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Master Thesis

Optimization of passive strategies towards animal welfare for livestock housing: A compost barn model in Brazil

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Dedicated to My Beloved Parents

ABSTRACT

Developing architectural passive techniques for the space can help to improve the environment's welfare and thermal conditions, whether it's outside or inside. However, the overall lack of research focusing on improving the comfort or welfare in the literature and, just a consideration of energy issues on the topic of passive strategies will affect animals negatively more than humans because most people do not prefer to use extra energy for animal comfort. This research aims to analyze micro-climate and design a barn model by using architectural passive strategies effectively in their living areas to improve animal comfort and welfare conditions and boost productivity as much as possible.

One of the design considerations was the local needs and desires and another one was some calculation methods such as sun azimuth and altitude, and wind to create optimal design solutions. So, the project has three main pillars to execute a proposal. Interviews with farmers, vets, and agricultural engineers were executed to understand the current view of the Minas Gerais agricultural activities, and livestock housing, and also to determine the applicable barn types in the region. Secondly, research has been carried out on animal welfare standards and suitable passive strategies from the literature. Thirdly, Ladybug and Honeybee projects were chosen since they were built on top of Rhinoceros, a sophisticated geometric modeler, and include several open source modules useful for map creations under the main purpose of creating microclimate analysis and finding comfort points for the proposal on the site. Subsequently, climate data had been provided by importing standard EnergyPlus Weather files (.epw) which is a US Department of Energy-validated engine that accommodates enough geometric detail of a building to assure that the resulting thermal metrics are accurate for microanalysis in Grasshopper, ladybug.

A compost barn's location was executed from those analyses. And, the design had been optimized for the location.

Keywords: passive strategies; animal welfare; thermal comfort; productivity; livestock housing; compost bedded pack barn; sustainable building; cow livestock

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List of Abbreviations

WHO	World Health Organization
FAWC	Farm Animal Welfare Council
FAO	Food and Agriculture Organization
NGO	World Animal Protection
UN	United Nations
OIE	World Organisation for Animal Health
BRE	Building Research Establishment
WQ	Welfare Quality
IBGE	Brazilian Institute of Geography and Statistics
CSR/UFMG	Brazilian Remote Sensing Center
BRL	Brazilian real (currency)
GDP	Gross domestic product
FW/FWS	Free-walk livestock housing systems
CB/CH	Cubical livestock housing systems
CV	Cross-ventilated free-stall barns
CBP	Compost-bedded pack barn
NV	Natural ventilated free-stall barn
UFLA	Universidade Federal de Lavras
Polito	Politecnico Di Torino
.epw	EnergyPlus Weather files
UTCI	Universal Thermal Climate Index

List of Symbols

R-value	The desired level of thermal resistance
°C	Celsius
°F	Fahrenheit

PART 1: THE RESEARCH

1. INTRODUCTION

1.1. Overview

Developing architectural passive techniques for the space can help to improve the environment's welfare and thermal conditions, whether it's outside or inside. However, the overall lack of research regarding not focusing on improving the comfort or welfare in the literature and, just a consideration of energy issues on the topic of passive strategies will going to affect animals negatively more than humans because most people do not want to use extra energy for animal comfort. This research aims to design and evaluate a barn model by using architectural passive strategies effectively to improve animal comfort and welfare conditions. The chapter will provide an introduction to the study by first discussing the background and context, followed by the research problem, the research aims, objectives and questions, the significance, and finally, the limitations.

1.2. Background of the study

Architectural passive strategies are built into the design of a building or a space to interact with natural elements like the sun and wind patterns on a site to offer natural heating, ventilation, and cooling of offers throughout the year to provide comfortable conditions around the space or inside buildings, the systems are mostly focused on decreasing energy demand (Scotland & Wales, 2018, published by BRE). There are researches in the literature that are just focusing on human comfort issues inside the buildings that do not seem very enough. However, the UN Recommendation was praised by the non-governmental organization World Animal Protection (NGO) as "ground-breaking" and "a tremendous step forward," as it was the first time in the UN's 71-year history that animal welfare was defined as a worldwide goal of sustainable agricultural policy and it can improve productivity. (Global Meat News, 2016). Under this approach, the livestock housing system plays a significant role in the health and well-being of cattle (Krunt et al., 2022) and also in the ecological footprint and consumer perception that influences sustainable agricultural production (Galama et al., 2020). For this purpose, the passive strategies can be a way to increase the health, welfare, and comfort of cattle with also contributing to production efficiency without extra energy.

1.3. Research problem

The population has been growing rapidly and it's affecting the needs. In 2009 Food and Agriculture Organization revealed that 2050 would require raising overall food production by %70 and this implies significant increases in the production of several key commodities. Annual meat production is expected by over 200 million tonnes to a total of 470 million tonnes in 2050. (FAO 2009). Increasing cow numbers is also fated to feed this population, but this means releasing more methane gas and increased usage of electricity and petrol that causes global warming so, improving the performance of agricultural products is an important issue without using any extra energy which causes global warming. According to this, passive strategies are critically important for improving the performance of the production. However, studies on passive strategies have traditionally focused just on energy issues in the buildings except for animals, comfort issues, or productivity. As a result, the existing research is inadequate for the welfare, comfort, or productivity issues of animals on passive strategies.

1.4. The research aims, objectives, and questions

Given the lack of research regarding livestock housing development under animal welfare, the goal of this study is to boost productivity as much as possible while simultaneously enhancing the cows' welfare and thermal conditions in their living areas.

1.4.1. Research questions

-What are the animal welfare standards especially in terms of livestock housing and what are their natural needs in the living space such as ventilation, and cooling?

-What are the passive strategies that can help design a barn in Brazil (tropical climate)?

- What is the current view of livestock housing, animal welfare, and production in Minas Gerais, Brazil?

- Which are the best barn types for improving animal welfare conditions in literature? and which one is suitable and applicable for the Minas Gerais from the eyes of farmers, vets, or agricultural engineers.

- What are the climate conditions in Lavras? How is it affecting the site under conditions of thermal comfort? What are the best locations for the proposal?

1.4.2. Objectives

-To determine the cow’s natural needs in the livestock housing and animal welfare standards from the literature.

-To determine applicable passive strategies for livestock housing and tropical climate.

-To make interviews with farmers, vets, and agricultural engineers in the Minas Gerais.

-Compare the information of literature with regional analysis to determine the most advantageous barn type option for the Lavras.

-To identify climate conditions and execute microclimate analysis on the thermal analysis with programs.

-Design a barn on the tropical climate (Minas Gerais, Lavras, Brazil).

1.5. Significance

The buildings are machines that people can control in a way to achieve their comfort zone but animals can not control them. The paper will improve the awareness of using those machines and enable the control methods to sustain production efficiency based on the animals' comfort zone and welfare standards for the agricultural activities in the industry. So, the paper leads us to achieve the animal needs in livestock housing for production efficiency by properly using architectural elements, strategies, and techniques which is a gap in the literature. Moreover, it is contributing to energy efficiency and helps reduce greenhouse gas emissions, on the other hand, the paper leads to improving the performance of the livestock housing for animals.

1.6. Limitations

The time of the study was 6 months and the limitation of the study was the lack of time to execute interviews and, use various programs for the thermal calculations. Moreover, Brazil had an emergency issue with the new coronavirus in this period, so finding people related to the subject within the time for an interview was a complication and, the people who were interviewed are limited. The study was executed in Brazil and consideration was on just for the tropical climates. The project may be a research subject for any climate and improved on. On the other hand, the data is figured out based on EPW climate data in this thesis. If climate data can be collected on the micro-climate by the researcher, the data can be more accurate.

1.7. Structural outline

Chapter 1: The overall context of the research has been introduced including the background of the study and context, followed by the research problem, the research aims, objectives and questions, the significance, and finally, the limitations.

Chapter 2: The literature will be examined to identify crucial findings regarding the livestock housing systems. The chapter covers the topics of the importance of livestock housing, compares the current housing systems, and also discusses compost barns and future development. Under the topic of compost barn models, welfare and satisfaction of the system and comparisons of compost barn models in different aspects are discussed. From the knowledge, a result section has been provided related to animal welfare and housing.

Chapter 3: The definition of animal welfare and the standards to provide welfare and comfort to the livestock are figured out in this section. Historical improvement and future development are discussed on the subject.

Chapter 4: In the chapter, architectural passive strategies are discussed and adapted under the condition of tropical climates. Starting with a definition and benefits of passive strategies, design techniques are figured out from the literature. Such as design parameters, solar control techniques, passive cooling and ventilation had been discussed.

Chapter 5: The method for the study is explained and the study location is defined in the section. This chapter is an introductory chapter for the methodology part.

Chapter 6: From the interviews and regional research, the importance of the cattle, an overview of the cattle business, types of production systems, and cattle housing in the region of Minas Gerais were discussed. Finally, a result section is placed to discuss the barn selected in Chapter 2, to detect if it is applicable or suitable in the region.

Chapter 7: The overall climate of the Lavras city was underlined and details of climate were provided under topics of clouds, precipitation, rainfall, sun, humidity, and wind. Microclimate analyses have been executed such as UTCI, incident radiation, direct sun hours, and wind focusing on especially hottest and coldest days of the Lavras. The result section is provided from the site microclimate analyses.

Chapter 8: Designed proposal executed in this section with details of planning, sections, elevations, and general decisions placed. The existing site and owner perspective are also explained in the section with photos and maps.

Chapter 9: In the section, the discussion and conclusion part is placed. Every chapter of this thesis includes its result part. So, in this chapter, the topics, main points of the research, the problems and the path followed, significance, results of the main points, limitations, recommendations, thoughts, and future expectations are discussed.

2. LITERATURE REVIEW

2.1. Importance of housing system in livestock

The housing system is one of the most important main factors which affects animal welfare and productivity of dairy cows and meat production performance by ensuring good quality of milk or meat and also considering animal priorities such as welfare (Kiełbasa et al., 2018) i.e. 'production which fulfills food security, environmental protection, economic and social needs in rural areas (FAO 2016).

2.2. Cattle housing systems and comparison

The cattle housing system can be categorized into two different sections to investigate based on the functions which are free walk housing systems (FW) and cubical housing systems (CB) (Galama et al., 2020; Benvenuti et al., 2018 et al). From the comparison between CB and FW based on animal welfare from literature, it is obvious that FW barn systems have improved cow comfort and welfare conditions. Blanco-Penedo et al (2020) investigate the basis of this assumption in free-walk housing systems (FWS) for dairy cows in Europe and they have conducted on 41 farms FWS and 20 cubicle housing (CH) from 6 European countries (Germany, the Netherlands, Italy, Austria, Slovenia, and Sweden) displaying a variety of management systems with scoring A total of 4,036 animals. They showed that FWS is an animal-friendly system even for European dairy farmers in a moderate climate, particularly for achieving improved cow comfort (Blanco-Penedo et al., 2020).

In cubicle systems such as tie-stall or free-stall, the animals have their stalls so, the interaction is less between animals and the space for cattle is generally lower to express their natural behaviors (Beaver et al., 2019) but, the most common advantage are cattle hygiene is greater than free walk systems (Biasato et al., 2019). Cubicle systems do not meet animal welfare in present and future demands (Bos et al., 2009), and free walk systems may also reduce footprints by comparing cubical systems so, they can provide better environmental control (Galama et al., 2020; Harner et al., 2007). On the other hand, in free walk systems, animals are free to show their natural behavior, the system made it easy for estrus recognition for cattle, and also it provides more space per animal, soft bedding, and free-roaming (Blanco-Penedo et al., 2020). Providing soft bedding is an important advantage to decrease the risk of foot and leg disorders, (Fulwider et al., 2007), and the system may also protect from poor udder health due to high exposure to environmental mastitis-causing by bacteria if a suitable bed can be provided (Fregonesi & Leaver, 2001) those represent majors of animal welfare problems for cattle housing.

2.3. Compost barn

Recent works show that those suitable beds can be provided in free walk systems to increase welfare by using compost in the bed. In this regard, the first compost barn was built-in Minnesota in late 2001 as an alternative free walk system to improve animal welfare conditions (Endres & Janni, 2019). Nowadays, farmers become interested in compost bedded pack barns which are increasing every passing year worldwide, especially since 2010 (Galama et al., 2012) likely the reasons can be to improve animal welfare and also lower the construction value of the system. Scientific research showed that animals are more comfortable than traditional systems. Cows in the compost barns presented a higher frequency of lying behavior (Black et al., 2014) and have healthier claws and legs likely due to the reduced hard surfaces and fewer injury-causing obstacles (Fulwider et al., 2007; Kester et al., 2014) which reduces medicines (von Keyserlingk et al., 2009). Moreover, composting barns can meet all realistic animal welfare requirements such as normal cow behavior, linked both to freedom of animal movement and secure footing (Woodford et al., n.d.).

2.3.1 Welfare and satisfaction of the system

Galama et al (2012) monitored and evaluated on sustainability aspects of a small group of three farms and discussed with 100 farmers looking for alternative housing systems for dairy cattle due to the problems in the free-stall system. The farmers are interested in improved animal welfare and economics. After the project, they agreed on the benefits of the compost barn system, and the main drivers for farmers to switch to bedded pack farms and participate in the process were the promised improved animal welfare with healthier cattle and less manure of better quality with little odor emission (Galama et al., 2012).

Leso et al (2013) studied the herd performance of cows with an observational study performed on 10 dairy farms in Italy. Each farm was visited once between July and September 2012 to collect on-site data. Results obtained in this survey confirmed that animal density is a key factor in compost-bedded pack barns and the producers identified animal welfare as the main benefit of this system and overall they appeared to be very satisfied (Leso et al., 2013).

Black et al (2013) have characterized herd performance, producer satisfaction and recommendations, and management practices used by compost bedded pack managers by visiting 42 farms and 47 compost barn facilities between October 2010 and March 2011. Of the 42 producers, 41 responded that they were satisfied with their compost barn facilities and 1 responded he was somewhat satisfied. Most producers cited increased cow comfort as a benefit to the compost barn system (n = 28). Others cited increased cow cleanliness (n = 14), the low maintenance nature of the system (n = 10), and the barn's usefulness for special needs and problem cows (n = 10). Additional cited benefits included (n = 1) lower bedding cost, cleaner pastures, lower investment cost, fewer odors, and fewer flies (Black et al., 2013).

2.3.2. Ventilation

Ventilation is one of the most important issues in the compost barn systems, especially in tropical climates and the farmers should consider the possibility of improving the compost barn ventilation system. Heat stress affects dairy cattle's productive and reproductive performances because cows react to high air temperature and humidity conditions by reducing their lying time, which negatively affects milk production (Lovarelli et al., 2020). Even in moderate climatic regions, heat stress is an important issue that affects productivity and reproduction (Hahn, 1981). Hempel et al (2019) monitored three reference barns in central Europe and the Mediterranean regions to take main measures to improve livestock's ability to cope with heat increasing (climate change impacts on animal welfare). They found from their research that with increasing heat stress risk, milk yield may decrease by about 2.8% relative to the present European milk yield, and farmers may expect financial losses in the summer season of about 5.4% of their monthly income (Hempel et al., 2019). In another resource, Vieira et al (2021) investigated whether spatial variability occurs in the thermal environment of a compost barn and how the behavior of dairy cows with different numbers of lactations differs in this system in the southwestern region of Paraná State, Brazil (tropical climate). From their resouches, the most important output was the compost barn system regarding air and bedding temperature, as well as wind speed, indicating the inefficiency of ventilation management in the facility so, special attention must be given to environmental control in a compost barn(Vieira et al., 2021). According to those resources, understanding compost barn ventilation systems is a very important subject to increase productivity, especially in the tropical climate such as Minas Gerais.

2.3.3. Comparisons of compost barn models in different aspects

Yameogo et al (2021) compared two barn solutions. One barn (CBP A) is closed and applies a wind tunnel ventilation (negative pressure). A second barn (CBP B) is open with natural ventilation, without curtains on the sides, and has fans placed in the resting area in Minas Gerais State (Brazil) with two different dairy barns in the winter season (July 7 – August 6, 2019) under air temperature and relative humidity, and consequently temperature and Humidity Index (THI). The cows were in thermal comfort conditions in both situations but THI in CBP A is significantly higher than in CBP B during the night and early morning (between 9 p.m. and 7 a.m.) while during the day (between 10 a.m. and 7 p.m.) THI in CBP A remains significantly lower than in CBP B (Yameogo et al., 2021).

Valente et al (2020) compared a closed-side shed with negative pressure ventilation (CBF) and an open shed with natural ventilation system (CBA) to analyze which compost barn system has an advantage under animal welfare conditions in Minas Gerais (Brazil) with using THI to measure animal comfort. Both THI values have in the normal range and it shows that using both compost barn models would be suitable for tropical climates (Valente et al., 2020). In this regard, designing with natural ventilation will be an important aspect of the sustainability of the compost barn model and it is another aspect to reduce closed shed areas to decrease maintenance and construction prices (Valente et al., 2020).

Lobeck et al (2011) have investigated animal welfare in 2 newer dairy housing options in the upper Midwest(US), cross-ventilated free-stall barns (CV) and compost-bedded-pack barns (CBP), compared with conventional, naturally ventilated free-stall barns (NV). The study was conducted on 18 commercial dairy farms, 6 of each housing type to investigate the relationship between housing options and the welfare of dairy cattle. Locomotion, hock lesions, body condition score, hygiene, respiration rates, mortality, and mastitis prevalence have been collected on each farm. The CV and NV barns were evaluated using the cow comfort index and the stall usage index. The CV barns tended to have a greater cow comfort index (85.9%) than the NV barns (81.4%) and had a greater stall usage index. Mean hygiene scores were 3.18, 2.83, and 2.77 for CBP, CV, NV barns, and Lameness prevalence was lower in CBP (4.4%) than in CV. Compost-bedded barns had a lower prevalence of Hock Lesions (3.8%) than CV and NV barns. On the other hand, they found no differences in Body Conditions among housing systems (Lobeck et al., 2011).

Andrade et al (2020) evaluated and compared lighting and noise levels in an open compost barn with natural ventilation and in a closed compost barn with a climate control system during August 2019. They found that the artificial lighting system distributed throughout the closed barn was not sufficient to maintain brightness within the recommended range for lactating cows and the sound pressure amplitude inside the barn with a climate control system was greater than in the open barn (Andrade et al., 2020).

2.4. Future development

Galama et al (2020) had reviewed to describe recent changes and expected developments in dairy cow housing systems based on animal welfare which they believed is the main driver of future housing systems and being aware of conflicts is important. According to their research, housing systems can affect through 4 different routes " (1) improved production efficiency and healthier cows, resulting in more milk per cow with a lower carbon footprint; that is, fewer emissions;(2) innovative floor types and storage of manure solids (feces) and liquids (urine), such as floors separating feces and urine or floors with bedding material in FW systems working as a biofilter; (3) delivery of a manure product that works as a soil improver (carbon sequestration); and (4) fewer young stock, as better animal health reduces the frequency of stock replacement." (Galama et al., 2020). Design solution based on a combination of CB and FW can be an answer to provide their needs.

2.5. Result

A housing system based on FW was selected due to the recent research that has shown that free walk systems have more advantages for cattle welfare than cubicle systems which was the main focus of the project. On the other hand, researches show that the compost barn livestock housing model is the most effective system which guards animal welfare standards.

3. ANIMAL WELFARE

Welfare generally refers to "the quality of an animal's life which is the physical and mental state of an animal until it dies (OIE, 2017). In a 1965 Brambell report, they published "Five Freedoms" to create standards for animal welfare for the first time. According to the Five Freedoms, an animal experiences good welfare when they have sufficient nutrition, provide mental and physical comfort, and express their normal behavior, keeping away from pain, injury, or diseases that are important for their physical and mental state. However, researches show that the Five Freedoms are not enough (McCulloch, 2013; Mellor, 2017) precise to be used as a basis for the assessment of the animal welfare of a particular animal (Broom, 2017) so, researchers worked on the Five Freedoms after 1965 to improve the standards in a more specific and proper way such as disease prevention and appropriate veterinary care, shelter, management and nutrition, a stimulating and safe environment, humane handling, and humane slaughter or killing while animal welfare also refers to the state of the animal, the treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane slaughter (Keeling et al., 2019). OIE is one of the most important institutions that worked on the welfare of terrestrial animals including the 'Five Freedoms' to improve those standards which also have several aspects related to directly animals' environment and livestock housing such as providing thermal comfort, letting them express their normal behavior, or designing the necessary environment to keep them away from injuries and diseases (OIE(Global animal welfares strategy, 2017). The first definition of animal welfare is expanded and the description or scope is improved and specialized with starting their born to until dying researchers. So, one of the best animal welfare definitions and its scope definition is defined by OIE more properly and comprehensively at present.

