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SUSTAINABLE CONSTRUCTION STUDY IN MAURITIUS

LOT 3 : DRY CONSTRUCTION TECHNOLOGIES REPORT

TECHNICAL ASSISTANCE FOR THE IMPLEMENTATION OF SUNREF III PROGRAMME - MAURITIUS

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Dry construction technologies report

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1. Construction technologies: two possible alternatives to concrete as the reference solution

This report is a study of the benefits and costs of developing the dry construction sector in Mauritius.

In Mauritius, generally all constructions are done using a reinforced concrete structural frame, with concrete cellular block infills. They are then plastered and painted internally and externally. The foundations use reinforced concrete in bases, ground beams and columns. In some cases, raft foundations are used. The superstructure is made of reinforced concrete steel and beams structural frame, with concrete block infills. Additional floor slabs or roof slabs are equally made of concrete. The works are considered wet, as reinforced concrete, plastering are considered as wet trades.

During the research, other types of construction technologies have been considered.

- The one that is widely used internationally is light gauge steel framed construction. Light gauge steel frames are made with cold formed steel sections. The foundations are similar to the traditional reinforced concrete construction. Generally, a ground floor slab acting as a raft foundation is casted, the steel frames are then built on top of the slab. Alternatively, reinforced concrete bases and ground beams are used. Ground beams can be replaced by steelwork beams. The works are considered dry because it does not involve wet trades or use limited wet trades. The superstructure made of steel sections, are then cladded externally and internally. Various cladding options exist such as fibre cement board, magnesium oxide board, Oriented Strand Board (OSB), itself cladded with fibre cement tiles or vinyl siding. Floors and roofs also have steel frame as support. Floors are made of boards that receive the floor finish, whilst roof received roof finishes such as corrugated iron sheets or roof tiles.

  The consumption of water and energy (carbon content) as well as the carbon content of imported products is taken into account. This means that the energy / carbon content is not in favour of steel solutions as it is an intensive energy solution. Steel products for construction are imported; this means that energy/carbon content is also imported and should be taken into account. If we consider concrete, it is locally produced and used with the local use of water and energy. Globally imported steel materials are much more energy intensive; this solution is therefore, not recommended from a ‘’carbon footprint’’ perspective.

- Timber is another construction technology. Cross laminated timber has gained popularity as it is considered more eco-friendly. However, this option has not been considered thoroughly as timber remains an imported product which is relatively expensive and considered high maintenance while also posing significant risks of termite attack and fire. Suppliers who have tried to enter the market have failed. This option is, therefore, not realistic as a wide scale solution. However, some niche markets are possible for environmentally oriented projects. Wood use in the construction faces high hygrometry with severe adverse impacts on the long-term requiring a constant need to protect and maintain the wood construction. Cyclonic events are also a factor considered by builders and project owners while making the choice of construction materials, wherein concrete structures are more favoured.

All the three technologies (concrete, light gauge steel and cross laminated timber) considered are on-site construction. They are different from prefabrication and then assembly on site, or modular construction. The latter generally uses reinforced concrete components.

The report details how these construction concepts are implemented with examples, to explain the positive aspects of alternatives solutions. This information should be forwarded to professionals of the building sector to help design new buildings locally, using less water, if this approach is relevant in the context of scarce water resources.

2. **Comparisons of dry construction technologies based mainly on steel component with two options of cladding externally.**

For the study, the light gauge steel framed construction has been considered with two different types of cladding externally.

The first option (**Option 1**) considers the use of fibre cement board, while the second option (**Option 2**) uses vinyl siding on OSB. Insulation is required for the wall panel to provide same with a good thermal transfer property.

The baseline building has a reinforced concrete frame with concrete blockwork infills.

As for the roof, the baseline building has a reinforced concrete roof slab, whereas option 1 and 2 has a corrugated iron sheet, with a suspended ceiling.

For future SUNREF activities in the construction sector (greenfield projects), the carbon footprint of the alternative solutions should be considered. The comparison of concrete and steel-based solutions should be addressed with a relevant methodology.

The different construction technologies have been compared using three criteria, namely:

a. the embodied carbon and embodied water,
b. the costs
c. the energy use

a) Embodied carbon and embodied water

As a comparison the tables below show the embodied carbon and embodied water for elements of a building envelope

Table 1: Comparison between 150 mm concrete roof slab and a corrugated iron sheet roof

	Embodied carbon	Embodied water
150mm concrete roof slab		
Concrete	29.33	0.24
Reinforcement	9.54	0.04
Total	**38.87**	**0.28**
Corrugated sheet roof		
Corrugated sheeting	35.40	0.51
Steel frame	28.92	0.01
Total	**64.32**	**0.52**

For the roof construction, the dry construction technology has 65% more embodied carbon, and 85.7% more embodied water based on the above data of the table. Water is used for finishing operations including coatings, paintings...

Table 2: Comparison between walls

	Embodied carbon	Embodied water
200mm block wall		
Concrete block	22.32	0.06
Total	**22.32**	**0.06**
Gypsum board wall		
Gypsum board x2	20.90	0.07
Steel frame	28.92	0.01
Total	**49.82**	**0.08**

The dry construction has 123% more embodied carbon and 33.3% more embodied water. It should be noted that a steel structure is however more recyclable than concrete. From a carbon footprint analysis, steel is much more carbon and water intensive if we compare concrete block and gypsum board associated with steel frame.

b) <u>Costs</u>

For comparison of costs, a 110 m^2 3-bedroom house with a flat roof.

Quotes were obtained for the different options. The cost for the dry construction was significantly higher. The variance between the baseline building is relatively high varying from 40.4% (with finishes) to 67.3% (basic building work) for **Option 1** (light gauge steel with fibre cement board) and 45.9% (with finishes) to 75.7% (basic building work) for **Option 2** (light gauge steel with vinyl siding on OSB). **These results are showing a negative gap for alternative solutions which have a strong economic disadvantage, which could be hardly balanced with incentives.**

Table 3: Cost comparison between the different options

	Baseline Building	Option 1	Variance	Option 2	Variance
Cost for basic works without openings and finishes (MUR per **m^2)**	15,000	25,092	67.3%	26,372	75.8%
With Openings (Cost MUR per **m^2)**	18,000	28,092	56.1%	29,372	63.2%
With Finishes (Cost MUR per **m^2)**	**25,000**	**35,092**	**40.4%**	**36,372**	**45.9%**

c) Energy use

Finally, to evaluate the energy efficiency of the construction technologies, a simulation was done on the three options. The simulation work focuses on the energy consumption of the building itself considering two alternative options. Based on ASHRAE (The American Society of Heating, and Air-Conditioning Engineers) parameters, the energy savings is 14.8% for Option 1 and 14.6% for Option 2.

	BASECASE	OPTION 1	OPTION 2
Total Annual Energy Consumption(MWh)	23.158	19.72	19.77

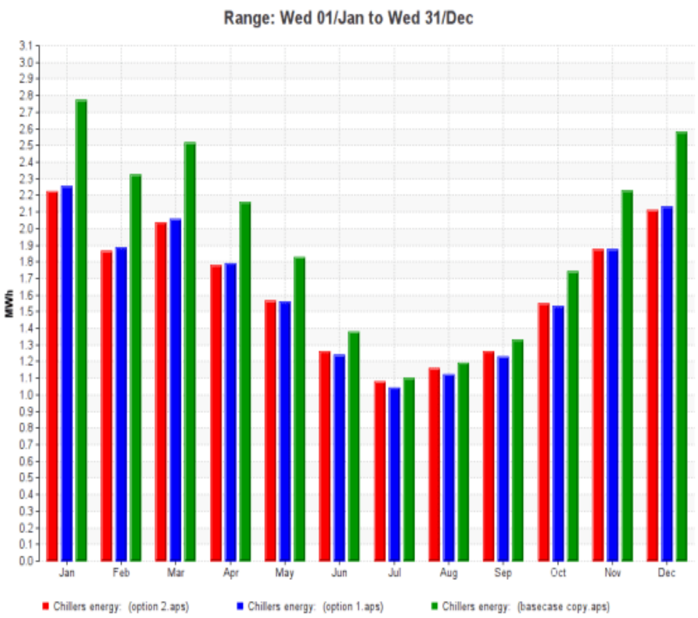


Figure 1: Results of the ASHRAE simulation to evaluate construction technologies energy efficiency.

Conclusion

Dry construction technologies using light gauge steel frames with different types of cladding offers a reduction in energy use of an average of 14.7% compared to a conventional construction using reinforced concrete frame and concrete block infills.

However, the dry construction technology has more embodied carbon and embodied water in the materials used. For the wall construction, the dry construction has 223% more embodied carbon and 33% more embodied water. It should be noted that a steel structure is however more recyclable and recycled than concrete. For the roof construction, dry construction technology has 65% more embodied carbon and 81% more embodied water.

The costs are also reasonably higher with an average of 43.15% for a finished 110 m^2 house, and 71.55% for basic building work. The gap can't be reduced with incentives.

For future SUNREF activities, the impacts of alternative solutions are positive on energy consumption by the energy efficiency gains are under 20%. Timber materials were not prioritised because a lack of stakeholders involved, dependence on imports, and necessity of maintenance under a tropical climate condition.

1. Introduction

Through its green finance label SUNREF (Sustainable Use of Natural Resources and Energy Finance), Agence Française de Développement (AFD) supports the energy and environmental transition in nearly 30 developing countries by helping private sector actors seize opportunities linked to green growth and implement their projects, while encouraging local partner banks to finance them.

SUNREF commissioned a study on green and sustainable building to better inform project developers and banks on the criteria adopted in the fields of mitigation and adaptation to climate change, and to facilitate and promote bankable projects. This will allow easier evaluation of the applications, and the eligibility of the expenses using appropriate frameworks and methodologies. They will be able to apply the methods for evaluating eligible expenses to their projects, in conjunction with the SUNREF partner banks. One of the key deliverables was to perform a cost/benefit analysis of the dry construction sector for its development in Mauritius by providing the following:

- A summary table comparing the solutions (conventional construction versus different types of dry construction)
- Economic elements for implementation (if the development of the solution in Mauritius is deemed relevant)
- Eligibility calculations for SUNREF building (If the development of the solution in Mauritius is deemed relevant)

2. Methodology

2.1. Desktop research

Desktop research was carried out to collect data from existing resources.
Research has been carried out on construction types, materials including their properties, technology providers and suppliers. Information was obtained from India, Reunion Island and specially Mauritius.

15 Environmental Product Declarations (EPDs) were reviewed for the construction materials considered in the study. Information such as technical properties, global warming potential and embodied water usage were investigated.
EPDs are standardised and verified documents reporting a product's environmental impacts. The environmental data is created using a holistic life-cycle assessment (LCA) and gets verified by a third-party expert. Every EPD provides the product's carbon footprint – called the Global Warming Potential (GWP). In addition to carbon, the EPD contains environmental impacts to air, soil, and water bodies. EPDs provide transparency about product impacts. (OneClick LCA, n.d.)

A properly developed EPD follows an ISO standard to report information over the entire product life cycle with quantitative measures of key environmental impacts.
An EPD follows a specific format described in an ISO-compliant Product Category Rule (PCR) and verified by the PCR program operator, listing all of the impacts of a product on the environment.
EPDs provide information about products from cradle to grave (or cradle) such that designers, specifiers, buyers, code officials and the general public can better understand a product's specific, as well as overall, environmental impact. This is known as the life cycle of the product.
Life-Cycle Assessment (LCA) assesses environmental impacts and potential impacts in multiple attribute categories across the stages of a product's life, from raw material extraction through materials processing, manufacturing, distribution, use (energy saved vs. lost during use phase), repair/maintenance and eventual disposal, recycling or recovery.

Life-cycle stages according to the EN standard are:

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

A1: Raw material extraction and processing, processing of secondary material input (e.g. recycling processes)
A2: Transport to the manufacturer
A3: Manufacturing

Module A1, A2 and A3 may be declared as one aggregated module A1-A3. All stages include the provision of all materials, products, and energy, as well as waste processing up to the end-of-waste state or disposal of final residues during the product stage.

A4: Transport to the construction site
A5: Installation of the material
Stages A4 and A5 include all impacts and aspects related to any losses during this construction process stage (i.e. production, transport, and waste processing and disposal of the lost products and materials).

B1: Use or application of the installed materials.
B2: Maintenance
B3: Repair
B4: Replacement
B5: Refurbishment
B6: Operational energy use (e.g. operation of the heating system and other building-related installed services)
B7: Operational water use
Stages B6 and B7 include also provision and transport of all materials, products, as well as energy and water provisions, waste processing up to the end-of-waste state or disposal of final residues during this part of the use stage.

C1: De-construction, demolition
C2: Transport to waste processing
C3: Waste processing for reuse, recovery and/or recycling
C4: Disposal
All C stages include provision and transport, provision of all materials, products and related energy and water use.

D: Reuse, recovery and/or recycling potentials expressed as net impacts and benefits. (Green building solutions, n.d.).

2.2. Interviews and visits

Structured interviews were conducted with material suppliers and technology providers. Site visits were arranged with some local to visit their operations and to carry out the interviews.

3. Materials: multicriteria analysis

The Global steel industry emitted around 3.6 gigaton of CO_2 (Gt CO_2) emissions in 2019. (Hasanbeigi, 2021)

About 1 kilogram of carbon dioxide is released for every kilogram of cement made that adds up to 4 gigatons (billions of tons) of cement, and of carbon dioxide emissions, produced annually. (Chandler, 2019).

Appendix A provides an overview on the different types of construction materials:

- Definition
- Applications of the material,
- Advantages and disadvantages
- Specifications
- Environmental performance

The Environmental Product Declarations (EPDs) of the different types of construction materials can be found in Appendix B.

The construction materials studied are:

1. Cement
2. Concrete
3. Concrete block
4. Reinforcement steel
5. Fibre cement board
6. Gypsum boards
7. Magnesium oxide (MgO) board
8. Oriented Strand Board (OSB)
9. Glass wool insulation
10. Light gauge steel
11. Corrugated iron sheets
12. Cross laminated timber
13. Vinyl siding

Table 4: Construction Material Properties

	Product type	Size/Density	LCA stages	Global warming potential (Kg CO2 eq)	Use of net freshwater (m³)	Thermal conductivity (W/mK)	Recyclability	Embodied carbon	Embodied water
1	**Cement (Portland composite cement)** **KOLOS 42.5 (Kolos, 2022)**	1 ton	A1-A3	785	2.33		Only a small percentage of Portland cement produced are recycled.	For 1m² of 12mm of plaster work = 2.3 kg Embodied carbon: 1.81 Kg CO2 eq	For 1m² of 12mm of plaster work = 2.3kg Embodied water: 0.005 m³
2	**Cement (Portland composite cement) KOLOS Ecoplus (Kolos Ltd, 2022)**	1 ton	A1-A3	723	3.4		Only a small percentage of Portland cement produced are recycled.	For 1m² of 12mm of plaster work = 2.3 kg Embodied carbon: **1.66 Kg CO2 eq**	For 1m² of 12mm of plaster work = 2.3 kg Embodied water: **0.008 m³**
3	**Average concrete cellular block (UBP)** **(UBP, 2020)**	1 ton	A1-A3	97.4	0.419	2.46 (U value with 15mm plaster both sides - 2.27	Concrete is 100% recyclable. (GCCA, n.d.). However, operations in Mauritius have stopped due to the cost involved in removing the reinforcement steel from the concrete. Worldwide not even 1% of concrete buildings are deconstructed at their end of life. Generally speaking, the constituents of concrete can be recycled materials, and concrete itself can also	For 1m² of 200mm thick block Embodied carbon: **22.32 Kg CO2 eq**	For 1m² of 200mm thick block Embodied water: **0.06 m³**

							be recycled. (MPA (The concrete centre), n.d.)		
4	**Ready -mixed concrete (NRMCA, 2019)**	1 m³	A1-A3	195.52	1.61	0.58-1.63	Generally speaking, the constituents of concrete can be recycled materials, and concrete itself can also be recycled. (MPA (The concrete centre), n.d.)	For 1m² of 150mm thick concrete slab Embodied carbon: **29.33 kg CO2eq**	For 1m² of 150mm thick concrete slab Embodied water: **0.24m³**
5	**Reinforcement steel (CMC, 2021)**	1 ton	A1-A3	707	3.33	80.4	Reinforcing steel is 100% recyclable and can be recycled infinitely.	For 1 m of 200x200 mm columns/beams, the weight of Reinforced steel is 4.5 kg. Embodied carbon is: **3.185 Kg CO2 eq**	For 1 m of 200x200 mm columns/beams, the weight of Reinforced steel is 4.5 kg. Embodied water is: **0.015 m3**

6	**Fibre cement board (Yapı et al., n.d.)**	1 ton	A1-A3	774	2.77	0.2	Fibre cement can be fully recycled at the end of its lifetime. (Riba Journal, 2015)	For 1m² of 14 mm thick fibre cement board, the weight is 13.5 kg Embodied carbon is: **10.45 Kg CO2 eq**	For 1m² of 14 mm thick fibre cement board, the weight is 13.5 kg Embodied water is: **0.037 m³**
7	**Gypsum board (American & Boards, n.d.)**	1m³	A1-A3	317.4	3.89	0.3	According to the gypsum association, the total recycled content (%) varies by manufacturer. post-consumer gypsum material collected from construction is not always fully recycled; part of it is regarded as waste. Not only is gypsum fully recyclable, but it can also replace waste management costs with a value-added product (Feeco, 2022)	For 1m² of 14 mm thick Gypsum board Embodied carbon: 4.**44 Kg CO2 eq**	For 1m² of 10 mm thick Gypsum board Embodied water: **0.055 m³**
8	**Magnesium oxide (MgO) boards (MagTech, 2018)**	1 m²	A1-A3	7.42	20	0.014	Magnesium oxide boards are recyclable and are also considered “nutritional waste.” This means that their lack of toxic substances does not compromise landfills or water sources. They can even be ground up and sprinkled into the soil as a nutrient. (Pro crew, 2020)	For 1m2 Embodied carbon is: **7.42 Kg CO2 eq**	For 1m2 Embodied water is: **0.014 m3**

9	**Glass wool insulations (Knauf Insulation, 2019)**	1 m³	A1-A3	20.6	0.178	0.035	Generally made up of up to 86% recycled materials. Recycled glass is in demand as a raw material for many production processes including the glass wool industry itself. However, for the glass to be of any use, any organic content must be removed prior to melting. Several strategies have been developed to counter this challenge. (Insulation superstore, n.d.)	For 1m² of 10 mm of glass wool insulation Embodied carbon is: **0.206 Kg CO2 eq**	For 1m² of 10 mm of glass wool insulation Embodied water is: **0.0018 m³**
10	**Oriented Strand Board (OSB) (American Wood Council, 2013)**	1 m³	A1-A3	248.3	0.3951	0.13	Common engineered wood products, such as oriented-strand board and plywood, can be recycled into biofuels when blended with clean dimensional lumber. (Jacob Forrest, 2021)	For 1m² of 12mm thick OSB Embodied carbon: **2.980 kg CO2eq**	For 1m² of 12mm thick OSB Embodied water: **0.0047 m³**
11	**Light gauge steel (Europrofil AB, 2020) - 1.2mm thick 2C**	1 ton	A1-A3	2560	0.5	0.15	81% of all steel products can be recovered for recycling at the end of the product's lifecycle. All light gauge steel framing contains a minimum of 25% recycled steel. This scrap is re-melted to produce new steel. (AISC, n.d.)	For 1 m of 1,2 mm of LGS stud 90x50mm the weight is 1.884kg Embodied carbon is: **4.82 Kg CO2 eq**	For 1 m² of 4 mm of LGS the weight is 33.48 kg. Embodied water is: **0.00094 m³**

12	**Corrugated iron sheet (Cembrite Holding A/S, 2016)**	1 ton	A1-A3	819.41	11.84	0.4	Corrugated galvanised iron commonly called corrugated iron is used to describe two different materials: galvanised wrought iron and galvanised mild steel. Originally made from wrought iron, corrugated iron is now made from light gauge high tensile steel. Steel has one of the highest recycling rates in the world and as it does not degrade in the process it can be recycled indefinitely. Recycling scrap steel uses only 75% of the energy required to smelt iron ore. The quantity of water required in recycling steel is also greatly reduced, as washing and enrichment of the iron ore is not required (Planet Ark, 2020)	For 1 m² of 6 mm of corrugated iron sheet, the weight is 43.20 kg. Embodied carbon is: **35.40 Kg CO2 eq**	FFor 1 m² of 6 mm of corrugated iron sheet, the weight is 43.20 kg. Embodied water is: **0.511 m³**
13	**Cross laminated timber (Stora Enso (Division Wood Products, 2020)**	1 m³	A1-A3	53.8	0.252	0.12	Upon the demolition of a CLT based construction project, leftover wood can be utilised or recycled for a magnitude of other uses due to its wood nature. The CLT contains biomass and its panels, and any other individual elements are recyclable, they are able to be sent back to the manufacturer for reuse and recycling. (SCS, 2013)	For 1 m² of 12 mm thick CTL Embodied carbon: **0.646 Kg CO2 eq**	For 1 m² of 12 mm thick CTL Embodied water: **0.003 m³**

14	**Vinyl sliding Industry Averaged Vinyl Siding (0.040" Double 4.5") (Vinyl Siding Institute, 2016)**	1 m³	A1-A3	5.49	7.96	0.17	Vinyl siding is completely recyclable. Waste-to-heat energy recovery can also utilize vinyl siding at the end of its useful service life to produce electricity. (Vinyl Siding Institute, 2016)	For 1 m² of 10 mm thick vinyl siding Embodied carbon: **0.055 kg CO2eq**	For 1m² of 10 mm thick vinyl siding Embodied water: **0.080 m³**

Based on the impact of the above materials, it should be noted that both the production of cement and metal are energy intensive: for 1 ton of cement, the embodied carbon can be 785 kgCO2e and can have an embodied water of 2.33m3, whereas 1 ton of light gauge steel can generate 2580 kgCO2e and uses 0,5m3 of water. Some steel products use relatively a large amount of water. For example, for manufacturing 1 ton of roof sheeting, 11.84m3 of water can be required. It should be noted however that steel can be easily recycled whereas cement and concrete are not usually recycled.

As a comparison between concrete and steel, the corrugated iron sheet roof can be compared to a concrete slab.

The comparison is provided below.

Table 5: Comparison table for the roofs

For the roofs:

	Embodied carbon	Embodied water
150mm concrete roof slab		
Concrete	29.33	0.24
Reinforcement	9.54	0.04
Total	**38.87**	**0.28**
Corrugated sheet roof		
Corrugated sheeting	35.40	0.51
Steel frame	28.92	0.01
Total	**64.32**	**0.52**

The dry construction has 65% more embodied carbon and 81% more embodied water.

For the walls, a similar comparison can be done.

Table 6: Comparison table for the walls

	Embodied carbon	Embodied water
200mm block wall		
Concrete block	22.32	0.06
Total	**22.32**	**0.06**
Gypsum board wall		
Gypsum board x2	20.90	0.07
Steel frame	28.92	0.01
Total	**49.82**	**0.08**

The dry construction has 223% more embodied carbon and 33% more embodied water.

4. Construction technologies

The main construction technology in Mauritius is the use of a reinforced concrete structural frame with concrete cellular blocks.

It can be categorised as wet construction, as it uses water, and liquid materials.

4.1. Concrete structure with concrete cellular block infill walls

The following describes the construction technology.

i) **Foundations**

Figure 2: Raft foundation Construction (Kolos Cement Ltd, 2019)

The building supported on the foundation is the lowermost part of the building that is in contact with the soil. The foundations can vary from reinforced concrete bases with concrete columns and ground beams, or it can be a raft reinforced concrete foundation. For the raft foundation, the whole floor is the foundation.

ii) Ground Beam and Slab

Figure 3: Ground beam

After the foundation work is done ground beam formwork preparation is started and poured with concrete. Over the ground beam, masonry work is started.

iii) Superstructure

The superstructure is the portion above the plinth level (ground beam) of the building. The main component of the superstructure is a column and beam. The columns are built up to slab level and the frame for further construction is prepared.

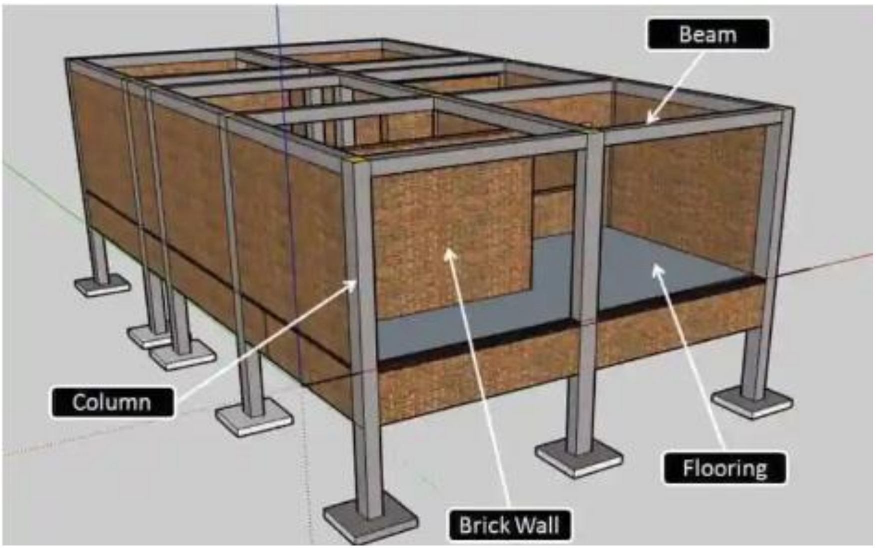


Figure 4: RCC Frame Structure

iv) Infill walls – External and internal

As the column and beam framework is ongoing, masonry work is carried out with concrete blocks. Masonry work is done with concrete cellular blocks and a cement mortar mix. It is a mixture of cement & rocksand.

v) The lintel over door window gaps

The lintel is constructed on the door and window to support the masonry work over it. After this further masonry work is done. The lintels are made of reinforced concrete.

vi) Floor Slab or Roof Structure

After the formwork installation, reinforcement steel is laid on the formwork, before concrete is poured slab resting to complete the reinforced concrete slabs.

vii) Door and windows installation

The doors and windows are installed.

viii) External finishes

Once this work is completed, external plastering and finishing work is started.

ix) Terrace and Roof Finishing

On top of the slab, a screed is normally poured, and waterproofing is done to prevent any leakage in the slab.

x) Internal finishes

Internal walls are plaster with a smooth finish and flooring. Later, the walls are painted.

xi) Fittings, mechanical and electrical work.

By following the above step, almost all construction work is completed, and then furniture work is started. Simultaneously, electrical fitting, switchboard, and plumbing fittings are completed in the bathrooms and kitchen areas too.

4.2. Light gauge steel structural frame with cladding

Another option for construction is the light gauge steelwork frames and cladding instead of the reinforced concrete structural frame and concrete infill.

This system is not widely used in Mauritius.

Even for industrial building hot rolled steelwork (I and H sections) are used instead of cold formed steel units.

Cold-Formed Steel (CFS) units, in other countries, are widely used in industrial/residential building component buildings. Cold formed sections can be applied to have high compressive strength and tensile strength local buckling, high flexural strength, fire resistance, adequate wind, and seismic response using the bracing shear wall, respectively. These tubular-like sections are cold-formed steel from low alloy steel sheet or carbon, plate, strip, or flat bar in cold-rolling machinery or through press brake or bending brake processes. (Venkatesan & Ganesan, 2021).

Light gauge steel systems consist of two main components, the structural component made out of the steelwork frames and the cladding. Light gauge steel sections can be of different thicknesses and in different shapes. The construction of the frame varies depending on the structural requirements, with different spacing and bracing.

The second component is the cladding, both internal and external.

Figure 5: Wall construction with a window open

Figure 6: External wall cladding

Cladding options

4.2.1.1. Fibre cement board

Fibre cement cladding is crafted using a combination of cement, cellulose, sand, synthetic fibres, and water, giving a long lasting and durable cladding board which lasts for years to come. It is one of the most practical solutions for building facades. These boards are manufactured using advanced technology to ensure the chemically bonded boards withstand a range of impacts. Some comes with a 10-year guarantee (Trade warehouse, 2022).

Boards come in thicknesses from 6 to 15mm with different surfaces offered. The boards can be finished by just two coats of paint, or they could even be wallpapered and even rendered.

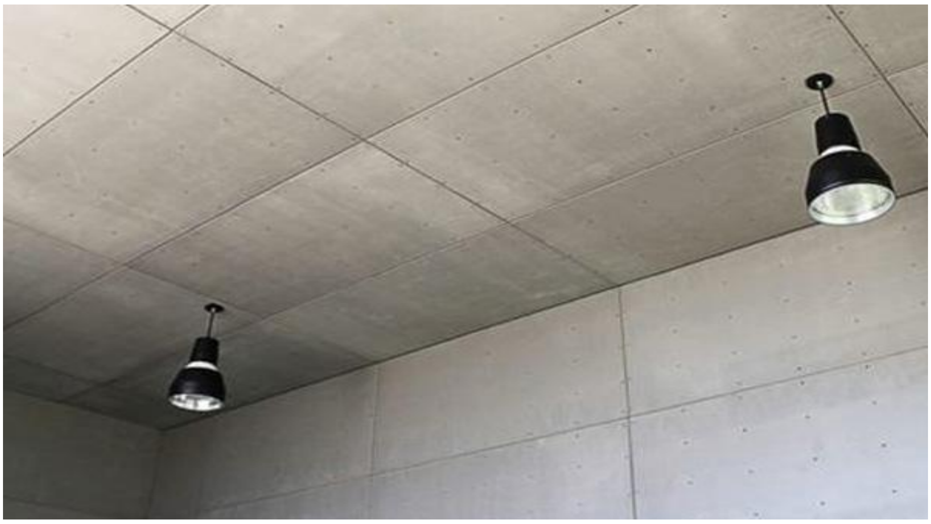


Figure 7: Fibre cement board

4.2.1.2. Magnesium oxide board

Magnesium Oxide boards are a man-made factory-produced non-insulating sheathing board products that are used for general construction applications. MgO board is like traditional drywall or cement board, but is much stronger, fireproof, and has a higher resistance to mould, mildew, moisture, and weather. It is made from magnesium oxide, which is type of mineral cement, and contains magnesium (which has a chemical symbol of Mg) and oxygen (chemical symbol of O). It has not only the lightweight and flexible properties of wood-based organic boards, but also the fire-resistant and water-resistant properties of inorganic boards.

