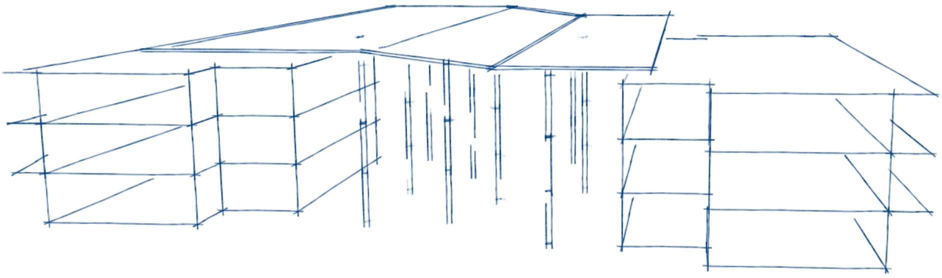
Sustainable and energy neutral 'European house' in Rwanda



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Preface

In the seven years that it took me to finalize my studies, I lived in four different countries. Most of this time I spent in Rwanda, the country that I saw changing fast, with a booming building sector that struggled with the lack of appropriate local materials. This gave me the idea to explore the possibilities for sustainable buildings in such a challenging surrounding.

The road I've traveled since learned me a lot about sustainability, about the challenges of building in a third world environment and about myself. The result is documented in the lines of this report. The journey seemed endless, but I enjoyed every moment of it.

I would like to express my sincere appreciation to the following people:

To em.prof.dr.ir. E.M. Haas, dr.ir. K.C.Terwel and ir. S. Broersma for their time, patience and encouragement. Thank you for never seizing to give me constructive and inspirational feedback and for pushing me forward on a road that was not always smooth.

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Last but not least to my sons David and Damian, who were a great distraction but also turned out to be two little sources of energy that kept me going.

Marija Markic

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Abstract

The importance of energy and sustainability issues related to buildings and built environment is constantly increasing. Developed countries are already dealing with these issues by adjusting their building codes and by introducing sustainability assessment methods as an important part of building projects. But how can developing countries with all its challenges and a focus that is understandingly more pointed towards escaping poverty than thinking about long term sustainability deal with these issues?

In this thesis, I assessed the possibilities for an integral design of an energy neutral and sustainable office building in Rwanda, a small country in the heart of Africa and one of the few developing countries that is progressing very fast. I chose to work out the design of a - potentially to be built - office space where the embassies of 6 EU countries could set up office, a project that I named the 'European House'.

The main research question of this study is How can a European house in Kigali be optimally designed in an energy neutral and sustainable way?

To find answers to this question, the climate of the location, its challenges and opportunities in terms of building design were studied. I also researched locally available construction materials and in general construction materials that could be applied on the project. To get some quantitative values of sustainable issues, a few rating systems were considered. Eventually, I applied the BREEAM International rating system and described how, in this specific context, the European House could score an outstanding rate.

Following a literature study, case studies were introduced in order to see what kind of strategies did similar projects use in similar climates (Kenia, Zimbabwe and Malaysia) and what were their achievements regarding sustainability issues.

As the European House physically did not exist, some space limitations/dimension requirements needed to be determined by interviewing potential users of the EU House. Representatives of 5 embassies in Kigali filled in my questionnaire, describing their potential spatial requirements, which helped defining the size of building and set further boundaries for the sketch design of the European House.

The following conclusions have been drawn based on the proposed sketch design:

Use of local/regional building materials

Multi-story buildings are almost exclusively made out of concrete in Rwanda, with currently very little focus on sustainability. Recently increased tax rates on cement imported out of east African community will hopefully contribute to the reduction of the embodied energy of the concrete used in Rwanda. With high demand of concrete on one side and its low availability on the other, Rwandan building market will have to search for some appropriate alternatives. When applying timber bearing structure on the European House, the total environmental cost of the bearing structure is 0,21€ per m^2 GFA. In this case, the wooden bearing structure offers much less environmental impact than other possible solutions (concrete and steel) and therefore it is the preferred choice. However, timber in Rwandan constructions is still not being used in structural applications, even though it offers great potentials and it is available and possible to be imported from DR Congo – Rwanda's neighboring country.

Passive and active design strategies

The following passive strategies proved to be effective in the Kigali climate and could therefor be applied to the European House design:

Orientation – long narrowly designed buildings with long side along north/south facade

Shading devices – horizontal devices should be installed on northern and southern facades

Size of windows: wall/window/ratio should be at least 40%, European House window dimensions should be 1,8x1,8m

Natural ventilation: On the proposed design of the European House, the best applicable method is natural side ventilation

Active design strategies

Focusing on sun and wind local potentials, Energy potential mapping gives encouraging results. Most of the locally available energy could be obtained from the sun, in case all the roof area would be covered by Photovoltaics. In order to assure buildings self-efficiency, it is essential to have an energy storage system/battery, to be able to use the harvested energy in different moments if needed. In the Equator area (which is the case in Rwanda), the solar generation does not change a lot during the year and therefore no large amount of storage is needed. Storage that equals to 3,5 days of average generation should serve as a reasonable backup (this equals to the storage capacity of 1061 kwh in case of Rwanda).

In conclusion - with integrating passive and active design strategies on the European House design, 2,5 times more energy is obtained than required.

BREEAM International sustainable assessment

BREEAM proved to be a very useful tool on the road to sustainable and energy neutral design in the Rwandan context. BREEAM International credits studied in the Rwandan context show that most of them are actually possible to reach, assuming that the project team is experienced in the BREEAM field and that clear goals are set from the very beginning of each project. In theory there are no real obstacles to obtain high credit scores in the Rwanda. However some of the BREEAM International credits would need to be adapted to the local Rwandan context. This regards mostly the credits that are referenced to the local legislations.

In conclusion – the example of the European House in Kigali shows that an energy neutral and sustainable office building is possible in Rwanda. Perfect climate conditions and renewable energy potentials are there, to be discovered and used in a smart and responsible way. Rwanda of course misses many things, without which some parts of my analysis would be hard to materialize – like an environmental database for different types of construction materials. Further more, many parts of the BREEAM analysis are assumed to be achieved under good management and financial means which are both hard to find in Rwanda. However, the realization of this or a similar project could inspire a new way to look at possibilities for sustainable and energy neutral buildings in Rwanda.

Recommendations for other developing countries

- Make a climate study of the location a 'must' for any type of construction project in order to reduce the overall energy costs and building performance, even if this is not required by local building regulations
- Introducing sustainable assessment methods (BREEAM International) in projects in developing countries encourages the use of passive strategies and influences sustainable outcomes. BREEAM International is a valuable tool to be applied on projects in developing countries. However, when certain datas are not available, one needs to be resourceful
- Often the choices of materials applied for structures is related to the fact that local workers only know specific methods and are 'afraid to build differently'; Rwanda's recent example shows that local workers can easily be trained to use different building techniques

- The benefits and high potentials of sustainable and energy neutral buildings in developing countries need to be better explained and promoted to all parties involved.

Suggestions for further research based on this thesis

- Further improvement of other widely used construction materials (adobe bricks) and their structural application in multi story buildings in Rwanda
- Possibilities of creating a Rwanda National scheme based on BREEAM International Assessment
- Challenges of building techniques from vernacular to modern in Rwanda
- In case of rising temperatures due to climate change, what kind of consequences would this have on the natural ventilation possibilities in European House

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1. Introduction

1.1 Sustainability of construction industry in the developing world

Global development and population growth have dramatically increased overall energy demand, consumption of the resources and production of the waste. This provoked more natural disasters and influenced the - until now relatively stable - climate to change. Only in the last few decades the world started taking more active measures to mitigate the consequences of economic development on our health, environment and natural resources. A lot of pressure has been put on the built environment to practice more sustainable ways and solutions as the built environment contributes the most to the environmental hazards.

In 1987, the UN published the Bruntland report 'Our common future' in which the term 'sustainable development' was defined for the first time. According to this report, sustainable development was to be composed of not only environmental factors but of social and economical factors as well.

Further on, some mandatory standards and codes related to sustainable and energy efficiency issues were introduced to the built environment in industrialized countries in order to secure sustainable future developments.

Base to these standards was a United Nations Conference on environment and development, better known as the Earth Summit organized in 1992 in Rio de Janeiro, Brazil. This conference was the result of a long process of negotiation, planning and education on sustainable development worldwide. At the Earth summit, representatives of 172 countries endorsed the Rio Declaration on Environment and Development, which set out 27 principles supporting sustainable development. They agreed a global plan of action, Agenda 21. This declaration states that human beings should be in the center of concerns for sustainable development, as they are entitled to a healthy and productive life in harmony with nature and sustainability.

The United Nations Agenda 21 for Sustainable Constructions has been promoted and encouraged on a global level as the blueprint for sustainable constructions. This guide was meant to serve national governments to produce better action plans.

However, the guide has found many critics for its limited use for application in developing countries, as it does not take into consideration the specific challenges that developing countries face and where sustainability scores low compared to more urgent challenges like demand and growth.

Even though these critics 'produced' an alternative document, 'Agenda 21 for sustainable constructions in developing countries', in practice very few steps forward have been made for sustainable constructions in the developing countries, particularly not in Africa. (Dania, 2013)

Sustainable rating systems too, are neither used nor promoted in construction projects. Some steps have been made in that direction lately, but until now this hasn't resulted in a code or even of a simple recommendation.

1.2 Introducing the project

Rwanda, a small country in the heart of Africa, is one of the few developing countries in the world that actually met most of the UN millennium goals by 2015 (National Institute of Statistic of Rwanda, Rwanda Statistical Yearbook 2015) (Figure 1). This means the country is changing fast.

The eight Millennium Development Goals are:
GOAL 1: Eradicate Extreme Hunger and Poverty
GOAL 2: Achieve Universal Primary Education
GOAL 3: Promote Gender Equality and Empower Women
GOAL 4: Reduce Child Mortality
GOAL 5: Improve Maternal Health
GOAL 6: Combat HIV/AIDS, Malaria and other diseases
GOAL 7: Ensure Environmental Sustainability
GOAL 8: Develop a Global Partnership for Development

Figure 1. Millennium development goals (source http://www.statistics.gov.rw/)

With a rapidly increasing population and related urbanization growth in Rwanda, demand for housing and access to energy is also increasing.

In such a need-driven environment, the most possible scenario is that the focus of the development will be on quantity without any consideration of sustainable issues.

Rwanda’s energy plans are among the most ambitious in the world. The country in which 85% of the population has still no access to the national grid has a plan to generate 90% of the electricity demand using renewable energy sources only. (Williams, 2012)

One of the key-elements of Rwanda’s development strategy is urbanization. Currently, the only ‘real’ city in Rwanda is Kigali, its capital with a population of 1,1 million. The government is implementing a strategy to create more urban centers in the country and is trying to move away from an agricultural driven economy towards a service oriented, modern society. (KCMP, 2007)

These ambitions are presented as the Vision 2020. Part of the Vision is a Kigali Master Plan. In this new Master plan, that has special focus on sustainability issues, an entirely new business administrative area is to be created at what are now still the outskirts of Kigali. Part of this plan is also the creation of a diplomatic area, where all embassies currently present in Rwanda should gather.

At the initiative of the EU representative from Brussels a meeting with members of the present European embassies in Rwanda has been organized in November 2012 in Kigali. During this meeting, five EU countries that are represented in Rwanda with a diplomatic mission (The Netherlands, EU, France, Sweden and Germany) have expressed interest in a joint office, named ‘European House’.

In the current situation, each embassy is renting a separate office building in the center of Kigali. Diplomats’ houses are scattered all over town.

Having one common building for more embassies would positively influence renting costs, make more efficient use of office space, reduce energy costs and foresee stronger and easier collaboration between the embassies.

Sustainability should play an important role in the whole project.

This thesis will study the limits of what is possible in the field of sustainable and energy efficient designs in Rwanda, in a context where no codes shape the design decisions and no restrictions have been applied on energy use.

This will be done considering the case study of the so-called 'European house' – an aspirated energy neutral office building, planned to be built to host five European embassies in Rwanda.

With lessons learned and recommendations from the study for a sustainable 'European house' office building I hope to make at least a small contribution to a sound knowledge base for future sustainable developments in Rwanda. One hopes that the sustainable European House could serve as a showcase model, showing all the advantages of the sustainable design that can be applied on buildings in general in the Rwandan context.

I would like to underline that this thesis has not been done on official request of the European Union. Embassies were kind enough to cooperate informally by providing some insight in their needs as user of the building and by welcoming me to their meeting on the topic. However, the design that will be the result of this thesis serves only an academic purpose and is not likely to be materialized in Kigali.

1.3 Objectives and main research question

The main objective of this research is to study the possibilities for the design of a sustainable and energy neutral office building in Rwanda. I will identify sustainable office design features in the Rwandan context and apply them on the 'European house', the design of which is also part of this research project. It is my ambition to show that it is possible to build an ***energy neutral*** office building whose energy needs will be satisfied by the energy produced on the spot, using as much as possible available construction materials and renewable sources of energy. The design of European house should meet the wishes of its users; it should comply with current Rwandan regulations and fit within the Vision 2020 agenda.

The main research question of my thesis is:

How can a European house in Kigali be optimally designed in an energy neutral and sustainable way?

To find the answers to this question, the climate of the location, its challenges and opportunities in terms of building design will be studied. Locally available construction materials and in general construction materials that could be applied on the project of this office buildings, will also be studied. To get some quantitative values of sustainable issues, few rating systems will be considered. Focus will further be on BREEAM International rating system and how, in this specific context, it could score an outstanding rate. Examples from the case study buildings, that all focus on the sustainable and energy efficient issues, should help making the design choices easier.

With this study, the 'European house' could hopefully act as a role model and mark a way for future environmentally friendly constructions in Rwanda.

2. Theoretical framework

2.1 Finding a balance between growth and sustainability

The construction industry ‘consumes’ about 40% of global natural resources, 12% of potable water reserves, 55% of wood products; 40% of raw materials, while generating between 45 and 65% of waste and emitting of 48% of harmful greenhouse gases. All this increases rapidly air and water pollution, harms natural resources and contributes to the global warming. (Castro-Lacouture 2009)

In Europe, buildings are responsible for 40-45 percent of total energy consumption in society and they significantly contribute to the emission of carbon dioxide (CO2) and consequently to global warming. Even though CO2 emission is still highest in industrialized countries at the moment, analyses show that with economic growth in the field of construction in developing countries, their contribution to global warming will increase rapidly in the following decades (UNEP, 2007).

Predictions show that by 2050, global economic activity will have increased fivefold. Until then, global population will increase by over 50 percent, global energy consumption will increase around threefold, and global manufacturing activity will increase at least threefold (Matthews *et. al.*,2000; Ilha *et al.*,2009). For these reasons, it is important to reduce the environmental impact of products and materials in terms of their production and use, and to optimize their longevity, either in terms of first life or via re-using or reprocessing (Akadiri, 2011).

Energy, that is indispensable for general growth of any country, can be produced out of natural resources of which some are finite (e.g. fossil fuels) while the others are renewable (e.g.biomass). Until now, the main energy sources in industrialized countries are fossil fuels while in the developing countries the dominating energy source is biomass. The process of getting energy out of both is not environmentally friendly (getting energy out of fossil fuels contributes to global warming while getting energy from biomass causes air pollution) (UNEP, 2007).

The challenge that the world is facing at the moment is to find, on one side, the best solution in which the industrialized countries can cope with their impact on environment and on the other side, the best solution that allows developing countries to grow economically in a sustainable way.

When we talk about the negative environmental impact that a building will have during its life cycle, this negative impact is for about 80 percent related to energy issues. Only approximately 20 percent of the negative impact is related to the construction material issues. This proportion will, however, change in the future when all buildings reach the level of energy neutrality (Haas, 2013).

Therefore it is important, already by now, to focus not only on the renewable energy sources while designing new buildings, but also on the use of environmentally friendly building materials, in order to secure a save environment for the next generations.

2.2 Definitions of sustainability, sustainable development and sustainable construction

Sustainability

The term 'sustainable' can be translated as enduring and lasting. In the Oxford English dictionary (2001) the term *sustainable* has been defined as:

Utilization and development of natural resources in ways which are compatible with the maintenance of these resources, and with the conservation of the environment, for future generations.

From Bruntland report (1987) sustainability and sustainable development are defined as an integrative and holistic process that keeps in balance 'what is ecologically possible' with the need and demands of people for prosperity, equity and quality of life. All these conditions are changing in time and they depend of several factors - geographical location, environmental conditions, economic viability, social relationships and local values and aspiration. This is described as the concept of *triple bottom line of sustainability (Figure 2)*; a concept that shows that sustainable projects are not only evaluated on the base of their economic performance and monetary gains, but also on their impact on society as a whole.

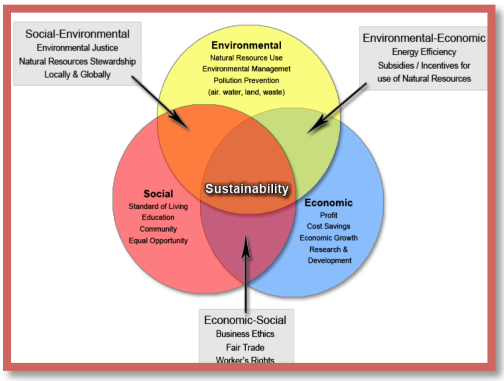


Figure 2 Triple bottom line of sustainability (source http://www.vanderbilt.edu/sustainvu/who-we-are/what-is-sustainability/)

Each country is blessed with different natural resources, resulting in different approaches towards sustainability from country to country. What a sustainable development is, depends on the availability and development of regional and local approaches and solutions (Du Plessis, 2007).

Sustainable construction

Charles Kibert was one of the first authors to define various terms related to sustainability in the built environment. Based on the definition from Conseil International di Batiment, Kibert proposes following definition of 'sustainable construction' during the First International Conference on sustainable construction in Florida in 1994:

Sustainable construction is the creation and responsible management of a healthy built environment based on resource efficient and ecological principles.

Another definition for sustainable construction comes from the National Institute of Building Science (NIBS)*: Sustainable construction is a subset of principles encompassing a high performance building that requires holistic approach to balance all interests for the greater good of the entire project.*

While NIBS proposes more detailed definition balancing the environmental concerns with others in its holistic approach for top performance, Kibert's definition is broader and it focuses on ecologically sound principles for developing a healthy environment (Prum, 2010).

Agenda 21 defines sustainable construction as: *a holistic process aiming to restore and maintain harmony between the natural and built environments, and to create settlement that affirms human dignity and encourage economic equity.*

According to OECD (Organization for economic cooperation and development), sustainable buildings are those with a minimum impact on a natural and a built environment that strike for the integral quality (social, environmental and economical) in a broad way, improving environmental qualities by using rationally natural resources and minimizing energy consumption. The main objectives that each sustainable project should have are: *Resource efficiency, Energy efficiency; Pollution prevention; Harmonization with environment and Integrated and systemic approaches.*

Furthermore the European Union proposes following definition of for sustainable construction as: *The use and/or promotion of a) environmentally friendly materials, b) energy efficiency in buildings, and c) management of construction and demolition waste.* (UNEP, 2003).

When talking about sustainable construction, one needs to consider constructions whole life with its functional and environmental qualities as well as its future values. So the design of sustainable construction should be an integration of different disciplines such are architecture and mechanical, electrical and structural engineering. Plus it should be sensitive on traditional aesthetics of massing, orientation, texture, shadow and light and it should take into account different aspects: environmental, social and economical (triple bottom line of sustainability) (Godfaurd et al. 2005).

As it can be seen from above mentioned, definition of sustainability contains wide range of issues. Consequently, sustainable constructions do so as well. If the aim is to create a sustainable construction this should be clear from the very first step of each project. Starting from the brief, in which the client should define the right scope, size and the location of the future project. The brief should help to the design a team to convert the starting wishes into the sustainable design while minimizing the impact and maximizing the performance. Points that should be taken into account in the very early stage are: integrated design – different disciplines should work together to bring sustainable solutions together, buildings should be designed and built thinking about their flexibility, deconstruction and recycling in the future. Furthermore, thinking of the lifetime energy that a building consumes is necessary. On the road to the sustainable constructions, the UK construction sector is introducing Building Information Modeling whose use in 2016 becomes an obligated part of all centrally produced public projects (Georgopoulos 2014).

The *definition of sustainable constructions used in this report* will be partly based on the one proposed by the European Union: *The use and/or promotion of a) environmentally friendly materials and b) energy efficiency in buildings*. In addition the attention will be drawn to the embodied energy of used construction materials as well.

Nowadays, it is mainly developed countries that focus on sustainable constructions and their implementation, creating different boundaries in forms of codes, laws, directives and other responsible bodies that are promoting sustainable constructions and sustainable development.

In developing countries, sustainable development and sustainable constructions are yet a ‘secondary problem’ in an already complex situation that these countries are facing. Furthermore, while developed countries have made progress in addressing the essential requirements of sustainable construction, developing countries are only now beginning to consider how to address these requirements together with the broader developmental challenges they are facing (Du Plessis 2007).

2.3 Sustainable construction materials

According to the research done by NIBE (Netherlands Institute for Building Biology and Ecology), *construction materials* will have the largest environmental impact once all buildings are energy neutral. Furthermore, it is expected that in the near future we will face a shortage of raw construction materials (Haas, 2013). Therefore it is important, next to the energy issues, to focus on renewable materials that are locally available and the possibilities of material recycling during the whole life cycle of the building while designing sustainable buildings for the future.

Building materials have big influence on the environment during their life cycle - from the extraction of the raw materials to the demolition process; and create different forms of pollution. Raw materials have to be processed before they become suitable for use in building constructions and that process requires large amounts of energy. By using the right building materials, sustainability of a building and its economic prosperity can be significantly increased. The use of different building materials that are composed of non-renewable recourses has a huge impact of the global environment with negative consequences for future generations (Akadiri 2011).

Studies done by Gonzalez and Navarro in 2006 underline the material selection phase as the core phase of construction process and show that the right selection of the low impact building material can reduce up to the 30% of CO_2 emission. A sound material selection further may help to reduce the total amount of buildings embodied energy consumption and environmental impact over the life cycle (Giudice et al. 2005) in between the other things.

Kibert and Bosch (1998) underline some of the characteristics that the building materials should have in order to be considered sustainable:

1. *Acceptable levels of environmental performance characteristics need be determined*
2. *All aspects of material's entire life cycle must be considered - resource extraction, production and processes, installation and use, disassembly and reuse recycling.*
3. *No permanent environmental contamination should occur during the production use or disposal of building materials.*
4. *Materials in their pure form are preferable. They should not be combined into composites, which cannot be disassembled.*
5. *Building material production and application need to be energy efficient.*
6. *Complete disclosure of ingredients is essential.*
7. *Third-party certification for certain products is desirable.*
8. *Deconstruction after building use must be possible.*

Akadiri agrees further that the cost of the building materials, appearance and their availability were the main factors in choosing the right building material for a project in the past. However, this has changed and nowadays the environmental consequence of the materials plays an important role in building projects.

In his book, Sustainable constructions, Kibert (2012) describes the selection of sustainable materials as one of the most challenging tasks that a building project offers. This is mainly because there is no universal approach around the globe on how different materials need to be evaluated and because there are so many products, materials, systems and components that need to be evaluated.

Even though the information sources related to the sustainable constructions and their definitions are constantly increasing, researchers still cannot agree upon a clear definition of the term sustainable construction (Glavic, 2007). Multiple factors need to be considered in the selection process in order to get optimal outcomes, which adds to the complexity of finding a common definition among researchers, increasing the difficulty of selecting the right materials. Information about different factors and their interrelations should be available to designers to perform a thorough process of materials selection (Heijungs, 2010).

Zhou et al. in 2009 developed a multi-objective optimization model for sustainable material selection that next to the traditional factors such as cost, mechanical properties and process performance includes environmental impact factors throughout the life cycle. They underline that the first important property of each construction material are its mechanical properties – strength, stiffness, and density etc, properties that should satisfy the basic requirements of the product design. As sustainability in different fields becomes more important for the overall quality of our life style, environmental issues like environmental pollution, energy consumption, material recycling and breakdown play an important role in the material selection process. Zhou et al. state that next to the mentioned properties, process properties should also be considered as good process performance can significantly reduce energy consumption and overall economic costs.

One of the methods on how to choose sustainable building material was proposed also by Anink *et al* (1996). They advice to choose materials with the least environmental impact through its whole life cycle, to specify the use of renewable and recycled materials in order to close the life-cycle loop of materials and to design building to be as efficient as possible.

The most used technique to evaluate the environmental impact related to the construction material products is life cycle assessment (LCA) method whose structure is described in ISO 14040 and consists of goal and scope definition, life cycle inventory analysis, life cycle impact assessment and the interpretation. Life cycle inventory analysis results in a long list of inputs and outputs with different environmental indicators. In order to easier compare them, results should be translated into one environmental indicator.

Studies done in the field of sustainable construction materials show that the environmental impact that the production of the construction material has, can be reduced by replacing the finite natural resources used in the process of material production with low-impact, eco-efficient technologies. Furthermore impact can be reduced by focusing on recycling and on the use of natural building materials in construction process (Bribian, 2011).

Studies further show that more than half of the total embodied energy that a building needs is used for the 'structure part' of the building. Which bring to the conclusion that by introducing the alternative materials for building structures could save up to 20% of the overall building energy over a 50-year period. High is the importance of recycling and of the reuse of the construction material. Recycling steel and aluminum up to 50% can be saved in buildings embodied energy consumption (Bribian, 2011),

In some cases a certain material might require less energy in the production process, but when the whole life cycle of the building is considered, it scores less. As an example, steel, that needs 25% less energy in the production process compared to concrete, but because of poorer thermal transfer that steel has compared to concrete, its environmental impact will be higher. Furthermore different studies show that buildings that use wood and wooden products for their structures have lower environmental impact and score better on sustainability scale (Bribian, 2011).

In general, most studies agree that current databases regarding construction materials should be updated and adjusted with the characteristics of the construction industries that each country has. Factors that are taken into account while doing the LCA can be numerous (primary energy demand, water demand, etc…) and they should be synchronized as well, so that the results can be easier compared. This could be done if the public institutions would make some obligatory requirements for the material producers like the use of environmental product declaration (EPD) (Bribian, 2011), which would both make a healthy competition between the manufacturers and rise the environmental awareness offering exact information of each product used in the construction process.

Material selection in this thesis will be softly constrained by the materials requirements stated in the BREEAM Assessment in order to get higher BREEAM score. BREEAM encourages steps taken to reduce the impact of construction materials through design, construction, maintenance and repair. The focus is on the procurement of materials that are sourced in a responsible way and have a low embodied impact over their life including extraction, processing and manufacture, and recycling. Materials that are extracted, processed, and manufactured regionally will be considered as preferable materials because they are easily accessible and their use help developing regional economies. BREEAM encourages and awards credits for the use of a life cycle assessment tool to measure the life cycle environmental impact of the building elements. This will also be considered in the material selection of the EU House.

2.3.1 Industrial construction materials and their future

The growing 'pressure' on building environment to reduce the total CO_2 emission will push the construction industry to find some alternative ways for material processing and to introduce some new alternative building materials. Steel and concrete products were for decades the most used materials in the construction industry.

Considering the fact that both, steel and concrete production consumes high amounts of energy, further technological improvements are needed. In case of concrete the most elaborative part of the concrete mix is the clinker, therefore it is logic that new alternative for the clinker replacing in concrete mix should be considered and studied.

2.3.2 Natural construction materials /Earthen materials

Next to Wood, Stone, Clay and Sand, Earth is the most important natural construction material. Earth is available abundantly over the world and it can usually be obtained directly from the construction site. Depending on the method that it is used, different names exist for earth products: handmade unbaked bricks: adobes, compressed unbaked bricks: soil blocks, compacted with a formwork – rammed earth.

Unfired clay bricks or adobes are normally used as load-bearing materials in masonry structures. They are usually produced during the warm summer months by mixing clay/silt-rich soil, organic fibers (e.g. straw or animal hair) and water to plastic consistency. The mixture is mostly empirical but consists roughly of 20-25% sand, 60-70% clay/silt and 20-30% organic material by volume. Studying embodied energy of the adobe elements it can be concluded that the use of local materials available in the vicinity of the construction site minimizes significantly the environmental footprint of the adobe production. Furthermore, the use of sawdust instead of wheat straw improves the end product significantly (Christoforou et al., 2016).

Adobe structures enter in the category of more environmentally friendly structures compared to the other conventional materials. While adobe requires very low amount of energy for its production process, it needs more energy for its maintenance processes. Still the total amount of the embodied energy related to production and maintenance is up to 2 times lower compared to the conventional materials (Shukla, 2009).

Use of local sustainable construction material in Rwanda is not a product of good will and ecological awareness, but of a need. Most of population uses clay bricks to construct their homes, usually of a poor quality. The potential of using sustainable materials in Rwanda exists, even thought the road for improvement of the local materials is still long.

2.3.3 New construction materials

As our population grows, we have to start searching for alternative ways of constructing and making new construction materials. On one side standard construction material industry (like cement and steel) searches for better ways and improvements to keep up with higher sustainable requirements implementing sustainable solutions in their production processes and on the other side new alternative construction materials are being studied and promoted in the construction industry.

Of course, the research in the field of new sustainable building materials still takes smaller steps, but some interesting studies have been done so far on how to develop new and how to improve the old building materials. Some major steps have been done studying the use of waste/recycling into the building materials. Adding the existing waste in the process of making building materials can contribute to both – environmentally friendly treatment of wastes and in some cases to the improving of the different properties of building material itself (Velasco, 2014).

Another example of applying the wastes as a part of the construction materials is agro-wastes. Agro-wastes have shown the potential to develop energy efficient and cost effective sustainable construction materials along with enhanced thermo-mechanical behavior. From the various literatures it is observed that construction products produced from various agro-waste materials are cheaper, have lower thermal conductivity and are durable, lightweight and more environmental friendly than the conventional one (Madurwar, 2013).

Furthermore, studies show that using selected waste to replace clinker in cement would contribute to the production of more sustainable cement (Bignozzi, 2011).

The newest material available on the building market is brick made of sand and bacteria called BioMasons biobrick. As brick is still being used today in 80% of global construction and their processing (of some forms) require big amounts of energy, it will be essential to search for some alternative options for brick making (and composition). An American based company has already been working on the mass production of this innovative brick following some principles from the nature and using materials that are globally abundant. These bricks are made out of sand (an abundant material that is traditionally not used in the construction materials but it is ideal for the brick growing process in the process that differs from the traditionally made clay bricks (made of clay mixed with water and fired at 2000 degrees for 3-5 days)) and a specific bacteria that bonds the sand together and makes sure the technical requirements of the brick are on satisfactory levels.

Bribina et al. underline that in general it is essential to introduce some radical changes in the way architectural and structural design work in order to facilitate the disassembly and reuse of some components. They study further some alternative materials that could replace currently highly processed insulation materials present on the market. Some of the mentioned alternative material that could be used for insulation are cork and sheep's wool. Sheep's wool has some great thermal insulation properties and it is available in abundance, but for now sorted as the unused waste. Getting cork straight out of the forest might be one of the most ecological production types there is. (Cork is extracted from the tree not harming the tree and the whole process helps the tree to maintain the ecosystem in equilibrium). Even though some cork products require high processing, the overall impact cork and its product have is really low.

Still, to introduce and integrate any sustainable innovation into the construction industry is not an easy step to take. Akadiri (2011) underlines some of the obstacles that this process faces:

1. The real or perceived financial cost and risks (which includes the problem of the upfront cost and the ongoing costs); 2. The lack of information and training of the designers, contractors, subcontractors and clients; 3. Lack of demand from the clients; 4. Lack of regulations and norms.

The mentioned obstacles are not encouraging the various industries to embrace the innovative approach and techniques, and may therefore influence their decision not to use new sustainable materials.

2.4 Sustainability assessment

A sustainable building is by definition not only an environmentally friendly building, but also an economically and socially friendly building, as the triple bottom line of sustainable development states (Haapio, 2008).

While on one hand there are enough tools (such as the life cycle assessment for example) to quantify the environmental impacts of buildings, on the other hand no methodology is available to quantify and assess the other two dimension of sustainable development – social and economic (Saparauskas, 2007).

Environmental building assessment methods have the most impact if applied already in the pre-design stage of the project when everything can still be discussed between the assessment team and the design team. As a consequence, environmental damages may be significantly minimized. However the assessment methods are still mostly used in the final design phase when no or very small changes in design are allowed. This is because the aspects that need to be assessed are often only available and defined in the later design stage (Ding, 2008).

Several environmental assessment tools are being applied worldwide. These tools can be divided in two categories: **criteria based tools/rating tools** and **tools that use life cycle assessment methodology**. Life cycle assessment tools provide quantitative performance indicators for design alternatives whilst rating tools determine the performance level of a building in stars (Ali et al, 2009).

First sustainable assessments are created in developing countries and the issues they rate are usually related to environmental concerns of sustainable developments (as these countries do not have greater concerns about economic and social side of sustainable developments). Use of sustainable assessment started in UK and very soon extended to more countries that adopted these assessments as a base, modifying them according to their own regulations and creating their own specific country related assessment. The assessments that are based on national systems are sometimes used globally without any modification related to local geographical, cultural, economic and social parameters. This can negatively influence the results of the assessment (Suzer, 2015).

2.4.1 Life cycle assessment (LCA)

The LCA methodology assesses the full life cycle of a building, from construction and operation till the disposal phase. It examines into detail all the energy, materials, water and waste and emissions created in the product life cycle, from material extraction and manufacture, to final use in the building. It also includes the impact of transportation between all these stages.

According to the philosophy of the Life Cycle Assessment, it is too simple to think that the most sustainable building is the one made of the most ecological materials. The impact that a building has on the environment is huge and it is very important to consider all the phases of the building life cycle in order to understand how to reduce the negative impact they have globally.

LCA is based on the International Standard Organization (ISO) 14040 norms and consists of four main steps: (1) *defining the goal and scope;* (2) *creating the life-cycle inventory*; (3) *assessing the impact* and (4) *interpreting the results*. LCA can be defined as ‘a technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases’ (Khasreen, 2009).

All materials used in construction have some impact on the environment but it is how these materials are used to construct buildings and how those buildings perform over their lifetime, which is the most important factor for achieving more sustainable construction (Saparauskas, 2007). Saparauskas agrees that a comprehensive building LCA study therefore should include quantification of embodied, operational and end life impacts.

Haas (2013) stresses the importance of raw materials as part of this cycle. Currently much focus is on the reduction of operational energy in buildings as the energy component of the building has the biggest impact on the environment (83 %). Once buildings are more efficient in their energy use, the choice of materials will have the biggest impact. Therefore, in the design process it is important to consider the whole life cycle of the building, starting from the extractions of the raw materials till the end of a buildings life.

In most methods that are based on LCA, building materials, energy resources, waste management and transportation options are selected in the early design phase. The biggest disadvantage of the LCA method is that as it includes all the phases of buildings life (even those once that building still did not 'experience') and those phases need to be predicted in some way.

Type of raw data, energy and transport data are all geographically dependent. That is why each country should have its own database related to its own construction industry resources and traditions (Marinkovic, 2013).

No international database for LCA studies exists where these predictions could be compared. Furthermore there are still a lot of difficulties in understanding and applying of the results.

Compared to the LCA, criteria based tools are easier to apply (following the check list) – that is why they became widely accepted and used.

2.4.2 Building Research Establishment Environmental Assessment Method (BREEAM)

BREEAM was developed in 1990 to raise awareness for sustainable buildings providing an independently assessed sustainability label for buildings. It was originally developed as a tool to measure the sustainability of new non-domestic buildings in the UK and it was related only to the UK building market. Other countries started adopting BREEAM consequently and that is how the 'country specific BREEAM schemes were developed. Country-specific schemes include; UK, Germany, Netherlands, Norway, Spain, Sweden and Austria and these BREEAM schemes are adjusted to the local climate conditions and regulations. For the projects in the countries which do not have a country specific BREEAM, an international BREEAM scheme is applied. The international scheme features a methodology that is flexible in order to recognize local standards and codes, as well as issues of cultural and climatic variations (BRE Global, 2014).

BREEAM awards credits in 51 individual assessment issues divided in 9 environmental categories: management, energy use, health and well-being, pollution, transport, land use, ecology, materials and water. Each category focuses on a specific building related environmental issue and has a number of credits assigned to it. Credits are awarded where a building demonstrates that it does meet the performance levels defined for that issue in the BREEAM.

In addition to the mentioned 9 categories, innovation category credits are assigned where an outstanding performance of the building has been met.

This innovation category reserves credits for the extraordinary project achievements in the field of sustainability that cannot be classified in any of the 9 categories already defined in BREEAM. This category of the BREEAM encourages the innovation in construction. Any new method, technology or design that can be seen as an improvement of the sustainability of the building or can be seen as innovative, can be potentially awarded with credits. This is the most 'difficult' category to achieve credits in, as it does not exist a real definition of what action yes and what not can be considered in order to get extra credits. 1 Extra credit in the innovation category is possible to achieve for reach of 10 assessment issues (for the total sum of 10 credits).

Therefore, the innovation credit is not specifically defined; it can be obtained in different categories as long as it is recognized by BREEAM as a valuable edition to the sustainability of the project.

Each category has several subcategories, each with different number of credits. Some of the categories are rated heavier than others. More 'important' issues have in general a higher number of credits that can be achieved. Considering the fact that the world faces fossil fuel shortage and that using fossil fuels has negative impact on the environment, issues related to the use of 'clean energy' are of the highest importance in all of the environmental assessment tools.

The 'weighting' method is applied to credits of each category in BREEAM. In a perfect scenario, each new project would have its own tailor made weighting criteria that reflects the objectives of a development (Ding, 2008; Lee et al., 2002).

In general, BREEAM offers different schemes for different construction types, residential, non-residential, new buildings, existing buildings etc. In some particular cases, when certain building types are not covered by the regular BREEAM schemes, 'Tailored Criteria' might be applied to the projects. In this case, specific criteria and particular alterations in BREEAM methodology could be more suitable.

BREEAM rating of a project is done by registered BREEAM assessors and reviewed by a third party (BRE Global) before being awarded a certificate. Since 2008 it is compulsory to undertake a 'Post Construction Review' for all BREEAM assessments to confirm that the 'as built' information correlates with the design information.

BREEAM rates projects in 5 different groups related to the score they reach. When the total score is higher than 30%, BREEAM rates the project with PASS grade; when higher than 45% with GOOD, when higher that 55 % VERY GOOD, 70% EXCELLENT and above 85% with an OUTSTANDING grade.

To get an outstanding BREEAM score, sustainability needs to be embedded in the whole project starting from the architectural brief on. In order to reach the needed scores, the entire design team needs to be educated and focused on what are the requirements to get the BREEAM outstanding rating. An outstanding score will deliver a very sustainable building that shows great performance in all aspects of the methodology.

New versions of BREEAM are updated on average every 2 years following the introduction of the new regulations and standards.

In order to make a BREEAM Assessment for a general building, a couple of steps and parties need to be defined:

1. Appoint a BREEAM Assessor and Sustainability champion- qualified individuals who work for a licensed BREEAM organization in the preparation phase;
2. Appoint an extra BREEAM Accredited Professional to set BREEAM target and to monitor and report the progress to BREEAM target;
3. Do the pre-assessment before the design phase;
4. Register BREEAM Assessment;
5. Do the design stage BREEAM assessment;
6. Undertake the post construction stage BREEAM assessment (Barlow, 2011).

For the complete BREEAM Assessment it is therefore important the involvement of all parties from the early start of the project.

BREEAM is the only sustainability assessment method for now that has an ‘international’ version of the original BREAAM Assessment, called very straight forward “BREEAM International”. BREEAM International was created with the intention to be used and applied in different countries. Therefore in this thesis the focus will be on BREEAM International assessment, how to apply it in the most successful way in Rwandan context and what measures should be taken to reach the outstanding BREEAM score for European house project in Rwandan context.

Further on, BREEAM Assessment will be done for 3 case study buildings in chapter 4 and for the EU house in chapter 10. As already mentioned, a complete BREEAM Assessment includes few parties who work together, in this thesis this will be done on a more simple level. This is done to get familiar with issues that BREEAM Assessment is dealing with.

2.4.3 BREEAM International

With time, BREEAM became more popular and more often used outside the UK borders as well. Therefore it needed to adjust its scheme for new and different contexts. The result of this adjustment was a separate rating system, BREEAM International that could be used for assessments of the projects placed in locations where specific BREEAM cannot be applied.

BREEAM International considers regional variations when assigning credits, as importance of certain categories may vary in different geographical locations. To name an example, BREEAM International makes distinction between different precipitation zones on earth for the issues of the responsible use of clean water and flooding risks (BRE Global, 2013).

Therefore, in BREEAM International ten environmental categories are grouped as ‘global’ or ‘local’, depending whether the category has a global impact, and does not depend on local factors, or can vary regarding the local social, environmental, political, and economic parameters (BRE Global, 2013).

Next to the existing local standards, the authorized BREEAM Assessor can, in some cases, go further and propose new construction codes, which are not recognized yet. Since the subject of this thesis is a sustainable office building in Rwanda, BREEAM International is being used in this project.

BREEAM International new construction 2016 written manual, available on the BREEAM website, explains each of the 10 categories and the requirements needed to receive every single credit. Each BREEAM category and correspondent subcategory is described below. Based heavily on the information from the BREEAM website, in this chapter it is explained what is needed in order to achieve each credit.

1. **Management**

The main focus of the management category is on the active involvement from all parties included in the building process through different project phases - from the design brief phase to the post construction and maintenance phase. The involvement from all parties will be encouraged by engaging the BREEAM Accredited Professional who will be responsible for highlighting phases and things that need to be considered and achieved through the whole design and post design process. It is not only important to aim for a sustainable building and sustainable solutions, but to monitor its real-life performance and to make occupants and building users aware of the sustainable issues on every day base.

There are **5 subcategories** in category **Management**.

01 Project brief and design (4 credits)

A clear sustainability brief is produced before the concept design. The brief includes client requirements regarding sustainability, BREEAM rating targets, and involvement of the other professional consultants in project, budget, time schedules and limitations of the project.

From the design brief stage different stakeholders (client, building occupiers, contractors and design team) work together making decisions together and identifying their roles, responsibility and contributions during each phase of the design and construction process (1 credit).

1 credit is obtained if the project can demonstrate how the stakeholder's contribution and involvement influenced or changed the initial project brief or concept design.

Compared to the previous versions of BREEAM international, a new role is introduced in the project in this version – a sustainability champion. He/She is there to help achieving BREEAM performance targets that are set between the client and the design team in the design brief stage (1 credit) (this credit can be obtained in the later design phases, if the targets set in the design stage assessment reports are met).

If a sustainability champion is hired to monitor and report progress through the whole design process 1 extra credit is achieved.

02 Life cycle cost (LCC) and service life planning (4 credits)

2 credits are awarded to the projects with an elemental life cost cycle analysis (service life, maintenance, operation and possible replacement costs) based on the conceptual design. 1 extra credit is awarded if the LCC of the building components (envelope, services finishes, landscaping) is done in technical design stage of the project.

If the capital cost of the building is reported via BREEAM Assessment scoring and reporting tool, 1 extra credit is assigned as well.

03 Responsible construction practices (6 credits)

This subcategory focuses on the willingness, knowledge and the involvement of the project contractor to manage the construction site in an environmentally friendly and socially responsible way. A set of very practical and detailed requirements requested from BREEAM can help to achieve the desired credits.

If the project team completes the checklist of actions to minimize air and water pollution, one credit is awarded (not all the points need to be met, even if the intent of each section (noise and vibration, air quality, water run-off management, hazardous materials) is met, that is enough to get the credit).

One extra credit is awarded if during the construction period the sustainability champion is appointed. A sustainability champion is site based or he/she monitors the site frequently. If the sustainability champion monitors the energy use, water consumption and transport data, 2 extra credits are rewarded (those credits can be obtained if instead of a sustainability champion another individual is appointed for monitoring and reporting).

Up to 2 credits can be achieved if the contractor shows that he is in line with BREEAM guidelines regarding responsible construction practices. This can be demonstrated by filling in the checklist (to be found in BREEAM).

04 Commissioning and handover (4 credits)

The main contractor needs to prepare the commissioning schedule that will be in the line with appropriate standards (best national practice commissioning codes or other standards) (1 credit). If the building services are commissioned 1 extra credit is appointed. For testing and inspecting of building fabric, 1 credit is awarded. And 1 credit if a buildings users guide is developed.

05 Aftercare (3 credits)

1 credit is appointed if there is monitoring of energy and water consumption for a period of at least 12 months. 1 credit is awarded if there is a seasonal commissioning where thermal comfort ventilation and lightning are measured on the base of the occupants' feedback at 3, 6 and 9 months intervals and all the deficiencies are collected into the manuals. If the post occupancy evaluation about internal environmental conditions is done after 1 year that the building was built, 1 credit is awarded.

2. Health and wellbeing

This category encourages the increased comfort, health and safety of building occupants and its visitors. Issues important for this category focus on the quality of life in buildings, putting the accent on healthy and safe internal and external environment for occupants.

01 Visual comfort (3 credits)

Glare controlled strategies have been defined and applied on all relevant building areas. Glare controlled strategies do not cause the increase of lighting energy consumption and do not block the daylight entrance in the building.

Sufficient daylight factor should be provided (1,5% for the latitude <that 40) (1 credit).

All workstations should have a view to outside within 7m and the view should be to a landscape or buildings, rather than the sky (1 credit).

Users should have the possibility to control the shading system on all windows, glazed doors and room lights (1 credit).

02 Indoor air quality (Up to 5 credits)

An indoor air quality plan is made (1 credit).

The building has been designed to minimize the concentration and recirculation of pollutants - the location of fresh air intakes are designed to minimize the entry of air pollutants into the building (1 credit).

Products that should be tested on volatile organic compound (VOC) content include: wood panels, timber structures, wood flooring, floor covering, suspended ceiling tiles, flooring adhesives, sealants and wall-coverings. If five categories are tested, 1 credit is awarded, if 6 categories or more are tested – 2 credits are awarded.

If there is a possibility for natural ventilation 1 extra credit is assigned.

04 Thermal comfort (3 credits)

The thermal comfort has to be simulated before construction phase starts. With the PMV- and PPD-method, local thermal comfort criteria have been used to determine the level of thermal comfort in the building (1 credit). In case that the climate change comfort levels stay in the same range or in case it changes, it needs to be demonstrated how the building can be adapted on changes (1 credit). Users should have the possibility to control the heating and cooling system in their area (1 credit).

05 Acoustic performance (2 credits for office areas)

Acoustics of the internal spaces should comply with relevant building standards. Before completion, acoustic testing should be carried out. Ambient noise level targets should stay ≤ 40 dB $L_{AeqT.}$

06 Accessibility (2 credits)

Where safe access (safe cycle paths, pedestrian area, delivery areas, parking spaces) from and to the building is guaranteed 1 credit is awarded.

The building is designed to fit the purpose, it is secure and accessible by all potential users (1 credit).

07 Hazards (1 credit)

Where risk assessment of potential hazards is carried out and appropriate mitigation measures are pointed out, 1 credit is awarded.

09 Water quality (1 credit)

All water systems should be designed in compliance with health and safety national practice guidelines. Potable water should be available on the permanent staffed areas (1 credit).

3. Energy

This category encourages the specification and design of energy efficient building solutions, systems and equipment that support the sustainable use of energy in the building and sustainable management in the building's operation. This section assesses measures to improve the inherent energy efficiency of the building, encourage the reduction of carbon emissions and support efficient management throughout the operational phase of the building's life.

01 Reduction of energy use and carbon emissions (15 credits)

Credits are obtained where the energy performance of the building is improved above the national building regulation in relation to heating, cooling, primary energy consumption and carbon dioxide emissions. There are two options to get credits in this category:

1. Energy efficiency must be calculated using specifically defined software – up to 15 credits can be achieved in this subcategory. The operational energy amount should be minimized compared to the delivered energy. Depending on the improvement percentage certain amount of credits are available.

2. Using checklist A5, a qualified energy modeling engineer or accredited professional determines the number of credits that can be awarded in this category.

02 Energy monitoring (2 credits)

All energy systems (lighting, cooling, etc.) should be monitored (1 credit).

Each functional area or department should have energy monitors (1 credit).

03 External lighting (1 credit)

External lighting of the project should consist of energy efficient light and have automatic light switch to prevent operation during the daylight.

04 Low carbon design (3 credits)

If the building design can deliver the appropriate thermal comfort one credit is achieved. Building uses passive design measures to reduce the building energy demand.

If free cooling is applied in the project building, 1 credit is achieved.

A feasibility study has been carried out by an Energy specialist (see Compliance notes) to establish the most appropriate local (on-site or near-site) low or zero carbon (LZC) energy sources for the building/development (1 credit).

05 Energy efficient cold storage N/A

06 Energy efficient transportation systems (3 credits)

An analysis of transport demand is done specifying the ideal number and size of lifts, escalators or moving walks. All the transportation systems are energy efficient.

08 Energy efficient equipment (2 credits)

Energy needed for office equipment demonstrates significant reduction in the total annual equipment energy consumption of the building.

4. Transport

This category encourages better access to sustainable means of transport for building users. Issues in this section focus on the accessibility of public transport and other alternative transport solutions (cyclist facilities, provision of amenities local to a building) that support reductions in car journeys and, therefore, congestion and CO_2 emissions over the life of the building.

01 Public transport accessibility (depending on the building type, up to 5 credits)

1 to 5 credits are awarded if the public transport Accessibility Index (AI) for the assessed building is calculated and BREEAM credits awarded in accordance with the building types, AI benchmarks and BREEAM credits OR 1 credit for a dedicated bus service. This last credit is only available in cases where a development is unable to achieve any of the available credits using the Accessibility Index criteria.

02 Proximity to amenities (Up to 2 credits)

1 or 2 credits are awarded if a building location facilitates easy access to local services and in that way reduces the environmental, social and economic impacts resulting from multiple or extended building user journeys, including transport-related emissions and traffic congestion.

03 Alternative modes of transport (Up to 2 credits)

During the preparation of the design brief, the design team has consulted the local authorities about the state of the local cycling facilities and how they could be improved. Extra bus lines and car sharing options have been set up (each of the mentioned options accomplished – 2 credits are assigned).

04 Max parking capacity (up to 2 credits)

1 or 2 credits are assigned if the building's car parking capacity is limited compared to the maximum car parking capacity benchmarks.

05 Travel plan (1 credit)

1 credit is assigned if a travel plan has been developed as part of the feasibility and design stages, in order to promote sustainable reductions in transport burdens.

5. Water

This category encourages sustainable water use in the operation of the building and its site. Issues in this section focus on identifying means of reducing potable water consumption (internal and external) over the lifetime of the building and minimizing losses through leakage.

01 Water consumption (5 credits)

Using BREEAM Wat 01 calculation an assessment of the efficiency of the buildings domestic water consuming components can result in up to 5 credits. Water consuming components are: wc, urinals, taps, showers, bath, dishwasher, washing machine.

(Rwanda in the precipitation zone 1 and 2) If the improvement over the baseline water consumption is above 12,5% 1 credit is awarded, for 25% 2 credits, for 40% 4, for 50% 4 and for 55% 5.

Gray water system should be specified and installed.

02 Water monitoring (1 credit)

The main water supply should be monitored (1 credit).

03 Water leak detection and prevention (1 credit)

1 credit is awarded if a leak detection system which is capable of detecting major water leak on the mains water supply within the building and between the building and the utilities' water meter is installed. 1 credit if flow control devices that regulate the supply of water to each WC area or facility to reduce water wastage are installed. 1 credit is awarded for easily accessible leak isolation valves, to allow leaks to be stopped and then fixed quickly and with minimum water wastage.

04 Water efficient equipment (1 credit)

1 credit is designed if the design team has identified all water demands from uses other than domestic-scale drinking and sanitary use components and systems or processes have been identified to reduce the water demand, and demonstrate a meaningful reduction in the total water demand of the building.