3.1. Importance

Sustainable development is getting more important every year by the communities, institutions, governments, and also people. One of the important subjects related to sustainability is animal welfare which is acknowledged by institutions such as the Food and Agriculture Organization (FAO), the World Organization for Animal Health (OIE), and the World Health Organization (WHO) conceded in 2010 to arrange global activities and share responsibilities (*FAO: WHO*, 2010). On 17 October 2016, the UN Committee on World Food Security proposed draft recommendations on sustainable agricultural development for food security and nutrition including the role of livestock (UN & FAO, 2016). Recommendation

"D" of Article VIII, entitled "Animal health and welfare" reads: "Improve animal welfare delivering on the five freedoms and related OIE standards and principles, including through capacity building programs, and supporting voluntary actions in the livestock sector to improve animal welfare". From the perspective of the World Organization for Animal Health (OIE), animal welfare is key to improving production, quality, food safety, and economic returns in the food production system so, there are direct or indirect relationships on financial impact which helps to reduce poverty and not only with improving production and productivity but also on new, "societally important" traits such as disease resistance, and reducing environmental impact (Kanis et al., 2005). People's willingness to pay also reflects beliefs about these attributes (Edwards, 2005; Grunert et al., 2004). There has been a growing focus on 'demand-side' solutions, especially on improving animal welfare through stimulating 'demand' for high-welfare products (Lawrence & Stott, 2009).

3.2. Welfare standards

Those standards are improved by different organizations, researchers, and institutions to find the correct way to improve animal welfare. The standards are useful to improve animal comfort and also productivity.

3.2.1. Basic standards by Brumbel report (FAWC)

Starting in 1965 Brambell's report stated that animals should have the freedom "to stand up, lie down, turn around, groom themselves and stretch their limbs." These freedoms became known as "Brambell's Five Freedoms" and were expanded on to create a more detailed list of the needs in time. The Farm Animal Welfare Advisory Committee was created in response to Brambell and colleagues' report to monitor the livestock production sector. In 1979, the name was changed to the Farm Animal Welfare Council (FAWC) and by the end of that same year, the initial Five Freedoms had been codified into the format below (McCulloch, 2013);

1. Freedom from Hunger and Thirst: by ready access to fresh water and a diet to maintain full health and vigor.
2. Freedom from Discomfort: by providing an appropriate environment including shelter and a comfortable resting area.
3. Freedom from Pain, Injury, or Disease: by prevention or rapid diagnosis and treatment

4. Freedom to Express Normal Behavior: by providing sufficient space, proper facilities, and the company of the animal.
5. Freedom from Fear and Distress: by ensuring conditions and treatment which avoid mental suffering.

3.2.2. Standards by Welfare Quality®

Welfare Quality® is a European research project focusing on the integration of animal welfare in the food quality chain. The project aims to accommodate societal concerns and market demands and to develop reliable on-farm monitoring systems, product information systems, and practical species-specific strategies to improve farm animal welfare (*Welfare Quality Network | Home*, 2022).

Principles and criteria of good Animal Welfare;

1. Animals should not suffer from prolonged hunger, i.e. they should have a sufficient and appropriate diet.
2. Animals should not suffer from prolonged thirst, i.e. they should have a sufficient and accessible water supply.
3. Animals should have comfort around resting.
4. Animals should have thermal comfort, i.e. they should neither be too hot nor too cold.
5. Animals should have enough space to be able to move around freely.
6. Animals should be free of physical injuries.
7. Animals should be free of disease, i.e. farmers should maintain high standards of hygiene and care.
8. Animals should not suffer pain induced by inappropriate management, handling, slaughter, or surgical procedures (e.g. castration, dehorning).
9. Animals should be able to express normal, non-harmful, social behaviors, e.g. grooming.
10. Animals should be able to express other normal behaviors, i.e. it should be possible to express species-specific natural behaviors such as foraging.
11. Animals should be handled well in all situations, i.e. handlers should promote good human-animal relationships.

12. Negative emotions such as fear, distress, frustration, or apathy should be avoided whereas positive emotions such as security or contentment should be promoted.

3.2.3. Standards by World Organisation for Animal Health

The OIE also used the Brumbel report as a reference and improved it in a more specific and detailed way by adding new important aspects. İt is a unique global intergovernmental organization in charge of intergovernmental standard-setting in the field of animal welfare. Animal health is an essential component of animal welfare. In the absence of a global normative framework to promote animal welfare and at the request of its Members, the World Organisation for Animal Health (OIE) has been developing international standards in this field since the early 2000s. These standards are, like all OIE international standards, science-based and adopted by consensus by all OIE Member Countries (*World Organisation for Animal Health*, 2022).

Animal welfare has been defined by OIE as:

"Animal welfare means the physical and mental state of an animal about the conditions in which it lives and dies. An animal experiences good welfare if the animal is healthy, comfortable, well-nourished, safe, is not suffering from unpleasant states such as pain, fear, and distress, and can express behaviors that are important for its physical and mental state. Good animal welfare requires disease prevention and appropriate veterinary care, shelter, management and nutrition, a stimulating and safe environment, humane handling, and humane slaughter or killing. While animal welfare refers to the state of the animal, the treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment. " (Chapter 7.1)

OIE principles for the welfare of animals in livestock production systems:

1. Genetic selection should always take into account the health and welfare of animals.
2. Animals chosen for introduction into new environments should be suited to the local climate and able to adapt to local diseases, parasites, and nutrition.
3. The physical environment, including the substrate (walking surface, resting surface, etc.), should be suited to the species to minimize the risk of injury and transmission of diseases or parasites to animals.

4. The physical environment should allow comfortable resting, safe and comfortable movement including normal postural changes, and the opportunity to perform types of natural behavior that animals are motivated to perform.
5. Social grouping of animals should be managed to allow positive social behavior and minimize injury, distress, and chronic fear.
6. For housed animals, air quality, temperature, and humidity should support good animal health and not be aversive. Where extreme conditions occur, animals should not be prevented from using their natural methods of thermo-regulation.
7. Animals should have access to sufficient feed and water, suited to the animals' age and need, to maintain normal health and productivity and prevent prolonged hunger, thirst, malnutrition, or dehydration.
8. Diseases and parasites should be prevented and controlled as much as possible through good management practices. Animals with serious health problems should be isolated and treated promptly or killed humanely if treatment is not feasible or recovery is unlikely.
9. Where painful procedures cannot be avoided, the resulting pain should be managed to the extent that available methods allow.
10. The handling of animals should foster a positive relationship between humans and animals and should not cause injury, panic, lasting fear, or avoidable stress.
11. Owners and handlers should have sufficient skill and knowledge to ensure that animals are treated by these principles.

Those are just principles that affect animal welfare under livestock housing systems but OIE also defined animal welfare standards in a more general perspective including animal transport, killing for disease control purposes, slaughter and killing for human consumption, animal production systems, and even use of animals in research and education (*World Organisation for Animal Health*, 2022).

3.3. Future development

Animal welfare may be a new subject it started in 1965 in Brambell's report but every passing year the importance of the subject is growing. Keyserlingk and Weary (2017) studied the history and development of the animal welfare area as reflected in the 100 years and they published a chart which is showing that resources are increasing every passing year related to the topic. They also evaluated the future of cattle welfare as short, medium, and long term. In the short term, they believe that the effectiveness and efficiency of social housing for animals will improve based on the dairy industry implementing proven science-based solutions in 10 years from the side of the livestock housing (von Keyserlingk & Weary, 2017). Moreover, the subjects still need to be improved to work on global livestock production, animal welfare science, and policy or adaptation of climate change to find a new holistic approach to stabilize continuingly robust and objective welfare science in the future (Buller et al., 2018).

3.4. Result

From the research output, the important aspects are underlined for the proposed decisions. On compost bedded pack barn systems, bigger space must be provided for animals so, physically, socially, and logistically creating an easy adequate exercise and natural behavior as well as for eating, drinking, defecating, and urinating. Secondly, the bedded pack barns' bedding material is soft and provides a trip without any injuries, lesions, or ailments. Thirdly, the bed is soft and provides much physical space so, animals can experience much rest, which reduces the burden on joints and claws. Fourth, Allows for good social contact within the herd because cows are free to move and not tie into the system. But, ventilation systems figured out mostly insufficient in these systems. So, a well-ventilated, open, and large-volume bedded pack barn may ensure acceptable air quality.

4. PASSIVE STRATEGIES FOR TROPICAL CLIMATE

4.1. What are passive strategies?

Passive strategies are integrated into the design of a building or a space to work with natural elements such as sun and wind patterns on a site to provide natural heating, ventilation, or cooling of spaces through different seasons to create comfortable conditions inside buildings.

According to Building Research Establishment (BRE);

"Passive design uses layout, fabric, and form to reduce or remove mechanical cooling, heating, ventilation, and lighting demand. Examples of passive design include optimizing spatial planning and orientation to control solar gains and maximize daylighting, manipulating the building form and fabric to facilitate natural ventilation strategies, and making effective use of thermal mass to help reduce peak internal temperatures." (Scotland & Wales, 2018, published by BRE)

Passive strategies can be categorized under 3 main sections by use;

1. Passive heating.
2. Passive cooling (focused).
3. Passive ventilation (focused).

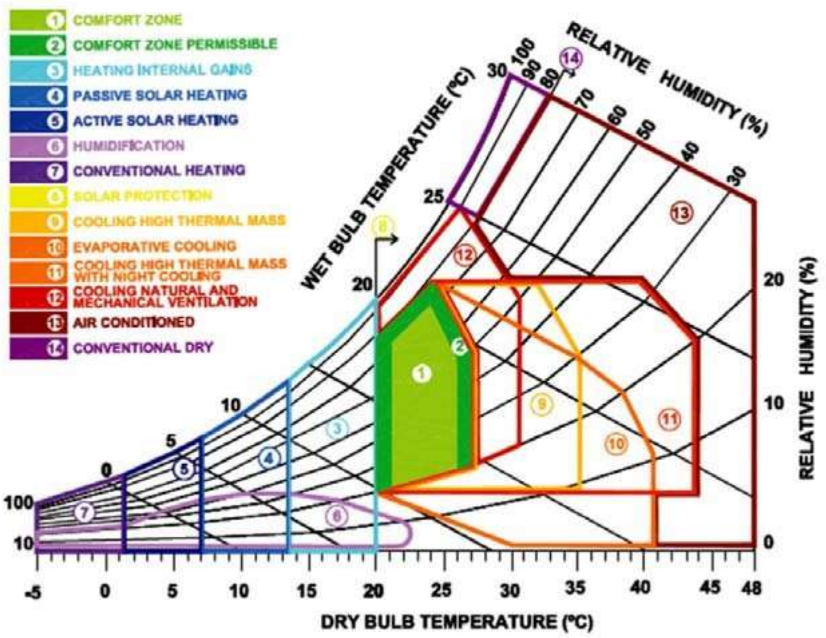


Figure 4.1. Psychrometric Chart (Givoni,1992)

Strategies can be complicated further by different climates, changing seasons, or from day to night, so it may allow the use of different logic of operation techniques. A strategy sometimes can reject the solar radiation to not heat the space, and sometimes it can take it in if it is necessary or even capture external inputs and retain internal conditions. The kind, for example, is primarily determined by temperature and humidity. The winters in Scotland necessitate passive heating strategies, whereas the summers in Brazil necessitate passive cooling strategies. Some portions of India, for example, require both heating and cooling systems. When constructing a project in a tropical climate, ventilation, and cooling are the most important factors to consider. It can also vary by region, and even microclimate can influence overall strategy. (Passive Building Design, 2022).

4.2. Benefits

To give comfort in the area, passive solutions do not use any additional energy sources such as electrical systems or gas. The internal environment is controlled by external factors such as solar radiation, cool night air, and air pressure changes. These tactics will maximize the amount of energy gained while minimizing the amount of energy lost. It will ensure efficiency while still maintaining comfort (Otricelli, 2016). It reduces temperature fluctuations, improves indoor air quality, and makes a space drier and more enjoyable to live in. It can also reduce energy use and environmental impacts such as greenhouse gas emissions which creates a sustainable approach.

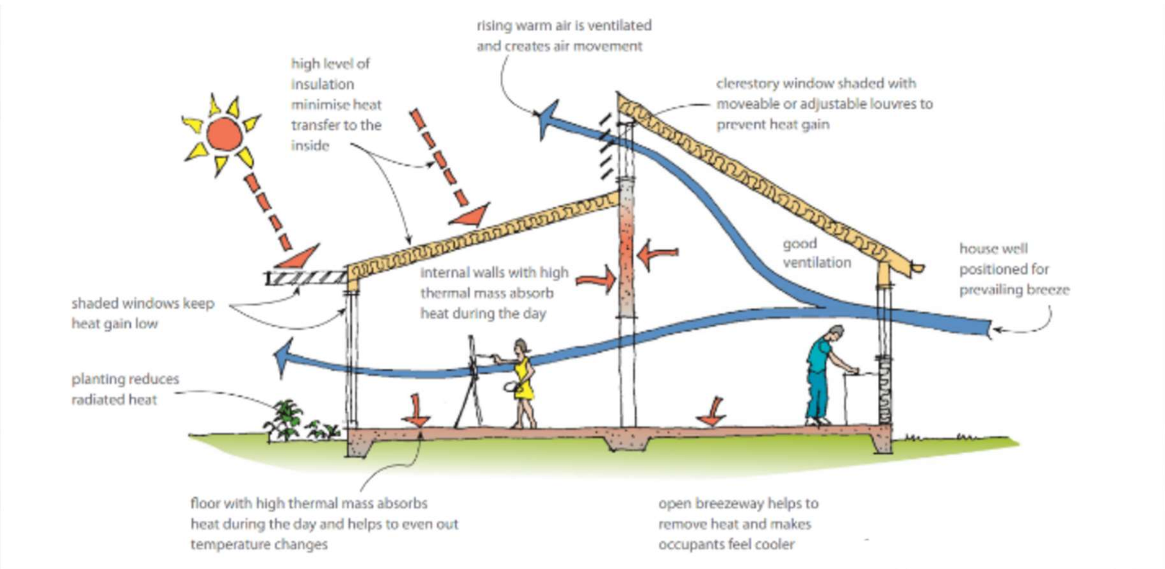


Figure 4.2. Passive design example chart (Archi-Monarch, 2020)

4.3. Passive design parameters

The passive design generally includes consideration of location, orientation, building form, shading, landscape, material selection, thermal mass, insulation, internal layout, building envelope, and also the position of openings (*Passive Building Design*, 2022). Orientation, layout, and location on site will all influence the amount of sun a building receives and therefore its year-round temperatures and comfort. Where passive cooling is more of a priority than passive heating such as in Minas Gerais climate (tropical), the building should be oriented to take advantage of prevailing breezes. Orientation, location, and form should be considered from the beginning of the design process. Once a building has been completed, it is impractical and expensive to reorient later.

4.3.1. Building form

The airflow pattern surrounding the building is determined by the architectural form, which has a direct impact on ventilation. Furthermore, the volume of space inside a building that needs to be heated or cooled is determined by the building form. The less wasteful it is to gain and lose heat, the more compact the shape is. To prevent heat intake and loss in hot and dry regions and cold climates, the building's design must be compact. In tropical climates, however, a compact shape is not required. In tropical regions, airflow is the most significant consideration when choosing a building form.

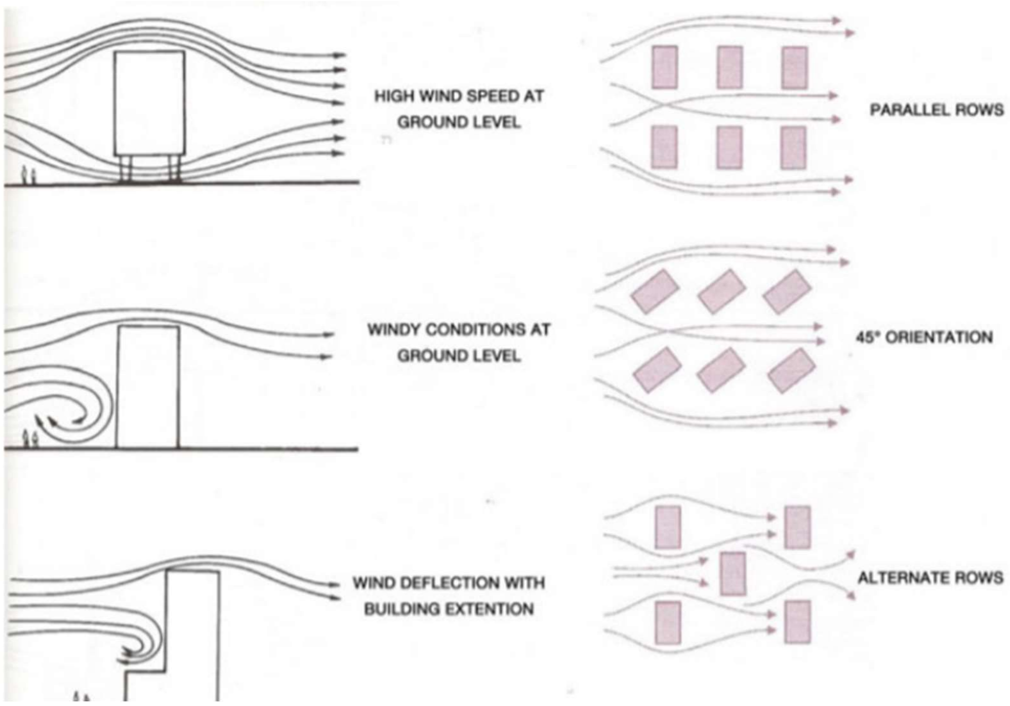


Figure 4.3. The massing of building blocks influence wind pattern (Pedata,2011)

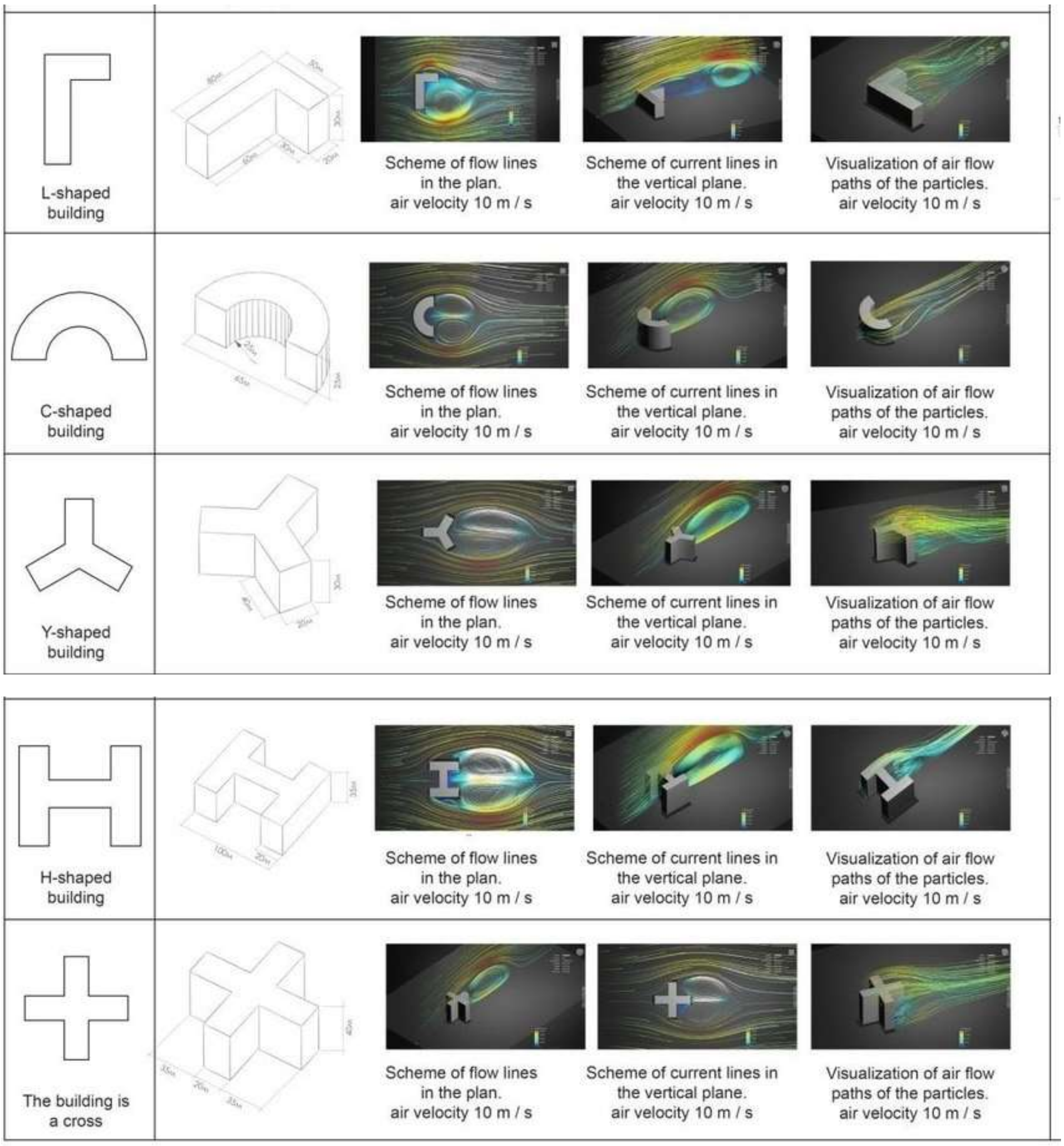
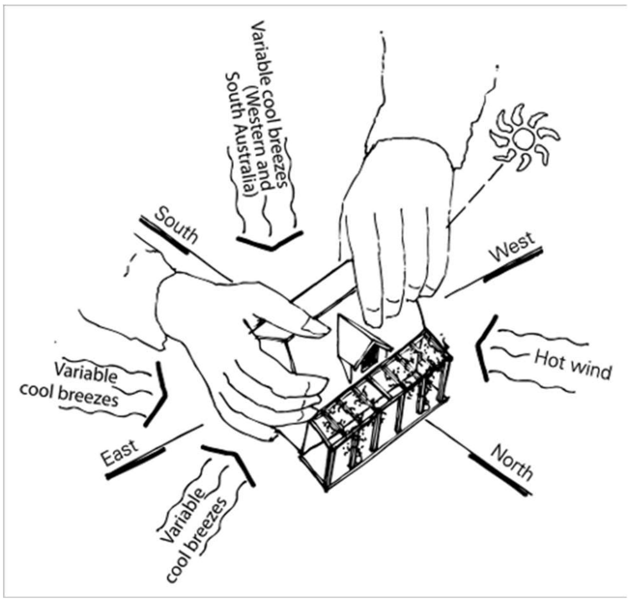


Figure 4.4. Airflow around the most common forms of buildings (A-Kazurov,2019)

Building form must allow wind to come inside, roam the inside easily, and block the sun in tropical climates.