Magnesium oxide boards are used in the same way as drywall or oriented strand board or any other board product.

Figure 8: Magnesium oxide boards

(Suparna, 2022)

MgO boards are also user friendly as they contain no carcinogenic dust, fly ash, or other toxins which makes them very safe to work with. The boards are 20% to 30% lighter than other cement-based boards, making them very lightweight and easy to transport.

4.2.1.3. Vinyl siding on OSB board

Vinyl siding can be installed over common wood sheathings such as plywood, oriented strand board (OSB), or other materials (e.g., foam plastic insulating sheathing). The thickness of wood sheathing counts toward the total thickness that the fasteners must penetrate nail-able material, usually 1 1/4” (32mm).

Figure 9: Vinyl sliding on OSB board

The following describes the construction technology

i) Foundations

Figure 10: Raft foundation Construction

Similarly, to the foundations for the reinforced concrete structural frames, reinforced concrete bases with ground beams can be used, or it can be a raft reinforced concrete foundation. For the raft foundation, the whole floor is the foundation.

Since the structure is lighter, especially if not concrete roof slab is specified.

ii) Ground Beam and Slab

Figure 11: Ground beam

After the foundation work is done ground beam formwork preparation is started and poured with concrete. Over the ground beam, steel framing starts.

iii) Superstructure

The main component of the superstructure is the frame construction using light gauge steel and the cladding.

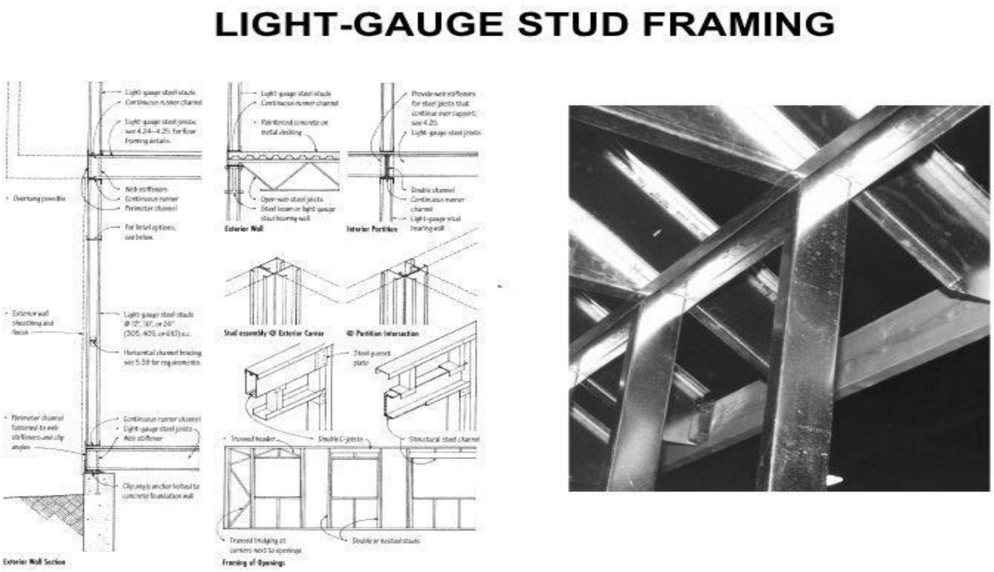


Figure 12: Light gauge steel frame Structure

iv) Cladding – External and internal

Various cladding options are available. Insulative materials are also used in the composition for the cladding.

v) The lintel over door window gaps

The lintels are constructed within the frame.

vi) Floor or roof structure

The structure is made of the light gauge steel framing, and the cladded. Various options are available similar to the walls.

Figure 13: Floor, roof truss, beam arrangement

vii) Door and windows installation

The doors and windows are installed.

viii) External finishes

Once this work is completed, external plastering and finishing work is started. In some cases, it is possible not to use plasterwork.

ix) Roof finishing

Several layered constructions are possible for the roof and ceiling space.

x) Internal finishes

Internal walls are plaster with a smooth finish and flooring is done with tiles. Later, the walls are painted.

xi) Fittings, mechanical and electrical work.

By following the above step, almost all construction work is completed, and then furniture work is started. Simultaneously, electrical fitting, switchboard, and plumbing fittings are completed in the bathrooms and kitchen areas too.

Case Study 1 – Gainsborough Travelodge, UK

Year built: October 2018

Project brief: The building contractor required steel panels to be produced for a new build Travelodge in the town centre of Gainsborough. The panelised build had a ground floor commercial area, supporting 4 storey bedroom accommodation.

Technology: This was a traditional panelised building project. The cold roll formed light gauge steel framing panels were ideal for this building, providing the strength to support the four upper levels of the hotel but without adding load weight to the overall construction. LGSF produced panels which were supplied and erected onsite in Gainsborough. The walls were then plaster boarded and clad in brick to ensure the building was in keeping with its town centre location and surroundings.

Key results:

- Light weight panels were easily and economically transported to site
- The structural integrity of LGSF panels ensured that the building could be erected quickly, with minimal time on site
- The versatility of this modern construction method accommodates external finishes to ensure the finished building met planning requirement (LGSF, 2018a)

Case Study 2 – Park Homes (USA)

Year built: November 2018

Project Brief: The project was to create a next generation park home which would conform to permanent housing building regulations allowing residents to live on a park all year around.

Technology: LGSF (Light gauge steel framing) designed and built, a two-storey home in pre-panelised 3D steel framing units. It was then transported by road, in two parts, to the client's factory for fitting. Inspired by Manhattan loft apartments, the home has cedar cladding and high spec contemporary touches including a full kitchen fit and spiral staircase.

Once fitted out, the home was then craned into place on the park. The ease and speed to erect the building meant siting the building only took one week. There was minimal disruption on the park and no construction delays as the building arrived fully completed only requiring final site connections.

The durability of the framing system was fundamental to achieving the building regulations and, thanks to LGSF steel framing system, The Loft is LABC (Local Authority Building Control) approved. This environmentally improved design also gained excellent U-values showing how highly energy efficient the new build is for owners.

Key results:

- Durability of the steel frame build surpasses the requirements for park homes and is LABC approved
- Excellent energy efficiency
- Surpasses the requirements of a park home and can be used as permanent living accommodation
- Volumetric 3D steel framing system supplied direct to Ting Dene
- Siting the building took only one week (LGSF, 2018b)

This study is replicable in Mauritius.

4.3. Cross Laminated Timber (CLT) structure

Another construction technology which is gaining more traction is the cross laminated timber technology.

The material consists of planks (or lamellas) of sawn, glued, and layered wood, where each layer is oriented perpendicular to the previous. By joining layers of wood at perpendicular angles, structural rigidity for the panel is obtained in both directions, like plywood but with thicker components. In this way, the panel has great tensile and compressive strength (Souza, 2018). It is a sustainable material because it's composed of wood, a renewable resource (usually from reforestation), and doesn't require the burning of fossil fuels during its production. It has been used for infrastructure and support in large construction sites, as forms for concreting bridges, or even as bases for tractors in unstable terrain during the construction of dams. Its potential for small constructions has been noted because of its interesting appearance and structural strength. Currently, there are even skyscrapers being built with CLT parts (Souza, 2018).

The panels can function as walls, floors, furniture, ceilings, and roofs; CLT's thickness and length can be adaptable to the demands of each project. Generally, panels made of CLT are assembled and cut in their production, already foreseeing the joints, openings, and drills specified in the design. The parts are then transported to the site, and then assembly takes place there.

Generally, the surfaces are only given the application of a transparent waterproofing, making the natural designs of the fibres of the wood evident.

CLT Building Examples

Figure 14: Skilpod

- <u>Skilpod #150 Zero Energy (ArchDaily, 2020)</u>

Architects: Skilpod, UAU Collective
Country: Belgium
Area: 280m2
Year: 2016
Product Description: The structure of the modules is completely made of CLT or Cross Laminated Timber. The largest boards that were used have dimensions of 12m by 4m and 14cm in thickness.

Figure 15: Minimod Catucaba

- **Minimod Catuçaba / MAPA (ArchDaily, 2020)**

Architects: MAPA
Country: Brazil
Area: 42 m2
Year: 2015

Figure 16: Cross-laminated timber cottage

- **Cross-Laminated-Timber Cottage / Kariouk Associates**

Architects: Kariouk Architects
Year: 2014
To minimize the cost of workers on the construction site while simultaneously ensuring the highest quality of construction, the decision was made early on to pursue the use of prefabricated parts. Specifically, the material selected was CLT, which can be fabricated in panels as large as sixty feet by ten feet. A detailed computer model was generated for every surface that would comprise the cottage whereby every opening and cut needed for assembly, apertures, and services was indicated.

5. Comparison of the solutions

For the study, 3 options have been selected.

They are:

1) Baseline – Reinforced concrete structural frame with concrete cellular block
2) Option 1 – Light gauge steel with fibre cement board externally and gypsum board internally
3) Option 2– – Light gauge steel with vinyl siding and OSB board externally and gypsum board internally

To be able to compare the options, a small three-bedroom house of 110m2 with a flat roof has been used as model.

The photo below was removed and added in a separate section: "The House floor plan after the table: Construction technologies option''

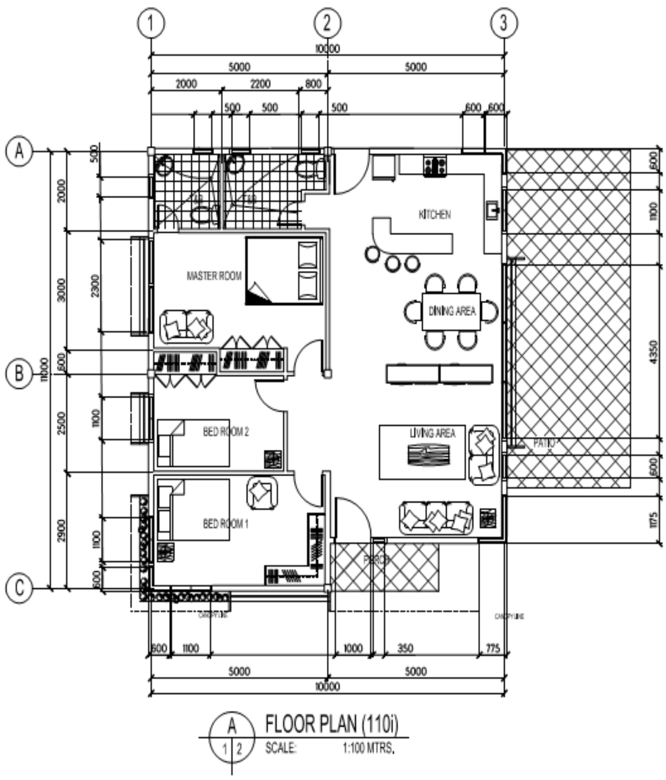


Figure 17: House floor plan

The CLT timber option has not been considered because of the following reason

a) Timber is imported and is relatively expensive
b) Labour is equally relatively expensive.
c) Market test has been done by a supplier but market entry failed
d) Generally, users have many concerns that act as barriers such as strength, maintenance, risk of termite attack and risk of fire.

The different options are provided in the table below.

Table 7: Construction technologies option

	Structure	Baseline	Option 1	Option 2
			Light gauge steel + MgO + Gypsum	Light gauge steel + OSB board with vinyl siding + gypsum
1	**Substructure**			
1.1	Foundation	R.C bases/strip footings	R.C bases/ground beams	R.C bases/ground beams
2	**Superstructure**			
2.1	Ground floor construction	Ground beam + Concrete floor on hardcore filling + screed	MgO floor board on steel frame + 10mm glass wool insulation	OSB board on steel frame + 10mm glass wool insulation
2.2	Structural frame	RC columns and beams	Light gauge steel	Light gauge steel
2.2.1	Columns	Reinforced concrete	Light gauge steel	Light gauge steel
2.2.1	beams	Reinforced concrete	Light gauge steel	Light gauge steel
2.3	External envelope	200mm blockwork (hollow blocks)	Magnesium Oxide board + 10mm glass wool insulation	Vinyl siding on OSB board incl damp proof membrane + 10mm glass wool insulation
2.3.1	Walls	200mm blockwork (hollow blocks)	MgO board - external, Gypsum board internal	Vinyl siding on OSB board incl damp proof membrane + gypsum board internal
2.3.2	Finishings	Plaster and paint - 16mm	Plaster and paint - 5mm	Plaster and paint - 5mm
2.3.3	Windows	Aluminium	Aluminium	Aluminium
2.3.4	Doors	Aluminium	Aluminium	Aluminium
2.4	Roof	150mm RC slab	Corrugated iron sheet + 10m glass wool insulation	Corrugated iron sheet + 10m glass wool insulation
2.5	Internal division	150mm blockwork	Gypsum partition	Gypsum partition
2.5.1	Walls	150mm blockwork	Gypsum partition	Gypsum partition
2.5.2	Doors	Timber	Timber	Timber
3	**Internal finishes**			
3.1	Floor finishes	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles
3.2	Internal wall finishes	Plaster and paint	Plaster and paint	Plaster and paint
3.3	Ceilings	Plaster and paint - underside fo slab	Gypsum ceiling	Gypsum ceiling
4	**Fittings**	General	General	General
5	**Services**			
5.3	HVAC	None	None	None
5.4	Special equipment	Photovoltaic/solar panels	Photovoltaic/solar panels	Photovoltaic/solar panels

5.1. Construction parameters

Table 8: Baseline construction parameters

CONSTRUCTION PROPERTIES	
External Wall	200mm concrete Hollow blocks + 16mm plaster on inner and outer ends with 'U' value 2.36w/m2k
Floor	150mm Concrete Floor+10mm screed with 'U' value 3.24 w/m2k
Glass	U-value : 5.6 W/m^{2}K; SHGC:0.68 & VLT - 66%
Roof	150mm RCC +16mm plaster on inner and outer ends with 'U' Value 3.75w/ m2k
Internal Partition	150mm Concrete Floor +16mm plaster on inner and outer ends with 'U' Value 2.37 w/ m2k

Table 9: Construction parameters for option 1

CONSTRUCTION PROPERTIES - PROPOSED FACILITY	
External Wall	14mm Fiber cement board + 10mm Glass wool Insulation with 'U' value 1.88w/m2k
Floor	14mm Fiber cement board + 10mm Glass wool Insulation with 'U' value 1.75w/m2k
Glass	U-value: 5.6 W/m^{2}K; SHGC:0.68 & VLT - 66%
Roof	Corrugated Iron sheet + 10mm Glass wool Insulation with 'U' Value 2.26 w/ m2k
Internal Partition	10mm Gypsum board +10mm Glass wool Insulation with 'U' value 1.64w/m2k

Table 10: Construction parameters for option 2

CONSTRUCTION PROPERTIES - PROPOSED FACILITY	
External Wall	10mm vinyl sliding + 12mm OSB board with 'U' value 1.15w/m2k
Floor	12mm OSB Board + 10mm Glass wool Insulation with 'U' value 1.54w/m2k
Glass	U-value: 5.6 W/m^{2}K; SHGC:0.68 & VLT - 66%
Roof	Corrugated Iron sheet+ 10mm Glass wool Insulation with 'U' Value 2.26 w/ m2k
Internal Partition	10mm Gypsum board +10mm Glass wool Insulation with 'U' value 1.64w/m2k

6. Energy performance

6.1. Design parameters

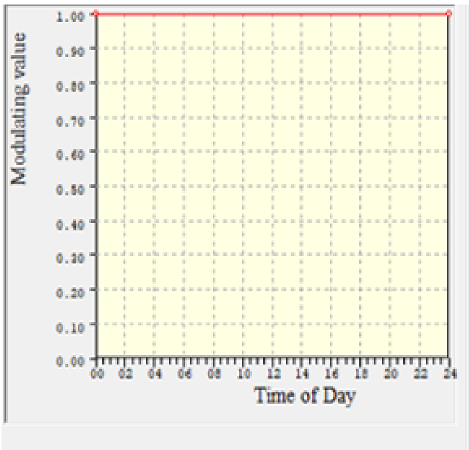
A simulation was done for an individual dwelling building, and was based on the following parameters from ASHRAE 2016:

Thermal Parameters

Description	Wattage
Lighting Load	6.57 W/Sq.m
Equipment Load	6.46W/Sq.m
People	4 person/dwelling unit

- ✓ *Thermal Parameters were considered based on baseline value of ASHRAE 2016*

People Sensible Heat Gain (W/Person) = 250
People Latent Heat Gain (W/Person) = 200



Occupancy Schedule (24hrs)

The project site comprises living, bedrooms. The site location is Vacoas, Mauritius.

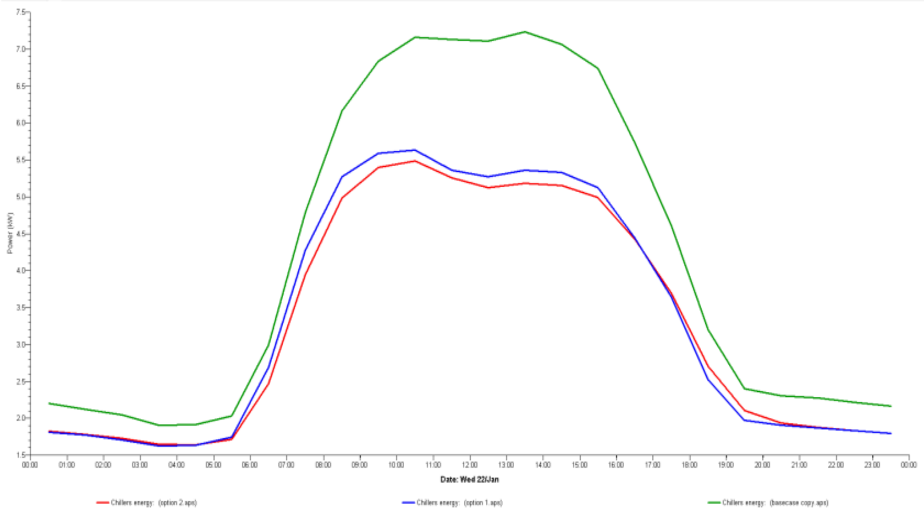
Table 11: Data considered for simulation

CONSTRUCTION PROPERTIES	BASECASE(U VALUE)	OPTION 1(U VALUE)	OPTION 2(U VALUE)
External Wall	2.36	1.885	1.15
Floor	3.24	1.75	1.54
Glass	5.6	5.6	5.6
Roof	3.75	2.26	2.26
Internal Partition	2.37	1.64	1.64

- **Total heat load (kW)**

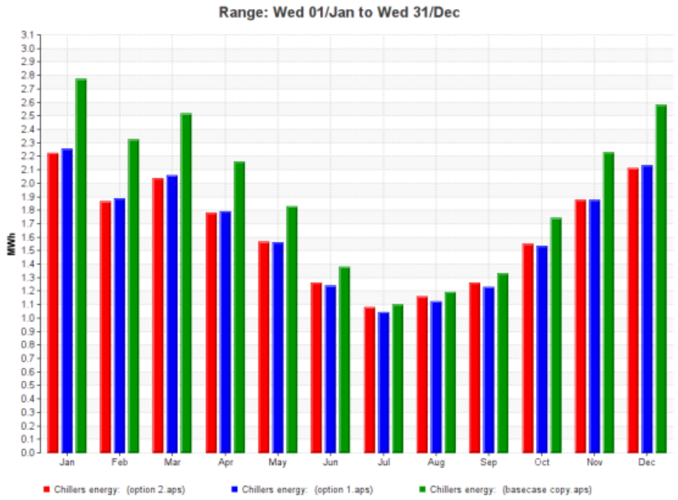
The total heat load for the different cases have been simulated. The calculation of the energy use is based on the heat load. The green line represents the base case, the blue line, Option 1 and the red line, Option 2.

	BASECASE	OPTION 1	OPTION 2
Total Heat Load (kW)	18.07	13.39	12.96



- Total annual energy consumption (MWh)

	BASECASE	OPTION 1	OPTION 2
Total Annual Energy Consumption(MWh)	23.158	19.72	19.77



- **Percentage savings from baseline**

(i) Option 1

% savings = ((23.158 - 19.72)/ 23.158) * 100 = 14.8%

(ii) Option 2

% savings = ((23.158-19.77)/23.158) *100 = 14.6%

Based on the simulation, the results show that the dry construction technique provides a reduction in energy use of 14.8% for Option 1, and 14.6% for Option 2.

The full report can be found in Appendix E.

7. Cost Analysis BE

The costs for the construction of a 110 m^2 are provided below

Table 7 Construction cost of a 110 sqm house

	Baseline Building	Option 1	Variance	Option 2	
Cost for basic works without openings and finishes (MUR/m^2)	15,000	25,092	67.3%	26,372	75.8%
With Openings (Cost MUR/m^2)	18,000	28,092	56.1%	29,372	63.2%
With Finishes (Cost MUR/m^2)	25,000	35,092	40.4%	36,372	45.9%

The variance between the baseline building is relatively high varying from 40.4% (basic building work) to 67.3% (finished) for Option 1 and 45.9% (basic building work) to 75.7% (finished) for Option 2

8 Conclusion

Establishing local channels while evaluating the availability of materials that require the minimum amount of water and energy is a promising solution for greening the construction sector. The objectives were to conduct a study on the significance of "dry" construction solutions for Mauritius and to determine the products' eligibility in terms of attenuation and adaptation.

Dry construction is a building technique that involves the use of prefabricated components that are assembled on-site without the need for wet trades such as plastering or concrete pouring. Dry construction has several advantages over traditional construction methods. It is faster, cleaner, and quieter, with less waste and lower labour costs. It also allows for greater flexibility in design and easier modification or expansion of the building.

The embodied carbon and embodied water were calculated using the Environmental Product Declaration (EPD), a document that provides information on energy consumption, greenhouse gas emissions, water consumption, and other environmental impacts.

Three construction technologies were used in this study which are reinforced concrete structural frame, light gauge steel frame and cross-laminated timber. Timber has been excluded as timber is considered high maintenance, and people are concerned with the risks of termite attack and of fire.

For the study, the light gauge steel framed construction has been considered with two different types of cladding externally. The first option (Option 1) is with using fibre cement board, and the second option (Option 2) is vinyl siding on OSB. Insulation is required for the wall panel to provide same with a good thermal transfer property.

The baseline building has a reinforced concrete frame with concrete blockwork infills.

As for the roof, the baseline building has a reinforced concrete roof slab, whereas option 1 and 2 has a corrugated iron sheet, with a suspended ceiling.

The different construction technologies have been compared using three criteria, namely:

a. the embodied carbon and embodied water,
b. the costs
c. the energy use

It was found that dry construction technologies using light gauge steel frames with different types of cladding offers a reduction in energy use of an average of 14.7% compared to a conventional construction using reinforced concrete frame and concrete block infills.

However, the dry construction technology has more embodied carbon and embodied water in the materials used. For the wall construction, the dry construction has 223% more embodied carbon and 33% more embodied water. It should be noted that a steel structure is however more recyclable and recycled than concrete. For the roof construction, dry construction technology has 65% more embodied carbon and 81% more embodied water

The costs are also reasonably higher with an average of 43.15% for a finished 110m house, and 71.55% for basic building work.

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Appendix

Appendix A: Types of construction materials

The construction materials studied are:

1. Cement
2. Concrete
3. Concrete block
4. Reinforcement steel
5. Fibre cement board
6. Gypsum boards
7. Magnesium oxide (MgO) board
8. Oriented Strand Board (OSB)
9. Glass wool insulation
10. Light gauge steel
11. Corrugated iron sheets
12. Cross laminated timber
13. Vinyl sliding

1. Cement

1.1. Definition

Cement is a key building material in both residential and commercial construction work. It is obtained from the calcination of a mix of limestone, clay, and iron ore at 1,450°C. The product of the calcination process is clinker (main ingredient) that is finely ground with gypsum and other chemical additives to produce cement. Cement is mixed with water and other substances to make mortar or concrete.(ConcreteNetwork.com, 2020)

All cement products are composed of specific combinations of calcium, silica, iron and alumina and small amounts of additives to achieve a desired profile of properties (e.g., strength, colour).

Material composition of the U.S. industry average Portland cement per mass of cement product. (Portland Cement Association, 2016)

Cement ingredient[a]	Portion of cement product (by weight)
Clinker	92.2%
Gypsum	4.63%
Uncalcined limestone	1.86%
Other materials	<1.0% each

1.2. Product types and their applications in the construction sector

There are several types of cement that are used in the construction sector. They have different and specific applications based on their composition.

Type 1 Portland Cement is the most used cement for construction activities. It is a basic ingredient of concrete, made using a closely controlled chemical combination of calcium, silicon, aluminium, iron, and small amounts of other ingredients to which gypsum is added in the final grinding process to regulate the setting time of the concrete.

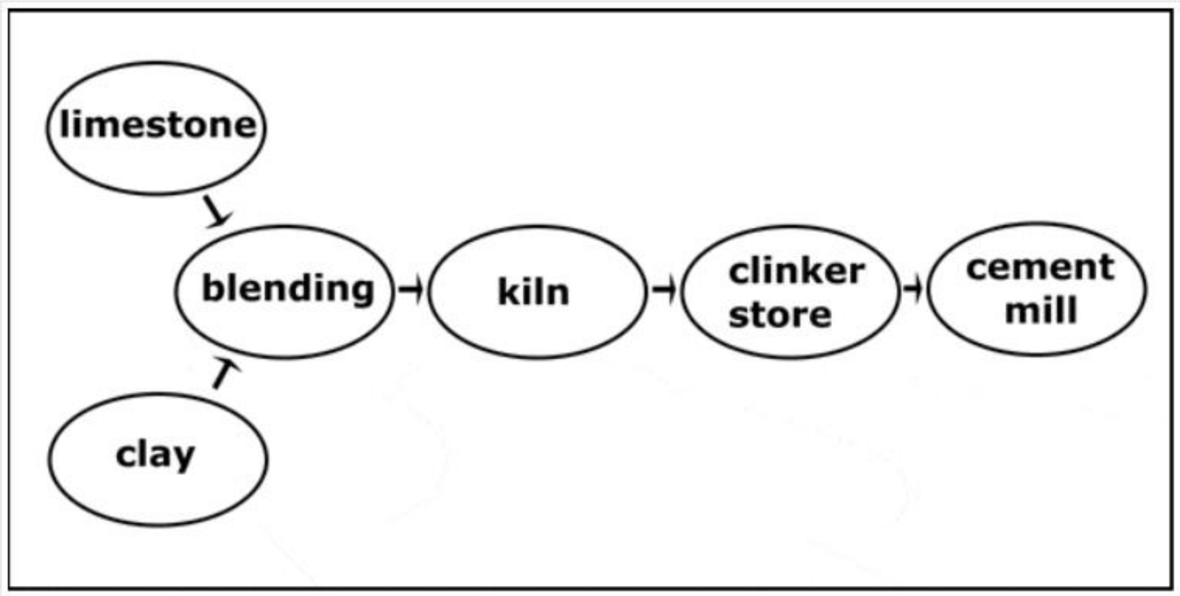
Type 2 is used for structures in water or soil containing moderate amounts of sulphate, or when heat build-up is a concern.

Type 3 is used when high strength is required at very early periods

Type 4 is also known as low heat Portland cement. It is used where the amount and rate of heat generation must be kept to a minimum.

Type 5 is known as sulphate resistant Portland cement. It is used where the water or soil is high in alkali. (ConcreteNetwork.com, 2020)

1.3. General cement manufacturing process



After collecting raw material at production site, raw material handling is the first stage. Here limestone and clay are mixed in proportion of 80% limestone 20 % clay. Then this mixture is ground under rollers crusher to prepare homogenous mixture.

After grinding material is heated in preheating chamber.

Kiln is the rotating furnace and known as heart of cement production plant. Here raw material is heated up to 1450 degree. At this temperature, decarbonisation process takes place were limestone releases carbon dioxide. Chemical reaction between calcium and silicon dioxide forms cement. (Calcium silicate). Kiln is fuelled by coal or natural gas.

After cooling material coming out of kiln using forced air from cooling air fan., final grinding is carried out. During final grinding, gypsum is added which controls setting of cement. (Mechtics, 2019)

1.4. Cement construction process

To start with, cement is used in the foundation process of the construction of cement buildings.

The construction process may include placing plain cement concrete alone or combined with rubble soiling at the bottom of the foundation to create a level surface, set up formworks, place reinforcements, pour concrete, and finally cure the concrete get the designated strength.

After the construction of the foundations and plinth beams (to connect different footings and provide a level surface for the construction of the superstructure.) is present, a reinforced concrete column would be constructed. The procedure involves constructing a column kicker, placing steel bars, setting up formwork, pouring concrete, and curing the concrete.

After the construction of columns on the ground floor is ended, the construction of slab and beams would begin. The process involves placing formworks for beams and slabs, installing reinforcements for beams and slabs based on drawings, embedding other objects is present, pouring concrete for beams and slabs, and finally cure the concrete properly. The sequence of constructing columns, beams, and slabs is followed for other storeys above.

When the construction of columns and beams is completed, the masonry wall construction will begin.

The process repeats for multistorey buildings. (The Constructor, n.d.)

1.5. Specifications

Environmental specifications (Global warming potential and Use of net freshwater)

Source: (UBP, 2020)

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ENVIRONMENTAL IMPACT DATA

Note: additional environmental impact data may be presented in annexes.