6. Materials

This category encourages steps taken to reduce the impact of construction materials through design, construction, maintenance and repair. Issues in this section focus on the procurement of materials that are sourced in a responsible way and have a low embodied impact over their life including extraction, processing and manufacture, and recycling.

01 Life cycle impact (Up to 6 credits)

1 to 5 credits are assigned if the project uses a life cycle assessment tool to measure the life cycle environmental impact of the building elements. 1 additional credit if a range of at least five products specified at the Design Stage and installed by Post-Construction Stage are covered by verified Environmental Product Declarations.

02 N/A

03 Responsible sourcing of construction products (4 credits)

(with the prerequisite that all timber and timber-based products used on the project are legally harvested and traded timber): 1 credit is awarded for a sustainable procurement plan that is disseminated to all relevant internal and external personnel, and included within the construction contract to ensure that they are enforceable on the assessed project. The documented policy and procedure must encourage the specification of products with responsible sourcing certification over similar products without certification. 1 to 3 additional credits if the available responsible sourcing credits can be awarded where the applicable construction products are responsibly sourced in accordance with the BREEAM methodology.

04 Insulation N/A

05 Designing for durability and resilience (1 credit)

1 credit if the building incorporates suitable durability and protection measures, or designed features or solutions to prevent damage to vulnerable parts of the internal and external building and landscaping elements. The relevant parts of the building incorporate appropriate design and specification measures to limit material degradation due to environmental factors.

06 Material efficiency (1 credit)

Opportunities have been identified, and appropriate measures investigated and implemented, to optimize the more efficient use of materials in building design, procurement, construction, maintenance and end of life. This is carried out by the design or construction team in consultation with the relevant parties at each of the following project work stages.

7. Waste

This category encourages the sustainable management (and reuse where feasible) of construction and operational waste through future maintenance and repairs associated with the building structure. By encouraging good design and construction practices, issues in this section aim to reduce the waste arising from the construction and operation of the building, encouraging its diversion from landfill. It includes recognition of measures to reduce future waste as a result of the need to alter the building in the light of future changes to climate.

01 Construction waste management (3 credits)

A construction waste management plan should be developed and verified constantly by an appointed individual. If there is any existing building on the construction site, its demolition and re-use or refurbishment of its components should be studied to see whether re-use/refurbishments are feasible or not (1 credit). Construction wastes should be divided in appropriate groups (at least 5 for office buildings) (1 credit) by an external contractor. If the targets to re-use of 60% of the waste are set 1 extra credit is awarded (if the target was 95%, 1 innovation credit is awarded).

02 Recycled aggregates (1 credit)

Recycled or secondary aggregate should count for more than 25% of the total new used aggregates. Secondary aggregate should come from the building site or be transported from the place that is no more than 30 km away from the construction site.

03 Operational waste (1 credit)

If the dedicated space for segregation and storage of operational waste is provided, 1 credit is awarded.

04 Speculative finishes (1 credit)

Finishes should be chosen by direct users to prevent their later replacement (in case they do not correspond with users whishes).

05 Adaptation to climate change (1 credit)

A systematical risk assessment for structural and fabric resilience should be done regarding the influence of the climatic change on the life cycle of buildings. Specific hazard identification, assesment, risk estimation, evaluation and management should be presented.

06 Functional adaptability (1 credit)

In case the use of building changes over its life span, the building is suitable for the functional adaptability. (1 credit)

8. Land use and ecology

This category encourages sustainable land use, habitat protection and creation, and improvement of long-term biodiversity for the building's site and surrounding land. Issues in this section relate to the reuse of brownfield sites or those of low ecological value, mitigation and enhancement of ecology and long-term biodiversity management.

01 Site selection (3 credits)

2 credits are awarded if previously occupied land is being used and 1 additional credit if contaminated land is being used.

02 Ecological value of site and protection of ecological features (2 credits)

1 credit is awarded if the building plot is classified as 'land of low ecological value' and 1 credit if all existing features of ecological value within the zone and site boundary area are adequately protected from damage during clearance, site preparation and activities.

03 Minimizing impact on existing site ecology (non applicable in BREEAM International)

04 Enhancing site ecology (3 credits)

1 credit is awarded if a suitably qualified ecologist has been appointed who provides an ecology report with appropriate ecological recommendations, of which at least 50% have been, or will be, implemented in the final design and build. One additional credit in case this percentage is 75% or 2 additional credits in case 95% of the recommendations will finally be addressed.

05 Long-term impacts on biodiversity (2 credits)

In case (1) a Suitably Qualified Ecologist is appointed prior to commencement of activities on site who confirms that all relevant EU, local and national regulations or legislation requirements relating to the protection and enhancement of ecology have been complied with during the process and (2) a landscape and habitat management plan (including impacts of the building both during construction and in operation), is produced covering at least the first five years after project completion, 1 credit is awarded if 2 additional measures to improve the assessed site's long term biodiversity are adopted, or 2 credits if 4 additional measures are adopted.

9. Pollution

In this category the focus is on prevention and control of the pollution and surface water run-off from the building location. The main idea is to reduce the negative environmental impact that the new building might cause.

01 Impact of refrigerants (4 credits)

4 credits are being automatically assigned to buildings that use no refrigerants.

Or in case refrigerants are used, credits can be awarded if specific requirements have been met: when applied, the refrigerants should have ozone depletion potential (ODP) of zero (1 credit) and a global warming potential (GWP) below ten (2 credits). When there is a leak detection system or a recovery system to reduce the emissions that are caused by leakages in the cooling services 1 credit is awarded.

02 NO_x emissions (2 credits for non industrial buildings)

The building hot water/heating system should have dry NOx emission levels as follows:

< 56 mg/kWh (1 credit)

<40 mg/kWh (2 credits)

03 Surface water run-off (5 credits)

If the building is situated in a low flood risk zone 2 credits are awarded, when in medium or high flood risk zone 1 credit is awarded. If the peak water run off is the same as it was before the building was built, 1 credit will be awarded.

In case of a failure of the local drainage system there will be no flooding on the property (1 credit).

One extra credit is awarded when there is no discharge from the developed area for the rain up to 5mm.

04 Reduction of night time light pollution (1credit)

External lighting is switched off between 11:00 PM and 07:00AM (except the safety lights). Lights that are on should have limited luminance level of 300 CD/m2.

05 Reduction of noise pollution (1credit)

When no noise sensitive areas exist within 800m of the building 1 credit is awarded by default. Otherwise, a noise impact assessment should be done – if the noise level stays below +5 dB during day and +3 dB during the night compared to the background noise level, 1 credit is awarded.

10. Innovation

Innovation category reserves credits for the extraordinary project achievements in the field of sustainability that do not correspond with any of credit in the 9 categories already defined in BREEAM. This is the last added category to the BREEAM with the aim to encourage the innovation in construction. Any new method, technology, design that can be seen as an improvement of the sustainability of the building, can be seen as innovative can be potentially awarded with credits. This is the most 'difficult' category to achieve credits in, as there is no definition of what action can be considered in order to get extra credits. In each category BREEAM offers 1 extra 'innovation credit', for a total sum of 10 credits.

2.4.4 Leadership in Energy and Environmental Design (LEED)

LEED building certification was developed in 2000 by the United States Green Building Council (USGBC). LEED became a known and recognized name in the sustainable assessment field as a tool for guidance and evaluation of green buildings through their life cycle. Through the years, LEED Expanded and in mid 2014 LEED had over 65000 certified project worldwide. LEED awards points in five categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Indoor Environmental Quality. There are various issues to fulfill under each related category and each issues is assigned certain points. The points earned from these issues are summed up to determine the final LEED score of the project. The higher the score, the higher the certification level achieved. Next to the mentioned 5 categories, there are two additional categories: Innovation and Regional Priority that can award up to 10 bonus points for each projects (USGBC, 2009). The possible points to receive from each category determine the weights of the categories. These weights imply the priorities among them (Neama, 2012; USGBC, 2009).

If the building receives a grade between the range of 40 and 49 points, it is granted 'Certified', if it gets points between 50 and 59, it is certified as 'Silver', if it gets points between 60 and 79, it is certified as 'Gold', and finally if it gets points higher than 80, it is certified as 'Platinum'. (Neama, 2012; USGBC, 2009).

Credits related to the most important category (which had the greatest weight) gained highest points. As a result of this weighing process, the primary concern was determined as reduction of energy consumption and Green House Gas emissions (USGBC, 2009). Credits that addressed these issues, such as credits related to energy conservation, and clean and alternative transportation gained higher points.

The weighing approach of this rating system that is used worldwide does not reflect environmental concerns and their priorities at a global scale. If the data regarding the environmental impact categories and point reassignment were to be derived from global parameters, the assigned points for the credits, thus the weights of categories might have changed.

This intention for providing a flexible framework for LEED, that can change its weighting system to be tailored to fit each case, actually points out the importance of local conditions when considering environmental impacts and their prioritization.

BREEAM and LEED compared

Comparing BREEAM and LEED, a few differences can be seen. One of the differences is that BREEAM uses the licensed professionals who get the info for their assessment from the client and design team. This licensed professional (assessor) submits his assessment to the BRE and BRE issues the BREEAM certificate. Info and data's for the LEED assessment are provided by the design team and preceded to the US Green Building Council, which assesses it before issuing the certificate. According to Sleeuw (2011) LEED assessment is more transparent because technical criteria proposed by the various LEED committees are publicly reviewed for approval by US Green Building Council (USGBC) members and organizations.

While BREEAM has an seperate rating system- BREEAM International- for the assessment of the projects placed in locations where specific BREEAM can not be applied, LEED introduced regional priority credits which were specific to the projects made in the US and these credit were not valuable for the projects outside the US.

2.4.5 Sustainable building assessment tool (SBAT)

BREEAM and LEED both originate in the industrialized countries (UK and the USA) and therefore their applications in developing countries are not always appropriate. While on one hand some development countries like Brazil adopt these assessment methods, the others like South Africa, made their own methods to assess sustainable development.

A framework called sustainable building assessment tool (SBAT) was developed by Gibberd in South Africa and is used as sustainable assessment tool in some other developing countries.

Architects in developed countries have the luxury to think about ways to maintain standards of living while reducing resource depletion and environmental damage. In developing countries, the average standard of living is far lower than in developed countries and in many cases basic human needs are not being met. The focus should therefore be on development that aims to address these basic needs while avoiding negative environmental impacts (Gibberd, 2002).

In order to reflect the priorities in developing countries, SBAT places a strong emphasis on social and economic aspects of sustainability as well as environmental issues (Figure 3). The tool also aims to develop awareness and support for sustainability among building stakeholders, including clients, building users, facilities managers and design teams (Gibberd, 2002).

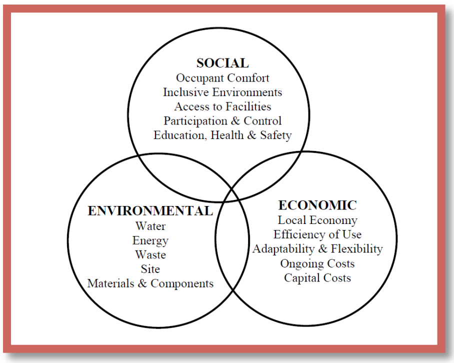


Figure 3 Objectives of sustainable development Reffat, R. (2004) Sustainable construction in developing countries

SBAT tool covers 15 different areas divided in 3 different groups – social, environmental and economic. Each group has 5 criteria whose assessment shows the impact that a certain building project makes on the local economy, environment and the social aspect.

SBAT tool was developed considering 9-stage process that is based on the life cycle of the building: Briefing, Site Analysis, Target Setting, Design, Design development, Construction, Handover, Operation, Reuse/refurbish/recycle. Mentioned strategies do not differ much from the conventional approach to design, management and construction of the buildings. Still, the conventional strategies combined with a sustainable tool like SBAT lead to a more sustainable building.

All mentioned sustainability assessment tools would be hard to compare even if we would want to. They are based on different guidelines and databases; they evaluate different phases of the life cycle process in buildings and often are made for different type of buildings.

Methods and techniques that are made in developed countries do often just do not work in developing countries. Until now there is no universal tool that could be easily adjusted and applied in different location contexts.

Therefore, the absence of a flexible weighting system that allows local adjustments is the main negative point of the current assessment tools.

In this thesis it has been decided to study the BREEAM International assessment in the Rwandan context, by applying it to the European House project. It will be studied what exactly would be necessary in the Rwandan context in order to obtain a BREEAM outstanding building.

2.5 Energy in (office) buildings

Energy is used in buildings through their whole life cycle. Energy is needed to extract raw materials and to process them, to assemble and to transport them to the construction site. Energy is needed to construct, to deconstruct, to repair and to maintain built constructions. Energy is needed to 'use' the building.

Based on the above written, energy in buildings can be divided in 3 categories:

Embodied Energy EE

Operational Energy OE

User related energy URE

The EE is the amount of non-renewable primary energy required for the extraction of raw materials, their transformation into semi-finished and finished products (**initial EE**), the replacement processes (**recurring EE**) and the disposal processes (**end-of-life EE**). Current interpretations of embodied energy are quite unclear and they vary greatly which makes databases of EE difficult to compare. As data's regarding recurring EE and end-of-life EE are not always easy to collect most of EE databases refers to the upstream process, or better extraction of the raw materials ignoring the other embodied energy phases, delivering uncompleted data info. Further more, as recurring and end-of-life EE are generally considered of minor importance they are often neglected. (Giordano et al., 2015)

The OE is the annual amount of non-renewable primary energy required for use during the life of a building. OE refers to Primary Energy Demand (PED) for heating, ventilation, cooling, hot-water production and for lighting. (Giordano et al., 2015)

The **URE** is the energy used for consumption categories like cooking, household appliances and other electrical appliances.

Case studies that focus on the phases of construction, demolition and relative transportation of materials, show that the total energy needed for these phases is very low and it accounts for approx. 1% of the total life cycle energy need. Some studies consider the energy for construction and relative transportation in the definition of the initial embodied energy, but without clear arrangement on how this should be handled. Only a few studies include the phase of recycling building materials after demolition in the building life cycle. (Sartori, 2007)

Sartori's research states that a linear relation between OE and EE exits unindipendently from the climatic and geographic context of the project. However, this should not mean that the differences in contexts can be ignored in the life cycle analysis, but on the contrary they have to be taken into account.

Numerous are strategies that can be applied on buildings in order to reduce total energy demand of its components and of building in total. Some studies show that by improving the building envelope (insulation) and by using energy efficient building materials, amount of operating energy in buildings can be reduced remarkably. In the low-energy buildings, where operating energy is reduced to a min, the energy used for the material production (embodied energy) can account for 40-60 percent of the total energy use of a building. Therefore, in the future, more and more attention will be focused on the embodied part of the building energy cycle in the future. Analysis of case studies of different buildings show that the design of low energy buildings induce both a net benefit in total life cycle energy demand and an increase in embodied energy. (Sartori, 2007)

Still for buildings that aim to energy efficiency throughout their life cycle, reduction of the demand for the operating energy is the most important effect of the design. Embodied energy concerns come on the second place. (Sartori, 2007)

Cole and Kernan (1996) focused on studies of the life cycle energy in office buildings specifically. They studied office buildings built out of different construction materials and found out that independently from the type of construction materials, certain parts of the buildings structure needed same proportions of embodied energy.

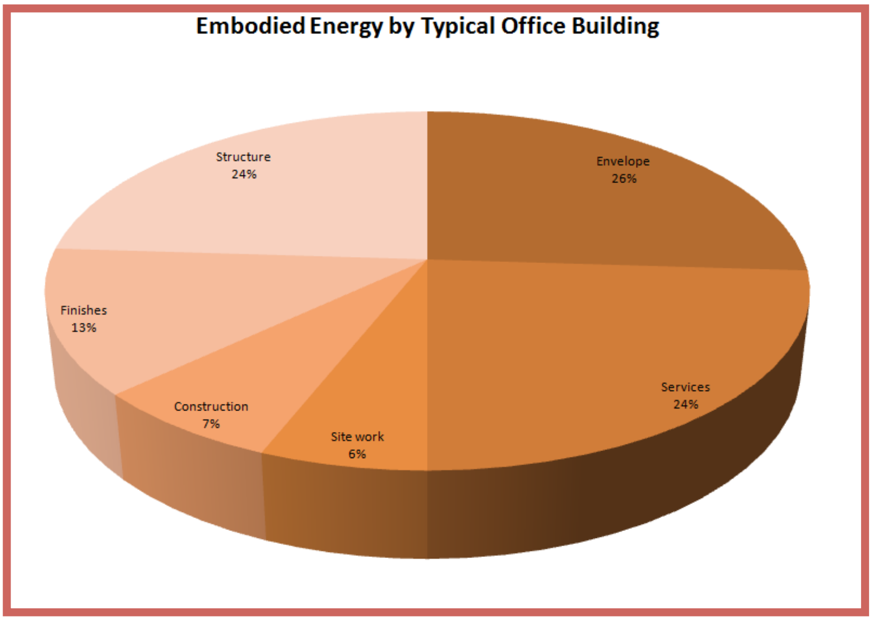


Figure 4 Initial Embodied Energy by Typical Office Building Components Averaged Over Wood, Steel and Concrete Structures [Cole & Kernan, 1996]

According to Cole and Kernan (1996) (Figure 4) the biggest part of building energy consumptions goes to the building structure, services and building envelope. Another thing their study highlights is the **effective life of the building**. The structure of a building usually last the whole life spam and does not need replacement. Consequently, building services and envelope become the most important factors that contribute to the amount of embodied energy used in a building in the long run. Over a longer period of time, the initial embodied energy of the structure represents a very small portion of the total amount of the embodied energy (less than 5 percent), which makes the distinction between different construction materials even less marked.

Therefore the choice of the construction materials should not depend only on their embodied energy but on the longevity of the construction materials and on how easy they could be replaced in the future, reused or repaired.

The attention should be paid in the same time to the building design, use of recycled materials and means of transport of the materials. With all this, we can contribute significantly to the energy efficiency in the building environment. However, practice shows that the goals to achieve complete energy efficiency are often substituted with goals to reduce the cost and not to compromise on the consumer’s comfort. (Sartori, 2007)

Haas (2013) stresses that until now the main focus of the latest standard was always on the operational energy. This will, as the prediction say, change in the future when building become more energy neutral.

In this thesis I will focus on operating energy and embodied energy in the life cycle of buildings. The recycling phase will not be taken into account. In order to get an overview of what is the total amount of the energy used in each building the life cycle analysis should be applied. In the life cycle analysis EE is only considered once, while OE accumulates over the total lifetime of a building. Service life of the building of 50 years will be taken into account. Following the conclusions of Cole (figure 4) for the calculation of the EE it is possible to only consider the structure as one of the major components that contribute to the tot amount of the EE used in building. To get the tot amount of EE the EE of the structure can be then multiplied by 3 (starting with the assumption that the building will need no mechanical ventilation, building services can be taken out of the calculations)

2.6 **Energy neutral buildings**

This subchapter is mainly based on the information obtained from the paper ' A literature review of Zero Energy Buildings definitions (authors Marszal and Heiselberg)

In the early eighties, parallel with the period in which the consequences of the oil crisis became obvious, scientific articles started referring to the concept of a 'zero energy house', 'a neutral energy autonomous house' or 'an energy independent house'. In that period the focus was more on the energy efficient technologies and the passive solutions integrated in the building. In the definitions of that time, with 'zero' reference was made only to the demand for space heating, domestic hot water and cooling (21).

Since then, thinking about energy neutral buildings took a flight and became increasingly sophisticated.

Many different definitions of the zero energy buildings can be found in the literature, distinguishing themselves especially when it comes to defining what should be 'zero' in the buildings. Torcellini (2006) claims that *'despite the excitement over the phrase "zero energy", we lack a common definition, or even a common understanding, of what it means.'*

In this chapter, I will briefly describe several definitions, after which I will come to a definition that shall be used in the context of this thesis.

The general definition for a *net zero-energy building (ZEB)* as given by the U.S Department of Energy Building Technology Program is: '*A net zero-energy building is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies'* (21).

At the heart of the ZEB concept is the idea that buildings can meet all their energy requirements from low-cost, locally available, nonpolluting, and renewable sources. At the strictest level, a ZEB generates enough renewable energy *on site* to equal or exceed its annual energy use (21).

Zero Energy Buildings are buildings that over a year are neutral, meaning that they deliver as much energy to supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid. As described by Torcellini (2006), a ZEB typically uses traditional energy sources such as the electric and natural gas utilities when on-site generation does not meet the loads. When the on-site generation is greater than the building's loads, excess electricity is exported to the utility grid. By using the grid to account for the energy balance, excess production can offset later energy use. As Torcellini argues, achieving a ZEB without the grid would be very difficult, as the current generation of storage technologies is limited. Despite the electric energy independence of off-grid buildings, they usually rely on outside energy sources such as propane (and other fuels) for cooking, space heating, water heating, and backup generators. Off-grid buildings cannot feed their excess energy production back onto the grid to offset other energy uses. As a result, the energy production from renewable resources must be oversized. In many cases (especially during the summer), excess generated energy cannot be used.

A similar, but more strict definition is offered by Kilkis (2007), who states that a zero-energy building (ZEB) is a building, which has a total annual sum of zero exergy transfer across the building district boundary in a district energy system, during any electric and any other transfer that is taking place in a certain period of time. Kilkis indicates that in balancing the 'zero' both quantity and quality (exergy) of energy should be taken into consideration. Kilkis explains that although the ZEB definition seems logical, it falls short in recognizing the importance of exergy in assessing the complete impact of buildings on the environment. If the building is not balancing the exergy of heat it receives and provides, this ZEB is still impacting the environment because the negative exergy balance must be made up by the district at a cost of additional fuel spending and harmful emission even though energy amounts of the heat and power flow across the building-district boundary are balanced. If the district generates power in the thermal power plant, and the ZEB generates electric power in a micro-combined heat and power (CHP) unit, and or by using wind turbine, all have different environmental impacts and exergy".

Lausten (2008) offers another view, by describing **Zero Carbon Buildings;** buildings that over a year do not use energy that entails carbon dioxide emission. Over the year, these buildings are carbon neutral or positive in the term that they produce enough CO2 free energy to supply themselves with energy. Zero Carbon Buildings differ from Zero Energy Buildings in the way that they can use for instance electricity produced by CO2 free sources, such as large windmills, nuclear power and PV solar systems which are not integrated in the buildings or at the construction site (22).

This is in line with the view of Mertz (2007), who focuses on the final goal of not adding CO2 to the atmosphere due to the operation of the building. What he calls a **Net zero CO2 neutral home** can also be accomplished by purchasing tradable renewable certificates generated by solar, wind or biogas. It could also be accomplished by purchasing CO2 credits on carbon trading market from who has CO2 to sell.

If a building is named zero energy building, then the total energy use should be included. In order to evaluate the total building environmental impact, embodied energy should be taken into account in the balance. Lot of data and values about embodied energy can be found in databases, which is very helpful for the total energy calculation in buildings.

And Energy Performance of Buildings Directive EPBD (2010) defines nearly zero energy buildings as "*buildings that have a very high energy performance […]. The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby."*

After considering the previously mentioned definition it is decided that as a guideline for the energy neutral building through this research will serve the following definition:

A building that produced as much energy as it consumes during a given time period. (A building that produces on annual basis as much as it consumes). It is important to underline that in this definition term energy considers all – embodied, operational and user related energy. Total amount of required energy should be covered by renewable energy sources and focus should be on the energy efficiency.

2.7 Renewable energy sources and technologies in Africa

In order to reduce and to, eventually, completely stop our dependency on fossil fuels, it is needed to turn into the direction of the renewable sources of energy that could replace the non-renewable ones that the world heavily use in the moment. Studies show that the whole African continent has a great potential of different renewable energy sources unevenly spread all over the continent among which hydro, marine, bioenergy, geothermal, solar and wind energy. (Figure 5) (Onyeji, 2014)

Rwanda's natural energy sources are not very huge and the small hydro resources are almost fully developed. Total energy generation capacity available in Rwanda is 155MW from thermal, hydro, Solar and Methane gas. Until 2018, Rwanda's plans are to achieve additional 408 MW next to the current capacity. (Rutagarama, 2014)

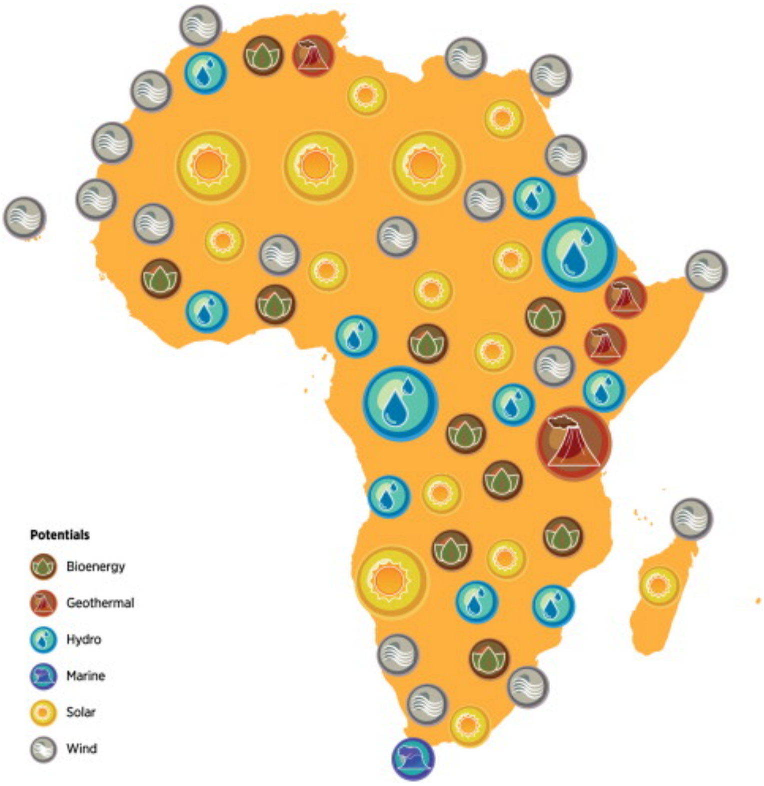


Figure 5 Renewable energy sources in Africa (Ijeoma Onyeji, 2014)

In order to reach this number most of the focus is put on the methane gas in Lake Kivu in Rwanda. Next to methane gas, energy is planned to be obtained from small hydro plants, geothermal, wind, solar and biomass.

2.7.1 Hydropower and hydropower plants

Hydropower takes the leading position in renewable energy sources in Africa, providing 94% of the total renewable power production and 16 % of African continent power generation in general. Hydropower potential is concentrated mostly along the river Nil and Congo River. (Onyeji 2014) Hydropower relies on the water cycles that are driven by the sun and therefore it is considered a renewable power source. Three are types of facilities/plants that can host hydropower: ***diversion*** (where a portion of the river goes through the small channel generating the electricity), ***pumped storage*** (stores energy by pumping water from a lower reservoir to a higher reservoir – when the electricity demand is high – the water is released back to the lower part – to generate the electricity) and ***impoundment (***the most widely used hydropower plant – uses a dam to store the water in the reservoir –water travelling on the way to the reservoir activates turbines that stats spinning activating generator to produce the electricity) The size of these hydropower plants depend on the individual situation (is plant used by many consumers or only by individuals) and vary from small (with capacity of less than 10MW) to large (capacity exceeding 50 MW)

Hydropower produces 59 percent of the whole generation capacity in Rwanda. In total there are 333 places in Rwanda where big or small hydropower plants have been installed (with capacity till max 28 MW). It is predicted that in the future it will be increased to 333 MW (RDB 2012).

Hydropower will further not be considered as the potential energy source for the EU Building as the focus will be on the sources whose plants/technologies can be directly made/installed on the building or the building plot.

2.7.2 Solar energy and solar technology

Another great renewable source present through the whole African continent is solar energy. With its power radiation intensity of 3000 – 7000 w/h/m2 solar power could more than satisfy the needs of an average domestic load.

Solar power can be used for both, passive and active solar design in buildings.

Passive solar technologies use solar energy directly in its pure shape and take into account the building position compared to the sun, window position, skylights, and materials used and shading devices.

Active solar design requires the use of different transforming systems/technologies in order to profit from solar energy. With the use of these systems solar energy can be used for heating, lighting, cooling and production of electrical energy.

One of the most promising active solar technologies is photovoltaic (PV) and building integrated photovoltaic (BIPV) system. They can be connected to the local grid (grid-connected or utility-interactive systems) or they can function independently from the grid as stand-alone systems.

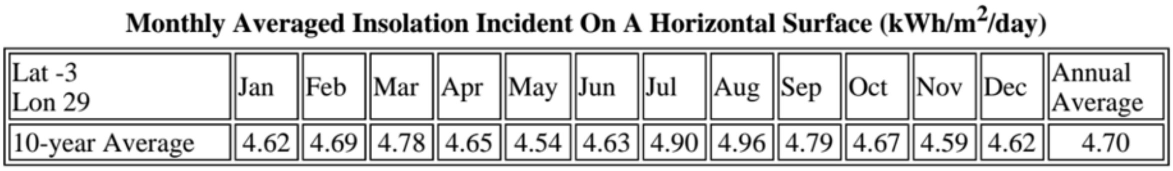
1. **Stand-alone**. Installed independently of the grid, mostly in the remote areas where there is no access to the grid. This is often a cheaper option, as no electricity cables need to be applied. A battery is used for storage of the excess energy (that can then be used in time when there is no radiation present) (this is currently the most common system of renewable energy used in Rwanda)

2. **Grid-connected:** In this system the building is connected to both, grid and to the solar system. The electricity supply from the sun can be first from the solar system and then connected to batteries, if installed, and finally to the grid if there is a need.

3. **Back up**: Is a system connected to an unreliable grid or one of poor quality. These types are usually installed in areas where a lot of power blackouts occur.

PV panels are mostly installed on the top of the buildings, receiving in that way the most of the solar radiation. To maximize the amount of generated electrical power PV panels can also be integrated in other parts of buildings – those systems are named BIPV (building integrated PV). One of the disadvantages of the BIPV is the non – transparency and direct influence on the day lighting in buildings. Another disadvantage of the PV cells in general is their low efficiency of 9-18% (check source), which makes more than 80% of the solar radiation reflected or dissipated as thermal energy. In this way working temperature of the PV cells increases and the conversion efficiency decreases. A newly developed system of hybrid photovoltaic thermal (HPVT) should reduce the temperature of the PV cells and use the heat to generate thermal energy, which makes it more efficient. (check source)

Thanks to the countries geographical position Rwanda enjoys all year around sunshine and the average annual daily mean solar radiation of about 5,2 kWh/m^2/day[1] (Safari, 2009). NASA source shows average monthly solar radiation of 4.7 kWh/m^2/day[1]. (Figure 6)



Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m^2/day)

Lat -3 Lon 29	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.62	4.69	4.78	4.65	4.54	4.63	4.90	4.96	4.79	4.67	4.59	4.62	4.70

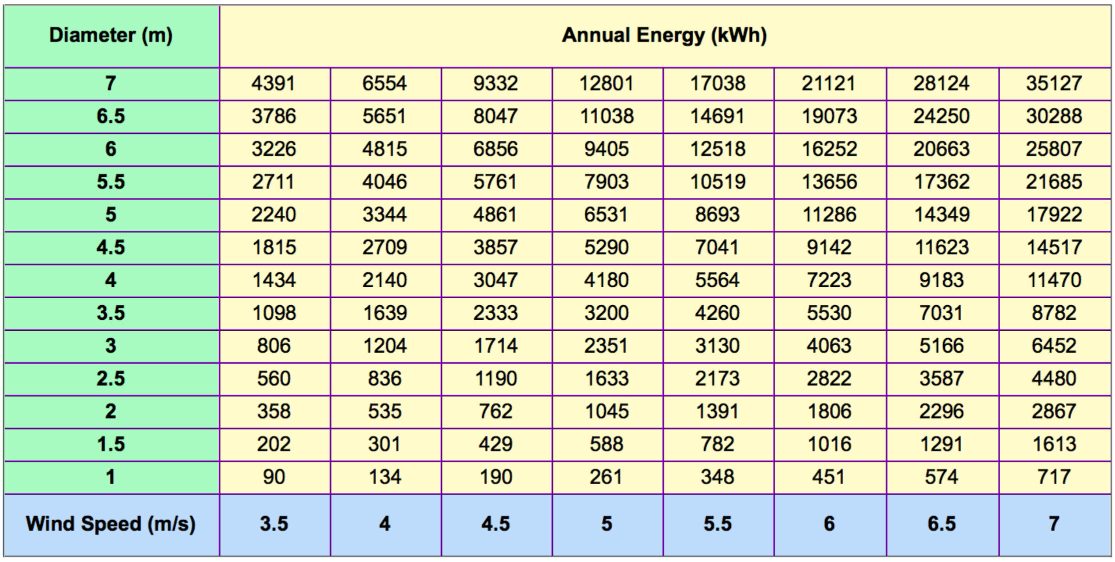
Figure 6 Monthly averages insolation Rwanda (NASA, 2016)

2.7.3 Wind energy

Africa's wind energy potential is mainly located in coastal areas of the continent. Mainland wind intensity is often too low to be considered for a large power generation. In some cases if the wind intensity exceeds certain speeds (of 5m/s) wind can be used for smaller power generation.

Wind can be turned into the wind power using wind turbines. Simply explained - the force of the wind (kinetic energy) acts on the rotor blades (rotational energy) that rotating produces torque (turning force or mechanical energy). This rotational energy is used then within a generator to produce electricity.

Figure 7 shows the relation between annual wind speeds, diameter of the turbine and the annual energy production



Diameter (m)	Annual Energy (kWh)							
7	4391	6554	9332	12801	17038	21121	28124	35127
6.5	3786	5651	8047	11038	14691	19073	24250	30288
6	3226	4815	6856	9405	12518	16252	20663	25807
5.5	2711	4046	5761	7903	10519	13656	17362	21685
5	2240	3344	4861	6531	8693	11286	14349	17922
4.5	1815	2709	3857	5290	7041	9142	11623	14517
4	1434	2140	3047	4180	5564	7223	9183	11470
3.5	1098	1639	2333	3200	4260	5530	7031	8782
3	806	1204	1714	2351	3130	4063	5166	6452
2.5	560	836	1190	1633	2173	2822	3587	4480
2	358	535	762	1045	1391	1806	2296	2867
1.5	202	301	429	588	782	1016	1291	1613
1	90	134	190	261	348	451	574	717
Wind Speed (m/s)	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**

Figure 7 relations between annual wind speeds, diameter of the turbine and the annual energy production (salacity.com)

Modern wind turbines, used to create electrical energy, can be divided into 2 groups: the horizontal-axis turbines (rotation around the horizontal axis – example traditional windmills) that are also widely used, and the vertical-axis turbines.

Several types of horizontal-axis turbines are present on the market - single bladed, two bladed, three bladed, multi-bladed, upwind and downwind turbines and many others. In order to catch the wind energy this type of turbines has to face the direction of the wind.

Vertical axis wind turbine generators have gearboxes and generators at ground level. By turning along vertical axis, a machine can accept wind from any directions without adjustment, while the horizontal axis design has to yaw first.

The advantages of vertical axis turbine are that it accepts the wind from any direction and its components can be easily mounted on the ground level.

Their principle disadvantages are: they require support on top of turbine rotor, they require the entire rotor to be removed to replace bearings, they have an overall poor performance and reliability and they have not been commercially so successful.

2.7.4 Bioenergy

After the hydropower, bioenergy is the most used renewable energy source in Africa. About 75% of the population in Africa relies on the traditional use of biomass. Methods, which are used for getting energy out of biomass (burning bio-residues) in most Africa, are having negative environmental consequences though. Bioenergy will however stay one of the leading energy sources in the future in Africa, and the negative environmental consequences should not discourage its use as there are many sustainable solutions that could be made for bioenergy plants.

On bigger scale – whole cities could benefit from sewages and other organic wastes to produce biogas. In Rwanda the government has been promoting biogas as an alternative fuel for cooking and lighting in households and institutions since 2009, encouraging every Rwandan that owns at least two cows to build a biogas plant.

Biomass is a biological material composed of plants and animals, including their wastes and residues. It can be used as a fuel – for heating and cooking, but also for electricity generation. It is an organic material that reacts with the oxygen in combustion and natural metabolic process to release heat (Twidell, 2006).

Biomass is number four on the list of the largest sources of energy worldwide. In Rwanda biomass is widely used as well. In the moment 85 percent of the population is using it, mainly for cooking, as the main source of energy. This should change in the near future and by 2020 it is predicted that number of users will be reduced to 50 percent (Best, 2009).

Biomass is the green source of energy in Rwanda, as most of the firewood and charcoal comes from man made local plantations. Still man made plantations do not cover all the demand for the biomass in the country, which leads to an environmental misbalance.

Numbers of modern biomass technologies are increasing worldwide. To generate energy from the biomass using boiler-steam turbine is already largely used in China and India (Bhattachara, 2002). These countries are ahead in using the biomass for energy generation. Till now the biggest step in renewable initiatives was made in Brazil with introduction of the ethanol program and generation of biofuel. Today Brazil is the biggest exporter of biofuel in the world.

At the moment, the price of biomass fuels on the global market is much higher compared to the price of fossil fuels. This makes the use of biomass fuels less attractive. With the growing awareness of the environmental issues hopefully the reduction of the price and consequently greater use of this renewable energy sources will be possible.

2.7.5 Geothermal

East African Area (Kenya and Ethiopia in particular) has rich sources of geothermal energy. The advantage of geothermal power is that it can provide electricity 24 h a day. It is a cost-effective and reliable base-load (has minimum level of demand for electricity for its functioning) technology and the only renewable energy resource without intermittency challenges.

Geothermal energy is formed deep within the earth's crust. Geothermal can be used for the electricity generation or other direct uses. The medium of this energy transfer is geothermal fluid. On the surface, these are manifested as hot grounds, fumaroles, geysers, mud-pools and hot springs.

Geothermal power plant construction involves high expenditures and capital costs at the beginning of the project. This upfront capital is especially necessary for the drilling and exploration phases. This stage of the project involves considerable risks. Indeed, the return on investment is essentially random or long-term programmed.

Wind, solar, and fossil fuels are less limited by location than traditional geothermal power systems. Geothermal plants must be placed near or directly above the resource.

Rwanda has very positive indicators of geothermal potential but the resource still need to be confirmed.

In Rwanda, methane is found in Lake Kivu. Currently different studies have been done to explore the possibility of its use. Till now it is estimated that using the methane from Lake Kivu, 700 MW of electricity can be generated in the period of 55 years. From this 350 MW or 50 percent would be the Rwanda's share; other 50 percent is share of the Democratic Republic of Congo (RDB 2012). Development of geothermal energy in Rwanda is still in an early stage and lots of further studies and investments should be done in order to benefit from this energy source.

Although there is general recognition among African governments that renewable power provides huge opportunities given the continent's enormous resources, the lack of coherent, consistent policies, technical skills, institutional capacity, infrastructure and financial incentives remains a major barrier for wide-spread adoption.

Energy efficiency programs in Africa have registered less than encouraging results. Efficiency programs are largely absent in most countries although the potential gains from energy efficiency are enormous.

Still, the future of the renewable energy sources has a very good prospectives in Sub-Saharan Africa. First of all its geographical position offers great benefits like the existence of the natural sources to be used. As overall cost of the introduction of renewable teccnologies and decreasing and their effiency improving, they have a great prospectives to play a major role in the electrification of the sub-saharan Africa.

In this thesis I will focus on renewable energy sources that can be used directly on the building spot and therefore the wind and the sun potentials on Kigali location will be studied more in detail.

2.8 Vernacular Architecture

Since humans exist, shelters exist. In the early beginnings these shelters were only functional, protecting people, mostly from the weather conditions and animals. As humans evolved, the shelters evolved into more complex structures as well. Their complexity was a result of different factors - individual needs, economic needs, individual wishes, availability of certain materials, local geographical context, climate and many others.

In response to different climates, locations and cultures, unique housing styles were constructed, following passive design principles, as no active principles were available at that moment. Therefore the context was always the most relevant factor for the 'responsible' type of architecture, better known in literature as a vernacular architecture.

Khaled (2014) describes vernacular architecture as *a creation produced through natural dynamic interactions among people's socio-cultural needs, ecological impacts, and technological solutions* (see figure 8).

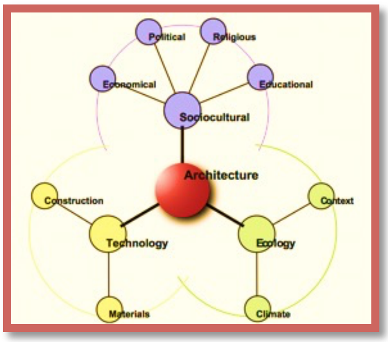


Figure 8 Disciplines integrated by vernacular approach

He agrees that creating a vernacular architecture is a complex system where cultural, environmental, climatic and functional needs meet.

According to Folkers (2010), vernacular architecture can also be defined as 'native, local informal architecture, completely opposite from formal academic and official architecture'.

Vernacular building traditions are passed from generation to generation by word of mouth. Vernacular buildings use local materials that are easy to be found in near surroundings and do not require long transport to the building site. They work in a perfect symmetry with a local climate, using all the potentials of the building location and in that way they balance environment, humans and buildings (Ryan 2011).

AlSayyad et al. (2011) define four following points that vernacular projects satisfy:

-*Local material use* (Indigenous dwellings and settlements are adaptive to their natural environments making use of natural, raw materials)

-*Climate responsive* (Their construction is responsive to local weather and climate conditions)

-*Satisfy socio economical standards* (Traditional societies have been able to successfully keep the equilibrium between population, resources and environment)

-*Adaptability* (Indigenous dwellings can be easily transformed in response to changing conditions)

Alkins too, sees vernacular architecture as an important foundation for the design based on sustainable principles. Lessons and advantages learned from vernacular architecture should be the base to the responsible and sustainable design of the future. Therefore studying vernacular architecture of the place should help spotting all the sustainable aspects and integrate them in the design creating more climate responsive and more sustainable buildings.

If vernacular approach in architectural and building environment brought passive solutions that worked in the past in many different climatological contexts, why would something like that not possible nowadays one could ask.

Following the principles from the past a new 'catalogue' of passive options could be made for the future buildings, options that consider local context and aim to the provide the comfort without using energy intensive means. Therefore studying local materials and climate conditions of Kigali some concrete proposals for the passive strategies can be underlined adapted and applied in future construction projects.

2.8.1 Vernacular architecture in Rwanda

As the vernacular architecture of a place is shaped by the local culture, weather and geographical position these will be discussed more in detail.

The Rwandan climate is tropical, with almost constant temperature and humidity all year long and with exchange of dry and rainy seasons through the year. In this kind of climatic conditions buildings are mostly designed in a way to offer protection from the high solar radiation and heavy rains. Therefore, the vernacular design of the building should mostly be focused on the building roof, as the roof protects from the heat and the rain to enter the building.

Rwanda used to have a rich history of vernacular constructions. Most of them were earth worked with a thatch roofs. ***Rugos*** (typical Rwandan dwellings) and ***Nyakasi*** (traditional huts) (figure 9) are examples of local vernacular architecture in Rwanda. They were built in a circular shape and made out of thatch and reed.

Till few years ago these examples were still to be found in the Rwandan countryside. Due to 'forced modernization' this is not the case anymore. Central government's decision that the thatch roof is not 'modern' enough forced all the owners to replace the existing roofs with metal sheets – solution that protects houses better in case of rain, but does not take into consideration the local climate – under the metal roof it can get very warm during the day. Another negative consequence of this solution is that people cannot repair these roofs by their selves, as it was the case with thatch, which makes it less sustainable solution too.

Examples of vernacular architecture in Rwanda show that the housing was used mostly as a shelter from bad weather and the place to sleep, not the place where one would make a 'comfortable sphere' and enjoy the time with the family. Daily activities of the local populations were related to the work outside in the field, cooking was done outside the houses too.

Figure 9 Nyakasi traditional hut

But vernacular architecture in general shows us the integration of the local materials and local techniques as well. From that perspective, more interesting conclusions related to vernacular architecture would be related to the use of building materials in traditional houses.

Clay constructions were very common in the past in Rwanda. The houses were usually constructed as solid structures with air-dried clay bricks (adobe constructions) or frame structures (wood or bamboo) filled with clay (Weisel 2012). (Figure 10 and Figure 11)

Clay is sustainable material and has great potential on the Rwandan construction market. Clay is still mostly used by the poor population, even though when constructing with clay the whole construction process - from generating clay to recycling it - can be done on site, using little energy and keeping the costs down.

Therefore it is important to improve the image that clay has and to use it for the architectural projects in private and public sector. Using clay in Rwandan context, the local tradition and techniques will be preserved, bringing down the total costs of construction material. Another advantage of building with clay is that it is a labor-intensive process, which generates income to the local people and in the same way helps to grow local economy.

Building with clay, however, has some challenges to meet. In its pure form (with no additives) used for earth building construction clay is very sensitive to water and when water gets on it it looses its strength. To cope with water of rain and flood, stabilizers like cement, lime, gypsum and straw can help stabilizing and reinforcing clay. After performing durability and strength tests on the bricks, results show that increasing cement content will lead to a durable brick but it becomes uneconomical. Same is the case for lime but handling of lime is difficult. Gypsum is durable in case of strength but in rain and flood, it cannot do the service due to its solubility in water. Straw should be used in specific amount. Studies show that reducing or exceeding a certain limit is unfavorable (Alam 2015). The limiting straw amount when combined with cement will serve the purpose up to some extent. On the basis of tests conducted in the study of Alam it could be stated that when 4% cement and 1% straw by weight is used in earth building construction, the resulted structure will show better results in rain and flood and will also be much economical.

Reevaluation of the heritage is a key to developing modern buildings and settlements that respond better to the local environment, and express a distinctive national style and identity. As the prosperity and population increases, the risk is that local sustainable materials and traditional building techniques and approaches could be lost. Therefore it is important to identify and record such built heritage assets before they disappear (Kent 2011).

Figure 10 Timber framed house filled with clay (personally taken photo) Figure 11 Adobe house (personally taken photo)

Recently built sustainable buildings that take care of the local context, socio-economic situations and climate in the whole African continent are not numerous. General knowledge and the awareness about the importance of the sustainable issues in construction practice are missing on different levels – from clients to the technicians, engineers and architects. As a result, there is not enough motivation or clarity to promote the sustainable issues into the local legislations. Consequently, no need or demand exists on the local markets to use any type of construction materials that would influence environmental performance of the local buildings. (Guedes, 2015)

2.9 Bioclimatic design and principles

Yeang (1996) defines the **bioclimatic design** as ‘the passive low-energy design approach that makes use of the ambient energies of the climate of the locality (including the latitude and the ecosystem, through siting, layout and construction) to create conditions of comfort for the users of the building.

In order to follow bioclimatic design principles it is essential to define and understand the climate of the determined location, and to apply the right choices of the passive design techniques.

Bioclimatic approach was already encouraged in building practices back in year 15 BC. In his book ’10 books of architecture’ Vitruvius describes his Tripartite model of Environment in which fabric and form of building mediates between the natural outside environment (climate) and the inside environment (occupant comfort).

Later on, in the 1960’s when technology stated being integral part of buildings, Olgyay created a new model, based on Vitruvius one, in which he discussed and included the influence of technology on buildings as well. In his book Design with climate (1963) states that:

To meet the problem of climate control in an orderly and systematic way requires a pooling of effort by several sciences. The first step is to define the measure and aim of requirements for comfort. For this the answer lies in biology. The next is to review the existing climatic conditions, and this depends on the science of meteorology. Finally, for the attainment of a rational solution, the engineering sciences must be drawn upon. With such help the results may then be synthesized and adapted to architectural expression.

Olygay proposed the following more practical steps in order to achieve this environmental comfort:

1. Study of the building location and its climate (temperature, relative humidity, solar radiation and wind);

2. Define and evaluate the benefits that can be obtained from the location and the climate;

3. Propose a technical solution for possible comfort problems (site orientation, shading devices, building shape, indoor temperature, air movement);

And finally:

4. Integrate previously mentioned steps into the architectural design.

Sustainable design approach embraces bioclimatic approach and goes further than considering of the issues related only to the impact of the building on the local environment. Next to the passive design strategies it considers the total embodied energy of the material and its durability and the use of water and energy.(Maciel, 2007)

In the book Aesthetic of sustainable architecture (2011), Bothwell explains the basic principles of passive environmental design. These principles are related to the **building orientation** (day lighting, natural ventilation), **materials** (building mass) and **envelope** (building form and fabric) with the ultimate aim to create comfort for the building occupants without use of the mechanical devices. He agrees that most of the buildings today use the mix of passive and active measures to create the inside comfort (these buildings are named **mixed mode** or **hybrid buildings**) and to save the energy while maintaining that comfort. Energy efficiency of these buildings will depend on the amount of passive strategies applied.

Passive strategies that can be applied to meet different comfort criteria in buildings can be divided into:

- *Passive solar principles related to cooling*
- *Day lighting design*
- *Passive design related to the ventilation*
- *Passive solar principles related to heating*

Following recommendations for the passive strategies are mostly taken from the book Sun, Wind Light, DeKay and Brown, 2014. First three above mentioned strategies will be further discussed. The last strategy – related to heating will not be further discussed, as it is not relevant in Rwandan context.

- Passive solar principles

Passive solar design can be used for both heating and cooling. When used for heating it deals with optimization of direct and indirect solar gains, thermal energy storage and the reduction of heat losses. When used for cooling it deals with keeping the heat away from building, removing the built-up heat and reducing the the sources that produce the heat. Depending on climatic conditions, adding or reducing the humidity also can be an effective strategy to increase the interior comfort in cooling periods. The basic idea behind passive cooling is to reduce the heat load (from external and internal factors) that building receives during day and to transfer that heat load in some other delayed moments backs to the surroundings. In this way the heat storage within construction elements becomes substantial factor of design.

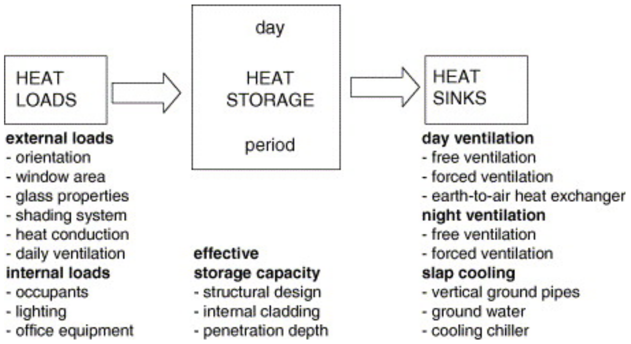


Figure 12 Principles of a passive cooling (Voss, 2007)

Main parameters influencing building energy balance are building heat loads, building heat storage capacity and building heat sinks (Figure 12)

Building heat loads are related to **building orientation**, **sun shading**, **windows size** etc. Studies show direct relation in between building orientation and shape and its energy intensity (figure 13) . With right orientation and shape choice the energy intensity can drop to more than a half values of the original one.

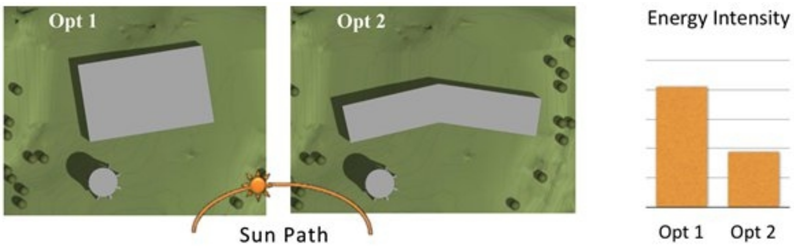


Figure 13 Relation Building - orientations - energy consumption (source http://sustainabilityworkshop.autodesk.com/buildings/building-massing-orientation)

Orientation has further a big impact on the thermal comfort and the daylighting comfort in the spaces adjacent to the façade because of the direct solar radiation. Gratia and De Herde studies show that orientating the building northsouth rather than east-west, reduces significantly both total cooling and heating demand. With positioning of the larger windows on the northern part (or southern part in the south hemisphere) influence the reduction of the cooling demand.
However, some other authors claim that the influence of the building orientation on overheating hours becomes rather small if the solar gains are lower than internal heat gains. Artmann, Manz et al. (2008)
Haase, Buvik et al. (2010) claim that windows on the east and west facades often cause the overheating hours because of the low angle of the sun in these directions.