4.3.2. Orientation

Orientation is the positioning of a building about seasonal variations in the sun's path as well as prevailing wind patterns. This is one of the first steps in managing the sun and wind. It accounts for differences in the sun's path between summer and winter and the direction and kind of winds, such as cooling breezes. However, orienting a home on a site to minimize sun exposure needs to be weighed with capturing the wind.



As indicated, orientation techniques can be adjusted based on the location, but the major focus will be on deciding on the action before the project, such as receiving solar radiation or not (heating) or using wind direction (cooling or ventilation) depending on the day to night, climate, or site. On the other hand, local climate research should study to achieve the optimal direction (archi-monarch, 2020):

Figure 4.5. Orientation chart (Archi-Monarch,2020)

• seasonal and daily temperature variations (day-night).

• humidity levels

• refreshing breezes, hot winds, cold winds, and damp winds.

• features of the season, including extremes

• the influence of geographical factors on climatic conditions.

• the impact of nearby structures and the current landscape

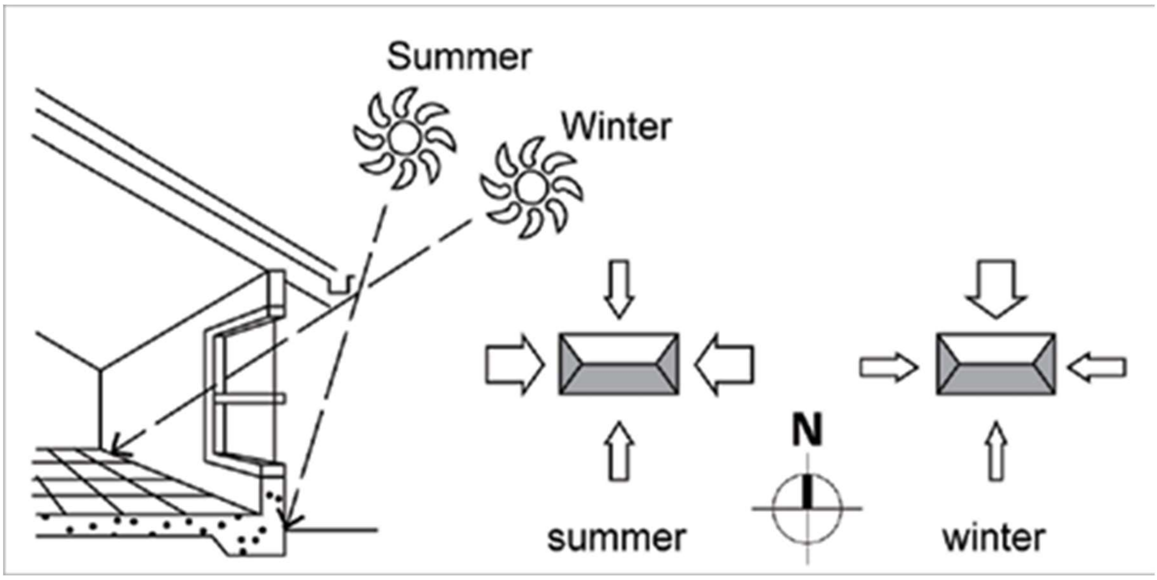


Figure 4.6. Orientation chart (Archi-Monarch,2020)

4.3.3. Building location and site

The optimal location for the solar barrier will vary based on the site form, orientation, topography, and shading from trees and other structures (or future buildings). Other factors such as views, wind, topography, and the location of trees and neighboring buildings will also influence a building's location on the site. In tropical areas, northerly solar access is not desirable: sites that allow maximum exposure to cooling breezes and designs that draw or funnel them through the building are preferable. The low sun angle can be shielded by nearby houses. On narrow blocks, however, careful planning is essential to ensure enough passive solar cooling or ventilation ('Form and Orientation', 2022).

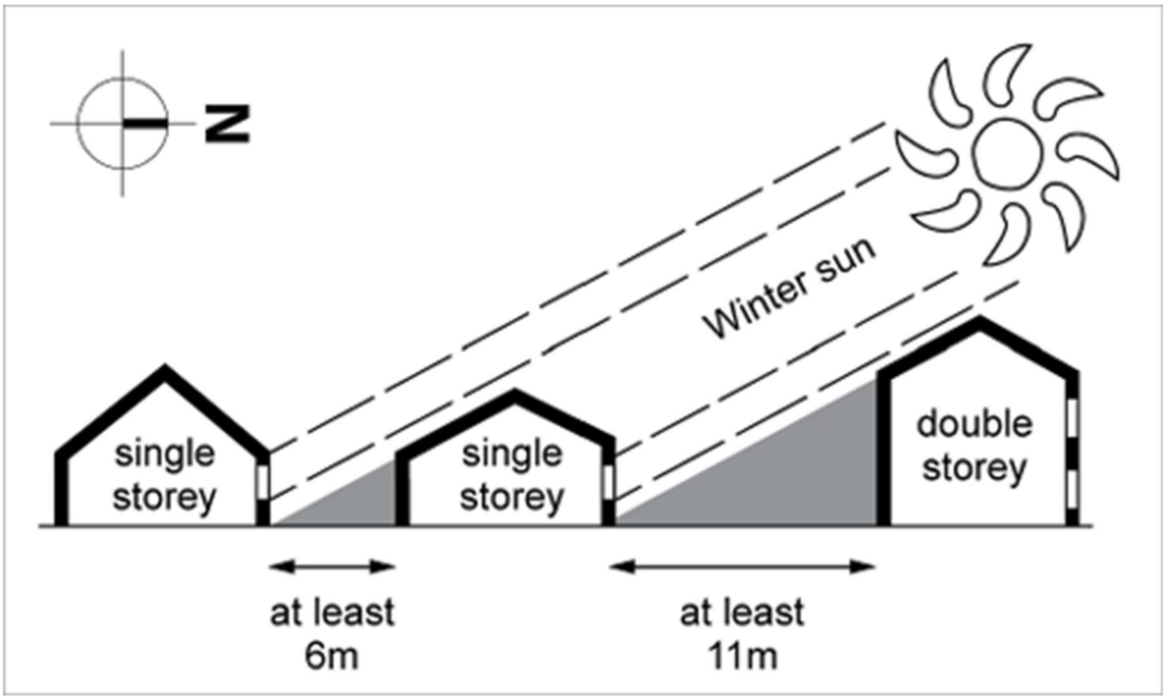


Figure 4.7. Neighborhood effects on location chart (Archi-Monarch,2020)

A south-facing slope increases the potential for access to the northern sun and a north-facing slope increases the potential for overshadowing. Design for not solar access should compromise that of your neighbors or select of location as explained to block solar radiation.

4.3.4. Building envelope

The building envelope is a physical divider between the conditioned and unconditioned environments of a building that includes the resistance to air, wind, water, heat, light, and noise transfer (Wikipedia,2022).

Figure 4.8. Simple Building Envelope (Iko, 2022)

For example, the material on the roof that faces the sun and their roof thermal design will let the sun come under the roof (high conductivity) which situation will help to heat the space in the summertime or tropical climate as we don't prefer.

4.3.4.1. Thermal mass

Thermal mass is a key component of passive solar architecture because it can receive, store, and release heat energy from the sun. Its density and conductivity serve to keep a building's internal temperature consistent. Thermal mass objects have inherent properties for both heating and cooling.

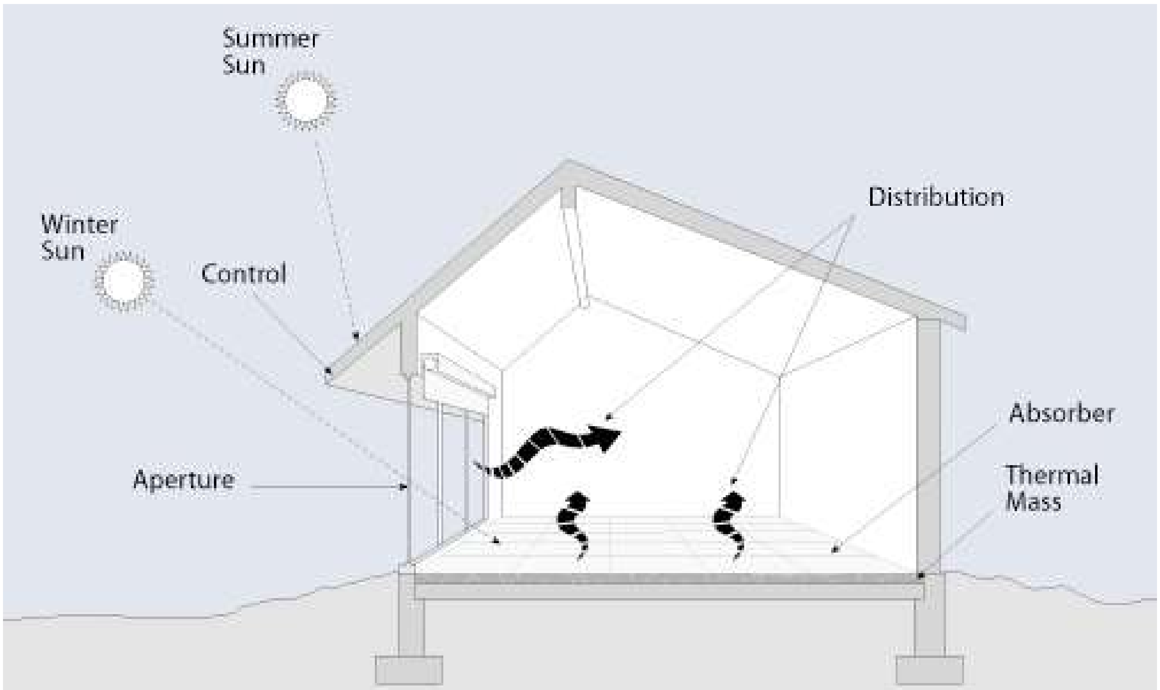


Figure 4.9. Basic Passive Solar Design (https://greenpassivesolar.com/passive-solar/building-characteristics/thermal-mass/)

They are often solid materials like concrete, stone, brick, or ceramic tile used on the floor or inner walls of a passive solar structure near the solar glazing to allow the sun's light to shine directly on them for storing and releasing the sun's heat energy to the inside of the building.

Thermal mass can also be employed to keep a structure cool in tropical climes or during the summer. When dense things (thermal mass) such as marble, granite, and other similar materials are kept out of the sun, they tend to stay cool and hence contribute to keeping the building cool. When the weather gets cooler outdoors, a passive solar structure can be opened up to absorb the cooler evening and night temperatures (*Thermal Mass | Green Passive Solar Magazine*, 2010). The dense material can cool and will absorb heat the following day. The solution can block solar radiation by using shading devices to shine on thermal mass for keeping the inside cool in tropical climates.

4.3.4.2. Material selection

In addition to an acceptable thickness, the designer must choose a material with a balance of thermal qualities to give thermal comfort in the room. The necessity to manage time lag and thermal amplitude inside a room, in particular, led the designer to select a material based on thermal diffusivity, but conductivity is also a consideration. To create all-around thermal comfort in a structure, a balance of thermal qualities must be achieved by mixing walls, ceilings, and other surfaces with the appropriate materials. In tropical climates, the roof, in particular, will play a key role in avoiding solar radiation by relying on material conductivity and defuse qualities. As a result, choices must take into account the location and climate difficulties. And, it is preferable to employ light materials that do not absorb solar energy (Thomas et al., 2006). The features of the material utilized, which determine their use, can be classified into three categories: color, insulating property, and assembly type. The amount of heat and light absorbed and reflected will vary depending on the color of the finish. The lighter color has higher reflection, whereas the deeper color has more absorbing characteristics (Altan et al., 2016).

4.3.4.3. Insulation

Insulation functions as a thermal barrier, preventing heat loss in the winter to keep the building warm and heat gain in the summer to keep it cool. The main reasons for heat loss are inadequate insulation and air leakage. Each portion of the building's insulation format (blanket, rigid, or loose-fill) and substance (for example, glass-fiber, wool, polyester), as well as the amount specified to achieve the target R-value (that is, the desired level of thermal resistance). But, It is better to use insulation materials that will not carry the heat that has no conductivity possible. Improved heat reflectivity and low-mass materials like plasterboard and wood paneling will act as insulators to the thermal mass, limiting their effectiveness. Lightweight construction responds to temperature changes more rapidly. As a result, it's ideal for rooms that need to heat or cool quickly. (Kleerekoper et al., 2012). For example, green roofs and walls can provide insulation and shading, creating better options in tropical climates (Ltd, 2022).

4.3.5. Internal layout

The size, proportion, and form of the inside layout design will have a direct impact on ventilation and cooling. The arrangement must be built to allow wind to enter from the prevailing wind direction and quickly exit without becoming trapped. A higher amount can prevent the space from breathing. The internal layout should be narrow and landscaped to the prevailing wind direction, and shape can also affect air velocity. On the other hand, high air velocity can be achieved by having a larger intake and a smaller output if necessary so, it is also important to know natural wind characteristics.

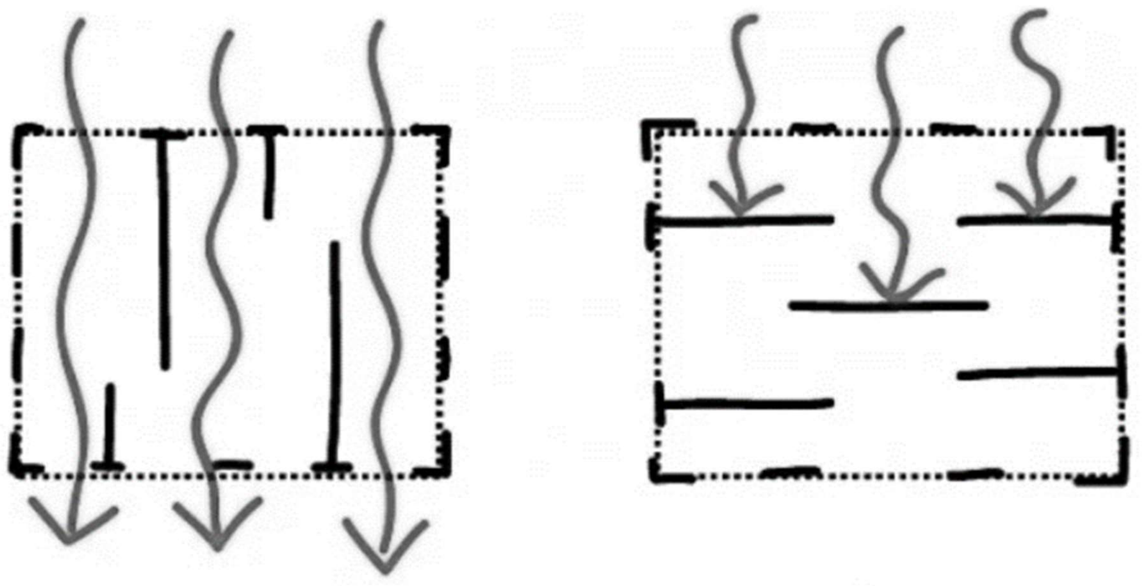


Figure 4.10. Obstacle effects on cross-ventilation (qnaguides.com, 2022)

4.3.6. Apertures

Openings can provide instant cooling effects in a space, but their size and placement are critical considerations. Thus, the design of apertures has a significant impact on passive cooling capacity, particularly natural ventilation. On the other hand, the shape of the entrance is important and can affect airflow efficiency. Long horizontal strip windows can help to evenly ventilate a space. Tall windows with openings at the top and bottom can employ convection and outside breezes to take the hot air out of the top and supply cool air at the bottom of the space. The size of the hole can alter the amount of air and its speed. A smaller inlet can be coupled with a bigger output opening to maximize cooling efficacy. The velocity of the input air can be increased using this setup. Because the same volume of air must travel through both the larger and smaller apertures in the same amount of time, the smaller opening must be passed through faster. Air moves from high-pressure locations to low-pressure ones. By creating localized zones of high or low pressure, air can be guided. Anything that alters the air's path will obstruct it, resulting in somewhat higher air pressure on the windward side and negative pressure on the leeward side of the building. Outside air will enter any windward apertures and be drawn out of any leeward openings to equalize the pressure. If air is forced to move uphill or downward to navigate a barrier without any corresponding rise or drop in temperature, this resistance to airflow is substantially higher due to pressure changes at different altitudes (‘Venturi Effect’, 2022).

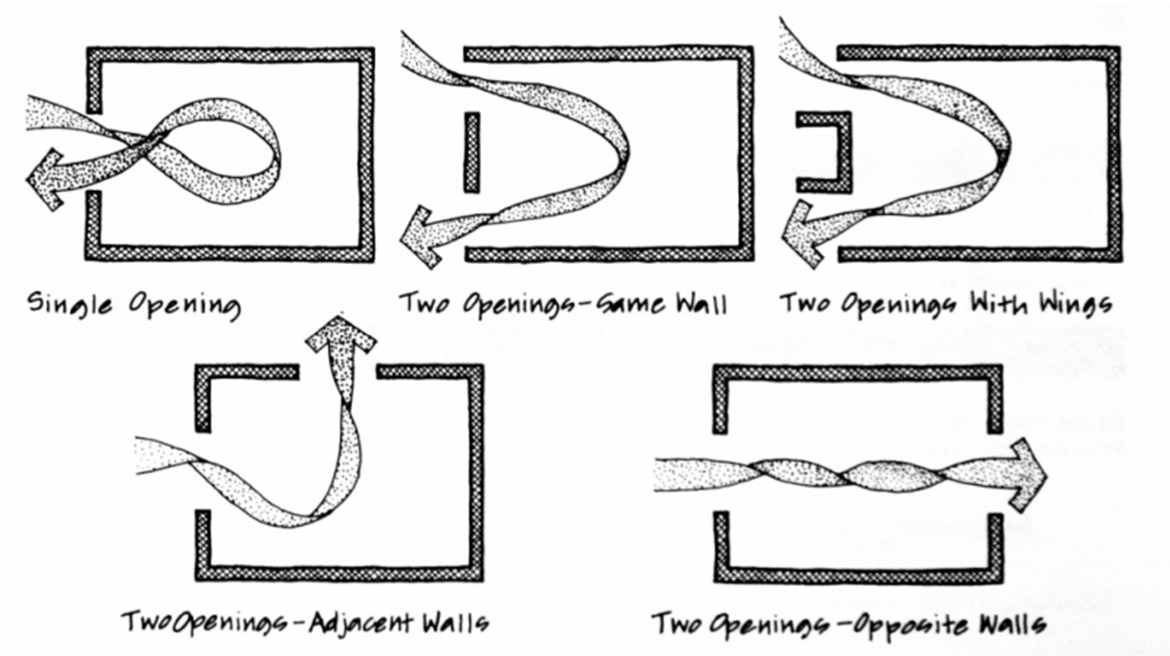


Figure 4.11. Opening effects on the internal layout (Mim, 2020)

4.3.7. Landscape

The landscape is crucial in keeping the environment cool. Instead of hard surfaces, gardens and green plants will help to lower the temperature of the air passing over them. Through the process of evapotranspiration, plants and soil cool the environment, and plants can also provide shade and funnel cooling winds. Green roofs and shaded areas around earth-coupled slabs can assist keep surface ground temperatures lower during the day while still allowing night-time cooling. In many regions, poor shading can cause soil temperatures to surpass inside comfort standards (Reardon, 2020). Water bodies, on the other hand, can act as a natural chiller in hot and dry climes. Where the moisture from the water bond can be utilized to cool the hot wind blowing above the construction block and therefore keep it cold. Planting trees and shrubs is vital for defining wind flow and achieving mutual shadowing on buildings and hard paving. When put around the site border, they operate as a sound barrier, preventing noise from entering the site, and providing shade when placed near the building exterior. The height of the tree, on the other hand, limits the number of stories that can benefit from this landscaping design feature. In general, landscaping can be used to prevent undesirable heat gain in the summer and tropical climates.

