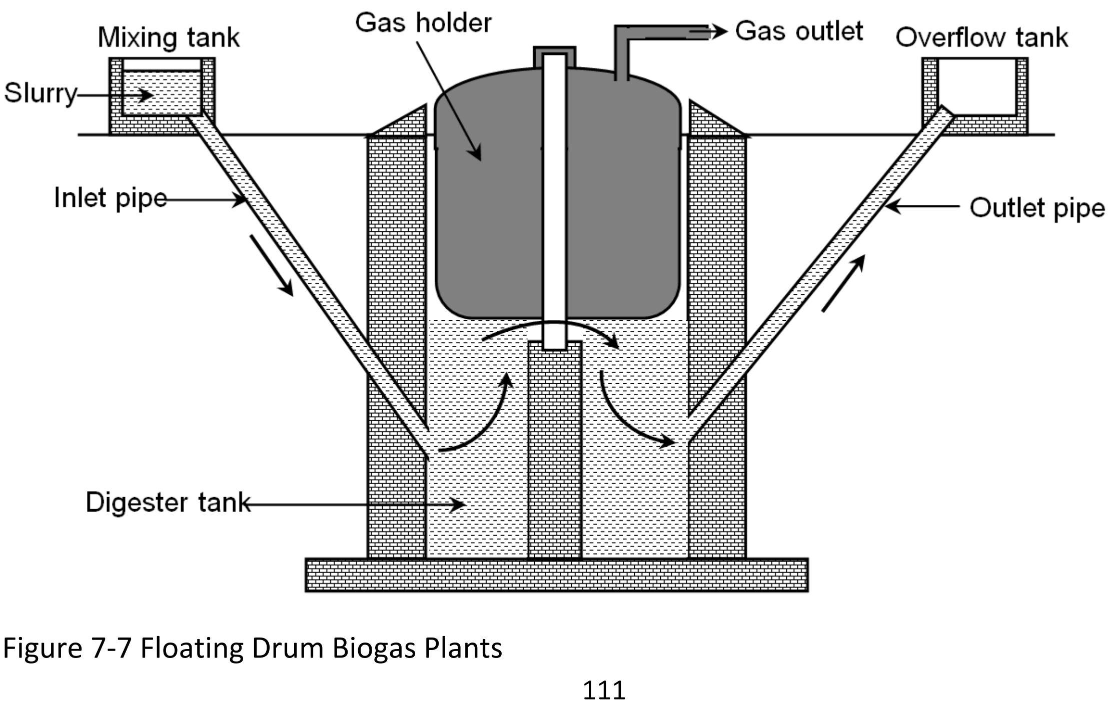


Figure 7-7 Floating Drum Biogas Plants

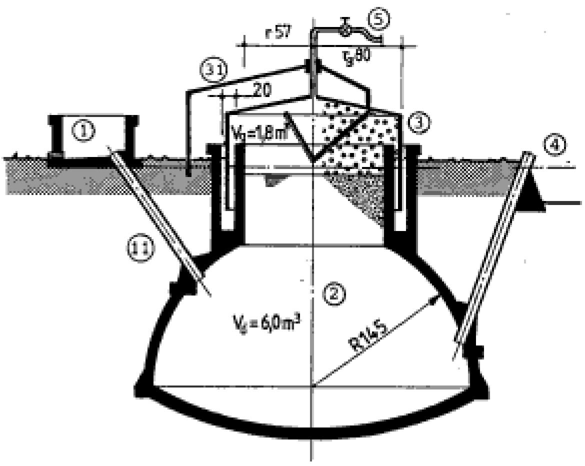


Figure 7-8 Floating Drum Biogas Plants

Digester

The digester is usually made of brick, concrete, or quarry-stone masonry with plaster. The gas drum normally consists of 2.5 mm steel sheets for the sides and 2 mm sheets for the top. It has welded-in braces which break up surface scum when the drum rotates. The drum must be protected against corrosion. Suitable coating products are oil paints, synthetic paints, and bitumen paints. Correct priming is important. There must be at least two preliminary coats and one topcoat. Coatings of used oil are cheap. They must be renewed monthly. Plastic sheeting stuck to bitumen sealant has not given good results. In coastal regions, repainting is necessary at least once a year, and in dry uplands at least every other year. Gas production will be higher if the drum is painted black or red rather than blue or white, because the digester temperature is increased by solar radiation. Gas drums made of 2 cm wire-mesh-reinforced concrete or fiber-cement must receive a gas-tight internal coating. The gas drum should have a slightly sloping roof, otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive and the gas in the tip cannot be used because when the drum is resting on the bottom, the gas is no longer under pressure. Floating-drums made of glass-fiber reinforced plastic and high-density polyethylene have been used successfully, but the construction costs are higher compared to using steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gas-tight, elastic internal coating. PVC drums are unsuitable because they are not resistant to UV.