In order to orientate the building in the most efficient way the daily and seasonal movements of the sun and the wind directions on the building spot need to be studied. Gut et al. (1993) agree that buildings in tropics should be orientated in a way that shade the majority of the walls and windows from the direct sun (south and north façade) while allowing the airflow and the natural light. It is very often the case that the direction of the sun and the wind are corresponding. In that case the wind direction should be redirected in order to enter the building in the right direction (using different solutions – for example vegetation or parapet walls). Another important impact of the orientation is the quantity of the natural light in the building. In order to avoid glare and direct solar radiation openings should be shaded by different shading techniques/devices.

Sun shading

Sun shading devises can be ***vertical, horizontal*** or a ***combination of two***. In the hot humid climates where buildings are situated far away from each other to encourage cross ventilation, a high horizontal shadings (roofs, tree canopies) are extremely effective shading techniques. Horizontal shades provide effective shading on the south façade (north facade in the Southern Hemisphere where Rwanda is) when the altitude is high. The depth of the device determines the lengths of the shadow on the window wall. In figure 15 dimensions/length of roof shading are presented related to their geographical position (latitude)

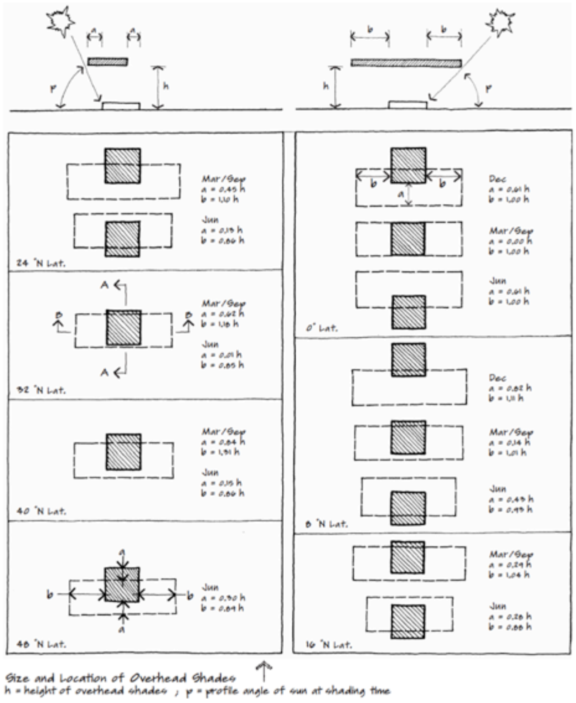


Figure 15 Sun shading (source book Wind Sun Light)

- ***Daylighting design***

The book Sun, Wind, Light (2014) underlines that the daylight design depends on the geometric relationship between building and the sky and that the key factors in day lighting design are room design and room organization. There are 4 main strategies that should be applied on buildings in order to secure the good day lighting design:

- Day lighting zones (activities that require more light should be placed at the edges of the building, closer to the light source; in order to facilitate the design spaces should be grouped according to their daylight needs)
- Day lighting room geometry (room shape should facilitate the light distribution from window to desired point that needs to be day-lighted)
- Glare-free room (importance of avoiding high contrast ratios in a day lighted room)
- Window placement (to make sure that the windows are placed in a way that they admit the light and direct it to reflective surfaces within the room)

Rwanda is situated just below the equator in the southern part of the sky hemisphere. Variation of the sunshine throughout the year is low (Figure 16) , contrary on the regions in high latitude.

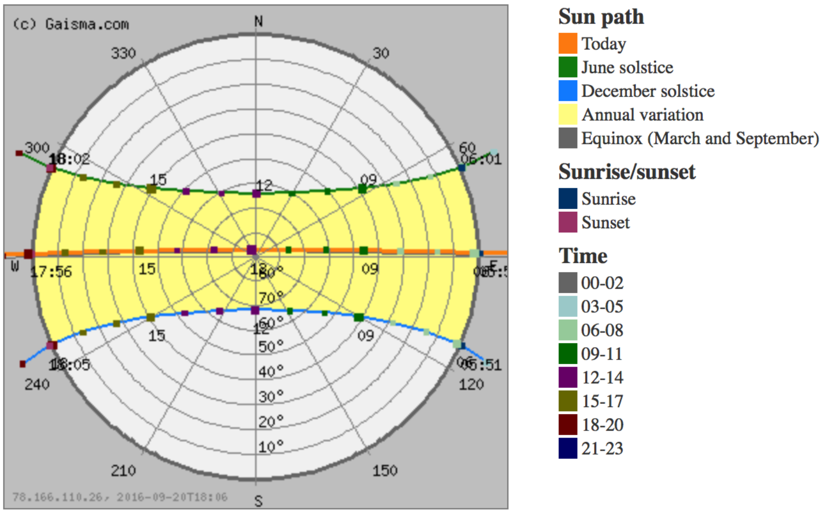


Figure 16 Sunpath diagram Kigali (source www.gaisma.com)

One of the important aspects of the daylight design is to make sure that the inside rooms receive enough daylight and that with the right choice of position, shape and orientation of the windows glare and overheating problems are avoided.

Gratia & De Herde (2003) studied the best design strategies for the low energy buildings in Belgium producing among others recommendations for efficient daylight design. Since the window position has a big influence on the light distribution – they suggest positioning the window high in order to let deeper the natural light into the room enlightening in the same way the bottom of the room.

Dubois and Foldberg (2012) studied the favorable wall to window ratios (WWR) for buildings in high latitudes. They concluded that for the best performance of buildings related to daylight issues, WWR for the south façade should be 20%, for the east and west façade 30% and for the north façade 40%.

Mangkuto et al. (2016) studied favorable wall to window ratios (WWR) for buildings in law latitudes and concluded that WWR of 30% works the most favorable with the wall reflectance of 0.8 and south orientation.

Effects of the sidelight window location and window shape is described is studies by DeKay (2014) as well. (Figure 17)

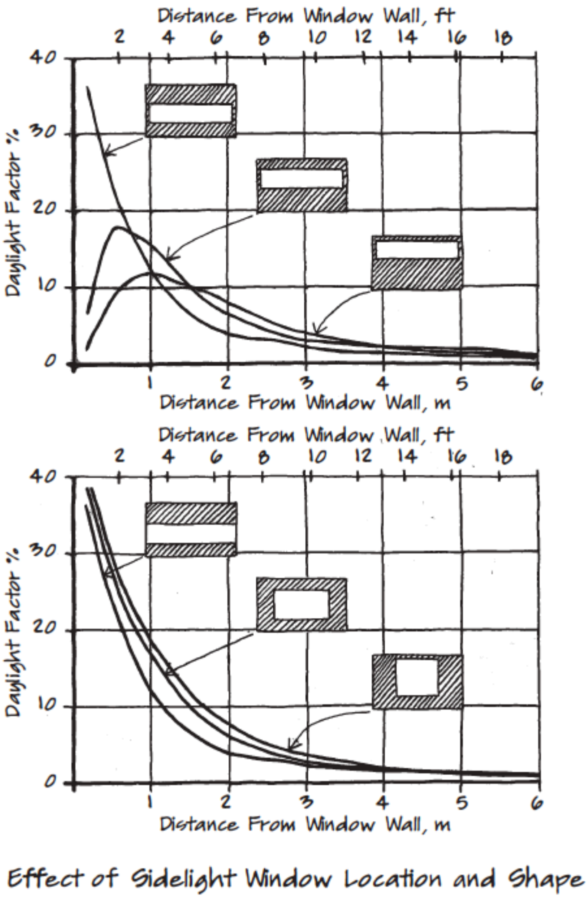


Figure 17 Effects of the sidelight window location and window shape

- **Passive *cooling* systems**:

Passive cooling systems use renewable energy sources (wind) to provide cooling and ventilation that buildings need. Using passive cooling methods high heat gain can be eliminated exchanging warm interior air with exterior cooler air when possible. Several are the strategies that can be applied when designing passive cooling systems. Bioclimatic charts offer some concrete solutions.

Regarding the worlds climate it is known that for hot arid climates more options for passive cooling are available (evaporative cooling towers, night cooled mass rooms, mass arrangements, shady courtyards) while in hot humid climates, like Rwanda has, a natural ventilation should be applied as the primary strategy.

In general, the first step when choosing strategies is to know the rate of the heat gain in certain building. Next to the recommendations obtained by bioclimatic charts there are couple of essential steps to be followed in order to have effective passive cooling in buildings:

1) To reduce drastically cooling loads
2) The remaining cooling load should then be met with good passive design as much as possible
3) Then supplement with mechanical assistance, such as fans or evaporative coolers
4) Then use efficient mechanical cooling systems for any remaining loads

Weather a passive strategy will be effective or not depends on the climates conditions of the place where we build.

Natural and Cross ventilation require lower inside temperatures compered to those outside to be effective. Difference of 5,5°C in inside and outside temperature should be guaranteed for natural and cross ventilations to be applied. Inside temperature can be cooled 5-7°C by the use of ceiling fans for example.

In some climates wind is calm during the day, so the cross ventilation becomes ineffective. In those situation night cool strategies could be a solution – collecting the heat during the day in the building mass and releasing in the night time. But for this solution as well the lower night temperatures and wind are required.

Stack ventilation is solution that assures the constant air move only by design, no matter weather the wind is present on the site or not. The hot air arises naturally (and is released through the higher openings) while cooler air enters through the lower designed openings into the room providing fresh air and constant ventilation.

Thermal storage /Thermal mass

Thermal mass is an essential component of passive design that prevents overheating and reduces big daily temperature variations. In some countries building with thermal mass has recently been made part of building regulations related to the energy use (UK). Designers are free to apply it in their project and to show the benefits the buildings are gaining with it. (Georgopoulos, 2014)

The term thermal mass is related to the material ability to absorb and release heat depending on the environmental conditions. Some authors agree that thermal mass has better influence on cooling energy savings as the cooling peak has daily variations that can be neutralized in more effective way with high thermal mass. (Kalema 2008).

Thermal mass has positive effect on inside thermal comfort during both summer and winter months. In summer month the efficiency of the thermal mass depends on the amount of cooling loads, which depend on many different factors (building design, orientation, insulation levels, climates, ventilation ecc.).(Balaras 1998) Still, even in summer months buildings with high thermal mass (shaded with operable windows) enjoy significantly lower temperatures than the one in the outdoors. (Givoni 1963)

Balaras underlines that materials that can be applied when working with thermal mass should satisfy the following conditions:

- have high specific heat capacity (maximized storage and absorption of heat)
- High density
- Moderate thermal conductivity (so that the time between absorption and release of heat is not too short)

Poured concrete, tiles and bricks are some of the materials that satisfy the mentioned characteristics.

Further on, materials with heavier weight are ideal for heat storage. For cooling with thermal mass - up to double the size of the floor area is needed, so decision where to locate the thermal mass will have a significant impact on design.

The position of thermal mass within the building is important for its effectiveness. South and west sides of the building need some lag in heat transfer (approx. 8 h for office buildings from noon till the evening) Therefore it is important to place the mass on south and west sides. Even though the roof is exposed to the solar radiation constantly through the day and it might seem logic to put the mass on the roof, that would require a very heavy and pricy roof construction. Therefore more economic solution in this case would be to add the extra insulation layers on the roof. (Balaras 1998)

Where weather permits it is the best to combine the thermal mass with night natural ventilation in order to get rid of the accumulated heat.

The challenge of the designer is to calculate the optimum thermal mass of the building and then to distribute it in a way to optimize the fluctuation of the temperature within the building during the working day. Zhou et al. (2008) developed a simple tool to estimate the amount of the thermal mass needed for the naturally ventilated spaces.

The application of thermal mass is most effective when the difference between daily min and max temperature exceeds 10°C. (Balaras 1998) In tropical zones in general passive cooling has a better effect on thermal comfort than thermal mass. In practice there are some well-insulated and shaded thermal mass design that show that even in tropical climates it is possible to design with thermal mass, if it is used properly.

Fluctuation of the temperature between day and night is not so high in Rwanda. Therefore the use of thermal mass is not a preferred option.

Principle Earth Wind Fire

Another passive strategy that can be applied in buildings is a principle of Earth Wind and Fire. Principle Earth Wind Fire is a nearly zero energy ventilation system that uses power of 3 natural forces to create the flow of the air through the building. It is has been proposed by the Dutch engineer Mr.Bronsema who studied the possibilities of refurbishment of many abandoned office buildings that the Netherlands continues to have. Different work and life style reduced the need for the typical office spaces where people would spent all their working hours when flexible offices and home working became more and more popular.

3 are main components of 'Bronsema's' EarthWindFire principle: Ventec roof , climate cascade and the solar chimney. (Figure 18)

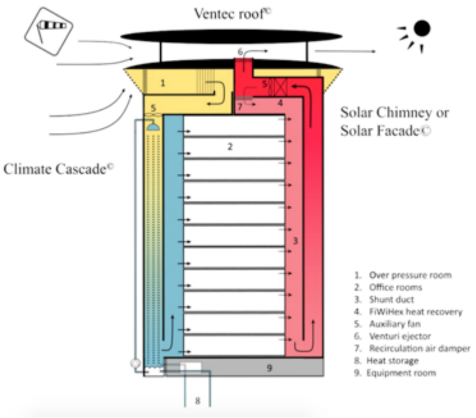


Figure 18 Sun Wind Fire Concept, Bronsema 2013

The whole principle follows couple of steps:

IN the Ventec roof wind is forced to pass through small passage increasing the air speed and creating the overpressure. The wind blows into the overpressure room and from there the air is leaded into the climate cascade. In the climate cascade drops of water cool or warm the air (depending if the air is needed for heating or cooling). Air overpressure is increased by falling water drops and the air is pushed in the shaft adjacent to the climate cascade and then distributed over different floors/rooms. On the sunny side of the building a solar chimney is installed where the air comes to the underpressure because of the heat that is generated in the solar chimney (from solar radiation) This underpressure helps sucking the warm air from the rooms and brings it to the solar chimney. Additional suction in the solar chimney is provided by the Ventec roof.

Principle EWF can also generate energy – using namely: wind power (using the wind turbines in the overpressure room) and the solar radiation (using PV cells on solar chimneys part and the Vantec roof)

To make the whole principle work not only the minimal temperature and pressure differences is needed but also a certain minimum height of the building. Development of the EWF principle is based on buildings with a minimum of 4 stories at 3,5 meters (low rise buildings) which is higher than the height of the EU House. Therefore the efficiency of the EWF principle applied on the EU House might be questionable.

2.10 **Thermal comfort and passive design strategies**

The main goal of each individual building design should be providing comfortable, livable and workable space for its users. To have this, a good thermal comfort is essential. Therefore the thermal comfort goals should be specified before the design stage of each project.

Olgyay (1963) was the first one to define the *comfort zone* in architectural terms, as “the range of environmental conditions within which the average person would feel comfortable”. He did this in graphic form (bioclimatic chart), with Dry Bulb Temperature (DBT) on the vertical axis and Relative Humidity (RH) on the horizontal. Figure bellow shows his original bioclimatic chart.

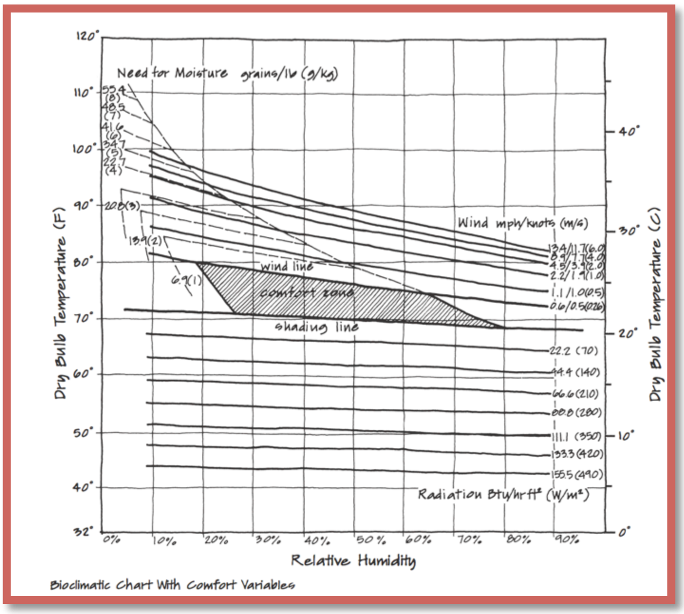


Figure 19 Olgyay’s bioclimatic chart Book sun wind light – electronic part pg E.342

Olgyay's chart (Figure 19) suggests strategies to apply in order to get into the comfort zone once the climate conditions are not favorable. Having air movement with different velocities, the upper limits of the thermal comfort can rise significantly providing needed comfort. On the other hand when the temperatures are lower than comfortable, various levels of radiations can be applied to compensate missing comfort, widening the lower comfort limits in this case. Climatic conditions of the certain location can be plotted on the chart and then analyzed.

Thermal comfort is in general strongly influenced by the conditions of the solar radiance and the wind. In general, good thermal comfort can be achieved using both passive and active design strategies or combining both of them when this is needed. (de Abreu-Harbich, 2015)

Numerous are standards and guidelines used nationally and internationally to evaluate and predict the thermal comfort in buildings. They are usually based on more or less extensive laboratory researches and made for both, naturally ventilated buildings and mechanically ventilated buildings.

Some of the most widely used international standards for thermal comfort within buildings are the American Adaptive model (as a part of ANSI/ASHRAE 55 an American standard that provides minimum requirements for acceptable thermal indoor environments), Fanger's comfort model, the European adaptive comfort model, and the Givoni's Building Bioclimatic Chart (Attia 2015)

American adaptive model can be used for the naturally ventilated buildings when the mean monthly outdoor air temperature stays in range of 10 - 33.5 °C and the European adaptive model can be used for buildings that use no mechanical cooling and have a range of mean temperature in between 10 and 30°C (Attia 2015) Thermal comfort for the mechanically ventilated buildings are usually defined following Fangers model while for the naturally ventilated buildings in hot and tropical climate Givoni's bioclimatic chart is used since the other mentioned models are not applicable in warm tropical area.

Fanger defined the thermal comfort as a function of air temperature, air velocity, humidity, radiation, activity levels and clothing, developing a PMV method (predicted mean vote). Since 1980s this method has been used in wide range of buildings all over the world. PMV method is made for buildings with mechanical - HVAC systems and the studies show that applying this method on non air-conditioned buildings higher thermal sensations are obtained than what the occupants really feel. All standards on thermal comfort basically agree with suggesting the adoption of Fanger's model for mechanically heated and/or cooled buildings (Attia 2015)

As in this thesis the focus is on energy neutrality Fanger model wll not considered.

Olgyay's chart was made keeping in mind the lightweight buildings in humid regions where ventilation is utilized during the day, and the indoor temperatures range is very close to the outdoor temperatures. Unfortunately, the chart is inappropriate for use in hot and dry regions where the indoor temperatures are significantly different from the outdoor temperatures (Givoni, 1976) .

Olgyay's chart served as a base for some further studies. First Givoni (1976) developed a new chart adapted to different types of buildings (not only lightweight buildings but for buildings with more envelope) and later in 1979 Milne and Givoni created a new chart that was proposing different design strategies in one chart in order to reach thermal comfort. (figure 20)

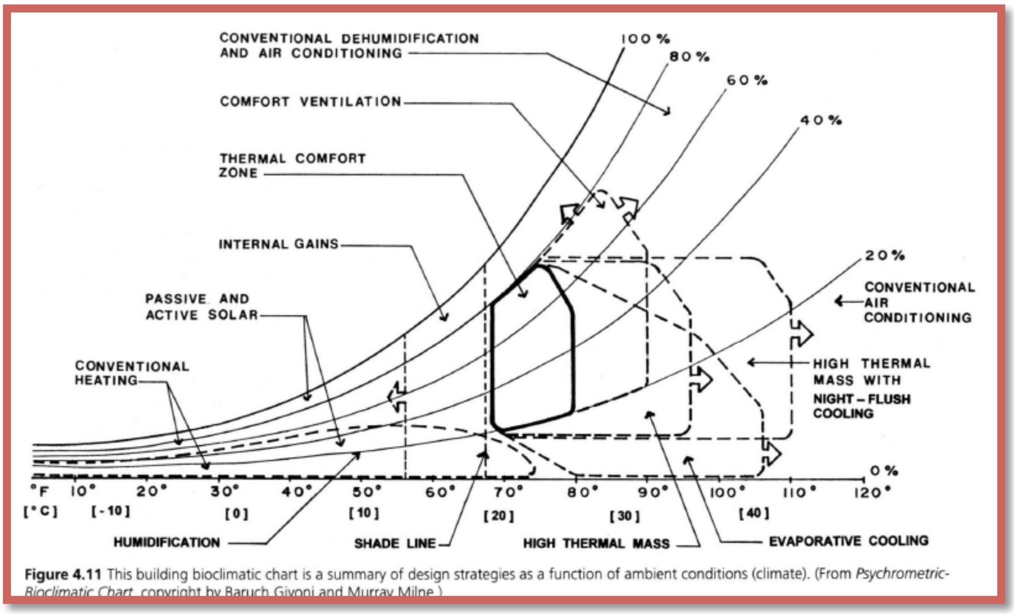


Figure 4.11 This building bioclimatic chart is a summary of design strategies as a function of ambient conditions (climate). (From *Psychrometric-Bioclimatic Chart*, copyright by Baruch Givoni and Murray Milne.)

Figure 20 Givoni Milne bioclimatic chart (from DeKay ,2014)

In order to define comfort limits and design strategies for the EU house both Givoni – Milne chart and Olgyay chart will be used in this research as well.

The Givoni's Building Bioclimatic Chart is not included in any standard, but it is often used in hot and tropical climate where applicability of adaptive models is limited (Attia, 2015)

Next to the mention charts numerous software design tools exist today; one of the interesting that offers graphical presentation and climatic analyses of the certain location is Climate Consultant. This tool offers registered climate data from different world location and shows the best design strategies that should be applied for project on certain location. Unfortunately Kigali is still not on the list of the available cities, but some other cities that have similar climates are. Nairobi for example – quick studies of Nairobi will be done to be compared to Givoni solutions for Kigali.

Mentioned criteria’s for comfort are often based on different studies, database and assumptions and therefore different comfort criteria can give different quantitative numbers. Consequently a most comfortable building according to one certain standard can be marked as less thermally comfortable according to the other standards.

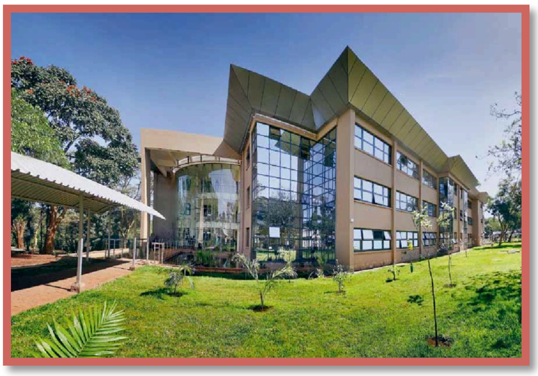
Furthermore, thermal comfort models are for now not included in any national legislation worldwide and their use and application is purely voluntary. In order to have more sustainable and more energy efficient building this should however change. Using thermal comfort models as a pre-requisite in the design phase would bring great energy reduction/sustainable benefits to each individual building project.

3. Case studies

Following case study buildings are chosen because they all focus on sustainable issues and are located in areas with the same or similar climatic conditions that Rwanda has. Furthermore chosen case study projects are all placed in developing countries where the resources are often limited and where certain construction materials are not always available.

3.1 United Nation Headquarters in Kenya

The UN has five headquarters spread over the world. For the one in Kenya, the new building has been built in 2011. UN organizations are, among other things, promoting environmental protection and sustainability. Therefore these issues were also crucial in designing the new headquarters in Nairobi. With this building UN wanted to create the most sustainable and the 'greenest' office building on the African continent in the moment.

Project Name:	***UN Headquarters***
Location	***Nairobi, Kenya***
Climate: ***Subtropical highland climate*** (two rainy, two dry seasons, temperature almost constant through the year)	
Passive strategies	
Orientation	The prevalent orientation of the building is **along east west axis** having long facades orientated north and south
Daylight	The large transparent **atrium** space in between building blocks makes sure that the natural light enters the building during the whole day.
Natural ventilation	Building has **no mechanical ventilation**. Thanks to the building design and the operable windows, the building can act as a **chimney** –where warm air from the office spaces moves upwards and escapes the building through the openings in the atrium.

Active strategies	
PV	750 000 kwh electricity per year with approx. 6000 m2 of PV solar panels
Energy performance	**42, 5 kWh/m^2** of energy per year
Local construction materials	Selected and applied when available in order to avoid excessive emissions caused by transport
BREEAM rate * (calculated by the author)	BREEAM rate – GOOD

3.2 Zero Energy Office (ZEO) building in Malaysia

This Zero Energy Office (ZEO) building is the first self-sufficient office building in Southeast Asia. In its design brief it was specified that the building should achieve zero energy consumption at minimal additional construction costs.

This office building (built in 2007) incorporates both passive and active techniques of sustainable design and uses available renewable sources for energy generation on-site. The area of 4000 m^2 of the ZEO building hosts a research laboratory for sustainable non-domestic buildings in tropics.

Project Name:	**Zero Energy Office Building**
Location	**Bandar Baru Bangi, Malaysia**
Climate : ***Tropical climate***	

Passive strategies	
Orientation	The prevalent orientation of the building is **along east west axis** having long facades orientated north and south
Daylight	High radiation level causes glare and discomfort when daylight enters the office spaces. To deal with it, double glazed windows with integrated blinds have been used in this project. The daylight reflects off an exterior light shelf and through the blinds onto the ceiling and continues further deeper in the office space.
Natural ventilation	No
Active strategies	
PV	building has integrated a PV roof that serves both as power plant (absorbs the sun energy during the day) and cooling tower (in the nighttime the roof is covered by the thin water layer which emits heat from the chiller to the sky radiation and to cool night air by evaporation and convection.
Energy performance	Even though this building uses an air conditioning system, its average annual consumption is estimated to **40 kWh/m^2** which makes is very energy efficient.
Local construction materials	-
BREEAM rate * (calculated by the autor)	BREEAM rate – GOOD

3.3 East Gate Centre office building in Zimbabwe

East Gate Centre is one of the first examples of sustainable office buildings on the African continent. This 5000 m2 building for mixed use as shopping center and office building is designed by the Zimbabwean architect Mick Pearce and was opened in 1996.

In order to satisfy the developer’s wish to have a building with only passive climate control system, the architect was studying possible passive systems and was surprised when he discovered how the local termites control the climate within their mounds. Even though the outside temperature in Harare can fluctuate from very low to very high within one day, the termites, thanks to the stack affect techniques, manage to keep the constant temperature within their mounds. Inspired by this example the architect applied the same principle for the climate control within East Gate Centre, with positive results. This building is an interesting example of biomimicrity – or how effective design solutions can be found just by following the principles from the local nature.

Project Name:	***East Gate Centre office building***
Location	***Harare Zimbabwe***
Climate : ***Tropical***	
Passive strategies	
Orientation	The building is orientated in the way that two short sides of the facades face east and west respectively. Two long facades where the offices have been placed face south and north. In this way the offices stays unexposed to the direct sunlight through the whole year, which influences the climate comfort in the building and provides lower temperatures during the day in the office area. Having long facades facing north and south is the preferred position for office buildings in the tropics.
Daylight	The large transparent **atrium** space in between building blocks makes sure that the natural light enters the building during the whole day.
Natural ventilation	The system of natural ventilation that this building has is based on the principle of African termite mounds. Termites build enormous mounds where they grow fungus as their food. Temperature in the mound needs to be constant (around 30 degrees) in order to have fungus growing. This is achieved by constantly opening and closing of a series of cooling and heating vents, done by termites. The air goes in the lower parts of the mound and comes back up through the channel to the top of the mound. The East Gate Centre's ventilation system follows the same principle. Air is drawn from the outside and is warmed or cooled by the building mass. Before it is

	disposed of through the big chimneys on the roof, the air is vented through the concrete building's floor.
Active strategies	
PV	No
Energy performance	35 percent less energy than comparable conventional buildings in Harare
Local construction materials	Thermal storage is a very important issue in a climate like the Zimbabwean. That is why it is important to choose materials with a good thermal mass that can absorb the heat during the day. For the construction of the East Gate Centre cast in situ concrete is used in combination with double thickness bricks. In this way the heat is absorbed and stored during the day in the building mass and a constant temperature is provided during the office hours. Thanks to the natural ventilation techniques, heat is released from the building envelope during the nighttime.
BREEAM rate * (calculated by the autor)	BREEAM rate – GOOD

3.4 Existing sustainable projects in Rwanda

The following three buildings are recent examples of existing sustainable projects in Rwanda. They are mentioned in this context to show what can be realistically expected in Rwanda. Each of these projects has a different character and the aim is not to compare them, but to highlight their design choices regarding sustainability.

3.4.1 Hospital in Butaro, Rwanda

Butaro hospital (figure 21) covers approximately 6000 m2 and serves as the biggest medical center in Butaro region in the northern part of Rwanda. This project brought great benefits to the local community, training more than 2000 people new construction skills that they can benefit from and apply in future projects they will work on.

Figure 21 Images of Butaro hospital (source google)

Materials used for the construction are all local low-impact materials. They are used mostly to create compressed-earth blocks (CEB) made on site, using excavated soil in combination with small amounts of cement.

Considering the fact that this project lies in a seismically active zone, the CEB needed to be supported with a structural reinforcement too. Both retaining walls and walls of the façade have been cladded in volcanic stone (available from the surrounding volcano region) using little mortar and creating a very nice aesthetical effect.

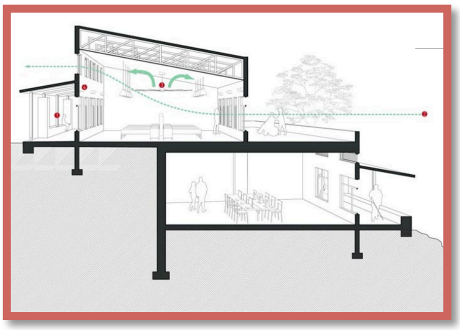


Figure 22 Cross ventilation principle (source google)

The project integrates some of the strategies of bioclimatic passive design: day lighting and natural ventilation.

In order to bring more daylight in the hospital extra skylights are used and the techniques of cross ventilations have been applied to the design. Still some large fans are installed in every ward and outdoor waiting space. (Figure 22)

3.4.2 Educational Centre in Nyanze, Rwanda

The total area of the project of the educational centre in Nyanze, in the central part of the country, occupies approximately around 5500 m2.

Figure 23 Images of Educational Centre in Nyanze (source google)

Inspired by the vernacular architectural forms of early Rwandan dwellings with closed courtyards, the project assumes a similar form, having outside walls completely closed with only ventilation openings and with all the rooms inward facing the central courtyard. (Figure 23 and Figure 24)

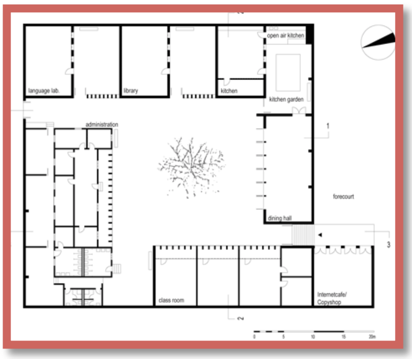


Figure 24 Floor plan Educational Centre in Nyanze (source google)

The three traditional building materials that are used through the whole project are: clay bricks, wickerwork and steel.

Clay bricks dominate as building material as over half million of hand made bricks are used to build floors, walls and columns. The manual firing process made each brick unique in color which creates a special aesthetic effect on each wall. Sheets of papyrus are made to construct the ceilings and local basket makers contributed in making doors using the wickerwork within steel frames.

Passive techniques incorporated in this project involve day lighting and natural ventilation as well. To facilitate natural ventilation gaps have been created in the brickwork all over the project.

Two other sustainable aspects that this project offers are related to the rainwater collection and involvement of the local community/craftsmen into the construction process.

3.4.3 Woman's opportunity center, Kayonza, Rwanda

Figure 25 Images of woman opportunity canter

The Woman's Opportunity Center, build to help women to grow and develop their farming and processing product skills, is located in the eastern part of the country.

The circular form of the project is inspired by vernacular building forms that Rwanda used to have. In this project, two local building materials dominate – half a million-clay bricks are hand made on the location and are used in combination with traditional Rwandan stonewalls to create several classrooms. (Figure 25) Classrooms are covered with corrugated metal roofs – the cleanest material that could be used for gathering and collection of the rainwater. The elliptical form of the roof is a product of study of annual solar coverage of the location. (Figure 26)

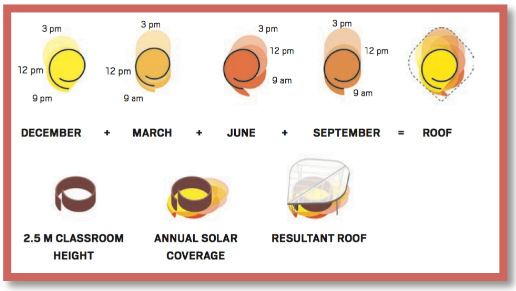


Figure 26 Annual solar study woman opportunity centre (source google)

Passive strategies used in the project are related to passive shading and cooling. Cooling is assured by the perforation in the brick walls. Another element responsible for shading and cooling is the elliptical metal roof which does not lean directly on the round wall structure and in this way all the heat collected on the roof does not go directly into the classrooms but gets dissipated creating comfortable temperature within classrooms.

3.5 Conclusions from the case studies

The focus of all three selected buildings was on reduction of energy use. The results show that all three projects have reduced energy consumption by considering climatic conditions of the locations and by applying bioclimatic principles. Furthermore all three projects integrate the day lighting in their design, creating healthier working environment and reducing the overall energy costs.

The examples of UN HQ and East Gate Center show how the local climate directly the influenced building design (for UN HQ long narrow floor plans are introduced to allow the natural cross ventilation and in the East Gate Centre natural cooling system inspired by the termite's methods influenced the chimney roof design).

East Gate uses no technologies to profit from the renewable energy sources. It is only by design decisions that its energy consumption is lowered by 30% compared to similar project on the same location. The other two mentioned projects integrate active strategies in order to profit more from the renewable sources - The ZEO project integrates different technological solutions (solar panels used for the energy production, harvest water on the roof used for cooling of the roof), while UN HQ applies only solar panels to satisfy the energy need of the whole building.

From the three mentioned projects UN HQ is the only project that both actively focuses on a life cycle assessment and considers the importance of the use of local construction material as well.

Further energy reduction in UN HQ and the ZEO building is obtained by introducing smart solutions in the IT sector and energy efficient office equipment and lighting. Both UN HQ and the ZEO building collect rainwater and reuse it – the UN HQ for the landscaping and the ZEO building as a part of the cooling roof process.

In conclusion, huge benefits of the integration of passive strategies can be seen on the proposed examples, especially on the UN HQ project in Nairobi and East Gate Centre project in Harare. The ZEO project is a great example that shows that even with different advanced technological solutions, energy consumption of an office building can be kept low. However, the aim of the European House is to create a pleasant thermal comfort for its occupants by applying as much as possible only passive strategies and locally available construction materials.

Furthermore, existing projects in Rwanda (3 mentioned earlier in this chapter) show that some small steps are being made on the road to more sustainable design solutions in local projects. These are however smaller projects, mainly one floor high. Still, they introduce the use of alternative local materials (not for structural purpose) and the involvement of the local people in the construction process. For both the use of local materials and the involvement of local people, I see great opportunities in the European House project as well.

4. Background on Rwanda and project boundaries

4.1 Rwanda – geographical position, population

As passive strategies are closely bonded to the climate of the building location, climate analysis study is essential part of every low energy-building project. Geographically Rwanda is located very close to the equator, in the heart of African continent (Figure 27). Its capital Kigali is situated on latitude of 1°57'S, and longitude of 30°7'E. Rwanda is known as 'the country of thousand hills' as hills and mountains occupy most of its territory. The country has no direct access to the sea. Its direct neighbor countries are: Democratic Republic of Congo (DRC), Tanzania, Burundi and Uganda. (Figure 28)

Figure 27 Rwanda geographical position

Figure 28 Rwanda and neighboring countries

With its surface of 26 338 km^2 it is the 149th largest country in the World (slightly more than half size of the Netherlands). Its population was estimated to be 12 million in 2013, which makes it among the most densely, populated countries of Africa (CIA world fact book 2013).

Even though Rwanda is located only two degrees south of the equator, its temperature (annual average of 22°C) and rainfalls (annual average of 904mm) are more moderate compared to the other equatorial regions thanks to its high altitude, which ranges from 950 - 4500m above sea level. Altitude of Kigali is 1497 m (UN Habitat 2009).

According to the Koeppen (Figure 29) (who divides climatic zones on Earth in 5 big groups, namely - tropical, dry, temperate, cold and polar, based on temperature and precipitation volumes) Rwanda enters in the (pleasant) tropical savanna climate group with two dry and two rainy seasons present through the year, with hottest months August and September. (Figure) During the rainy seasons (from February to April and November to January) heavy rain occurs daily, alternating with the sunny weather (CIA world fact book 2013).

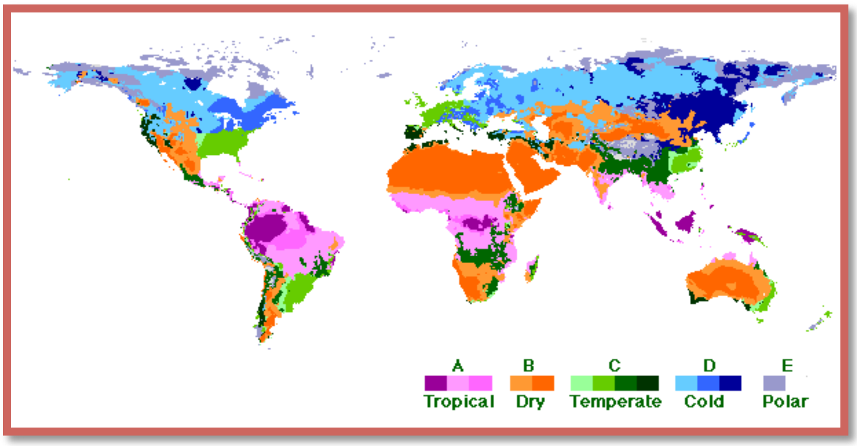


Figure 29 Major climatic zones (Koeppen)

Pleasant climate (of Kigali city in particular) makes Kigali an ideal location for the application of several passive design strategies.

4.2 Temperature

Kigali has stable air temperatures throughout the year, with daily min of 15 and max of 28 degrees Celsius. (Figure 30) Average year temperature in Kigali is very comfortable and measures around 21 degrees Celsius with a small diurnal air temperature range. With this temperature range cooling strategies become the only challenge to consider in passive building design.

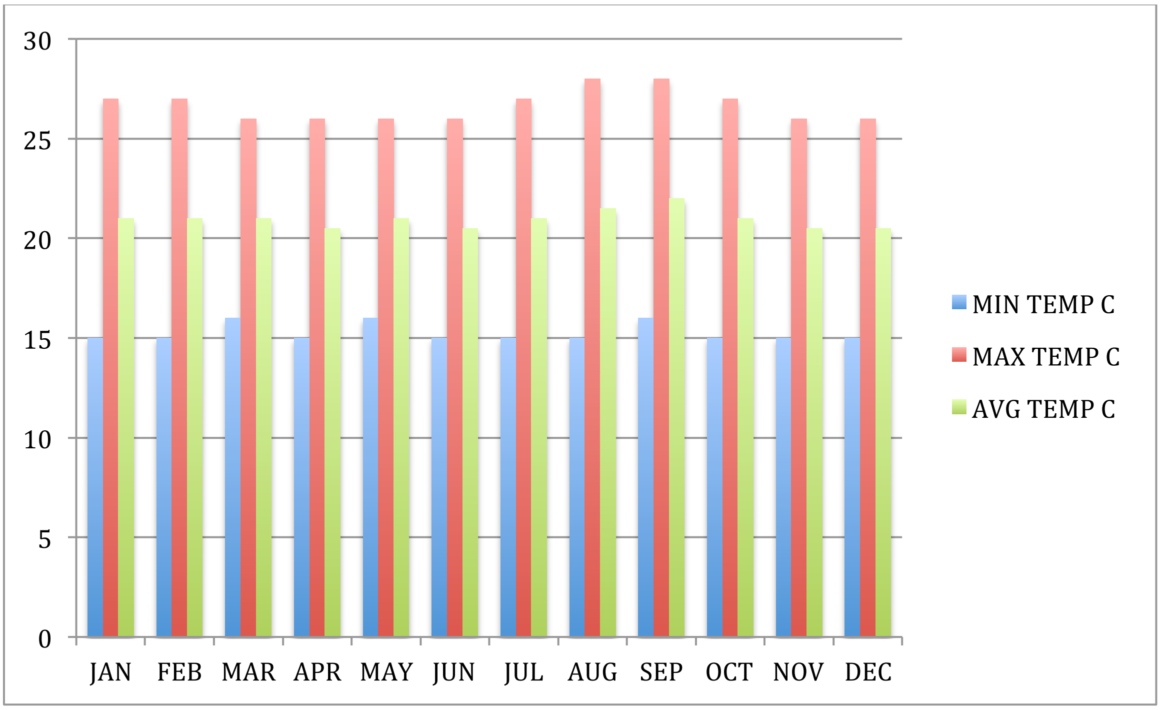
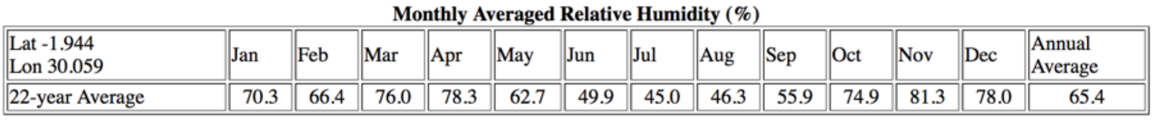


Figure 30 Min, Max and Mean daily temperatures, Kigali

4.3 Relative Humidity

Relative humidity of Kigali is in general not so high - it reaches its highest levels during rainy months (up to 81% in November) and its lowest levels in dry months (lowest in July 45%) (NASA, 2016) (Figure 31)



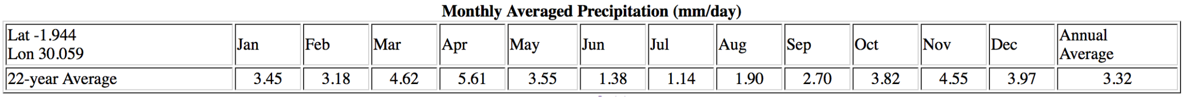
Monthly Averaged Relative Humidity (%)

Lat -1.944 Lon 30.059	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	70.3	66.4	76.0	78.3	62.7	49.9	45.0	46.3	55.9	74.9	81.3	78.0	65.4

Figure 31 Monthly averaged relative humidity – taken from http://eosweb.larc.nasa.gov/sse/

4.4 Precipitation

Monthly averaged Precipitation in Kigali is 3,32 mm/day, around 1028 mm year (NASA, 2016) (Figure 32)



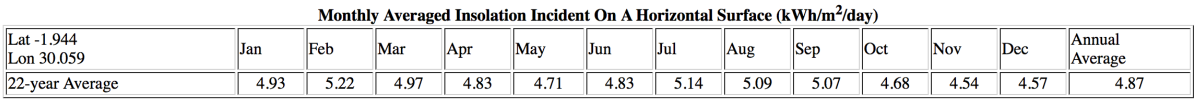
Monthly Averaged Precipitation (mm/day)

Lat -1.944 Lon 30.059	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	3.45	3.18	4.62	5.61	3.55	1.38	1.14	1.90	2.70	3.82	4.55	3.97	3.32

Figure 32 Monthly averaged relative humidity – taken from http://eosweb.larc.nasa.gov/sse/

4.5 Solar radiation

Figure 33 shows monthly averaged insolation rate of 4,87 kWh/m^2/day.



Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m^2/day)

Lat -1.944 Lon 30.059	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	4.93	5.22	4.97	4.83	4.71	4.83	5.14	5.09	5.07	4.68	4.54	4.57	4.87

Figure 33 Monthly averaged insolation rate – taken from http://eosweb.larc.nasa.gov/sse/

4.6 Wind

No detailed and reliable study about the wind energy in Rwanda has ever been done. Based on the data from a period of 20 years, Safari & Gasore (2009) studied the wind potentials in 5 bigger cities of Rwanda. They concluded that the windy season usually overlaps with the rainy season (November – January; February – April). Exception is the west of the country where more wind is present during the dry season (July – September). From the wind roses it can be seen that the prevalent direction of the wind is south and southeast and that averaged annual wind speed is about 4m/s. (Figure 33-1 and Figure 33-2) Intensity and direction of the wind during the dry season are again prevailing from the south (with the exception of September, where dominant registered direction is north west)

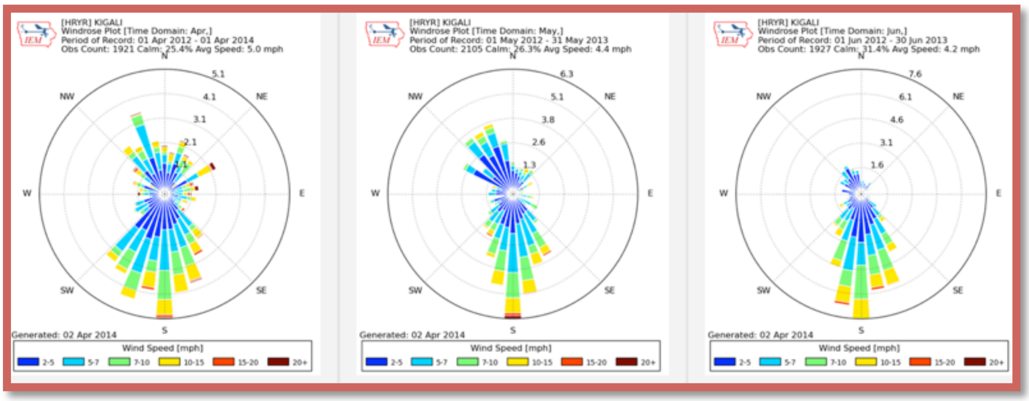


Figure 33-1 Wind rose data for Kigali - source IEM website

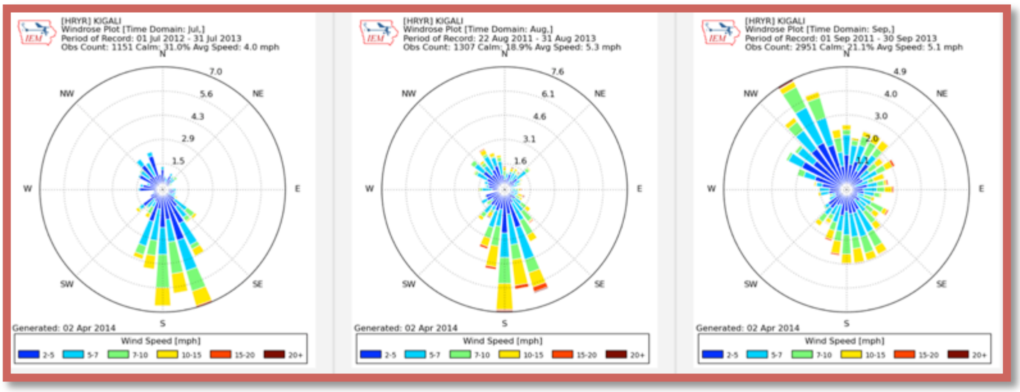


Figure 33-2 Wind rose data for Kigali - source IEM website

Data taken from NASA website show lower values ormonthly average wind speed for Kigali (3 m/s)

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

Lat -1.944 Lon 30.059	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	2.87	2.97	2.75	2.77	3.31	3.89	3.60	3.44	2.99	2.65	2.50	2.37	3.00

4.7 Kigali comfort zone

Kigali's comfort zone was studied using Olgyay and Givoni's bioclimatic charts. Thanks to the very favorable temperature and humidity conditions, Kigali climate offers most of the time a very good thermal comfort. From Olgyays chart (Figure 34) it results that the comfort zone often needs to be expended and adopted by introducing the air movement of up to 2 m/s. This air movement is to be obtained by applying the natural ventilation strategies into the design choices.