CORE ENVIRONMENTAL IMPACT INDICATORS – EN 15804+A2, PEF

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
GWP – total	kg CO_2e	7,31E2	4,31E1	1,06E1	7,85E2	6,46E0	7,77E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
GWP – fossil	kg CO_2e	7,24E2	4,31E1	1,46E1	7,81E2	6,52E0	8,83E-2	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
GWP – biogenic	kg CO_2e	6,95E0	-2,11E-2	-3,96E0	2,96E0	3,38E-3	7,68E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
GWP – LULUC	kg CO_2e	2,52E-1	3,64E-2	1,88E-2	3,07E-1	2,24E-3	5,68E-5	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Ozone depletion pot.	kg CFC_{11}e	2,49E-5	8,57E-6	1,4E-6	3,48E-5	1,46E-6	1,48E-8	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Acidification potential	mol H^+e	2,08E0	1,25E0	8,56E-2	3,42E0	2,72E-2	6,67E-4	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
EP-freshwater[2)]	kg Pe	1,06E-2	2,22E-4	4,76E-4	1,13E-2	5,96E-5	1,61E-6	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
EP-marine	kg Ne	6,05E-1	2,82E-1	1,98E-2	9,07E-1	8,03E-3	2,71E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
EP-terrestrial	mol Ne	7,03E0	3,15E0	2,14E-1	1,04E1	8,87E-2	1,91E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
POCP ("smog")	kg NMVOCe	1,75E0	8,29E-1	5,77E-2	2,63E0	2,76E-2	1,39E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
ADP-minerals & metals	kg Sbe	5,2E-2	3,96E-4	5,67E-4	5,29E-2	1,48E-4	9,86E-7	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
ADP-fossil resources	MJ	3,39E3	5,5E2	1,31E2	4,07E3	9,82E1	1,22E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Water use[1)]	m^3e depr.	5,65E1	1,4E0	5,23E0	6,31E1	3,72E-1	3,49E-2	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR

1) GWP = Global Warming Potential; EP = Eutrophication potential; POCP = Photochemical ozone formation; ADP = Abiotic depletion potential. 2) EN 15804+A2 disclaimer for Abiotic depletion and Water use and optional indicators except Particulate matter and Ionizing radiation, human health. The results of these environmental impact indicators shall be used with care as the uncertainties on these results are high or as there is limited experienced with the indicator. 3) Required characterisation method and data are in kg P-eq. Multiply by 3,07 to get PO_4e.

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Total use of non-re. PER	MJ	3,39E3	5,5E2	1,31E2	4,07E3	9,82E1	1,22E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Secondary materials	kg	MNR	MNR	1,59E-2	1,59E-2	MNR	MNR	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Renew. secondary fuels	MJ	MNR	MNR	MNR	MNR	MNR	MNR	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Non-ren. secondary fuels	MJ	MNR	MNR	MNR	MNR	MNR	MNR	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Use of net fresh water	m^3	2,19E0	5,6E-2	8,13E-2	2,33E0	1,84E-2	8,92E-4	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR

6) PER = Primary energy resources

Source: (UBP, 2020)

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ENVIRONMENTAL IMPACT DATA

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CORE ENVIRONMENTAL IMPACT INDICATORS – EN 15804+A2, PEF

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
GWP – total	kg CO_2e	6,79E2	3,61E1	7,92E0	7,23E2	4,59E0	8,51E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
GWP – fossil	kg CO_2e	6,74E2	3,61E1	2,1E1	7,31E2	4,63E0	1,8E-1	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
GWP – biogenic	kg CO_2e	5,42E0	-1,72E-2	-1,32E1	-7,76E0	3,36E-3	8,33E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
GWP – LULUC	kg CO_2e	1,52E-1	2,98E-2	4,06E-2	2,22E-1	1,39E-3	1,35E-4	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Ozone depletion pot.	kg CFC_{11}e	2,2E-5	7,12E-6	2,08E-6	3,12E-5	1,09E-6	3,83E-8	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Acidification potential	mol H^+e	1,93E0	1,02E0	1,29E-1	3,08E0	1,94E-2	1,58E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
EP-freshwater[2)]	kg Pe	1,04E-2	2,19E-4	9,88E-4	1,16E-2	3,77E-5	3,8E-6	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
EP-marine	kg Ne	5,51E-1	2,31E-1	2,9E-2	8,11E-1	5,86E-3	6,17E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
EP-terrestrial	mol Ne	6,42E0	2,58E0	3,08E-1	9,3E0	6,47E-2	4,53E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
POCP ("smog")	kg NMVOCe	1,59E0	6,8E-1	8,62E-2	2,36E0	2,08E-2	3,21E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
ADP-minerals & metals	kg Sbe	4,98E-2	3,48E-4	7,12E-4	5,09E-2	7,9E-5	2,6E-6	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
ADP-fossil resources	MJ	3,19E3	4,62E2	2,16E2	3,87E3	7,2E1	3,08E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Water use[1)]	m^3e depr.	5,85E1	1,29E0	1,07E1	7,05E1	2,68E-1	7,74E-2	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR

1) GWP = Global Warming Potential; EP = Eutrophication potential; POCP = Photochemical ozone formation; ADP = Abiotic depletion potential. 2) EN 15804+A2 disclaimer for Abiotic depletion and Water use and optional indicators except Particulate matter and Ionizing radiation, human health. The results of these environmental impact indicators shall be used with care as the uncertainties on these results are high or as there is limited experienced with the indicator. 3) Required characterisation method and data are in kg P-eq. Multiply by 3,07 to get PO_4e.

Total use of non-re. PER	MJ	3,19E3	4,62E2	2,16E2	3,87E3	7,2E1	3,08E0	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Secondary materials	kg	2,02E2	MNR	3,59E-2	2,02E2	MNR	MNR	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Renew. secondary fuels	MJ	MNR	MNR	MNR	MNR	MNR	MNR	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Non-ren. secondary fuels	MJ	MNR	MNR	MNR	MNR	MNR	MNR	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR
Use of net fresh water	m^3	2,22E0	5E-2	1,58E-1	2,43E0	1,5E-2	2,02E-3	MND	MND	MND	MND	MND	MND	MND	MNR	MNR	MNR	MNR	MNR

6) PER = Primary energy resources

1.6 Recyclability of cement

Recycling concrete provides sustainability several different ways. Recycling of concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality. In addition to the resource management aspect, recycled concrete aggregates absorb a large amount of carbon dioxide from the surrounding environment. (PCA, 2019)

Only a small percentage of Portland cement and traditional plastic produced are recycled, so a more readily recyclable alternative should be sought. (Royal Society of Chemistry (Material Advances), 2020).

According to a 2004 FHWA study, 38 states recycle concrete as an aggregate base; 11 recycle it into new Portland cement concrete. (PCA, 2019)

The LEED® Green Building Rating System recognizes recycled concrete in its point system. Credit 4 (Materials and Resources) states, "specify a minimum of 25 percent of building materials that contain in aggregate a minimum weighted average of 20 percent post-consumer recycled content material, OR a minimum weighted average of 40 percent post-industrial recycled content material." Using recycled aggregates instead of extracted aggregates would qualify as post-consumer. Because concrete is an assembly, its recycled content should be calculated as a percentage of recycled material on a mass basis. (PCA, 2019)

2 Concrete

2.1 Definition

The material is a stable mix of cement, basalt aggregates, dense expanded fire-retardant grade polystyrene, fibreglass mesh, dry and wet additives, and water. Cement, usually in powder form, acts as a binding agent when mixed with water and aggregates. This combination, or concrete mix, will be poured and harden into the durable material. There are 3 basic components in a concrete mix:

- Portland Cement - The cement and water form a paste that coats the aggregate and sand in the mix. The paste hardens and binds the aggregates and sand together.
- Water- Water is needed to chemically react with the cement (hydration) and to provide workability with the concrete. The amount of water in the mix in pounds compared with the amount of cement is called the water/cement ratio. The lower the w/c ratio, the stronger the concrete. (Higher strength, less permeability)
- Aggregates- Sand is the fine aggregate. Gravel or crushed stone is the coarse aggregate in most mixes.(ConcreteNetwork.com, 2020)

Aggregates, water, and cement are combined to create a mixture that can be poured into a mould. The combination of water and cement sparks a chemical reaction called 'hydration'. Shortly after hydration has started, the concrete will begin to harden, so it's important that concrete is placed in the desired mould before it gets too hard. (Total concrete limited, n.d.)

2.2 Product types and their applications

2.2.1 Mauritian context

In the case of Mauritius, there are several companies that manufacture different types of concrete based on their raw material composition. The composition of the aggregates will determine the applications of the concrete in the construction sector.

<u>Aggregates</u>
Macadam 4-6 mm - Production of blocks and bitumen. Obtained from processed basalt

Macadam 6-10 mm - Production of blocks, bitumen, and concrete. Obtained from processed basalt

Macadam 10-14 mm - Used in concrete mix and the production of sand. Obtained from processed basalt

Macadam 14-20 mm - used in concrete mix and the production of sand. Obtained from processed basalt

Macadam 20-31.5 mm - used in driveways, road filling and paving Obtained from processed basalt
Crusher run 0-20 mm - Filling, road building and sinks. Obtained from the processing of basalt stone
Crusher Run (0-31.5mm) - Obtained from the processing of basalt stone. Basic material for road construction and car parks

2.2.2 Ready mixed concrete

Ready mixed concrete (RMC) is a ready to use materials with a prearranged combination of cement, sand, aggregates, and water. Ready mixed refers to concrete that is batched for delivery from a central plant instead of being mixed on the job site. Each batch of ready-mixed concrete is tailor-made according to the specifics. Ready-mixed concrete is particularly advantageous when small quantities of concrete or intermittent placing of concrete are required. Ready-mixed concrete is also ideal for large jobs where space is limited and there is little room for a mixing plant and aggregate stockpiles.

The objectives of ready mixed concrete are:

a) Higher quality concrete is produced,
b) Elimination of space for storing for primary materials on site and
c) Dissipation of primary materials is prevented. (America's cement manufacturers (PCA), 2019)

2.3 General manufacturing process

The main concrete manufacturing process is as follows

Batching- The measurement of materials like aggregates, cement, water necessary for preparing different grades of concrete is Batching. It is by two processes. One is volume and other is weight batching. The volume batching is by mixing materials with its volume. And weight batching is by the self-weight ratio of materials. It has ratios according to standard codes. Some of the different grades of concrete are M10, M20, M25, M30.

Transporting- After mixing, the concrete transports to site. The mixing carries near the construction site. A bucket, ropeway, belt conveyor uses to transport concrete. Ready-mix conveyor trucks use mostly in the modern construction times. The concrete transporting by conveyor truck has time limits. The concrete transporting by trucks reaches the construction plant early.

Placing- Concrete to place in a good manner. It places without segregation to reach maximum efficiency. The concrete not to pour over a height of 1.5m

Curing- Adequate moisture, temperature and time are provided to aid the hydration process and maximise the concrete's structural properties. This is known as curing. Technically, concrete never stops curing, but after 28 days it will have gotten close enough to its maximum strength that whatever you make will be ready to be use reliably. (CFORCIVIL, 2018)

2.4 Properties of concrete

2.4.1 Advantages

i. Ingredients of concrete are easily available in most of the places.
ii. Unlike natural stones, concrete is free from defects and flaws.

iii. Concrete can be manufactured to the desired strength with an economy.
iv. The durability of concrete is very high.
v. It can be cast to any desired shape.
vi. The casting of concrete can be done in the working site which makes it economical.
vii. The maintenance cost of concrete is almost negligible.
viii. The deterioration of concrete is not appreciable with age.
ix. Concrete makes a building fire-safe due to its non-combustible nature.
x. Concrete can withstand high temperatures.
xi. Concrete is resistant to wind and water. Therefore, it is very useful in storm shelters.
xii. As a soundproofing material cinder concrete could be used. (Civil Today, n.d.)

2.4.2 Disadvantages

i. Concrete exhibits a strain-softening behaviour these materials are called quasi-brittle materials. This is a major disadvantage of plain concrete.
ii. Compared to other binding materials, the tensile strength of concrete is relatively low.
iii. Concrete is less ductile.
iv. The weight of compared is high compared to its strength.
v. Concrete may contain soluble salts. Soluble salts cause efflorescence.
vi. Concrete has low toughness
vii. Formwork is required
viii. Long curing time

2.5 Environmental performance (Global warming potential and Use of net freshwater of average ready mixed concrete)

Parameter	Unit	A1-A3
Global warming potential	kg CO_2-eq	2,71E+02
Depletion potential of the stratospheric ozone layer	kg R11-eq	8,36E-09
Acidification potential of land and water	kg SO_2-eq	7,81E-01
Eutrophication potential	kg PO_4^{3-} eq	7,82E-02
Formation potential of tropospheric ozone photochemical oxidants	kg ethene-eq	5,66E-02
Abiotic depletion potential for non-fossil resources	kg Sb-eq	7,60E-04

Table 7: Summary of life cycle impact analysis for 1m3 of average ready-mix concrete

Parameter	Unit	A1-A3
Abiotic depletion potential for fossil resources	MJ	1,44E+03
Renewable primary energy as energy carrier	MJ	0
Renewable primary energy resources as material utilization [MJ]	MJ	0
Total use of renewable primary energy resources	MJ	0
Non-renewable primary energy as energy carrier	MJ	1,44E+03
Non-renewable primary energy as material utilization	MJ	0
Total use of non-renewable primary energy resources	MJ	1,44E+03
Use of secondary material [kg]	kg	1,36E+01
Use of renewable secondary fuels [MJ]	MJ	0
Use of non-renewable secondary fuels [MJ]	MJ	3,54E+02
Use of net fresh water	m3	1,58E-03

Table 7: Summary of life cycle inventory indicators for 1 m^3 average ready-mix concrete

2.6 Recyclability of concrete

Concrete is recycled as an aggregate.

3 Concrete blocks

3.1 Definition

A Concrete Block is a 'Building Block' composed entirely of concrete that is then mortared together to make an imposing, long-lasting construction. These construction blocks can be 'Hollow' or 'Solid,' formed of ordinary or lightweight concrete in various specified sizes, depending on the precise requirements.(Engineering civil, n.d.)

3.2 Types of concrete blocks

The United Basalt manufacture several concrete products. The building materials used are classic blocks, light blocks, and smart blocks.

The classic blocks are aggregate concrete masonry unit carved or moulded and it has two or three formed holes which do not pass through the block. all have the same benefits (Optimal strength, cost-saving). They are used for general block-walling purposes. The blocks are available in three dimensions: 100mm, 150mm and 200mm thick.

The light blocks are revolutionary lighter block. Designed bottomless, unlike the traditional blocks, the LIGHT BLOC is lighter and therefore handier while being as resilient as the traditional one. Less mortar is used which result in a cost saving installation. The blocks are available in three dimensions: 100mm, 150mm and 200mm thick.
The smart blocks are block 20.15, corner blocks, U blocks, and Eco blocks (UBP, 2016a)

Other concrete products are: screen blocks, drains, kerbs, hollow blocks, precast slabs, beams, wall retaining blocks, mega blocks, amongst others. (UBP, 2022)

3.3 Application of concrete blocks

- Concrete Blocks are a great option for partition walls because they are quick and easy to install. The inclusion of steel reinforcement adds to the structure's strength.
- Exterior and Interior Load-bearing Walls, Partition Walls, Panel Walls, and Boundary Walls are common uses for Hollow Concrete Blocks.
- Solid Concrete Blocks are perfect for Chimney and Fireplace building, but they also work well for Non-load Bearing Walls and Garden Walls.
- Concrete blocks are also used in a variety of smaller landscaping projects. Many Outdoor Furniture & Patio ideas, for example, include Outdoor Seating, Decorative screens, Outdoor Bar, Flower Bed, and many others.
- Concrete blocks can cover stored commodities from the effects of changing weather. (Engineering civil, n.d.)

The product systems are concrete cellular blocks that are widely used in Mauritius for construction of load bearing and nonload bearing walls. They are used in conjunction with cement-based mortar and sometimes with reinforcing steels.(UBP, 2020)

3.4 Composition of concrete blocks (Classic blocks)

Table 2 : Material Content for an average concrete cellular block

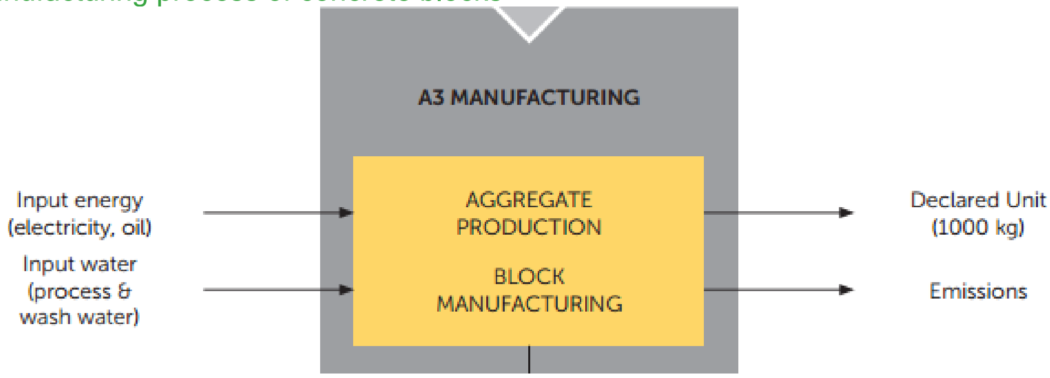
Material	Mass, % of block
Cement	5-8%
Aggregate	80-90%
Admixture	0.01-0.1%
Batch water	3-6 %

Note 2 : For confidentiality purposes, a range of values are given

Products do not contain any substances that can be included in "Candidate List of Substances of Very High Concern for Authorization"

(UBP, 2020)

3.5 Manufacturing process of concrete blocks



Manufacturing of the product, including aggregate production, batching and mixing of the concrete, forming units and curing of units. This includes average or specific transportation from manufacturing site to disposal for pre-consumer wastes and unutilized by-products from manufacturing, including empty backhauls. No secondary materials, secondary fuels and waste has been used in the manufacturing.(UBP, 2020)

3.6 Properties of concrete blocks

3.6.1 Advantages

The reduced wall thickness due to narrower Concrete Blocks than a traditional brick masonry wall makes the space is larger by increasing the carpet surface.

Concrete block building is more systematic, faster, and stronger than brick masonry because of the vast size of the blocks.

Better thermal insulation is provided.

It effectively absorbs sound and protects the interiors from noise pollution. Using concrete blocks provides additional fire protection.

Protects precious agricultural land that is extensively mined to produce clay bricks.

Individual pieces can be manufactured to a larger customized size and shape, allowing for a quick building cycle turnaround.

Concrete Blocks, unlike traditional bricks, have a consistent size that lowers the need for plaster, making them a more cost-effective solution. The mortar consumption rate is lower than in traditional masonry construction, but the overall strength of the structure is increased.(Engineering civil, n.d.)

3.6.2 Disadvantages

The expense of constructing a residence out of concrete blocks is significantly higher.

Some of the blocks may need to be cut to reach critical systems.

Concrete block homes aren’t usually attractive from the outside.

Over time, concrete blocks may be subject to water seepage.

Some regional preferences may not be compatible with this material.

Windows and doors can easily detract from the environmental benefits. (Engineering civil, n.d.)

3.7 Technical properties

3.7.1 Technical specifications for classic UBP blocks

(UBP, 2016a)

Technical Specifications

- External shell and web thickness of concrete cellular blocks available: 25mm thick, 32mm thick
- Tolerances on work sizes

Dimension Maximum	Dimensional Deviation
Length	+3mm – 5mm
Height	+3mm – 5mm
Thickness (Width)	+2mm – 2mm
Shell / Web Thickness	+3mm – 3mm

- Weight of UBP Concrete Cellular Blocks

Type of Block	External Shell and Web Thickness	
	25mm	32mm
100mm thk	±13kg	±14kg
150mm thk	±17kg	±20kg
200mm thk	±21kg	±23kg

- Compressive strength of UBP Concrete Cellular Blocks
  The average crushing strength of 10 blocks shall not be less than 3.5MPa at delivery.
  The corresponding lowest crushing strength of any individual block shall not be less than 2.8MPa.
- Overall heat coefficient factor
  U value block only: **2.46 w/m²k**
  U value with ±15mm plaster each side: **2.27 w/m²k**

Note: Blocks with higher compressive strength can be also produced on prior request.

3.7.2 Technical specifications for light UBP blocks (UBP, 2016b)

Technical Specifications

- External shell and web thickness of concrete LIGHT BLOC available: 25mm thick
- Tolerances on work sizes

Dimension Maximum	Dimensional Deviation
Length	+3mm – 5mm
Height	+3mm – 5mm
Thickness (Width)	+2mm – 2mm
Shell / Web Thickness	+3mm – 3mm

- Weight of UBP Concrete Light Blocks

Type of Block	25mm Web & Shell Thickness
LIGHT BLOC 400 - 100 (4")	±10kg
LIGHT BLOC 400 - 150 (6")	±13kg
LIGHT BLOC 400 - 200 (8")	±14kg
LIGHT BLOC 450 - 100 (4")	±12kg
LIGHT BLOC 450 - 150 (6")	±16kg
LIGHT BLOC 450 - 200 (8")	±17kg

- Compressive strength of UBP Concrete LIGHT BLOC
  The average crushing strength of 10 blocks shall not be less than 3.5MPa at delivery.
  The corresponding lowest crushing strength of any individual block shall not be less than 2.8MPa.
  Note: Blocks with higher compressive strength can be also produced on prior request.

Environmental properties (global warming potential and Use of net freshwater)

(UBP, 2020)

Table 3 : Life Cycle Impact Assessment (LCIA) Category Indicators

Parameter	Unit	A1-A3
Parameters describing environmental impacts		
Global warming Potential (GWP)	kg CO_2 equiv.	97.4
Ozone Depletion Potential (ODP)	kg CFC -11	4.47E-6
Acidification Potential for Soil and Water (AP)	kg SO_2 equiv.	0.478
Eutrophication Potential (EP)	kg PO_4^{3-} equivalents	0.0711
Photochemical ozone creation (POCP)	kg C_2H_4 equivalents	0.0182
Abiotic Depletion Potential (ADPE)	kg Sb equivalents	6.84E-5
Abiotic Depletion Potential (ADPF)	MJ net calorific value	606
Human Toxicity	kg 1.4-DB eq	13.8
Freshwater aquatic ecotoxicity	kg 1.4-DB eq	7.28
Marine water aquatic ecotoxicity	kg 1.4-DB eq	3.83E 4
Terrestrial ecotoxicity	kg 1.4-DB eq	0.129
Parameters describing resource use, primary energy		
Use of renewable primary energy excluding renewable primary energy used as raw materials (PERE)	MJ	6
Use of renewable primary energy resources used as raw materials (PERM)	MJ	0
Total use of renewable primary energy resources (PERT)	MJ	6
Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials (PENRE)	MJ	606
Use of non-renewable primary energy resources used as raw materials (PENRM)	MJ	0
Total use of non-renewable primary energy resources (PENRT)	MJ	606
Parameters describing resource use, secondary materials and fuels, use of water		
Use of secondary material (SM)	kg	0
Use of renewable secondary fuels (RSF)	MJ	0
Use of non-renewable secondary fuels (NRSF)	MJ	0
Net use of fresh water (FW)	m^3	0.419

3.8 Recyclability of concrete blocks

Concrete can be re-used, and the end of life is 100% recyclable.(GCCA, n.d.)

4 Reinforcement steel

4.1 Definition

Reinforcement steel, also known as rebar, is used in concrete to provide additional strength, as concrete is weak in tension, while steel is strong in both tension and compression. Steel and concrete have similar coefficients of thermal expansion, so a concrete structural member reinforced with steel will experience minimal stress as the temperature changes.(Concrete Reinforcing Steel Institute (CRSI), 2022)

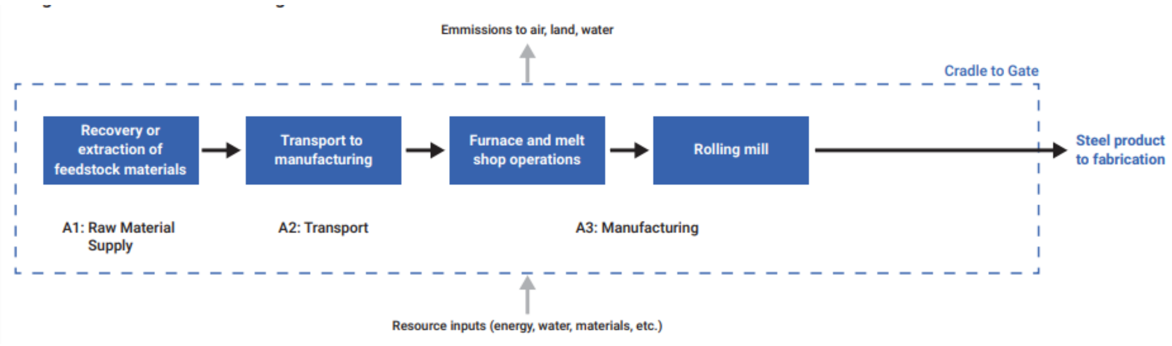
In general, the steel will be >97% recycled iron and a total of 2% or less of the following elements: Carbon, Manganese, Silicon, Chromium, Nickel, Molybdenum, Vanadium, Copper, Tin, Sulphur, and Phosphorus.(CMC, 2021)

4.2 Product types and their applications

1. Hot Rolled Deformed Steel Bars- Most widely recognized sort of reinforcement for regular RCC structures.
2. Cold Worked Steel Bar- A cold-worked reinforcement bar is made by letting the hot moved steel bars to experience cold working. In this process, the bars will undergo twisting and drawing. The procedure is performed at room temperature. The raw worked steel bars don't experience a plastic yield; in this way have less flexibility when contrasted and hot-rolled bars.

3. Mild Steel Plain Bars- Mild steel bars are utilized for tensile stress of reinforced cement concrete slab beams, etc., in RCC work.
4. Prestressing Steel Bars- Prestressing cables or tendons are comprised of numerous standards, which are thus included of different wires of average seven-wire strand consists of seven wires hectically spun together into a strand.

4.3 General manufacturing process



4.4 Local context

Locally based in the Industrial Zone of Plaine Lauzun, Port Louis, Kosto Ltd is a leading supplier of rebar on the Mauritius market in lengths and/or cut & bend rebar. Kosto Ltd is the only rebar distributor on the island with a technical support unit for customers with permanent resident civil and industrial engineers.

Our principles and values are established to meet international standards and Kosto Ltd is an ISO 9001, ISO 14001, and OHSAS 18001 certified company; we have committed ourselves to provide quality service and excellence to our highly esteemed customers and markets.

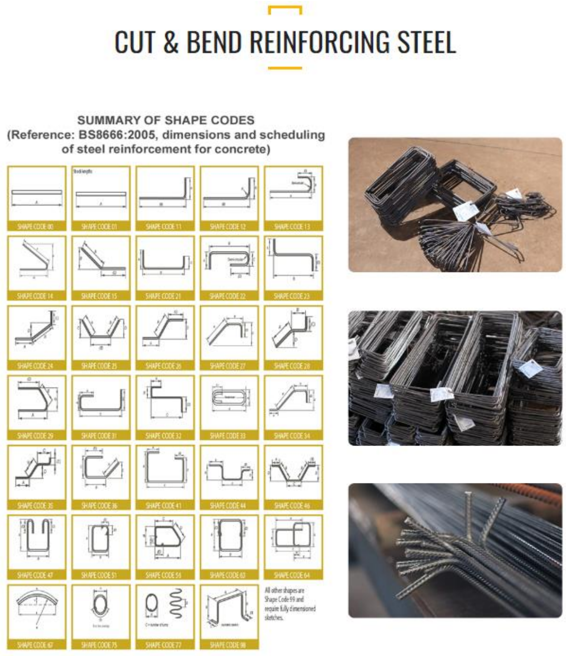
Kosto Ltd also provides cut and bend services according to international standards (BS 4449 & BS 8666). This alternative solution to traditional unscientific cutting and bending on site has proven to be highly effective and encompasses numerous advantages such as: 1) Rebars that are cut and bent according to the quantity, shape and length required, consistent quality and accuracy, amongst others.