Floating-drum Gasholders

Most floating-drum gasholders are made of 2-4 mm thick sheet steel, with the sides made of thicker material than the top to compensate for the higher degree of corrosive attack. Structural stability is provided by L-bar bracing that also serves to break up surface scum when the drum is rotated. A guide frame stabilizes the gas drum and prevents it from tilting and rubbing against the masonry. The two equally suitable and most frequently used types are:

- an internal rod & pipe guide with a fixed (concrete-embedded) cross pole (an advantageous configuration in connection with an internal gas outlet).

- external guide frame supported on three wooden or steel legs.

For either design, substantial force can be necessary to rotate the drum, especially if it is stuck in a heavy layer of floating scum. Any gasholder with a volume exceeding 5 m3 should be equipped with a double guide (internal and external). All grades of steel normally used for gasholders are susceptible to moisture-induced rusting both in- and outside. Consequently, a long service life requires proper surface protection, including:

- thorough de-rusting and de-soiling
- primer coat of minimum 2 layers
- 2 or 3 cover coats of plastic or bituminous paint.

The cover coats should be reapplied annually. A well-kept metal gasholder can be expected to last between 3 and 5 years in humid, salty air or 8-12 years in a dry climate. Materials regarded as suitable alternatives to standard grades of steel are galvanized sheet metal, plastics (glass-fiber reinforced plastic (GRP), plastic sheeting) and ferro-cement with a gas-tight lining. The gasholders of water-jacket plants have a longer average service life, particularly when a film of used oil is poured on the water seal to provide impregnation.

Disadvantages: The steel drum is relatively expensive and maintenance intensive. Removing rust and painting must be carried out regularly. The lifetime of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the resultant floating scum.

7-4-3 Low-Cost Polyethylene Tube Digester

In the case of the Low-Cost Polyethylene Tube Digester model which is applied in Bolivia (Peru, Ecuador, Colombia, Centro America, and Mexico), the tubular polyethylene film (two coats of 300 microns) is bended at each end around a 6-inch PVC drainpipe and is wound with rubber strap of recycled tire-tubes. With this system a hermetic isolated tank is obtained (following figure).

One of the 6" PVC drainpipes serves as inlet and the other one as the outlet of the slurry. In the tube digester finally, a hydraulic level is set up by itself, so that as much quantity of added prime matter (the mix of dung and water) as quantity of fertilizer leave by the outlet. Because the tubular polyethylene is flexible, it is necessary to construct a "cradle" which will accommodate the reaction tank, so that a trench is excavated.