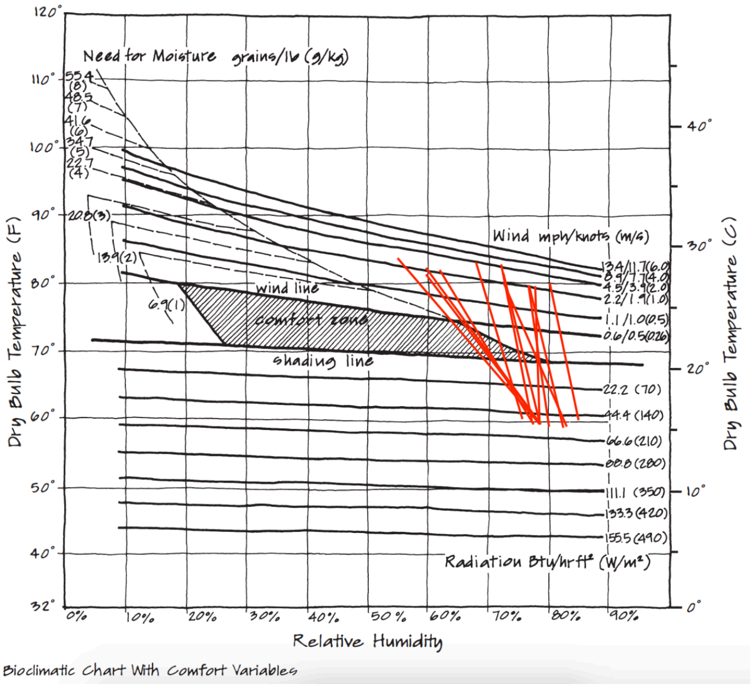


Figure 34 Olgyays chart for Kigali

Givoni's chart suggests the introduction of comfort ventilation in order to retain the thermal comfort zone in good limit. (Out of this analysis introduction of high thermal mass in constructions in Kigali comes as an option as well, but as this applies for only one month a year, high thermal mass will not be further considered as possible design strategy) (Figure 35)

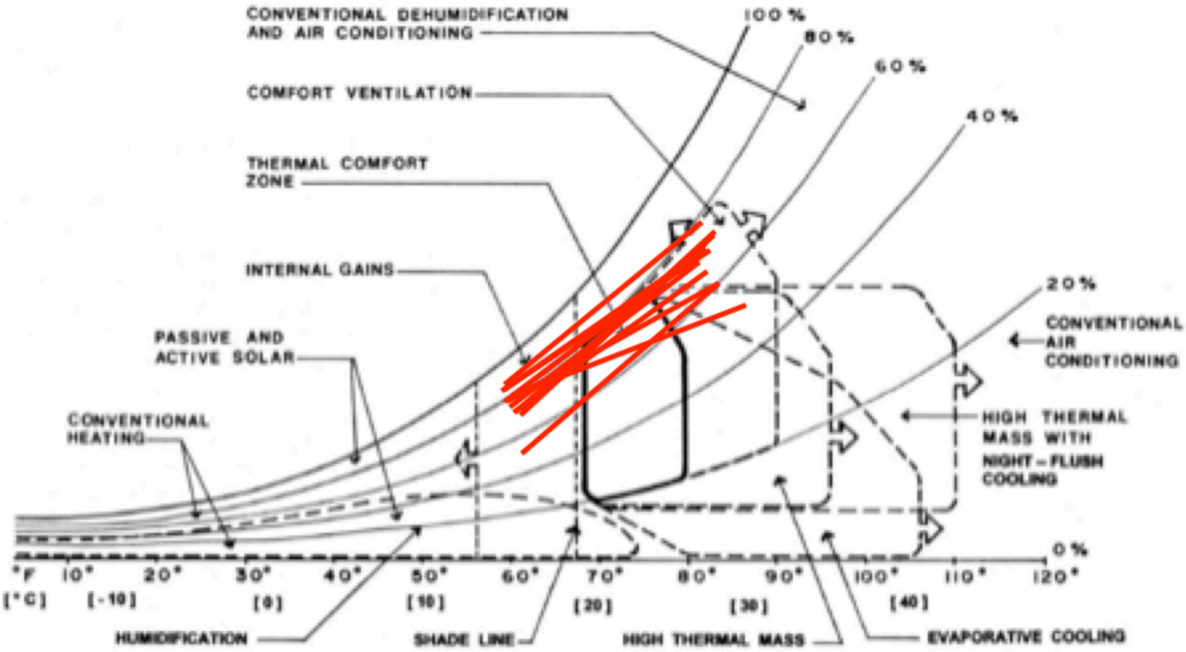


Figure 35 Givoni's chart for Kigali

Using Climate Consultant design tool for the city of Nairobi (climate conditions very close to Kigali) similar conclusions have been drawn (in order to reach thermal comfort, natural ventilation strategies need to be applied on the building design) Psychometric chart from Climate Consultant tool is presented in following figure:

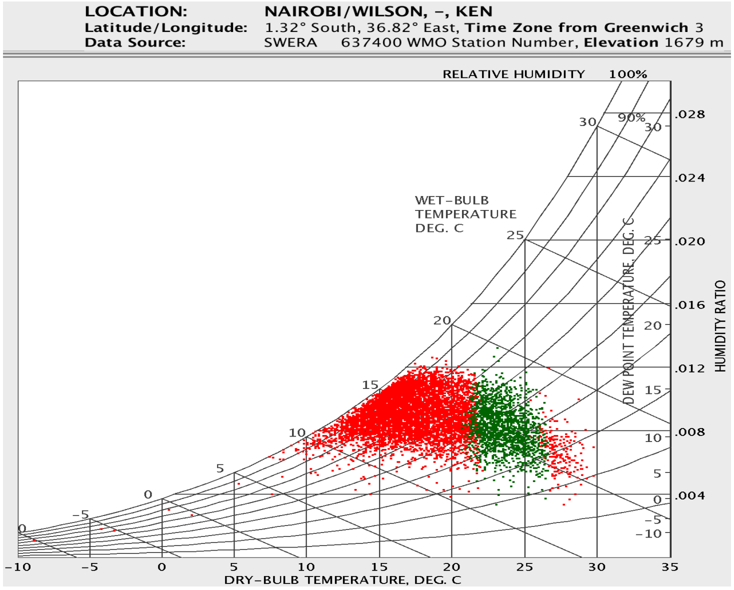


Figure 36 Climate Consultant Chart for Nairobi (comparable to Kigali's climate)

Furthermore, the recommendations that Climate Consultant tool has for the design of buildings in Kigali -like climate are related mainly to the use of solar shading to protect buildings from direct solar light and to the introduction of natural ventilation to assure satisfying levels of comfort.

4.8. Kigali Master Plan

As the capital of one of the most densely populated countries in Africa, Kigali sits at the center of intense rural-urban migration. The population and build-up area inside of Kigali increased enormously in the last 60 years, as the following images illustrate. (Figure 37)

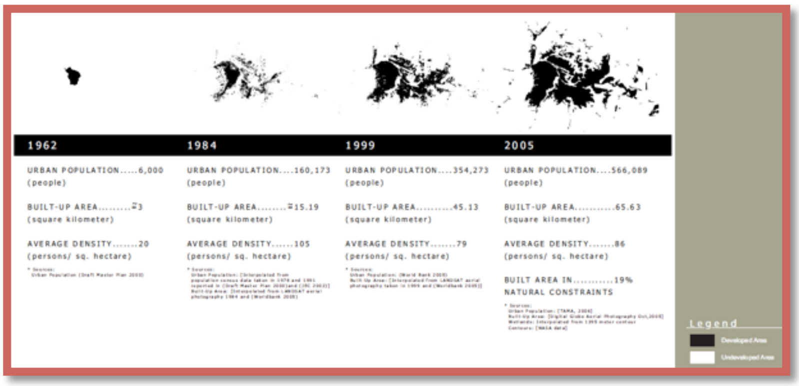


Figure 37 Kigali city expansions (source Kigali Master Plan 2007)

People are increasingly attracted to the opportunities of the capital. Rwandan authorities foresee an ongoing expansion of Kigali, and are planning to accommodate another 2-3 million people in the coming 100 years. In order to manage this expansion, the Kigali Master Plan has been developed.

The Kigali Master Plan highlights the basic needs and livability of the city for its citizens: adequate housing, education and workplace opportunities, infrastructure and transport, healthcare and services, and quality of life.

Under the Kigali Master Plan, Rwandan authorities envision to develop an urban structure that helps expand its economy by supporting internal entrepreneurship as well as attracting international business, industry, and service investment. At the same time, it must provide for the existing and future population growth that will occur; sustainable and well planned ways to address both the urban structures of economic development and social settlement.

Environmental sustainability plays a prominent role in the development of the Kigali Master Plan. In the words of the municipality of Kigali: “The vision is to create a city set in a greenbelt/urban agricultural framework that celebrates the country’s rural/ agricultural heritage, while accommodating the new urban opportunities of an emerging modern 21st century Rwandan population.”

By focusing on social and environmental sustainability, this plan intends to create long term economic viability in a way that contrasts with the development of most urban centers in the developing world. The Kigali Master Plan is predicated on a Rwandan economic development strategy that emphasizes light and clean industry, entrepreneurial innovation and vitality in the service economy, and high technology in medicine, education, and communications.

The City of Kigali will provide the structure for these uses, including the New City Center as a center of national political and administrative activity, healthcare, research and education, and commercial/retail uses. Other new areas of Kigali will be developed by clustering uses at many scales ranging from co-housing, to community centers, neighborhoods and urban centers. One of the new clusters to be developed is a diplomatic hub, to be located in Gasabo district.

4.9. Planned location of the European House: Gasabo district

According to the Gasabo District detailed Master plan, the population of Gasabo, in the northern part of Kigali, is larger as compared to the other districts. Approximately 400.000 people, or 40 percent of the total population of Kigali, reside in this district. However, large parts of Gasabo are not developed and have many natural features such as hills, forests, wetlands and watershed. These areas are also being utilized for agricultural purposes. The wetlands enjoy environmental protection from the authorities.

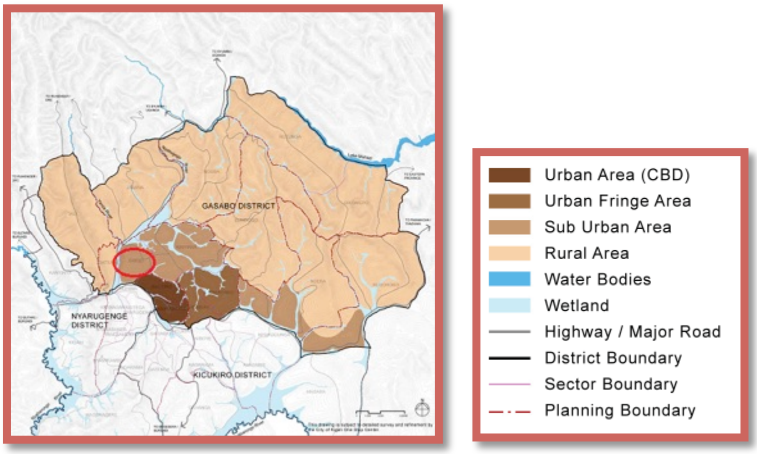


Figure 38 Gasabo district – existing land urbanization plan (source Gasabo district detailed master plan 2012)

Rural Gasabo has mostly unpaved roads, which are sparsely connected with steep terrain that is not suitable for large scale urban development.

The urban sectors of Gasabo - Kacyiru, Kimihurura and Kimironko – all have an extensive road network of both paved and unpaved roads. As urbanization of Kigali becomes more rapid, the urban sectors of Gasabo are facing more development pressure due to their good connectivity and location with respect to the employment centers of the city. The development pressure in Gasabo District is visible from the large number of residential projects approved within the district. The approved projects occupy large areas of relatively flat developable land and are characterized by their relatively low density. This is a major constraint since the city needs to develop higher density developments within core areas of district.

The diplomatic hub is foreseen to be built in Gisozi area of Gasabo district (Red circled in the figure 38, close up of the area with land use plan in the figure 39).

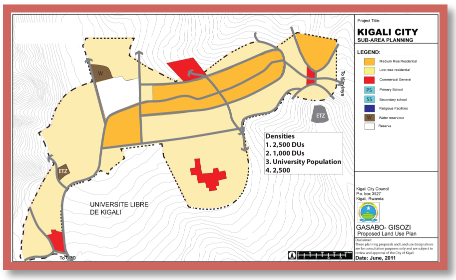


Figure 39 Proposed land-use plan Gisozi (Gisozi Master Plan&Zoning 2011)

According to the Gisozi detailed Master plan, diplomatic plots (colored purple in the figure 5) are situated in the central part of the area and occupy approx 32 ha. The whole diplomatic area is divided in several plots as it is planned to host both, offices and residences for diplomats. The European House plot is red circled in the figure (approx 3ha). The plot is gently sloped with the great view over the city (Figure 40).

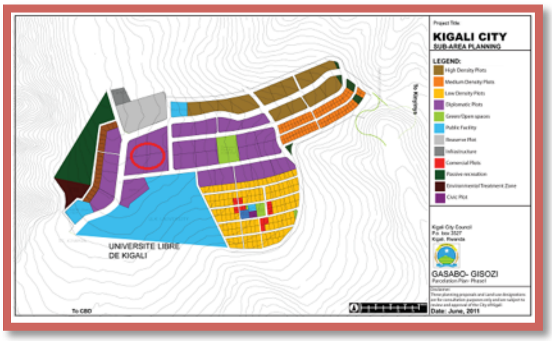


Figure 40 Proposed parcelation plan (source Gisozi Master Plan&Zoning 2011)

Figure 41 Current situation of the building plot for the EU house

Parts of the building plot where the European house will be built are currently populated and it is the intention of the government of Rwanda to buy occupied land and to resell it later to the interested embassies. (Figure 41)

4.10. (Sustainable) Construction materials locally available in Rwanda

Population growth influence urbanization growth and need for housing in Rwanda. Constant growing demand for the construction material allows local construction material manufactures to set higher prices for their products that sometimes grow even double the price that same products have in the neighboring countries. Recent tax add to the imported building materials does not help in finding an alternative to the high local prices and makes the construction costs even higher.

Passing through the Rwandan countryside one can notices that the local houses are almost exclusively made out of earthen materials made out of mud right at the construction site and then sundried, to later be used for the construction of the simple low cost housing. These simplest housing structures are the most environmentally friendly ones whose costs and embodied energy are very low compared to the more sophisticated construction materials like concrete masonry and fired bricks. Soil blocks, stone masonry and bricks are in general the most sustainable building materials in Rwanda and they are usually found on the site or locally. The overall quality of all mentioned materials is questionable though, as no standards or quality control institutions exist in Rwanda. (Rollins, 2006).

Adobe brick is the simplest form of a construction material that exist – it uses the earth, water and the straw. Brick making in Rwanda is still dominantly hand made using the earth directly from or very close by the building site. The earth is mixed with water and the staw, put in molds and dried on sun to later be directly used for construction.

Modern form of adobe brick is the (compressed) earth block. These blocks are usually made of adobe or as a compressed earth blocks (**CEB**). Blocks made manually are used for construction of smaller low cost houses, while the once made with powered machines offer better quality and are used for institutional or commercial constructions. CEB are usually stabilized with cement or lime to gain higher strengths and better performance.

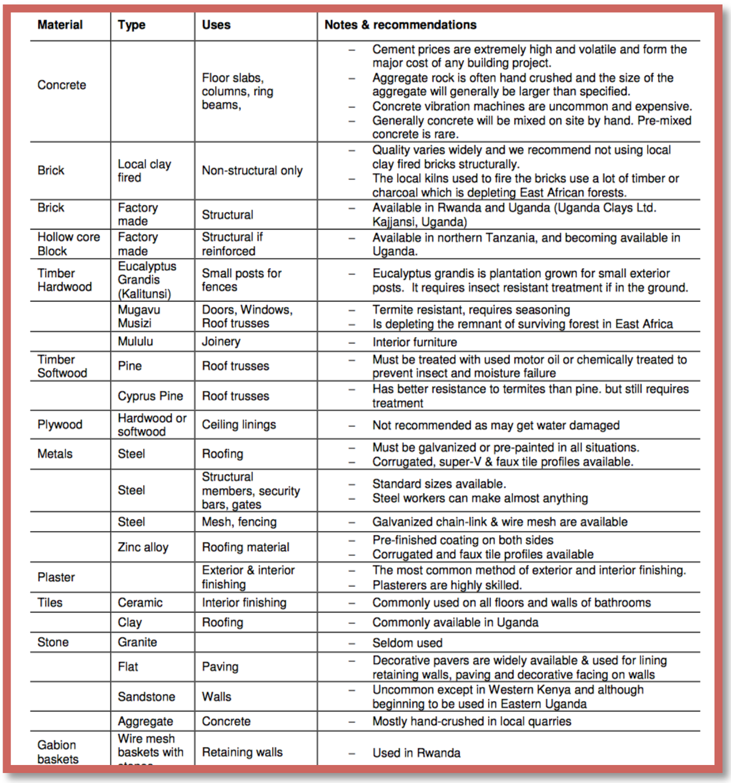
Other material that is locally available is **stone**. Usually, masons are available near stone deposits, but construction skill can vary. Stone is mostly used for the foundations. Cost of stone transportation can be very high if the material is not local.

Terracotta tiles – are locally made of baked clay and are usually used to cover the roofs. They are done on the spot and have usually satisfactory quality.

Eucalyptus is locally available and used often for the roof constructions of simple single houses.

The design guideline for the East African region (that includes Rwanda as well) makes some recommendation about proper use of locally available construction materials. (Figure 42)

These guidelines recommend in the moment the use of **concrete as the** safest choice for the structure, even though the price of cement is very high. Further on it should be kept in mind that aggregate rocks are often crushed by hand offering different sizes than specified which influences the quality of the concrete. Concrete is mixed on site by hand and using pre-mixed concrete is rare which makes the quality of the concrete questionable.



Material	Type	Uses	Notes & recommendations
Concrete		Floor slabs, columns, ring beams,	– Cement prices are extremely high and volatile and form the major cost of any building project. – Aggregate rock is often hand crushed and the size of the aggregate will generally be larger than specified. – Concrete vibration machines are uncommon and expensive. – Generally concrete will be mixed on site by hand. Pre-mixed concrete is rare.
Brick	Local clay fired	Non-structural only	– Quality varies widely and we recommend not using local clay fired bricks structurally. – The local kilns used to fire the bricks use a lot of timber or charcoal which is depleting East African forests.
Brick	Factory made	Structural	– Available in Rwanda and Uganda (Uganda Clays Ltd. Kajjansi, Uganda)
Hollow core Block	Factory made	Structural if reinforced	– Available in northern Tanzania, and becoming available in Uganda.
Timber Hardwood	Eucalyptus Grandis (Kalitunsi)	Small posts for fences	– Eucalyptus grandis is plantation grown for small exterior posts. It requires insect resistant treatment if in the ground.
	Mugavu Musizi	Doors, Windows, Roof trusses	– Termite resistant, requires seasoning – Is depleting the remnant of surviving forest in East Africa
	Mululu	Joinery	– Interior furniture
Timber Softwood	Pine	Roof trusses	– Must be treated with used motor oil or chemically treated to prevent insect and moisture failure
	Cyprus Pine	Roof trusses	– Has better resistance to termites than pine. but still requires treatment
Plywood	Hardwood or softwood	Ceiling linings	– Not recommended as may get water damaged
Metals	Steel	Roofing	– Must be galvanized or pre-painted in all situations. – Corrugated, super-V & faux tile profiles available.
	Steel	Structural members, security bars, gates	– Standard sizes available. – Steel workers can make almost anything
	Steel	Mesh, fencing	– Galvanized chain-link & wire mesh are available
	Zinc alloy	Roofing material	– Pre-finished coating on both sides – Corrugated and faux tile profiles available
Plaster		Exterior & interior finishing	– The most common method of exterior and interior finishing. – Plasterers are highly skilled.
Tiles	Ceramic	Interior finishing	– Commonly used on all floors and walls of bathrooms
	Clay	Roofing	– Commonly available in Uganda
Stone	Granite		– Seldom used
	Flat	Paving	– Decorative pavers are widely available & used for lining retaining walls, paving and decorative facing on walls
	Sandstone	Walls	– Uncommon except in Western Kenya and although beginning to be used in Eastern Uganda
	Aggregate	Concrete	– Mostly hand-crushed in local quarries
Gabion baskets	Wire mesh baskets with	Retaining walls	– Used in Rwanda

Figure 42 Some of the recommendations for material use in the East Africa Region (source Architectural Design Guide - EMI East Africa)

Over the past years however, there has been an intense research on possibilities of use of the local Rwandan timber for building construction. A first ever entirely timber project is in the moment on going in Kigali – the project that combines the glue-laminated eucalyptus and Strawtec compressed straw panels for the construction of a 5-store restaurant in the center of Kigali. Few other projects have looked into the use of the eucalyptus and dried local exotic timber Grevalia (known as silky oak in Australia) for joinery and flooring.

The use of structural timber – using carefully sourced eucalyptus – is a viable solution for building for all building types, especially housing, so it is expected that the structural timber becomes a serious alternative to predominately concrete built environment in the future.

In this thesis I will focus mainly on the possibility of use of simple (sawn) timber for the structural purposes. Neighboring Congo is extremely rich in different types of structural timber and therefore this option becomes even more interesting.

4.11. Rwandan (building) regulations

There are two important documents in Rwandan regulations regarding sustainability and energy efficiency in buildings. In discussed assessment methods from chapter 3, energy and sustainability issues are examined within the same assessment while in Rwandan regulations these two issues are separated.

One document is the ***Environmental Impact Assessment*** (EIA) and focuses on evaluation of a project to determine its impact on the environment and natural recourses. The other document is ***Building control regulation*** that deals with energy efficiency issues.

Environmental Impact Assessment *(EIA)* is made to prevent damage and to control the environmental impact caused by socio-economic development. This assessment is made mandatory for approval of major development projects and activities in Rwanda. Based on the EIA report (done by the EIA Expert), the Rwanda

Environment Management Authority (REMA) approves the project as environmentally friendly and gives it the green light for further development.

Rwandan Environmental Impact Assessment is divided into four parts:

- ***Environmental Impact Initiation part***- deals with screening and scoping of the project
- ***Impact Study part*** – deals with the impact analysis, development of mitigation measures and preparation of the report
- ***Decision making and authorization part*** – deals with the approval of the project
- ***Environmental management and follow-up part*** – deals with the monitoring of the project in the implementation phase

Through these four stages EIA can show that a proposed project is ecologically viable focusing particularly on the following elements:

- *Effects of domestic wastewater*
- *Contamination of groundwater by generated wastewater and fecal matter*
- *Noise generated by storage platform, crusher and concrete mixer plant*
- *Risk of noise pollution during construction, loading and unloading of construction materials*
- *Effects of generated solid wastes and stored solid wastes*
- *Risks of accidents during and operation phase*
- *Impact of rain water on the project site*
- *Physical and biological environment*
- *Baseline data on relevant environmental characteristics of the study area*
- *Characteristics of alternatives of present socio economic, technical and environmental situation;*
- *Hygiene of the plant in general*

Building Control Regulation - Current building control regulations in Rwanda propose the following points regarding ***energy efficiency*** in buildings:

- *The construction of all buildings whether public or residential should be done with due regard to techniques that prevent system losses as a result of inefficiencies of transporting and converting delivered energies;*
- *Heating losses in buildings should be mitigated by limiting their exposed surface areas, improving the insulation of building fabrics, reducing ventilation losses and selecting efficient heating systems that possesses effective controls;*
- *Cooling in buildings should be kept at its optimum level by controlling solar gains through glazing, reducing internal heat gains, making sure of thermal mass and night ventilation to reduce peak temperatures; these measures should be accompanied by a necessary increase in natural ventilation for maximum result;*
- *In line with Rwanda's geographical location, design of buildings need to maximize natural ventilation by advocating for a better window design, the use of mixed mode of ventilation and by selecting energy efficient mechanical ventilation systems;*
- *Building should be designed in such a manner that there is promotion of the use of daylight to the maximum, the use of task lighting, the installation of energy efficient luminaries with a high light output to energy ratio and installing effective controls that prevent lights being left on unnecessarily;*
- *Buildings should be designed such that they are fitted with water harvesting systems. In addition, water conduit systems should be properly insulated as to avoid the loss of water. The installation of economic water taps should be the norm in all public buildings;*
- *All public buildings should give priority to the installation of energy efficient appliances so as to avoid unnecessary lost of electricity and the production of excess heat inside buildings.*

Sustainability is highly promoted in Rwanda, although still only on paper. In practice it does not have an impact on the design considerations and choices. Issues that Environmental Impact Assessment is dealing with are similar to the ones that can be (partly) found in BREEAM International Assessment (where more aspects of sustainability were studied)

In the building control regulations only a few points regarding energy efficiency in buildings have been made, more as a recommendation than as a rule. However the guidelines related to the energy are not presented as *a must* for a project, and it is not checked if the above-mentioned recommendations have been applied within the project. No concrete, numerical limitations are present in the building control regulation.

4.12. Recommendation for the design of the European house:

The climate in Kigali offers great potential for the application of passive design strategies on the European House. Studying the local climate proves that only by making the right design choices, thermal comfort for the occupants of the building can be reached.

In the first place, by choosing the right **building orientation** that will facilitate **natural ventilation** choices. Furthermore, attention needs to be put on **solar protection** and **shading methods** to avoid building overheating and to reduce the cooling loads.

Regarding the orientation - buildings should have their longer facades facing north and south, with smaller facades facing east and west. The long sides of the facades should be designed perpendicularly to the wind direction (south and south east) in order to **allow cross natural ventilation.**

The climate study shows that no mechanical ventilation is needed. Compactness of the shape is therefore not crucial for the design. Because of the relatively high solar radiation during the whole year, appropriate shading devices should be applied in order to reduce the direct sun light on the building facade and the heat gain: this means horizontal shading on the north side and vertical shading on east and west side.

Regarding building materials – **lighter structures are preferred**. In this thesis it is decided to experiment the use of the new (existing) construction material – timber – material that is regionally available but not commonly used in Kigali. Timber structures are ideal for the climate condition that Rwanda has. Still, traditionally timber constructions were never present on this territory.

In terms of local norms and building regulations, the European House faces no restrictions. However it is recommended to imply some limitations, for example introducing some sustainable assessment in the projects (in this thesis by using BREEAM International assessment some limitations will be set). For the norms regarding structural design in this thesis Eurocodes will be applied and where no local data are available (wind load for instance) Dutch norms will be applied.

5. Energy potential mapping study (EPM)

The idea behind the Energy Potential Mapping (EPM) method is to explore the renewable energy potentials of a certain area and to document them in a form of an energy catalog, providing useful information to the developers, policy makers, urban planners, architects, engineers and to all of the interested parties to design effective sustainable energy systems.

In this way, if local energy potentials would be effectively used, each country could greatly benefit from their local potentials for its energy systems and would not depend on the import.

The EPM method has evolved over the years. Initially it was developed to visualize local (renewable) energy potentials and demand of energy, in order to support spatial planning towards more energy-efficient urban or rural environments. EPM has led to a process whereby energy becomes an extra parameter of spatial planning during the design of sustainable built environments. (Broersma, 2013)

Most of the energy required in the building sector is medium and low quality energy that is used for cooling, heating, hot water and cooking. To satisfy these needs in a most sustainable way, one should use the low quality energy.

Currently this is not the case. We still satisfy this low quality tasks with the high quality energy having high energy and environmental costs.

This practice of using fossil fuels to satisfy the energy demand will lead to the energy poverty and will address more global climate issues (more than half of the world greenhouse gas emission is connected to the fossil fuel use)

So in practice electrical energy is still used for heating and cooling, while it would be more efficient to use solar energy for heating and thermal design for passive cooling.

Therefore it is important to turn to the renewable sources - solar, wind, biomass and geothermal, explore their potentials and implement them into the building projects.

Not only the availability of the source, but also their geographical, temporal and qualitative component are of a crucial importance, as transporting low-quality energy over longer distance results in energy losses and its dissipation into the environment.

Having access to the mentioned data will help to have better and more effective connection between the energy source and the sinks.

In Figure 43 (Broersma, 2013) basic scheme of EPM methodology is proposed:

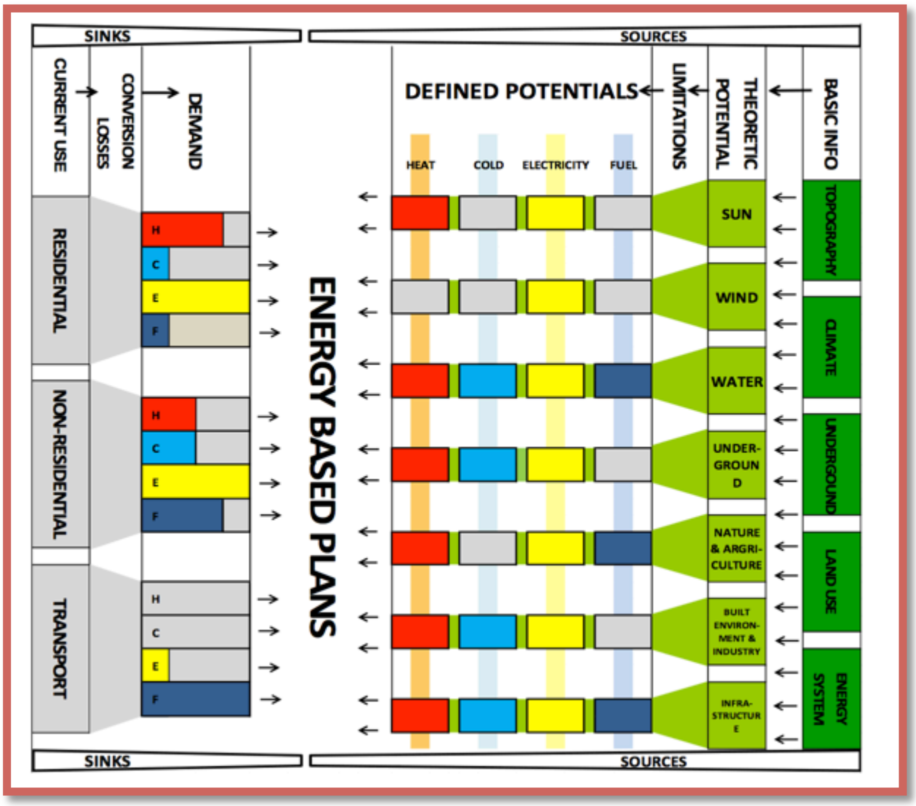


Figure 43 Energy Potential Mapping methodology ((Broersma, 2013)

The aim of the energy potential mapping is to study a certain area and to give an overview of what kind of energy sources, sinks and infrastructure are possible within that area. Usually EPM studies renewable and anthropogenic (e.g. residual heat) sources of energy.

Energy demand of buildings can be divided into heat demand, cooling loads and electricity demand.

Considering Rwandan climate energy demand of EU Building will consist of cooling loads and electricity demand.

5.1. EPM in Rwanda, Kigali

For the purposes of this thesis EPM study will be adjusted and instead of focusing on bigger areas and whole neighborhoods, it will focus on a single office building. In order to calculate the energy potentials of the European House first the output of the data needs to be defined. The output usually consist of energy demands and renewable energy sources available (transport and storage possibilities of an area will not be considered as the study is focused on single building)

Demand The building in consideration has not yet been built, so its real energy demand is not know a priori. Therefore the wished limit of cca 45kWh/m2/year will be set as a demand value.

For a building of 2500m2 that would bring cca 112500kwh/year

Solar PV Potential Solar potential will be calculated considering the installation of PV on the roof area – and considering the PV efficiency rate. Average annual daily solar radiation in Rwanda is 4,87 kwh/m2/day

In this case photovoltaic panels convert sunlight into electricity. These typically convert about 16% of the energy into electricity.

Wind

Studies of wind data for Rwanda vary. In this analysis worse case scenario is considered, applying the average wind speed of 3m/s (data available from NASA website)

Demand

	area m2	kWh/m2	kWh
European House	2500		
Energy demand		45	
TOT demand			**112500**

Supply

	kwh/m2	m2	kWh
Solar collectors			
Global radiation	4,87		
Solar collectors on roof area		889,38	
Efficiency 16%			
Supply solar collectors			**252946,8**
Wind	3	m/s	
Wind turbine diameter	7	m	
Supply wind power			**2765,07**

The output of the EPM studying shows that renewable energy sources of sun and wind in Kigali can deliver 2,5 times more kwh/m2 of energy than what European House demands, which is very positive.

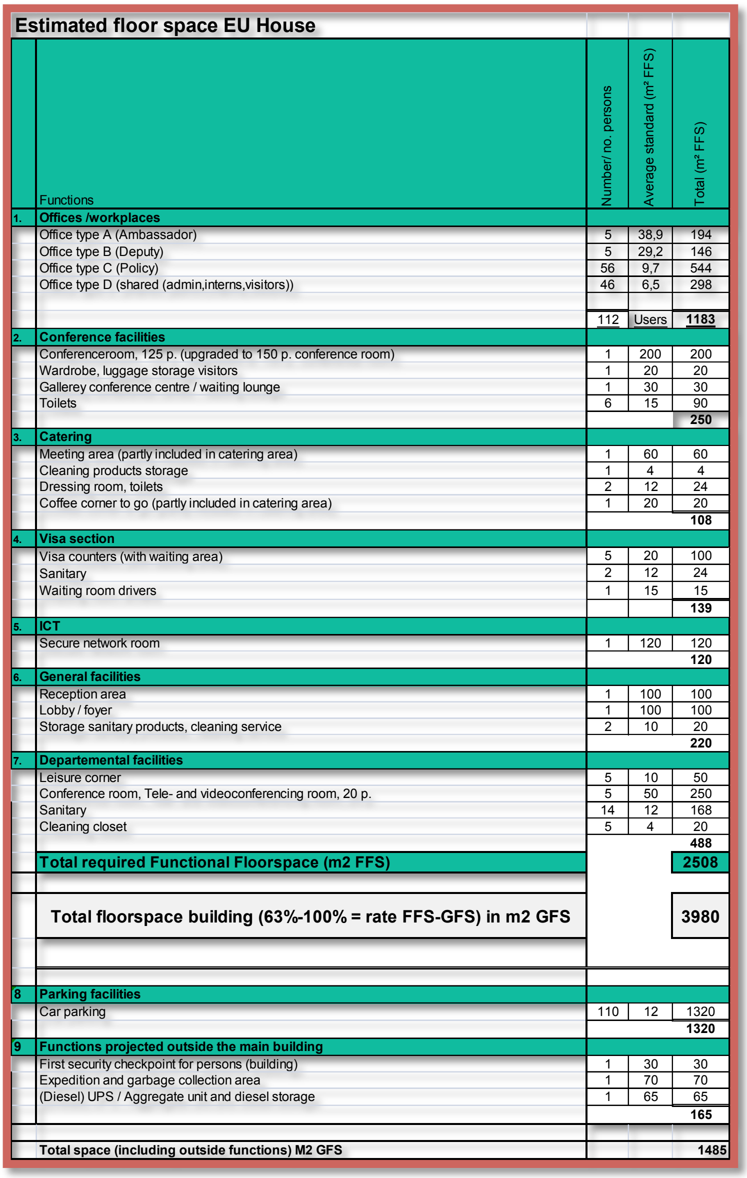
Storage

Through the year solar generation might differ. In order assure buildings self-efficiency it is therefore essential to have an energy storage system/battery, to be able to use the harvested energy in different moments if needed. In the Equator area (case of Rwanda) the solar generation does not change a lot during the year and therefore no large amount of storage is needed. Storage that equals to 3,5 days of average generation should serve as a reasonable backup (that equals to the storage capacity of 1061 kwh of energy in case of Rwanda)

6. Client requirements

Program of requirements for the European House office building is set after the meeting with the representatives of 5 European Embassies that this office building will host. Most of the Embassies have filled in a small questionnaire (see appendix) regarding their current energy use and their needs for space. Data's I got have been used as a reference in this research.

Their future wishes and needs are summarized below (Figure 44). Based on the information obtained a new European house office should fulfill the following space requirements:



Estimated floor space EU House

	Functions	Number/ no. persons	Average standard (m^2 FFS)	Total (m^2 FFS)
1.	**Offices /workplaces**			
	Office type A (Ambassador)	5	38,9	194
	Office type B (Deputy)	5	29,2	146
	Office type C (Policy)	56	9,7	544
	Office type D (shared (admin,interns,visitors))	46	6,5	298
		112	Users	**1183**
2.	**Conference facilities**			
	Conferenceroom, 125 p. (upgraded to 150 p. conference room)	1	200	200
	Wardrobe, luggage storage visitors	1	20	20
	Gallerey conference centre / waiting lounge	1	30	30
	Toilets	6	15	90
				250
3.	**Catering**			
	Meeting area (partly included in catering area)	1	60	60
	Cleaning products storage	1	4	4
	Dressing room, toilets	2	12	24
	Coffee corner to go (partly included in catering area)	1	20	20
				108
4.	**Visa section**			
	Visa counters (with waiting area)	5	20	100
	Sanitary	2	12	24
	Waiting room drivers	1	15	15
				139
5.	**ICT**			
	Secure network room	1	120	120
				120
6.	**General facilities**			
	Reception area	1	100	100
	Lobby / foyer	1	100	100
	Storage sanitary products, cleaning service	2	10	20
				220
7.	**Departemental facilities**			
	Leisure corner	5	10	50
	Conference room, Tele- and videoconferencing room, 20 p.	5	50	250
	Sanitary	14	12	168
	Cleaning closet	5	4	20
				488
	Total required Functional Floorspace (m2 FFS)			**2508**
	Total floorspace building (63%-100% = rate FFS-GFS) in m2 GFS			**3980**
8	**Parking facilities**			
	Car parking	110	12	1320
				1320
9	**Functions projected outside the main building**			
	First security checkpoint for persons (building)	1	30	30
	Expedition and garbage collection area	1	70	70
	(Diesel) UPS / Aggregate unit and diesel storage	1	65	65
				165
	Total space (including outside functions) M2 GFS			**1485**

Figure 44 Space requirements EU House

European Office – the building

The European office building will be divided into 3 main zones: *public, semi – public and private zone*. Each zone will have a separate entrance and there will be secured access from private to semi – public zone. No direct access will exist between public with semi-public and private zone.

Building zones

- **Public zone (Consular/visa section)**
- **Semi public zone (Conference zone, Social zone)**
- **Private zone (Policy zone, Administrative zone)**

Public zone

Public zone will be accessible via separate (outside) entrance and will host consular/visa counter with some extra room space (waiting room)

Semi public zone

Semi public zone will be reached via reception and lobby and will contain conference and catering area with sanitary rooms. This zone will be used by the employees on everyday basis and will serve as hosting area of representative functions organized by the embassies. Cultural activities and national day's celebrations will take place in this area as well.

Private zone

Private zone is reserved for the office area and it is accessible only by the embassy employees.

7. Preliminary design for EU House

7.1. Location

In the northern part of Kigali city lays Gisozi neighborhood. In the near past well known mainly because of the Genocide Memorial Museum frequently visited by locals and tourists. The zone in its vicinity used to be poorly inhabited with predominant low mud houses. Implementation of the Master Plan will enrich this area not only with new residential areas but also with a public park, a civic center, a health center, a community facility center, a day care, schools and children playing areas. The new proposed skyline for this area will range between 3-6 story buildings. Next to the previous mentioned, the whole new area of the city called 'diplomatic zone' is planned to become a part of Gisozi neighborhood. Master Plan for this diplomatic zone proposes the area that occupies approximately 32,2 hectare composed of bigger plots ranging from 5000m2 to 9000m2 in order to provide plots usable for offices/embassies as well as houses. In the moment no surrounding buildings have been built which makes it a big challenge to place European House in this 'empty' context, not knowing what the real physical obstacles might once arise. (Figure 45)

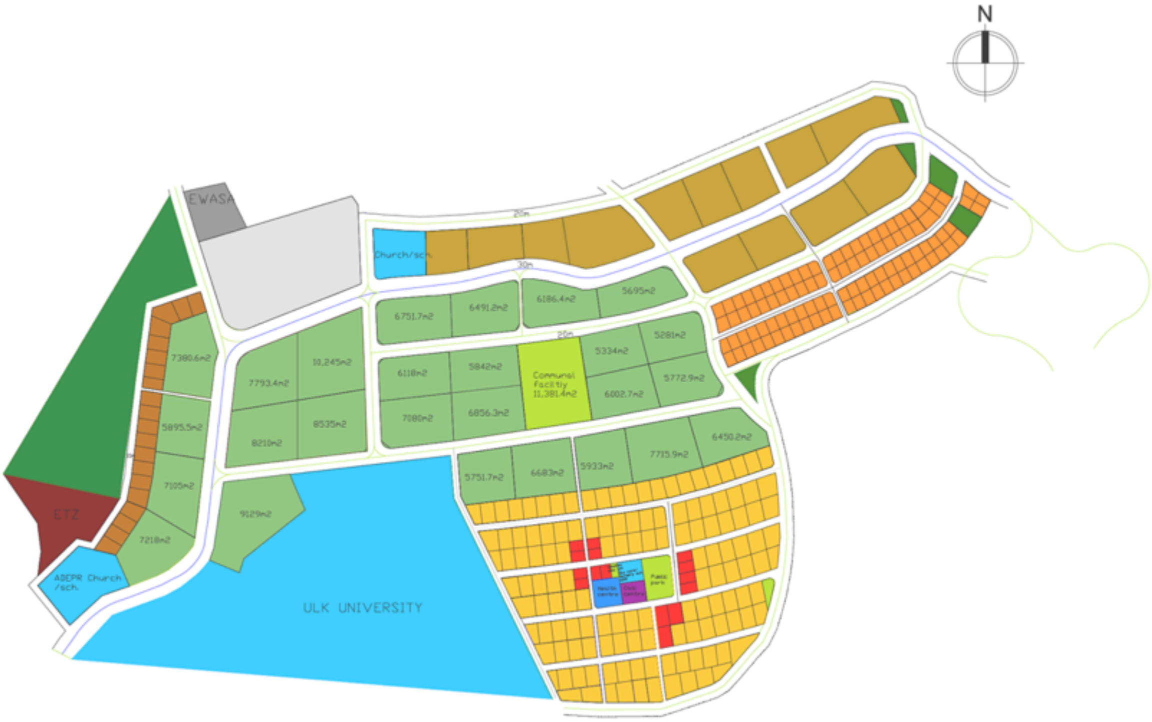


Figure 45 Gisozi parcelation plans according to the new Master Plan ('diplo plots are colored mint green)

7.2. Building plot

Current plot reserved for the EU House has an area of 3,5 ha in total and in a register it is divided into 4 parts. The plot has a strategic position, direct access to the main street from its 2 sides, its terrain is slightly sloped and it offers great view over the city of Kigali. (Figure 46)

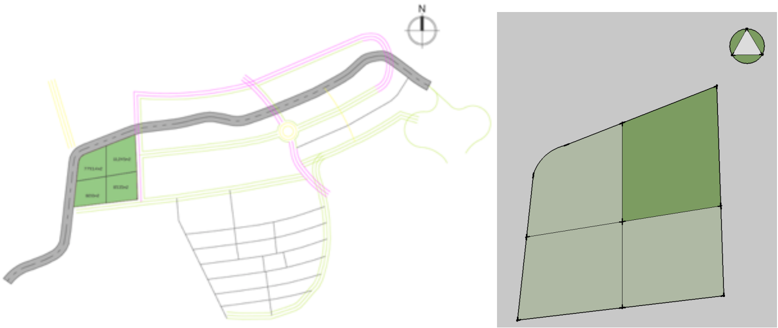


Figure 46 Plot (in green) with adjacent roads

From the program of requirements the criteria for the location of the EU building is that it has to be big enough to host approximately 3500 m2 of space (inside and outside functions). Proposed plot offers more than enough of needed space, so only part of it will be used as a building plot.

7.3. Building Massing study

Following massing study was done in order to facilitate the whole designing process and to get some more idea and inspiration about the shape of the future building. The idea behind it is to make sure that all the requirements individual embassies expressed can fit the future building on the proposed location. Mass study will help defining the best form/shape of the building and will underline what aspects will need to be taken care of and considered in the future designing process.

According to the requirements the program of the EU House is divided into 2 common and 5 individual zones. Each of them will have different space requirements as it follows:

Common zones are:

1. Consular/visa zone – public area

Tot Area: **124 m^2 / 207 m^2** GFA

2. Conference/Meeting area – semi private area (large conference room + meeting area + toilets)

Tot Area: **358 m^2 / 570 m^2** GFA

Individual zones are:

3. Offices – private area (meeting room + leisure corner + ICT + toilets + cleaning closets)

Tot Area: **1791 m^2 / 2850 m^2** GFA

(Office area is divided in sub functions per embassy)

4-1 EU Embassy (Area: **517 m^2 / 820 m^2** GFA)

4-2 NL Embassy (Area: **387 m^2 / 620 m^2** GFA)

4-3 DE Embassy (Area: **313 m^2 / 500 m^2** GFA)

4-4 SWE Embassy (Area: **293 m^2 / 470 m^2** GFA)

4-5 FR Embassy (Area: **280 m^2/ 450 m^2** GFA)

All functions have a total area of **2273 m^2** of Functional Floor Space or **3788 m^2** of Gross floor space.

Following the client requirements and relative space requirements for the building, this mass study started from a very basic rectangular square form where 3788 m^2 were divided upon 3 floors (36m x 36m approx. per floor), respecting the limitations for the max height of the constructions in the given area of the city. With the first basic shape one can get the idea about the minimum requirements for the size of the construction plot. Emerging from this basic squared shape different options have been considered and more shapes are developed as shown in the following figures:

Basic squared shape – space required by the tenants spread over 3 different floors. (Figure 47)

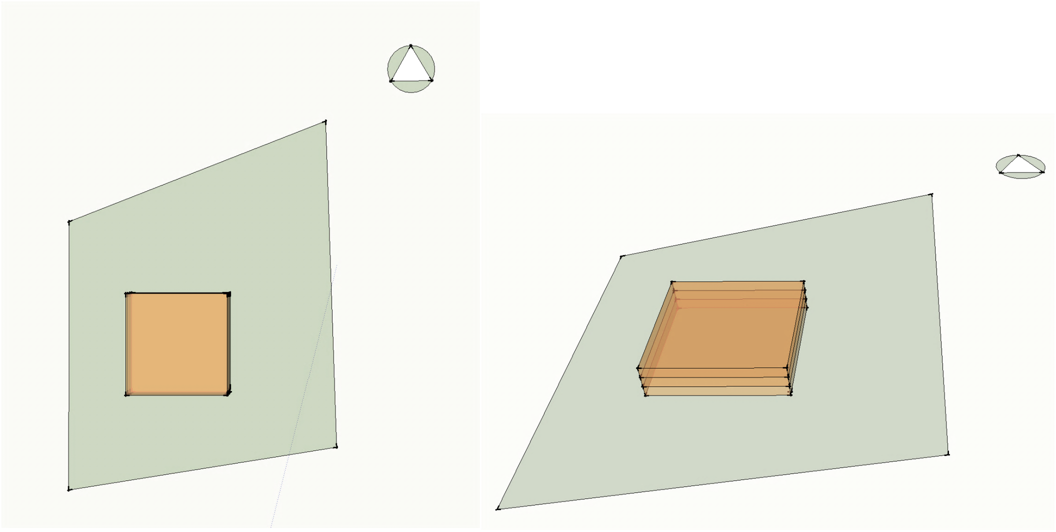


Figure 47 Top view and prospective

Alternative 1.

In the first presented alternative all the zones and functions are hosted by two identically shaped rectangular buildings. Considering the daily and seasonal movement of the sun and wind orientation on the building plot it is decided that the long façade of the building should face north-south benefiting in the best way from the sun and wind. In this alternative two identical building blocks are made opposite each other hosting a 'common outside space/garden' that would be used by building occupants. (Figure 48)

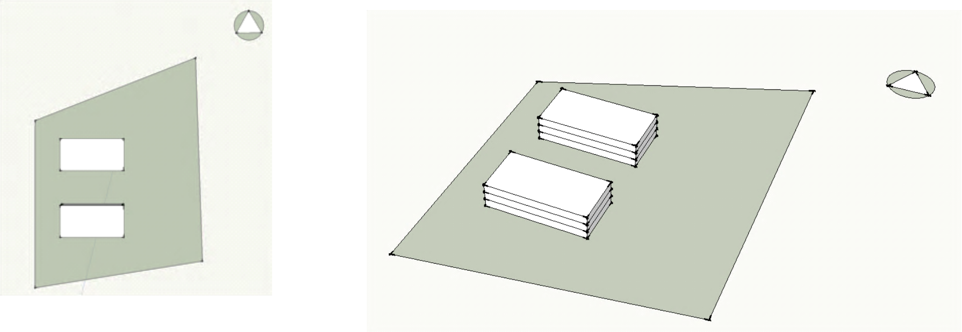


Figure 48 Top view and prospective

Alternative 2.

The challenge of alternative 1 is how to divide and fit in the best way 3 different functions in two building blocks. Therefore in alternative 2 I thought of splitting buildings by their function. The long shape works very well when building is naturally ventilated, so it will repeat in this alternative as well. (Figure 49)

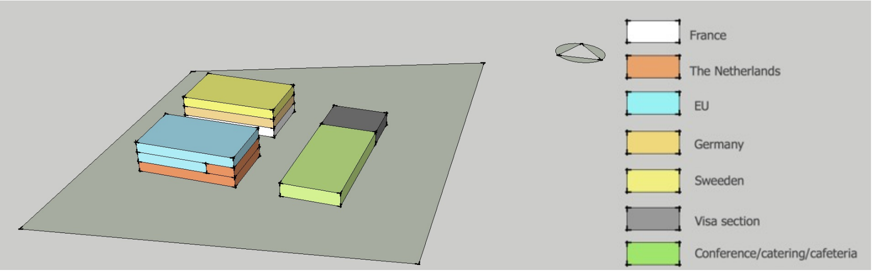


Figure 49 Prospective view Alternative 2

The part of the conference area is quite big though and if it was to be situated with a short axes south north – the plot needed for the whole complex would have to be significantly bigger. Another disadvantage is large amount of façade we would have in this case.

Alternative 3.

In this alternative alternative 1 served as basis having simple basic longitudinal shape that works well with the natural cross ventilation. All functions would be hosted in 2 builidngs that will be connected with the common garden that visualy unites the two buildings. Condidering the length of the builidng it is decided to have some 'breaks' in the floor plan – in order not to have the 'corridor/tunnel' effect. This 'break' could be obtained by introducing atriums, or by introducing some ' irregularities' in the floor plan, or just by having more 'open' façade on some parts of the building allowing more light and fresh air to come in . (Figure 50)

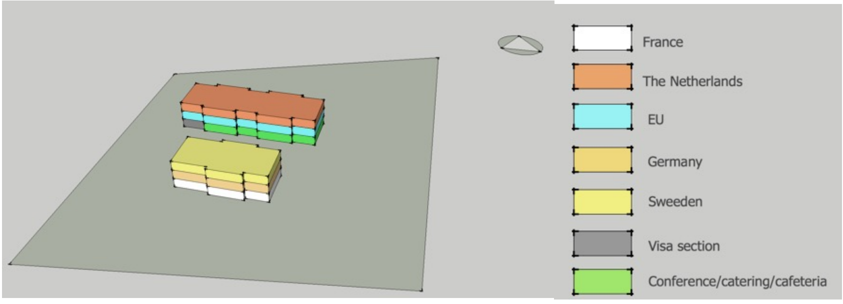


Figure 50 Prospective view alternative 3

7.4. Chosen option

As the focus of this thesis is not about architectural design, no deeper massing study will be done. It is decided to continue further with a sketch design based on alternative 3 as that alternative offers a simple but not completely ordinary solution that embraces the potentials of the building plot location and the Kigali climate.