REINFORCING STEEL

Sizes: R6 & Y8, 10, 12, 16, 20, 25, 32, 40

Specification:

- MS 10 (BS 4449)
- MS 34 & 35 (BS 4482 & 4483)
- All products are MSB certified



4.5 Advantages and disadvantages

Advantages

1. Compatibility with concrete
2. Robustness of steel reinforcement
3. Bent property of steel reinforcement
4. Recycling property: The steel reinforced left over after the service life of a structure is recycled again and used for new construction.
5. Easily available: Every region of a country will have a steel supplier or manufacturer. Hence steel reinforcement is easily available.
6. Availability – Reinforcing steel is available in every region of the country. Due to the number and distribution of plants, the United States Green Building Council's Leadership in Energy and Design (LEED®) program and other sustainability credits are available.(CRSI, 2022)

Disadvantages

1. Reactive Nature of Steel Reinforcement: In concrete structures where the cover is small and subjected to external moisture and salt action, the reinforcement undergoes reaction and starts to corrode. These can lessen the strength of concrete and finally to failure.
2. Expensive: The cost of steel reinforcement in high.
3. Melts at high temperature: At higher temperatures, the steel reinforcement may melt. This is the reason why the steel reinforcement is tied up and not welded.(the constructor)

4.6 Specifications

Technical specifications

Source: (Concrete Reinforcing Steel Institute (CRSI), 2022)

Name	Value	Unit
Density	7,833	kg/m^3
Modulus of elasticity	199,900	N/mm^2
Coefficient of thermal expansion	11.8	$10^{-6}K^{-1}$
Thermal conductivity	80.4	W/(mK)
Melting point	1,504	°C
Electrical conductivity at 20°C	10,000,000	$\Omega^{-1}m^{-1}$
Minimum yield strength	By grade	N/mm^2
Minimum tensile strength	By grade	N/mm^2
Minimum elongation	By grade	%
Tensile strength	By grade	N/mm^2
ASTM Specification	ASTM A615/A615M, A706/A706M, A1035 CL, A1035 CM, A1035 CS	-

Environmental performance (Global warming potential and Use of net freshwater)
Source: ep(Gerdau facility, 2021)

Table 3. *Results for 1 metric ton of Carbon Steel Rebar produced at Midlothian mill, Texas.*

				PRODUCT STAGE		
				Unfabricated Rebar Production	Transport to the Fabricator	Fabrication
Impact Category	**Category Indicator**	**Indicator Description**	**Unit**	**A1**	**A2**	**A3**
Global warming [a]	Global Warming Potential	Global Warming Potential (GWP)	Metric ton CO_2 eq	1.02	2.99×10^{-2}	2.88×10^{-2}
Ozone Depletion [a]	Ozone Depletion Potential	Depletion potential of the stratospheric ozone layer (ODP)	Metric ton CFC-11 eq	3.12×10^{-9}	1.28×10^{-12}	6.57×10^{-12}
Acidification of land and water [a]	Acid Emissions	Acidification Potential of soil and water (AP)	Metric ton SO_2 eq	4.77×10^{-3}	1.65×10^{-4}	6.93×10^{-5}
Eutrophication (freshwater) [a]	Phosphorus and nitrogen emissions	Eutrophication potential (EP)	Metric ton N eq	1.45×10^{-3}	9.25×10^{-6}	4.80×10^{-6}
Photochemical Ozone Creation [a]	Max. Pot. for Ozone Formation	Formation potential of tropospheric ozone (POCP)	Metric ton O_3 eq	3.95×10^{-2}	4.41×10^{-3}	4.96×10^{-4}
Depletion of abiotic resources (elements) [b,c]	Aggregated Depletion of Extracted Resources	Abiotic depletion potential (ADP-elements) for non-fossil resources	Metric ton Sb eq	-2.28×10^{-6}	1.39×10^{-11}	6.57×10^{-9}
Depletion of abiotic resources (fossil) [b]	Fossil fuel consumption	Abiotic depletion potential (ADP-fossil fuels) for fossil resources	MJ	1.32×10^{4}	4.23×10^{2}	3.46×10^{2}

[a] Calculated using TRACI v2.1.
[b] Calculated using CML-IA v4.1.
[c] This indicator is based on assumptions regarding current reserves estimates. Users should use caution when interpreting results because there is insufficient information on which indicator is best for assessing the depletion of abiotic resources.

Environmental performance (Global warming potential and Use of net freshwater)
Source:(Gerdau facility, 2021)

Table 4. *Results for resource use, wastes, and output flows for 1 metric ton of Carbon Steel Rebar produced at Midlothian mill, Texas.*

		PRODUCT STAGE		
		Unfabricated Rebar Production	Transport to the Fabricator	Fabrication
Impact Category	Unit	A1	A2	A3
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	MJ, net calorific value [a]	$9.12x10^2$	0.00	$4.57x10^1$
Use of renewable primary energy resources used as raw materials	MJ, net calorific value [a]	0.00	0.00	0.00
Total use of renewable primary energy resources	MJ, net calorific value [a]	$9.12x10^2$	0.00	$4.57x10^1$
Use of nonrenewable primary energy excluding nonrenewable primary energy resources used as raw materials	MJ, net calorific value	$1.38x10^4$	$4.27x10^2$	$4.01x10^2$
Use of nonrenewable primary energy resources used as raw materials	MJ, net calorific value	$4.14x10^2$	0.00	0.00
Total use of nonrenewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, net calorific value	$1.42x10^4$	$4.27x10^2$	$4.01x10^2$
Use of secondary materials	Metric ton	1.11	0.00	0.00
Use of renewable secondary fuels	MJ, net calorific value	0.00	0.00	0.00
Use of nonrenewable secondary fuels	MJ, net calorific value	0.00	0.00	0.00
Net use of fresh water	m^3	2.19	0.00	$7.74x10^{-2}$
Nonhazardous waste disposed	Metric ton	$6.19x10^{-4}$	0.00	0.00
Hazardous waste disposed	Metric ton	$1.75x10^{-5}$	0.00	0.00
Radioactive Waste disposed	Metric ton	0.00	0.00	0.00
Components for re-use	Metric ton	0.00	0.00	0.00
Materials for recycling	Metric ton	$1.66x10^{-1}$	0.00	$3.30x10^{-2}$
Materials for energy recovery	Metric ton	$8.26x10^{-6}$	0.00	0.00
Exported energy	MJ per energy carrier	0.00	0.00	0.00

[a] Net calorific value is applicable to combustible fuels and is not applicable to other forms of renewable energy (e.g., solar, wind).

5 Fibre cement board

5.1 Definition

Fibber cement board, also known as fibre reinforced cement board, is a building cement board with fibre and cement as the main raw materials. It is widely used in various fields of construction industry. The cement in the raw material of fibre cement board is autoclaved with siliceous material, which is not the traditional cement board. (Sino Power, 2017)

5.1 Properties, product type and their applications

The excellent performance of green environmental protection, fire retardant, waterproof and moisture-proof, anti-corrosion and anti-corrosion, sound-absorbing, light-weight and high-strength, convenient construction and good weather resistance, make the fibre cement board and its post-processing extension products suitable for building decoration and many other fields: external wall insulation and decoration system, partition wall (fire, sound insulation, etc.) system, ceiling system, floor system, wall material (board) lining board system, billboard, pipe coating, furniture partition and other fields. (Sino Power, 2017)

5.2 Local context

Fibre cement boards are not manufactured in Mauritius. Instead, our main supplier for the material is the Siam Cement Public Company Limited.

5.3 Advantages, disadvantages, and applications

1) Durable
2) High Strength-The lowest strength (In parallel direction) is ≥15 Mpa while the highest (In cross direction) is ≥20 Mpa which meets the national anti-typhoon requirement.
3) Light Weight and Low Water Absorption-The density is more than 1.4 g/cm3 while the water absorption is less than 28%. It can be used in both new and old building, as the light weight of building board settles the problems of the renovation for the old building facade and the leaking from the facade. It won't affect its original construction structure.
4) Sound Insulation-Outstanding sound insulation capability is good for indoor partition and ceiling, even the building which has a strict demand in privacy.
5) Incombustible Material-Meeting the standard of GB 8624-2006 grade A (The highest grade) and ISO-1182 which is the guarantee of fireproof.
6) Low Moisture and Water Absorption-It can be used in indoor swimming pool, bathroom, laundry, kitchen, and some other wet places.
7) Non-radioactive-All our products including Clad board meets the national standard and there are all allowed to be used in any place of the building to ensure the security of user.
8) Surface Nature Look(HBD, 2017)

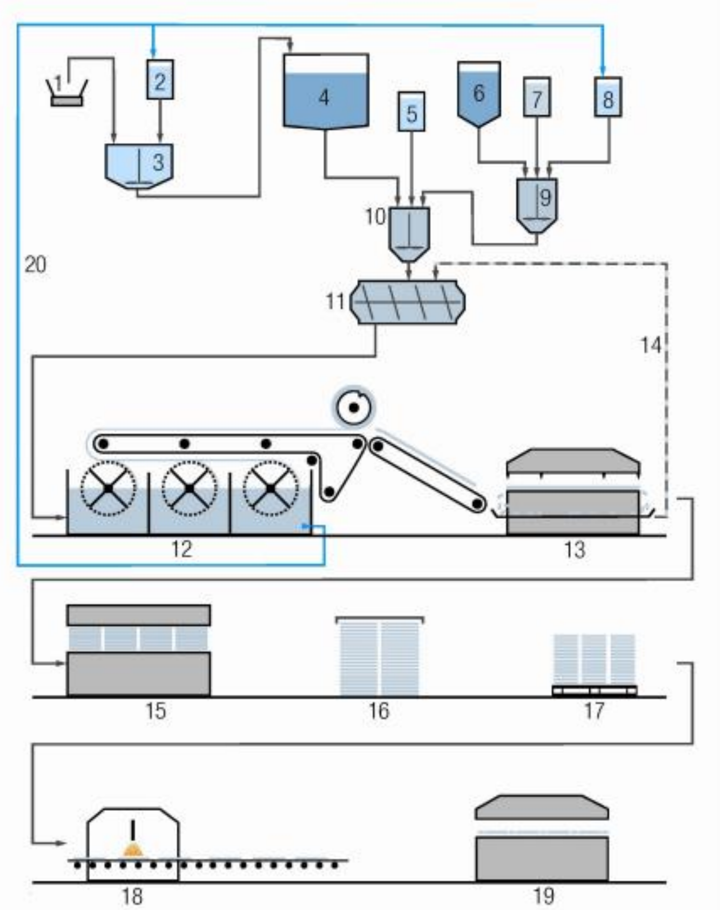
The properties and advantages of fibre cement boards provide a range of applications. The dimension of the material also determines the applications of the latter.

Building decoration and many other fields: external wall insulation and decoration system, partition wall (fire, sound insulation, etc.) system, ceiling system, floor system, wall material (board) lining board system, billboard, pipe coating, furniture partition and other fields. (Sino Power, 2017)

Source: (EPD of Cembrit Holding A/S)

Dimension	**Applications**
-3.5-6mm	Interior ceiling and can be used for the facing panel of Sandwich Board
-8-15mm	Interior partition
-8-12mm	External sliding, cladding, or façade
-18-22 mm	Furniture desk
-18-30 mm	Indoor floor decking
-22-30 mm	Indoor stair

5.4 General manufacturing process



1 Scales for process fibres (pulp)	11 Horizontal mixer
2 Water	12 Platen machine
3 Pulper	13 Punching machine
4 Vat process fibres in water	14 Punching sections
5 Reinforcing fibres (synthetic fibres)	15 Press
6 Portland cement	16 Setting
7 Admixed substances	17 Half-finished products' warehouse
8 Water	18 Coating
9 Intensive mixer 1	19 Punching
10 Intensive mixer 2	20 Water cycle

The raw materials are treated with water to a homogeneous mixture. The mixture is pumped into head boxes, in which sieve cylinders rotate, that are dewatered inside. Thereby the sieve surface is covered with a thin fleece of fibre cement, which is transferred to the endless circulating conveyor belt (transport felt). From there, the fleece of fibre cement reaches a format roller, which is gradually covered with a thickening layer of fibre cement. Once the desired material thickness is achieved, the still moist and formable layer of fibre cement (fleece) is separated and unrolled from the format roller.

In the next step, the layer of fibre cement (fleece) is punched, residual material is returned to the production process, so that no waste is left. The cut, not yet hardened, mouldable board is stacked with intermediate layers and pressed. Subsequently, the boards are stored for hardening, later stacked on pallets, and stored for further hardening in a maturation store. The setting time is about four weeks. The visible side is usually coated for which high-grade pure acrylate paint is twice applied and hot-filmed in the casting process and spray treatment. The back side gets a single or double coating which is usually rolled on. A quality management system according to the /EN ISO 9001:2015/ has been introduced and certified in the manufacturing plants.

5.5 Specifications

Technical and physical specification of fibre cements boards
Source: (EPD of Cembrit Holding A/S)

Name	Value
Density	Density: ≥1.10g/cm3 -Low Density: 1.1-1.3g/cm3 -Middle Density: 1.3-1.4g/cm3 -High Density: 1.4-1.6g/cm3
Moisture Content	≤10%
Water Absorbing Capacity	≤35%
Thermal Conductivity	**Average≤0.20W/MK**
Bending Strength	Transverse≥11.0N/mm3 Vertical≥8.5N/mm
Radioactivity	Conforming to GB6566-2001 A Class
Fire resistance	It is Flame Resistant to Combustion at 800 and Remains Flameless at 1200. Non-Flammability: Grade A (GB8624-A)
Weather resistance	Resistant to Deformation in Wet, Hot and Dry Conditions. Can be used at -40 degree. Out of Shape Rate in the Condition of Wet or Dry is 0.26%.
Water & Damp Proof	The board keeps Intact after being Soaked in Water for One Month, the Phenomenon of Swelling and Out of Shape will Not Happen. It will NOT Disintegrate when Immersed in Water or Exposed to Freeze/Thaw Cycles for Prolonged Periods of Time.
Bug & Mildew free	After tests under ASTM G-21, this board has been found to be Non-Nutrient to Mold, Fungus Growth, or Insect Life
Insulation:	Superior Sound Insulation Factor of a Wall built from the board ranges between 44dB and 47 dB

Environmental performance (Global warming potential and Use of net freshwater)

(Yapı et al., n.d.)

ENVIRONMENTAL IMPACTS FOR 1 TON				
Parameter	Unit	PRODUCT STAGE	DISPOSAL	TOTAL
		A1-A3	C4	
GWP	[kg CO_2 eq.]	774	5.04	779
ODP	[kg CFC^{11} eq.]	2.68×10^{-5}	0.087×10^{-5}	2.77×10^{-5}
AP	[kg SO_2 eq.]	0.384	0.001	0.385
EP	[kg PO_4^{3-} eq.]	2.86	0.032	2.89
POCP	[kg C_2H_4 eq.]	2.48	0.010	2.49
ADPE	[kg Sb eq.]	0.0823	2.12×10^{-8}	0.0823
ADPF	[MJ]	6 410	74.3	6 485
Legend	GWP: Global Warming Potential, ODP: Ozone Depletion Potential, AP: Acidification Potential, EP: Eutrophication Potential, POCP: Formation potential of tropospheric ozone photochemical oxidants ADPE: Abiotic depletion potential for non-fossil resources, ADPF: Abiotic depletion potential for fossil resources			
RESOURCE USE FOR 1 TON				
PERE	[MJ]	783	0.462	783
PERM	[MJ]	0	0	0
PERT	[MJ]	783	0.462	783
PENRE	[MJ]	6 414	74.3	6 488
PENRM	[MJ]	0	0	0
PENRT	[MJ]	6 414	74.3	6 488
SM	[kg]	0	0	0
RSF	[MJ]	0	0	0
NRSF	[MJ]	0	0	0
FW	[m³]	2.77	-	2.77
Legend	PERE: Use of renewable primary energy excluding resources used as raw materials, PERM: Use of renewable primary energy resources used as raw materials, PERT: Total use of renewable primary energy resources, PENRE: Use of non-renewable primary energy excluding resources used as raw materials, PENRM: Use of non-renewable primary energy resources used as raw materials, PENRT: Total use of non-renewable primary energy resources, SM: Use of secondary material, RSF: Use of renewable secondary fuels, NRSF: Use of non-renewable secondary fuels, FW: Use of net fresh water			

6 Gypsum boards

6.1 Definition

Gypsum is a construction material, being provided with superheating of gypsum CaSO4+2H2O and evaporating of its water and grinding. When it is mixed with water, gypsum gains bounding property again. Gypsum plaster is used to make plaster boards, fibrous plaster, building decorations and moulds for many applications.

All types of the gypsum products which are available in the market consist of gypsum as a core material and its surface is wrapped with other materials such as fiberglass. Gypsum boards are also known as wallboard, plasterboard, or drywall (American & Boards, n.d.)

An average composition of gypsum-based plasterboard is as follows:

Raw materials	Composition (%)
Gypsum	90-95
Paper	3.0-7.0
Glassfiber	0-0.1
Additive	0-0.1

6.2 Product types and their applications

Standard Plasterboard- Ceiling, wall linings and partitions, drywall installation.

Moisture and water-resistant Plasterboard- Ceiling, wall linings and partitions, drywall installation, wet areas, shaft walls.

Fire resistant plasterboard- wall linings and partitions, drywall installation, shaft walls and steel structures.

Fire- and water-resistant plasterboard- Ceiling, wall linings and partition, drywall installation, wet areas, shaft walls and steel structures. (GİPS A.Ş., 2021)

6.3 Advantages & disadvantages

Advantages

- Versatility
- They are proven to be outstanding fire-resistive building material.
- Their non-combustible core restraints chemically combined water around 21%.
- The study shows that steam will not exceed 100 degrees Celsius. This characteristic helps in retarding the transfer of heat and spread of fire.
- Low flame-spread index and a low smoke-density index.
- Sound isolation- Installing gypsum board on drywalls & ceilings effectively help in controlling sound transmission.
- Durability
- Economy- They are readily available in various sizes & easy to apply either on wall or ceiling.
- There is no shrinkage while setting and hence it does not develop cracks on heating or setting. (Plasterceil, 2021)
- It does not require curing like conventional plaster (Daily civil, n.d.)

Disadvantages

i. Storing gypsum plaster is much more difficult.
ii. Gypsum is not recommended to be used in extreme or continuous moisture areas(Daily civil, n.d.)

6.4 Specifications

6.4.1 Environmental performance (Global warming potential and Use of net freshwater)

Source(Rigips, 2014)

Environmental impacts: 1 kg					
Indicator	**Unit**	**A1**	**A2**	**A3**	**A1-A3**
Global warming potential	[kg CO_2 eq.]	0,133	0,003	0,045	0,181
Depletion potential of the stratospheric ozone layer	[kg CFC 11 eq.]	1,79E-08	6,50E-10	3,80E-10	1,90E-08
Acidification potential of soil and water	[kg SO_2 eq.]	7,35E-04	2,25E-05	2,70E-04	1,03E-03
Eutrophication potential	[kg $(PO_4)^{3-}$ eq.]	1,53E-04	3,97E-06	1,10E-05	1,68E-04
Formation potential of tropospheric ozone	[kg Ethene eq.]	3,61E-05	1,64E-06	1,04E-05	4,82E-05
Abiotic depletion potential (ADP-elements) for non-fossil resources	[kg Sb eq.]	1,52E-03	1,48E-04	3,45E-04	2,01E-03
Abiotic depletion potential (ADP-fossil fuels) for fossil resources	[MJ]	1,970	0,169	0,378	2,517

Water emission	Unit	Total
Water consumption	m^3	6662
Waste water	m^3	6662
BOD	mg/l	19,0
COD	mg/l	67,5
Suspended matter	mg/l	36

7 Magnesium Oxide (MgO) boards

7.1 Definition

Magnesium oxide building boards are a generic group of building boards widely used in construction industries throughout the world. Magnesium oxide boards have been used in construction for over twenty years. Typically, they are used as a component in a building. Magnesium oxide boards are used as an alternative for conventional gypsum drywall which are used as ceiling and wall covering materials.

Composition of the material (HBD, 2017)

Material	Amount (kg)	Percentage of Total Mass
Mineral Panel		
Fiberglass mat	0.1	1%
Magnesium Oxide/Magnesium Sulfate	5.2	67%
Perlite Filler	1.4	18%
Additives	0.7	9%
Fly Ash Filler	0.4	5%
Total	**7.8**	**100%**

7.1 Properties and applications

i. dimensions and tolerances
ii. strength and stiffness
iii. Fireproof- Level A (non-flammable level) according to the National Centre for Quality Supervision and Testing of Fire Building Materials (NFTC).
iv. structural performance
v. Durability
vi. Moisture-resistance (CIBSE, n.d.)

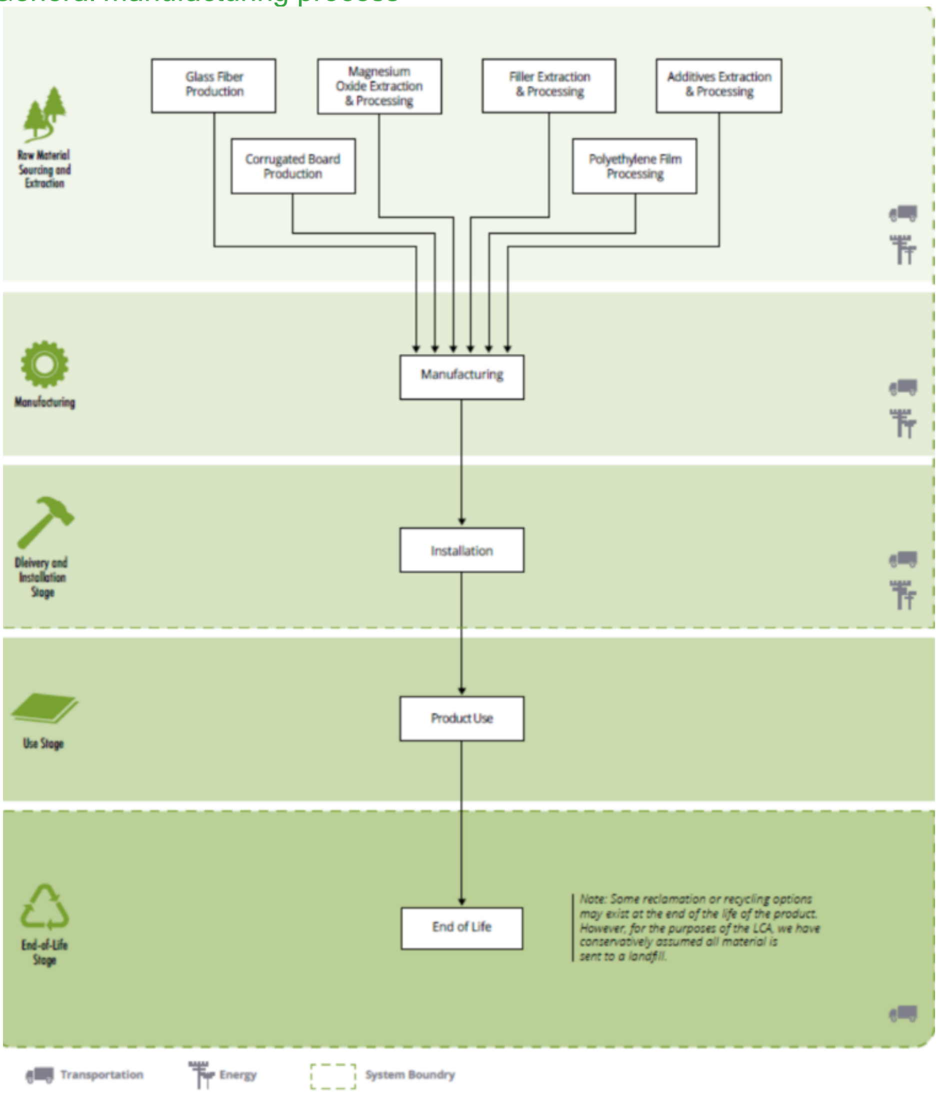
The following properties determine the applications of the material.

Magnesium Oxide Boards are commonly used both indoors and outdoors. (North America MgO's MagTech, 2018). For examples:

i. Structural walls
ii. Interior walls for indoor (Ceilings, floors, corridors, subflooring, flooring, stairways, and even support for the tiles)(Fortune Business Insights, 2020)

They are generally selected for their strength to weight ratio, structural strength, performance when exposed to fire and workability (Fortune Business Insights, 2020)

7.2 General manufacturing process



According to the EPD of an USA facility manufacturing MgO boards, the manufacturing process is as follows:

Firstly, there is the mixing of various materials to create a cement mixture. This mixture is then cast into thin panels and a fiberglass scrim is applied to both sides of the panel. These panels are then stored in the facility under proper conditions allowing them to fully cure. The cured panels are then stacked on pallets and prepared for shipment to the customers.

(North America MgO's MagTech, 2018),

7.3 Specifications

Technical specifications

Name	Value
Density (g/cm3)	0.85-1.2
Bending strength (M/mm)	18 Mpa
Breaking load	113-498
Thermal resistance	1.14 m2k/w
Sound insulations	>44dB
Shrinking rate when heated	1.0%

Rate of length change (wetting %)	Below 0.26%
Non flammability	Fireproof First grade
Width Additional dimensions and thickness options available upon client's request	1220 mm
Length Additional dimensions and thickness options available upon client's request	2440/2700/3050 mm
Thickness Additional dimensions and thickness options available upon client's request	3-20 mm

Environmental performance (Global warming potential)

Source: (North America MgO's MagTech, 2018)

Impact Category	Unit	A1-3	A4	A5	B1-7	C1	C2	C3	C4	D
Global Warming Potential	kg CO_2 eq	7.42	1.01	0.082	MND	0	0.096	0	0.126	N/A
Acidification Potential of Land and Water	kg SO_2 eq	0.0153	$3.26x10^{-3}$	$2.42x10^{-4}$	MND	0	$3.21x10^{-4}$	0	$7.42x10^{-4}$	N/A
Eutrophication Potential	kg PO_4^{3-} eq	$2.15x10^{-3}$	$8.77x10^{-4}$	$2.32x10^{-5}$	MND	0	$8.63x10^{-5}$	0	$1.01x10^{-4}$	N/A
Depletion Potential of the Stratospheric Ozone Layer	kg CFC-11 eq	$6.85x10^{-10}$	$8.36x10^{-12}$	$6.91x10^{-13}$	MND	0	$8.23x10^{-13}$	0	$1.18x10^{-13}$	N/A
Formation Potential of Tropospheric Ozone	kg C_2H_4 eq	$5.51x10^{-4}$	$3.39x10^{-4}$	$3.04x10^{-5}$	MND	0	$3.33x10^{-5}$	0	$5.84x10^{-5}$	N/A
Abiotic Depletion Potential for Non-Fossil Resources (Elements)	kg Sb eq	$1.52x10^{-5}$	$1.72x10^{-7}$	$4.95x10^{-6}$	MND	0	$1.69x10^{-8}$	0	$4.41x10^{-8}$	N/A
Abiotic Depletion Potential for Fossil Resources (Fossil Fuels)	MJ eq	85.6	14.2	0.869	MND	0	1.40	0	1.62	N/A

MND = Module not declared

8 Oriented Strand Boards (OSB)

8.1 Definition

Oriented Strand Board is a widely used, versatile structural wood panel. They engineered wood panel shares many of the strength and performance characteristics of plywood. They are manufactured from waterproof heat-cured adhesives and rectangularly shaped wood strands that are arranged in cross-oriented layers. Relative to their strength, OSB panels are light in weight and easy to handle and install.(APA Wood, n.d.)Their composition consists of wood species such as softwoods (spruce, pine) and some hardwood (aspen). OSB is readily identified by its relatively large and long wood strands. Although OSB is made up of relatively large strands of wood, its surface is relatively smooth, and this can be further enhanced by sanding without losing the aesthetic character which is unique to OSB. (European Panel Federation, 2021).

8.2 Properties (advantages & disadvantages)

Advantages

i. Extremely strong
ii. Availability. There are several types and grades of OSB, and they are application-specific
iii. High water resistance (some product types are waterproof)
iv. consistent from one side to the other.

v. Affordable
vi. High eco-friendly value as the wood used for OSB generally comes from small and fast-growing trees. Additionally, a maximum amount of wood fibres possible are used from each tree (Handyman's world, 2021)

Disadvantages

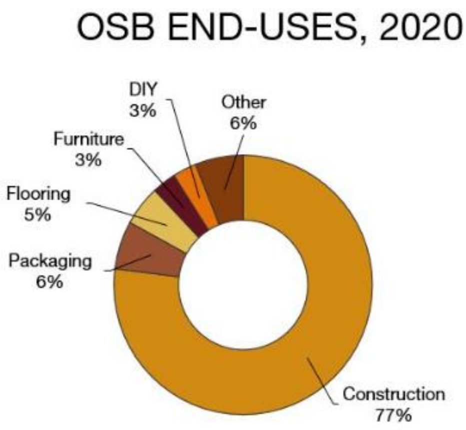
i. More pliable which cause issues for flooring purposes
ii. the edges of it can swell by up to 15% when exposed to high amounts of moisture
iii. Cleaning process is tedious
iv. OSB is usually made with formaldehyde, a very poisonous chemical
v. High density (Heavy material) (Handyman's world, 2021)

8.3 Product type and their applications

There are four grades of OSB according to EN 300. They differed in terms of their mechanical performance and relative resistance to moisture.

OSB/1 - General purpose boards and boards for interior fitments (including furniture) for use in dry conditions.
OSB/2 – Load-bearing boards for use in dry conditions.
OSB/3 – Load-bearing boards for use in humid conditions
OSB/4 – Heavy-duty load-bearing boards for use in humid conditions.(European Panel Federation, 2021)

According to Europanel.org, OSB applications are shown in the diagram below:



The applications can be further detailed into

i. Load-bearing cladding of exterior walls or roofs,
ii. Structural floor decking
iii. Sub- floors and base boards for flooring systems
iv. Internal non-load-bearing cladding of walls and ceilings, partitions
v. Attic conversions or extensions
vi. Framework for upholstered furniture
vii. Packaging
viii. Warehouse management (racks, fences, etc.) ((Environmental Product Declaration (OSB), (n.d).)

8.4 General manufacturing process

Wood strands are cut tangentially from debarked logs which are held longitudinally against rotating knives. After drying, these flakes are generally sprayed with a synthetic resin binder and wax and then bonded under heat and pressure between steel belts. (European Panel Federation, 2021)

8.5 Specifications

Physical specifications

Thermal conductivity- The thermal conductivity (l) of OSB is 0.13 W/m. K for a mean density of 650 kg/m.