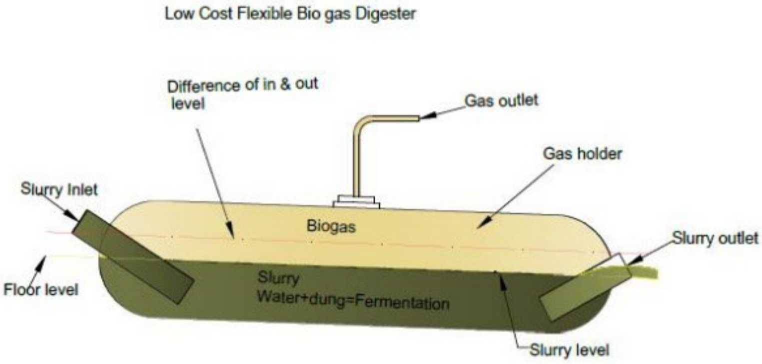


Figure 7-9 Floating Drum Biogas Plants Figure 7-10 Floating Drum Biogas Plants

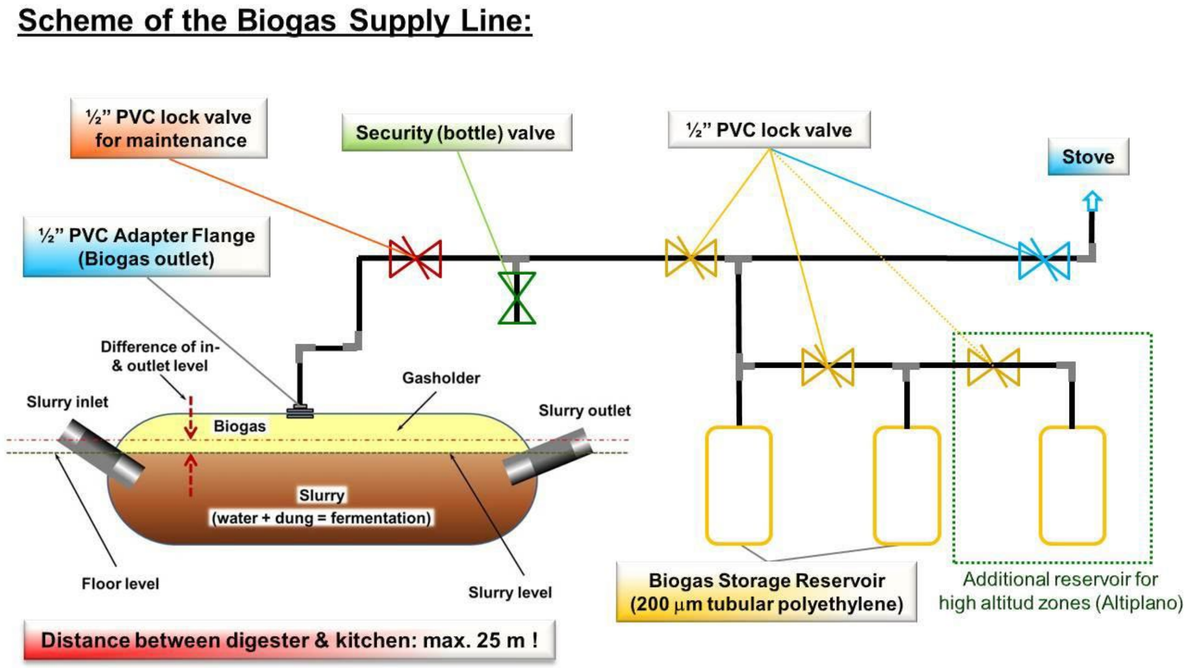


Figure 7-11 Floating Drum Biogas Plants

Low-Cost Polyethylene Tube Gasholders

The capacity of the gasholder corresponds to 1/4 of the total capacity of the reaction tube (figure td1). To overcome the problem of low gas flow rates, two 200 microns tubular polyethylene reservoirs are installed close to the kitchen, which gives a 1,3 m³ additional gas storage.

Figure 7-12 Floating Drum Biogas Plants

7-4-4 Balloon Plants

A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gasholder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required. Since the material must be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl. The useful lifespan does usually not exceed 2-5 years.

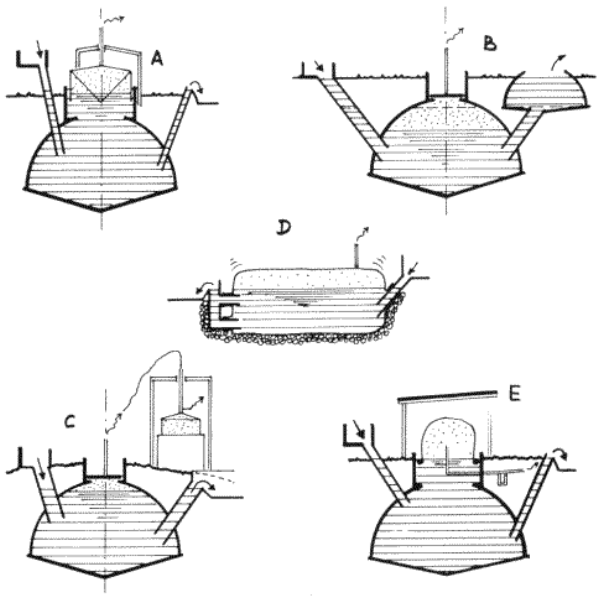


Figure 7-13 Balloon Plants

Figure 7-14 Balloon Plants

Advantages:

- Standardized prefabrication at low cost,
- low construction sophistication,
- ease of transportation,
- shallow installation suitable for use in areas with a high groundwater table.
- high temperature digesters in warm climates.
- uncomplicated cleaning,
- emptying and maintenance.
- difficult substrates like water hyacinths can be used
- Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

Disadvantages:

- Low gas pressure may require gas pumps.
- scum cannot be removed during operation.
- the plastic balloon has a relatively short useful lifespan and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely able to repair a damaged balloon. There is only little scope for the creation of local employment and, therefore, limited self-help potential.