8. Climate design of EU House

8.1. Site analysis and boundary conditions for the design

Kigali has a pleasant tropical savanna climate, with two seasons, wet and dry, and very little temperature variation whole year around. Temperature and humidity through the year never reach extreme values and stay in a comfortable range. (Average temp 21, average humidity 64,5%)

Sun path diagram

Sun path diagram shows that the sun altitude in Kigali varies in between 32 and 87 degrees through the year (Figure 51). In the 'summer' months sun is on the northern part of equator, while in 'winter' months sun path goes from east to west via south. Therefore the shadings for European House in Kigali are necessary on both, northern and southern part. For the high sun (64-87 degrees in the noon) that Kigali has most of the day, horizontal shading on the roof is needed on European House. (For lower altitudes of the sun (morning and afternoon sun in Kigali) horizontal shading on the façade are sufficient) (Figure 52)

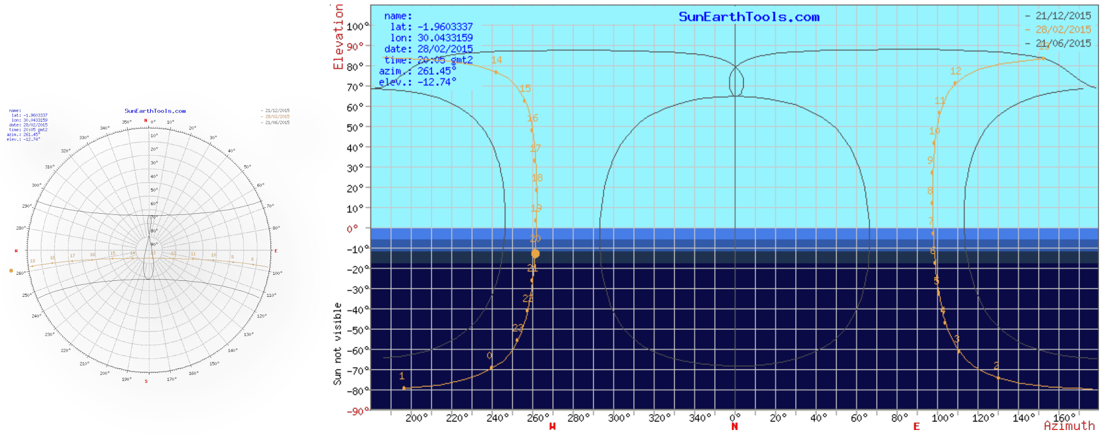


Figure51 Sun path diagram and the sun elevation (source http://www.sunearthtools.com/dp/tools/pos_sun.php#annual

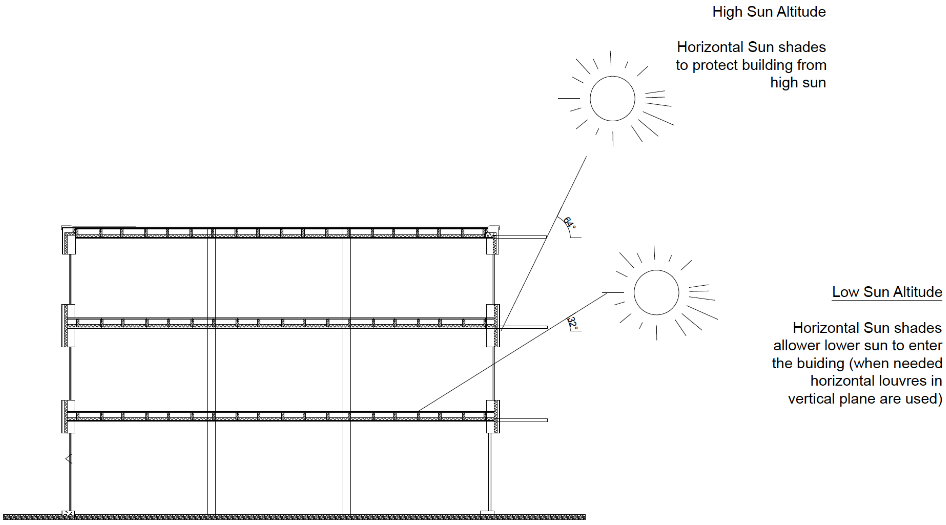


Figure 52 High and low sun angles on the European House

Wind

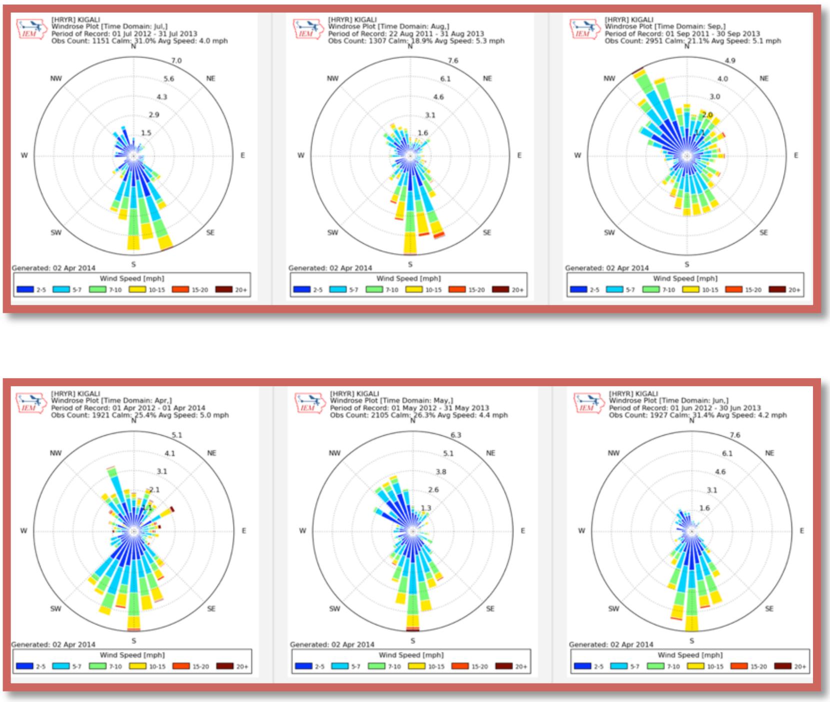


Figure 53 Kigali wind roses (source http://mesonet.agron.iastate.edu/sites/windrose.phtml?station=HRYR&network=RW_ASOS)

Wind presence on the building location plays a crucial factor when using passive design strategies. It influences in the first place the orientation of the building. Information about wind speed and directions are usually collected and presented in the form of a wind rose. Wind rose for the city of Kigali is based on wind information related to location of the city airport. Building site of the European House is situated in still poorly built building area that offers no natural obstacles like trees, or other higher buildings around the building plot that could influence or block the wind on the site. Prevalent direction of the wind is ***south to southeast*** and that should be taken into account when orientating the building in order to profit from the natural ventilation of the building. (Figure 53 and Figure 54) So the main axis of the building should be perpendicular on south direction.

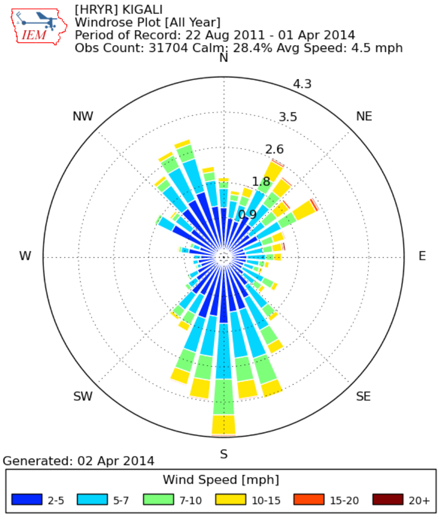


Figure 54 Annual wind rose Kigali (source http://mesonet.agron.iastate.edu/sites/windrose.phtml?station=HRYR&network=RW_ASOS)

8.2. Energy strategies

Kigali enjoys almost perfect climatic conditions. Therefore energy neutrality of office buildings should be possible to meet, combining good design decisions (passive strategies) and smart technologies (active strategies) if and where needed.

8.2.1 Passive strategies

Orientation Long axes of the building will be along south/north (with short faces on east west) and perpendicular to the main wind direction (south) to facilitate the best the natural ventilation possibilities (figure 55)

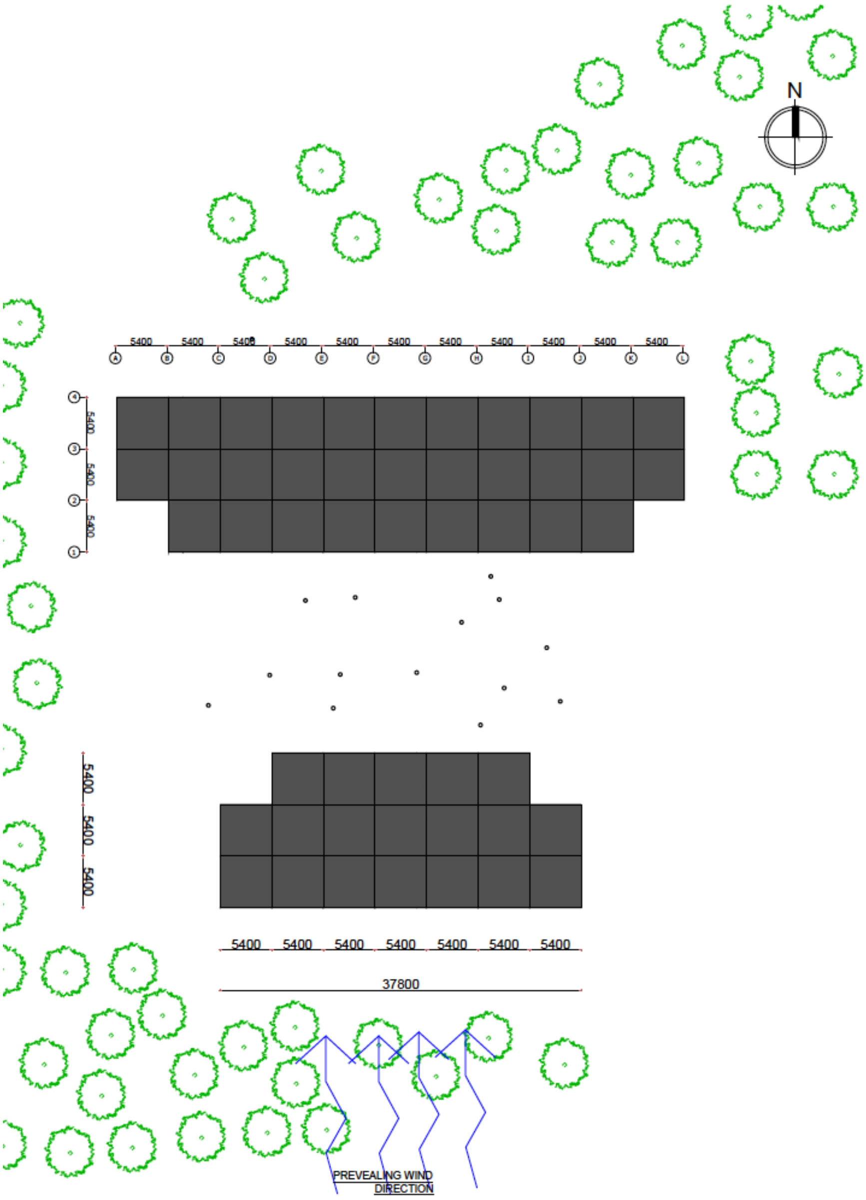


Figure 55 Prevailing wind direction and building orientation

Sun shading In the hot humid climates high horizontal shadings (roofs, tree canopies) are extremely effective shading techniques. Horizontal shades provide effective shading on the south façade (north facade in the Southern Hemisphere – Rwanda) when the altitude is high. The depth of the device will determine the lengths of the shadow on the window wall. Some recommendations about the length of the shades are shown in the figure 56 (taken from the book Sun, wind and light, DeKay and Brown).

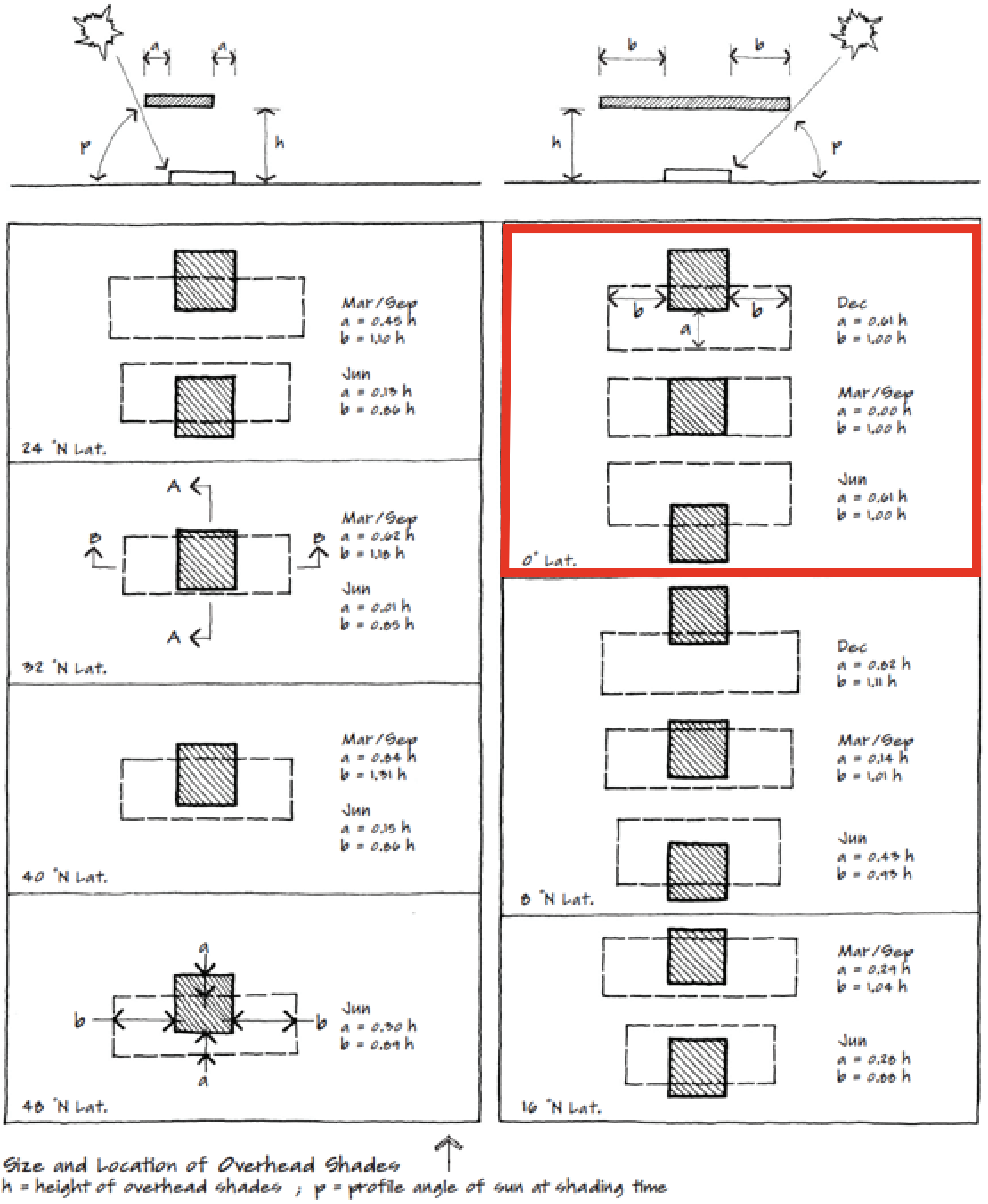


Figure 56 Recommended overhead shades for Kigali (source book Sun, Wind, Light)

Protection from the sun of the building envelope is extremely important in tropics – in order to protect the European house from the direct sun, sun shading needs to be introduced on all parts of the building (circled in red Figure 56).

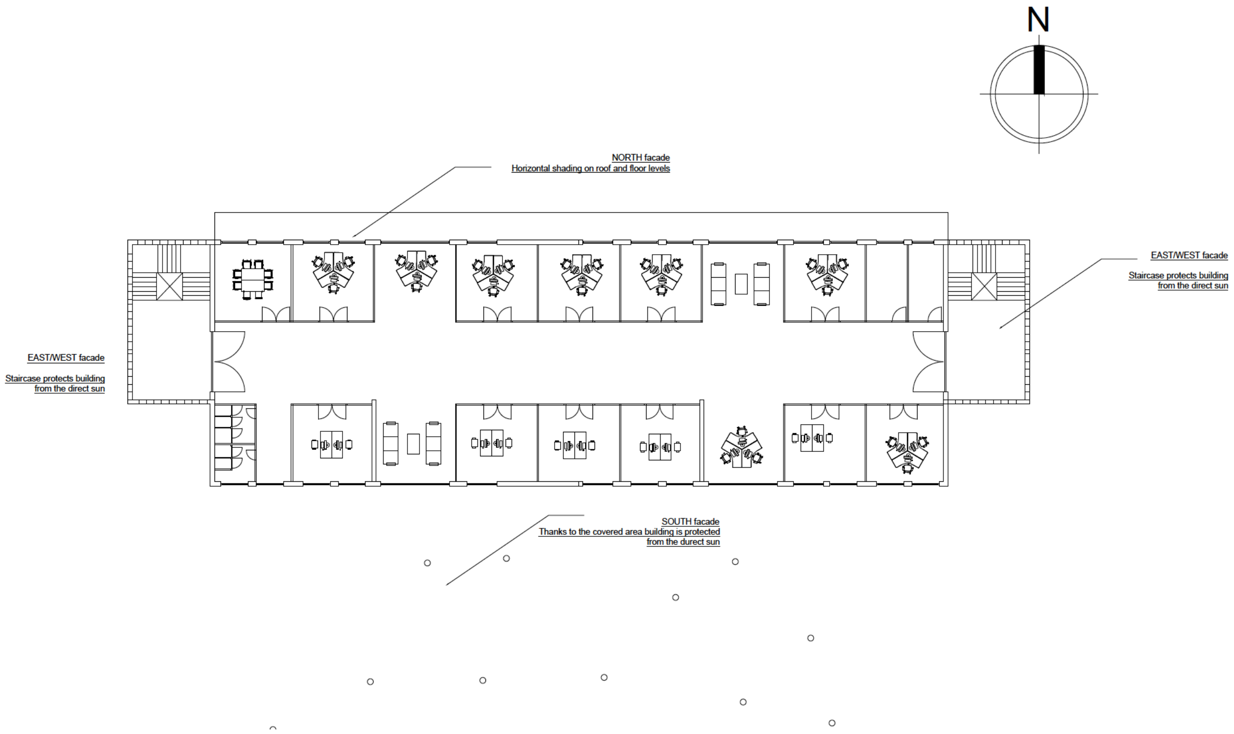


Figure 57 Shading choices European House

Shading needs influenced the design choices of the European House (Figure 57) On the east and west façade it is decided to place the staircase and in that way to avoid the direct sun on the building envelope. Long facades (north and south) are shaded as well – on north side horizontal shading of min 1,8 m is needed (figure 58) to avoid high sun (for lower sun horizontal louvre are needed to control sun entrance inside of the building) (Figure 52) On the south façade direct sun is avoided thanks to the covered area in between 2 buildings.

Daylighting design/Window type

Recommendation followed from the book Sun, Wind, Light (2014) (Figure 58) underline that the daylight design depends on the geometric relationship between building and the sky and that key factors in day lighting design are room design and room organization.

A common rule of thumb states that a net window area / gross wall area should be less than 40%. In warmer climate, ratios above 40% are acceptable as long as windows are well shaded. Considering the fact that the average daylight factor for office buildings is 5% the most efficient window type to apply to European House will be the one having squared shape and dimensions of 2times 1,8x1,8 per room.

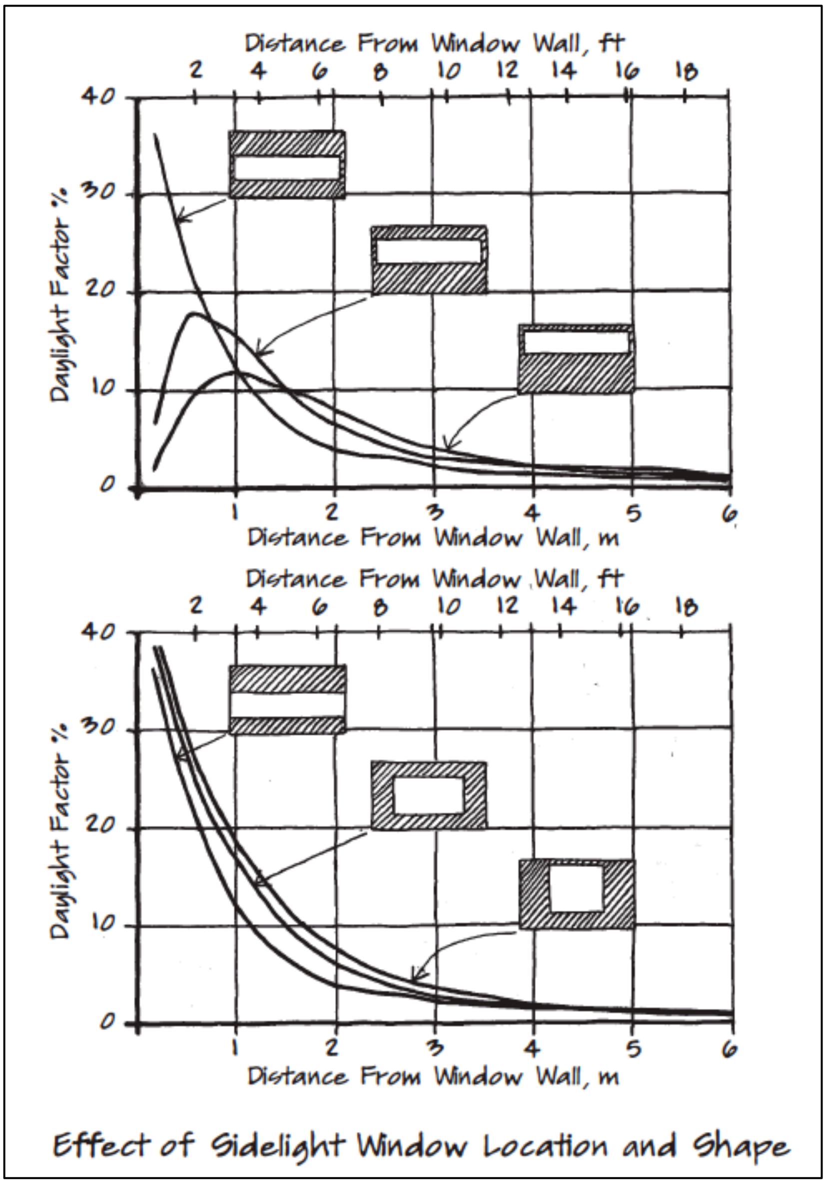


Figure 58 Effect of Sidewindow Location and Shape

Rainwater collection

Water is a concerning issue in whole Rwanda. Therefore is the rainwater harvesting introduced in the project of European House as well. Harvested water is stored in underwater tanks and from there used partly for the irrigation of the landscape, partly is pumped back in the building for toilet flushing and Partly filtered and used as potable water. (figure 61)

Natural ventilation

Principle of natural ventilation that can be applied on European House is shown in the following figure. Natural side ventilation is combined with the big window areas along the long façade. (Figure 59)

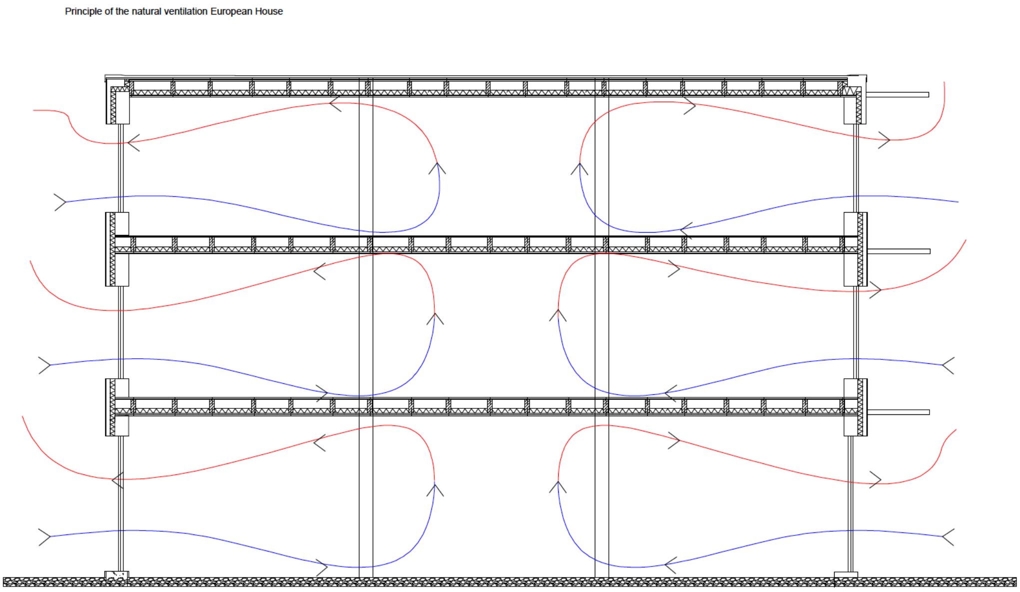


Figure 59 Principal of natural side - ventilation

8.2.2 Active strategies

Next to passive strategies few active strategies can be considered for the project of European House. Studying Kigali climate it is concluded that the best active strategies that can be applied on the European House are the introduction of PV panels and small wind turbines in order to embrace local solar and wind potentials.

8.2.3 Operating energy demand

CEMS engineering studies (Figure 59) did a study of (operating) energy consumption in tropical countries and found out that the percentage of the building components that use most energy in tropics is following:

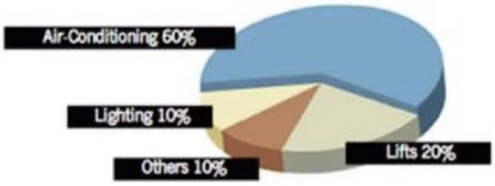


Figure 60 energy consumption in tropical countries (CEMS)

In order to get energy neutral building in tropics it is therefore needed to reduce the major energy consumption components (specifically air conditioning component). Kigali climate offers perfect conditions for the introduction of passive cooling strategies that will completely remove the cooling load of European House. Lighting of the office spaces in European House will be mostly covered by the good daylight design. European House has 1 elevator, but as the building has only 2 floors it is expected that it will not be heavily used.

Therefore the major components for the operating energy consumption will be the equipment and energy used for lightning (elevator is expected to be used only in very rear occasions, so its energy use will not be significant)

8.3. Applied construction materials for European House

As concluded in chapter 4.7 it is decided to experiment the use of timber in the project of European House. Timber use in construction industry in Rwanda is still in the very beginning phase. Timber is mostly used in its raw un-engineered forms (cut, brought to the construction site and used directly) and almost exclusively for the roof constructions.

However, first steps toward the wood introduction into Rwandan construction market have recently been made. In one small manufacturing school in the middle of the country first glue laminated eucalyptus beams have been locally produced. This is an important step on the road to the first possible timber building in Rwanda.

For the simplicity of the design and connections of the whole structural bearing system the bearing system that will be taken into the consideration for European House will be timber framed structure. Considering the local context it is better to reduce the need for any engineered wood as much as possible. In this project of European House -sawn timber with class D50 will be applied.

8.3.1. Embodied energy calculation

Service life of the building of 50 years will be taken into account. Following the conclusions of Cole (chapter2) for the calculation of the EE only structure will be taken into account, as structure is one of the major components that contribute to the tot amount of the EE used in building. To get the tot amount of EE the EE of the structure will be then multiplied by 3 (building services will be taken out of the calculations as building will need no mechanical ventilation. Only major construction components will be considered in calculations – in this case timber and timber products, timber openings (windows) and PV.

8.3.2. Renewable energy technologies used:

Studying Kigali climate it is concluded that the best active strategies that can be applied on the European House are the introduction of PV panels and small wind turbines in order to embrace local solar and wind potentials.

8.4. Energy neutrality calculation

8.4.1. Intro

Energy calculation of a building is an important step for the evaluation of the impact that the building has on the environment.

The first step in energy calculation of European House will be **to set its energy goals**. Using the energy targets in the pre design phase will help framing design challenges and problems and in the same time it will help searching best design options to solve these challenges.

The goal of the European house as earlier described is to achieve energy neutrality – where annual energy produced on site will equal the buildings energy demand. This goal needs to be achieved using only on-site renewable energy.

8.4.2. Calculation

The calculations are done with the assumption that the total annual amount of energy equals to the sum of Embodied and Operating energy.

Operating Energy OE

Equipment	**14**	**W/m2**
Lighting	**11**	**W/m2**
TOT	**25**	**W/m2**
TOT OE	**36**	**kWh/m2/year**

European House

TOT OE	90000	kWh/year

EMBODIED ENERGY

European House

Material	*Energy* **MJ/m3**	**kWhr/m3**	**m 3**	**kWhr/m2**	**m2**	**kWhr**
Sawnwood(beam, columns,floor)	7,40	2,06	360,00			740,59
PV				1112,00	889,38	988990,56
Windows (wood)				100,00	461,16	46116,00
		TOT EE in 50 yr				1035847,15
		TOT EE in 1 yr		**8,29**		20716,94

TOT ENERGY European House	**110716,943**	**kWh/year**

8.4.3. Conclusions

In order to meet energy neutrality of European House the energy demand of the building should be met by two studied renewable sources – by applying the solar panels on buildings roof and by introducing the small wind turbine on the building spot.

By applying solar panel on the entire roof area of the building it is possible to reach a bit more than 270000 kWh per year which is about 2,5 times more than what is needed and therefore the energy neutrality is guaranteed even only by using photovoltaic. Through the year solar generation might differ. In order assure buildings self-efficiency it is therefore essential to have an energy storage system/battery, to be able to use the harvested energy in different moments if needed. In the Equator area (case of Rwanda) the solar generation does not change a lot during the year and therefore no large amount of storage is needed. Storage that equals to 3,5 days of average generation should serve as a reasonable backup (that equals to the storage capacity of 1061 kwh of energy in case of Rwanda)

Data's related to the wind's speed and intensity in Kigali vary. Wind speed is in general low and because the energy need of European House can be completely met by introducing PV on the roof area, wind technologies application in this project will not further be considered.

8.5. Final design concept European House

8.5.1. Sustainability concept European House

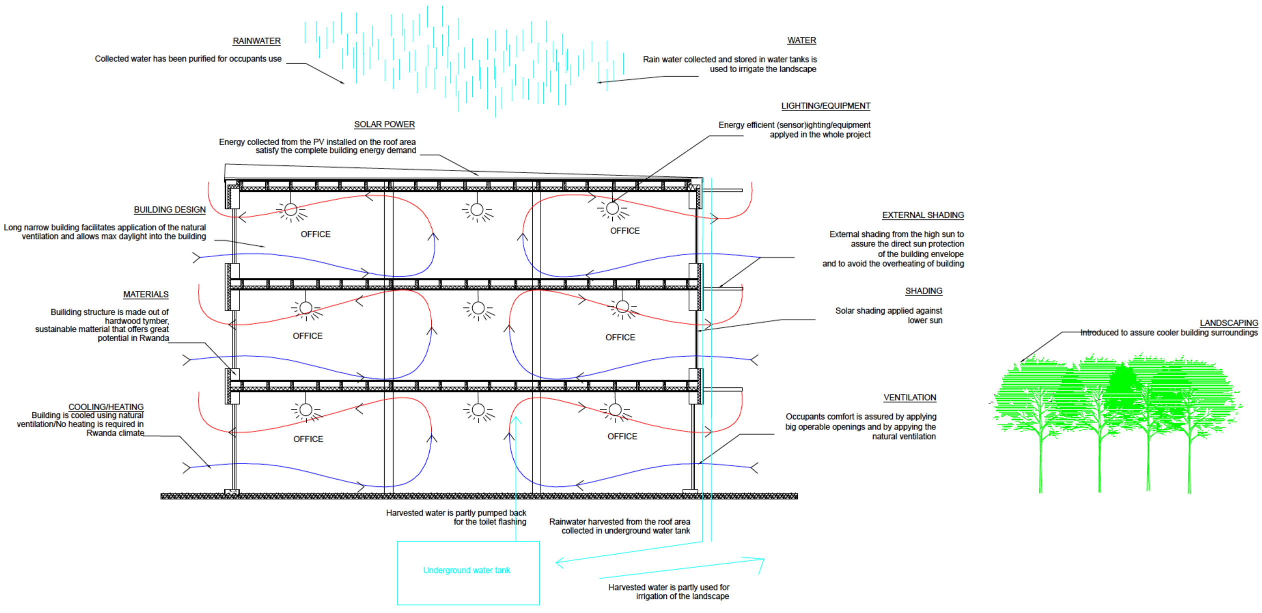


Figure 61 Sustainability concept European House

8.5.2. European House proposed design concept

European House Project is made out of two 3-storey buildings with a common covered space/garden in between them . Floor plan of both buildings is rectangular. Space in between two buildings is meant to function as a 'covered garden' that serves as an informal meeting (break) space for buildings occupant. Ground floor of the bigger building is slightly different than other floors (offices), it is more 'open' and it hosts meeting space e and a larger conference room. Proposed design concept for the European House is shown in the following figures:

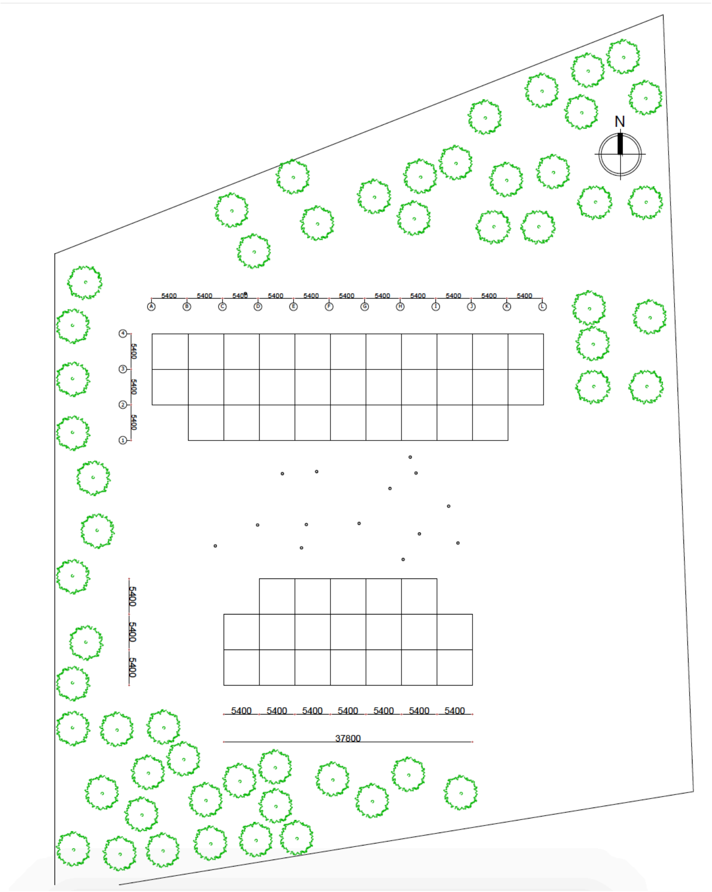


Figure 62 European House situation

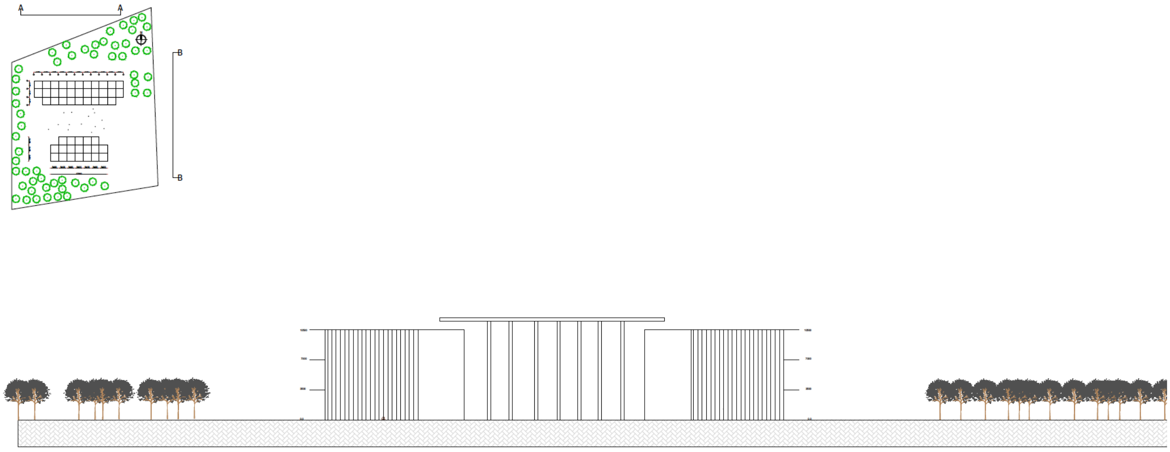
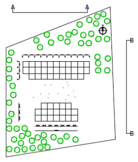


Figure 63 View B-B/Elevation of the shorter façade



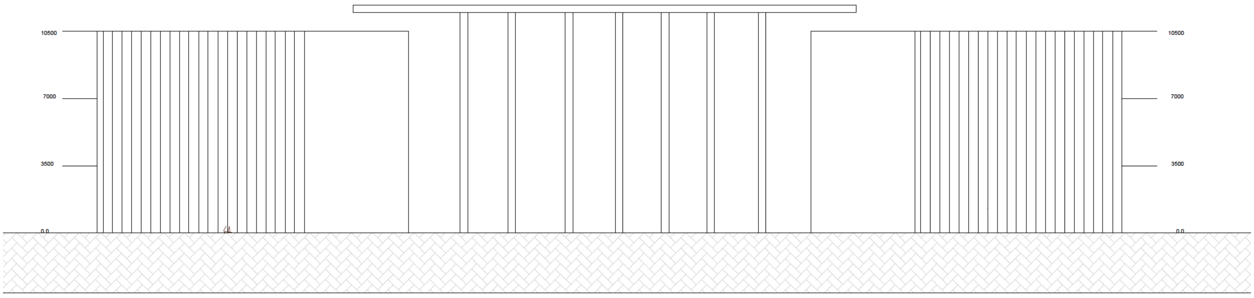


Figure 63 View B-B/Elevation of the shorter façade - building only

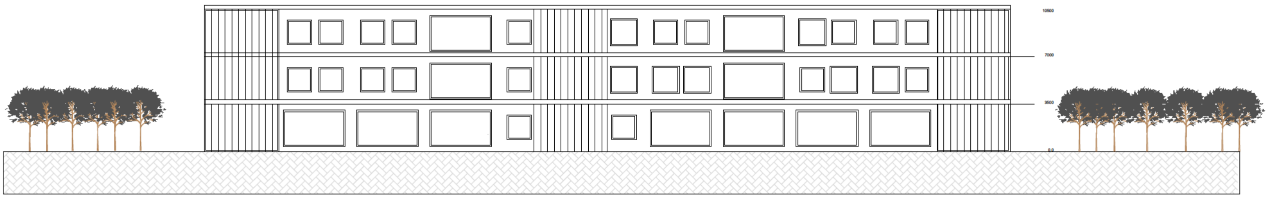


Figure 63 View A-A /Elevation of the longer façade

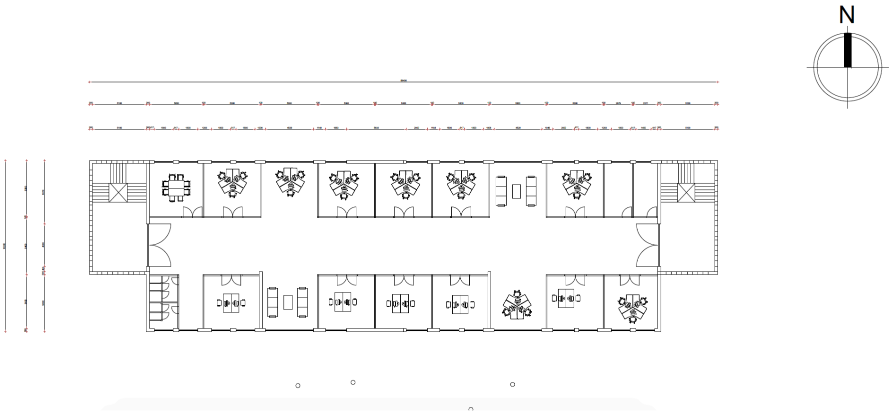


Figure 64 Typical floor plan bigger building

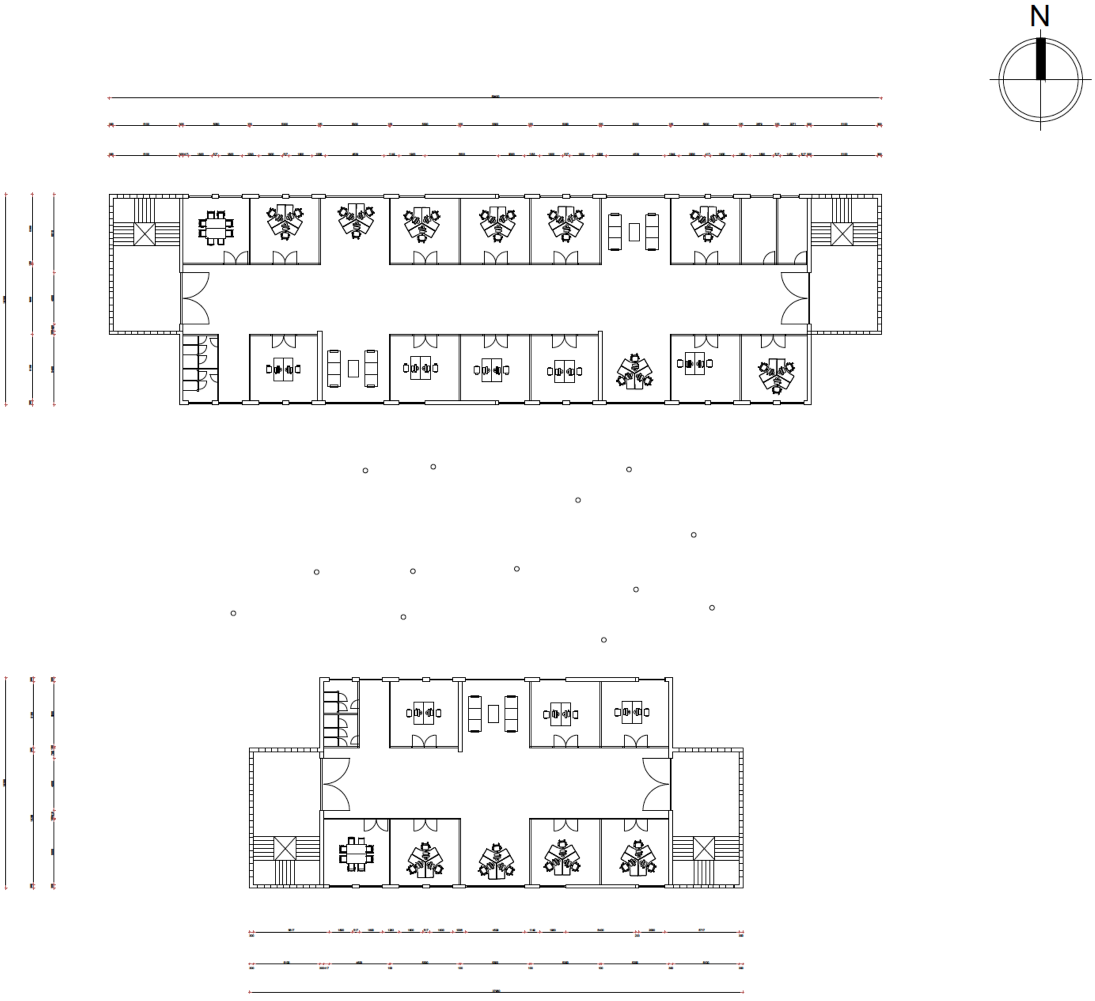


Figure 64 Typical Floor plan office areas

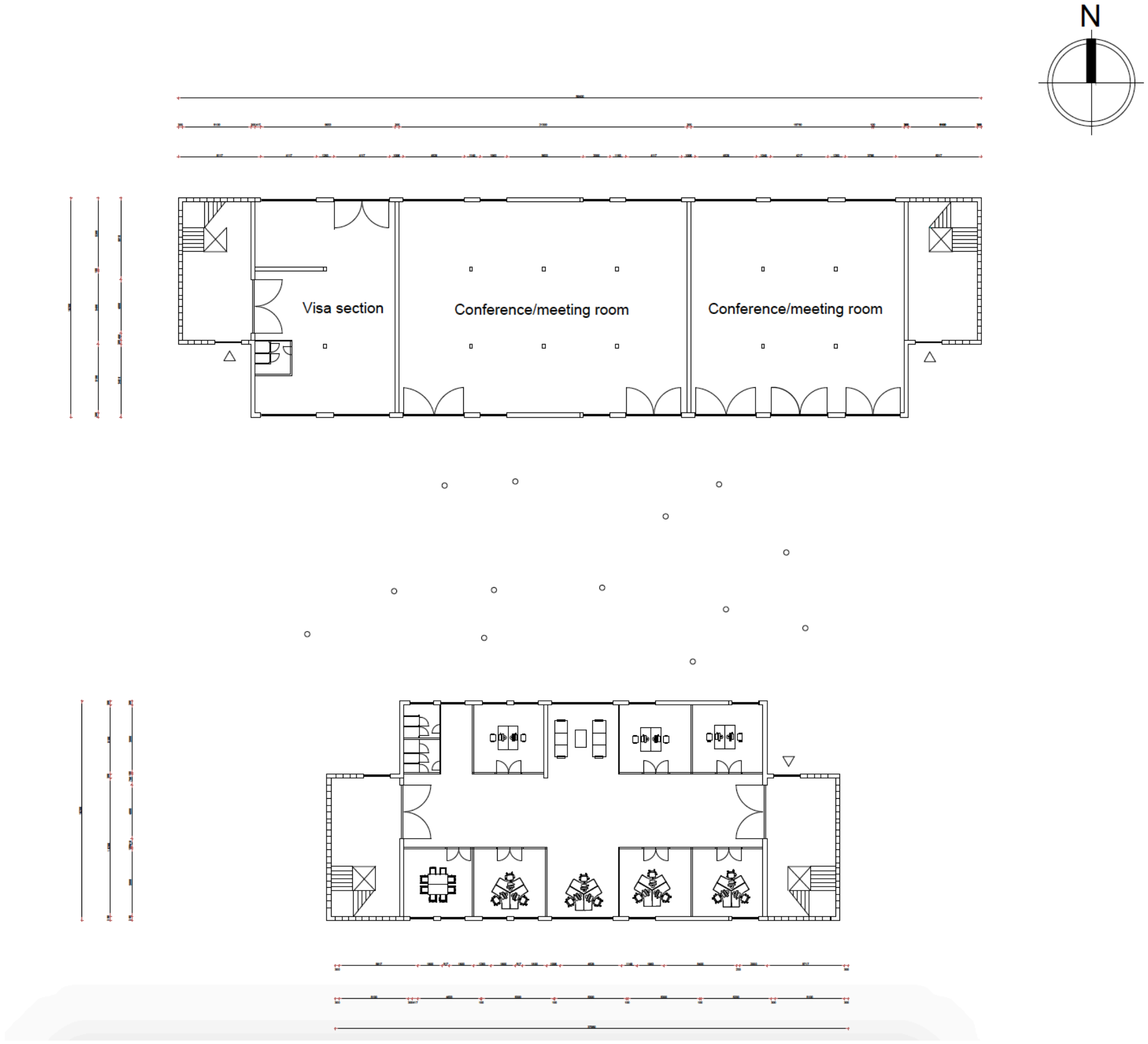


Figure 64 Floor plan ground floor

9. Preliminary structural design

9.1. Introduction

The aim of this part of the thesis is to consider some alternatives for the load bearing structure regarding construction materials. Timber, steel and concrete options, with short reflection on their environmental aspects, will be studied. The idea is to make manual analysis with rough calculations verifying one (middle) bay of the complete structure. This method is useful to get the dimensions of structural elements and consequently a rough estimate of the environmental impact that each material choice for European house would have.

The same building layout is considered for all three materials in order to compare three options more accurately. Column positions are therefore the same in all 3 options. In reality steel and concrete allow larger spans compared to sawn timber. Sawn timber beam are usually made up to span the distances to max 6m. For the sake of this study therefore, the beams in each option will have the same length of 5,4 m.

Environmental impact related to different options is calculated with a help of a DuCo calculation method. DuCo is a great tool that can be used in a preliminary design phase to calculate the total amount of 'environmental costs' of the main load bearing structure. A range of designs, related to the use of different building materials, can be calculated and compared on the basis of their environmental performance. DuCo method, followed by appropriate sustainable solutions, is an encouraging step on the road to sustainable building design.

9.2. Building description

In this analysis only the bigger building will be considered as both buildings have identical typical floor plan. Ground floor of the bigger building is slightly different than other floors (offices), it is more 'open' and it hosts cafeteria space and a larger conference room. The covered garden will not be part of this structural analysis. (Figure 65)

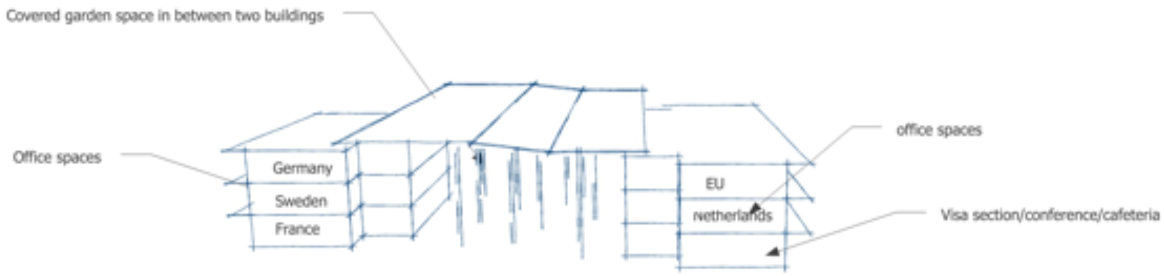


Figure 65 Sketch European House

9.3. Building dimensions

Building plan is based on a regular squared grid with dimensions of 5,4 m in both longitudinal and transversal direction (Figure 66). The overall building length is 59,4m and building width 16,2m. The area per building floor is 904m2. The total building height is approximately 10,5m divided over 3 stories. Floor height of each storey will depend on the construction material choice, just as other structural and non-structural members will do as well.

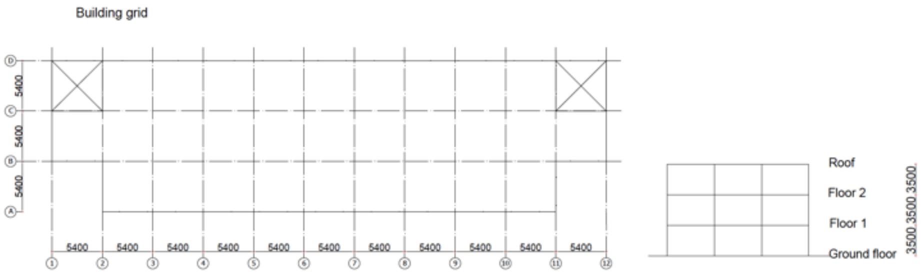


Figure 66 European House grid and elevation

9.4. Option Timber

Timber, in the construction world, scores very high when it comes to the overall energy issues during the whole life of buildings. Timber requires less energy than other common construction materials to be processed from the raw material to the forms that are used in constructions. Trees, while growing, absorb carbon dioxide from the atmosphere and they keep it internally stored for their whole lifetime. Timber can be recycled or at the end of its useful life it can be used as a biomass, producing in that way more useful energy (the carbon that is emitted with burning the timber is a neutral carbon, unlike the one produced by burning the fossil fuels). (Lippke et al.2010)

Even though the use of wood has many advantages like affordability and high strength to weight ratio, its application in constructions faces many challenges. Wood is an anisotropic material that has different properties in different directions (up to 10times weaker in one direction compared to the other direction). Wood properties depend on species, cellular arrangement, moisture content, and location of the tree and location within the same tree (Forest Products Lab, 2010).

Because of its anisotropic nature calculations of timber structures become challenging. The simplest form of timber used in constructions for the structural purposes is a sawn timber.

In order to encourage the use of wood and to use it more efficiently many engineering wood products were developed. To mention few - Oriented Strand Board (OSB) panels, Medium Density Fiberboard (MDF), and glued laminated timber (Glulam). These products are manufactured in such a way to achieve desired engineering properties, such as high strength, durability, and consistency. Development of adhesion technologies and mechanical connections has increased the possibilities for wood based constructions. Beams can be glued/connected together to span larger lengths and to carry heavier loads.

Several **Timber Structural systems** can be find in the literature: (source structuraltimber.co.uk; trada.co.uk)

Most common structural form for timber structures is ***a platform structure*** (Figure 67) in which small sections of timber - wall studs, are used to support floor joists. Wooden panels are attached to these studs to form walls and floors. This kind of structural systems are generally lightweight and therefor can experience problems with structural stability. In cases in which strong wind forces occur this structural system could have problems related to 'lifting up' of the whole structure, causing large tension forces in wall panels. These large tension forces might be too large to be transferred on the lower levels and foundation and need to be properly addressed.

It is often to be seen in practice that lower floors of this type of timber buildings are made out of concrete. There are few reasons for that; firstly the concrete is strong enough to redistribute the large tensile forces to the foundation and secure the overall structural stability and secondly because of the moisture issues – moisture content in wood may vary from 0% in a very dry wood to more than 200% in a living tree. Moisture percentage affects the structural properties of the wood (strength, dimensions and weight) in general, which may cause larger stability problems.

(Timber) ***Framed structure*** (Figure 67) is another structural form in which large beams and columns (usually connected by steel dowels) form primary and secondary beam layout (just like frame structures in concrete and steel). This option offers bigger openness and flexibility of the floor plan with structural elements larger in size compared to previously mentioned platform structure. Glulam beams are usually used in this kind of systems. Glulam is type of beam whose layers are cut in the same grain and then jointed and glued together. Being jointed and glued in one direction consequently gives the predominant strength to the beam in that same direction. This is exactly the reason why glulam is used for structural beams. The biggest disadvantage of glulam is that the size of the structural elements is usually bigger compared to concrete and steel. On the other hand it has much lighter weight and consequently higher strength to weight ratio than concrete and steel. In order to keep this type of structure stable diagonal bracing is usually used, because bracing is more economic solution compared to a moment resisting connections in the frames.

Framed structures are not made exclusively out of glulam beams, sawn beams can be applied as well on this type of structural system. They do cover though shorter spans compared to the glulam beams.