Environmental performance (Global warming potential and Use of net freshwater)

Source: (American Wood Council and Canadian Wood Council, 2013)

Table 2: Cradle-to-Gate Impact Assessment Results - 1m³ North American Oriented Strand Board				
Impact category indicator	**Unit**	**Total**	**Forestry operations**	**OSB production**
Global warming potential	kg CO_2 eq.	248.30	17.40	230.90
Acidification potential	H+ moles eq.	130.48	8.98	121.50
Eutrophication potential	kg N eq.	0.1021	0.0298	0.0723
Ozone depletion potential	kg CFC-11 eq.	0.0000	0.0000	0.0000
Smog potential	kg O_3 eq.	34.55	4.49	30.06
Total primary energy consumption	**Unit**	**Total**	**Forestry operations**	**OSB production**
Non-renewable fossil	MJ	4260.78	268.10	3992.68
Non-renewable nuclear	MJ	513.83	2.53	511.30
Renewable, biomass	MJ	3590.40	0.00	3590.40
Renewable, other	MJ	93.43	0.74	92.69
Material resources consumption	**Unit**	**Total**	**Forestry operations**	**OSB production**
Non-renewable materials	kg	2.11	0.00	2.11
Renewable materials	kg	661.47	0.00	661.47
Fresh water	L	395.10	5.51	389.59
Non-hazardous waste generated	**Unit**	**Total**	**Forestry operations**	**OSB production**
Solid waste	kg	30.72	0.17	30.55

Recyclability of OSB

According to the woodguide website, OSB are considered as a low recycled material. Due to difficult recycling, OSB waste can only be incinerated. Additionally, because of its low durability, OSB cannot be easily reused.(The wood guide, n.d.)

9 Glass wool 50 mm insulation

9.1 Definition

Glass wool (originally known also as fiberglass) is an insulating material made from fibres of glass arranged using a binder into a texture like wool. Glass wool and stone wool are produced from mineral fibres and are therefore often referred to as 'mineral wools. Mineral wool is a general name for fibre materials that are formed by spinning or drawing molten minerals. Glass mineral wool is approximately 95% glass; this comprises recycled glass (external cullet, up to 80% of the composition) with other mineral raw materials - mainly sand and dolomite. The remaining 5% comprises a bio-based resin binder, and small quantities of additives that aid performance. Glass mineral wool is used for thermal and acoustic insulation in buildings. The principal performance characteristic of thermal insulation is its thermal conductivity (Lambda, λ). The product is mainly marketed in Northern Europe, particularly the UK and Scandinavia.

9.2 Properties and applications (Advantages & disadvantages)

Applications of glass wool include structural insulation, pipe insulation, filtration, and soundproofing. Glass wool is a versatile material that can be used for the insulation of walls, roofs, and floors. It can be a loose fill material, blown into attics, or, together with an active binder sprayed on the underside of structures. During the installation of the glass wool, it should be always kept dry since an increase of the moisture content causes a significant increase in thermal conductivity. Glass Wool is primarily used as a sound resisting material in partition walls. Glass wool through roof insulation is one of the most effective ways to improve the energy efficiency of a building. The use of glass wool in the ceiling/soffit provides the advantages such as Thermal Comfort, provides a quiet indoor environment, reduces cooling time, and fire safety. Glass Wool as floor insulation in intermediate floor acts as sound resistant preventing impact sound to transmit other parts of the building through the designed structure (Thermal engineering, 2019)

However, glass wool is very irritating to the skin and eyes; hence its installation cannot be done without gloves, mask, glasses, and protective clothing. It is sensitive to water, because of such reason it is only suitable for rooms that are completely waterproof and not humid. Though glass wool is made of recyclable materials, it possesses a negative ecological balance, particularly because its raw materials are non-renewable. The sound resistance property of Glass Wool is limited to restrained value.(Civiconcepts, n.d.)

9.3 General manufacturing process

Glass wool is a furnace product of molten glass at a temperature of about 1450 °C. From the melted glass, fibres are spun. This process is based on spinning molten glass in high-speed spinning heads somewhat like the process used to produce cotton candy. During the spinning of the glass fibres, a binding agent is injected. Glass wool is then produced in rolls or in slabs, with different thermal and mechanical properties. It may also be produced as a material that can be sprayed or applied in place, on the surface to be insulated.(Thermal engineering, 2019)

9.4 Specifications

Technical

Source:(Knaug Insulation, 2019)

Parameter	Value
Thermal conductivity (EN 12667) at 10°C	ʌ 0.034 - 0.035 W/mK
Gross dry density range (EN 1602)	17 - 28 kg/m³
Water vapour diffusion resistance factor (BS EN 13162)	1
Water absorption Wp (BS EN 29767)	<1 kg/m²
Reaction to fire (BS EN 13501-1:2002)	Euroclass A1

Environmental performance (LCA results, embodied carbon & water)

Source: (Knaug Insulation, 2019)

Glass mineral wool insulation, Λ 0.034 - 0.035 W/MK, density 26.5 Kg/m3

Environmental indicator results for the A1 - A3 modules on an aggregated basis and the A4, A5, C2 & C4 modules are shown in the following tables the declared unit of 1m² at 100mm thickness (0.1m³).

ENVIRONMENTAL IMPACT POTENTIALS

INDICATOR	UNIT	TOTAL A1-A3	A4	A5	C2	C4
GLOBAL WARMING POTENTIAL (GWP)	KG CO_2 EQ.	2.80E+00	4.47E-02	8.79E-02	2.79E-02	1.42E-02
STRATOSPHERIC OZONE LAYER DEPLETION POTENTIAL (ODP)	KG CFC 11 EQ.	5.78E-07	8.04E-09	1.15E-08	5.02E-09	4.69E-09
ACIDIFICATION POTENTIAL (AP)	KG SO_2 EQ.	1.18E-02	1.10E-04	2.45E-04	1.05E-04	1.05E-04
EUTROPHICATION POTENTIAL (EP)	KG PO_4^{3-} EQ.	2.79E-03	1.41E-05	6.21E-05	1.85E-05	1.80E-05
FORMATION POTENTIAL OF TROPOSPHERIC OZONE (POCP)	KG C_2H_4 EQ.	4.30E-04	6.96E-06	8.62E-06	4.64E-06	5.15E-06
ABIOTIC RESOURCES DEPLETION POTENTIAL – ELEMENTS (ADPE)	KG SB EQ.	1.40E-04	4.31E-07	2.81E-06	3.61E-07	4.75E-08
ABIOTIC RESOURCES DEPLETION POTENTIAL – FOSSIL RESOURCES (ADPF)	MJ	4.64E+01	6.76E-01	9.14E-01	4.19E-01	4.01E-01

INDICATOR		UNIT	TOTAL A1-A3	A4	A5	C2	C4
PRIMARY ENERGY RESOURCES – RENEWABLE (PERE)	USE AS ENERGY CARRIER	MJ, NET CALORIFIC VALUE	1.93E+00	8.16E-03	9.06E-02	6.39E-03	1.03E-02
	USED AS RAW MATERIALS	MJ, NET CALORIFIC VALUE	2.39E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, NET CALORIFIC VALUE	4.32E+00	8.16E-03	9.06E-02	6.39E-03	1.03E-02
PRIMARY ENERGY RESOURCES – NON-RENEWABLE (PENRE)	USE AS ENERGY CARRIER	MJ, NET CALORIFIC VALUE	5.79E+01	6.85E-01	1.15E+00	4.28E-01	4.07E-01
	USED AS RAW MATERIALS	MJ, NET CALORIFIC VALUE	5.04E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, NET CALORIFIC VALUE	5.84E+01	6.85E-01	1.15E+00	4.28E-01	4.07E-01
SECONDARY MATERIAL (SM)		KG	1.80E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RENEWABLE SECONDARY FUELS (RSF)		MJ, NET CALORIFIC VALUE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NON-RENEWABLE SECONDARY FUELS (NRSF)		MJ, NET CALORIFIC VALUE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NET USE OF FRESH WATER (FW)		M^3	2.42E-02	1.25E-04	8.75E-04	8.35E-05	4.51E-04

Resource use

INDICATOR		UNIT	TOTAL A1-A3	A4	A5	C2	C4
PRIMARY ENERGY RESOURCES – RENEWABLE (PERE)	USE AS ENERGY CARRIER	MJ, NET CALORIFIC VALUE	1.42E+00	6.01E-03	6.67E-02	4.70E-03	7.61E-03
	USED AS RAW MATERIALS	MJ, NET CALORIFIC VALUE	1.76E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, NET CALORIFIC VALUE	3.18E+00	6.01E-03	6.67E-02	4.70E-03	7.61E-03
PRIMARY ENERGY RESOURCES – NON-RENEWABLE (PENRE)	USE AS ENERGY CARRIER	MJ, NET CALORIFIC VALUE	4.26E+01	5.04E-01	8.49E-01	3.15E-01	3.00E-01
	USED AS RAW MATERIALS	MJ, NET CALORIFIC VALUE	3.71E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TOTAL	MJ, NET CALORIFIC VALUE	4.30E+01	5.04E-01	8.49E-01	3.15E-01	3.00E-01
SECONDARY MATERIAL (SM)		KG	1.32E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RENEWABLE SECONDARY FUELS (RSF)		MJ, NET CALORIFIC VALUE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NON-RENEWABLE SECONDARY FUELS (NRSF)		MJ, NET CALORIFIC VALUE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NET USE OF FRESH WATER (FW)		M^3	1.78E-02	9.20E-05	6.44E-04	6.14E-05	3.32E-04

10 Light Gauge Steel

10.1 Definition

This steel is cold formed, which creates long, thin sheets that are then shaped into guided “C” or “Z” patterns capable of holding heavy loads. Light gauge supports come in a galvanized finish of zinc, aluminum or a combination of the two. For this construction process, a load-bearing wall is constructed first, then interior partitions and exterior cladding follow. (Beck_Beyond Fastening, 2019)

10.2 Material composition

The steel used in light gauge members is manufactured to ASTM standard A1003 and is metalliccoated with zinc or aluminum-zinc alloy to provide long-term protection against corrosion. The thickness of the metallic coating can be varied, depending on the severity of the environment in which the members will be placed. The Concept of Light Gauge Steel Construction (construction53.com)

10.3 General manufacturing process

A very wide range of lightweight structural sections are produced by cold forming thin gauge strip material to specific section profiles. These are often termed light gauge or cold formed steel sections. In most cases, galvanized steel strip material is used. The cold rolling process begins with coils of galvanized strip steel that are uncoiled, slit into appropriate widths and then cold roll-formed into the final product form. Profile shapes and section sizes do vary but most sections use lips at free edges and indented profiles to provide stiffness and avoid premature failure by local buckling. Thicknesses for load bearing products typically vary from 1.2 mm to 3.2 mm. I(Metro metro supply, n.d.)

10.4 Application of material

These steel framing products are used in a variety of construction applications for both load bearing and non-load bearing conditions including, but not limited to: interior walls and ceiling systems, exterior walls, floor and roof framing, soffit framing, and other architectural features. These products are used for both commercial and residential construction.(Scafco Steel Stud Company, 2019)

- Wall System

A load bearing wall is one which carries vertical loads from the construction above or lateral loads resulting from the wind. These loads may act separately or in combination. Both internal and external walls may be load bearing. Other types of walls include non-load bearing walls, wall cladding, and partitions.

- Flooring System

The flooring system can be made up of C-sections as joists connected to C section bearers. The floor joists can be designed from a range of C-section sizes depending on loading parameters.

- Roof System

The roof structure is generally a steel truss system which can be designed for metal sheets or tiles. The steel roof framing system can suit all types of roof design. (ideas, n.d.)

10.5 Properties of LGS

10.5.1 Advantages

Buildability, strength, design flexibility, sustainability, and light in weight which makes it easy to handle and hence increase speed; safety; and quality of construction. Nonetheless, it is easily influence by fire, that is why fire protection coating shall be provided. (The Constructor, n.d.)

10.5.2 Disadvantages

- Light structures permit more sound transmission than regular masonry. Hence may not be suitable for such applications.
- Light gauge steel loses its strength faster in case of continuous exposure to fire. This will call for adequate fire protection systems in the building.

- Usage of plastic-based elements (like covering, insulation elements, gypsum boards etc) may result in biological livings like termites settling in and damaging the system.
- LGSF system uses fragile elements like plaster boards, which are easily damaged and may need replacement.

10.6 Environmental specifications (Global warming potential and Use of net freshwater)

(Scafco Steel Stud Company, 2019)

Impact category	Unit	Module A1 - Raw Materials	Module A2 - Transport to fabricator	Module A3 - Manufacturing	SYSTEM BOUNDARY Module D - EOL
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	BTU/short ton (MJ/metric ton)[a]	$2.3x10^6$ 2,700	120,000 140	$1.4x10^6$ 1,700	4,600 5.3
Use of renewable primary energy resources used as raw materials		None	None	None	None
Total use of renewable primary energy resources	BTU/short ton (MJ/metric ton)[a]	$2.3x10^6$ 2,700	120,000 140	$1.4x10^6$ 1,700	4,600 5.3
Use of nonrenewable primary energy excluding nonrenewable primary energy resources used as raw materials	BTU/short ton (MJ/metric ton)[a]	$3.0x10^7$ 34,000	$3.2x10^6$ 3,800	$3.2x10^6$ 3,700	$-1.3x10^7$ -15,000
Use of nonrenewable primary energy resources used as raw materials		Negligible	Negligible	Negligible	Negligible
Total use of nonrenewable primary energy resources (primary energy and primary energy resources used as raw materials)	BTU/short ton (MJ/metric ton)[a]	$3.0x10^7$ 34,000	$3.2x10^6$ 3,800	$3.2x10^6$ 3,700	$-1.3x10^7$ -15,000
Use of secondary materials	ton/ton[b]	0.13	-	$3.1x10^{-4}$	-
Use of renewable secondary fuels	ton/ton[b]	Negligible	Negligible	Negligible	Negligible
Use of nonrenewable secondary fuels	ton/ton[b]	Negligible	Negligible	Negligible	Negligible
Net use of fresh water	gal/short ton (m^3/metric ton)[a,c]	17,000 69	1,600 6.8	880 3.7	75 0.31
Nonhazardous waste disposed	ton/ton[b]	0.95	$2.9x10^{-2}$	0.14	0.18
Hazardous waste disposed		-	-	$1.6x10^{-5}$	-
Radioactive Waste disposed	ton/ton[b]	$7.7x10^{-6}$	$3.5x10^{-6}$	$3.9x10^{-6}$	$4.6x10^{-7}$
Components for re-use		Negligible	Negligible	Negligible	Negligible
Materials for recycling	ton/ton[b]	Not available [d]	None	$3.5x10^{-2}$	-
Materials for energy recovery		Negligible	Negligible	Negligible	Negligible
Exported energy		Negligible	Negligible	Negligible	Negligible

Impact Category	Impact Assessment Method	Units	A1	A2	A3	D
			Steel Production	Transport to the Fabricator	Fabrication	CREDITS AND BURDENS BEYOND THE SYSTEM BOUNDARY
Global Warming Potential	TRACI 2.1	ton CO_2 eq/ ton[b]	2.8	0.26	0.23	-1.2
Ozone Depletion Potential	TRACI 2.1	ton CFC-11 eq/ ton[b]	$1.7x10^{-7}$	$3.6x10^{-8}$	$3.7x10^{-8}$	$5.1x10^{-9}$
Acidification Potential	TRACI 2.1	ton SO_2 eq/ ton[b]	$1.4x10^{-2}$	3.2x10-3	1.1x10-3	-2.8x10-3
Eutrophication Potential	TRACI 2.1	ton N eq/ ton[b]	$2.1x10^{-2}$	$5.9x10^{-4}$	$3.3x10^{-4}$	$-1.2x10^{-4}$
Photochemical Ozone Creation Potential	TRACI 2.1	ton O_3 eq/ ton[b]	0.15	$6.7x10^{-2}$	$2.3x10^{-2}$	$-2.6x10^{-2}$
Depletion of Abiotic Resources (Elements)[a]	CML-IA	ton Sb eq/ ton[b]	$3.8x10^{-5}$	$2.9x10^{-7}$	$6.7x10^{-7}$	$8.4x10^{-8}$
Depletion of Abiotic Resources (Fossil)	CML-IA	BTU/short ton (MJ/ metric ton)[c]	$2.8x10^{7}$ (33,000)	$3.1x10^{6}$ (2,400)	$3.1x10^{6}$ (3,500)	$-1.2x10^{7}$ (-14,000)

10.7 Recyclability of LGS

LGS are 85% of steel recyclable at the end of a building lifespan and it can continue to be recycled infinitely with no degradation. LGS framing contains a minimum of 25% recycled steel, making it a more environmentally friendly option than traditional methods of building. (Howick, n.d.)

11 Corrugated iron sheets (CIS)

11.1 Definition

Corrugated iron sheet (CIS) are relatively light, portable and adaptable, which made them ideal for traditional construction. Made by passing thin flat iron sheets through rollers, the corrugations provided rigidity and added structural strength.

A broad range of ironworkers made corrugated iron sheets up until the 1920s. The sheets came in various lengths, usually up to a maximum of 10 feet. Gauges (thicknesses) ranged from around 0.5mm to 1.5mm depending on the end use. Corrugated iron is still made today, though it comes in a limited range of gauges. (Scotland, n.d.)

11.2 Material composition and types of CIS

Many materials today undergo the corrugation process. The most common materials for corrugated iron are ferrous alloys (e.g. stainless steels), aluminium and copper. Regular ferrous alloys are the most common due to price and availability. Common sizes of corrugated material can range from a very thin 30 gauge (0.012 inches, 0.3 mm) to a relatively thick 6 gauge (0.1943 inches, 5 mm). Thicker or thinner gauges may also be produced.

Other materials such as plastic and fiberglass are also given the corrugated look. Many applications are available for these products including using them with metal sheets to allow light to penetrate below.(Wikipedia, n.d.)

11.3 General manufacturing process

(Cembrite Holding A/S, 2016)

A very thin slurry of water, binder and fibres is mixed and introduced into each of the vats of the Hatschek machine. The rotating sieve cylinder in the vats collects a thin layer of solid material that is further dewatered as it is transferred to a felt and further on to an accumulating format roller. At the required thickness, the accumulated layers are automatically. cut into the required product size, corrugated, and transferred into the pre-curing area, and waste is returned to the manufacturing process. After precuring, the products are stored under continued control of temperature and humidity. Cembrit corrugated sheets are delivered in natural grey and coated versions in various colours with a smooth and even surface. The backside has an anti-blocking treatment.

11.5 Application of material

Corrugated iron was used frequently for roofing and walling, and less often for fencing and other innovative uses.

Manufacturers soon developed other components so that a building could be constructed from a frame and corrugated sheet. Ridging details, ventilators, windows and most other such components can no longer be sourced.

Specialist fixings were needed for the corrugated sheets, particularly given the various profiles available. Original hooks and bolts (which were usually galvanised) and specially shaped washers (to make watertight seals) should be cleaned and reused.

Prefabricated structures could be erected by securing corrugated sheets to an internal timber or metal frame. This was sufficient for agricultural purposes, or such structures could be internally insulated and covered in timber lining or plaster to meet domestic needs. (Scotland, n.d.)

11.6 Properties of CIS

11.6.1 Advantages

Mostly used in agricultural buildings, corrugated roofing sheets feature repetitive folds on their surface. Because of their unique shape, they offer years of reliable utility and enhanced strength. Their corrugated design with ridges and grooves makes them stronger than before. The wavy construction paves the way for increased strength across smaller surface areas. (Roofing Sheets: Their types, applications and costs in India, 2019)

11.6.2 Disadvantages

- Corrosion - The main aim when dealing with a corrugated iron roof is to slow down how quickly this happens. Corrosion can lead to 1) coating loss, 2) loss of structural strength or integrity and 3) the complete loss of the sheets
- Corrugated iron sheets are impermeable to moisture. But while rain is kept out, condensation is trapped in. Wetting and drying cycles are the main cause of decay, both inside and out. (Scotland, n.d.)
- Coating failure is common on galvanised surfaces. The effective coating requires the use of either a mordant wash to provide a chemical etch for the primer lyer, or an etching primer for galvanised surfaces. Often, neither was used.
- The oxidised surface (rusted appearance) that results from coating failure is often thought attractive due to its natural colouration. In many cases, the rusted roofs are seen as an integral part of the rural landscape.
- Rainwater run-off from a rusted corrugated iron roof can cause serious staining to masonry below, however. This is virtually impossible to remove from exposed stone. (Scotland, n.d.)

11.7 Technical specification

(Cembrite Holding A/S, 2016)

Name	Value	Unit
Thermal conductivity	0.4	W/(mK)
Gross density	1480 - 1700	kg/m^3
Moisture content at 23 °C, 80% humidity	11	M.-%
Coefficient of thermal expansion	10	$10^{-6}K^{-1}$
Min. breaking load	2000-4250	N/m
Min. breaking moment	30-55	Nm/m
Water vapour permeability	10	mmHg*hr* m2/g
Moisture expansion	0	mm/m

11.8 Environmental specifications (Global warming potential and Use of net freshwater)

(Cembrite Holding A/S, 2016)

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 ton of fibre cement corrugated sheets

Parameter	Unit	A1	A2	A3
Global warming potential	[kg CO_2-Eq.]	8.04E+2	1.38E+1	1.61E+0
Depletion potential of the stratospheric ozone layer	[kg CFC11-Eq.]	1.03E-5	4.40E-9	7.08E-9
Acidification potential of land and water	[kg SO_2-Eq.]	2.39E+0	1.04E-1	2.73E-2
Eutrophication potential	[kg $(PO_4)^{3-}$- Eq.]	2.27E-1	1.52E-2	8.44E-3
Formation potential of tropospheric ozone photochemical oxidants	[kg Ethen Eq.]	2.29E-1	7.35E-4	1.86E-2
Abiotic depletion potential for non-fossil resources	[kg Sb Eq.]	9.57E-4	1.32E-6	1.40E-5
Abiotic depletion potential for fossil resources	[MJ]	5.95E+3	1.73E+2	2.10E+2

RESULTS OF THE LCA - RESOURCE USE: 1 ton of fibre cement corrugated sheets

Parameter	Unit	A1	A2	A3
Renewable primary energy as energy carrier	[MJ]	1.05E+3	2.73E+1	6.33E+0
Renewable primary energy resources as material utilization	[MJ]	6.87E+2	0.00E+0	1.84E+2
Total use of renewable primary energy resources	[MJ]	1.74E+3	2.73E+1	1.91E+2
Non-renewable primary energy as energy carrier	[MJ]	6.67E+3	2.12E+2	1.93E+2
Non-renewable primary energy as material utilization	[MJ]	3.55E+2	0.00E+0	3.04E+1
Total use of non-renewable primary energy resources	[MJ]	7.02E+3	2.12E+2	2.24E+2
Use of secondary material	[kg]	IND	IND	IND
Use of renewable secondary fuels	[MJ]	1.84E+2	2.09E-3	1.25E-2
Use of non-renewable secondary fuels	[MJ]	1.04E+3	2.18E-2	1.43E-2
Use of net fresh water	[m^3]	2.26E+0	5.34E-2	-4.78E-1

11.9 Recyclability of CIS

Corrugated galvanised iron commonly called corrugated iron is used to describe two different materials; galvanised wrought iron and galvanised mild steel. Originally made from wrought iron, corrugated iron is now made from light gauge high tensile steel. Steel has one of the highest recycling rates in the world and as it does not degrade in the process it can be recycled indefinitely. Recycling scrap steel uses only 75% of the energy required to smelt iron ore. The quantity of water required in recycling steel is also greatly reduced, as washing and enrichment of the iron ore is not required.(Planet Ark, 2020

12. Cross laminated timber

12.1 Definition

Cross laminated timber (CLT) is classified as an engineered wood product. It consists of layers of kiln-dried dimension lumber in usually three, five, seven or nine) oriented at right angles to one another and then glued to form structural panels.By gluing layers of wood at right angles, the panel delivers excellent structural rigidity in both directions. In special cases, double outer laminations may be parallel and not alternating crosswise. (Naturally wood, n.d.)

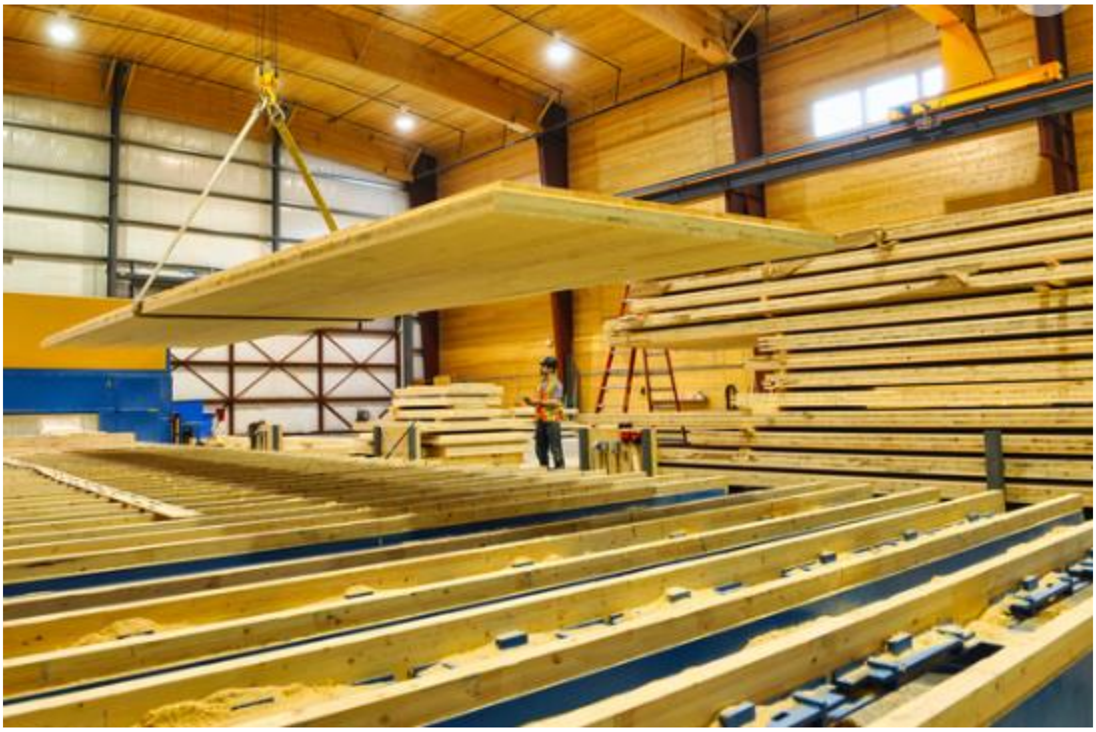
12.2 Material composition

(Stora Enso (Division Wood Products, 2020)

Materials / chemical substances	kg	%	Notes
Wood (Picea abies & Pinus sylvestris)	465,2	99	Water content 10,7%
Polyurethane (PUR) resin	4,2	0,9	Surface and fingerjoint gluing
Emulsion polymer isocyanate (EPI) resin	0,5	0,1	Narrow side gluing
Hardener	0,1	< 0,1	Narrow side gluing
TOTAL	470	100	

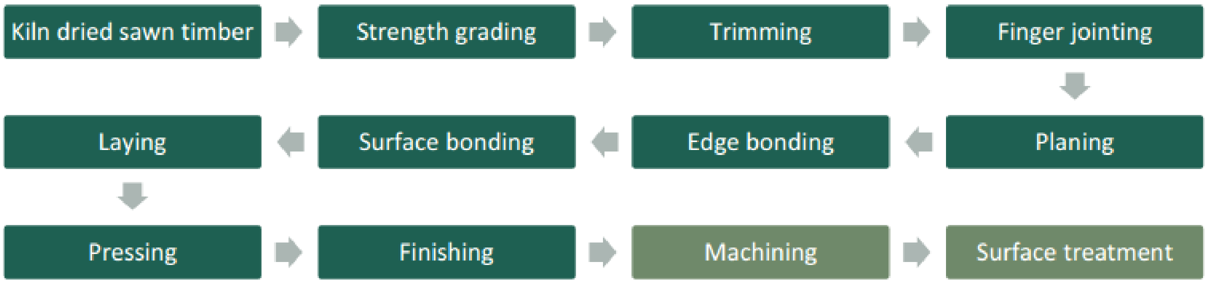
12.3 General manufacturing process of CLT

CLT fabrication begins with lumber selection, defect removal and cutting, followed by adhesive application, panel lay-up, and assembly pressing. Panels are cut to size, along with the completion of any other prefabrication requirements. Final quality control is carried out prior to delivery to the building site. CLT panels can be manufactured as custom dimensions, though transportation restrictions tend to dictate their size. CLT is manufactured in a controlled factory setting and must meet specific quality and performance requirements. The vast majority of CLT panels are made for a specific application with prescribed size, shape, appearance, and machined sections (e.g. recesses, holes, slots). Precise fabrication often relies on building information modelling (BIM) and other prefabrication technologies. Similar to other mass timber products, CLT panels can be topped with concrete to form timber concrete composite (TCC), a hybrid system used to reduce cross sections, increase spans and lessen noise transfer and vibrations. (Naturally wood, n.d.)



The production of CLT can be summarised in 12 steps.

They are as follow:



(CLT-EPD, n.d.)

12.4 Types of CLT

There are five primary CLT stress grades:

Stress grades E1, E2 and E3 consist of MSR lumber in all longitudinal layers and visually graded lumber in the transverse layers,

Stress grades V1 and V2 consist of visually graded lumber in both longitudinal and transverse layers. (Canadian Wood Council, 2022)

12.5 Applications of CLT

It can be used in virtually any building type from residential and office towers to schools and civic buildings.

- Alternative to concrete to form the walls, roofs, floors and ceilings of a building
- Well-suited to multistorey taller wood construction (including pre-insulated wall and roof sections)
- Cantilevered floors and balconies, load-bearing elevator shafts and stairs.

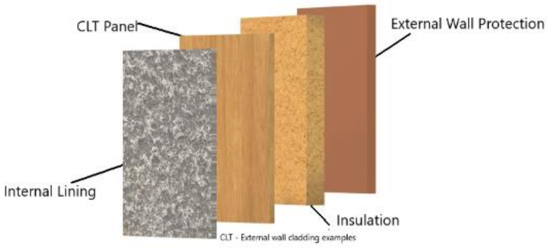
It can be left exposed for its aesthetic appearance or encapsulated when needed. Lumber in the outer layers of CLT wall panels are normally oriented up and down to maximize its load capacity vertically. Likewise, for floor and roof systems, the outer layers run parallel to the direction of the longer span. (Naturally wood, n.d.)