Factors	Fixed dome	Floating drum	Tubular design	Plastic containers
Gas storage	Internal Gas storage up to 20 m³ (large)	Internal Gas storage drum size (small)	Internal eventually external plastic bags	Internal Gas storage drum sizes (small)
Gas pressure	Between 60 and 120 mbar	Upto 20 mbar	Low, around 2 mbar	Low around 2mbar
Skills of contractor	High; masonry, plumbing	High; masonry, plumbing, welding	Medium; plumbing	Low; plumbing
Availability of Material	yes	yes	yes	yes
Durability	Very high >20 years	High; drum is weakness	Medium; Depending on chosen liner	Medium
Agitation	Self agitated by Biogas pressure	Manual steering	Not possible; plug flow type	Evtl Manual steering
Sizing	6 to 124 m^3 digester vol	Up to 20 m^3	Combination possible	Up to 6 m^3 digester vol
Methane emission	High	Medium	Low	Medium

Table 7-3 comparison table

Chapter 8

strategies for the analyzed case study

8-1 Ventilation

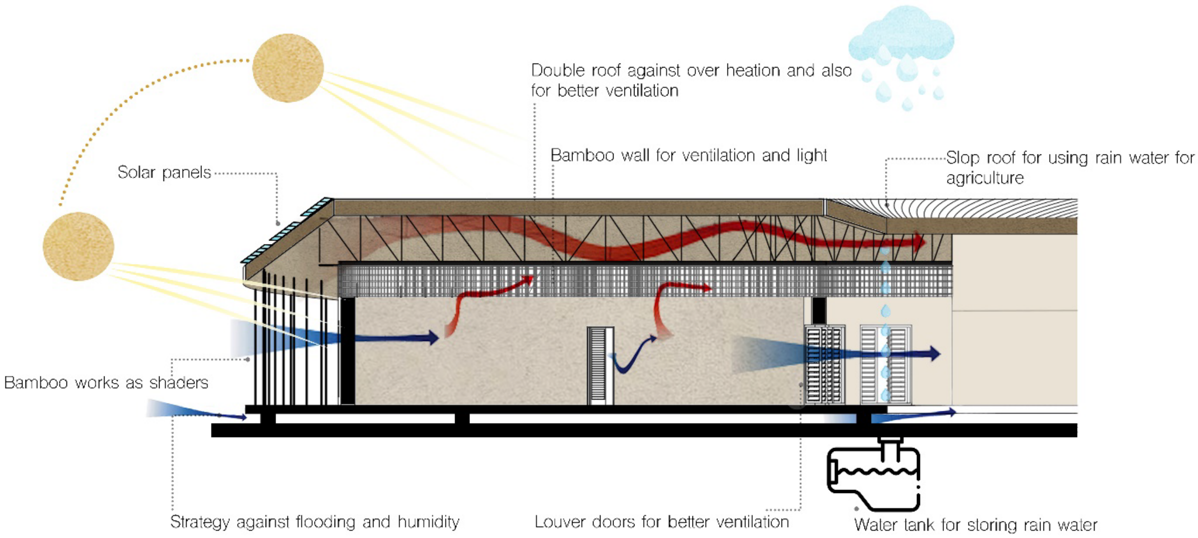


Figure 8-1 Schematic design of ventilation

All around the buildings there are operable shaded louvers for ventilation. The buildings are sounded by bamboos for safety reasons and shading.

The roof is constructed with two layers to help heat transfer from inside and preventing from overheating.

Also, there is a gap from the ground because of accessibility to the water tanks and pipe and having ventilation from the ground.