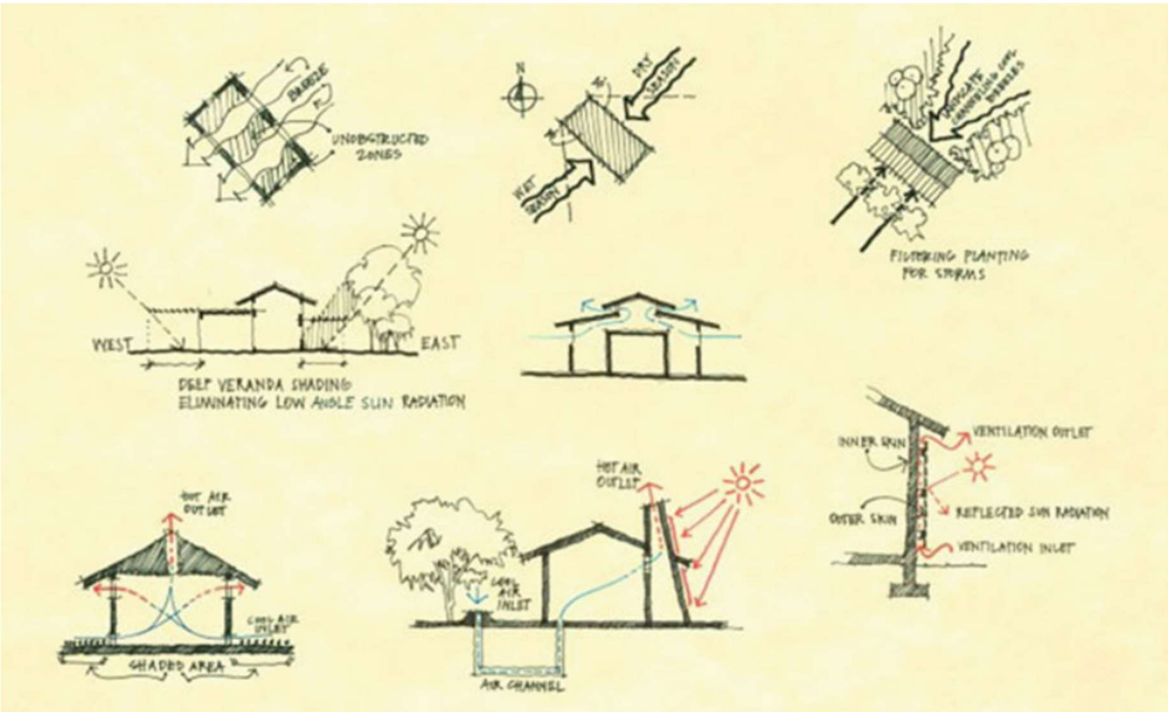


Figure 4.12. Landscape cooling effect (Amble Resorts, 2009)

4.4. Passive solar control (shading)

Passive solar design refers to the use of the sun's energy for the heating and also cooling of living spaces by exposure to the sun. When sunlight strikes a building, the building materials can reflect, transmit, or absorb solar radiation as explained above. By limiting sun radiation, it is possible to keep materials cool. In general, the sun's heat creates air movement in designed spaces that can be controlled. These fundamental responses to solar heat lead to design components, material selections, and placements in buildings that can give heating and cooling effects. Passive solar cooling systems reduce undesired heat absorption during the day, produce non-mechanical ventilation, exchange heated interior air for cooler outdoor air when possible, and store nighttime coolness to regulate warm daytime temperatures. Passive solar cooling systems are made up of overhangs or screens on south-facing windows, shade trees, thermal mass, and cross ventilation at their most basic level.

All apertures should be shaded by an overhang or other devices such as awnings, shutters, and trellises to limit undesired heat gain. Overhangs on east and west-facing windows are less effective because the sun is low on the horizon during sunrise and sunset. If cooling is a primary concern, such as in tropical areas, it is preferable to reduce the number of east and west-facing windows. Vertical shading techniques will be beneficial if the prevalent wind direction is from those locations. Vegetation can also be used to shade such windows. On the other hand, keeping shading devices on the North and roof with vegetation will be effective in tropical climates such as Brazil (*Passive Solar Design*, 2022).

4.4.1. Shading by overhangs, louvers, awnings, etc.

Sun control and shading systems, whether integrated into a building or installed separately from the exterior, can significantly reduce peak heat gain and cooling requirements while also improving the natural lighting quality of interior spaces. The solar direction of a building facade will influence the design of effective shading systems. When correctly calculated sun angles are applied, simply fixed overhangs, for example, are quite effective in shading from sun sides.

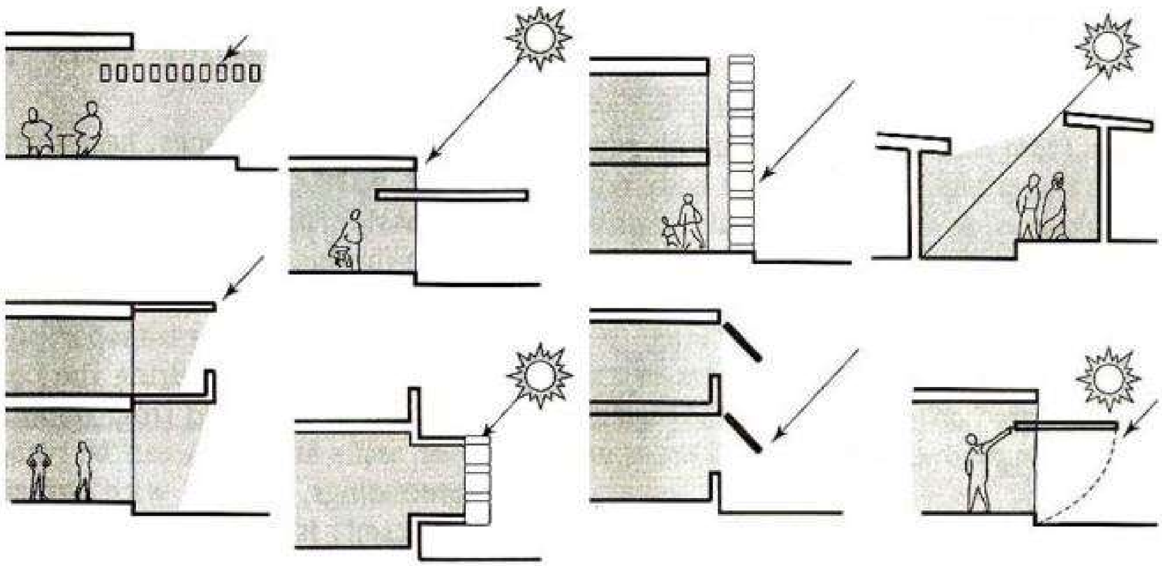


Figure 4.13. Different types of shading devices (https://sustainability.williams.edu)

Horizontal devices on the west and east sides, on the other hand, are inefficient at blocking the low-angle sun. It will be better to use vertical shade devices as well as plants, especially in tropical areas.

4.4.2. Shading of roof

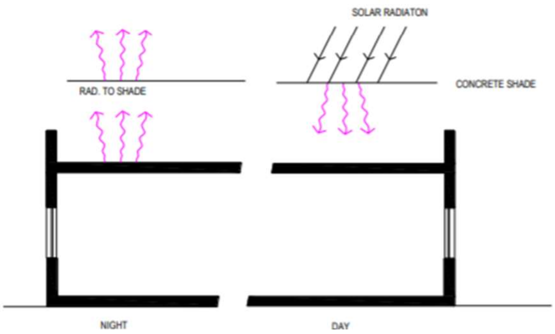


Figure 4.14. Roof shading by the solid cover (Kamal, 2012)

Shading the roof is an effective way to reduce heat input. Roofs can be shaded by concrete, plants, canvas, earthen pots, and other materials. Externally provided shading should not interfere with nighttime cooling. Direct radiation is protected by a roof cover constructed of concrete or galvanized iron sheets. (Figure 4.14)

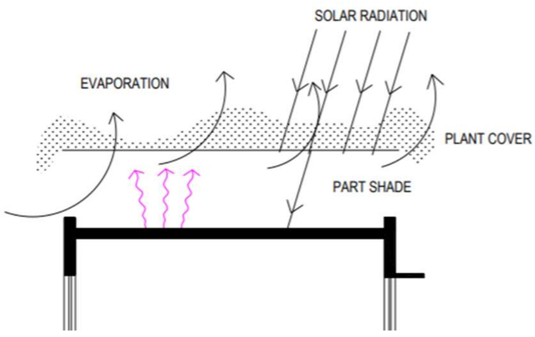


Figure 4.15. Roof shading by plant cover (Kamal, 2012)

As previously said, a canopy of deciduous plants and creepers is a superior option. The temperature of the roof is lowered by evaporation from the leaf surfaces to a level lower than the daytime air temperature. It is even colder at night than the sky temperature. (Figure 4.15).

The surface area for radiative emission is increased by covering the entire surface area with tightly packed inverted earthen pots, as was done in traditional houses. The roof's insulating coating prevents heat from entering the structure. It does, however, make the roof inaccessible and upkeep difficult (Figure 4.16.). For incident radiation reflection, broken china mosaic or ceramic tiles can be used as the top layer on the roof. A removable canvas cover positioned near the roof is another affordable and useful technique. Radiative cooling prevents heat from entering during the day and removes it at night. Figure 4.17. shows the working principle of removable roof shades. Painting the canvas white minimizes the radiative and conductive heat gain.

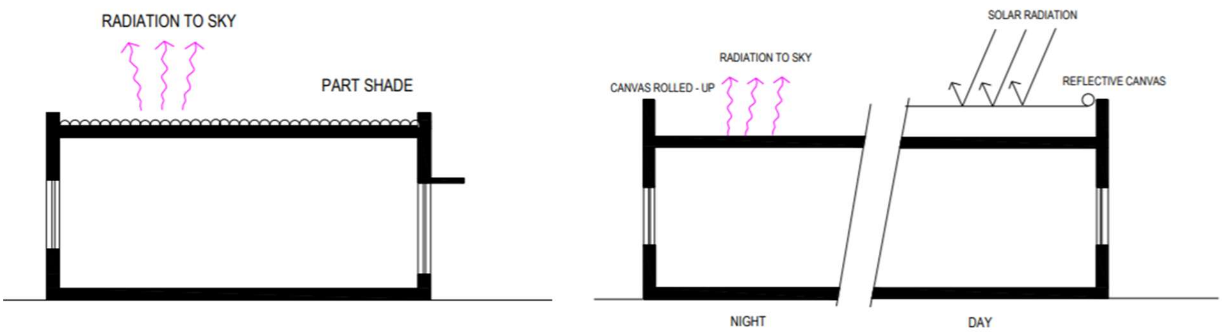


Figure 4.16. Roof shading by earthen pots and removable roof shades (Kamal, 2012)

4.4.3. Shading by trees and vegetation

Shade and heat gain is effectively reduced by vegetation, particularly trees. Roofs, walls, and windows can all benefit from the shade provided by trees. Trees can reduce surrounding air temperatures by up to 5°C by shading and evapotranspiration (the process by which a plant actively releases water vapor). To offer the necessary degree of shading for various window orientations and scenarios, several species of plants (trees, shrubs, vines) can be selected based on their growth habit (tall, low, dense, light-permeable). In tropical climates, the following points should be addressed for shading.;

1. Deciduous trees and bushes provide summer shade while still allowing access in the winter. When these trees lose their leaves in the winter, sunlight may penetrate the interiors and heat the space. Non-deciduous trees, on the other hand, are best suited to tropical regions due to the need to shield against solar radiation in the winter.
2. Heavy leaf trees are excellent in blocking the sun's rays and casting a deep shadow. Filtered sunshine is warmer than dense shade. Shades can be provided by high branching canopy trees that shade the roof, walls, and windows.
3. The finest shielding from the setting sun is provided by evergreen trees on the north and west sides.
4. Dense shrubs, trees, deciduous vines supported on a frame, and shrubs used in combination with trees provide the finest vertical shading for east and west walls and openings to protect against the harsh sun at low angles.
5. Plants that stick to the wall, such as English ivy, or plants that are supported by the wall, such as jasmine, can provide shading and insulation for walls.
6. For north-facing windows, horizontal shading is optimal; for example, deciduous vines (which shed their leaves in the winter) such as ornamental grape or wisteria can be grown over a pergola to provide shade.

4.4.4. Shading by textured surfaces

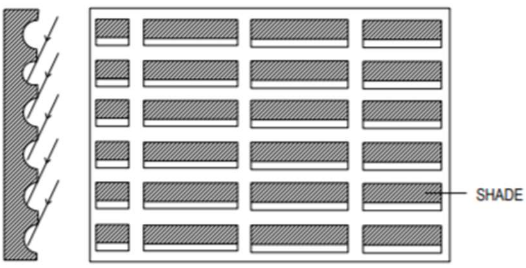


Figure 4.17. Shading due to surface texture (Kamal, 2012)

Surface shading can also be included as a component of the structure. As seen in Figure 4.18, highly textured walls have a piece of their surface that is shaded. Because of the increased surface area of such a wall, the outer surface coefficient increases, allowing the sunny surface to stay cooler and cool down faster at night (Figure 4.18.).

4.5. Passive cooling and ventilation

Passive systems are those that rely solely on natural resources to fulfill their objectives without the use of any additional mechanical devices. The process of delivering and removing air from an indoor place is known as passive ventilation. It describes the movement of outside air into an enclosed place due to pressure differences caused by natural factors. Passive cooling, on the other hand, focuses on heat gain control and heat dispersion to increase a building's thermal comfort (Samuel et al., 2013).

4.5.1. Induced ventilation techniques

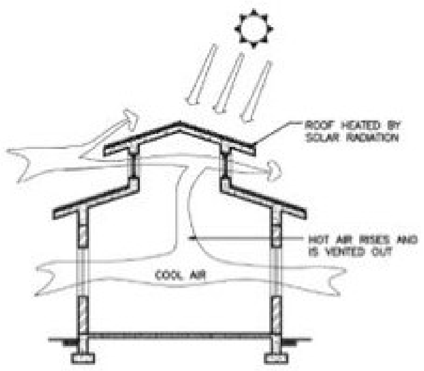


Figure 4.18. Induced ventilation (slideshare.net)

Thermal induction systems are used to conduct air cooling in induced natural ventilation. Warm air is lighter than cold air, hence in this instance, warm air rises and cold air falls in an exterior or internal environment. The apertures in this ventilation system are close to the ground, allowing cold air to enter the area by forcing warm air upwards, where air outlets are located on the roof. Vertical ventilation flow through the chimney effect is employed continually in vertical constructions. In induced ventilation, cold air exerts pressure beneath warm air, forcing it to rise. In this situation, however, the project center or towers have opened regions that allow the same air to flow around the environment, departing through the roof, clerestory, zenithal apertures, or wind exhausts (Pereira & Matheus, 2020).

4.5.2. Radiative cooling

By releasing energy away from man-made buildings through the atmosphere, the idea leverages outer space as a virtually unlimited energy sink. The emission of radiation over a range of different wavelengths - a trait shared by all surfaces - plus the substantial difference in temperature between space and objects on Earth cause energy transmission.

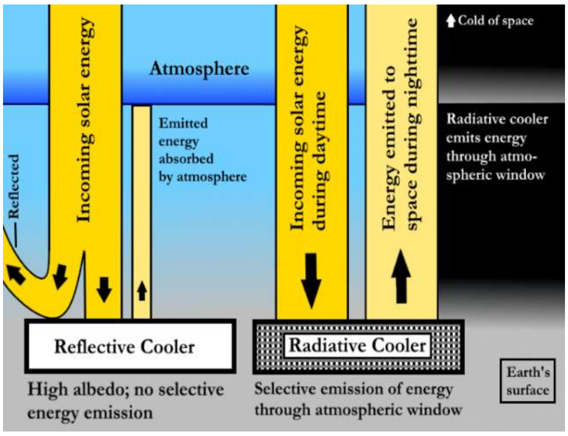


Figure 4.19. Reflective and radiative coolers (M. Burnett, 2022)

This cooling method is "passive" in the sense that it does not require any additional energy input to achieve cooling; rather, radiative heat transfer occurs continuously and spontaneously. However, while the amount of radiation emitted by surfaces such as roofs and roads remains constant, cooling requires a net negative change in radiative energy. During the day, incoming solar radiation normally outnumbers outgoing radiation to space, resulting in a net gain of energy, which heats the surface. As a result, passive radiative cooling is most typically used at night, when outgoing radiation to space exceeds incoming radiation due to the lack of incoming solar radiation (see figure 4.20) (Givoni, 1994). Because peak cooling demand occurs during the day, most energy-efficient "cool roofs" employ high-albedo paints and materials to simply reflect incoming sunlight towards the sky, resulting in significant cooling energy savings (Bretz & Akbari, 1997).

4.5.3. Evaporative cooling

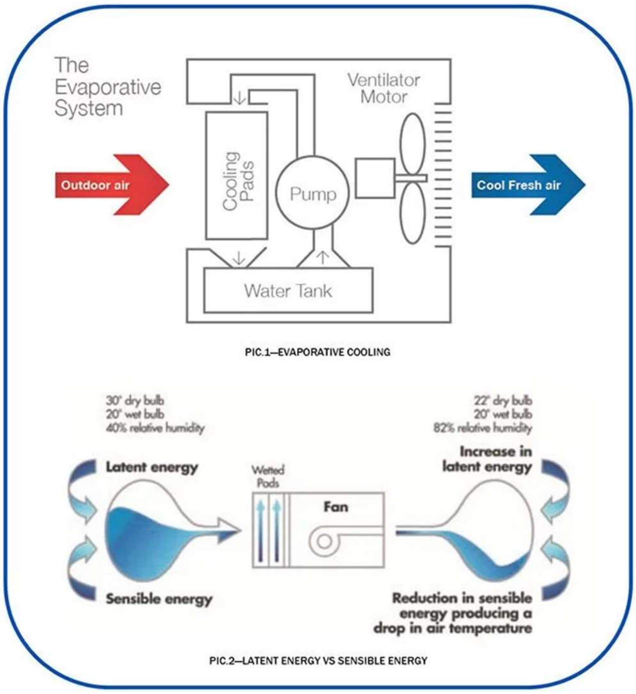


Figure 4.20. Evaporative cooling system (Cristina Piattelli, 2022)

The use of evaporated water to cool heated air is known as evaporative cooling. When you get out of a hot day's swimming pool, you experience a chill from the breeze hitting your wet body. This is due to the water evaporating. A motor-driven fan forces hot outside air through wet cooling pads in an evaporative cooling system. A water pump feeds water to the cooling pads constantly, keeping them moist. The cooled air is then blasted throughout the structure (Kooij, 2022).

4.5.4. Earth air tunnel (Ground cooling)

A pre-cooling or pre-heating system that consists of a pipe or network of pipes buried at an acceptable depth below the ground surface is known as an earth air tunnel or earth air heat exchanger. It either cools or heats the air by rejecting or absorbing heat from the earth. It takes advantage of the fact that the deep soil temperature is nearly identical to the location's annual average mean air temperature (Hollmuller, 2022).