Panelized or volumetric timber structures (Figure 67) *have* prefabricated roof-, floor- and wall-panels that can be easily assembled on site. Main form of this structural system is cross-laminated timber (CLT) panel. CLT panels are composed out of several layers (min 3, max 7 cross layers) of wooden boards that are glued perpendicular to their adjacent layers. Being perpendicularly glued it gives to a panel the strength in both directions rather than in one, as it does in glulam beams. Size of panels can vary and depends mainly on the transportation options. The biggest advantage of CLT is that the panels form strong and stiff structure that can be assembled relatively fast as the whole manufacture process is done off-site. Connections used for CLT panels are simple and easy to perform. Connections are usually performed with self-drilling threaded screws. These screws assure stable constructions that respond well to both vertical and horizontal forces. Next to the self-drilling screws concealed metal plates and dowels are also often used for connections. With panelized timber structures, the whole building design and calculations are shifted from frame to plate's issues.

The biggest disadvantage of this structural system is the non-flexibility of the floor plan, because CLT panels as load-bearing elements cannot be moved nor removed from its original position. Further, all openings on the panels need to be done in the factory and this needs to be well and precisely planned prior to cutting.

Figure 67 Timber structural systems - platform, framed and panelized

Timber use in construction industry in Rwanda is still in the very beginning phase. Timber is mostly used in its raw un-engineered forms (cut, brought to the construction site and used directly) and almost exclusively for the roof constructions.

However, first steps toward the wood introduction into Rwandan construction market have recently been made. In one small manufacturing school in the middle of the country first glue laminated eucalyptus beams have been locally produced. This is an important step on the road to the first possible timber building in Rwanda.

For the simplicity of the design and connections of the whole structural bearing system the bearing system that will be taken into the consideration for EU House will be timber framed structure. Considering the local context it is better to reduce the need for any engineered wood as much as possible.

9.4.1 Structural analysis

Considering only one (middle) structural bay only the governing load bearing members have been dimensioned. Verifications are done following the Eurocode5 for timber structures.

9.4.1.1 Material properties

Trees used for building purposes come from two groups of wood – softwoods and hardwoods. Softwoods type (marked in literature with letter C) is produced out of trees that are evergreen and that have needle-like leaves, while hardwoods (marked with letter D) come from broad-leaved trees. Strength class of timber combines timber type and the strength grade. Timber made out of softwoods has its strength class in the range of C14 to C40 while hardwoods timber has strength class ranging in between D30-D70.

Both softwood and hardwoods are used for the structural timberwork. Hardwoods, especially those timbers that are in the medium to high-density range, offer great advantages when compared to softwoods. They can reach longer spans, floors are thinner when compared to softwoods, have greater strength and stiffness and can consequently carry heavier loads. Additionally greater density of the hardwoods contributes to the additional fire resistance. Last but not least, hardwoods offer a great esthetical appearance.

Generally hardwoods are relatively easily worked and connected with simple hand or power tools. Hardwoods are available in different cross-sections whose dimensions are specified in similar way to the one that softwood has. (Figure68)

Sawn structural members are made of both mentioned groups of wood and their strength and stiffness will depend on several factors like moisture, slenderness, duration of the application of load, direction of the stress within timber and defects in timber, quality of joints, integrity of the cross-section. In this analysis-sawn timber with class D50 will be applied.

There where the structural members exceed the standard dimensions available on the market, a build up of two or more standard dimensions should be considered.

A built up structural members are constructed from several parallel wood members, which are nailed or bolted together to function as a composite member. Build up members are often used because they are easy to fabricate. The combination of several members in a build up member results in a member with a larger cross sectional dimension d and therefore smaller slenderness ratio l/d. For columns this will mean that larger stresses are allowed compared to single element from which the build up is made. However the bearing capacity of the build up Is not directly proportional to the number of members added, but it is needs to be reduced considering some safety factors. (Brayer et al.2003)

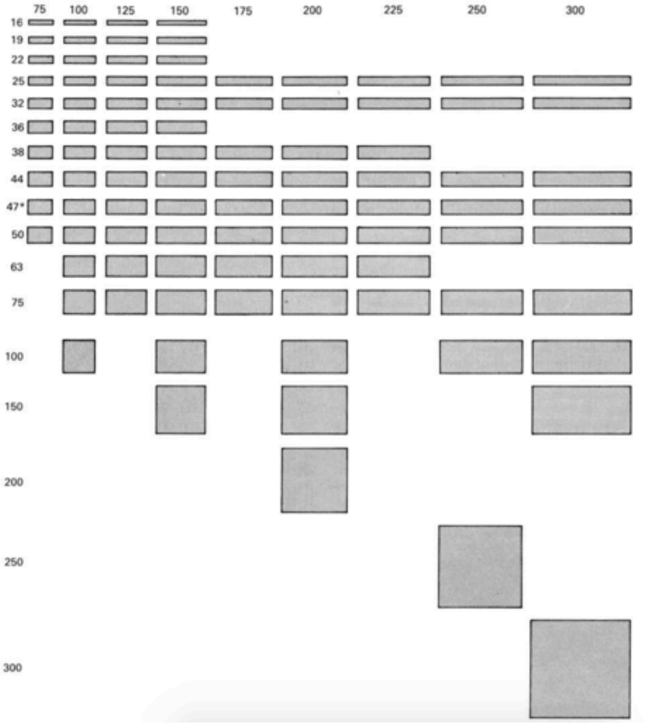


Figure 68 Standard dimensions structural softwoods (source Trada.com)

9.4.1.2. Loads

Estimation of the dimensions of the structural elements is initially done by using rules of thumbs and was adjusted later in order to optimize the dimensions. Loads have been calculated for two floors – the intermediate office floor and the roof floor. Governing loads between these two options have been used further for the calculation of the design load. The dead load of a typical wood floor an systems usually ranges in between 0,3 – 0,9 kN/m2 depending on the material of construction, span length, weather the ceiling is suspended below the floor or roof. For wood wall systems it is usually 0,2 – 0,9 kN/m2 depending on a stud size and spacing and the type of wall sheathings is used. (Brayer et al.2003)

Following load assumptions are applied:

Dead load:

-Self-weight will depend on the dimensions of the bearing elements

-Roof finishes: 0,20 kN/m^2

-Floor:

- Floor covering: 0,30 kN/m^2
- Separating walls: 0,20 kN/ m^2

Wood structural panels are used in two ways in floor construction: as one layer panel or as two layers panel. One system involves two layers of panels and the other system a single layer. Additionally a finish floor covering is provided in form of hardwood/tiles or carpeting. Figure 69 (Breyer et al., 2003)

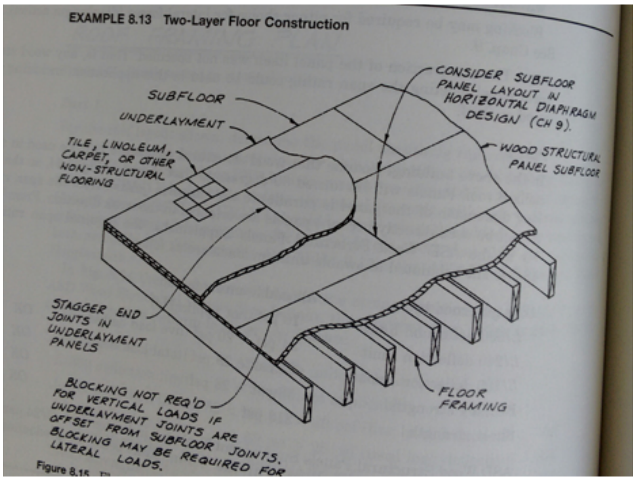


Figure 69 Two layer floor construction

Wood floor in the analysis is composed of wooden girders ctc 600 mm on which two layers of multiplex of 18 mm is placed.

Live load:

-Office: 3kN/m^2

-Roof: 1kN/m^2

Roof

Solar photovoltaic panels, that will need some checks and maintenance, are planned to be installed on the roof. This is considered in the calculations.

Walls -Inner walls

Inner separating walls are made out of wooden panels with plasterboards on both sides with insulation in between them. Different configurations and weight ranges can be applied– for this analysis inner separating walls with 0,2 kN/m2 of the dead load was considered.

9.4.1.3. Load bearing system:

Examples from various studies show that the most used load-bearing systems for higher multi storey buildings in timber are structural core in combination with glulam columns/ curtain walls or shear walls (interior or exterior).

Lateral force resisting systems used in ordinary rectangular buildings include moment frames, vertical trusses (braced frames) or shear walls. (Brayer et al.2003)

Moment frames resist lateral forces by bending in the frame members. Usually moment frames are constructed of concrete or steel and they are rarely constructed of wood.

Shear wall structures make use of a specially designed wall sections to resist the lateral forces. A shear wall is essentially a vertical cantilever with a span of the cantilever equal to the height of the wall. The depth of shear walls (the length of the walls) is in general much higher compared to the depth of the structural elements in moment frame option. Having the high depth of shear walls (respect to their height) in these elements the shear deformation will be governing (and not anymore the bending). (Brayer et al.2003)

European House is a low-rise building (3 story high) where no core is needed for its stability. Lateral stability, in this case, is guaranteed by shear timber walls (Figure 4-6) while sawn timber columns carry the entire vertical loads.

Position of the shear walls is in the line with design whishes for both ground floor and upper floors. Shear walls are connected on each floor and cover the total height of the building.

As the position of the shear walls of EU House is quite symmetric no torsional moments in the building are expected.

A timber-framed structure is the most convenient structural option in a developing country such as Rwanda. Therefore this type of structural system will be considered in further analysis. The ground floor will be made out of concrete and laid on the concrete foundation. On the upper floors, wooden paneled floor will be applied.

<u>Stability and bearing structure:</u>

Ground floor of the bigger building is slightly different than other floors (offices) as it host cafeteria space and a larger conference room (Figure 70) . It offers more 'transparent' space (intermediate/separating walls are taken out). Columns on the ground floor are in the same line as the ones on the upper floors (Figure 71).

Using only outside walls for stability of the ground floor would be impossible in this case, as timber panels screwed on timber girders are not suitable to span such a big distances. That is why the option with intermediate shear walls is chosen. Timber shear walls will assure buildings lateral stability. However, when various panels are mounted on girders, they can form a diaphragm, which usually is able to transfer horizontal forces. An additional reason is that the horizontal loads on a single wall are already quite high, so it would not be wise to reduce the number of walls.

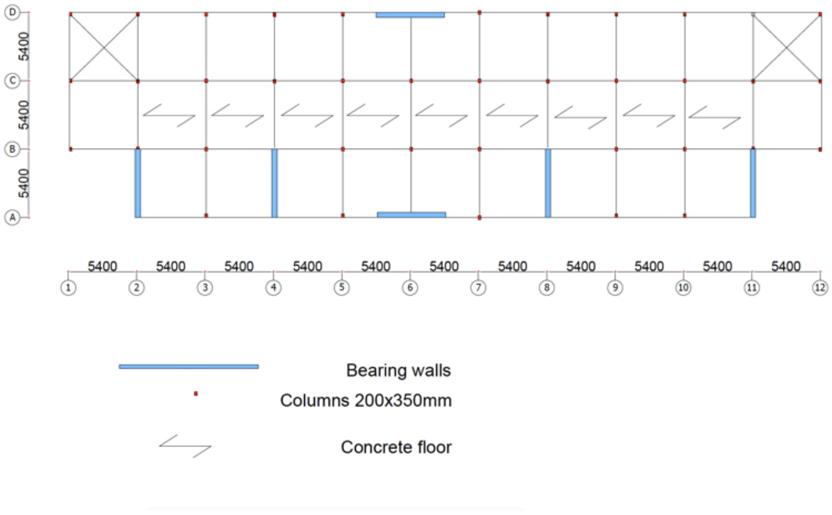


Figure 70 Ground floor load bearing system

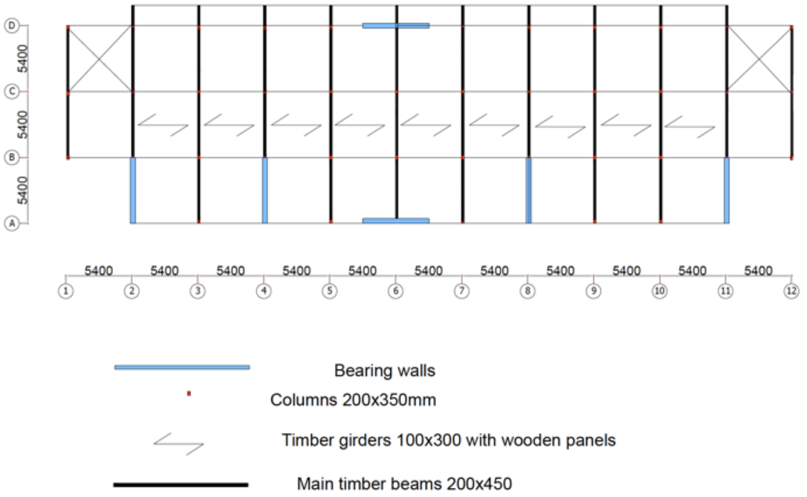
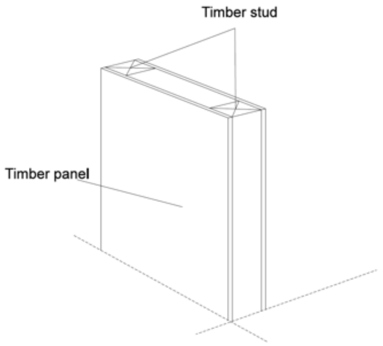


Figure 71 Load bearing system first second floor

Shear wall design:

For the calculation of the shear walls following assumptions are made:

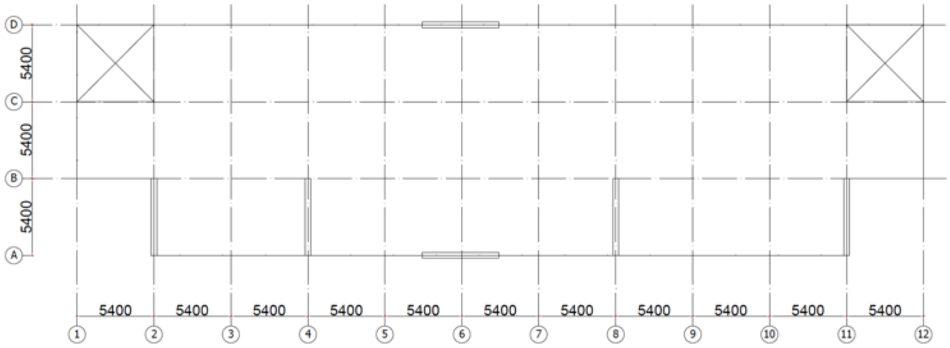
- Shear walls are composed of: 'skeleton' made of timber studs on each end of the shear walls and of timber panels that are connected on both sides of the skeleton



Shear wall

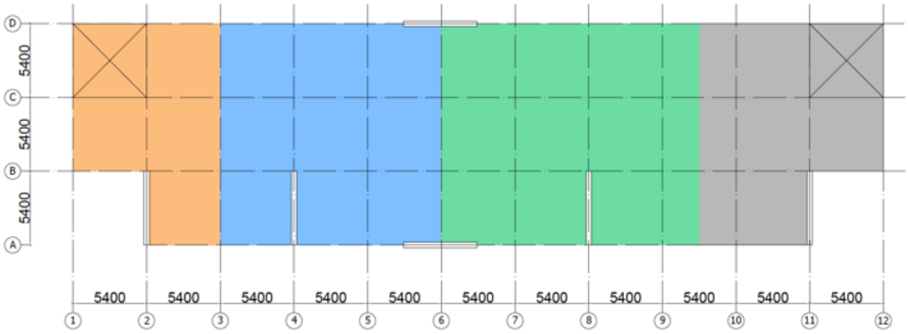
- If the length of the shear walls is 5,4 m the columns can be directly ‘used’ as studs
- Min amount of shear walls will be calculated in both directions (for the wind on short and long face)
- More walls with smaller dimensions would be a possible alternative
- 1 kN/m^2 of wind load in total (suction and pressure) is considered for each building side (following the map of the wind regions in the Netherlands it is assumed that Kigali area fits the best in the Area III (rural) on the map)
- 4 shear walls resisting lateral loads on the long side of the building
- 2 shear walls resisting lateral loads on the short side of the building

Building grid with shearwalls



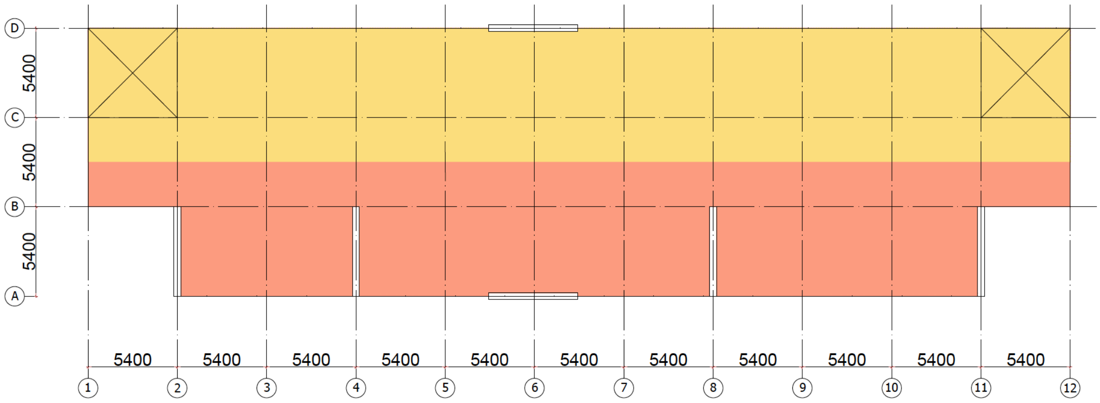
- tributary area of the shear walls on the long face of the building

Shearwalls (long face) with tributary areas



- (In the long direction the building will act as a beam on 4 supports with 5,4 m cantilever on each side) The governing shear wall (with the green tributary area) will be checked
- Tributary area of the shear walls on the short face of the building

Shearwalls (short face) with tributary areas



- *Wind load determination: (when no data is available – I used the Dutch values)*

Building height: 10,5m

Wind load = 1kN/m^2

Simplified formula for the wind load on a structure:

$q_{wind} = c_s c_d c_f q_p(z_e)$;

where

$c_s c_d$ are equal to 1 for low rise buildings

c_f has a value of 0,8 (pressure), or -0,5 (suction)

$q_p(z_e)$ = 0,71 kN/m^2 (Area III, rural)

F_i =1 x 0,8 x 0,71 kN/m^2 = 0,57 kN/m^2

F_i =1 x 0,5 x 0,71 kN/m^2 = 0,36 kN/m^2

Assuming the worse ever case scenario that wind suction and pressure have in the same time max values, the wind force in the calculation in rounded to 1 kN/m2.

LONG FACE

Wind load on the long face of the biggest tributary area (see figure 72) along the height of the shear wall:

$1kN/m^2$ x 18,9 m = 18,9 kN/m

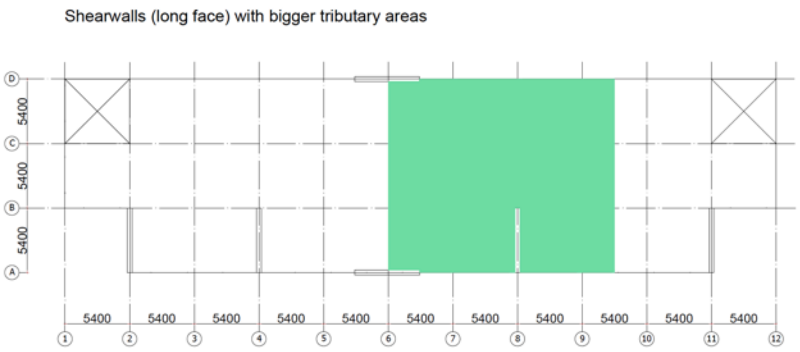

Shearwalls (long face) with bigger tributary areas

Figure 72 Biggest tributary area for the wall caring the wind load on the long face

<u>Distribution of the wind load by the length of the shear wall):</u> *(Figure 73)*

Wind load on the roof level = 3,5 m/2 x 18,9 kN/m = 33,1 kN x 1,5 (safety factor) = 49,6 kN

Wind load at Floor 1 and Floor 2 = 3,5 m x 32,4 kN/m = 66,2 kN x 1,5 = 99,2 kN

Vtot = 248,05 kN

M_{tot} = 49,6 kN x 10,5 m + 99,2 kN x 7m + 99,2 kN x 3,5m = 520,8 kNm + 1041,6 = 1562,4 kNm

T=C= M / 5400 mm = 289,33 kN

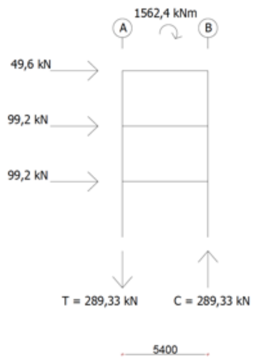


Figure 73 Wind load on different levels of the shear wall

Next to the wind forces, shear wall studs will carry vertical loads from floors and the façade as well (depending on their position in the building). Different tributary areas for timber studs have been marked in figure 74.

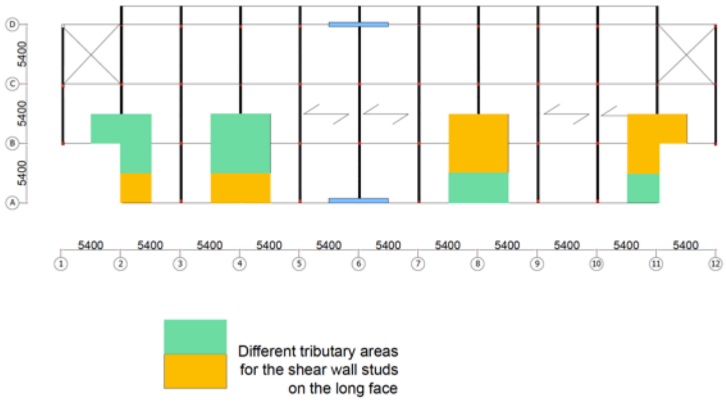


Figure 74 Tributaty area for timber studs

The biggest tributary area for the studs is 5,4m x 5,4m (timber studs/columns at B4 and B8) and the smallest 2,7m x 2,7m (timber studs/column at A2)

Timber studs/columns will be checked for min and max tributary areas in order to see weather the problem of tension in foundation will arise.

Timber studs/columns of the shear walls are made of wood class D50. For this analysis shear capacity of Kerto-Q panels will be verified. (Shear strength $f_{v0\,k} = 4,5\ N/mm^2$)

Area of studs needed:

$A_{studs} > C / f_c > 695020^*\ N/2/\ 6,21\ N/mm^2 > \ 55959,74\ mm^2$

Column 200x350 (Area 70000 mm^2) **O.K.**

*where 695020 N is the largest force acting on studs.

Verifying shear capacity of timber panels

$\tau = 3/2 \times V/A < f_{v0d}$

$\tau = 3/2 \times 248{,}05/2/\ (0{,}027 \times 5{,}4) = 1{,}28\ N/mm^2 < 2{,}77\ N/mm^2$ **O.K.**

In addition maximal bending of the shear wall panels will be checked (Figure 75) Max deflection of the shear wall panels can be calculated as: $\delta_{max\,=}\ \delta_{bending} + \delta_{shear}$

Max horizontal displacement allowed H/500 where H is the total height of a building.

$\delta_{max\ allowed} = H / 500 = 10500/500 = 21mm$

$\delta_{bending} = \Sigma\ F_i \times h_i^2 \times (3H - h_i) / (6EI)$

Where

F is the resulting wind force on different levels

h_i the height of the floors

E and I related to timber studs

$\delta_{shear} = k \times \Sigma\ F_i \times h_i / (GA)$

Where k is a shape factor that equals to 6/5 for the rectangular cross section

G and A related to the timber panel

$\delta_{shear} = k \times \Sigma\ F_i \times h_i / (GA) = 6/5 \times 1562{,}4 /(GA)$

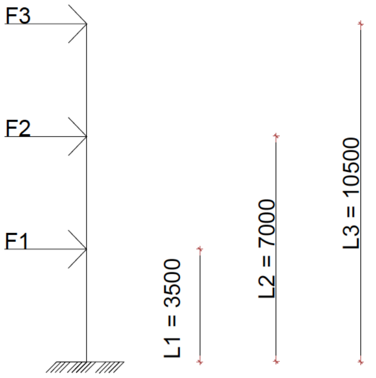


Figure 75

F1	99,2	kN
F2	99,2	kN
F3	49,6	kN

L1	3500	mm
L2	7000	mm
L3	10500	mm

L tot (height)	10500	mm

M tot from lateral forces	3753,108648	kNm

studs

number of studs	1	
b	200	mm
h	300	mm
E	7777,77	N/mm2
I	450000000	mm4

panels

number of panels	2	
width	27	mm
length	5400	mm
A	291600	mm2
G	500	N/mm2

δmax = L/500	21	mm

δ tot deflection = δbending + δshear

δbending	5,482987883	mm
δshear	25,74148593	mm
δ tot deflection	31,22447381	**FALSE**

Total deflection of the shear walls does not satisfy limit requirements when using timber panels of 27mm. By introducing for example thicker panels (with doubling the panel size on both sides, the deflection becomes 18,35mm which is under the limit of 21mm) or alternatively by introducing the intermediate studs (figure 76) this problem can be solved.

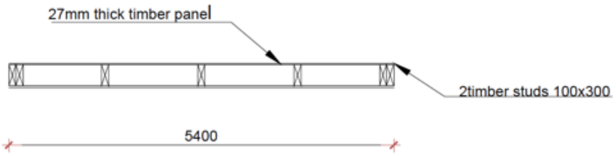


Figure 76 Shear wall section principle (columns take over the stud function in this case)

In the following lines studs/columns with min tributary area (2,7 x 2,7 m) are checked. (live load in load combination is considered to be extreme on 2 floors and on the rest of the floors reduced by the factor (factor 0,5)(EC); for the permanent load factor 1,35)

Shear wall on the long façade - less loaded

	Load	Width	Length	Live load	Live load factored	Permanent load
Roof	(kN/m2;kN/m)	m	m	kN	kN	kN
Live load	1,00	2,70	2,70	7,29	7,29	
Permanent load	1,34	2,70	2,70			9,77
Girders	0,17		5,40			0,92
Columns	0,50		3,50			1,75
Façade	0,50	5,40	3,50			9,45
Second floor						
Façade	0,50	5,40	3,50			9,45
Live load	3,00	2,70	2,70	21,87	21,87	

Permanent load	1,29	2,70	2,70			9,40
Girders	0,17		5,40			0,92
Columns	0,50		3,50			1,75
First floor						
Façade	0,50	5,40	3,50			9,45
Live load	3,00	2,70	2,70	21,87	10,94	
Permanent load	9,19	2,70	2,70			67,00
Girders	0,17		5,40			0,92
Columns	0,50		3,50			1,75
			TOT	51,03	**40,10**	**122,52**
			FACTORED		**60,14**	**165,40**

(timber studs 2x100x300)

number of studs	2,00	
width	100,00	
height	300,00	
L(height of the stud)	3500,00	mm
W	3000000,00	mm3
I	450000000,00	mm4
A (sectional area)	60000,00	mm2
Emodulus (D40)	7777,78	N/mm2

N from the wind	289,33	kN
N live load	60,14	kN
N permanent load	165,40	kN
N TOT	**514,88**	**kN**

σ = Ntot/A	8,58	N/mm2	
Md = Ntot x e	12,87	kNm	

Where:

e is the max value among:

lc/300	11,67	mm
h/10	**25,00**	**mm**
>10mm	10,00	mm

Euler critical Force:

Fcr = π2 * EI/l2	2817,03	kN	
n=Fcr/Ntot	5,47		
Md/W*n/(n-1)	3,51	N/mm2	
Max allowed bensing stress for D40	24,64	N/mm2	
TOT σ = Ntot/A + Md/W*n/(n-1)	12,09	N/mm2	**TRUE**

Following the same principle most heavily loaded studs in long direction have been checked.

N from the wind	289,33	kN
N live load	240,57	kN
N permanent load	165,12	kN
N TOT	**695,02**	**kN**
σ = Ntot/A	11,58	N/mm2
Md = Ntot x e	17,38	kNm

Where:

e is the min value among:

lc/300	11,67	mm
h/10	**25,00**	**mm**
>10mm	10,00	mm

Euler critical Force:

Fcr = π2 * EI/l2	2817,03	kN

n=Fcr/Ntot	4,05		
Md/W*n/(n-1)	4,36	N/mm2	
Max allowed bensing stress for D40	24,64	N/mm2	
TOT σ = Ntot/A + Md/W*n/(n-1)	15,95	N/mm2	**TRUE**

In case of less heavily loaded studs however, forces resulting from wind are higher than the forces from the structure, and therefore if no measures are taken the tension will be present in the foundation.

As mentioned in the introduction of this chapter, timber structures have usually ground floors constructed in concrete for this reason also – to provide the building with the additional weight avoiding the tension. For the purpose of this thesis further analysis on this will not be done.

SHORT FACE (Figure 77)

Wind load on the short face: 1kN/m^2 x 16,2/2 m = 8,1 kN/m

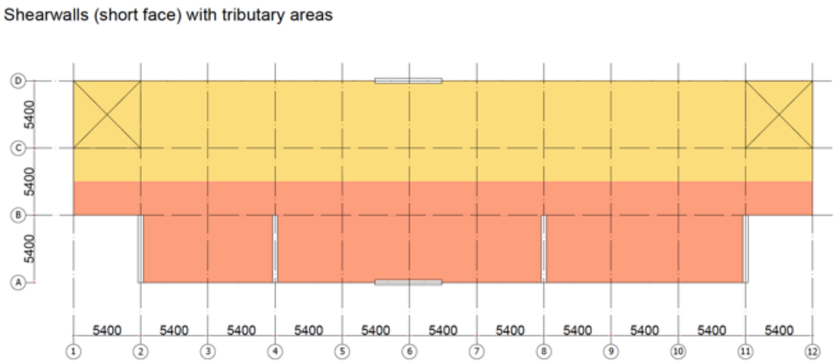


Figure 77 tributary area for the wall caring the wind load on the short face

Wind load on the roof level = 3,5 m/2 x 8,1 kN/m = 14,175 kN x 1,5 (safety factor) = 21,26 kN

Wind load at Floor 1 and Floor 2 = 3,5 m x 8,1 kN/m = 28,35 kN x 1,5 = 42,525 kN

V_{bottom} = 70,88 x 1,5 (factored load) = 106,31 kN

M_{tot} = 14,175 kN x 10,5 m + 28,35 kN x 7m + 28,35 kN x 3,5m = (148,83 + 297,65)kNm x 1,5 (factored load) = 669,76 kNm

For the wall 5,4m long : T = C = 124,03 kN

For wall 2 m long : T = C = 334,88 kN

Area of studs needed:

$A_{studs} > C / f_c > 334880\ N/ 5,72\ N/mm^2 > 58\ 341,1\ mm^2$

2 stud 100x300 (Area 60 000 mm^2) **O.K.**

Verifying shear capacity

$\tau = 3/2 \times V/A < f_{v0d}$

$\tau = 3/2 \times 106,31/2/ (0,027 \times 5,4^*) = 0,55\ N/mm^2 < 2,77\ N/mm^2$ **O.K.**

*Shear walls on the short façade can be much shorter than the ones on the long façade. They should however not be shorter than 2m .

$\tau = 3/2 \times 106,31/2/ (0,027 \times 2) = 1,49\ N/mm^2 < 2,77\ N/mm^2$ **O.K.**

Shear walls on the short face will carry the min amount of the load (**only the lateral load**) as the main beam that lies on the grid line 6 will carry all the loads resulting from the floor.

Having only lateral force acting on the shear walls the tension is almost obvious.

To minimize tension therefore, it should be best to place the shear walls in between two grid lines. (5-6 or 6-7). (It would be good to have a stud at grid line 6 for example (corresponding with a column A6) to carry the vertical loads from the main beams) In that case the wall would be longer – 5,4 m. Or alternatively to use shorter shear walls of 2 m and to couple the studs sideways to the adjacent columns over the whole length; then the tensile force can be (partly) compensated by the vertical compression in the columns (the columns would be functioning as the studs in that case as well).

Checking the bending of the shear wall panels (wall length 2000 mm) (Figure 78)

F1	42,52	kN
F2	42,52	kN
F3	21,26	kN
L1	3500	mm
L2	7000	mm
L3	10500	mm
L tot (height)	10500	mm
M tot from lateral forces	669,69	kNm
studs		
number of studs	2	
b	100	mm
h	300	mm
E	7222,22	N/mm2
I	450000000	mm4
panels		
number of panels	2	
width	27	mm
length	2000	mm
A	108000	mm2
G	500	N/mm2
δmax = L/500	21	mm
δ tot deflection =	δbending + δshear	
δbending	2,530948176	mm
δshear	12,40166667	mm
δ tot deflection	14,93261484	**TRUE**

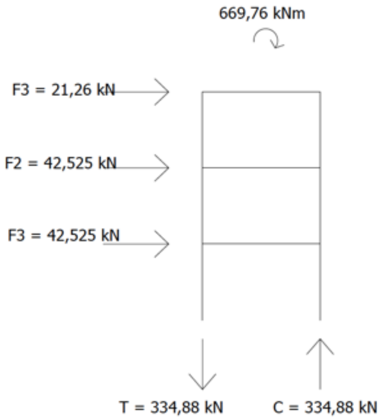
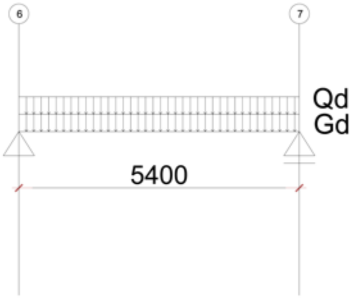


Figure 78 Shear wall panel

9.4.1.4. Timber girder 100 x 300

Floor system of the EU house consists of timber girders on which timber panels are nailed. Girders span 5400 mm from one load-bearing beam to the other. Centre to center distance between girders is 600 mm. In this analysis girder that lies on gridline B in between the grid lines 6 and 7 has been considered. The factors that are considered in calculations are bending, shear, deflection and bearing. First three items are governing the size of a wood member and the fourth item must be considered in the design of the supports. In many beams the bending stress is the critical design item. For this reason the trial size is got from the bending analysis and for the remaining items the trial size is then simply checked. The actual bending stress must be under the allowable bending stress (that takes into account all the adjustment factors that are required by the wood member. Girder is considered as simply supported beam loaded with continuous permanent and variable loads. The analysis of bending stress is usually introduced by assuming that the lateral torsional buckling of the beam is prevented (continuous support of the compression side (from diaphragm) prevents the member from buckling.

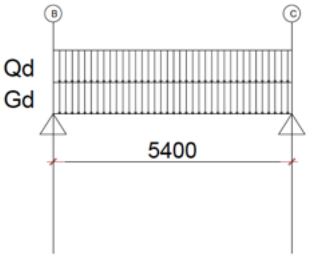


Verification	Unity check
Flexure	0,25
Shear	0,17
Deflection	0,65

Figure 79 Timber girder 100 x 300 verification

9.4.1.5. Load bearing beam design 200x450

Beam that lays on grid 7, in between grids B and C is calculated. The load to the beam in the analysis can be considered as a number of concentrated reaction loads from the girders. In practice, however, it is more common to assume that the load is uniformly distributed. Timber beam 200 x 450 mm is verified to be sufficient. From unity checks results that the deflection and the support stress check are just above their limits - as the load combination was considered to be really conservative this small exceed for this analysis is acceptable.

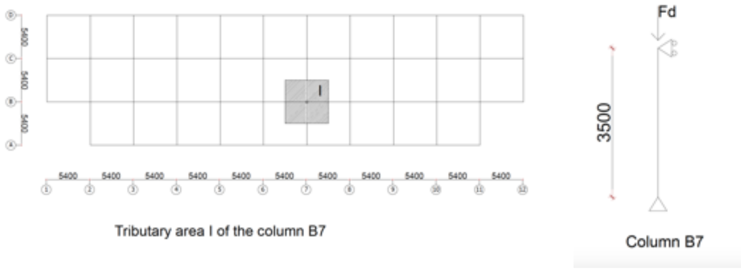


Verification	Unity check
Flexure	0,59
Shear	0,62
Deflection	1,05
Compresion/support stress	1,14

Figure 80 Load bearing beam 200 x 450 verification

9.4.1.6. Timber column design 200x300

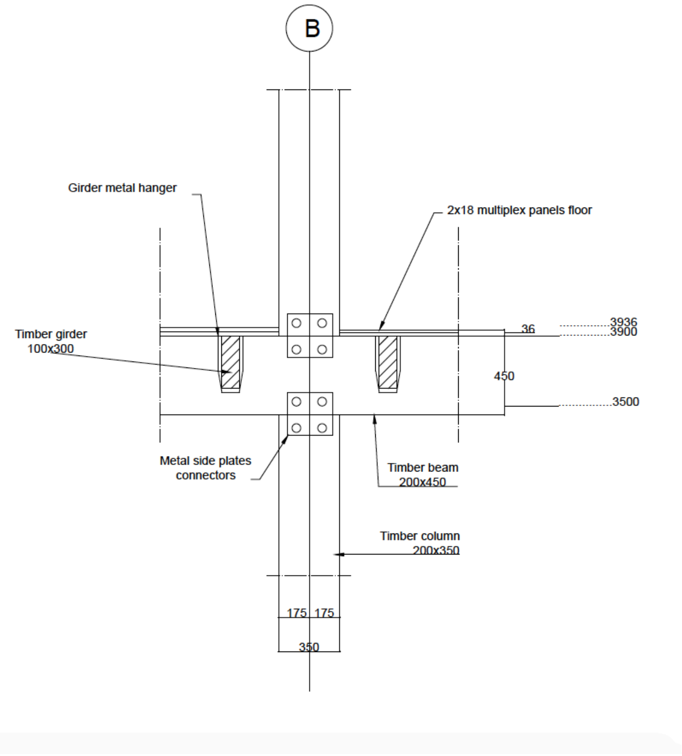
Column will be checked on axial compressive forces. No combination with bending forces will be considered as the columns are assumed to carry vertical loads only. Majority of the connection in ordinary wood buildings are simple connections and generally the effective length of the column is equal to the un-braced length of the column. Governing column B7 with its tributary area of 5,4 x 5,4 m has been verified. Column of a cross section 200x300 satisfy unity check requirements. (Detailed calculation in appendix) As the column is a non square column – weak axis is checked as well.

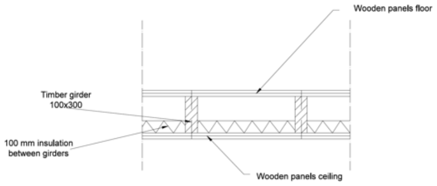


Verification	Unity check
Compression	0,48
Buckling	0,54

Figure 81 Timber column tributary area, mechanical scheme and verification

9.4.1.7. Construction detail of column/beam//floor connection and floor principle





9.5. Option Steel

Steel structures are not so common in Rwanda. Until the day of writing no steel building exist in Rwanda. Structural steel is locally not manufactured and it needs to be imported. That makes the steel less attractive material choice in construction sector. Considering its high embodied energy and additional transportation costs (and negative environmental impact) steel in this thesis will be analyzed only to compare the overall impacts that steel structure could have with other two options.

Detailed calculations are done followed the same steps as for the option timber (see appendix A4)

9.6. Option Concrete

Multi-story buildings are almost exclusively made out of concrete in Rwanda, with currently very little focus on sustainability. Recently increased tax rates on cement imported out of east African community shall contribute largely to the reduction of the embodied energy of the concrete (related to transport issues) used in building industry in Rwanda. On the other hand high demand against low availability does not encourage further investments neither in quality nor in sustainability issues (more efficient clinker production, more optimized mix design, use of sequestration technologies or new binders used in concrete production)

Detailed calculations are done followed the same steps as for the option timber (see appendix A5)

9.7. DuCo Analysis

Analysis of different options for load-bearing systems resulted in different dimensions of structural elements for each option. Following step will be to compare the environmental impact related to each option. That will be done with a help of a DuCo calculation method. DuCo is a great tool that can be used in a preliminary design phase to calculate the total amount of ‘environmental costs’ of the main load bearing structure. In DuCo analysis following load-bearing options have been considered and compared.

Option concrete:

Floor: Slab 250mm depth

Load bearing beam: 300x500

Column: 300x300

Option Steel:

Floor: composite floor

Main beam: HE280A

Girder: HE200A

Steel column: RHA 250x250x6,5

Option timber:

Timber girders: 100x300

Sawn beam: 200X450

Sawn column: 200x300

Tot shadow cost per kg of different materials is composed of 11 subcategories that have been tested and presented in data base form in the Dutch national environmental database. Shadow cost of the wood has been taken from the calculation software DGBC materialentool (where 11 subcategories are not visible, but only the final shadow cost; the program offers data of tot shadow cost of a reference building*. These datas have been divided by the m^2 and that price was used in DuCo analysis (*reference building is generated automatically after the amount of total building floor area is filled in together with building type and sustainability choices)

Following figures represent the shadow prices of load bearing structures of the European house considering the options timber, steel and concrete. Only floor, columns, and beams have been considered in this analysis and for the complete environmental analysis of the European building other building components should be considered as well.

Total shadow price per m^2 GFA per year for option timber is 0,21€, which is only 14% of the environmental cost that the structure of European house would have in case it was built in concrete, and only 25% of the total environmental cost in case that steel components would be chosen for the bearing structure.

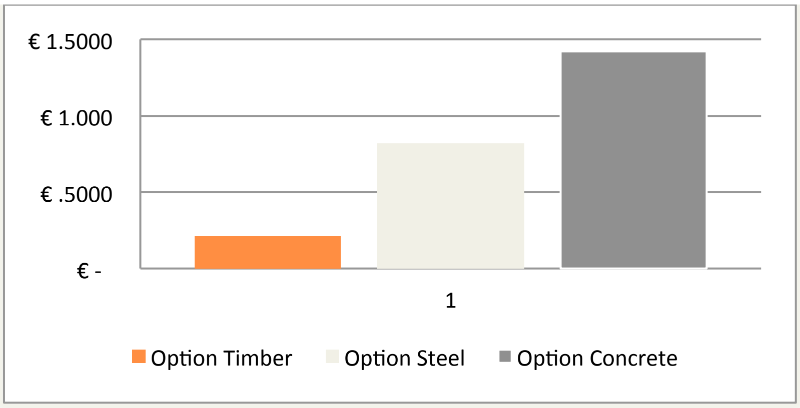


Figure 82 Shadow price European House

Pie charts below (Figure 83, 84 and 85)show percentages of the structural components for 3 analyzed options. In all three options floors take the biggest percentage in the environmental cost calculation. That is also expected as the floor volume is much larger compared to beam and column volumes in general. Having floors for the biggest contributors to the environmental cost, for the further optimization of the system different floor options should be considered and compared on base of their environmental impact

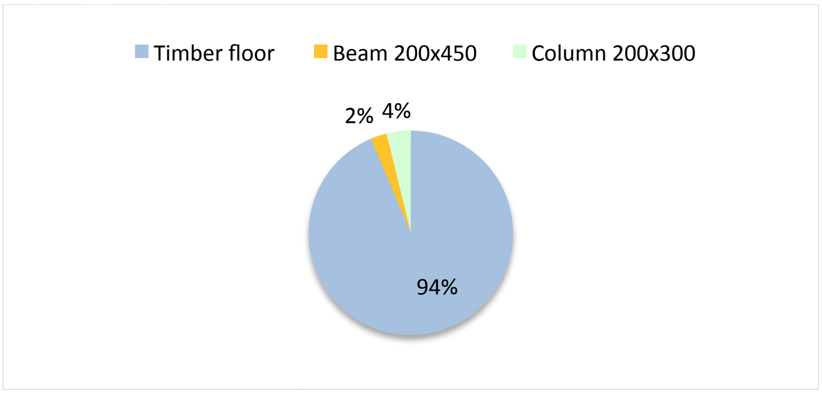


Figure 83 percentages of the structural components option timber

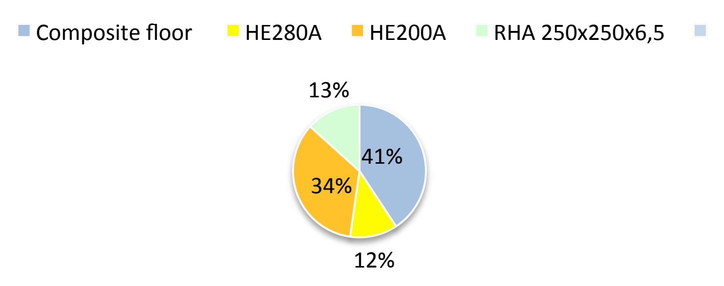


Figure 84 percentages of the structural components option steel

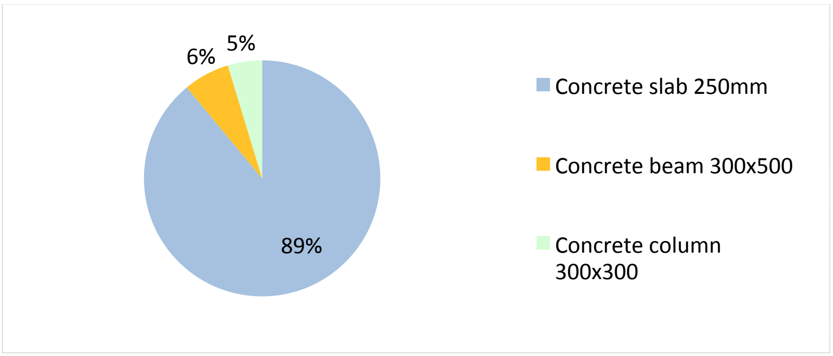


Figure 85 percentages of the structural components option concrete

Conclusions

Knowing a priori that concrete and steel have higher environmental impact, the results of the DuCo analysis does not come as a surprise. The final material choice for the structure is therefore clear – in the case of the European House, a wooden bearing structure offers much less environmental impact compared to other 2 options and therefore it is the preferred choice.

With the total environmental cost of the bearing structure of 0,21€ per m^2 GFA, the European House scores very high – this final price will positively influence the sustainable assessments of the European House as well (for example, the Material category of the BREEAM analysis offers extra credits for projects whose environmental cost price is kept low compared to the reference price (the reference price of around 1€ per m^2 GFA comes out of a hypothetical building that uses 'non sustainable materials') and for the projects that consider the Life Cycle Analyis of the Materials used in project.

For some further optimization, different floor options should be considered and compared on the base of their environmental impact as the floor area is the biggest contributor to the environmental cost (among considered components in this analysis).

Further on, as concrete scores environmentally the worst in this analysis, some alternative additives for concrete could be considered and compared to see how that would influence the total environmental impact.

10. BREEAM Assessment of EU House

10.1 Challenges of applying BREEAM International in Rwanda

BREEAM International credits in the category management are not related specifically to the location. In theory, all credits in management category should be equally possible to achieve on any place on earth. The number of achieved credits will depend on the capabilities, willingness and experience of all the stakeholders involved in project. A BREEAM Accredited Professional and a sustainability champion, both hired from the beginning of the project, are responsible for highlighting phases and things that need to be considered and achieved through the whole design and post design process. Therefore, by hiring the right expert or by training the professionals, this category can score the highest number of credits in Rwanda as well. Furthermore all the subcategories of Management category are relevant and can be applicable in Rwandan context as well. The subcategory of ‘Responsible construction practice’ might face some challenges though, as no certified timber is locally used in Rwanda.

In the category Health and wellbeing, the biggest accent is on the right design decisions, as most of the credits are directly related to the design choices. Taking into account passive choices from the early stage of the project is crucial to score high in this category, in the Rwandan context in the same way as in any other context. While some of the design choices are already common practice in Rwanda (like designing to maximize natural light and to control glare), other possibilities like the making of an indoor air quality plan, post construction indoor quality measurements and acoustic performance, are not. The subcategories of Health and Well Being category are applicable and relevant in Rwandan projects as well. Challenges in this category are related to the absence of local standards for internal noise levels and standards for the ventilation.

In this thesis, the accent is on energy neutrality. Therefore, the Energy category is expected to score high. Challenges related to this category will be to compare the energy performance with local standards as there are no energy efficiency requirements legislated by the current Rwandan building code standards. To meet this challenge and to get some ‘numbers’ about the energy performance of existing office buildings in this thesis, a questionnaire related to the energy consumption issues was made for few other offices that have similar functions. In this way it was possible to get some reference points. The application of the passive principles is also important to score high in the Energy category. The Rwandan climate is very favorable for the passive design application; therefore it is the design team’s responsibility to integrate the passive strategies as much as possible into the design. Even though the energy monitoring is not a common practice in Rwanda it is easily applicable on local projects.

BREEAM International uses calculations for Transport accessibility index that would probably need some adjustment in the Rwandan context. Another challenge of the transport category might be the fact that no reliable bus travel plan exists yet in the city. Busses run rather sporadically and without a fixed schedule. This could be solved by introducing car sharing/collective bus service for the building occupants. Kigali is one of the few cities in Africa that has invested in good master plan studies. The Kigali Master plan was made keeping sustainability into account. When developing certain parts of town, it was kept in mind the distances of the different amenities as well. Therefore it is expected that once the master plan is implemented, credits related to this category will be easier achieved.

Water category is one of the categories that are location dependent. As most cities in developing countries, Kigali faces water shortage. Next to that, the quality of drinking water is an issue in Rwanda. In the Rwandan context it will be important therefore to make a good water management plan and to use the separation between gray water systems and clean water systems (and to install the equipment that is water use efficient).

Water monitoring and water leak detection are not common practice in Rwanda even though they can be easily applicable on the local projects.

Challenges in the Material category might be related to the Environmental Product Declaration of the used materials. This certificate/declaration is produced by third parties and does not depend on the projects stakeholders; therefore the credits will depend on the competences of the companies that supply the construction material, which in Rwandan context can be a challenge. Locally no certified timber is available. Furthermore, the use of local materials should be encouraged and explored as this would influence positively the amount of the embodied energy of the used materials (a significant proportion of building components, materials and finishes used in Rwandan projects are imported from overseas).

Waste category encourages good design and construction practices in any context in order to reduce the waste arising from the construction and operation of the building. Therefore this category is relevant for Rwanda as well. The whole market of recycling of construction waste is still underdeveloped in Rwanda. Local experts estimate that projects in Rwanda could reuse or recycle up to 70% of all demolition and construction waste. In the moment no recycled aggregates are present on the construction market, even though there are possibilities for that (local volcanic ash). However this action would require further studies. Great performance of the design team and the local contractor is essential to score high in this category. To get a local contractor who can deliver satisfactory results in this field is challenging in Rwanda, therefore some experts should be hired.

Land Use and ecology category might bring some challenges as well, as many of the buildings and neighborhoods in the Master Plan are planned on previously unoccupied land. Therefore, this category is very relevant within the Rwandan context. By engaging professional ecologist in the project, it should be possible to reach credits reserved for this category.

Pollution category is relevant for the Rwandan context as well. This category will have no big impacts on the building design choices. Issues of the biggest relevance and challenge for Rwanda are flood risk and watercourse pollution.

Innovation category is relevant for Rwandan context as well as it promotes sustainable innovations that are better or even out of scope of current regulations. In addition, the category innovation promotes the introduction of new initiatives in sustainable design, which contributes to the new sustainable design solutions.