Beams-CLT is much better than traditional wood and other wood materials because the hollow and knotted parts of the timber are removed during the CLT manufacturing process.

Flooring and decking- CLT flooring is a durable and better option. Some floor experts say that to make a better floor, the thickness of the CLT should be at least 4 inches.

Roof- CLT has many features such as insulation, optimal air humidity, soundproofing, excellent fire protection, high load-bearing capacity, and earthquake-proof construction. All this goodness makes this construction material better for roof use. It is also used with glulam timber as a hybrid construction.

Walls- Multiple layers are used with CLT for such as weather protection(on the outermost wall), insulation, CLT Panel, and Internal Lining(From the inside). This is very important for external walls. CLT is an environmentally friendly building material. Its use does not cause any harm. This material is used to reduce energy consumption.(Timber blogger, 2021)



12.6 Properties of CLT

(Naturally wood, n.d.)

12.6.1 Advantages

- CLT naturally resists fire because it chars. In the event of a fire, this char on the outside forms a protective layer while retaining strength.
- CLT will not rot or acquire mold when correctly installed and maintained. CLT elements must be protected to avoid direct contact with moisture for a long period of time. This can be achieved through proper detailing and use of sealants, coatings, and flashing, especially on the CLT panel edges.
- CLT is strong, with its crosswise design giving it exceptional structural stability. It can be a substitute for concrete, replacing a carbon-intensive material with a renewable, low carbon alternative.
- CLT is 5x lighter than concrete. CLT has comparable strength to concrete and, as a multi-layer wooden panel, it can span in two directions. Its lighter weight offers lower foundation costs, easier transportation to the site and rapid prefabricated assembly. (Naturally wood, n.d.)
- Faster installation
- A cleaner, drier construction site
- No specialized construction experience needed (Simpson, n.d.)

12.6.2 Disadvantages

- CLT is more expensive than steel or concrete
- Code restrictions on timber building heights
- Costs of electrical, plumbing and other services can increase (no wall cavities)
- There can be higher architectural/design costs
- A higher material transportation cost (relatively few manufacturing plants)

Less long-term flexibility (think future renovations) (Simpson, n.d.)

12.7 Technical properties

(Stora Enso (Division Wood Products, 2020)

Properties	Definition
Use	Structural applications; wall, ceiling and roof panels
Maximum width	3,50 m (on request up to 4,00 m)
Maximum thickness	350 mm (in accordance with ETA 14/0349)
Maximum length	16,00 m
Wood species	spruce *(Picea abies)*, pine *(Pinus sylvestris)*
Adhesives	polyurethane adhesive (PUR), emulsion-polymer-isocyanate adhesive (EPI)
Moisture content	12% ± 2% when dispatched from the mill
Density	Mean density 470 kg/m^3
Thermal conductivity	λ = 0,12 W/(mK) (EN ISO 10456)
Specific heat capacity	c = 1600 J/(kg-K) (EN ISO 10456)
Service class	1 and 2 (EN 1995-1-1)
Reaction to fire	D-s2, d0 (EN 13501-1)

12.8 Environmental specifications (Global warming potential and Use of net freshwater)

(Stora Enso (Division Wood Products, 2020)

Environmental performance – product / construction stage

Potential environmental impact - 1m³ CLT

PARAMETER		UNIT	A1	A2	A3	TOTAL A1-A3	A4	A5
Global warming potential (GWP)	Fossil	kg CO_2 eq.	3,19E+01	1,42E+01	7,61E+00	**5,38E+01**	3,84E+01	1,47E+01
	Biogenic *	kg CO_2 eq.	-7,62E+02*	1,58E-02	3,34E-01	**-7,62E+02***	1,34E-02	1,00E-01
	Land use and land transformation	kg CO_2 eq.	6,82E-01	5,58E-03	1,61E-01	**8,48E-01**	1,01E-02	1,90E-03
	TOTAL *	kg CO_2 eq.	-7,29E+02*	1,42E+01	8,10E+00	**-7,07E+02***	3,84E+01	1,48E+01
Ozone depletion potential (ODP)		kg CFC 11 eq.	2,44E-06	3,90E-06	2,01E-06	**8,36E-06**	9,58E-06	2,82E-06
Acidification potential (AP)		mol H+ eq.	1,45E-01	5,86E-02	1,97E-01	**4,01E-01**	1,30E-01	7,17E-02
Eutrophication potential (EP)	freshwater	kg PO_4 eq.	3,53E-03	2,70E-03	4,30E-03	**1,05E-02**	3,17E-03	2,22E-03
	marine	kg N eq.	2,36E-02	1,21E-02	3,85E-02	**7,42E-02**	2,73E-02	2,53E-02
	terrestrial	mol N eq.	2,39E-01	1,45E-01	8,46E-01	**1,23E+00**	3,04E-01	2,77E-01
Formation potential of tropospheric ozone (POCP)		kg NMVOC eq.	2,26E-01	4,71E-02	9,09E-02	**3,64E-01**	1,17E-01	8,02E-02
Abiotic depletion potential – Elements **		kg Sb eq.	1,07E-04	2,75E-05	1,99E-05	**1,55E-04**	7,40E-05	2,61E-05
Abiotic depletion potential – Fossil resources **		MJ, net calorific value	5,44E+02	2,62E+02	1,12E+02	**9,18E+02**	6,25E+02	1,90E+02
Water scarcity potential **		m^3 eq.	1,39E+01	2,06E+00	5,27E+00	**2,12E+01**	4,71E+00	1,40E+00

Use of resources - 1m³ CLT

PARAMETER		UNIT	A1	A2	A3	TOTAL A1-A3	A4	A5
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	2,75E+00	1,23E+01	1,06E+03	**1,08E+03**	6,77E+00	2,68E+00
	Used as raw materials	MJ, net calorific value	7,52E+03	0,00E+00	0,00E+00	**7,52E+03**	0,00E+00	0,00E+00
	TOTAL	MJ, net calorific value	7,52E+03	1,23E+01	1,06E+03	**8,60E+03**	6,77E+00	2,68E+00
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	1,73E+02	2,71E+02	3,41E+02	**7,86E+02**	6,35E+02	1,93E+02
	Used as raw materials	MJ, net calorific value	1,22E+02	0,00E+00	0,00E+00	**1,22E+02**	0,00E+00	0,00E+00
	TOTAL	MJ, net calorific value	2,95E+02	2,71E+02	3,41E+02	**9,07E+02**	6,35E+02	1,93E+02
Secondary material		kg	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00
Renewable secondary fuels		MJ, net calorific value	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00
Non-renewable secondary fuels		MJ, net calorific value	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00
Net use of fresh water		m^3	2,52E-01	0,00E+00	0,00E+00	**2,52E-01**	0,00E+00	0,00E+00

12.9 Recyclability of CLT

Upon the demolition of a CLT based construction project, leftover wood is able to be utilised or recycled for a magnitude of other uses due to its wood nature. The CLT contains biomass and its panels and any other individual elements are recyclable, they are able to be sent back to the manufacturer for reuse and recycling. While items such as sawdust and wood-scraps are not as easily reused or recycled, they can be converted to energy through burning. Alternatively they can be made into chips or compressed into pallets that can be shipped to companies where they're burned in a similar fashion to coal as a source of energy.(SCS, 2013)

13 Vinyl siding

13.1 Definition

Vinyl siding is a plastic wrapping that's used for the exterior of homes and buildings. It's the most popular type of cladding for all kinds of buildings thanks to its modern appearance and weatherproofing capabilities. (Proside select, 2018)

13.2 Material composition

Constituent	% in Siding with PVC Capstock	% in Siding with ASA Capstock
PVC	80%	70%
ASA	--	11%
Calcium Carbonate	11%	11%
Impact modifier	2%	2%
Titanium dioxide	1.5%	1%
Acrylic filler	1%	1%
Other additives	4.5%	4%

(Vinyl Siding Insitute, 2016)

13.3 General manufacturing process

Vinyl siding manufacturing is an extremely efficient extrusion process requiring relatively low inputs of energy and water and, the ability to immediately return scrap and off-specification materials (regrind) directly into the manufacturing process results in virtually no manufacturing waste. Water is not one of the constituents of vinyl and is only used for cooling the siding after it has been extruded. Modern technology in the manufacturing phase allows for vinyl siding to be co-extruded with a substrate and a capstock. Co-extrusion allows for a more durable product, enabling colors and textures to retain their original (Vinyl Siding Insitute, 2016)

appearance and performance capabilities over time.

13.4 Product types

Clapboard vinyl siding (most popular types)

Board and batten siding (Vertical siding)

Cedar shake vinyl siding (Aesthetically look like real cedar wood shakes)

13.5 Application of vinyl siding

Known for its outstanding performance, vinyl siding is increasingly the exterior cladding of choice for homeowners, remodelling contractors, architects, and builders. Vinyl is attractive, durable, easy to maintain, and cost-effective compared to other siding products. Vinyl siding is available in a variety of architectural styles, eye-catching colours, design-enhancing profiles, finishes, and textures. (Institute, 2011)

Vinyl siding is plastic exterior siding for houses and small apartment buildings, used for decoration and weatherproofing, imitating wood clapboard, board and batten or shakes, and used instead of other materials such as aluminium or fiber cement siding. (Vinyl siding, 2022)

13.6 Properties of vinyl siding

13.6.1 Advantages

- Durability for life (It can withstand harsh weather conditions)
- High quality, high value
- Maintenance-free

- Energy efficient
- Eco-friendly and certified green Source: (BlueLinx, n.d.)

13.6.2 Disadvantages

The Occupational Safety and Health Administration (OSHA) maintains strict workplace exposure limits for employees in vinyl siding plants. Studies are inconclusive as to whether applying vinyl siding to homes causes health problems for residents. (BERNARD, 2022)

13.7 Technical specification

(Vinyl Siding Institute, 2016)

Name	Value	Unit
Length	12	ft
Width	0.75	ft
Thickness	0.040	in
Density	89.27	lb./ft3

13.8 Environmental specifications (Global warming potential and Use of net freshwater)

(Vinyl Siding Institute, 2016)

Part B- Life Cycle Impact Assessment Results

Functional Unit: 100 square feet

Part B.1 TRACI 2.1		**A1**	**A2**	**A3**	**A4**	**A5**	**B2**	**C1**	**C2**	**C3**	**C4**	**Units**
GWP	Global warming potential	4.47E+01	1.27E+00	5.07E+00	9.40E-01	7.66E-01	4.79E-01	0.00E+00	3.58E-02	0.00E+00	9.75E+00	kg CO_2 Eq.
ODP	Depletion potential of the stratospheric ozone layer	2.61E-06	7.55E-08	1.46E-07	3.59E-11	5.11E-08	2.90E-08	0.00E+00	1.37E-12	0.00E+00	2.67E-07	kg CFC 11 Eq.
AP	Acidification potential	1.93E-01	9.86E-03	3.90E-02	5.61E-03	4.17E-03	2.46E-03	0.00E+00	2.14E-04	0.00E+00	2.33E-02	kg SO_2 Eq.
EP	Eutrophication potential	4.86E-02	1.14E-03	5.45E-03	3.13E-04	3.33E-03	2.08E-03	0.00E+00	1.19E-05	0.00E+00	1.54E-02	kg N Eq.
POCP	Photochemical ozone creation potential	1.73E+00	2.78E-01	3.19E-01	1.54E-01	3.46E-02	2.93E-02	0.00E+00	5.85E-03	0.00E+00	2.37E-01	kg O_3 Eq.
ADPF	Abiotic depletion potential for fossil resources	1.37E+02	2.23E+00	5.42E+00	1.69E+00	6.47E-01	3.63E-01	0.00E+00	6.45E-02	0.00E+00	2.69E+00	MJ surplus energy

Part C- Use of Resources													
Part C Resource Use		A1	A2	A3	A4	A5	B2	C1	C2	C3	C4	Total	Units
PERE	Use of RENEWABLE primary energy excluding the RENEWABLE primary energy used as raw materials	6.86E+02	1.78E+01	7.78E+01	1.28E+01	1.08E+01	5.41E+00	0.00E+00	4.88E-01	0.00E+00	5.37E+01	8.65E+02	MJ (LHV)
PERM	Use of RENEWABLE primary energy resources used as raw materials	2.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.89E+02	MJ
PERT	Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	9.75E+02	1.78E+01	7.78E+01	1.28E+01	1.08E+01	5.41E+00	0.00E+00	4.88E-01	0.00E+00	5.37E+01	1.15E+03	MJ
PENRE	Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	MJ
PENRM	Use of NON-RENEWABLE primary energy as raw materials	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	MJ
PENRM	Total use of NON-RENEWABLE primary energy	2.12E+01	7.83E-02	1.34E+01	0.00E+00	3.39E-01	1.09E+01	0.00E+00	0.00E+00	0.00E+00	2.00E+00	4.79E+01	MJ
SM	Use of secondary materials	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	kg
RSF	RENEWABLE secondary fuels	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	MJ
NRSF	Use of NON-RENEWABLE secondary fuels	1.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-01	MJ
FW	Use of fresh water resources	7.13E+01	5.21E-01	2.15E+00	0.00E+00	2.44E+00	6.60E-01	0.00E+00	0.00E+00	0.00E+00	1.26E+01	8.97E+01	m^3

All use phase stages have been considered and only maintenance (B2) contains non-zero environmental impacts, which is reported above.

13.9 Recyclability of vinyl siding

Vinyl siding is completely recyclable as it is a thermoplastic; however, the infrastructure to recycle vinyl siding may be limited in certain regions of the US and Canada.(Vinyl Siding Institute, 2016)

Recycling post-consumer PVC is both difficult and expensive. Recycling plastic typically means polyethylene terephthalate (PETE), the type used to make soda bottles and other household products. Most recycling centres will not accept items containing PVC. Once siding arrives at the landfill, it is usually burned. Incinerated and biodegraded plastic are large sources of pollution around the world.

(BERNARD, 2022)

Appendix B

EPDs of the different types of construction materials

Appendix C: Potential suppliers in Mauritius

	Structure	Baseline Building	Suppliers	Option 1	Suppliers	Option 2	Suppliers	Option 3	Suppliers	Option 4	Suppliers
				Light gauge steel + MgO + Gypsum	**EMCON**	**Light gauge steel + OSB board with vinyl siding + gypsum**		**light gauge steel + Prefab concrete insulated panel +**		**Timber frame + OSB board with vinyl siding + gypsum**	
	Substructure										
	Foundation	R.C bases/strip footings	Cement - KOLOS, CEMENTIS Concrete - PREMIX, GAMMA, EASTERN MIX Reinforcement steel - DESBRO, JOONAS Marine plywood - GREWALS, Chantier Plaisance partition steel studs -	R.C bases/ground beams	Cement - KOLOS, CEMENTIS Concrete - PREMIX, GAMMA, EASTERN MIX Reinforcement steel - DESBRO, JOONAS Marine plywood - GREWALS, Chantier Plaisance partition steel studs -	R.C bases/ground beams	EMCON, Framecad, Knauf	R.C bases/strip footings	EMCON, Framecad, Knauf	R.C bases/strip footings	EMCON, Framecad, Knauf

	Structure	Baseline Building	Suppliers	Option 1	Suppliers	Option 2	Suppliers	Option 3	Suppliers	Option 4	Suppliers
			INTERIOR SOLUTIONS LTD		INTERIOR SOLUTIONS LTD						
	Superstucture										
	Ground floor construction	Ground beam + Concrete floor on hardcore filling + screed	Gamma Construction, General Construction	MgO floorboard on steel frame	EMCON, Knauf	OSB board on steel frame	EMCON, Knauf	Prefab concrete insulated panel on steel frame	EMCON, Knauf	OSB board on timber frame	EMCON, Knauf
	Structural frame	RC columns and beams	Gamma Construction, General Construction	Light gauge steel	EMCON, Framecad, Knauf	Light gauge steel	EMCON, Framecad, Knauf	Light gauge steel	EMCON, Framecad, Knauf	Timber	HEFTY, Charles Giblot Ducray Construction
	Columns	Reinforced concrete	Gamma Construction, General Construction	Light gauge steel	EMCON, Framecad, Knauf	Light gauge steel	EMCON, Framecad, Knauf	Light gauge steel	EMCON, Framecad, Knauf	Timber	HEFTY, Charles Giblot Ducray Construction

	Structure	Baseline Building	Suppliers	Option 1	Suppliers	Option 2	Suppliers	Option 3	Suppliers	Option 4	Suppliers
	Beams	Reinforced concrete	Gamma Construction, General Construction	Light gauge steel	EMCON, Framecad, Knauf	Light gauge steel	EMCON, Framecad, Knauf	Light gauge steel	EMCON, Framecad, Knauf	Timber	HEFTY, Charles Giblot Ducray Construction
	External envelope	200mm blockwork (hollow blocks)	GAMMA Materials, UBP	Magnesium Oxide board	EMCON, Interior Solutions ltd	Vinyl siding on OSB board incl damp proof membrane	EMCON, Interior Solutions ltd	Prefab concrete insulated panel on steel frame	EMCON, Interior Solutions ltd	Vinyl siding on OSB board incl damp proof membrane	EMCON, Interior Solutions ltd
	Walls	200mm blockwork (hollow blocks)	GAMMA Materials, UBP	MgO board - external, Gypsum board internal	EMCON, Interior Solutions ltd	Vinyl siding on OSB board incl damp proof membrane + gypsum board internal	EMCON, Interior Solutions ltd	Prefab concrete insulated panel on steel frame	EMCON, Interior Solutions ltd	Vinyl siding on OSB board incl damp proof membrane	EMCON, Interior Solutions ltd
	Finishings	Plaster and paint - 16mm	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint - 5mm	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint - 5mm	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint - 5mm	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint - 5mm	Interior Solutions, Riteseal (Mtius) Ltd
	Windows	Aluminium	JK Aluminium Ltd, Neetoo	Aluminium	JK Aluminium Ltd, Neetoo	Aluminium	JK Aluminium Ltd, Neetoo Industrie	Aluminium	JK Aluminium Ltd, Neetoo Industrie	Aluminium	JK Aluminium Ltd, Neetoo

	Structure	Baseline Building	Suppliers	Option 1	Suppliers	Option 2	Suppliers	Option 3	Suppliers	Option 4	Suppliers
			Industries &Co Ltd		Industries &Co Ltd		s &Co Ltd		s &Co Ltd		Industries &Co Ltd
	Doors	Aluminium	JK Aluminium Ltd, Neetoo Industries &Co Ltd	Aluminium	JK Aluminium Ltd, Neetoo Industries &Co Ltd	Aluminium	JK Aluminium Ltd, Neetoo Industries &Co Ltd	Aluminium	JK Aluminium Ltd, Neetoo Industries &Co Ltd	Aluminium	JK Aluminium Ltd, Neetoo Industries &Co Ltd
	Roof	150mm RC slab	PREMIX' Betonix	Corrugated iron sheet	Profilage Ltee, Metal Sheets Industries Ltd	Corrugated iron sheet	Profilage Ltee, Metal Sheets Industries Ltd	Corrugated iron sheet	Profilage Ltee, Metal Sheets Industries Ltd	Corrugated iron sheet	Profilage Ltee, Metal Sheets Industries Ltd
	Internal division	150mm blockwork	UBP, GAMMA	Gypsum partition	EMCON, Interior Solutions ltd	Gypsum partition	EMCON , Interior Solutions ltd	Gypsum partition	EMCON , Interior Solutions ltd	Gypsum partition	EMCON, Interior Solutions ltd
	Walls	150mm blockwork	UBP, GAMMA	Gypsum partition	EMCON, Interior Solutions ltd	Gypsum partition	EMCON , Interior Solutions ltd	Gypsum partition	EMCON , Interior Solutions ltd	Gypsum partition	EMCON, Interior Solutions ltd
	Doors	Timber	Interior Solutions/ Menuiserie	Timber	Interior Solutions/ Menuiserie	Timber	Interior Solutions/	Timber	Interior Solutions/	Timber	Interior Solutions /

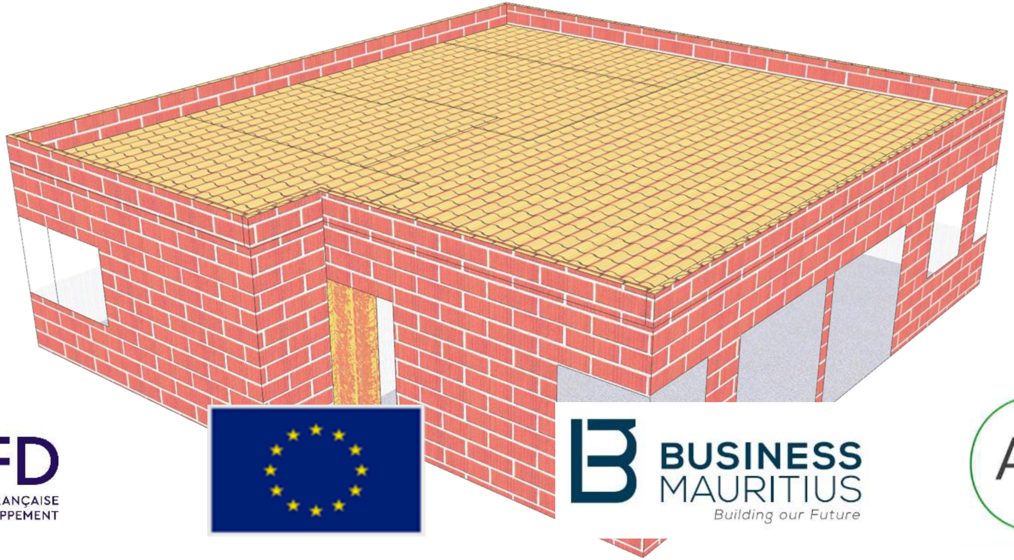
	Structure	Baseline Building	Suppliers	Option 1	Suppliers	Option 2	Suppliers	Option 3	Suppliers	Option 4	Suppliers
			de l'Ocean Indien Ltee		de l'Ocean Indien Ltee		Menuiserie de l'Ocean Indien Ltee		Menuiserie de l'Ocean Indien Ltee		Menuiserie de l'Ocean Indien Ltee
	Internal finishes										
	Floor finishes	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles	Interior Solutions, Ideco Ltd	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles	Interior Solutions, Ideco Ltd	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles	Interior Solutions, Ideco Ltd	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles	Interior Solutions, Ideco Ltd	Vinyl covering/Tiling/Laminated floor/Luxury vinyl tiles	Interior Solutions, Ideco Ltd
	Internal wall finishes	Plaster and paint	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint	Interior Solutions, Riteseal (Mtius) Ltd	Plaster and paint	Interior Solutions, Riteseal (Mtius) Ltd
	Ceilings	Plaster and paint - underside for slab	Interior Solutions, Riteseal (Mtius) Ltd	Gypsum ceiling	Interior Solutions	Gypsum ceiling	Interior Solutions	Gypsum ceiling	Interior Solutions	Gypsum ceiling	Interior Solutions
	Fittings	General	Interior Solutions, Manser Saxon	General	Interior Solutions, Manser Saxon	General	Interior Solutions, Manser Saxon	General	Interior Solutions, Manser Saxon	General	Interior Solutions, Manser Saxon

	Structure	Baseline Building	Suppliers	Option 1	Suppliers	Option 2	Suppliers	Option 3	Suppliers	Option 4	Suppliers
			Contracting Ltd		Contracting Ltd		Contracting Ltd		Contracting Ltd		Contracting Ltd
	Services										
	HVAC	None		None		None		None		None	
	Special equipment	Photovoltaic/solar panels	Solar Centre, Duraco	Photovoltaic/solar panels	Solar Centre, Duraco	Photovoltaic/solar panels	Solar Centre, Duraco	Photovoltaic/solar panels	Solar Centre, Duraco	Photovoltaic/solar panels	Solar Centre, Duraco

Appendix D

Simulation analysis as per ASHRAE

SIMULATION ANALYSIS



PROPOSED INDIVIDUAL DWELLING BUILDING

✓ *The project site comprises of Living, Bedrooms*

Site Location	: Vacoas, Mauritius
Key Blocks	: Proposed Individual Dwelling Unit
Location	: Vacoas, Mauritius

Simulation has been carried out for the parameters listed on slide 3 – the sky light, windows and doors have been modelled as per drawings.

- Simulation was performed for the whole year with latest available weather data.

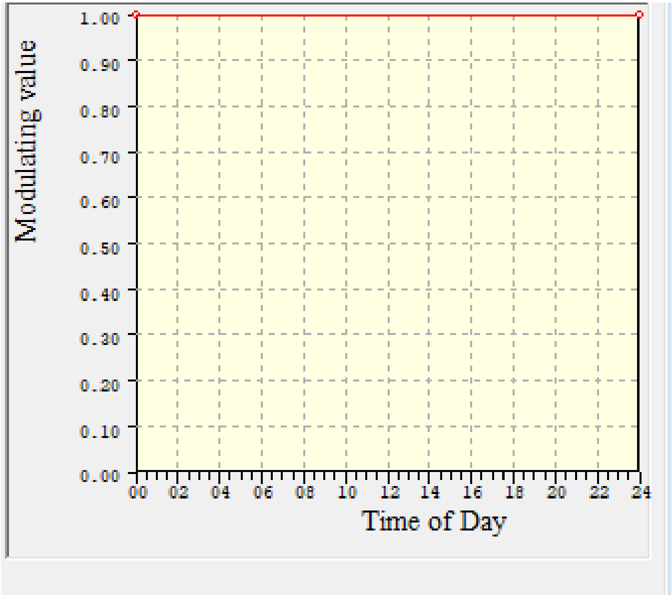
PROPOSED BUILDING – DATA CONSIDERED FOR SIMULATION

Thermal Parameters

Description	Wattage
Lighting Load	6.57 W/Sq.m
Equipment Load	6.46W/Sq.m
People	4 person/dwelling unit

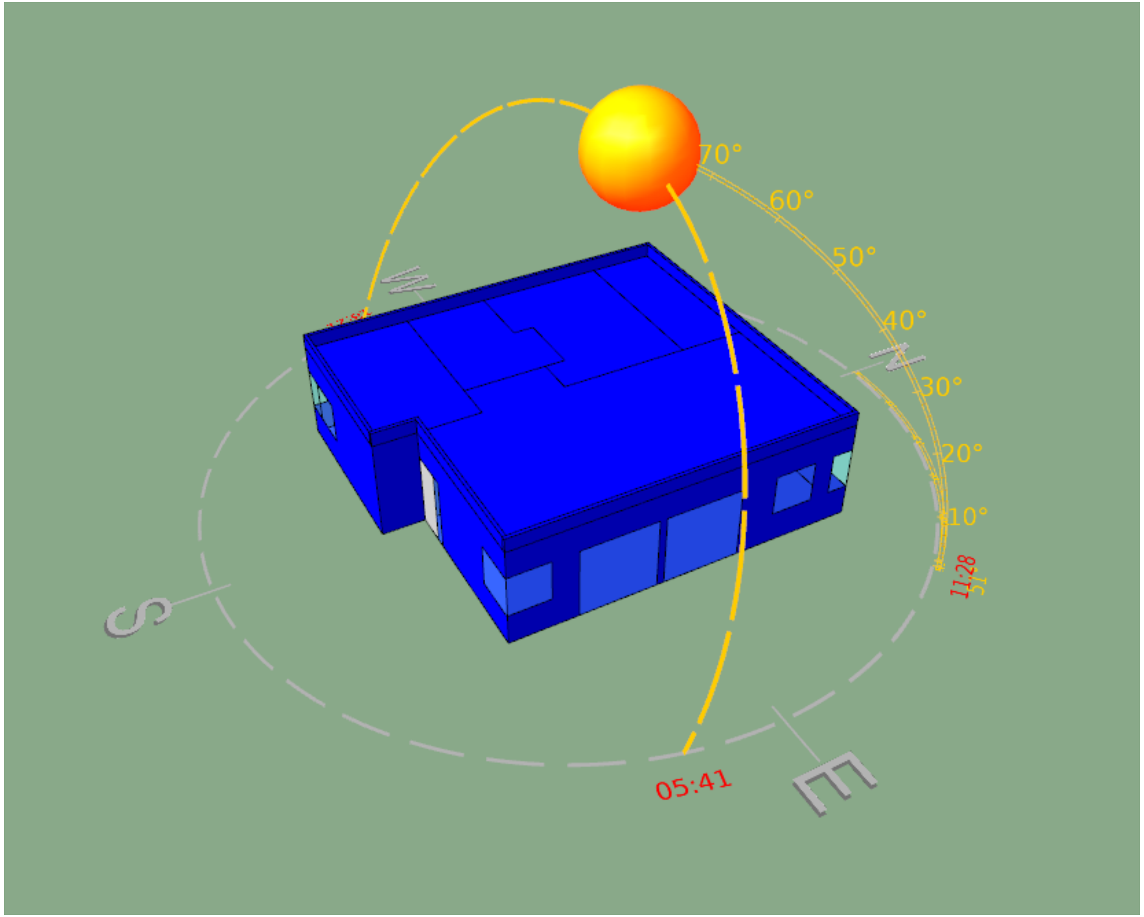
- ✓ *Thermal Parameters were considered based on baseline value of ASHRAE 2016*

People Sensible Heat Gain (W/Person) = 250
People Latent Heat Gain (W/Person) = 200