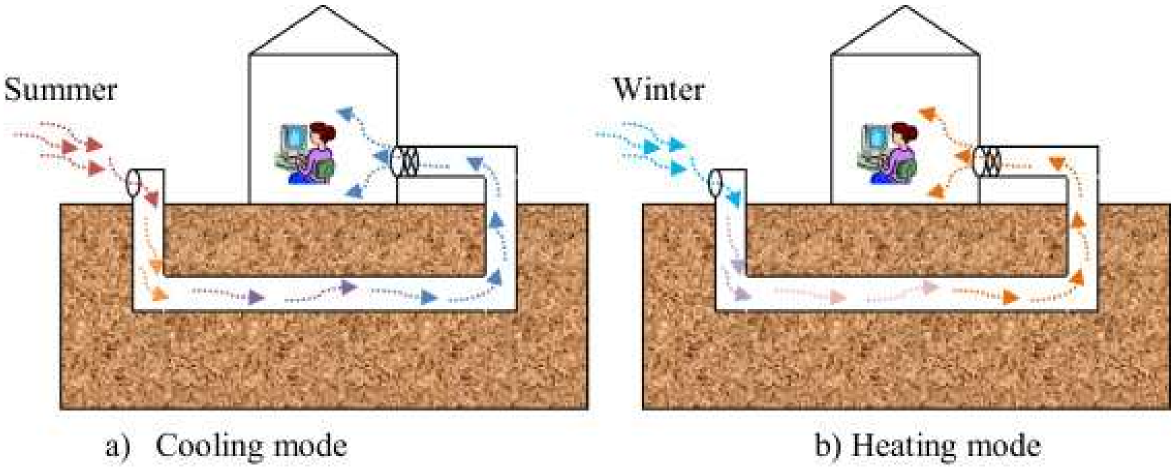


Figure 4.21. Earth air tunnel (Singh et al., 2018)

4.5.5. Desiccant cooling

Heat-driven desiccant cooling systems are an alternative to traditional vapor compression and absorption cooling systems. A desiccant cooling system works by dehumidifying air using a rotational dehumidifier (desiccant wheel). The resulting dry air is cooled slightly in a sensible heat exchanger (rotary regenerator) before being cooled even more by an evaporative cooler. Cool air is then directed into the room. In ventilation or recirculation modes, the system can be run in a closed cycle or, more often, in an open cycle. To replenish the desiccant, you'll need heat. Low-grade heat at 60–95°C is sufficient for regeneration, therefore renewable energies like solar and geothermal heat, as well as waste heat from traditional fossil-fuel systems, can be employed (Dincer & Rosen, 2007).

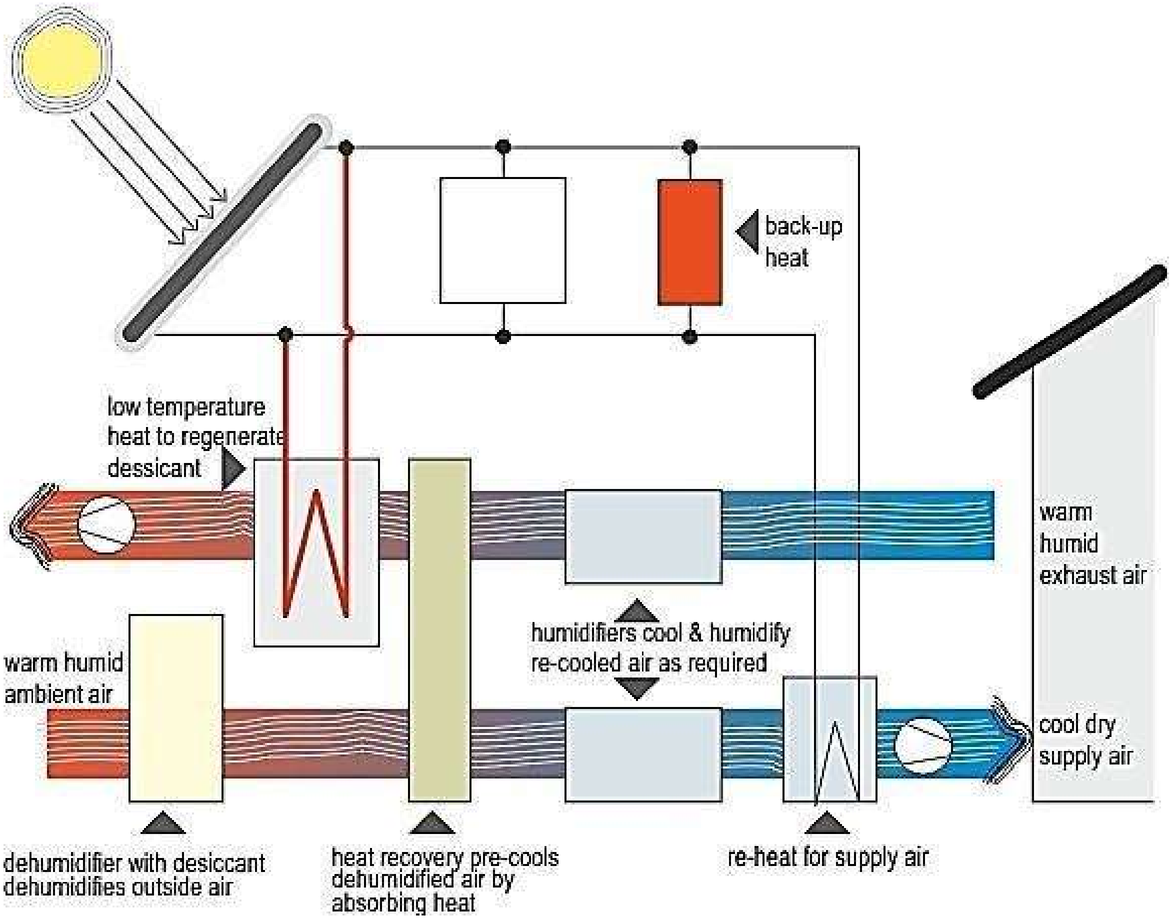


Figure 4.22. Schematic diagram of desiccant cooling system (Anfas Mukram, 2022)

PART 2: METHODOLOGY

5. METHOD AND LOCATION

5.1. Method

The project was executed within the Agriculture Engineering Department of the Federal University of Lavras (Universidade Federal de Lavras - UFLA) and Architecture for the Sustainability Design master of science program of Politecnico di Torino (Polito), Italy. The project has three pillars to execute a barn proposal. Interviews with farmers, vets, and agricultural engineers were executed to understand the current view of the Minas Gerais agricultural activities and livestock hog and, the research has been carried out on animal welfare from the literature. On the other hand, programming was used for site analysis to increase animal thermal comfort as much as possible.

In Grasshopper, Ladybug imports standard EnergyPlus Weather files (.epw) which were decided early on to base the method of computing the metrics on EnergyPlus, a US Department of Energy-validated engine that accommodates enough geometric detail of a building to assure that the resulting thermal metrics are accurate (EnergyPlus Input Output Reference, 2014). While EnergyPlus is a solid engine, the Department of Energy currently does not provide an interface for it other than a specialized text editor, therefore it was vital to choose a platform that made it simple to set up EnergyPlus models. Because many complicated geometric computations are required to calculate the maps, having an interface that is near to a robust and trustworthy geometric library is especially desired. Under the conditions, the open-source Ladybug and Honeybee projects were chosen since they were built on top of Rhinoceros, a sophisticated geometric modeler, and include several open-source modules useful for map creations, written by the founder, Mostapha Sadeghipour Roudsari such as solar radiation assessments, view analysis, sunlight-hours simulations, wind analysis and other tools (*Ladybug Tools*, 2022). The site model mesh was created on Sketchup based on topography information which is taken from google earth. The connection between the Sketchup and Google earth is used but, the exact site model created in Rhinoceros from this mesh file and existing context placed on it. In this way, all analyses and maps were executed using Ladybug and Honeybee on the Rhinoceros using various matrices as figure below.

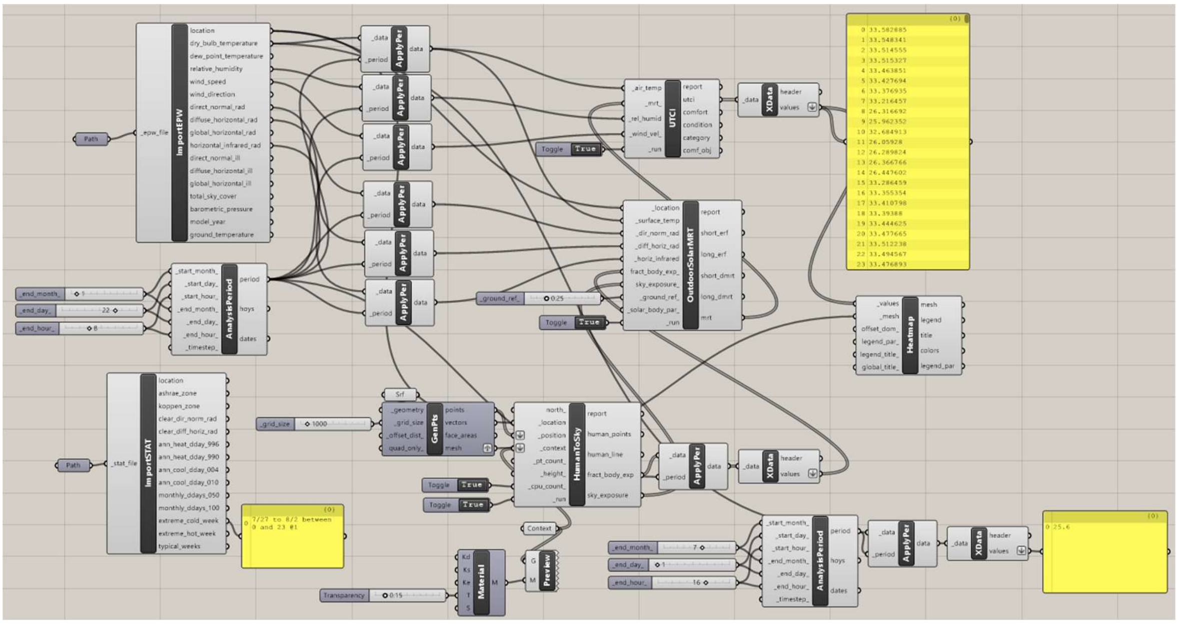


Figure 5.1. UTCI site analysis matrixes.

5.2. Location

Figure 5.2. Lavras bird's eye view (Google,2022)

The project was conducted near the municipality of Lavras, Minas Gerais, Brazil, 425km away from Rio de Janerio and 378 km from São Paulo. Located in the southern microregion of the state in Minas Gerais. The site is located 26km away from the Lavras at the geographical coordinates of 21°15'49.3"S latitude, and 45°09'10.1"W longitude, and located at 920 meters of altitude.

6. LIVESTOCK HOUSING IN MINAS GERAIS: CURRENT SITUATION

6.1. Importance of cattle in Minas Gerais

Minas Gerais is one of the most critical states in Brazil which generated 190 Billion BRL from agricultural activities and represents 14% of total Brazilian agricultural activities in GDP. Cattle ranching is among the main agricultural activities in Minas Gerais and, it has been prominent year by year and is the 2nd largest cattle herd in the country in 2015 with about 22.5 million animals, or 10.95% of the national herd according to IBGE (Brazilian Institute of Geography and Statistics). Minas Gerais has an area of more than 30 million hectares of pastures (native and planted), according to data from the UFMG Remote Sensing Center (CSR/UFMG), which represents a large part (above 40%) of its entire territory so, the raising of cattle stands out among the strongest vocations in Minas. The income of agribusiness from cattle ranching, notably beef, is centered on primary activity. Federal State and Municipal inspections have published about Minas, that 3.2 million heads of cattle were slaughtered in the year 2014 which is the 10% of the national total.

6.2. Overview of the cattle business

Breeding, growing, and fattening are considered complete cycle activities. The males are sold as fattened cattle for slaughter, aged between 15 and 42 months depending on the production system in use. Females are sold immediately after weaning, generally between 7 and 9 months of age. In addition to weaned females, weaned calves, heifers, cows, and bulls are sold. In general, weaned heifers and young heifers (1 to 2 years old) are sold for breeding, while 2 to 3-year-old heifers, cows, and discarded bulls are destined for slaughter (Cezar, 2005). Calves are ready for slaughter a minimum of 10 months later after the born between weights of 30kg a 200kg (*Melhor peso e idade para abate de bovinos*, n.d.), when the aim is the production of the super-early steer, slaughter takes place between 440-500 kg, at 13-15 months of age (PS & M, 2016).

6.3. Types of production systems

The Minas Gerais cattle production has 3 main focused strategies for livestock housing systems based on farmer selection, these are extensive production systems (pasture), semi-confinement, and confinement production systems. The first one is famous around the Minas which represent 80% of beef production systems (*Semiconfinamento e confinamento* |

Cenários para a pecuária, n.d.). These are small producers who use a system they learned from their parents. Those producers are located in mountainous ness outside the cities and they do not use confinement or genetic improvement methods to improve productivity which causes low productivity because of the variation in performance too high. The animals are loose in the pasture and they feed on the pasture freely. Some producers don't have enough pasture to feed their animals, so they have been complemented their diet with ready-made silage or made their silage, planting corn, sugarcane, grass, etc.

The semi-confinement production system also has pasture and mineral supplements as a food base, plus protein/energy supplements. Those areas are fenced off during the end of the waters, February to April, where enough forage will be accumulated for the animals to graze for a certain period of drought. The objective is to achieve a shorter cycle of livestock, supplementing the animals in their different stages of growth (breastfeeding, growing, and fattening), depending on the production goals of each system.

Thirdly, the confinement system aims to supply the animal's total diet in the trough, which can be formed by the combination of roughage and concentrated feed. In most cases, the system has been used for milk production. Currently, it does not exceed 20%. In confinement, the cost of the arroba produced is higher due to the demand for facilities, machines, and specific labor, among others. Cattle gain more weight as long as the diet is balanced. Mostly, large producers are selecting this system to raise the animals.

6.4. Cattle housing

In Minas Gerais, the closed barn model is not famous and basically, the barn structure based on a roof is the preferred shelter only to protect from solar radiation and rain without any exterior walls.

There are 2 main barn structures based on the farmer's work plan and his choices: cubicle and free walk barn systems. Due to the high construction cost and greater demand for cleaning management in cubicle systems such as tie-stall or free-stall, farmers are not mostly preferring to use those systems and it is also an economic problem to mechanize those systems, without mechanized workers are suffering from the management of the system. On the other hand, free walk systems such as loose housing or compost barn systems are becoming more famous in Minas Gerais because of their huge opportunity to lower installation costs and it also provides better working conditions for employees.

Especially compost barn system is one of the most preferred systems because of the getting more advantages such as reduction of hull problems and healthier sanitary conditions and also easy management of the feces cleaning. In those systems, finding beds is an issue, and a greater demand for care and money when changing the bed every time. Farmers get an advantage from this in the compost barn system by using it on their land or selling it. The compost with animal jerks can be very useful in the land for growing products. The compost bed generally changes every year but, some farmers have sold the compost every 6 months to get more money from it in Minas Gerais. Those are the main reasons, compost barn systems are getting more valuable and famous around Minas Gerais.

6.5. Result

From the interviews with farmers and regional research, it is observed that the compost barn system is getting famous in the Minas Gerais because of its benefits from farmers' eyes such as economical, maintenance, easy management, lower construction value, and even getting more profit with selling compost so, mostly farmers wanted to change their system with this system and their perspective was generally positive. Compared with other systems from the regional perspective, it seems that the compost barn system is getting the future of the Minas Gerais and, it seems more suitable than other systems in their eyes.

Research suggests directly to this system and the model seems suitable for the application in the region.

7. MICRO-CLIMATE ANALYSIS

7.1. Overview of the Lavras climate

According to the Köppen climate classification, the climate of the Lavras region is Cwa, rainy temperate (mesothermal), with dry winters and rainy summers, and subtropical, with dry winters and warmer monthly temperatures higher than 22 °C (DANTAS et al., 2007). The rainy season in Lavras is humid and mostly gloomy, whereas the dry season is mostly clear and warm all year. The temperature normally ranges from 52°F (11°C) to 85°F (29°C) throughout the year, with temperatures rarely falling below 46°F (8°C) or rising over 93°F (34°C).

From August 27 to November 10, the warm season lasts 2.4 months, with average daily high temperatures exceeding 83°F (28°C). October is the hottest month in Lavras, with average highs of 85°F (29°C) and lows of 61°F (16°C). From May 2 to July 20, the chilly season lasts 2.5 months, with average daily high temperatures below 77°F (25°C). June is the coldest month in Lavras, with average lows of 53°F (11°C) and highs of 75°F (24°C).

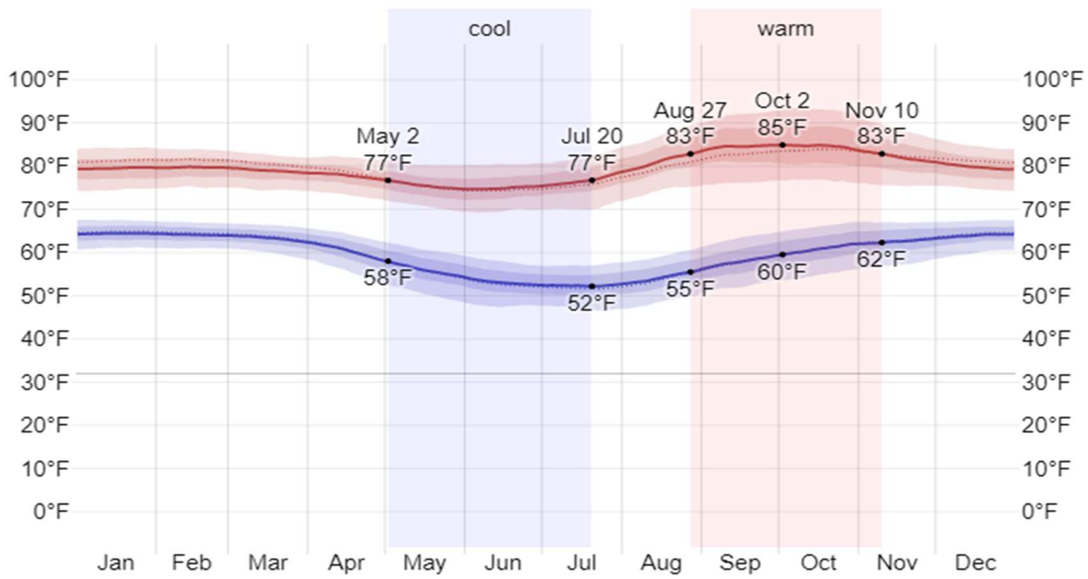


Figure 7.1. Average High and Low Temperature in Lavras (weatherspark.com, 2022)

The graph below depicts a summary of hourly average temperatures for the full year. The hue represents the average temperature for that hour and day, while the horizontal axis represents the day of the year.

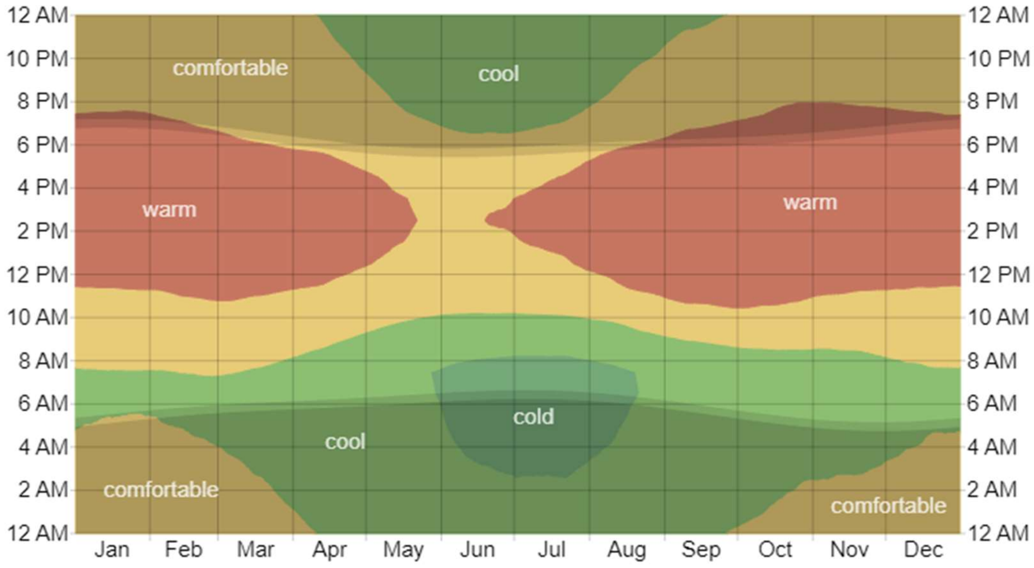


Figure 7.2. Average Hourly Temperature in Lavras (weatherspark.com, 2022)

7.1.1. Clouds

Over the year in Lavras, the average proportion of the sky covered by clouds varies dramatically. In Lavras, the clearer season starts about April 7 and lasts for 6.1 months, finishing around October 12. August is the clearest month of the year in Lavras, with the sky being clear, mostly clear, or partly overcast 74 percent of the time. The rainier season starts around October 12 and lasts 5.9 months, ending around April 7. In Lavras, the cloudiest month of the year is January, when the sky is overcast or mostly cloudy 77 percent of the time.