8-2 Water collection

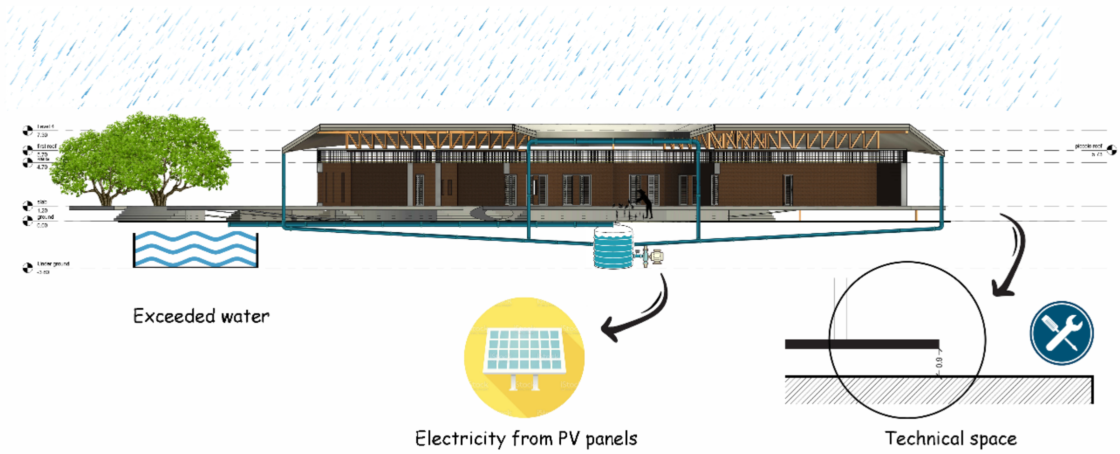


Figure 8-2 Schematic design of rainwater collection

Around the roof there are water pipes which can collect rainwater to a water tank which is in the underground. Then by using a pump the water will be usable. The exceeds water will export to the underground.

The power which is needed for water pump will provide by PV panels.

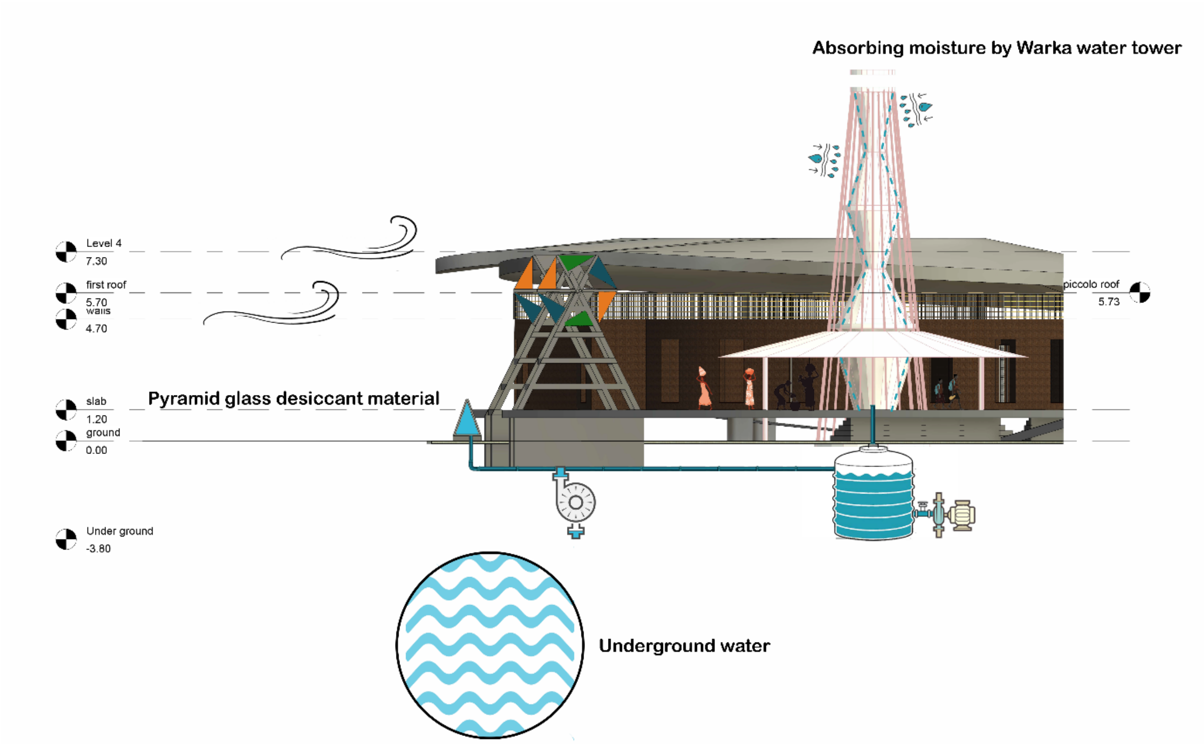


Figure 8-3 Schematic design of wind pump, Warka water and Pyramid glass

Wind pump will extract water from the underground resources by using a semi-rotary pump which will work with wind power. This type of water is drinkable water, therefore, will be connected to water tank of Warka water.