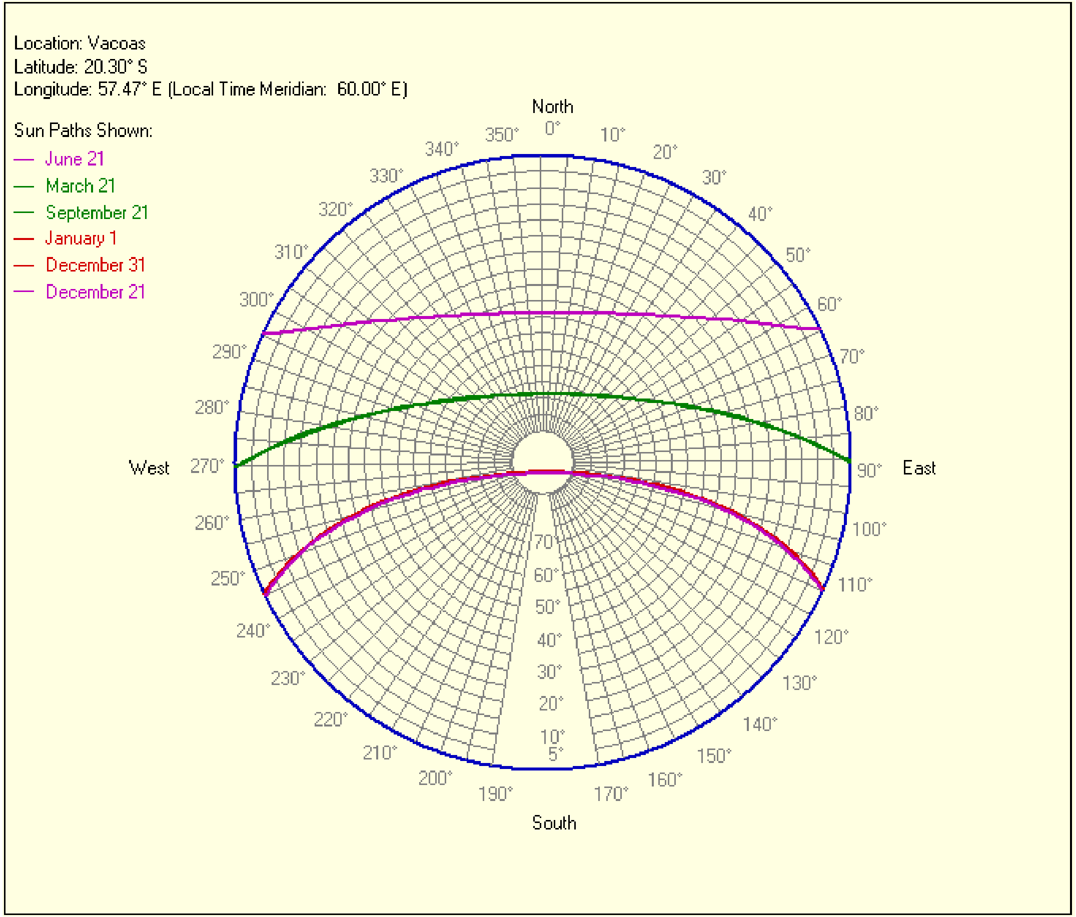


Occupancy Schedule (24hrs)

CLIMATE ANALYSIS

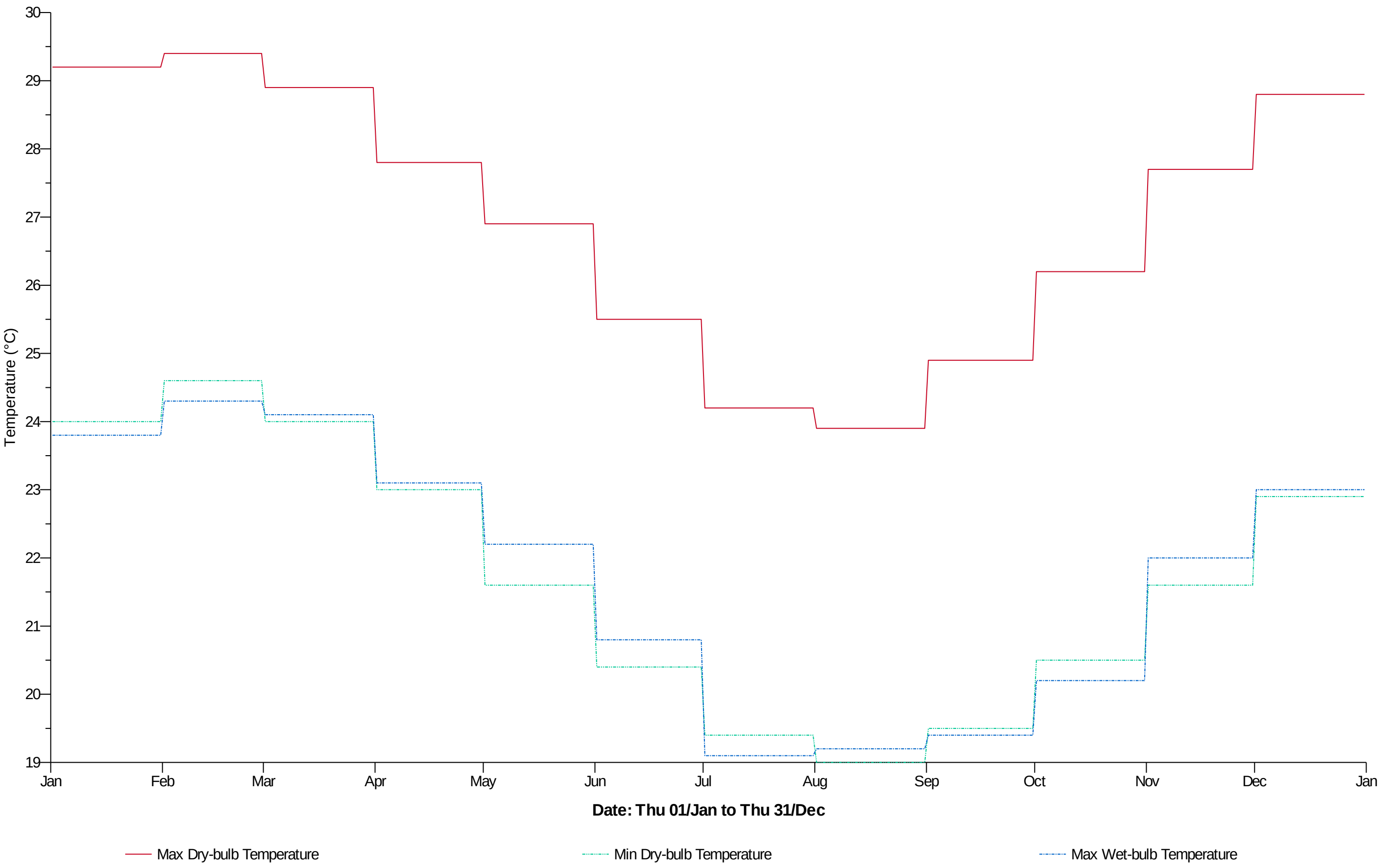


SUNPATH

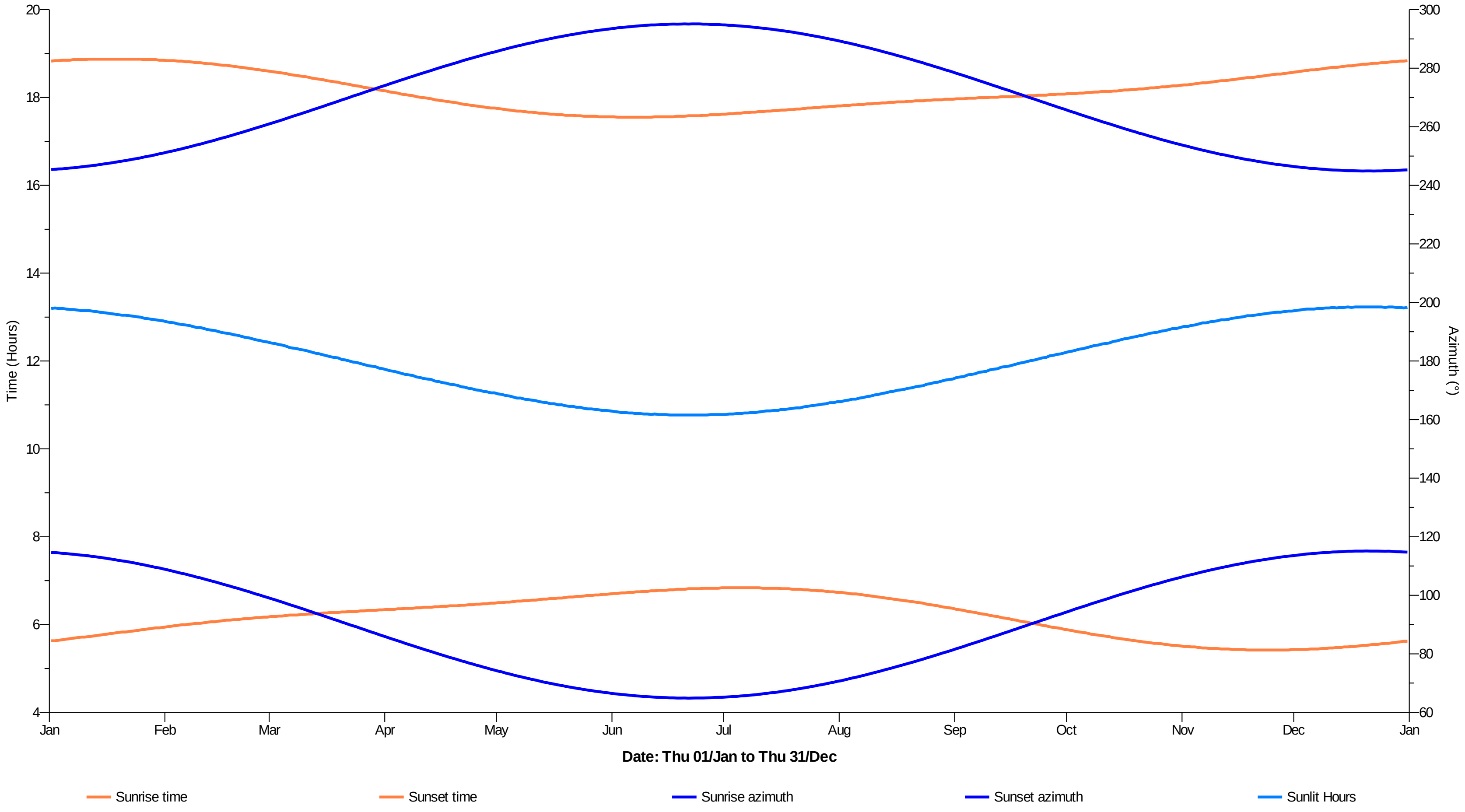


Location: Vacoas
Latitude: 20.30° S
Longitude: 57.47° E (Local Time Meridian: 60.00° E)
Sun Paths Shown:
June 21
March 21
September 21
January 1
December 31
December 21
North
South
East
West
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
70°
60°
50°
40°
30°
20°
10°
5°

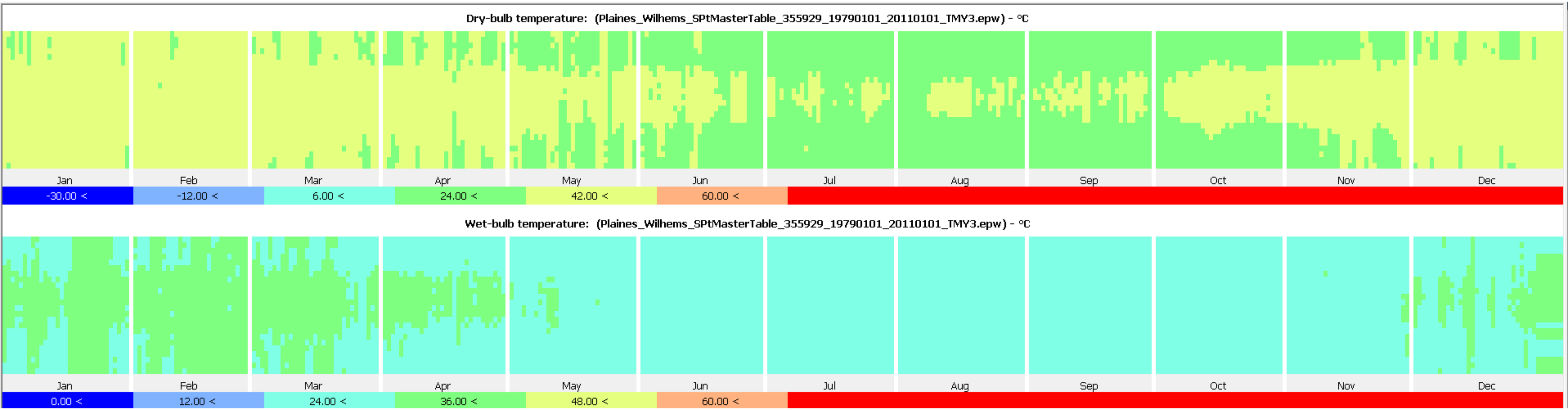
Max & Min Dry-bulb Temperature; Max wet-bulb Temperature



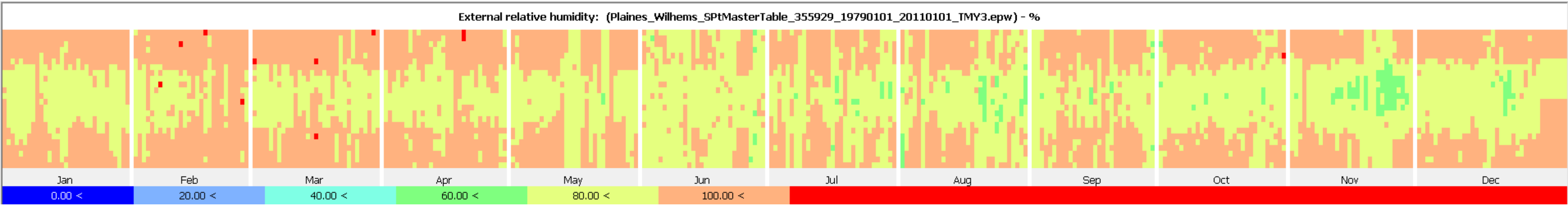
Sun Rise & Sun Set



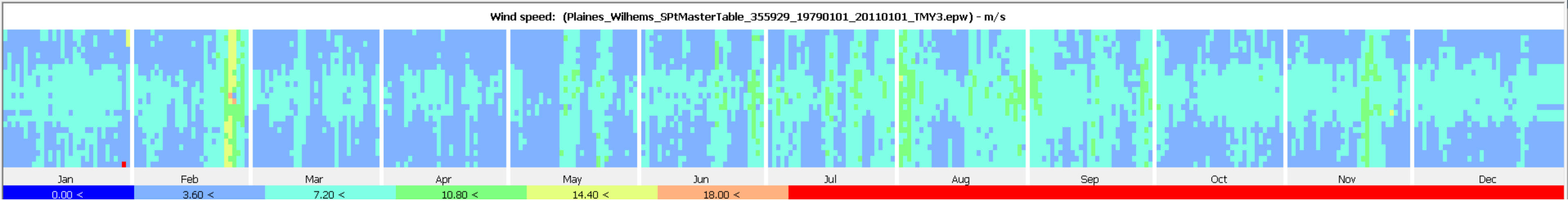
Dry bulb [Max-32.8°C; Min-16.2°C] & Wet bulb Temperature [Max-27.47°C; Min-13.75°C]



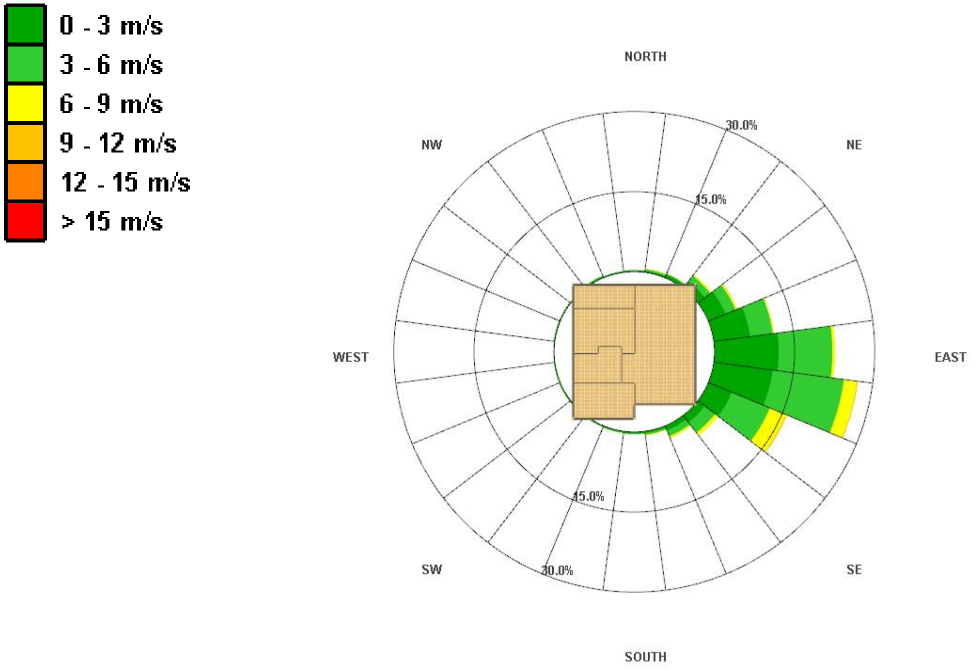
External Relative Humidity [Max-100%; Min-43%]



Wind Speed [Max- 22 m/s @ 31st Jan 00:00 AM; Min- 0m/s @ 2nd Jan 3 AM]



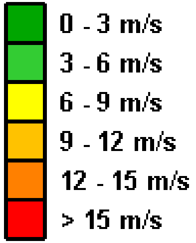
Windrose diagram – Annual

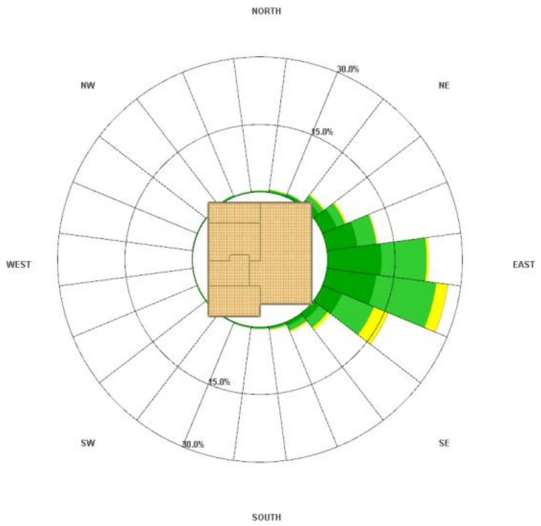


Wind Rose:01/Jan to 31/Dec
Airflow Unit: l/s

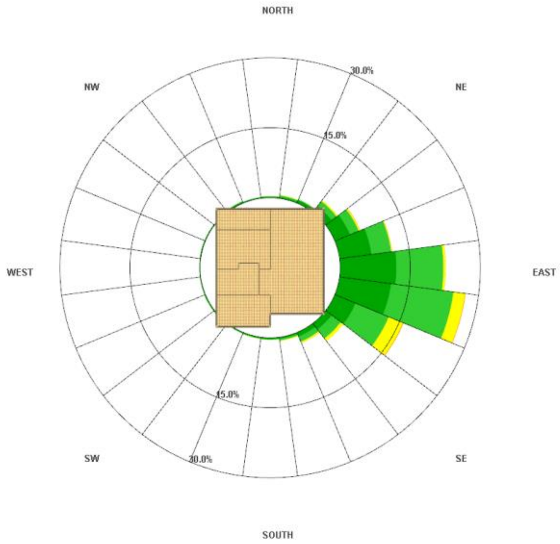
Direction specific quantum and speed of wind flow

Windrose diagram – Month wise

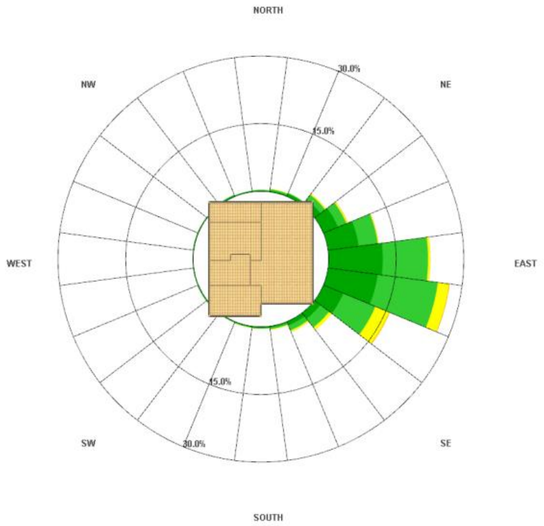




JANUARY



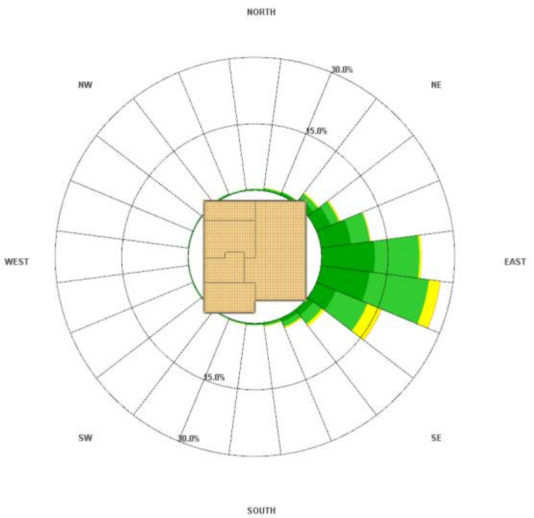
FEBRUARY



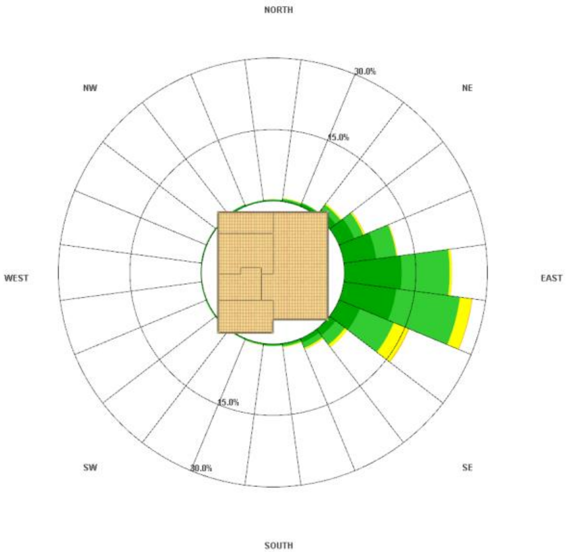
MARCH

Windrose diagram – Month wise

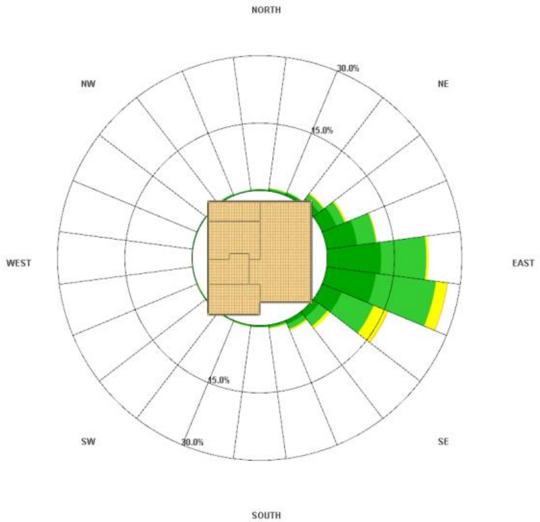
- 0 - 3 m/s
- 3 - 6 m/s
- 6 - 9 m/s
- 9 - 12 m/s
- 12 - 15 m/s
- > 15 m/s



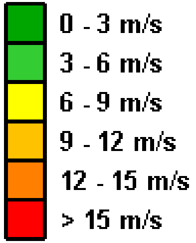
APRIL



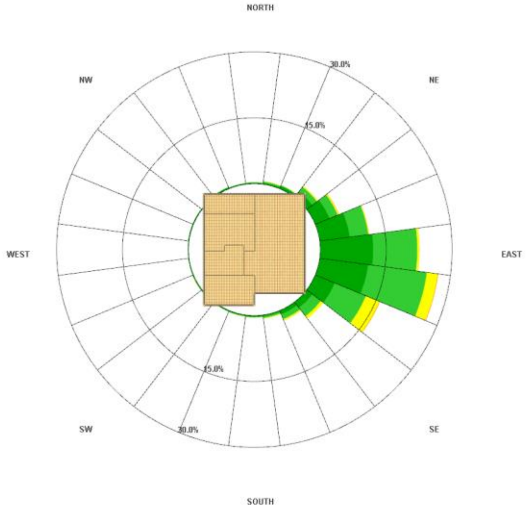
MAY



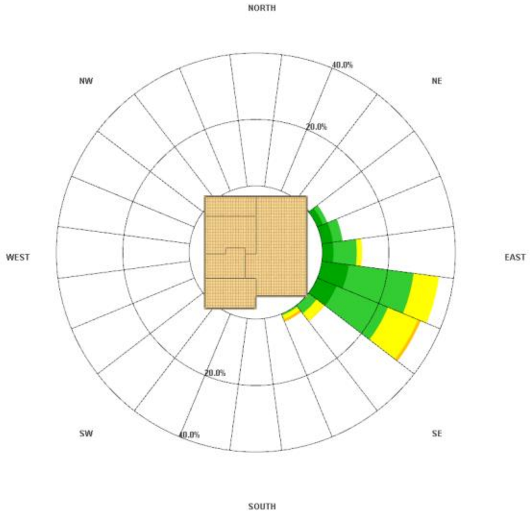
JUNE



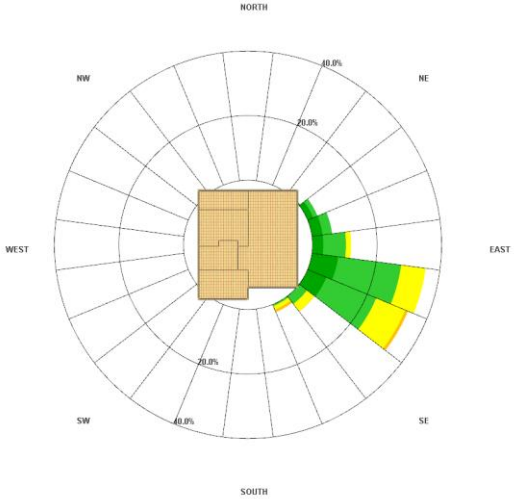
Windrose diagram – Month wise



JULY



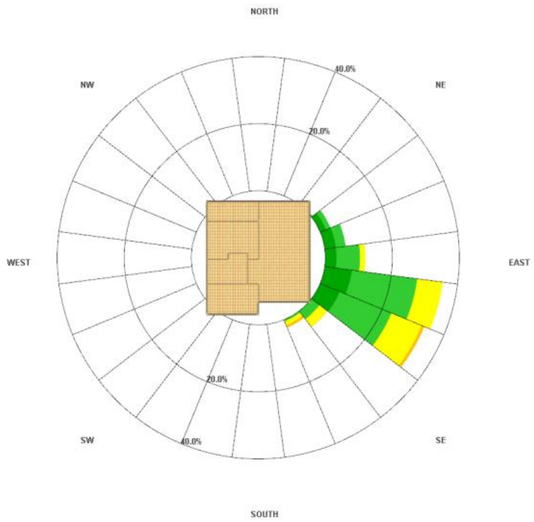
AUGUST



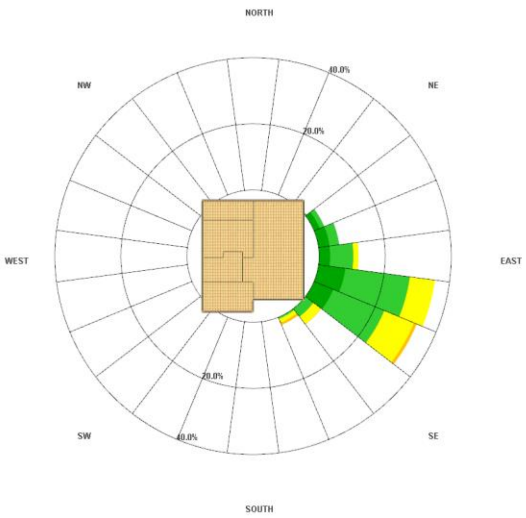
SEPTEMBER

Windrose diagram – Month wise

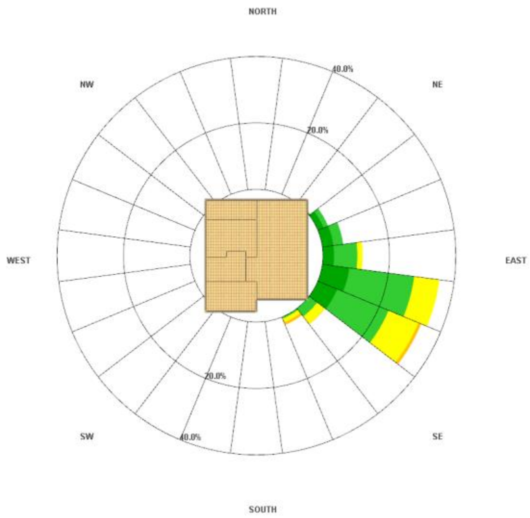
0 - 3 m/s
3 - 6 m/s
6 - 9 m/s
9 - 12 m/s
12 - 15 m/s
> 15 m/s