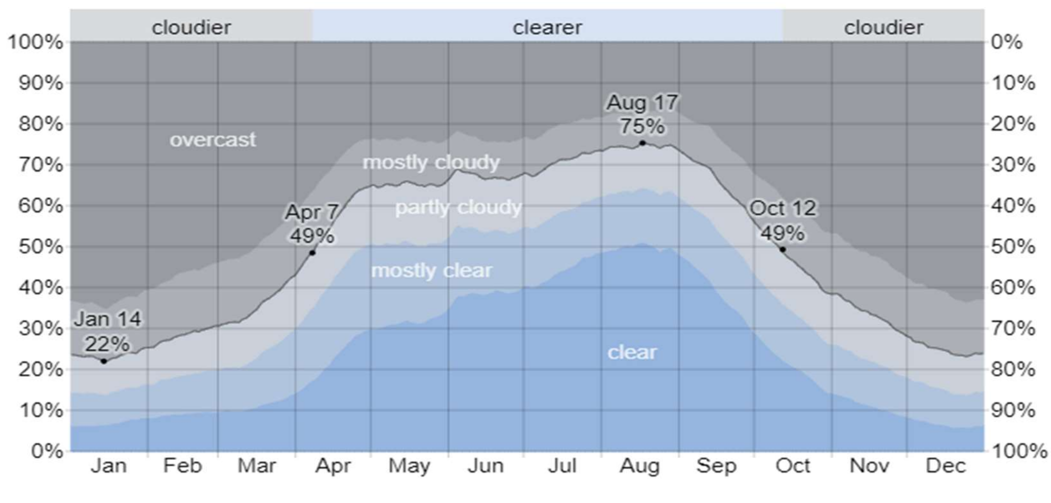


Figure 7.3. Cloud Cover Categories in Lavras (weatherspark.com, 2022)

7.1.2. Precipitation

A wet day is defined as one in which there is at least 0.04 inches of liquid or liquid-equivalent precipitation. The probability of rainy days fluctuates dramatically throughout the year in Lavras. Between October 20 and March 29, the wetter season lasts 5.3 months, with a greater than 39% chance of rain on any given day. December is the wettest month in Lavras, with an average of 21.9 days with at least 0.04 inches of rain. From March 29 to October 20, the dry season lasts about 6.7 months. In Lavras, July has the fewest wet days, with an average of 1.9 days with at least 0.04 inches of precipitation. We distinguish between wet days that have only rain, snow, or a combination of the two. December has the rainiest days in Lavras, with an average of 21.9 days. Rain alone is the most common sort of precipitation throughout the year, according to this classification, with a high likelihood of 74 percent on December 23.

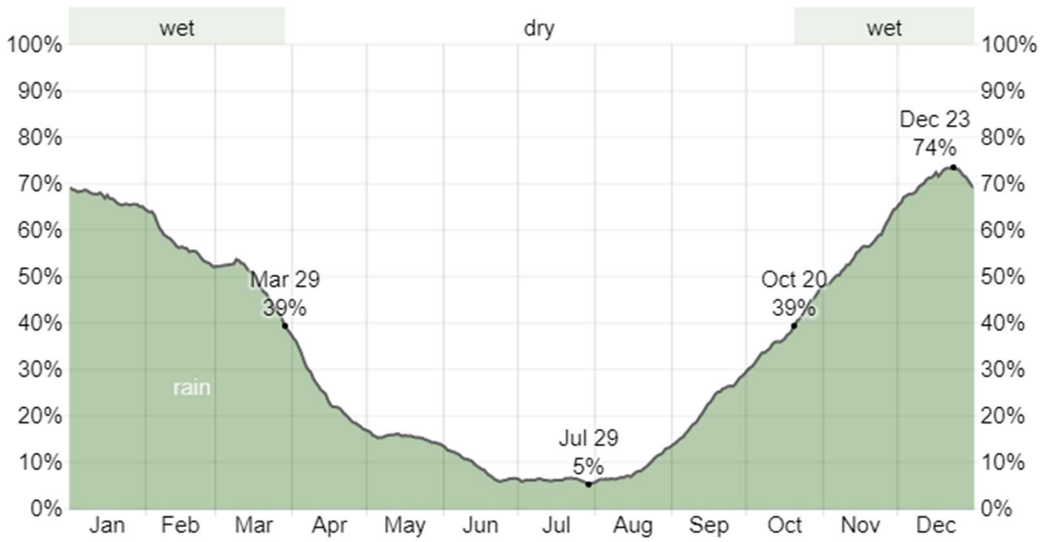


Figure 7.4. Daily Chance of Precipitation in Lavras (weatherspark.com, 2022)

7.1.3. Rainfall

We showed the rainfall gathered over a sliding 31-day period centered on each day of the year to show variance between the months rather than just the monthly totals. The monthly rainfall in Lavras varies greatly depending on the season. From August 12 to June 27, the rainy season lasts ten months, with a typical 31-day rainfall of at least 0.5 inches. January is the wettest month in Lavras, with an average rainfall of 9.3 inches. From June 27 to August 12, the year's rainless period lasts 1.5 months. July is the driest month in Lavras, with an average rainfall of 0.4 inches.

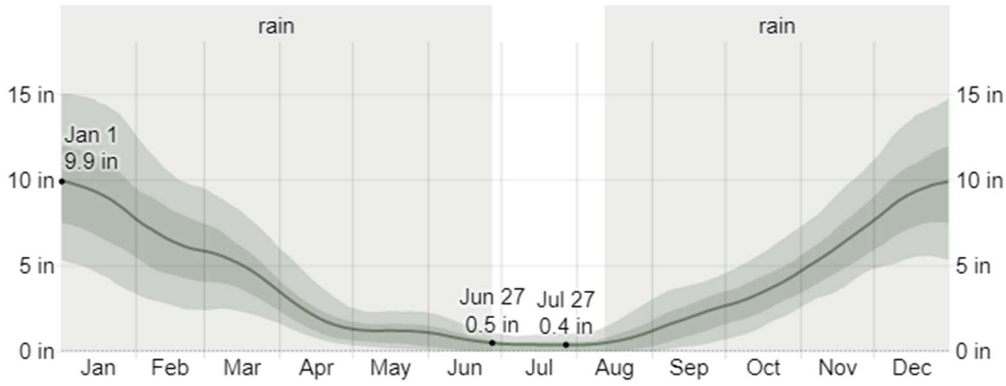


Figure 7.5. Average Monthly Rainfall in Lavras (weatherspark.com, 2022)

7.1.4 Sun

The length of the day changes throughout the year in Lavras. The shortest day in 2022 will be June 21, with 10 hours and 50 minutes of daylight, and the longest day will be December 21, with 13 hours and 26 minutes of daylight.

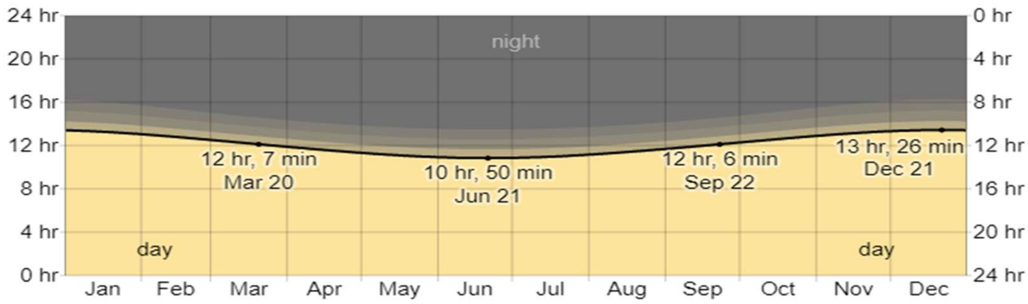
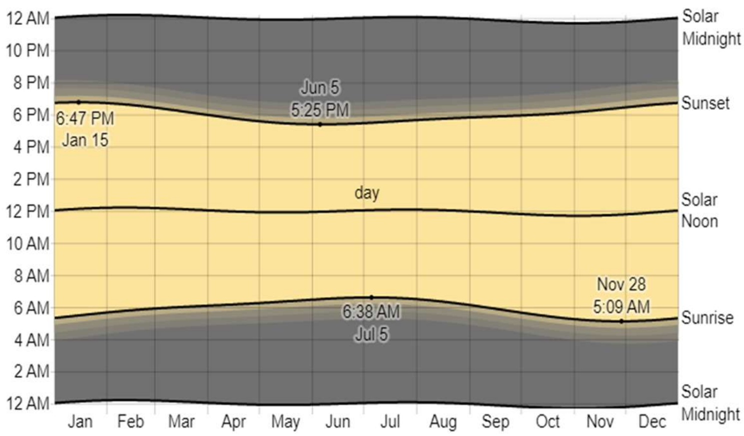


Figure 7.6. Hours of Daylight and Twilight in Lavras (weatherspark.com, 2022)



On November 28, the earliest sunrise is at 5:09 a.m., and on July 5, the latest sunrise is at 6:38 a.m. On June 5, the earliest sunset is at 5:25 PM, and on January 15, the latest sunset is at 6:47 PM.

Figure 7.7. Sunrise & Sunset with Twilight in Lavras (weatherspark.com, 2022)

7.1.5. Humidity

The perceived humidity in Lavras varies dramatically throughout the year. From November 3 to April 22, the hottest part of the year lasts 5.6 months, during which time the comfort level is muggy, oppressive, or awful at least 16 percent of the time. January has the muggiest days in Lavras, with 18.7 days that are muggy or worse. July has the fewest muggy days in Lavras, with 0.0 days classified as muggy or worse.

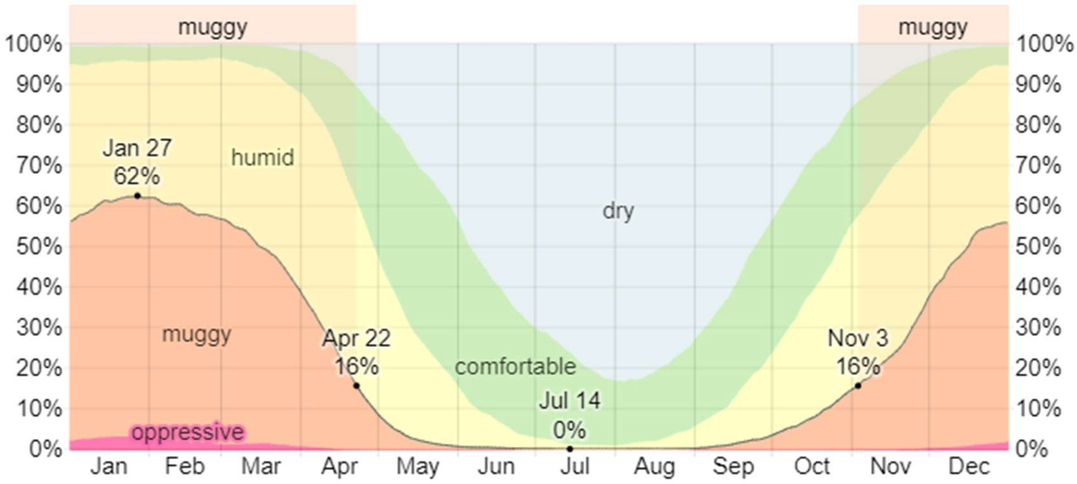


Figure 7.8. Humidity Comfort Levels in Araras (weatherspark.com, 2022)

7.1.6. Wind

The wide-area hourly average wind vector (speed and direction) at 10 meters above the ground is discussed in this section. Over the year, the average hourly wind speed in Lavras shows some seasonal variation. From August 1 to December 18, the windier half of the year lasts 4.5 months, with average wind speeds of more than 7.5 miles per hour. September is the windiest month in Lavras, with an average hourly wind speed of 8.6 miles per hour. From December 18 to August 1, the calmer season lasts 7.5 months. With an average hourly wind speed of 6.4 miles per hour, April is the calmest month in Lavras.

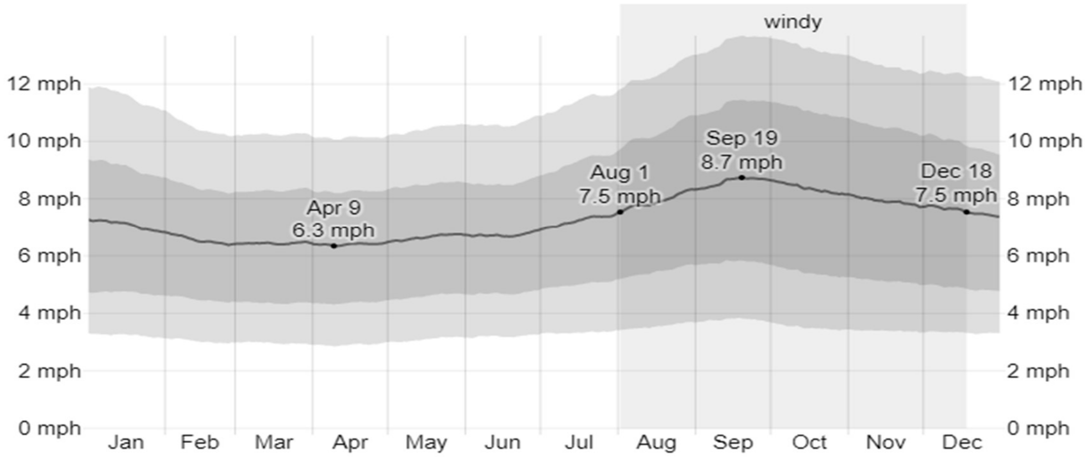


Figure 7.9. Average Wind Speed in Lavras (weatherspark.com, 2022)

From February 9 to December 7, the wind is most commonly from the east, with a peak percentage of 55 percent on April 10. For 2.1 months, from December 7 to February 9, the wind is most typically from the north, with a peak proportion of 46 percent on January 1. (Weather Spark, 2022).

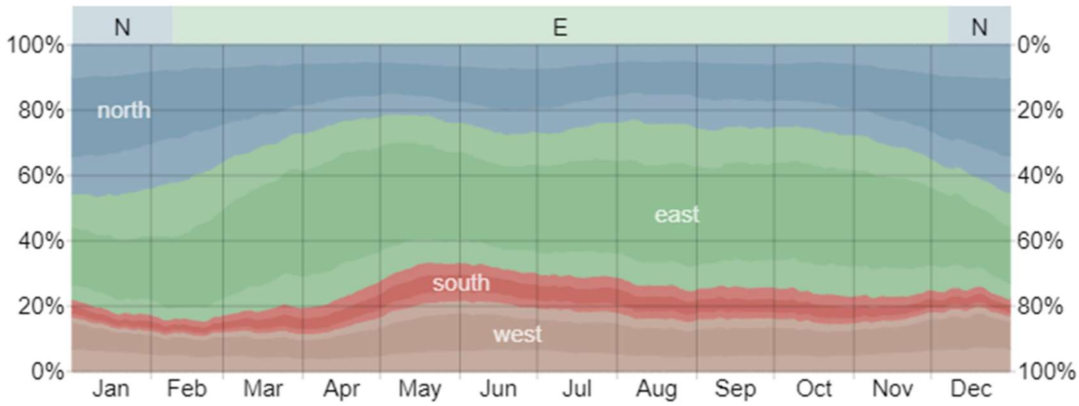


Figure 7.10. Wind Direction in Lavras (weatherspark.com, 2022)

7.2. UTCI (Universal Thermal Climate Index)

Based on UTCI calculations carried out on the ladybug, the hottest week and coldest week of the climate are detected. According to that, the hottest week is between 20 January to 26 January and, the coldest week is from 27 July to 02 August. Every single day is calculated separately based on hours 8 am, 12 am, and 4 pm to detect the hottest day and coldest day. From the result, the hottest day is 22 January with an average heat of 28.2 °C, and the lowest heat is detected on 24 January with an average of 24.2 °C this week. On the coldest week of the year, the coldest day is detected on 30 July with an average heat of 12.7 °C and the hottest day is 01 August with 17.7 °C. Moreover, based on research, 01 January and 02 October are mentioned as the hottest days of the Lavras, and 01 June and 01 July are mentioned as the coldest days. So, the calculation is also covered those days as visible in the table below.

HOTTEST DATES	08. AM	12. AM	16. PM	COLDEST DATES	08.AM	12.AM	16.PM
20/01	24.4	27.1	32	27/07	15.1	15.9	18.2
21/01	23.5	26.9	32.2	28/07	13.3	17.1	20
22/01	24.9	27.7	32.2	29/07	12.3	14.1	16
23/01	23.5	26.7	31	30/07	7.4	12.7	18
24/01	22.2	25.7	31.6	31/07	8.6	15.3	23.4
25/01	22.7	24.3	25.6	01/08	12.4	16.7	22.2
26/01	23.2	25	28	02/08	11.8	17.6	23.7
01/01	22.9	25.2	29	01/06	15.1	19.2	23.2
02/10	21.1	27.4	32.4	01/07	13.3	17.7	25.6

Table 7.1. The hottest week and coldest week of the year

The table below represents azimuths/altitudes of the 22 January and 30 July at different times at 8,10 am and 12,14,16 pm.

Azimuth/Altitude	22 JANUARY	30 JULY
8 AM	100.73/31.38	61.21/17.76
10 AM	93.09/59.09	40.27/39.59
12 PM	61.46/86.77	2.51/50.23
2 PM	-91.31/64.70	-36.93/41.56
4 PM	-99.20/36.90	-59.45/20.49

Table 7.2. The Azimuth/Altitude of 22 January and 30 July (*PD: 3D Sun-Path*, 2022)

After detecting the hottest day and coldest day, the borders of the site are selected for microclimate analysis with a size of 5077mx5534m, and a total area is calculated as 28.096.118 m^2. The area was placed by 1mx1m grids and created 2750 analysis points between each grid on the site to calculate UTCI on microclimate. The calculation is executed with detected days as hottest and coldest on the site with those points. Green represents existing buildings and trees on the site and the legend on the right side shows the range of UTCI values from dark blue to dark red for each point on the site.

7.2.1 Hottest days

22 January

At 8 am, the values range from 24.25 to 33.71 on the site. The closest comfort points are near the stream and trees and at noon, the values range from 27.98 to 34.71 on the site which shows us heat is getting much as compared with 8. am. Previous blue points before seems yellow on thıs hour. On the other hand, shadows are getting lower and the closest comfort points are near the stream and trees like the figure at 8 am. Finally, at 2 pm the values range from 31.30 to 34.60 which shows the hottest hour on the site. The shadow range is longer as compared with 12. pm but, comfort points are getting much away from the range.

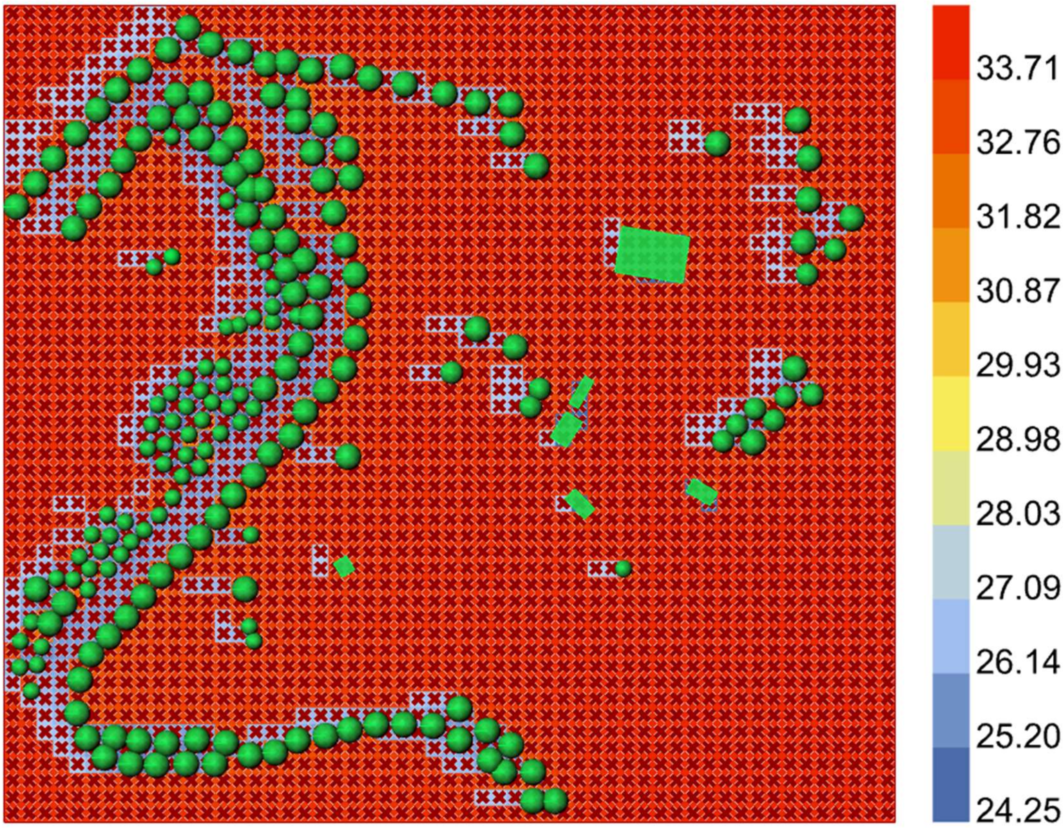


Figure 7.11. 22 January UTCI analysis at 08 am.