Pyramid glass desiccant material will absorb moisture during the night and by solar radiation will release it during the day. Also, this type of water will be drinkable and will be connected to the water tank of Warka water.

Every meter of roof will collect 1 liter of water for every 1 mm rain.

According to the calculation for roofs, the water tank have a 3 meter high, and a volume around 15 cubic meter.

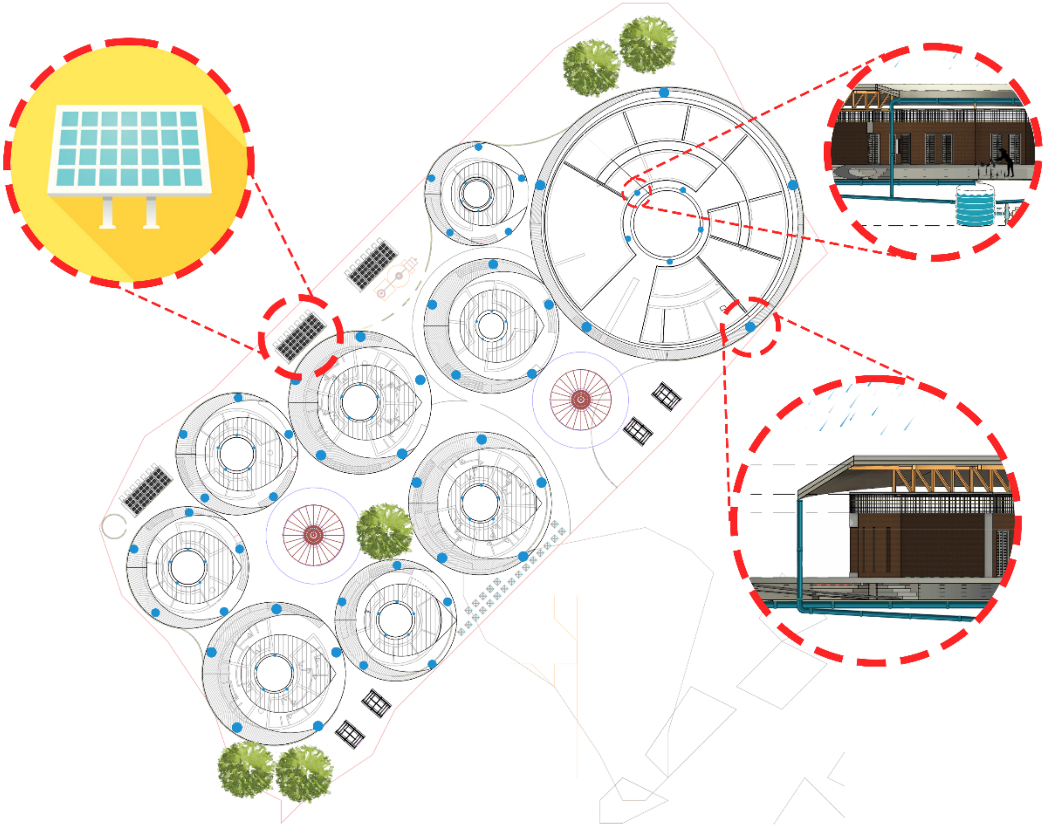


Figure 8-4 Schematic design of roof plan

8-3 Biodigester

Human waste, animal waste and organic waste will be used in biodigester for proving gas which is usable for cooking and water boilers.

The product can be used for agriculture parts as fertilizer.

The other types of waste will be collected in the other part of the site which will be collect by municipality.

300 people will produce around 180 feedstocks.

The volume of digester based on the retention time (30 days) would be 5.4 cubic meters.

If we add 25% for gasholder the total volume of unit 7.2 cubic meters.