OCTOBER

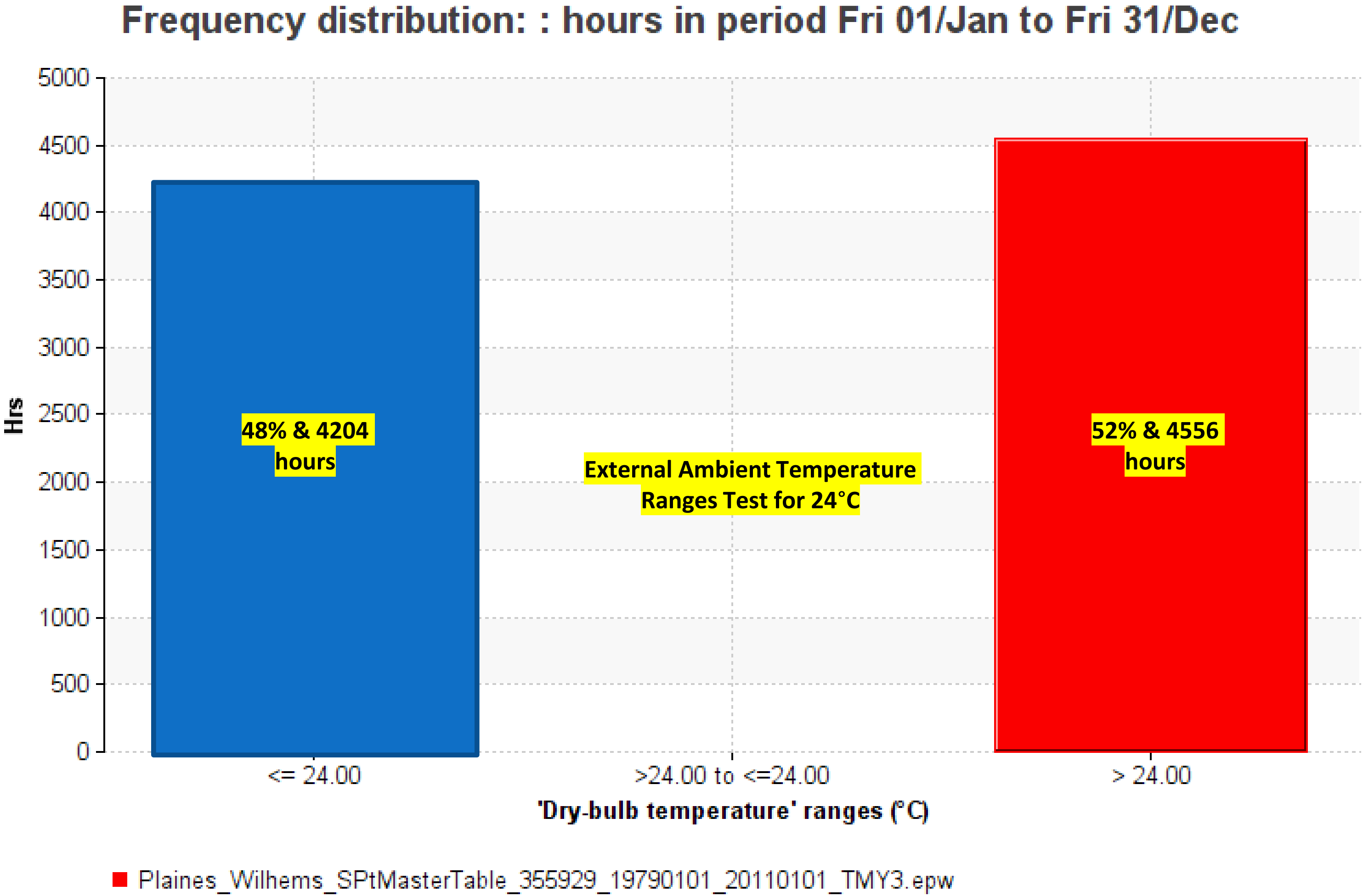


NOVEMBER

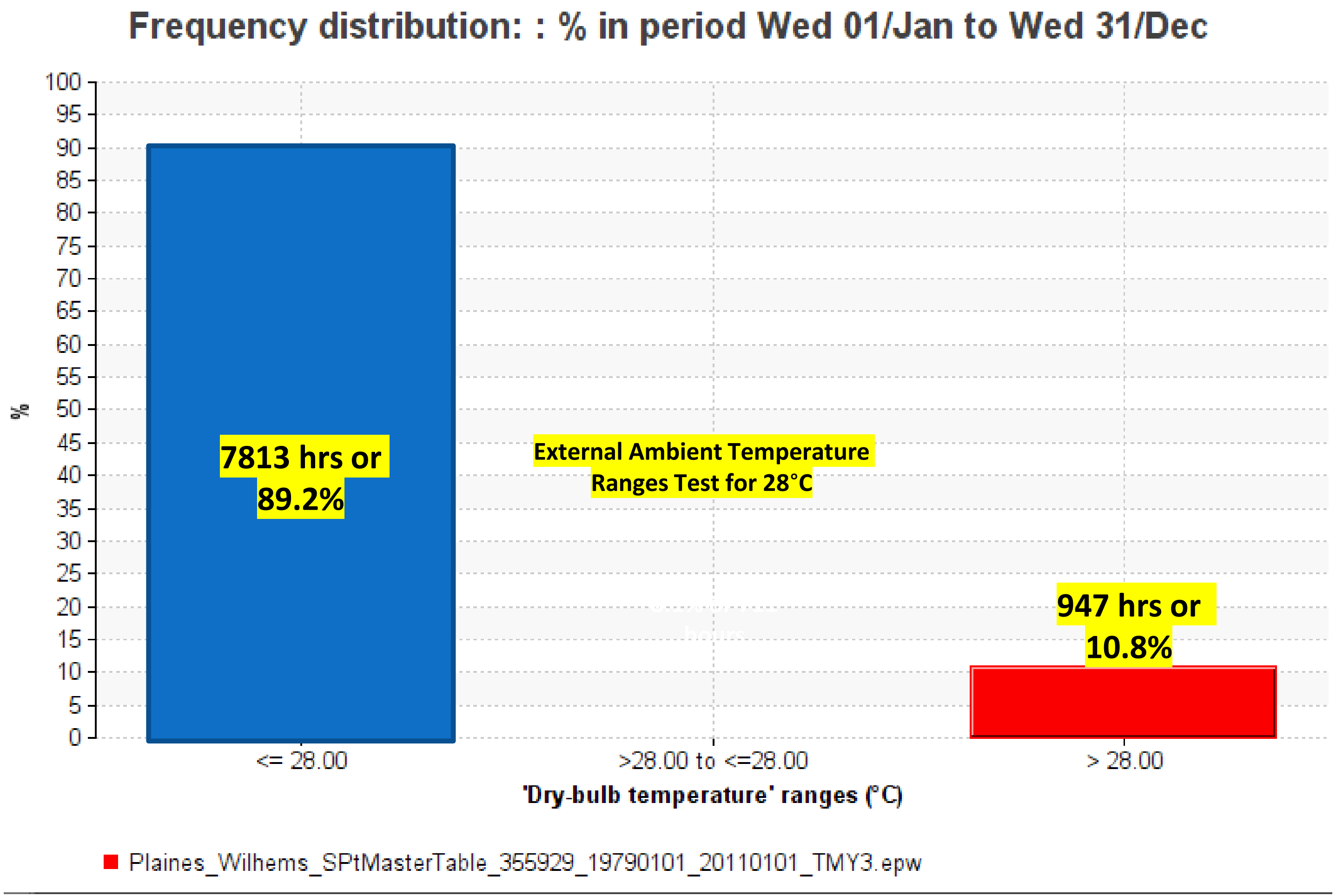


DECEMBER

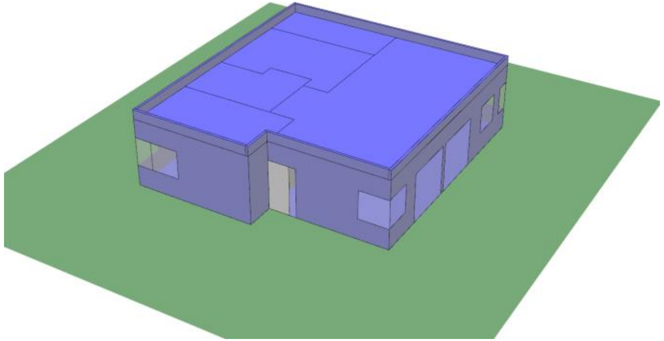
External Temperature Range test greater than & lesser than 24deg.C

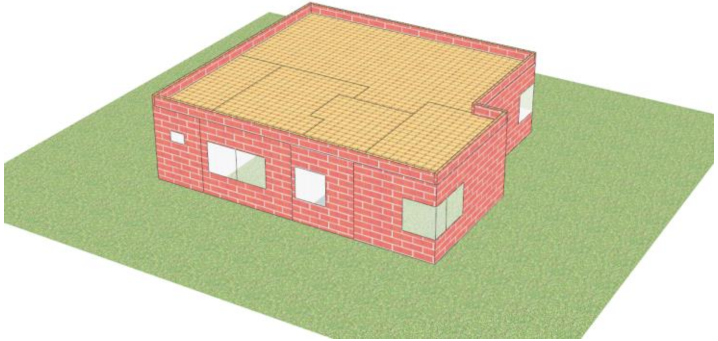


Ambient External Temperature Range test greater than & lesser than 28 °C



MODEL SNAPSHOTS





PROPOSED BUILDING – DATA CONSIDERED FOR SIMULATION

CONSTRUCTION PROPERTIES	*BASECASE(U VALUE)*	*OPTION 1(U VALUE)*	*OPTION 2(U VALUE)*
External Wall	**2.36**	**1.885**	**1.15**
Floor	**3.24**	**1.75**	**1.54**
Glass	**5.6**	**5.6**	**5.6**
Roof	**3.75**	**2.26**	**2.26**
Internal Partition	**2.37**	**1.64**	**1.64**

PROPOSED BUILDING – DATA CONSIDERED FOR SIMULATION

BASELINE - Construction Parameters

CONSTRUCTION PROPERTIES	
External Wall	200mm concrete Hollow blocks + 16mm plaster on inner and outer ends with ‘U’ value 2.36w/m2k
Floor	150mm Concrete Floor+10mm screed with ‘U’ value 3.24 w/m2k
Glass	U-value : 5.6 W/m^2K; SHGC:0.68 & VLT – 66%
Roof	150mm RCC +16mm plaster on inner and outer ends with ‘U’ Value 3.75w/ m2k
Internal Partition	150mm Concrete Floor +16mm plaster on inner and outer ends with ‘U’ Value 2.37 w/ m2k

PROPOSED BUILDING – DATA CONSIDERED FOR SIMULATION

OPTION1 - Construction Parameters

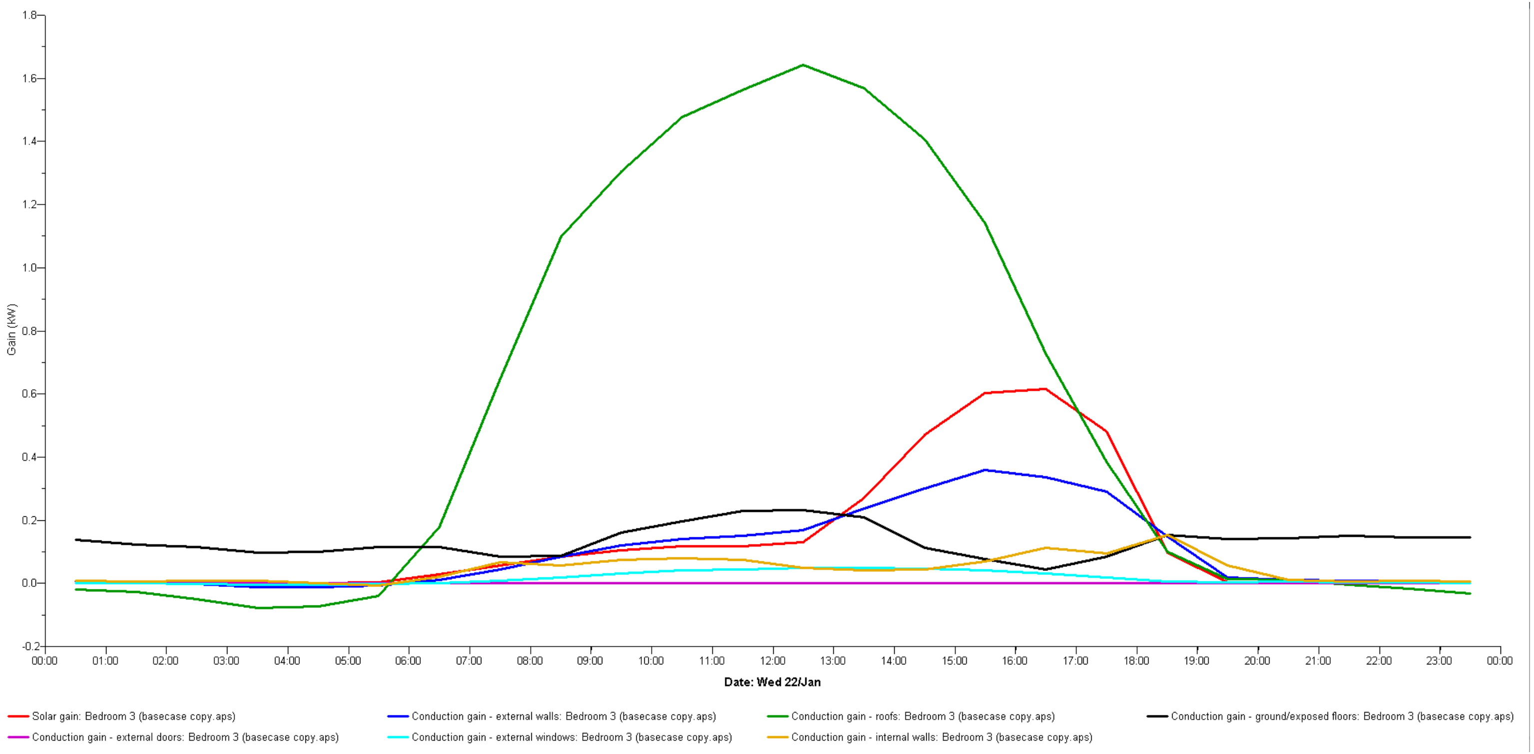
CONSTRUCTION PROPERTIES – PROPOSED FACILITY	
External Wall	14mm Fiber cement board + 10mm Glass wool Insulation with ‘U’ value 1.88w/m2k
Floor	14mm Fiber cement board + 10mm Glass wool Insulation with ‘U’ value 1.75w/m2k
Glass	U-value : 5.6 W/m^{2}K; SHGC:0.68 & VLT – 66%
Roof	Corrugated Iron sheet + 10mm Glass wool Insulation with ‘U’ Value 2.26 w/ m2k
Internal Partition	10mm Gypsum board +10mm Glass wool Insulation with ‘U’ value 1.64w/m2k

PROPOSED BUILDING – DATA CONSIDERED FOR SIMULATION

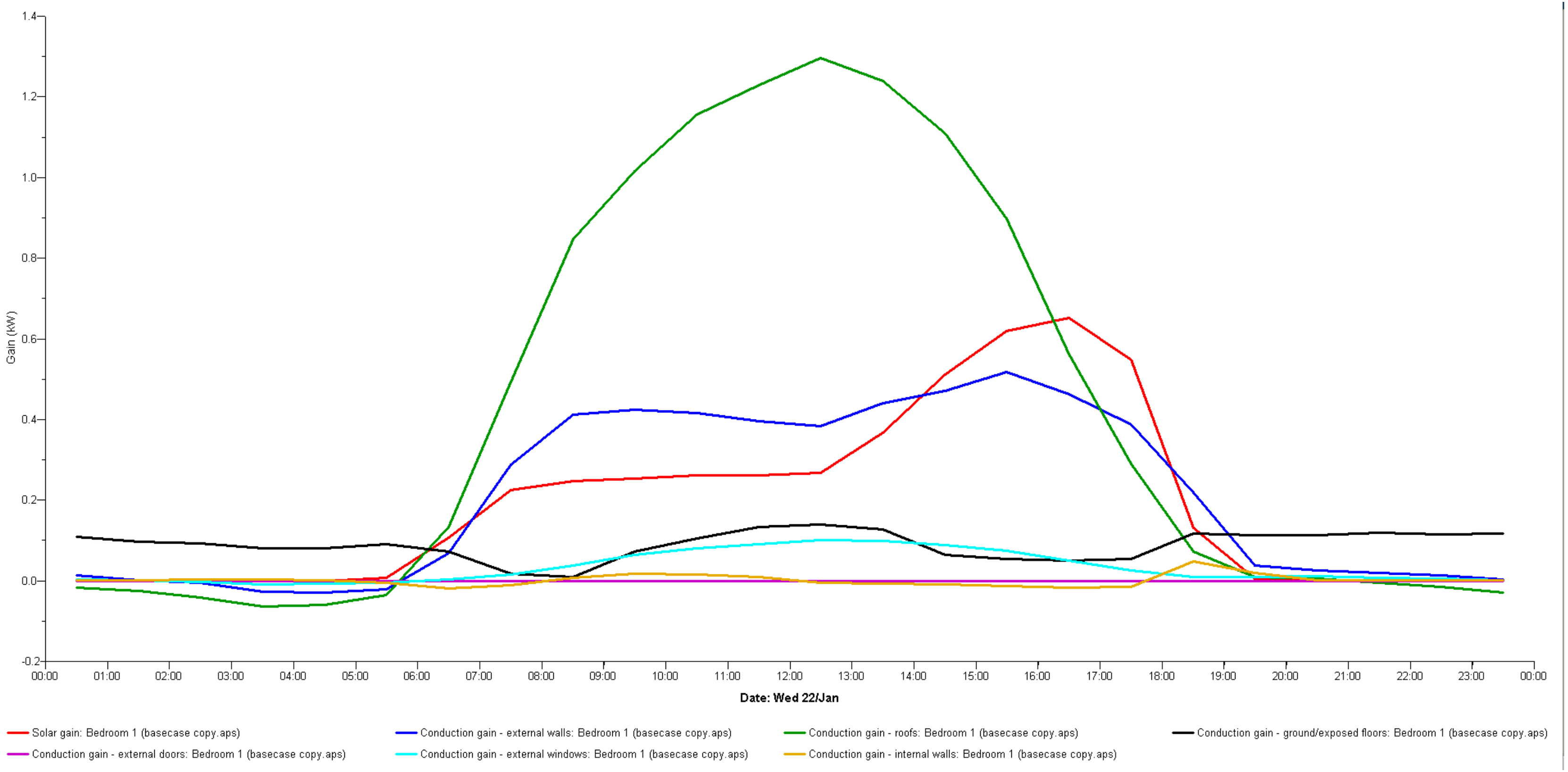
OPTION 2 - Construction Parameters

CONSTRUCTION PROPERTIES – PROPOSED FACILITY	
External Wall	10mm vinyl sliding + 12mm OSB board with 'U' value 1.15w/m2k
Floor	12mm OSB Board + 10mm Glass wool Insulation with 'U' value 1.54w/m2k
Glass	U-value : 5.6 W/m^2K; SHGC:0.68 & VLT – 66%
Roof	Corrugated Iron sheet+ 10mm Glass wool Insulation with 'U' Value 2.26 w/ m2k
Internal Partition	10mm Gypsum board +10mm Glass wool Insulation with 'U' value 1.64w/m2k

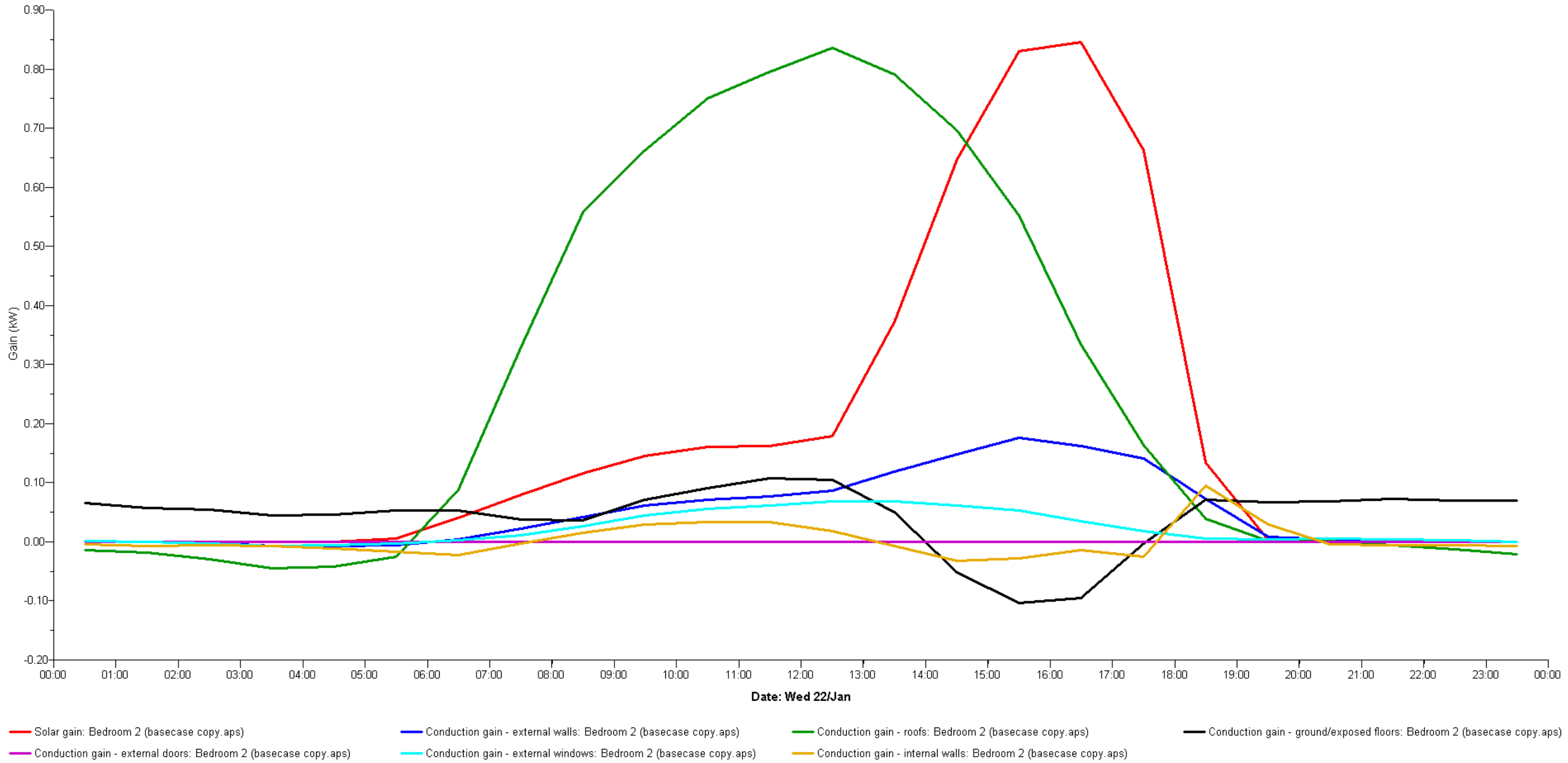
ANNUAL HEAT GAIN -MASTER BEDROOM



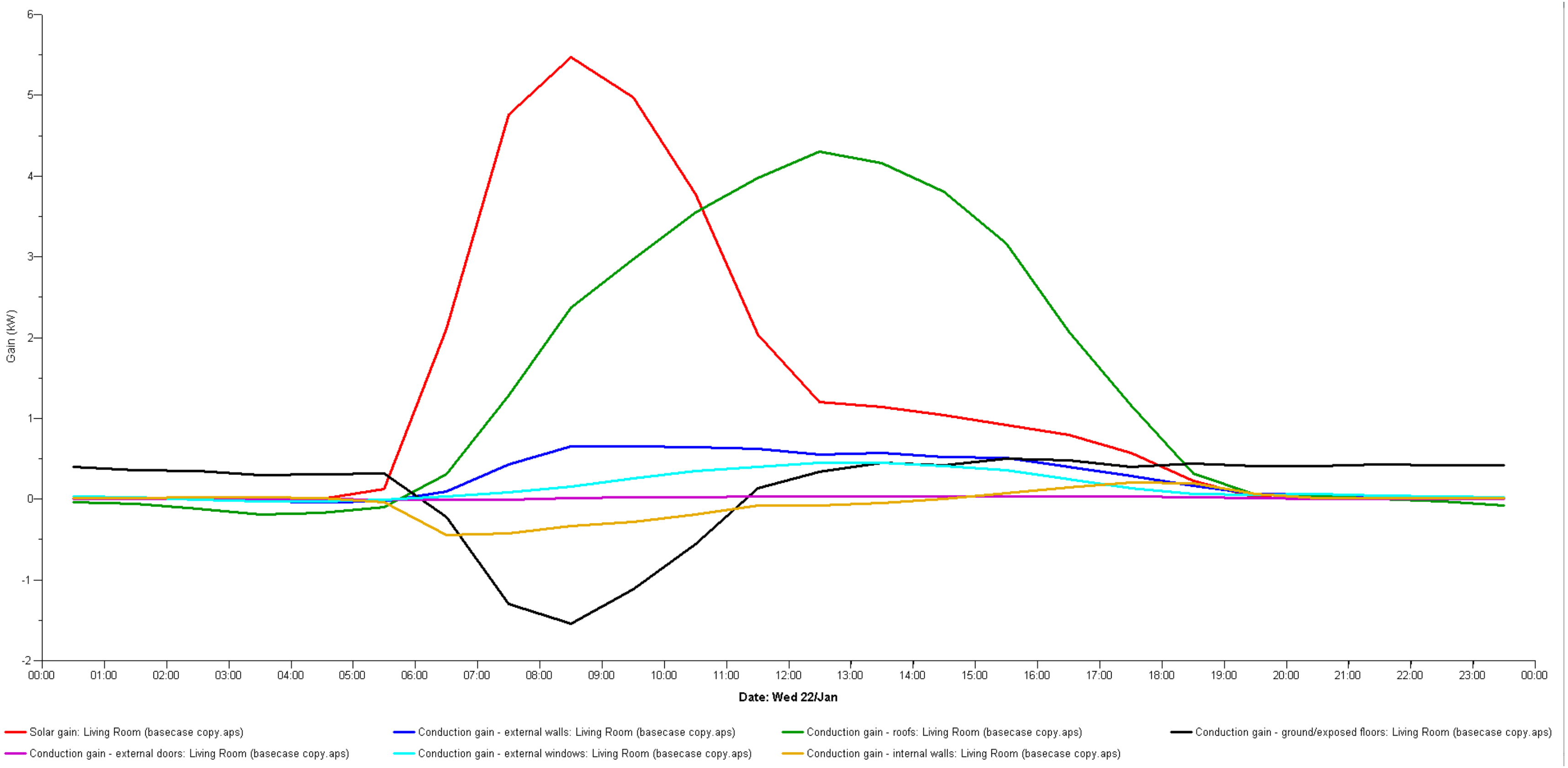
ANNUAL HEAT GAIN –BEDROOM 1



ANNUAL HEAT GAIN –BEDROOM 2

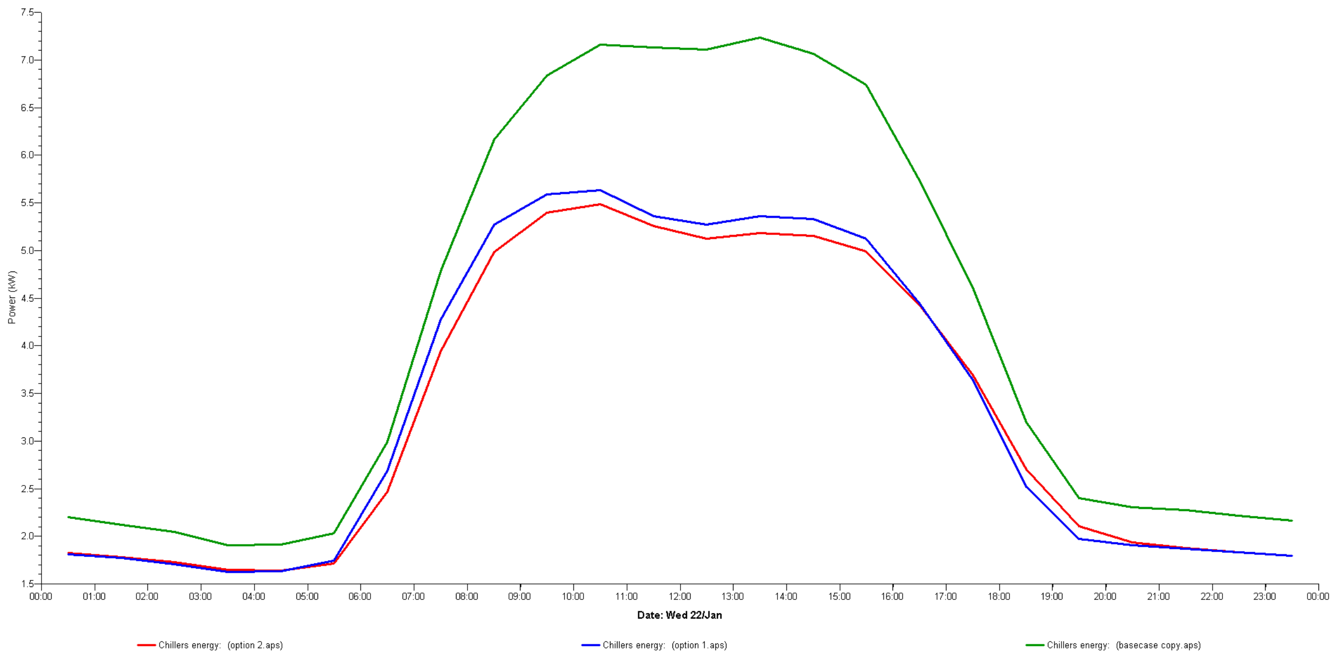


ANNUAL HEAT GAIN –LIVING AND DINING



TOTAL HEAT LOAD (kW)

	BASECASE	*OPTION 1*	*OPTION 2*
Total Heat Load (kW)	**18.07**	**13.39**	**12.96**



TOTAL ANNUAL ENERGY CONSUMPTION (MWh)

	BASECASE	*OPTION 1*	*OPTION 2*
Total Annual Energy Consumption(MWh)	**23.158**	**19.72**	**19.77**