In conclusion, all categories and subcategories offered by BREEAM International are relevant and applicable in the Rwandan context. However, some of the BREEAM International credits would need to be adapted to the local Rwandan context. This regards mostly the credits that are referenced to the local legislations. They are summed up in Figure 86:

Management	***Challenges in Rwandan context***
Man 03 Responsible construction practices	*no certified timber used until now in Rwanda
Health and Well being	
Hea 02 Indoor air quality	*no requirements are stated for the minimum percentage, positions, arrangement and size of openable area
Hea 05 Acoustic performance	*there is no specific standard for internal noise levels in Rwanda.
Energy	
Ene 01 Reduction of energy use and carbon emissions	*There are no energy efficiency requirements legislated by the current Rwandan building code standards
Ene 05 Energy efficient cold storage	*There are no energy efficiency requirements legislated by the current Rwandan building code standards
Ene 06 Energy efficient transport systems	*There are no energy efficiency requirements legislated by the current Rwandan building code standards
Transport	
Tra 01 Public transport accessibility	*probably the calculatons of AI will need to be adopted to the Rwandan context
Tra 04 Maximum car parking capacity	* this credit would refer to the Rwandan local, provincial or national authority planning allowances for car parking spaces
Water	
Wat 01 Water consumption	*calculation should take into account local rainfall values
Materials	
Mat 03 Responsible sourcing of construction products	*no certified timber used until now in Rwanda
Waste	
Wst 02 Recycled aggregates	* more study on recycled aggregates needed
Polution	
Pol 02 NOx emissions	*Many projects do not comply with this credit because of the high cost associated with the type of generator
Pol 04 Reduction of night time light pollution	*there is no specific standard for night time light levels in Rwanda.
Pol 05 Reduction of noise pollution	*there is no specific standard for internal noise levels in Rwanda.

Figure 86 BREEAM International credits that meet challenges in Rwandan context

In theory, there are no real obstacles to obtain high credit scores in the Rwandan context in BREEAM International Assessment. However the experience and the knowledge of project stakeholders, the knowledge of the challenges that Rwandan context offers and the creativity and capability in embracing of those challenges are essential factors to reach high BREEAM scores.

10.2 Route to BREEAM Outstanding in Rwanda

Among results from target zero studies (studies of comparison of newly built non domestic buildings in the UK), there is a guideline on how to most cost effectively achieve the BREEAM outstanding score.

Target zero proposes 9 intermediate steps to the final BREEAM outstanding goal:

1. Define planning policy and client requirement

2. Determine the target rating

3. Determine site factors and influence on credit

4. Review min standards for target rating

5. Experience of design and construction team for rating BREEAM

6. Review strategic design credits

7. Review potential costs of highest cost credits

8. Propose a route to target rating

9. Compare potential and target rating

Each step will further be applied and discussed related to Rwanda context.

1. Define planning policy and client requirement

This is a quite straightforward step. For the projects that are orientated on sustainable solutions it is important to hire adequate individuals (accredited professionals and a sustainability champion) from the first phase of the project. They will help making the planning policy, writing the right brief and monitoring the further project process.

2. Determine the target rating

The target rating will depend on the requirements in the brief. If the target of the project is an energy neutral and sustainable building, then it would be logical that the focus of the project is on incorporating sustainable solutions and reducing energy demands by applying passive design strategies into the project and therefore aiming to an outstanding rating for BREEAM.

3. Determine site factors and influence on credit

Factors that contribute to the high scores in Rwanda are related to: the use of passive design principles, choice of strategic site position, use of natural ventilation, reduction of CO_2 emission by energy saving

Factors that contribute to the low scores in Rwanda: water shortage**,** reliable transport network**,** use of recycled and reused materials, waste management, environmental product declaration, non existing of the local regulations.

4. Review minimum standards for target rating

Minimum standards for BREEAM outstanding rating are defined by BREEAM international as follows:

Minimum standards for BREEAM OUTSTANDING

Man 03 Responsible construction practices	2 credits (Considerate construction)
Man 04 Commissioning and handover	Criterion 10 (Building or home user guide)
Man 05 Aftercare	One credit (Seasonal commissioning)
Hea 01 Visual comfort	Criterion 1 only (High frequency ballast)
Hea 02 Indoor air quality	Criterion 1 only (No asbestos)
Hea 06 Accessibility	Two credits (Inclusive and accessible design -residential buildings and residential institutions only)
Hea 08 Private space	One credit
Hea 09 Water quality	Criterion 1 only (minimise legionellosis risk)
Ene 01 Reduction of energy use and carbon emissions	Ten credits
Ene 02a Energy monitoring	One credit (First sub-metering credit)
Wat 01 Water consumption	Two credits
Wat 02 Water monitoring	Criterion 1 only (mains water meter)
Mat 03 Responsible sourcing of construction products	Criterion 1 only (Legal timber)
Wst 01 Construction waste management	One credit
Wst 03a Operational waste	1 credit

5. Experience of design and construction team for rating BREEAM

Experience of the whole project team is essential for rating BREEAM. Experience of the team should be part of the criteria when selecting all the project stakeholders. The desired BREEAM rating should be included in brief and all the parties should work towards the desired score from the very first beginning of the project.

6. Review strategic design credits

Credits that influence design decisions should be taken into account from the early phase of the projects. These credits come from the following BREEAM categories:

- Management category (based on LCA different options related to the structure, envelope and finishes are possible)
- Health and well being category (visual comfort – day lighting, size and arrangements of the operable areas to facilitate good ventilation)
- Energy category (passive design strategies; potential for natural ventilation)
- Waste category (flexibility of the floor plan to accommodate different functions in the future)

7. Review potential costs of highest cost credits

N/A in this project

8. Propose a route to target rating

The target rating Of European House is BREEAM **outstanding**, which means that project need to score at least 85% of all the weighted credits. Categories are weighted in following way in BREEAM International:

Management 12%, Health and Wellbeing 14 % (with the exception of Hazard subcategory of 1%) Energy 19%, Transport 8%, Water 6%, Materials 12,5%. Waste 7,50%. Land use and ecology 10%, Pollution 6,5% for a total of 100% (plus additional 10% for innovation credits)

In order to adopt weightings criteria for local conditions, the weightings are reviewed for the first project that registers for BREEAM assessment in the country. These weightings become a base to all other projects thereafter in that country/region that are rated with that version of BREEAM International. The weightings outcome is based on robust and independent information forwarded from a 'local experts' who know the local environmental conditions and who can be a team member or another relevant expert. (BREEAM International 2016) Until this moment (September 2016) no BREEAM International rated building exists in Rwanda and therefore the general weightings proposed by the BREEAM International will be applied on European House.

The first and the most important step on the road to BREEAM outstanding in Rwanda is to form a professional and experienced project team. It should be aimed to have *Management* category fulfilling all the credits available.

As the focus of this particular thesis is on Energy neutrality it is logical to aim for the *Energy* category is to fulfill 100% of the credits. Rwanda has a great climate that offers a lot of possibilities for the passive design strategies to be incorporated into the project. All the possibilities of the passive design should be studied and applied on project.

Further on, the local zero carbon energy sources should be studied and included into the project as well. Focusing on passive design choices *Health and well-being* categories credits can be easier reached.

Water is category that is very important for Rwanda and therefore specific solutions should be proposed to achieve max number of credits in this category.

In addition, credits from category Pollution offer great possibilities to be completely reached in this specific project.

Category *materials* could loose some credits for the verified products declarations, but in general if life cycle assessment tools are used for the comparison and selection of the construction material, most of the credits are expected to be reached.

10.3 Conclusions

BREEAM International credits studied in the Rwandan context show that most of them are actually possible to reach, assuming that the project team is experienced in the BREEAM field and that clear goals are set from the very beginning of each project. In theory there are no real obstacles to obtain high credit scores in the Rwandan context in BREEAM International Assessment. However some of the BREEAM International credits would need to be adapted to the local Rwandan context. This regards mostly the credits that are referenced to the local legislations.

Categories of Management and Energy have realistic potential to score high credit numbers in European House project. It can be expected that the category that will prove to be the most challenges in Rwandan context is the category Materials. Construction materials are in general of a poor quality in Rwanda and the chance of their reuse is very small. Environmental declaration of the material products will depend on the information provided by the supplier, which is a third party and the quality of their services cannot be guaranteed. Some of the factors that contribute to the low credits score are therefore related to the use of recycled and used materials and the environmental product declarations.

One other issue is worth mentioning. The importance of local conditions is crucial when considering environmental impacts and their prioritization. Climatic conditions, natural resources, location, contractors and design team assumptions – all influence the framework of the sustainable rating system. In order to be used in a different context with different regional priorities, assessment tools should offer flexible frameworks that could be adjustable from project to project. BREEAM International is one of the few assessments that offer possibilities for assessments of projects worldwide. However, the weighting of the categories in BREEAM International assessment are still universal. Rwanda experiences unique challenges that can be very different from the other countries where BREEAM International is used. In the case of Rwanda, the categories that should be weighted heavier are the categories Water, Land Use and Ecology and the Surface run-off as these categories present environmental and real danger that Rwandan inhabitants are exposed to.

10.4 European House BREEAM assessment

Through the BREEAM international assessment, it is studied whether it is possible in the Rwandan context to create the European House building that score outstanding on sustainability. (detailed study in the appendix)

Based on the combination of concrete proofs and realistic assumptions score of 85,3 % is achieved). In this scenario European House reaches max credits in categories of Management, Energy, Water and Pollution. (Figure 87)

It is to underline that credits in category water, previously descried as ‘challenging’ can be fully achieved when proper water collector, storage and monitoring system is introduced in the project. Category materials, Waste, Transport and Health and wellbeing score the lowest as it was expected. (Figure 88)

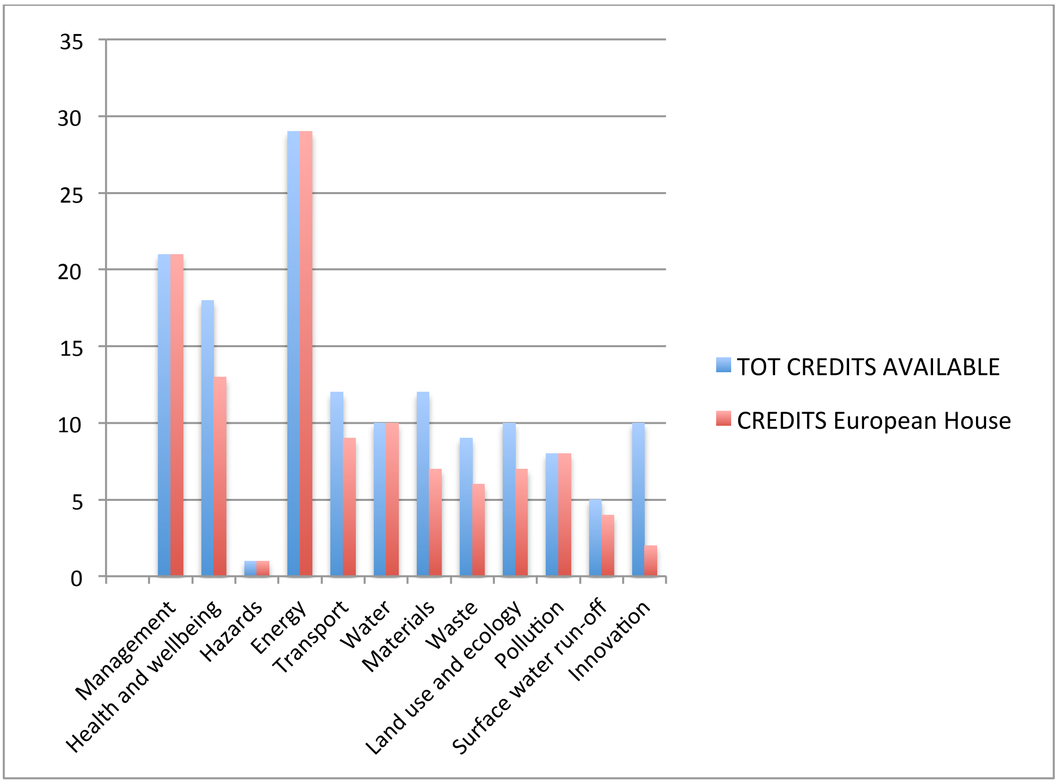


Figure 87 BREEAM International assessment European House – credits achieved per category vs tot credits available

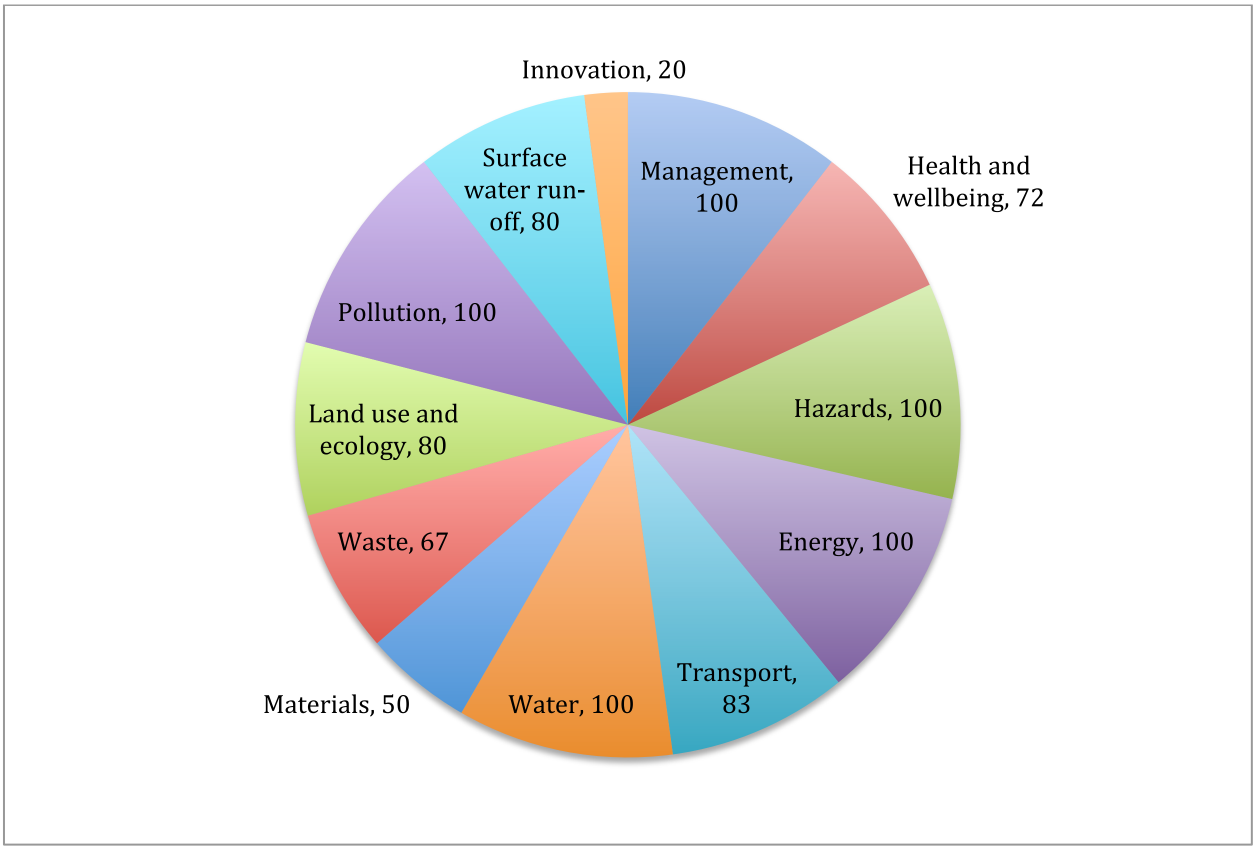


Figure 88 Percentage of the credits that each category achieved in the European House project

11. Conclusions

The aim of this thesis was to find answers on the question: *How can a European house in Kigali be optimally designed in an energy neutral and sustainable way?*

To determine the answers, the following issues applied on the proposed design of the European House were studied: use of local building materials, passive and active design strategies and BREEAM International sustainable assessment.

Use of local building materials

When applying timber bearing structure on the European House, the total environmental cost of the bearing structure is 0,21€ per m^2 GFA. In this case, the wooden bearing structure offers much less environmental impact than other possible solutions and therefore it is the preferred choice. However, timber in Rwandan constructions is still not being used in structural applications, even though it offers great potentials and it is available and possible to be imported from DR Congo – Rwanda's neighboring country.

Passive and active design strategies

The following passive strategies proved to be effective in the Kigali climate and could therefor be applied to the European House design:

<u>Orientation</u> – long narrowly designed buildings with long side along north/south facade

<u>Shading devices</u> – horizontal devices should be installed on northern and southern facades

<u>Size of windows</u>: wall/window/ratio should be at least 40%, European House window dimensions should be 1,8x1,8m

<u>Natural ventilation</u>: On the proposed design of the European House, the best applicable method is natural side ventilation

Active design strategies

Focusing on sun and wind local potentials, Energy potential mapping gives encouraging results. Most of the locally available energy could be obtained from the sun, in case all the roof area would be covered by Photovoltaics. In order to assure buildings self-efficiency, it is essential to have an energy storage system/battery, to be able to use the harvested energy in different moments if needed. In the Equator area (which is the case in Rwanda), the solar generation does not change a lot during the year and therefore no large amount of storage is needed. Storage that equals to 3,5 days of average generation should serve as a reasonable backup (this equals to the storage capacity of 1061 kwh in case of Rwanda).

In conclusion - with integrating passive and active design strategies on the European House design, 2,5 times more energy is obtained than required.

BREEAM International sustainable assessment

BREEAM proved to be a very useful tool on the road to sustainable and energy neutral design in the Rwandan context. BREEAM International credits studied in the Rwandan context show that most of them are actually possible to reach, assuming that the project team is experienced in the BREEAM field and that clear goals are set from the very beginning of each project. In theory there are no real obstacles to obtain high credit scores in the Rwanda. However some of the BREEAM International credits would need to be adapted to the local Rwandan context. This regards mostly the credits that are referenced to the local legislations.

In conclusion – the example of the European House in Kigali shows that an energy neutral and sustainable office building with an outstanding BREEAM rate is possible in Rwanda. Perfect climate conditions and renewable energy potentials are there, to be discovered and used in a smart and responsible way. Rwanda of course misses many things, without which some parts of my analysis would be hard to materialize – like an environmental database for different types of construction materials. Further more, many parts of the BREEAM analysis are assumed to be achieved under good management and financial means which are both hard to find in Rwanda. However, the realization of this or a similar project could inspire a new way to look at possibilities for sustainable and energy neutral buildings in Rwanda.

Recommendations for other developing countries

- Make a climate study of the location a 'must' for any type of construction project in order to reduce the overall energy costs and building performance, even if this is not required by local building regulations
- Introducing sustainable assessment methods (BREEAM International) in projects in developing countries encourages the use of passive strategies and influences sustainable outcomes. BREEAM International is a valuable tool to be applied on projects in developing countries. However, when certain datas are not available, one needs to be resourceful
- Often the choices of materials applied for structures is related to the fact that local workers only know specific methods and are 'afraid to build differently'; Rwanda's recent example shows that local workers can easily be trained to use different building techniques
- The benefits and high potentials of sustainable and energy neutral buildings in developing countries need to be better explained and promoted to all parties involved.

Suggestions for further research based on this thesis

- Further improvement of other widely used construction materials (adobe bricks) and their structural application in multi story buildings in Rwanda
- Possibilities of creating a Rwanda National scheme based on BREEAM International Assessment
- Challenges of building techniques from vernacular to modern in Rwanda
- In case of rising temperatures due to climate change, what kind of consequences would this have on the natural ventilation possibilities in Rwanda?

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APPENDICES

A1 BREEAM International of European House

A2 Interview questionnaires

A3 BREEAM Assesment of case studies

A4 Preliminary structural design option steel

A5 Preliminary structural design option concrete

A1

BREEAM INTERNATIONAL
European HOUSE, Kigali, Rwanda

BREEAM RATING ACHIEVED: **OUTSTANDING**
BREEAM SCORE EUROPEAN HOUSE **85,32777778**

Weight.f	CATEGORY/Subcategory	Available Tot Credits	Total credits possible to achieve in European HOUSE Rwanda	Remarks
12%	**Management**	**21**	**21**	**Credits in management category are expected to be fully achieved by importing external BREEAM consultants from abroad*
	Man 01 Project brief and design	**4**	**4**	
	A clear **sustainability brief** is produced before the concept design. The brief includes: client requirements regarding sustainability, BREEAM rating targets, and involvement of the other professional consultants in project, budget, time schedules and limitations of the project. From the design brief stage different stakeholders (client, building occupiers, contractors and design team) work together making decisions together and identifying their roles, responsibility and contributions during each phase of the design and construction process	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where project can demonstrate how the stakeholder's contribution and involvement influenced or changed the initial project brief or concept design	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where sustainability champion is involved in the design brief stage	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where sustainability champion is involved in the whole design process	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Man 02 Life cycle cost and service life planning	**4**	**4**	
	Where an elemental life cost cycle (LCC) analysis (service life, maintenance, operation and possible replacement costs) is done based on the conceptual design	2	2	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where LCC of the building components (envelope, services finishes, landscaping) is done in design stage of the project.	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where the capital cost of the building is reported via BREEAM Assessment scoring and reporting tool	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Man 03 Responsible construction practices	**6**	**6**	
	Where project team completes the checklist of actions to minimize air and water pollution	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where sustainability champion is appointed during the whole **construction** phase	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where sustainability champion monitors the energy use, water consumption and transport data as well	2	2	
	Where the contractor shows that he is in the line with BREEAM guidelines regarding responsible construction practices. This can be demonstrated by filling in the checklist	2	2	Applicable in Rwanda needs to be done with the help of an expert imported from abroad Min standard requirement for BREEAM Outstanding
	Man 04 Commissioning and handover	**4**	**4**	
	Where the main contractor prepares the commissioning schedule in the line with appropriate standards (best national practice commissioning codes or other standards)	1	1	Applicable in Rwanda Min standard requirement for BREEAM Outstanding needs to be done with the help of an expert imported from abroad
	Where the building services are commissioned as well	1	1	Applicable in Rwanda needs to be done with the help of an expert imported from abroad
	Where testing and inspecting of building fabric is done (thermographic survey or airtightness test and inspection)	1	1	Applicable in Rwanda - needs to be done with the help of an expert imported from abroad as in general no air tightness tests conducted on buildings in Rwanda
	Where buildings users guide is developed	1	1	Applicable in Rwanda
	Man 05 Aftercare	**3**	**3**	
	Where monitoring of energy and water consumption is done for a period of at least 12 months after the building is built	1	1	Applicable in Rwanda even though it is not common practice in Rwanda
	Where sessional commissioning about the thermal comfort, ventilation and lightning are measured on the base of the occupants feedback at 3, 6 and 9 months intervals and all the deficiencies are collected into the manuals	1	1	Applicable in Rwanda even though it is not common practice in Rwanda Min standard requirement for BREEAM Outstanding
	Where after 1 year of builidng use, the post occupancy evaluation about internal environmental conditions is done	1	1	Applicable in Rwanda even though it is not common practice in Rwanda
14%	**Health and Well being**	**18**	13	**credits related to indoor air quality issues might be difficut to test and verify*
	Hea 01 Visual comfort	**4**	4	
	Where sufficient daylight factor is provided (1,5% for the latitude < 40)	1	1	It is already a practice to design to maximise natural light in projects
	Where glare control strategy is aplied through builidng form and layout or builiding design measures (shades)	1	1	Comes with the design; Min standard requirement for BREEAM Outstanding *Glare can easily be controlled through louvers, blinds or types of glass
	Where all workstations have view to outside within 7m and the view should be to a landscape or buildings, rather than the sky	1	1	Comes with the design - buildings are already designed in Rwanda to maximise external views to the floor plate
	Where the illumincance level aappropriate the task that is undertaken and where users have the possibility to control the shading system on all windows, glazed doors and room lights	1	1	Assumed that it comes with the design
	Hea 02 Indoor air quality	**6**	**3**	
	Where an indoor air quality plan is made (related to removal of contaminated sources, control of contaminany source, third party testing and keeping up the level of the indoor air quality in use)	1	1	Min standard requirement for BREEAM Outstanding not common in Rwanda but applicable
	The building has been designed to minimize the concentration and recirculation of pollutants providing fresh air into the builidng in accordance with the criteria of the national best practice standard for ventilation	1	1	Comes with the design (natural and cross ventilation) *no requirements are stated for the minimum percentage, positions, arrangement and size of openable area
	Products that should be tested on emission limits content include: wood panels, timber structures, wood flooring, floor covering, suspended ceiling tiles, flooring adhesives, sealants and wall-coverings.			
	Where at least four categories of above mentioned products are tested	1	0	depending on the suppliers, might be difficult to achieve
	Where post construction indoor quality measurements are done	2	0	not a common practice in Rwanda but it can be applicable on local projects (need of external eperts)
	Where there is a possibility for the natural ventilation in builiding	1	1	Comes with the design
	Hea 03 Safe containment in laboratories	**0**	**0**	
	N/A			
	Hea 04 Thermal comfort	**3**	**1**	
	Where local thermal comfort critera is used to determine a themal comfort level of the builidng	1	1	This streategy comes with the design
	In case that the climate change comfort levels stay in the same range or in case they change, it needs to be demonstrated how the building can be adapted on changes	1	0	would need additional studies, but applicable in Rwanda
	Where the users have the possibility to control the heating and cooling system in area they occupy	1	0	

	Hea 05 Acoustic performance	**2**	**2**	*there is no specific standard for internal noise levels in Rwanda.
	Where acoustics of the internal spaces comply with relevant building standards.	2	2	assumed it is achiavable
	Where, before completion, acoustic testing is carried out.			
	Where ambient noise level targets stay ≤ 40 dB LAeqT.			
	Hea 06 Accessibility	**2**	**2**	
	Where safe access (safe cycle paths, pedestrian area, delivery areas, parking spaces)	1	1	Comes with the design
	from and to the building is guaranteed			
	Where the building is designed to fit the purpose, it is secure and accessible by all potential users	1	1	Comes with the design
1%	**Hea 07 Hazards**	**1**	**1**	** possible to achieve by hiring the external expert*
	Where risk assessment of potential hazards is carried out and appropriate mitigation measures are pointed out	1	1	when required by the client
	Hea 08 Private space	**0**	**0**	
	N/A in BREEAM INTERNATIONAL			
	Hea 09 Water quality	**1**	**1**	
	Where water systems are designed in compliance with health and safety national practice guidelines			
	Where potable water is available on the permanent staffed areas	1	1	Min standard requirement for BREEAM Outstanding / Assumed to be achieved
				Achiavable with water purification
19%	**Energy**	**29**	**29**	**The European House serves as a showcase of an energy neutral concept, threfore the am is to achieve max number of credits in category Energy*
	Ene 01 Reduction of energy use and carbon emissions	15	15	Min standard requirement for BREEAM Outstanding
	Where energy efficiency must be calculated using specifically defined software			*There are no energy efficiency requirements legislated by the current Rwandan building code standards.
	OR			
	Using checklist A5			*The natural ventilation report describes how the building has been designed to be naturally ventilated
				and confirms that analysis has been carried out to check that internal conditions will be acceptable to the occupants.retrofitted
				or be uncomfortable and require air conditioning This is to avoid rewarding buildings which will overheat
	a qualified energy modeling engineer or accredited professional			
	determines the number of credits that can be awarded in this category			
	Ene 02a Energy monitoring	**2**	2	Energy monitoring is not a very common practice in Rwanda currently
	Where all energy systems (lighting, cooling, etc.) are monitored	1	1	when required by the client credit can be achieved; Min standard requirement for BREEAM Outstanding
	Where each functional area or department has energy monitors	1	1	When required by the client credits can be achieved
	Ene 03 External lighting	**1**	1	
	Where external lighting of the project consists of energy efficient light			
	and has automatic light switch to prevent operation during the daylight.	1	1	When required by the client credits can be achieved
	Ene 04 Low carbon design	**3**	3	
	Where the building design can deliver the appropriate thermal comfort	**1**	1	Comes with the design
	Where building uses passive design measures to reduce the building energy demand.			
	Where free cooling is applied in the project building	**1**	1	Comes with the design
	Where a feasibility study has been carried out by an Energy specialist			
	to establish the most appropriate local (on-site or near-site) low or zero carbon			
	(LZC) energy sources for the building/development	**1**	1	When required by the client credits can be achieved (Energy Potential Mapping study)
	Ene 05 Energy efficient cold storage	**3**	3	
	Where no refrigerating systems are used	**3**	3	no refrigerating systems are used
	Ene 06 Energy efficient transport systems	**3**	3	
	Where an analysis of transport demand is done specifying	**3**	3	When required by the client credits can be achieved
	the ideal number and size of lifts, escalators or moving walks.			
	Where all the transportation systems are energy efficient.			
	Ene 07 Energy efficient laboratory systems	**5**	0	
	N/A			
	Ene 08 Energy efficient equipment	**2**	2	
	Where energy needed for office equipment demonstrates	2	2	When required by the client credits can be achieved
	significant reduction in the total annual equipment energy consumption of the building.			
	Ene 09 Drying space	**0**		
	N/A			
	INNOVATION POINT		1	
	Introduction of the monitors where the current energy consumption of builidng would be displayed (to make users			
	constantly aware of the energy issues and motivated to keep the levels low)			
8%	**Transport**	12	10	**Master Plan proposes the trasport network along the area where European House is located;*
	Tra 01 Public transport accessibility	**5**	4	*master plan hower is still not completely implemented (expected to be implemented in 2040)*
	Where public transport Accessibility Index (AI) for the assessed building is calculated and BREEAM credits awarded			*probably the calculatons of AI will need to be adopted to the Rwandan context
	in accordance with the building types.	5	4	Expected to be achieved
				(once the proposed master plans transport network is implemented, therefore for the time being only partial number of credits have been assigned)
	Where a dedicated bus service for the building users exist	1	0	
	only available in cases where a development is unable to achieve			
	any of the available credits using the Accessibility Index criteria.			
	Tra 02 Proximity to amenities	**2**	1	
	where building location facilitates easy access to local services and in that way			
	reduces the environmental, social and economic impacts resulting from multiple or extended building	2	1	Bus stop within 5 min walk, amenities as well, source masterplan (available in the document Gisozi Master plan and zoning - Proposed Parcelation Plan for Gisozi)
	user journeys, including transport-related emissions and traffic congestion.			**(**Medium rise areas (where European House is located) in the master plan (2040) of Gasabo district are proposed along major transport corridors)
	Tra 03a Alternative modes of transport	**2**	2	
	Where during the preparation of the design brief, the design team has consulted the local authorities about			
	the state of the local cycling facilities and how they could be improved.	1	1	Expected to be achieved
	Where extra bus lines and car sharing			
	options have been set up	1	1	Expected to be achieved
	Tra 04 Maximum car parking capacity	2	2	
	Where building's car parking capacity is limited compared to the maximum car parking capacity benchmarks	2	2	Expected to be achieved (*In the context of Rwanda, this credit would refer to the Rwandan local, provincial or national authority planning allowances for car parking spaces)
	Tra05 Travel plan	1	1	
	Where a travel plan has been developed as part of the feasibility and design stages,	1	1	Applicable in Rwandan context; Expected to be achieved
	in order to promote sustainable reductions in transport burdens.			
	Tra 06 Home office	1	0	
	N/A on offices		0	
6%	**Water**	10	10	**by introducing a sustainable water treatment for the European House together with water efficient equipment maximum number of cedits is reached*
	Wat 01 Water consumption	**5**	5	
	Where BREEAM Wat 01 calculation is used			
	for the assessment of the efficiency of the buildings domestic water consuming components.			
	: wc, urinals, taps, showers, bath, dishwasher, washing machine.			
	where the improvement over the baseline water consumption is above 12,5%	1		
	where the improvement over the baseline water consumption is above 25%	2		Min standard requirement for BREEAM Outstanding
	where the improvement over the baseline water consumption is above 40%	3		

	where the improvement over the baseline water consumption is above 50%	4		
	where the improvement over the baseline water consumption is above 55%	5	5	*water treatment and water re-use on site, applicable in Rwanda
	Wat 02 Water monitoring	**1**	1	Not common practice in Rwanda but applicable
	Where the main water is monitored by using the watermeter	1	1	Required by the client; Min standard requirement for BREEAM Outstanding
	Wat 03 Water leak detection and prevention	**3**	3	
	Where water leak detection system is installed in the building	1	1	Not common practice in Rwanda but applicable
	Where flow control devices that regulate the supply of water to each WC area or facility is installed	1	1	Not common practice in Rwanda but applicable
	Where easily accessible leak isolation valves are installed, to allow leaks to be stopped and then fixed quickly	1	1	Not common practice in Rwanda but applicable
	Wat 04 Water efficient equipment	**1**	1	
	Where the total water demand of the building is reduced by introducing the efficient water use equipment	**1**	1	Not common practice in Rwanda but applicable
12,50%	**Materials**	**12**	**6**	**credits related to certified material products are challanging to achieve as these certificates are difficult to get from local supliers*
	Mat 01 Life cycle impacts	6	4	
	where the project uses a life cycle assessment tool to measure the life cycle environmental impact of the building elements	5	4	might be difficult to reach in Rwanda; however European Project takes into account embodied energy of materials used in project and therefore some credits are expected to be reached for the subcategory life cycle impact
	where range of at least five products specified at the Design Stage and installed by Post-Construction Stage are covered by verified Environmental Product Declarations	1		
	Mat 02 Hard landscaping and boundary protection	**0**	0	
	N/A			
	Mat 03 Responsible sourcing of construction products	**4**	1	
	prerequisite is that all timber and timber-based products used on the project are legally harvested and traded timber			Min standard requirement for BREEAM Outstanding no Certified Timber within the Rwandan market
	Where sustainable procurement plan that is disseminated to all relevant internal and external personnel and included within the construction contract to ensure that they are enforceable on the assessed project			*a significant proportion of building components, materials and finishes used in Rwandan projects are imported into the country from overseas having certified products might be challanging
	The documented policy and procedure must encourage the specification of products with responsible sourcing certification over similar products without certification.	1	1	Not common practice in Rwanda but applicable
	Where the applicable construction products are responsibly sourced in accordance with the BREEAM methodology.	3	0	Might be challanging to achieve in Rwanda
	Mat 04 Insulation	0		
	N/A			
	Mat 05 Designing for durability and resilience	1	0	
	Where the building incorporates suitable durability and protection measures or designed features or solutions to prevent damage to vulnerable parts of the internal and external building and landscaping elements			
	Where The relevant parts of the building incorporate appropriate design and specification measures to limit material degradation due to environmental factors.	1	0	*not present in Rwandan projects until now, but applicable
	Mat 06 Material efficiency	**1**	1	
	Where opportunities have been identified, and appropriate measures investigated and implemented, to optimize the more efficient use of materials in building design , procurement, construction, maintenance and end of life.			
	This is carried out by the design or construction team in consultation with the relevant parties at each of the following project work stages	1	1	Expected to be achieved, by the use of external experts
	INNOVATION POINT		1	
	By introducing timber in project of EU - material that until now has never been used for structural purposes			
7,50%	**Waste**	**9**	6	**Re-use of waste in countries like Rwanda is very high; having shortage of materials in general, waste products tend to be re-used to the max*
	Wst 01 Construction waste management	4	3	
	A construction waste management plan is developed and verified constantly by an appointed individual			*the market for the recycling of demolition and construction waste in Rwanda is still developing in Rwanda
	If there is any existing building on the construction site, its demolition and re-use or refurbishment of its components should be studied to see whether re-use/refurbishments are feasible or not	1	1	Expected to be achieved; Min standard requirement for BREEAM Outstanding
	Construction wastes is divided in appropriate groups (at least 5 for office buildings) by an external contractor.	1	1	Expected to be achieved
	Where the targets to re-use of 60% of the waste are set	1	1	Expected to be achieved *it is believed thatprojects in Rwanda could reuse or recycle at least 30%, 50% or 70% of all demolition and construction waste.
	Where the target to re-use of waste is set to 95%	2	0	
	Wst 02 Recycled aggregates	**1**	0	
	Recycled or secondary aggregate counts for more than 25% of the total new used aggregates. Secondary aggregate comes from the building site or is transported from the place that is no more than 30 km away from the construction site.	1	0	*relevant but not present in Rwandan projects until now
	Wst 03a Operational waste	1	1	*relevant in Rwandan context
	If the dedicated space for segregation and storage of operational waste is provided	1	1	Required by the client; Min standard requirement for BREEAM Outstanding
	Wst 04 Speculative finishes	**1**	1	
	Finishes should be chosen by direct users to prevent their later replacement	1	1	Required by the client
	Wst 05 Adaptation to climate change	**1**	0	
	risk assessment for structural and fabric resilience should be done regarding the influence of the climatic change on the life cycle of buildings. Specific hazard identification, assesment, risk estimation, evaluation and management should be presented	1	0	Expected to be achieved when Required by the client
	Wst 06 Functional adaptability	**1**	1	
	In case the use of building changes over its life span the building is suitable for the functional adaptability		1	Floor plan of the builidng is flexible, in course of time builiding can host different functons
10%	**Land use and Ecology**	10	8	**builiding site is the area that was previously not developed, therefore not all credits are achiavable in this cathegory*
	LE 01 Site selection	**3**	1	
	Where previously occupied land is being used	2	0	From site visit it was clear that the land was not occupied before
	Where already contaminated land is being used.	1	1	From site visit it was clear that the land was contaminated before
	LE 02Ecological value of site and protection of ecological features	**2**	2	
	Where the building plot is classified as 'land of low ecological value'	1	1	from Kigali Master plan - Gisozi Master plan and zoning document pg.40
	Where existing features of ecological value within the zone and site boundary area are adequately protected from damage during clearance, site preparation and activities	1	1	Required by the client (achieved following reccomandations from the expert ecologist who should be hired and imported from abroad)
	LE 04 Enhancing site ecology	**3**	3	
	Where a suitably qualified ecologist has been appointed who provides an ecology report with appropriate ecological recommendations, of which at least 50% have been, or will be, implemented in the final design and build	1		
	In case this percentage is 75%	2		

	In case 95% of the recommendations will finally be addressed	3	3	Required by the client- the expert ecologist should be hired and imported from abroad
	LE 05 Long term impact on biodiversity	**2**	2	
	Where a Suitably Qualified Ecologist is appointed prior to commencement of activities on site		2	Required by the client - the expert ecologist should be hired and imported from abroad
6,50%	**Polution**	8	**8**	
				**Maximum number of credits is expected to be achieved*
	Pol 01 Impact of refrigerants	**4**	**4**	
	Where no refrigerants have been used	4	4	no air-conditioning is used in EU Builiding
	OR			
	The refrigerants should have ozone depletion potential (ODP) of zero (1 credit)	1		
	and a global warming potential (GWP) below ten (2 credits).	2		
	When there is a leak detection system			
	or a recovery system to reduce the emissions			*systems to monitor for refrigerant leaks and pump down refrigerants exist in Rwanda
	that are caused by leakages in the cooling services 1 credit is awarded.	1		*it is possible to include a system of this type within the building system designs
	Pol 02 NOx emissions	**2**	2	Apllicable for projects in Rwanda
	The building hot water/heating system should have dry NOx emission levels as follows:			*Many projects do not comply with this credit because of the high cost associated with the type of generator.
	< 56 mg/kWh (1 credit)	1		
	<40 mg/kWh (2 credits)	2	2	Required by the client (when boilers are not available localy they will need to be imported from abroad)
3,50%	**Pol 03 Surface water run-off**	**5**	4	
				**by identifying the risk and developing the right mitigation strategies it is expected that majority of the credits is achieved*
	Where building is situated in a low flood risk zone	2		
				Info taken from:
	Where building is situated in a medium or high flood risk zone	1	1	http://www.preventionweb.net/files/28208_highriskzonesreportfinalpublication.pdf (pg. 16)
				From the research available on the above mentioned site Gasabo area where European House is located, results to enter in a higher risk zone
				In addition, floods and the landslide increase due to the land use change (case of European House) and therefore building can be considered to be in high flood risk zone
	Where the peak water run off is the same as it was before the building was built	1	1	Required by the client - expected to be achieved by hiring the expert who will help developing mitigation strategies
	Where In case of a failure of the local drainage system there will be no flooding on the property	1	1	Required by the client - expected to be achieved by hiring the expert who will help developing mitigation strategies
	When there is no discharge from the developed area for the rain up to 5mm.	1	1	Required by the client - expected to be achieved by hiring the expert who will help developing mitigation strategies
	Pol 04 Reduction of night time light pollution	**1**	1	
	Where external lighting is switched off between 11:00 PM and 07:00AM (except the safety lights).	**1**	1	Expected to be fulfilled (all builiding users should be educated and encouraged to use builidng in sustainable way
	Lights that are on should have limited luminance level of 300 CD/m2.			
	Pol 05 Reduction of noise pollution	**1**	1	
	Where no noise sensitive areas exist within 800m of the building	1	1	source master plan (Gasabo district pg.15)
	Otherwise, a noise impact assessment is done – if the noise level stays below +5 dB during day			
	and +3 dB during the night compared to the background noise level	1		*there is no specific standard for internal noise levels in Rwanda.
	Innovation	**10**	**2**	
	by meeting ‘exemplary performance criteria’ for an existing BREEAM issue			
	for example, increasing the daylight factors from 2% to 3%;			
	where an application is made to BRE Global to have a particular building			
	feature, system or process recognised as innovating in the field of sustainable			
	performance, above and beyond the level that is expected			

A2

Questionnaires

Office name: Embassy of................ **Location: Kigali, Rwanda**

	Details		
Office Building	Finishing year of construction		
	Number of employees		
	Floor area		
	Materials used for construction		
	Indoor temperature		
	Office hours		
HVAC	(**H**eating, **V**entilation, **A**ir **C**onditioning)	Heating source	
		Ventilating source (mechanical/natural)	
		Cooling source	
Lighting		Installed power (W/m^2)	
Other	Other sources of renewable energy (solar panels, solar boilers, etc.)		
Energy use		Heating (kwh/m2,year)	
		Cooling (kwh/m2,year)	
		Warm water (kwh/m2,year)	
		Electricity (kwh/m2,year)	
		Total (kwh/m2,year)	

A – Federal Republic of Germany

Office name: Embassy of Federal Republic of Germany Location: Kigali, Rwanda

	Details		
Office Building	Finishing year of construction		
	Number of employees		
	Floor area		
	Materials used for construction		
	Indoor temperature		
	Office hours		
HVAC	(**H**eating, **V**entilation, **A**ir **C**onditioning)	Heating source	
		Ventilating source (mechanical/natural)	
		Cooling source	
Lighting		Installed power (W/m^2)	
Other	Other sources of renewable energy (solar panels, solar boilers, etc.)		
Energy use		Heating (kwh/m2,year)	
		Cooling (kwh/m2,year)	
		Warm water (kwh/m2,year)	
		Electricity (kwh/m2,year)	
		Total (kwh/m2,year)	

B – The Embassy of the Kingdom of the Netherlands

Office name : Embassy of the Kingdom of the Netherlands Location: Kigali, Rwanda

	Details		
Office Building	Finishing year of construction		1990
	Number of employees		27
	Floor area		???
	Materials used for construction		Cement,Sand,Iron rod, Tiles,
	Indoor temperature		Ambient
	Office hours		Monday to Thursday 8h00-17h30 Friday 8h00-13h00
HVAC	(**H**eating, **V**entilation, **A**ir **C**onditioning)	Heating source	None
		Ventilating source (mechanical/natural)	Natural
		Cooling source	Air Conditioners
Lighting		Installed power (W/m^2)	80W/m^2(estimation)
Other	Other sources of renewable energy (solar panels, solar boilers, etc.)		NONE
Energy use		Heating (kwh/m2,year)	NONE
		Cooling (kwh/m2,year)	64800W/h
		Warm water (kwh/m2,year)	10Kwh
		Electricity (kwh/m2,year)	90132KWh/Year (average of three years)
		Total (kwh/m2,year)	

C – Sweden

Office name: Embassy of the Kingdom of Sweden Location: Kigali, Rwanda

	Details		
Office Building	Finishing year of construction		June 2005
	Number of employees		16 employees
	Floor area		767 m2
	Materials used for construction		Mixture of fired bricks and concrete bricks.
	Indoor temperature		24-26 degrees
	Office hours		08.00-17.00 (Monday-Thursday) 08.00-14.00 (Friday)
HVAC	(**H**eating, **V**entilation, **A**ir **C**onditioning)	Heating source	Natural
		Ventilating source (mechanical/natural)	Natural
		Cooling source	AC and fans
Lighting		Installed power (W/m^2)	
Other	Other sources of renewable energy (solar panels, solar boilers, etc.)		
Energy use		Heating (kwh/m2,year)	
		Cooling (kwh/m2,year)	
		Warm water (kwh/m2,year)	
		Electricity (kwh/m2,year)	
		Total (kwh/m2,year)	

D – France

Office name: Embassy of The Republic of France **Location: Kigali, Rwanda**

	Details		
Office Building	Finishing year of construction		
	Number of employees		17
	Floor area		477,4 m^2
	Materials used for construction		
	Indoor temperature		
	Office hours		
HVAC	(**H**eating, **V**entilation, **A**ir **C**onditioning)	Heating source	
		Ventilating source (mechanical/natural)	
		Cooling source	
Lighting		Installed power (W/m^2)	
Other	Other sources of renewable energy (solar panels, solar boilers, etc.)		
Energy use		Heating (kwh/m2,year)	
		Cooling (kwh/m2,year)	
		Warm water (kwh/m2,year)	
		Electricity (kwh/m2,year)	
		Total (kwh/m2,year)	

E- EU

Office name: Embassy of EU **Location: Kigali, Rwanda**

	Details		
Office Building	Finishing year of construction		
	Number of employees		45
	Floor area		1807 m^2
	Materials used for construction		
	Indoor temperature		
	Office hours		
HVAC	(**H**eating, **V**entilation, **A**ir **C**onditioning)	Heating source	
		Ventilating source (mechanical/natural)	
		Cooling source	
Lighting		Installed power (W/m^2)	
Other	Other sources of renewable energy (solar panels, solar boilers, etc.)		
Energy use		Heating (kwh/m2,year)	
		Cooling (kwh/m2,year)	
		Warm water (kwh/m2,year)	
		Electricity (kwh/m2,year)	
		Total (kwh/m2,year)	

A3

BREEAM Assessment (Eastgate Office building Harare, Zimbabwe)

While searching for the information about the East Gate Center not so many documents were found that would allow the good BREEAM assessment. That is why the BREEAM assessment for East Gate Center is done very roughly, based more on the personal conclusions rather than the real information.

Focus of all the information that I have found, was particularly on the **Health and Wellbeing, Energy and Material Category**. This is the reason why these categories were assessed with the maximum credits available.

Following this approach the East Gate Centre is awarded with very good BREEAM rating. Details on following pages.