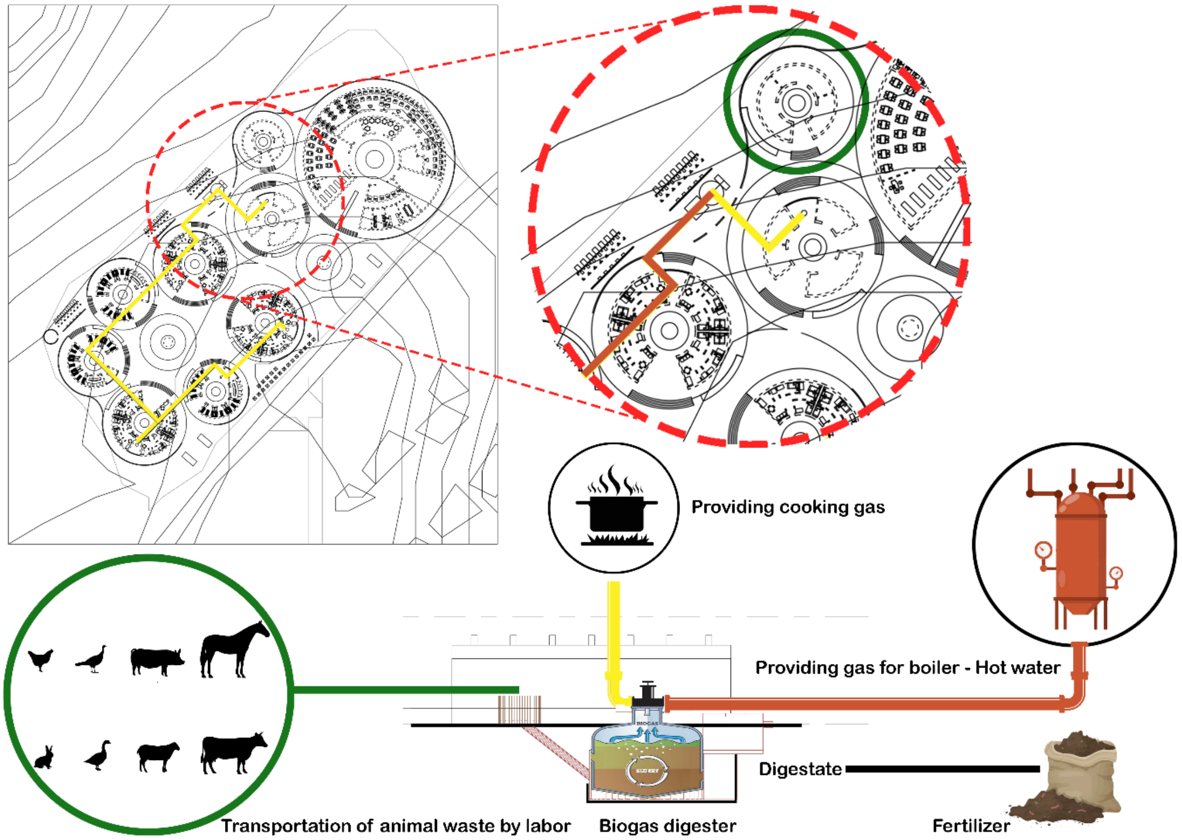


Figure 8-5 Schematic design of biodigester and gas pipes

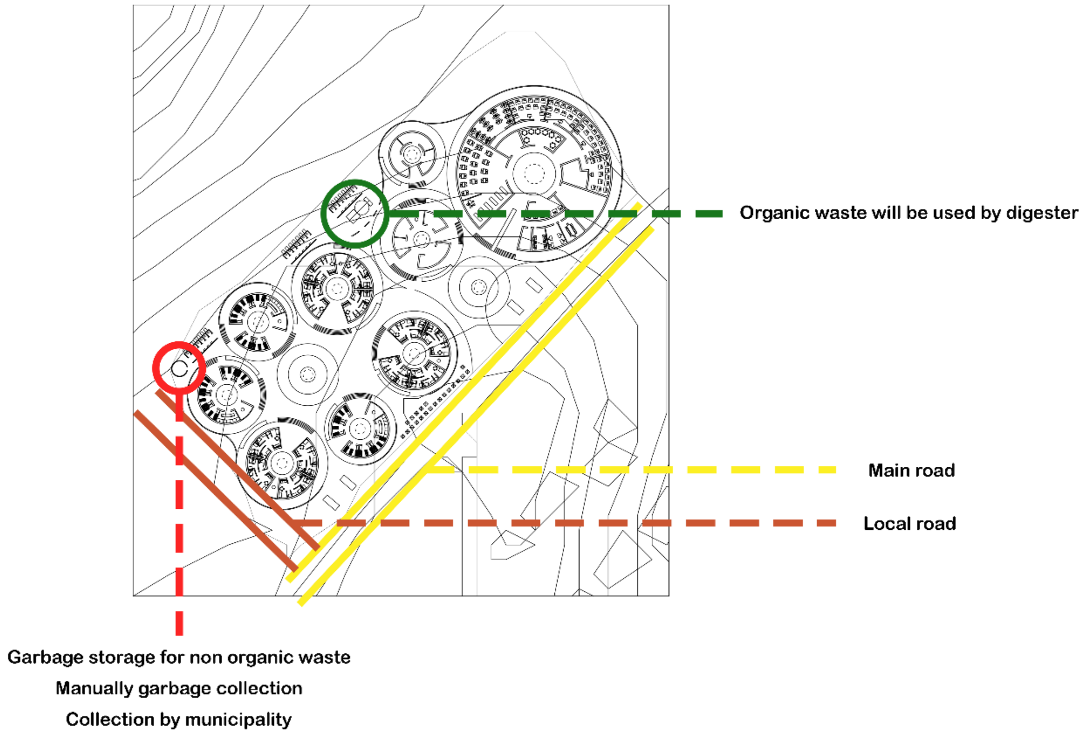


Figure 8-6 Schematic design garbage collection

Conclusion

In chapter 2, I tried to figure out the main problems in Benga, Malawi.

There are several problems in their routine life and choosing the most important one was very difficult.

One of the goals of this project was to improve their life quality, and it did not suppose to be just a building.

According to the research, a lack of drinking water, a lack of sanitation system, a lack of farming knowledge, lack of gas and electricity are the main problems, which are barriers to improving their life quality.

I attempted to work on water management for supplying the need for drinking water, sanitation, agriculture, bathing, and cooking.

Also, I worked on waste management, and there are many details in the correlated chapter about that.

All the strategies are chosen by considering the climate of Benga.

According to the introduced strategies for water management, the Wark water tower, Pyramid glass desiccant material, and wind pump can supply what need for drinking water.

Warka water tower is a tower easy construction by bamboo and a kind of mesh which absorb the moisture in the air and condense it to drinking water. Every tower in a climate with more than 70% humidity can provide 100 liters drinking water per day. This strategy can be a solution for different aspect, firstly it will provide drinking water and secondly it will reduce the humidity and help to provide the comfort.

Pyramid desiccant material is a strategy for water collecting during the night and it will need to manage manually. Because the glass parts should be open during the night and close during the day. During the night, when they are open, they will absorb moisture in the air and during the day they will release water by absorbing solar radiation.