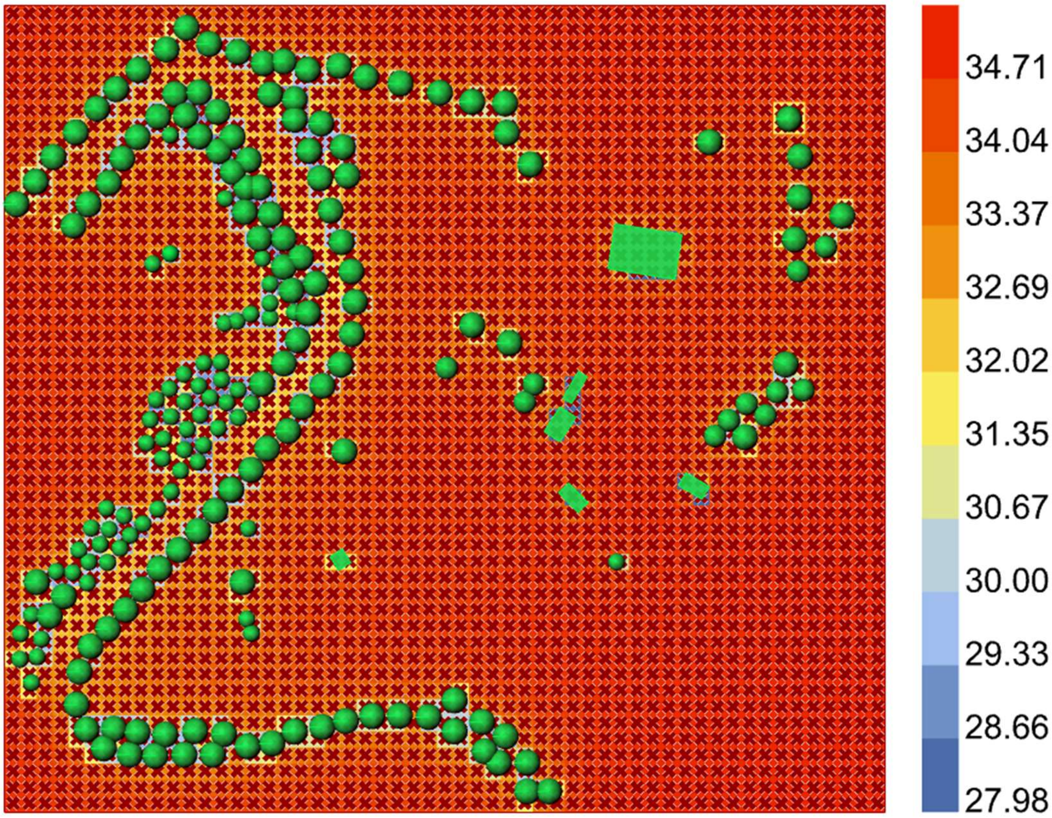


Figure 7.12. 22 January UTCI analysis at 12 pm.

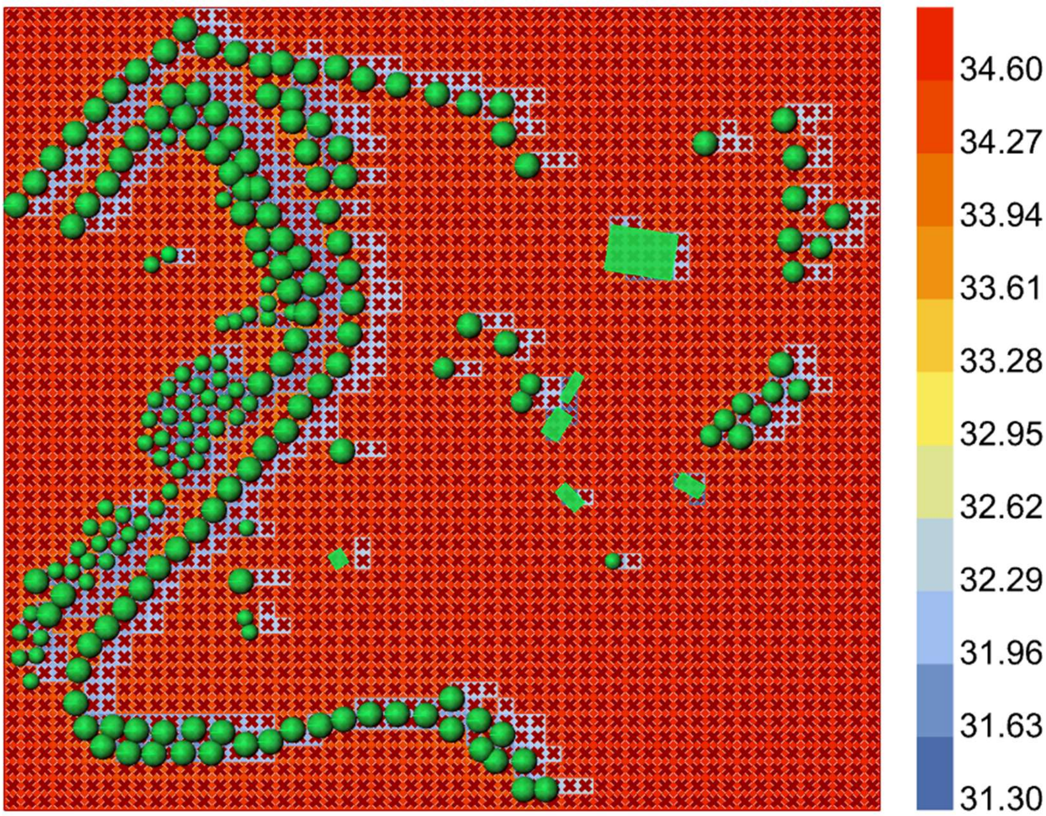


Figure 7.13. 22 January UTCI analysis at 4 pm.

2 October

At 8 am, the values range from 20.80 to 30.90 on the site and the shadow range is bigger than 4 pm. On the other hand, at 1noonpm the values range from 26.37 to 32.89 and it is getting higher values. Near existence, context points are getting more heated, too, and showed themselves as yellow clour. Moreover, at 4 pm, the highest shadow ranges are observed but heat is also getting higher. The range is between 30.09 to 33.22.

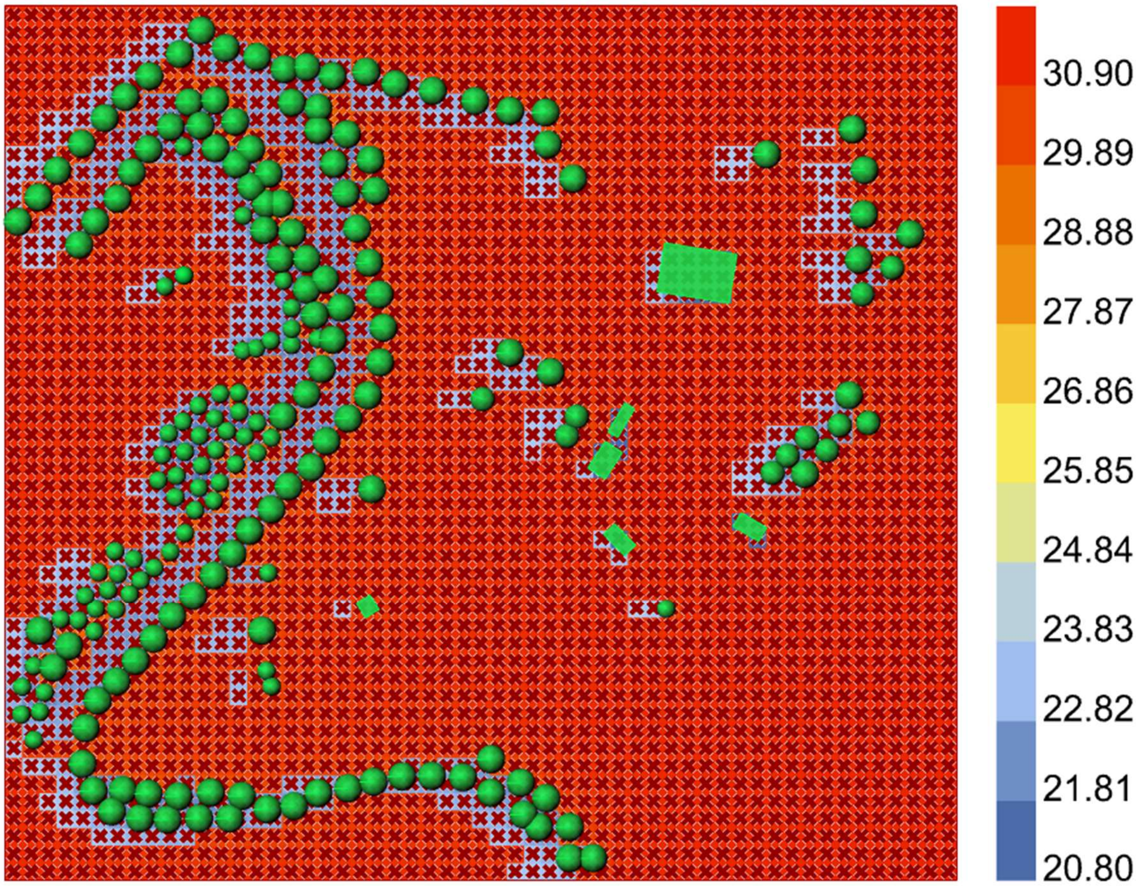


Figure 7.14. 02 October UTCI analysis at 08 am.

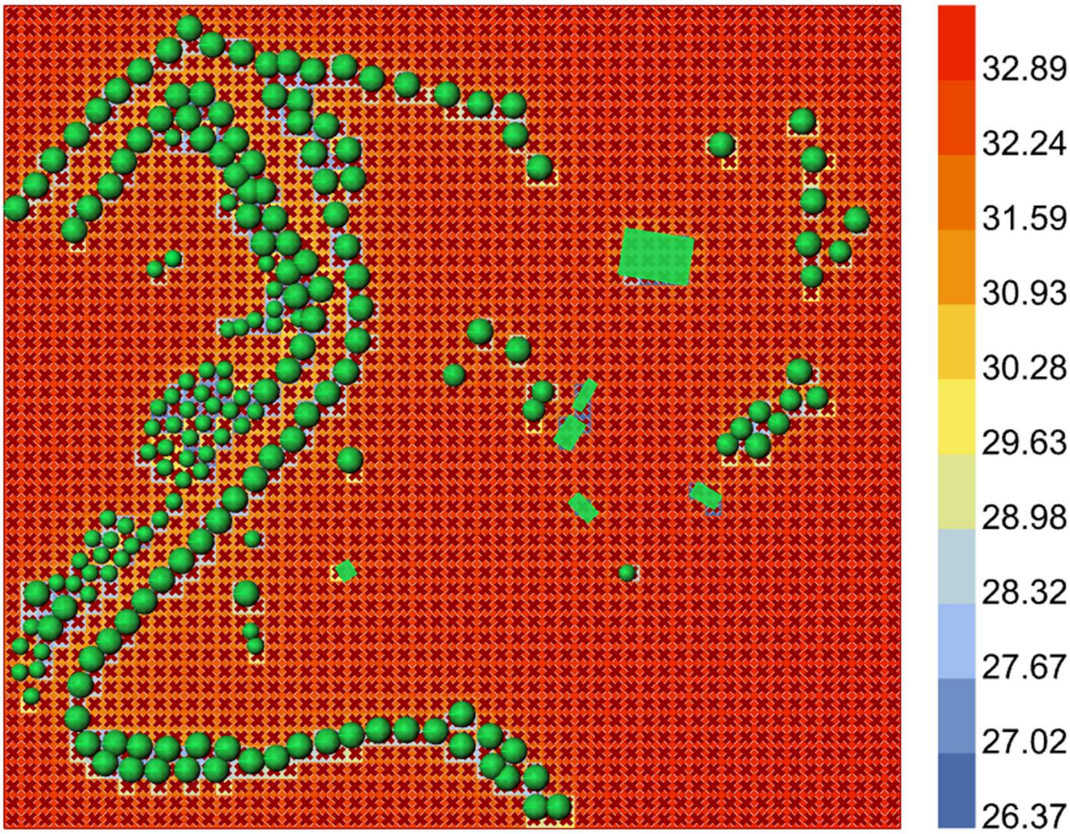


Figure 7.15. 02 October UTCI analysis at 12 pm.

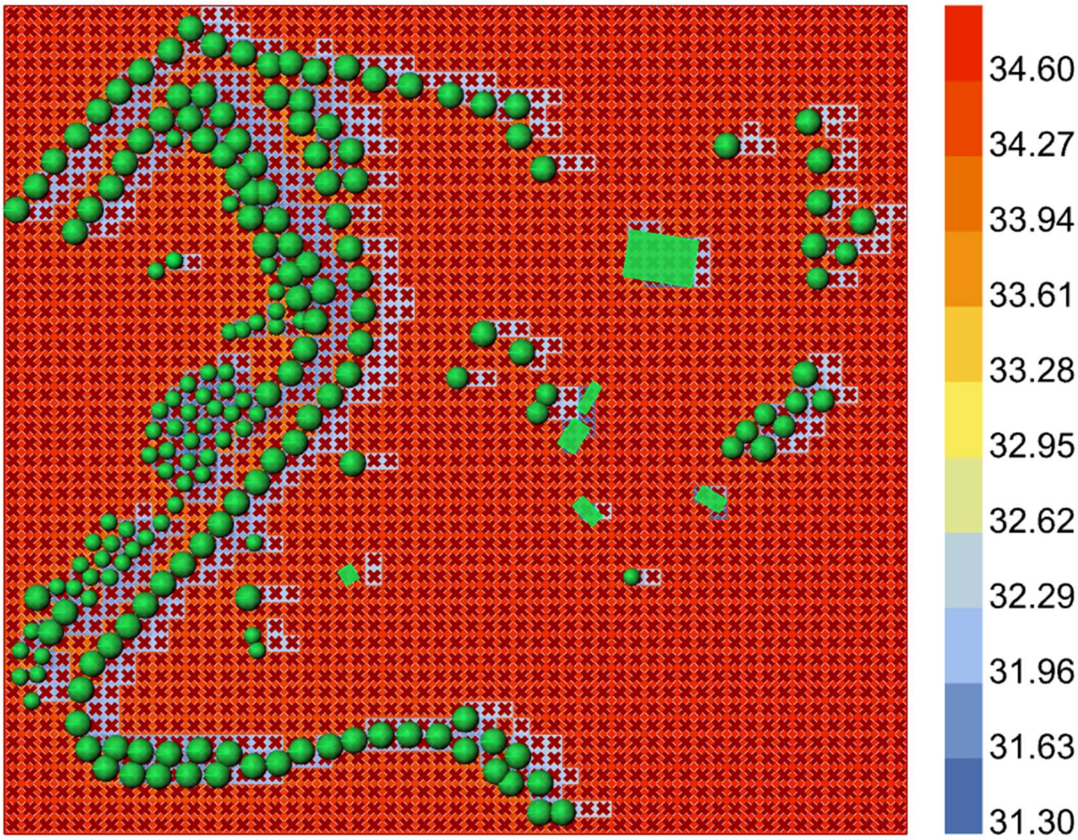


Figure 7.16. 02 October UTCI analysis at 4 pm.

7.2.2. Coldest day

30 July

On the coldest day, It is observed that the temperature is not going below 0 on the day but, at the coldest time at night, 05 am, the temperature ranges between -5.19 to -1.88. This hour also showed that water surfaces, trees, and buildings are increased heat surfaces around themself at night. Moreover, The UTCI values range from 0 to 9.76 at 8 am and the shadow range is getting bigger than the hottest day. Greater blue surfaces showed themselves near the trees and buildings but, it is getting yellow and red at noon, the temperature is rising at this hour. The range is between 5.96 to 15.75. On the other hand, at 4 pm the range is showed themself between 11.09 to 16.06 so, the hottest hours detected on this hour. Topography mostly showed itself in the middle range as yellow.

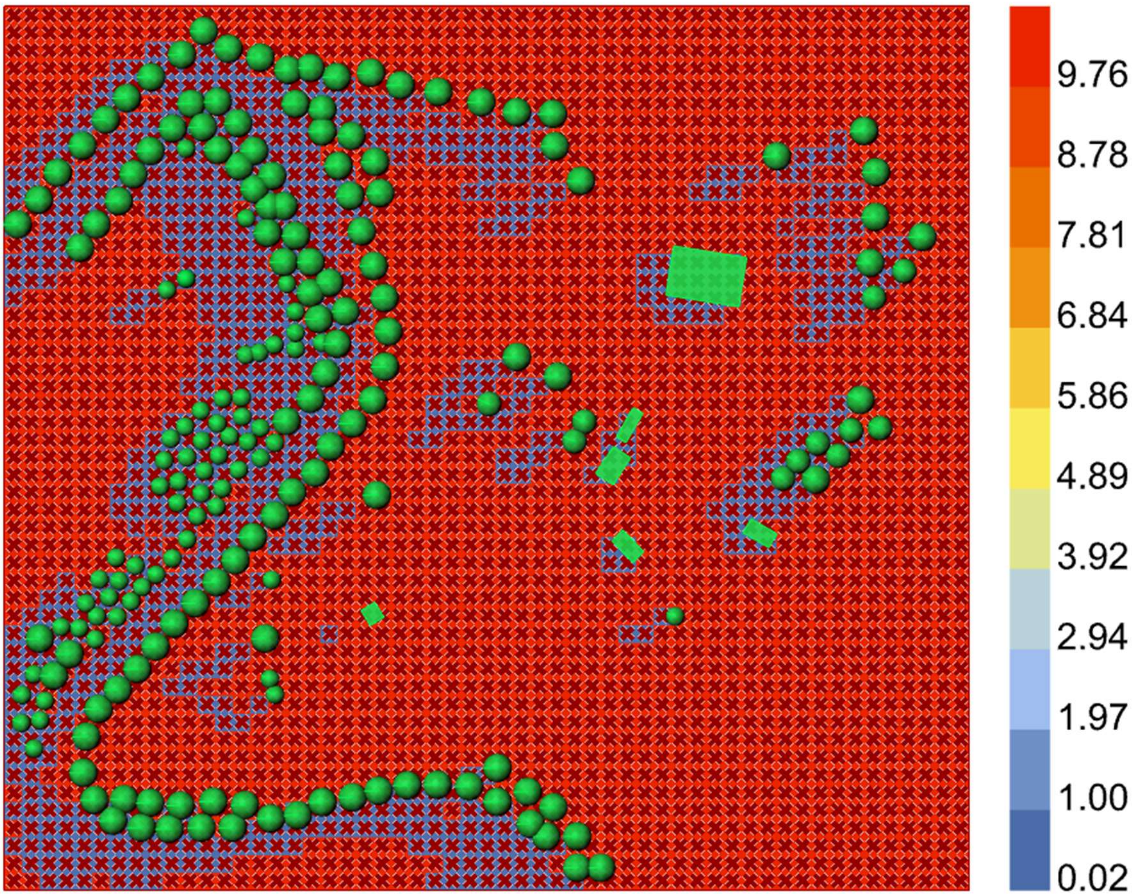


Figure 7.17. 30 July UTCI analysis at 08 am.

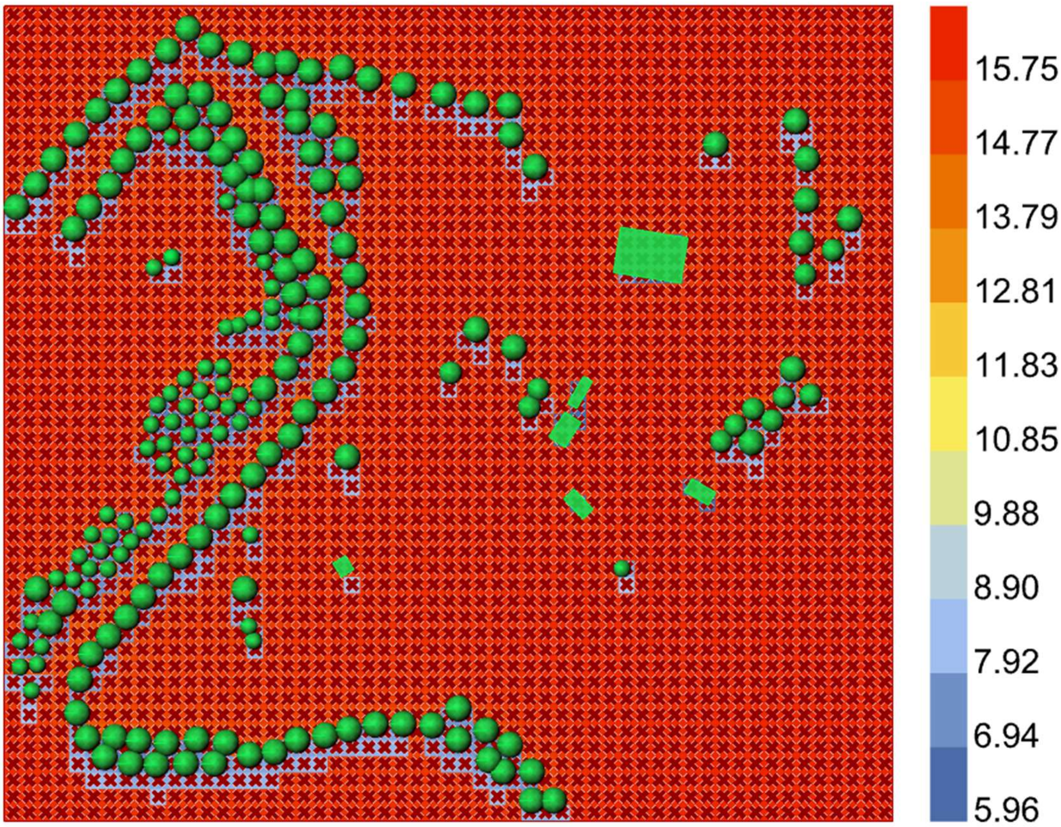


Figure 7.18. 30 July UTCI analysis at 12 pm.