Management Category		Max credits	Credits obtained	Information category C = Own prediction	Notes
Man01	Sustainable procurement	8			
Man02	Responsible construction practices	2			
Man03	Construction site impacts	5			
Man04	Stakeholder participation	4			
Man05	Life-cycle cost and service life planning	3			
Tot. credits Man. Category		22			
Weighted % score of 1 credit		0,55			
Tot credits awarded					

Health Category		Max credits	Credits obtained	Information category C = Own prediction	Notes
Hea01	Visual comfort	3	3	C	
Hea02	Indoor air quality	4	4	C	
Hea03	Thermal comfort	2	2	C	
Hea04	Water quality	1	1	C	
Hea05	Acoustic performance	2	2	C	
Hea06	Safety and security	2	2	C	
Total credits available		14	14		
Weighted % score of 1 credit		1,07			
Tot credits			**14,98**		

Energy Category		***Max credits***	***Credits obtained***	***Information category C = Own prediction***	***Notes***
Ene01	Reduction of CO2 emissions	15	15	C	
Ene02	Energy monitoring	2	2	C	
Ene03	External lighting	1	1	C	
Ene04	Low- and zero-carbon technologies	5	5	C	
Ene05	Energy-efficient cold storage	2	2	C	
Ene06	Energy-efficient transportation systems	2	2	C	
Ene07	Energy-efficient laboratory systems	0	0	C	
Ene08	Energy-efficient equipment	2	2	C	
Ene09	Drying space	0	0		
Total credits available		27	27		
Weighted % score of 1 credit in Energy Category		0,7			
Tot credits awarded			**18,9**		

Transport Category		***Max credits***	***Credits obtained***	***Information category C = Own prediction***	***Notes***
Tra01	Public transport accessibility	3			
Tra02	Proximity to amenities	1			
Tra03	Cyclist facilities	2			
Tra04	Maximum car parking space	2			
Tra05	Travel plan	1			
Total credits available		9			
Weighted % score of 1 credit		0,89			
Tot credits Awarded					

Water Category		***Max credits***	***Credits obtained***	***Information category C = Own prediction***	***Notes***
Wat01	Water consumption	5			
Wat02	Water monitoring	1			
Wat03	Water leak detection and prevention	2			
Wat04	Water-efficient equipment	1			
Total credits available		9			
Weighted % score of 1 credit		0,67			
Tot credits awarded					

Materials Category		***Max credits***	***Credits obtained***	***Information category C = Own prediction***	***Notes***
Mat01	Life-cycle impacts	5	5	C	
Mat02	Hard landscaping and boundary protection	1	1	C	
Mat03	Responsible sourcing of materials	3	3	C	
Mat04	Insulation	2	2	C	
Mat05	Designing for robustness	1	1	C	
Total credits available		12	12		
Weighted % score of 1 credit		1,04			
Tot credits awarded			**12,48**		

Waste Category		***Max credits***	***Credits obtained***	***Information category C = Own prediction***	***Notes***
Wst01	Construction waste managment	4			
Wst02	Recycled agregates	1			
Wst03	Operational waste	1			
Wst04	Speculative floor and ceiling finishes	1			
Total credits available		7			
Weighted % score of 1 credit		1,07			
Tot credits Awarded					

Land use and ecology		**Max credits**	**Credits obtained**	**Information category C = Own prediction**	**Notes**
LE 01	Site selection	2			
LE 02	Ecological value of site	1			
LE 03	Mitigating ecological impact	2			
LE 04	Enhancing site ecology	3			
LE 05	Long term impact on biodiversity	2			
Total credits available		10			
Weighted % score of 1 credit		1			
Tot credits awarded					

Polution		**Max credits**	**Credits obtained**	**Information category C = Own prediction**	**Notes**
Pol 01	Impact of refrigerants	3			
Pol 02	NOx emission	3			
Pol 03	Surface water run off	5			
Pol 04	Reduction of night time light pollution	1			
Pol 05	Noise attenuation	1			
Total credits available		13			
Weighted % score of 1 credit		0,77			
Tot credits awarded					

Innovation		***Max credits***	***Credits obtained***	***Information category C = Own prediction***	***Notes***
Inn 01	Innovation	10	4		Building shows great performance especially in the following categories Ene 05,Ene 04, Ene 01, Hea 01
	Total credits available	10			
	Weighted % score of 1 credit	1			
	Tot credits awarded		4		

TOT BREEAM CREDITS: 55 % ***BREEAM RATE: VERY GOOD***

BREEAM Assessment (UN headquarters Nairobi, Kenya)

Management Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Man01	**Sustainable procurement**	8	**2**	C	I suppose there was a meeting to identify and define the roles, responsibilities and contributions during different construction phases (1 credit – project brief and design) I guess that thermal comfort, ventilation, and lighting have been measured and checked regularly either by measurement or occupant feedback (after care 1 credit)
Man02	Responsible construction practices	2	**-**		No info or prediction can be made whether the principal contractor has used a ‘compliant’ organizational, local or national considerate construction scheme
Man03	Construction site impacts	5	-		No info or prediction on the monitoring and recording data on energy, water of construction plant or transport of construction materials

Man04	Stakeholder participation	4	3	C	I assume that during the preparation of the design brief, all relevant parties and relevant bodies are identified and consulted with by the design team. The findings of the consultation influences the design and therefore must have been held before key and final design decisions were made (Consultation 1 credit) The building is designed to be fit for purpose, appropriate and accessible by all potential users (inclusive and accessible design 1 credit) I suppose that Building User Guides are provided and are appropriate to all users of the building (general users including staff and if applicable residents, as well as the non technical facilities management team/building manager) (Building user information 1 credit)
Man05	Life-cycle cost and service life planning	3	-		There are no relevant data to show that life cycle cost have been done
Tot. credits Man. Category		22	5		
Weighted % score of 1 credit		0,55			
Tot credits awarded			**2,75**		

Health Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Hea01	Visual comfort	3	1	C	Daylighting and artificial lighting are considered at the design stage to ensure visual performance and comfort for building occupants
Hea02	Indoor air quality	4	2	B	Occupied spaces of the building are designed to be capable of providing the fresh air entirely via the natural ventilation strategy
Hea03	Thermal comfort	2	1	C	There are no info weather the thermal modeling has been done (in the literature it is found that comfortable inside temperature was obtained thanks to chimney effect incorporated into building design) so I suppose that thermal modeling was considered or done Therefore one credit is assigned
Hea04	Water quality	1	1	B	Water has been purified and recycled for use One credit assigned
Hea05	Acoustic performance	2	-		There are no relevant info weather building acoustic performance (including sound insulation) meet the appropriate standards

Hea06	Safety and security	2	-		No relevant info found about security on site and building, nor about safe access Therefore no credits awarded
Total credits available		14	5		
Weighted % score of 1 credit		1,07			
Tot credits awarded			**5,35**		
Energy Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Ene01	Reduction of CO2 emissions	15	10	C and B	Reduction of CO2 emission is very high on the list of the preferences of this project (one of the examples - carbon emissions are substantially reduced through a single bulk shipment of needed equipment rather than multiple smaller international dispatches Design of the building encourages reduction of the operational energy demand
Ene02	Energy monitoring	2	2	B	Monitoring for lighting system is present

Ene03	External lighting	1	1	C	Because of the accent on the overall energy reduction of the building I can only suppose that energy – efficient light fittings are used for the external areas of the building
Ene04	Low- and zero-carbon technologies	5	3	B	Energy efficient lighting system and green IT systems are used
Ene05	Energy-efficient cold storage	2	2	B	Data centers that use air and cool water to maintain server temperatures are used (this removes the need for costly air conditioning)
Ene06	Energy-efficient transportation systems	2	2	C	Elevators exist in the building and I suppose the attention is being paid on their energy efficiency
Ene07	Energy-efficient laboratory systems	0	-		Not applicable on this type of building (building has no laboratory space)
Ene08	Energy-efficient equipment	2	2	B	Energy efficient computers (that replace traditional desktop comp)
Ene09	Drying space	0	-		Not applicable for this office building
Total credits available		27	17		
Weighted % score of 1 credit in Energy Category		0,7			
Tot credits awarded			**11,9**		

Transport Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Tra01	Public transport accessibility	3	-		No info found about public transport accessibility
Tra02	Proximity to amenities	1	-		Building is situated in the outskirts of the city of Nairobi and it is not easily accessible – therefore no credits are awarded for this subcategory
Tra03	Cyclist facilities	2	-		No info about cyclist facilities have been found
Tra04	Maximum car parking space	2	1	C	From the google maps it is possible to see that plenty of parking spaces are available around the building. (It is assumed that cca 400 parking spaces are constructed – which awards this subcategory with one credit)
Tra05	Travel plan	1	-		No relevant info were found for this subcategory but I suppose that the only option to reach the place is using proper car – option that does not allow any credit in this subcategory
Total credits available		9	1		
Weighted % score of 1 credit		0,89			
Tot credits Awarded			**0,89**		

Water Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Wat01	Water consumption	5	5	B	Example of the water reduction in Nairobi UN headquarter - by introducing dual flush lavatories in bathrooms consumption is reduced by 40-60%
Wat02	Water monitoring	1	1	C	I suppose the amount of water has been monitored as there is the automated irrigation system present on the site
Wat03	Water leak detection and prevention	2	-		No relevant info have been found for the assessment of this subcategory
Wat04	Water-efficient equipment	1	1		Automated irrigation system is applied
Total credits available		9	7		
Weighted % score of 1 credit		0,67			
Tot credits awarded			**4,69**		

Materials Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
					The whole material Category with its subcategories was not assessed as there were no relevant info found to award the credits. While in the other categories own estimation was very often used, in the Material category I found it challenging even to make my own estimation.
Mat01	Life-cycle impacts	5	-		There are no relevant info weather the life cycle impact of this building has been done or not
Mat02	Hard landscaping and boundary protection	1			No relevant info available
Mat03	Responsible sourcing of materials	3			No relevant info available
Mat04	Insulation	2			No relevant info
Mat05	Designing for robustness	1			No relevant info
Total credits available		12			
Weighted % score of 1 credit		1,04			
Tot credits awarded			-		

Waste Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Wst01	Construction waste managment	4	3	C	A green construction site is set up by contractor, there were no detailed info found, so the assigned number of credits might be even lower
Wst02	Recycled agregates	1			No info about recycled aggregates available
Wst03	Operational waste	1			No info about recycled aggregates available
Wst04	Speculative floor and ceiling finishes	1			No info about recycled aggregates available
	Total credits available	7	3		
	Weighted % score of 1 credit i	1,07			
	Tot credits awarded		**3,21**		

Land use and ecology		*Max credits*	*Credits obtained*	*Information category* *A = soft info* *B = hard info** *C = Own prediction*	*Notes*
LE 01	Site selection	2	-	C	Building site is situated in the outskirts of Nairobi city , in the area that is not so developed (based on the views through the Google maps) , so no credits are awarded for this category
LE 02	Ecological value of site	1	1	B	More than 600 indigenous tree species are found on the compound (source UNEP Making the UNEP Climate Neutral) Therefore one credit has been given
LE 03	Mitigating ecological impact	2	1	B	More than 600 indigenous tree species are found on the compound (source UNEP Making the UNEP Climate Neutral) Therefore one credit has been given
LE 04	Enhancing site ecology	3	1	B	A landscape designer is appointer to take care of the site ecology and to encourage the biodiversity Two credit
LE 05	Long term impact on biodiversity	2	-		No info found weather the suitable qualified ecologist has been appointed prior to start of the activities on site
Total credits available		10	3		
Weighted % score of 1 credit		1			
Tot credits awarded			**3**		

Polution		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Pol 01	Impact of refrigerants	3	3	C	The United Nations Environment Programme (UNEP) hosts a HCFC Help Centre which contains information about the management and phase out of HCFCs and alternatives to HCFCs in the refrigeration and air conditioning sector (www.breeam.org/BREEAM2011SchemeDocument) Based on this it is concluded that the UNEP building should score in this category with max number of credits
Pol 02	NOx emission	3	3	C	No heating equipment has been installed in the building
Pol 03	Surface water run off	5	4	B	Rainwater is harvested in the water storage tanks
Pol 04	Reduction of night time light pollution	1	1	C	Because of the focus on energy reduction of the building I can assume that it was thought about the lower level of lighting during the night hours (23:00 – 07:00) Therefore 1 credit for this category

Pol 05	Noise attenuation	1	1	C	There are no document available stating about the noise reduction (for example from fixed installations), considering the fact that there is no HVAC system in the building, possibility of installation noise is zero (1credit)
Total credits available		13	12		
Weighted % score of 1 credit		0,77			
Tot credits awarded			**9,24**		
Innovation		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Inn 01	Innovation	10	5		Building shows great performance especially in the following categories Ene 05,Ene 04, Ene 01, Hea 01, Wat01
	Total credits available	10			
	Weighted % score of 1 credit	1			
	Tot credits awarded		5		

TOT BREEAM CREDITS: 46 % ***BREEAM RATE: GOOD***

*(*hard info available from the document 'Building for the future, AUN showcase in Nairobi' February 2011)*

BREEAM Assessment (PTM Zero Energy Office, Bandar Baru Bangi, Malaysia)

Management Category		Max credits	Credits obtained	Information category A = soft info B = hard info* C = Own prediction	Notes
Man01	Sustainable procurement	8	2	C	ZEO building is planned to be a research laboratory for the future sustainable non-domestic buildings in the tropics – because of a big importance of this project I think that there was a meeting to identify and define the roles, responsibilities and contributions during different construction phases (1 credit – project brief and design) I also believe that that thermal comfort, ventilation, and lighting have been measured and checked regularly either by measurement or occupant feedback (after care 1 credit)
Man02	Responsible construction practices	2	-		No relevant info found whether a construction site was managed in an environmentally and socially considerate and responsible manner.
Man03	Construction site impacts	5	-		No relevant info found whether construction site was managed in environmentally friendly way regarding the resource use, energy consumption and pollution

Man04	Stakeholder participation	4	1	C	I assume that during the preparation of the design brief, all relevant parties and relevant bodies are identified and consulted with by the design team. The findings of the consultation influences the design and therefore must have been held before key and final design decisions were made (Consultation 1 credit)
Man05	Life-cycle cost and service life planning	3	-		There are no relevant data to show that life cycle cost have been done
Tot. credits Man. Category		22	3		
Weighted % score of 1 credit		0,55			
Tot credits awarded			**1,65**		
Health Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Hea01	Visual comfort	3	1	B	Building is day lighted 100 % during the day time
Hea02	Indoor air quality	4	2	B	Occupied spaces of the building are designed to be capable of providing the fresh air entirely via the air cooling system
Hea03	Thermal comfort	2	1	C	There are no info weather the thermal modeling has been done (in the literature it is found that comfortable

					inside temperature was obtained thanks to the v.a.v air cooling system) so I suppose that thermal modeling was considered or done Therefore one credit is assigned
Hea04	Water quality	1			There are no relevant info about the water quality
Hea05	Acoustic performance	2	-		There are no relevant info weather building acoustic performance (including sound insulation) meet the appropriate standards
Hea06	Safety and security	2	-		No relevant info found about security on site and building, nor about safe access Therefore no credits awarded
Total credits available		14	4		
Weighted % score of 1 credit		1,07			
Tot credits awarded			**4,28**		

Energy Category		***Max credits***	***Credits obtained***	***Information category A = soft info B = hard info* C = Own prediction***	***Notes***
Ene01	Reduction of CO2 emissions	15	10	C and B	Reduction of CO2 emission is very high on the list of the preferences of this project (one of the examples - carbon emissions are substantially reduced through a single bulk shipment of needed equipment rather than multiple smaller international dispatches Design of the building encourages reduction of the operational energy demand
Ene02	Energy monitoring	2	2	B	Monitoring for lighting system is present
Ene03	External lighting	1	1	C	Because of the accent on the overall energy reduction of the building I can only suppose that energy – efficient light fittings are used for the external areas of the building
Ene04	Low- and zero-carbon technologies	5	3	B	Energy efficient lighting system and green IT systems are used
Ene05	Energy-efficient cold storage	2	2	B	Data centers that use air and cool water to maintain server temperatures are used (this removes the need for costly air conditioning)
Ene06	Energy-efficient	2			Elevators exist in the

	transportation systems		2	C	building and I suppose the attention is being paid on their energy efficiency
Ene07	Energy-efficient laboratory systems	0	-		Not applicable on this type of building (building has no laboratory space)
Ene08	Energy-efficient equipment	2	2	B	Energy efficient computers (that replace traditional desktop comp)
Ene09	Drying space	0	-		Not applicable for this office building
Total credits available		27	17		
Weighted % score of 1 credit in Energy Category		0,7			
Tot credits awarded			**11,9**		

Transport Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Tra01	Public transport accessibility	3	-		No info found about public transport accessibility
Tra02	Proximity to amenities	1	-		Building is situated in the outskirts of the city of Nairobi and it is not easily accessible – therefore no credits are awarded for this subcategory
Tra03	Cyclist facilities	2	-		No info about cyclist facilities have been found
Tra04	Maximum car parking space	2	1	C	From the google maps it is possible to see that plenty of parking spaces are available around the building. (It is

					assumed that cca 400 parking spaces are constructed – which awards this subcategory with one credit)
Tra05	Travel plan	1	-		No relevant info were found for this subcategory but I suppose that the only option to reach the place is using proper car – option that does not allow any credit in this subcategory
Total credits available		9	1		
Weighted % score of 1 credit		0,89			
Tot credits Awarded			**0,89**		
Water Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Wat01	Water consumption	5	5	B	Example of the water reduction in Nairobi UN headquarter - by introducing dual flush lavatories in bathrooms consumption is reduced by 40-60%
Wat02	Water monitoring	1	1	C	I suppose the amount of water has been monitored as there is the automated irrigation system present on the site

Wat03	Water leak detection and prevention	2	-		No relevant info have been found for the assessment of this subcategory
Wat04	Water-efficient equipment	1	1		Automated irrigation system is applied
Total credits available		9	7		
Weighted % score of 1 credit		0,67			
Tot credits awarded			**4,69**		
Materials Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
					The whole material Category with its subcategories was not assessed as there were no relevant info found to award the credits. While in the other categories own estimation was very often used, in the Material category I found it challenging even to make my own estimation.
Mat01	Life-cycle impacts	5	-		There are no relevant info weather the life cycle impact of this building has been

					done or not
Mat02	Hard landscaping and boundary protection	1			No relevant info available
Mat03	Responsible sourcing of materials	3			No relevant info available
Mat04	Insulation	2			No relevant info
Mat05	Designing for robustness	1			No relevant info
Total credits available		12			
Weighted % score of 1 credit		1,04			
Tot credits awarded			-		

Waste Category		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Wst01	Construction waste managment	4	3	C	A green construction site is set up by contractor, there were no detailed info found, so the assigned number of credits might be even lower
Wst02	Recycled agregates	1			No info about recycled aggregates available
Wst03	Operational waste	1			No info about recycled aggregates available
Wst04	Speculative floor and ceiling finishes	1			No info about recycled aggregates available
	Total credits	7	3		

	available				
	Weighted % score of 1 credit i	1,07			
	Tot credits awarded		**3,21**		
Land use and ecology		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
LE 01	Site selection	2	-	C	Building site is situated in the outskirts of Nairobi city , in the area that is not so developed (based on the views through the Google maps) , so no credits are awarded for this category
LE 02	Ecological value of site	1	1	B	More than 600 indigenous tree species are found on the compound (source UNEP Making the UNEP Climate Neutral) Therefore one credit has been given

LE 03	Mitigating ecological impact	2	1	B	More than 600 indigenous tree species are found on the compound (source UNEP Making the UNEP Climate Neutral) Therefore one credit has been given
LE 04	Enhancing site ecology	3	1	B	A landscape designer is appointer to take care of the site ecology and to encourage the biodiversity Two credit
LE 05	Long term impact on biodiversity	2	-		No info found weather the suitable qualified ecologist has been appointed prior to start of the activities on site
Total credits available		10	3		
Weighted % score of 1 credit		1			
Tot credits awarded			**3**		
Polution		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Pol 01	Impact of refrigerants	3	3	C	The United Nations Environment Programme (UNEP) hosts a HCFC Help Centre which contains information about the management and phase out of HCFCs and alternatives to HCFCs in the refrigeration and air conditioning sector (www.breeam.org/BREEAM2011SchemeDocument) Based on this it is concluded that the UNEP building should score in this

					category with max number of credits
Pol 02	NOx emission	3	3	C	No heating equipment has been installed in the building
Pol 03	Surface water run off	5	4	B	Rainwater is harvested in the water storage tanks
Pol 04	Reduction of night time light pollution	1	1	C	Because of the focus on energy reduction of the building I can assume that it was thought about the lower level of lighting during the night hours (23:00 – 07:00) Therefore 1 credit for this category
Pol 05	Noise attenuation	1	1	C	There are no document available stating about the noise reduction (for example from fixed installations), considering the fact that there is no HVAC system in the building, possibility of installation noise is zero (1credit)
Total credits available		13	12		
Weighted % score of 1 credit		0,77			
Tot credits awarded			**9,24**		

Innovation		***Max credits***	***Credits obtained***	***Information category*** ***A = soft info*** ***B = hard info**** ***C = Own prediction***	***Notes***
Inn 01	Innovation	10	5		Building shows great performance especially in the following categories Ene 05,Ene 04, Ene 01, Hea 01, Wat01
	Total credits available	10			
	Weighted % score of 1 credit	1			
	Tot credits awarded		5		

TOT BREEAM CREDITS: 46 % ***BREEAM RATE: GOOD***

*(*hard info available from the document 'The design of the zero energy office building for Pusat Tenaga Malaysia' , conference on Sustainable Builidin South East Asia, 5-7 November 2007)*

A4

A4 Structural analysis European House – Option Steel

Just like in previous option (timber) one (middle) structural bay was considered for the analysis. Verifications are done following the Eurocode3 for steel structures. Steel S355 was considered.

Loads

Estimation of the dimensions of the structural elements is initially done by using some rules of thumbs and was adjusted later in order to optimize the dimensions. Loads have been calculated for two floors – the intermediate office floor and the roof floor. Governing loads between these two options have been used further for the calculation of the design load. Eurocode safety load factors and combination factors have been applied.

Following loads are considered:

Intermediate Floor

Permanent loads g		
Floors (Colflor 95)	2,90	kN/m2
Installations	0,20	kN/m2
Finishings	0,20	kN/m2
Separating walls + façade	1,10	kN/m2
TOT	4,40	kN/m2
Variable loads for office builidngs (3 kN/m2) q		
TOT	3,00	KN/m2

Roof

Permanent loads g		
Floors (Colflor 95)	2,90	kN/m2
Installations	0,20	kN/m2
Finishings	0,20	kN/m2
TOT	3,30	kN/m2
Variable loads roofs - used for maintanance (1 kN/m2) q		
TOT	1,00	KN/m2

Load bearing system

Steel framing plan in general can be rather simple for most of the buildings. It is preferred to have constant sizes of bays interrupting them only on the sites where elevators shafts and stairs occur. A Three-story European House office building has rectangular plan of 11 bays of 5,4 m long in the E-W direction and 3 bays of 5,4m wide in the N-S direction (FigureA4-1). So the building is a framed steel building with 5,4m bay in each direction. Floors are composite made of lightweight concrete laid on the metal deck. The elevator and stairs (main and escape stairs) are located in the two edge bays. The roof is used for maintenance purposes only.

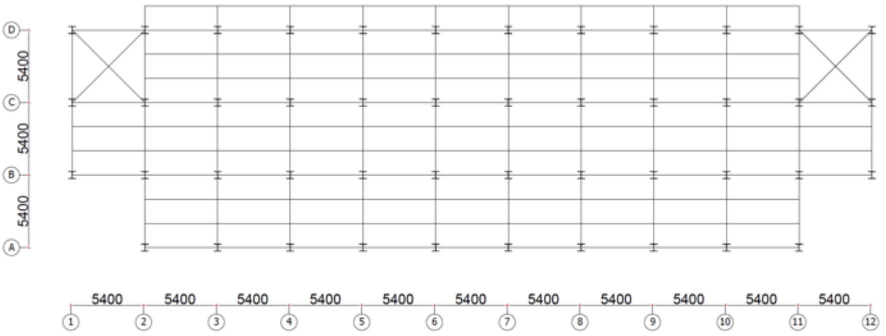


Figure a4-1 Typical floor framing

Figure a4-2 Building section along long face

Structural alternatives used for steel buildings are:

- Un-braced or moment frames
- Braced or simple systems

Portal frames are the best representatives of the **unbraced** – moment frames. Portal frames are composed of system of beams and columns that are connected with moment connections among each other. Connections in the portal frames are characterized by full rotational stiffness and rigidity. Therefore moments and forces can be easily transferred from beams to column and the rigidity of the system assures that these moments and forces can be easily carried. Portal frames are used in the situations where flexibility of the floor plan has priority (frame systems in general offer more 'open' floor plans so the position of the separating walls can be arrange according to users wishes and changed easily in the future if that is needed)

The entire lateral and vertical loads in portal frames are carried by the rigidity of the connections and the bending stiffness of the members. Making of the moment resisting connections is labor intensive and much more costly compared to a hinged or shear connection (which are consequently preferred in most of the projects) (Salmon, 1980)

Simple systems are characterized by simple hinge connections between structural members. Hinge connections do not transfer moments to the adjacent members (as moment in hinged connection is itself zero). To stabilize this kind of systems against sway usually bracing in both directions is introduced. Vertical and horizontal bracing resist lateral loads and secure the overall stability of the building. The big advantage of simple system is that it is easy to get assembles and it is much cheaper option compared to the un-braced frame. (Salmon, 1980)

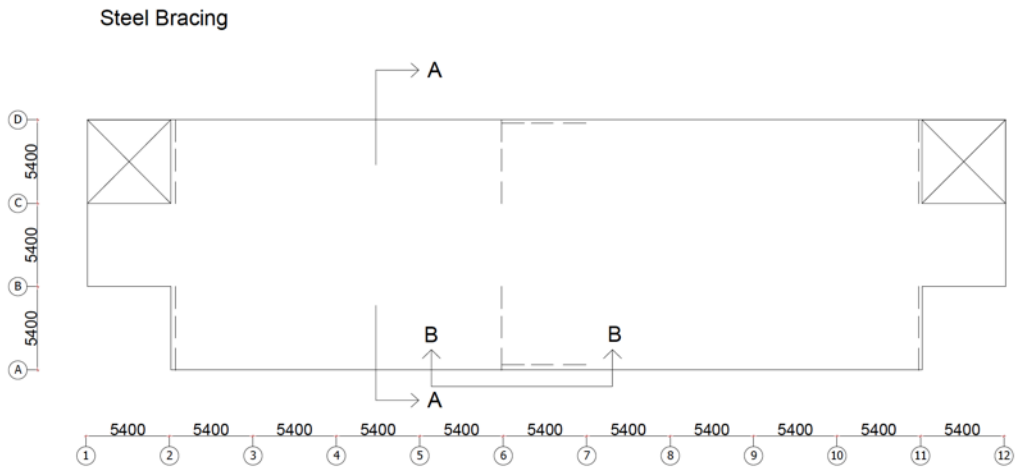
Load bearing system EU House

Load bearing system for the EU house is a braced frame (Figure 11). Horizontal force resistance is provided by braced frames while pinned frames resist vertical actions only. Both systems are connected to eachother by means of composite concrete steel floor. Floor structure (composite concrete steel floor) provides a rigid diaphragm at each storey level.

Bracing design:

Assumptions:

- 6 bays of bracing total (long face)
- 2-bays of bracing total (short face)



Section A:

– bracing for the long face: Two alternatives / options can be considered:

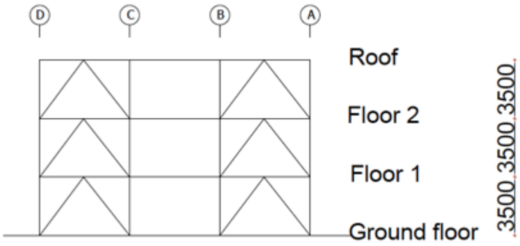


Figure a4-3 Section A Option 1

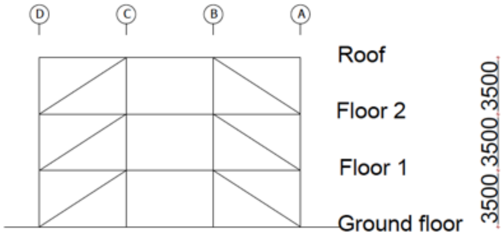


Figure a4-4 Section A Option 2

Option 1 vs Option 2

Option 1 (Figure a4-3) : likely smaller members, more connections but smaller forces, therefore smaller copmponents

Option 2(Figure a4-4): longer brace members with higher forces (larger sizes), fewer connections but larger forces (larger components)

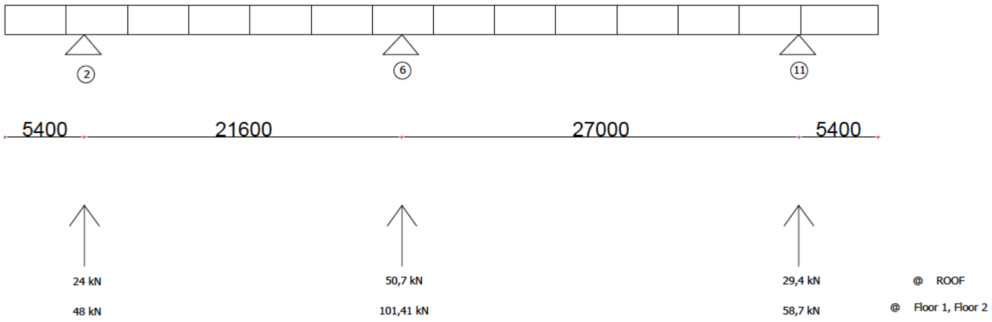
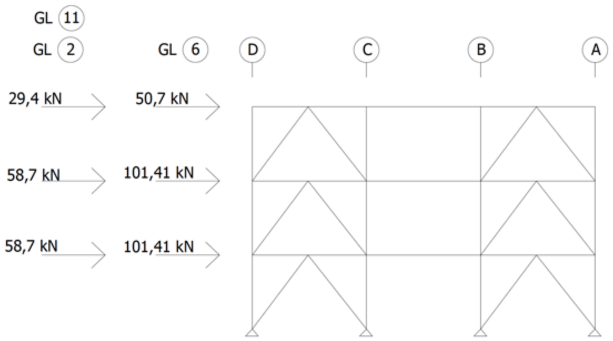


Figure a4-5 Wind load analysis on the long face



One could argue however, that V braces introduce significant bending moments in the beams (usually V bracing is used in earthquake prone areas because they can dissipate a lot of energy).

For this reason X-braces or just diagonals (figure a4-4) are usually more often to be found in practice in Europe. The disadvantage of this option is that it offers limited possibilities for openings of any kinds if needed. Another disadvantage would be that the braces cannot easily cross each other in the heart of the columns so in case of x bracing it is better to use strips, slender enough to cross each other. On the other hand their advantage is that these braces are dimensioned on tension and therefor very slender steel strips will already be sufficient for their design (hence they offer material efficient design).

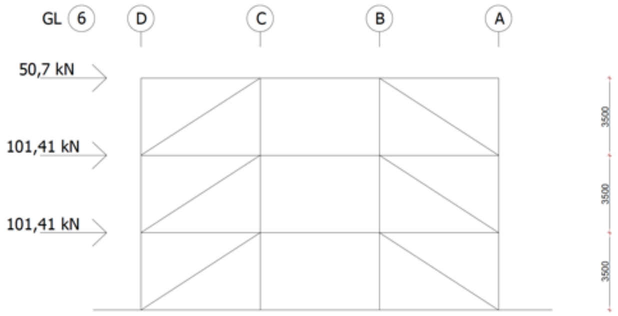
For the long face bracing placed on the grid line 6 is governing.

'Option 2', having one bay with diagonals in one direction and the other with diagonals in the opposite direction (In that case for each wind direction only one brace can be used on tension) will be checked further.

Force in the bracing on the ground floor is used for the dimensioning of the diagonals.

F_{bottom} = 253,5 kN x 1,5 = 380, 25 kN.

$F_{in\ the\ diagonal}$ = 453,14 kN



Nd	453,1354903	kN	
Lc	6435,060217	mm	
A	1520	mm2	
I	2320000	mm4	
A>Nd/fyd	1276,438001	mm2	
σ = Nd/A	298,1154541	N/mm2	**TRUE**
σallowed	355	N/mm2	

Profile RHS 100 x 100 x 4 would be sufficient for all the requirements.

Section B:

- bracing for the short face: Two alternatives / options can be considered in this case as well (figure a4-6 and a4-7):

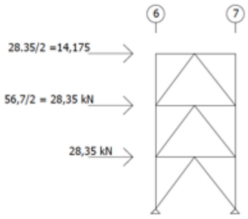


Figure a1-6 Section B Option 1

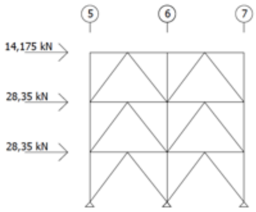


Figure a4-7 Section B Option 2

Option 1 vs Option 2

Option 1: Shorter moment arm (5,4 for the whole bay) result in higher T and C forces in columns

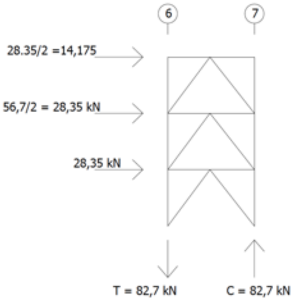
Option 2: Longer moment arm (2 x 5,4) result in lower T and C forces in columns

Further analysis will be done considering option 1

M = 14,175 kN x 10,5m + 28,35 kN x 7m + 28,35 x 3,5m = 446,5 kNm

T and C = 446,5 kNm / 5,4 m = 82,7 kN

V_{bottom} = 70,88 kN x 1,5 = 106,32



Dimensioning the bracing:

Tan θ = 2,7m / 3,5m = 0,77

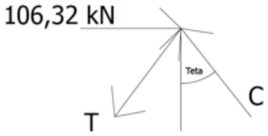
Θ = 37,7°

C = - T

106,32 kN = 2 x C x sin 37,7

C = 86,9 kN

T = - 86,9 kN



Sizing for tension :

Amin = Tu / fyd = choose the profile

Amin > 86 998N/ 355 N/mm^2 = 245,06 mm^2

Profile chosen RHS 80 x 80 (area 1090 mm^2 ; I = 1050000 mm^4)

Sizing for compression:

C = 86,9 kN

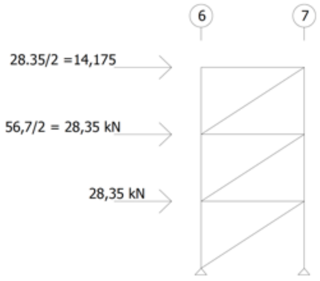
Length of the compression member = $(2,7^2+3,5^2)^{1/2}$ = 4,42 m

V bracing

Compression member

Nd	86998	N
Length compr.member	4420	mm
A	1090	mm2
I	1050000	mm4
i = (I/A)^1/2	31,03711894	mm
λ = Lc/i	142,4101254	
λe=Π(E/fy)^(1/2) for 355	75,45576075	
λrel = λ/λe	1,887332709	
ωbuc = 1/((λrel)^2)	0,280739206	
Nysd = fyd A	386,95	kN
Nd/(ωbuc*Nysd)	**0,800850316**	**<1 O.K**

Alternatively in case of using only diagonals:



Diagonal bracing (tension only)	(RHS 50x50x3)	
Nd	126,6872688	kN
Lc	6435,060217	mm
A	554	mm2
I	202000	mm3
A>Nd/fyd	356,865546	mm2
σ = Nd/A	228,6773806	N/mm2
σallowed	355	N/mm2

Following the same principle as in the option timber columns next to bracing are checked. Respected tributary areas have been first identified and columns carrying the biggest and the smallest tributary area have been checked (calculations are done for the short face, same principle applies for the long face as well). (Figure a4-8 and a4-9)

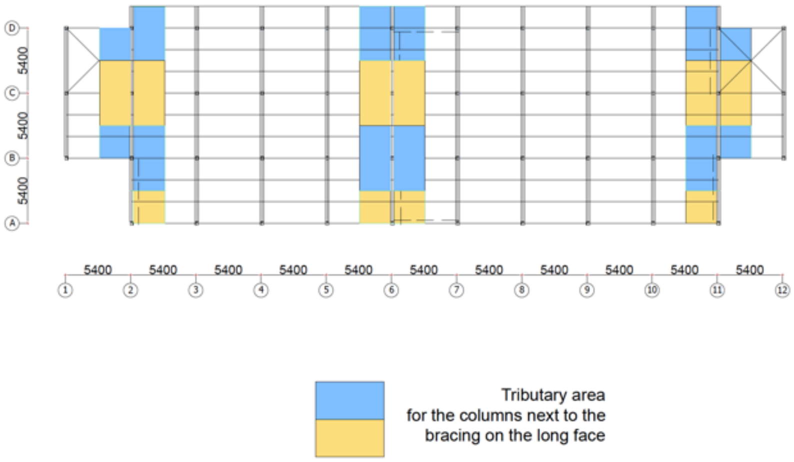


Figure a4-8 Tributary area of columns next to the bracing (long face)

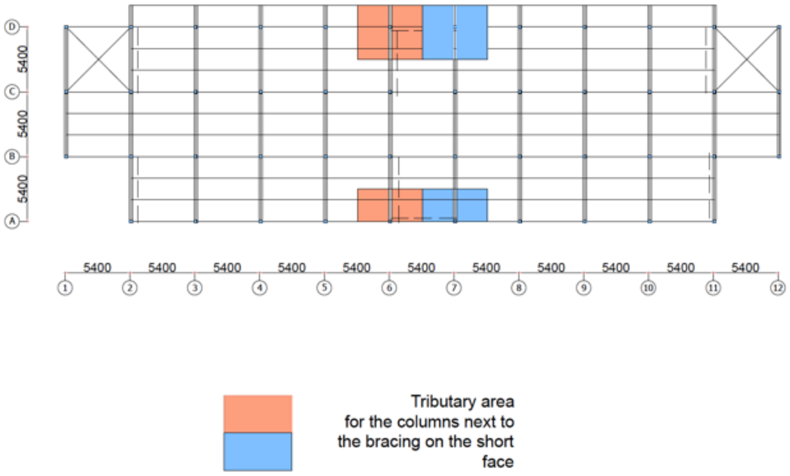


Figure a4-9 Tributary area of columns next to the bracing (short face)

Biggest tributary area has dimensions of 4,7m x 5,4m and the smallest tributary area 2,7m x 5,4m. For both area column RHS 250 x 250 x 6,5 satisfy all the requirements.

Column with smaller tributary area:

N from the wind	82,7	kN
N live load	126,846	kN
N permanent load	259,9344	kN
N TOT	**469,4804**	**kN**
σ = Ntot /A	76,964	N/mm2
Md = Ntot x e	11,73701	kNm
Where e is the max value among:		
lc/300	11,66666667	mm
h/10	**25**	**mm**
>10mm	10	mm
Euler critical Force		
π2 * EI/l2	10158,20503	kN
n=Fcr/Ntot	21,63712272	

σ = Md/W*n/(n-1)	25,58366501	N/mm2
Max allowed bending stress	355	N/mm2
TOT σ = Ntot/A + Md/W*n/(n-1)	102,547665	**O.K profiel column**

Column with bigger tributary area:

N from the wind	82,7	kN
N live load	220,806	kN
N permanent load	416,7504	kN
N TOT	**720,2564**	**kN**
σ = Ntot /A	118,0748197	N/mm2
Md = Ntot x e	18,00641	kNm

Where e is the max value among:

lc/300	11,66666667	mm
h/10	**25**	**mm**
>10mm	10	mm

Euler critical Force

π2 * EI/l2	10158,20503	kN
n=Fcr/Ntot	14,10359565	
σ = Md/W*n/(n-1)	40,29224104	N/mm2
Max allowed bending stress	355	N/mm2
TOT σ = Ntot/A + Md/W*n/(n-1)	158,3670607	**O.K profiel column**

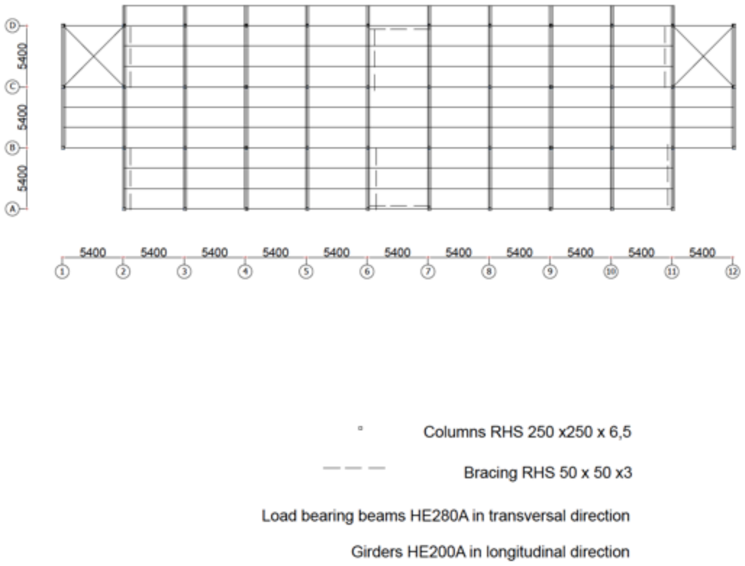


Figure a4-9 Load bearing system European House

Floor system

Floor system chosen, using design tables from The Dutch Engineering Company, is a ComFlor95. For a span of 5400 mm a min suitable thickness of this composite steel/concrete floor is 155mm, with a self-weight of 290kg/m^2. (Figure a4-10)

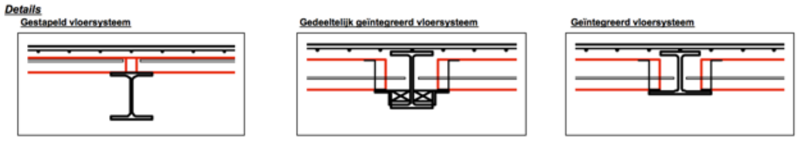


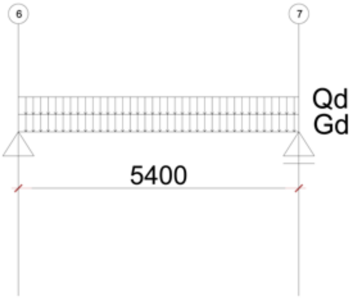
Figure a4-10 Different types of floor systems

Few are further the options for the composite floor systems – with supporting girder under it, or partly or entirely integrated in the floor system. As there are no restrictions regarding the height, it is decided in this analysis to opt for the first version – with supporting girder under the metal deck and concrete floor.

Girders span 5400 mm and have center-to-center distance of 1800 mm.

Steel Girder

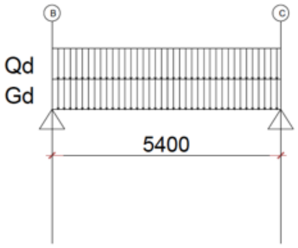
Girder that lies in between grid lines 6 and 7, with c-t-c distance of 1800 mm is calculated as a simply supported beam with a uniform load. HE200A profile is verified to be sufficient. From unity checks results that the deflection was the governing factor (detailed calculation in appendix) for the dimensioning.



Verification	Unity check
Flexure	0,93
Lateral tors. Buck	0,62

Beam

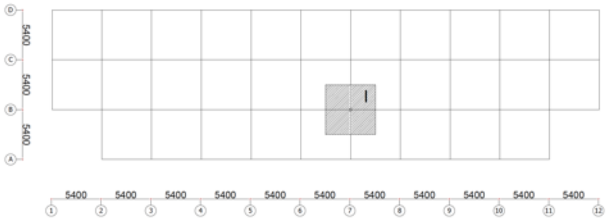
Governing beam is the one that lies on the grid line 7. For this calculation a simply supported beam between B and C grid was considered. An HE280A profile was adopted. (See detailed analysis in the appendix)



Verification	Unity check
Flexure	0,75
Lateral tors. Buck	0,63

Column

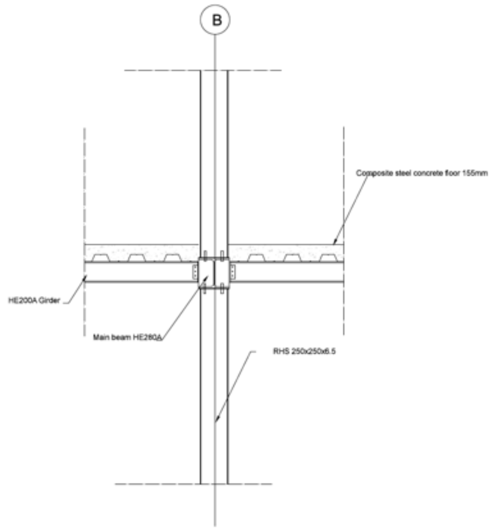
Column B7 with its tributary area of 5,4 x 5,4 m was dimensioned. An RHS 250x250x6,5 profile column satisfy structural requirements.



Tributary area I of the column B7

Column B7

Construction Detail (beam-column-floor connection)


B
Composite steel concrete floor 155mm
HE200A Girder
Main beam HE280A
RHS 250x250x6.5

A5

A5 - Structural analysis Option Concrete

- Material properties

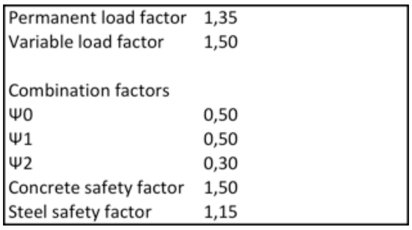
Beams and columns: Concrete class – C28/35

Slab: Concrete class C30/37

Reinforcement: Steel B500

- Loads

Eurocode safety load factor and combination factors are applied in the load calculations. Variable load of 3 kN/m2 for offices was considered.



Permanent load factor	1,35
Variable load factor	1,50
Combination factors	
Ψ0	0,50
Ψ1	0,50
Ψ2	0,30
Concrete safety factor	1,50
Steel safety factor	1,15

- **Load bearing system**

Similarly to the two previous material options most common load bearing systems for office buildings built in concrete are:

Bearing walls system

This load bearing system consists of reinforced bearing walls. Structures using this type of load bearing system are usually rectangular with regular floor plan and centrally located core element.

Moment resisting frames system is another possible type. Moment resisting frames consist of columns and beams that are connected together and act as a space frame system. Columns and beams resist to the vertical (gravity) and horizontal/lateral forces while strong moment connection in joints (connections beam and columns) provide overall stability of moment frames.

Frame/shear hybrid system

The combination of both – frames and bearing/shear walls – is called hybrid frame system. Here the frame supports vertical loads (no moment connections between column and beams). Lateral loads are taken by the core and extra shear walls that provide overall stability of the whole system.

- *Load bearing system EU house*

Just like in previous two options, load-bearing system will be a (reinforced concrete) frame structure.

Slabs, beams, and columns will carry the vertical loads and shear walls will carry the horizontal (wind loads). The structure of EU House consists of concrete frames connected to each other. 10 frames with 3 bays with a 3 storey height + 2 frames on each side with 2 bays and 3 storey high. Distance between columns within the frame is 5400 mm, with distance between two frames of 5400 mm as well. Lateral loads will be taken by the shear walls.

Considering lateral stability following starting points are assumed:

- Same layout/proportions are used as for option steel and timber
- Diaphragm in long direction is too long to span end to end – therefore it is important to rearrange the walls in direction perpendicular to long direction
- L shaped or double T shaped shear walls will be preferred as they are stiffer than the single line of wall on its own
- In case of encountering the problem of rebar congestion, boundary elements can be added (figure a5-1)

Figure a5-1 Regular wall and wall with boundary elements

Options for lateral stability/shear walls

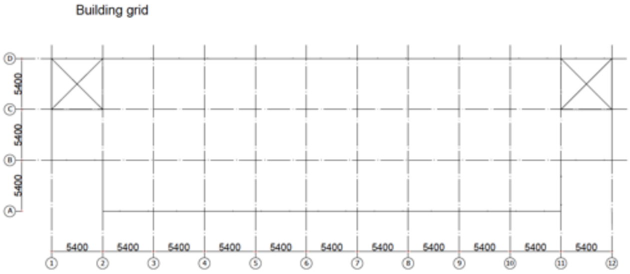


Figure a5-2 European House grid

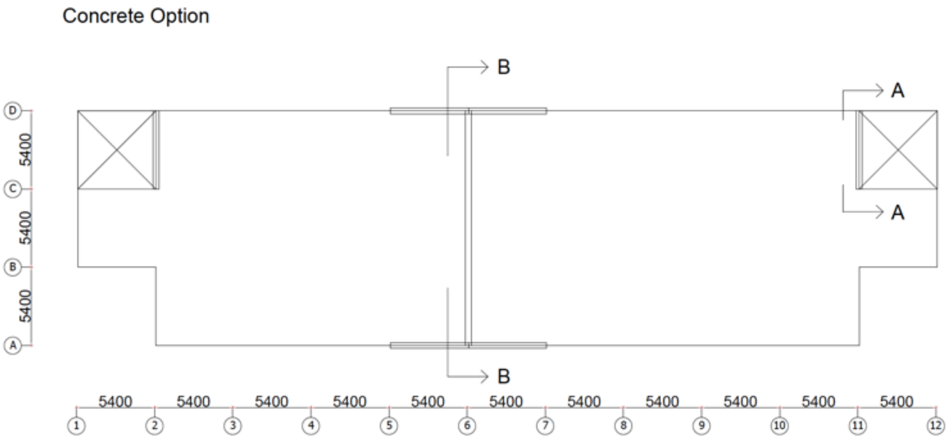


Figure a5-3 Shear walls option

The option on figure a5-3 offers 3 shear walls resisting loads in the long face (2 of them are shorter with length of 5,4m and the central shear wall is longer with the length of 16,2m) the central core that would be really stiff. In reality this option offers slightly un-symmetrical solution but since the eccentricity is small it can be ignored for the simplicity.

Central core element allows openings, but the size of the corridor should be minimized (Figure a5-4). (Because of the high shear in the link beam above openings (in between two walls))

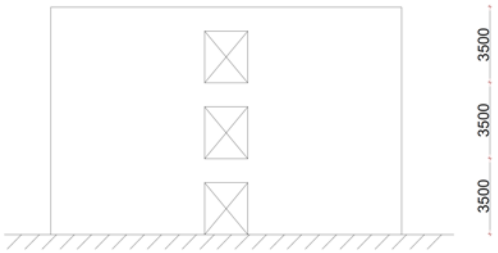


Figure a5-4 width of the corridors in concrete option

- ***Shear wall design:***

Building height: 10,5m

Wind load = 1kN/m^2

Wind load resisted by short face:

$1 kN/m^2$ x 59, 4m = 59,4 kN/m

Wind load at roof = 3,5 /2 x 59,4 kN/m = 103,95 kN

Wind load at Floor 1 and Floor 2 level = 3,5 x 59,4 kN/m = 207,9 kN

Wind load resisted by long face:

Wind load at roof = 103,95 kN x (16,2 /59,4) = 28,35 kN

Wind load at Floor 1 and Floor 2 = 207,9 kN x (16,2 /59,4) = 56,7 kN

Distribution of the wind load by the length of the each shear wall:

Wind load on long face:

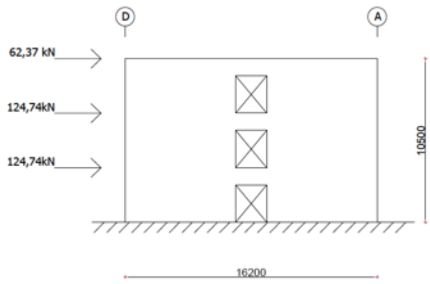
Roof wind load short walls = (5,4 m/ (2 x 5,4m + 16,2m)) x 103,95 kN = 20,79 kN

Roof wind load long wall = (16,2 m/ 27 m) x 103,95 kN = 62,37 kN

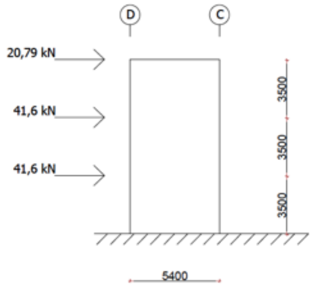
Wind load short walls at Floor 1 and Floor 2 = 20,79 kN x (207,9/103,95 kN) = 41,6 kN

Wind load long walls at Floor 1 and Floor 2: = 62,37 x (56,7 / 28,35) = 124,74 kN

Section B



Section A



Section A

Total shear force at the bottom = 103,99 kN

M_{tot} at the bottom = 20,79 x 10,5 + 41,6 x 7 + 41,6 x 3,5 = 655,1 kNm

Factored shear force: 103,99 x 1,5 = 155,98 kN

Factored moment: 655,1 x1,5 = 982,65 kNm

Shear capacity of the concrete wall:

V_{rd} = 0,3 x 0,525 x 35 x 2/3 x 5400 x 300 = 5953,5 kN > 155,98 kN ; O.K

Compression and tension reinforcement shear wall:

M/(5,4m x 2/3) = 982,65 kNm / (5,4m x 2/3)= 272,9 kN

$C_{compression}$ = T_{ension} = 272,9 kN

Tension reinforcement:

Area reinforcement needed

As = M/(0,87 x fyk x z)

As= M / (0,87 x fyk x 0,8 x 5400 x 2/3) = 982,65 kNm/(0,87 x 500 N/mm^2 x 0,8 x 3600mm) = 784,36 mm2

Min tension reinforcement A_{tmin}= 0,0015 x b_t x d = 0,0015 x 200 x 5400 = 1620 mm^2

Tension reinforcement adopted – 6 ɸ 20 with Area = 1885 mm^2

Compression reinforcement:

If M>0,167 f_{ck} x b x d^2 – compression reinforcement is needed

0,167 x 28 x 200 x 5400^2 = 27 270,43 kNm

Min compression reinforcement is adopted:

$A_{min\ horiz}$ = 0,4% x Ac = 0,4 % x 200 x 5400 = 4320 mm^2

$A_{min\ vert}$ = 0,5 x $A_{min\ horiz}$ = 2160 mm^2

Concrete slab

All the slabs in the project are one-way slabs (figure a5-5). Slabs span in between two main loadbearing beams with a length of 5,4 m. Calculations are done for 1m wide strip of the slab. Following rules of thumbs thickness of the concrete slab is determined, reinforcement is calculated and slab is checked on bending, shear and deflection. Reinforced concrete slab of 250 mm height with the reinforcement φ12 150 satisfy the verifications.

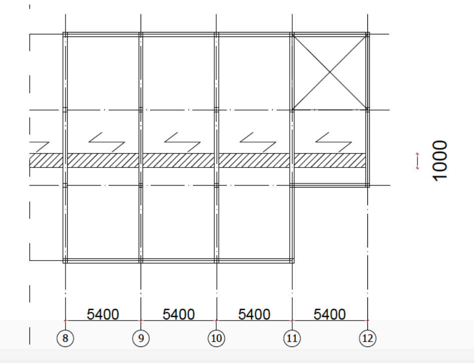


Figure a5-5 Slab span direction

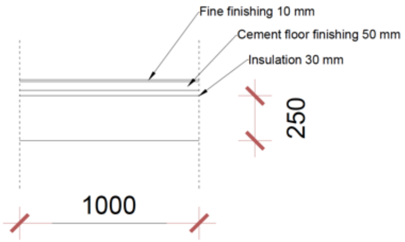


Figure a5-6 Slab section

Load bearing beam

Beam lying on grid 7 was dimensioned. In order to make the comparison with other two options fair, only one bay is considered for the calculations. For the analysis simply supported beam with uniformly distributed loads that lies in between grids B and C was considered and dimensioned. Dimensions of 300x500mm are verified and adopted. Bending reinforcement adopted is 6Φ16. Min shear reinforcement of 2 Φ 12 every 300 mm is applied.

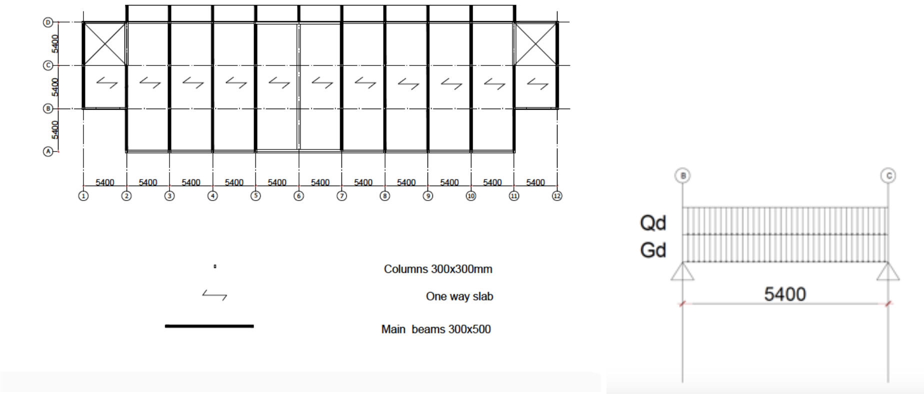


Figure a5-7 Main load bearing structure

Reinforced concrete column design

Governing column B7 on the ground floor is dimensioned, just like in the other two options. The length/height of the column is 3500 mm. Loads on column from upper floors are summed and applied. Dimensions of 300x300 with reinforcement of 6 φ 25 are verified and applied.

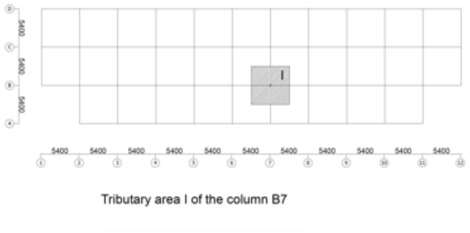


Figure a5-7 Column B7 tributary area