It can be a part of education, because one of the main goals of the project is to teach them how they can be self-sufficient.

Wind pump is simple strategy for using the underground resources of water. Simply the power of wind will rotate the semi-rotary pump and will bring underground water to the tanks.

The amount of water that is required for agriculture, cooking, and bathing can be supplied, by using rainwater harvesting and underground water tanks.

Rainwater harvesting will be done by pipes from the roof to the tanks and the exceeds water will export to the ground. The pipes will manually manage for filtering. Because there is the possibility of pollution with dust in the pipes. Therefore, some faucets which can be open and close. After some minutes the dust will be remove by rain and the faucets should be close manually. Also, this should be a part of students' duty as an education part.

The biodigester is another introduced solution for providing gas for cooking and hot water.

Human waste, animal waste and organic waste can be used for providing gas, which can be used for cooking and providing hot water.

The mentioned waste types can produce methane gas which can be used for cooking etc.

Also, the product from this cycle will be very useful for agriculture.

At the end I would mention that there is a primary school near the project that can also be a part of this project for using these strategies and being more efficient.

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Kabambo, Nicholous. Head of ATC, Bweri, Mara Project, SCC-Vi Agroforestry, Tanzania. Personal contact.

Assey, Felix. Staff at ATC, Bweri, Mara Project, SCC-Vi Agroforestry, Tanzania. Personal contact.