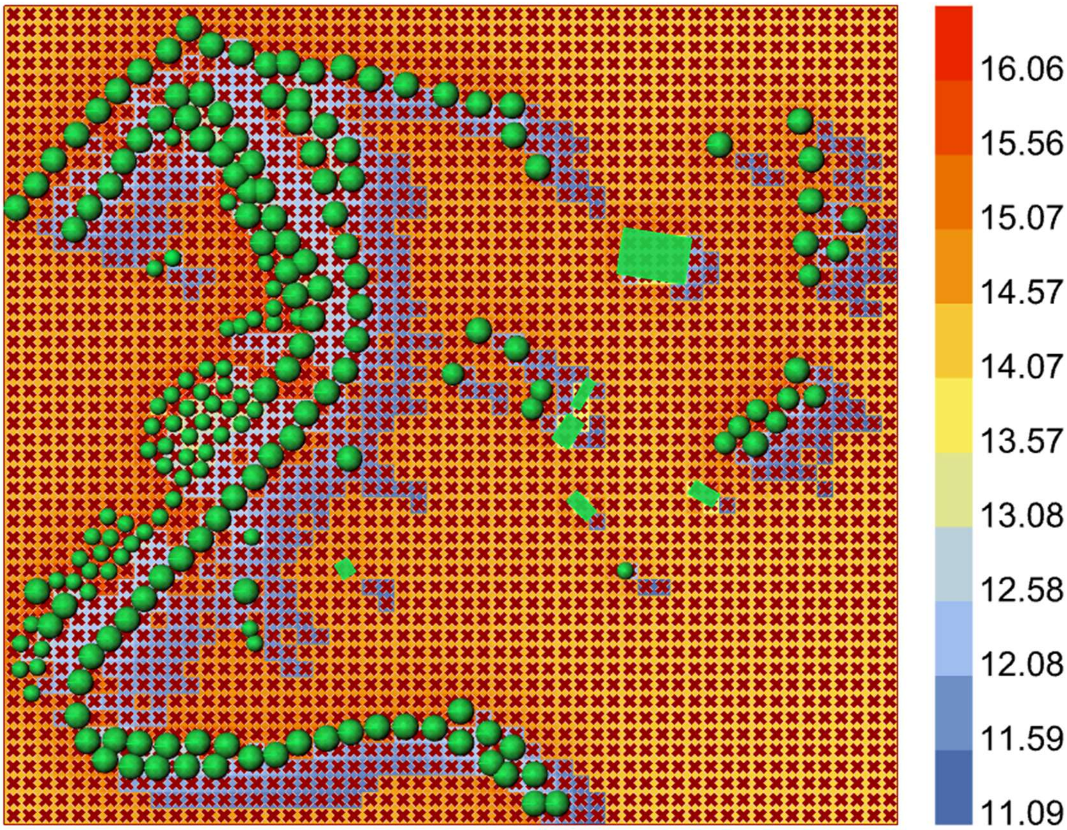


Figure 7.19. 30 July UTCI analysis at 4 pm.

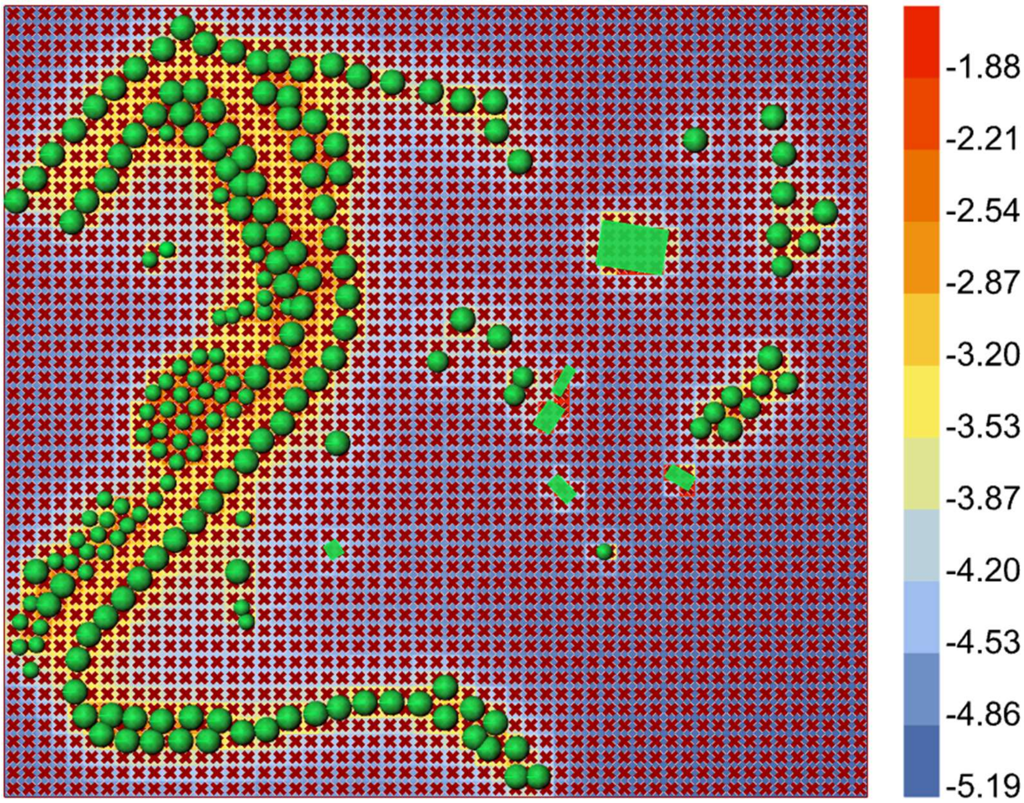


Figure 7.20. 30 July UTCI analysis at 05 am.

7.3. Incident radiation

On the 30 July winter, the sunrise at 06:33 and sunset time at 17:41 with azimuth 32.53, an altitude of 43.75° with total daylight is 11.08 hours. In summertime on 22 January, the sunrise at 06:33 and sunset time at 17:41 with azimuth 32.53, an altitude of 43.75°and total daylight is 13.12 hours (*PD: 3D Sun-Path*, 2022, p.). Based on the information's incidence of radiation is calculated on those days for the site and also total radiation is calculated.

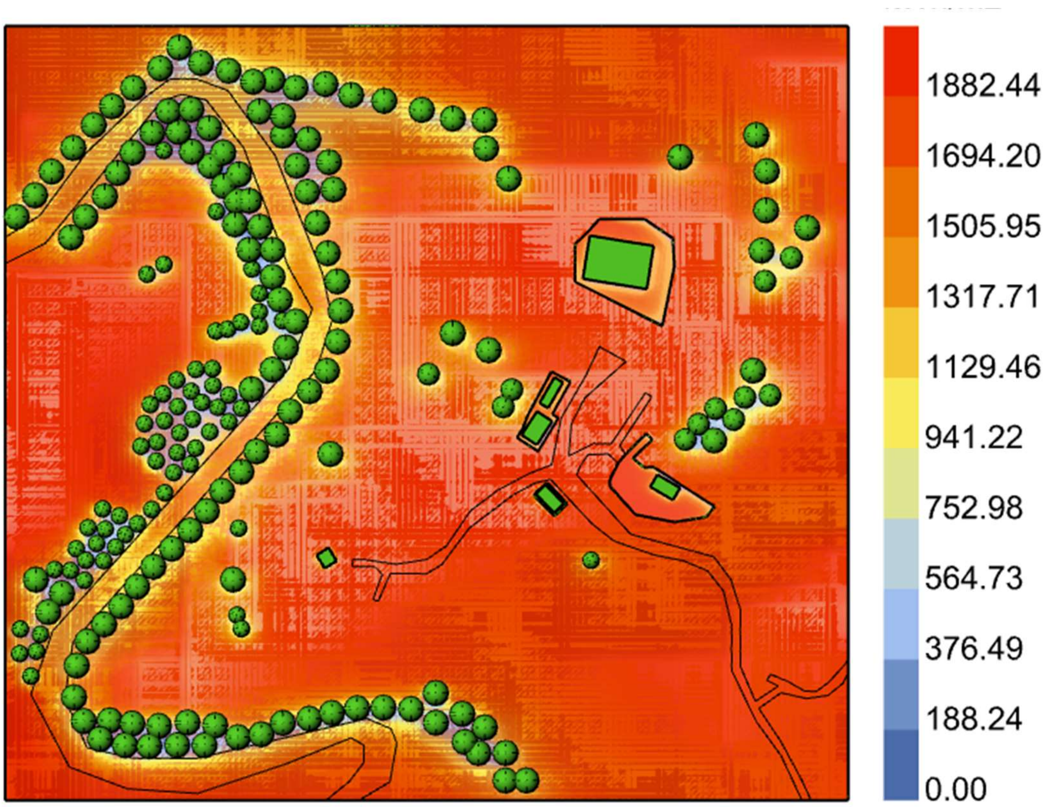


Figure 7.21. Annual incident radiation analysis.

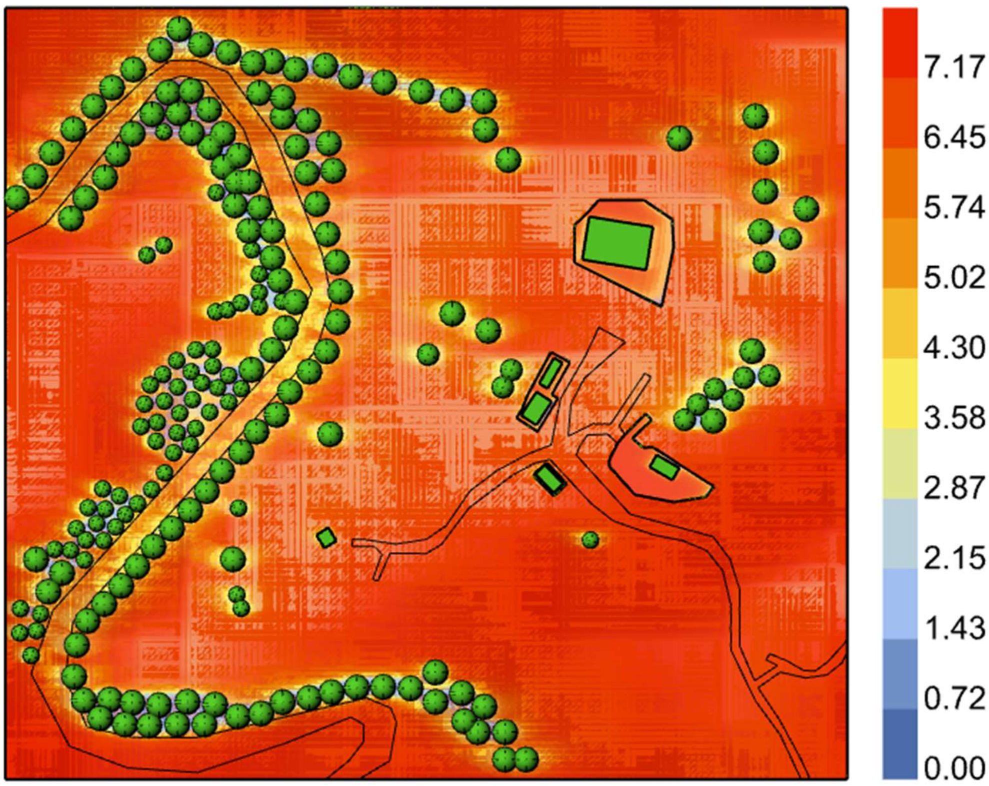


Figure 7.22. 22 January incident radiation analysis.

Figure 7.23. 30 July incident radiation analysis.

Annual total radiation is range from 0 to 1882.44 kWh/m2 on the site. The highest points without a shadow figure out has maximum radiation. On 22 January, the incident radiation ranged from 0 to 7.17, and in wintertime, the range is 0 to 5.7.

7.4. Direct sun hours

Direct sun hours analysis executed starting from 8 am until 6 pm every 2 hours in axonometric view so, they represent several hours for 22 January and 30 July as a figure in below. On the other hand, every single hour of 8 am, 12 pm, and 4 pm are also calculated for each day and placed below the axonometric view to analyze direct solar effects on the side. On the analysis, the slope effects on the site are much clear with the lowest altitude providing an advantage with decreasing direct solar radiation at some points within hours. The range is between 0 to 0.2 effects were observed.

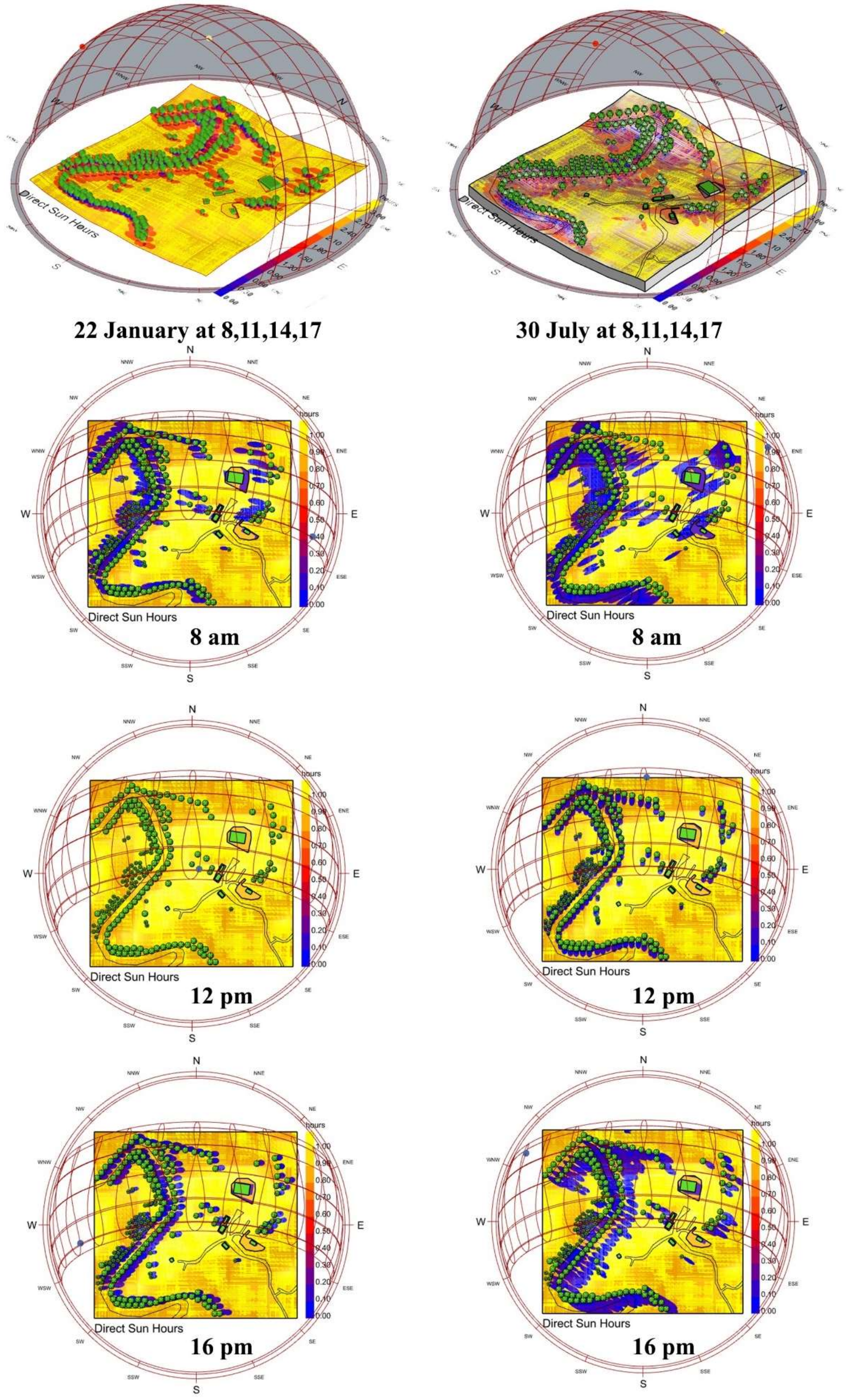
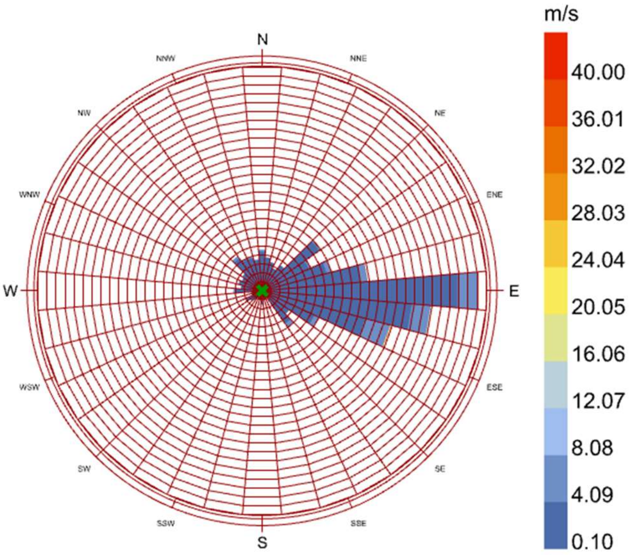


Figure 7.24. 22 January and 30 July direct sun hours analysis 8 am,12 pm, and 4 pm.

7.5. Wind



Wind Speed (m/s)

City: Lavras, Country: Brazil

Time-zone: -3.0

Source: SRC-TMYx, Ladybug microanalysis

Period: 1/1 to 12/31 between 0 and 23

Calm for 2.92% of the time =256hours

Each closed polyline shows a frequency of 0.6%= 50hours

Figure 7.25. Total wind speed m/s analysis.

The figure above shows the prevailing wind direction and the wind speed(m/s) on the site for all year. Wind speed range from 0.1 to 40.00 and wind direction figures out as mostly from the east and from the east southeast between January to December.

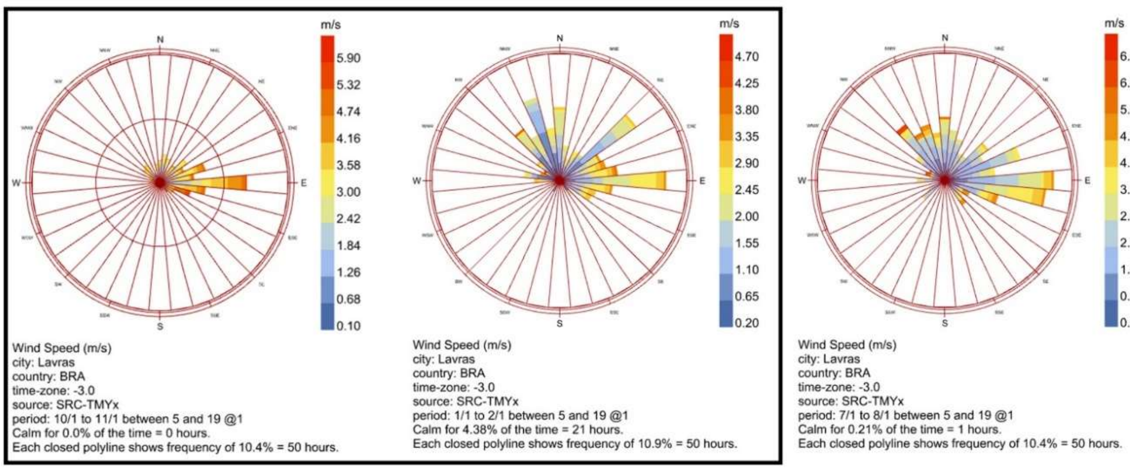


Figure 7.26. Summer and winter wind speed m/s analysis.

The figures in the black rectangle above represent the summer months and, the winter month graph is on the right side. The wind speed is calculated based on 1th day of the month until the end by covering all months of January, October, and July. The prevailing wind showed itself on the east side all over the months but, in January it also showed itself from the north side, too. The wind speed is bigger in the wintertime as compared with summertime ranging from 0.3 to 6.70.

7.6. Result

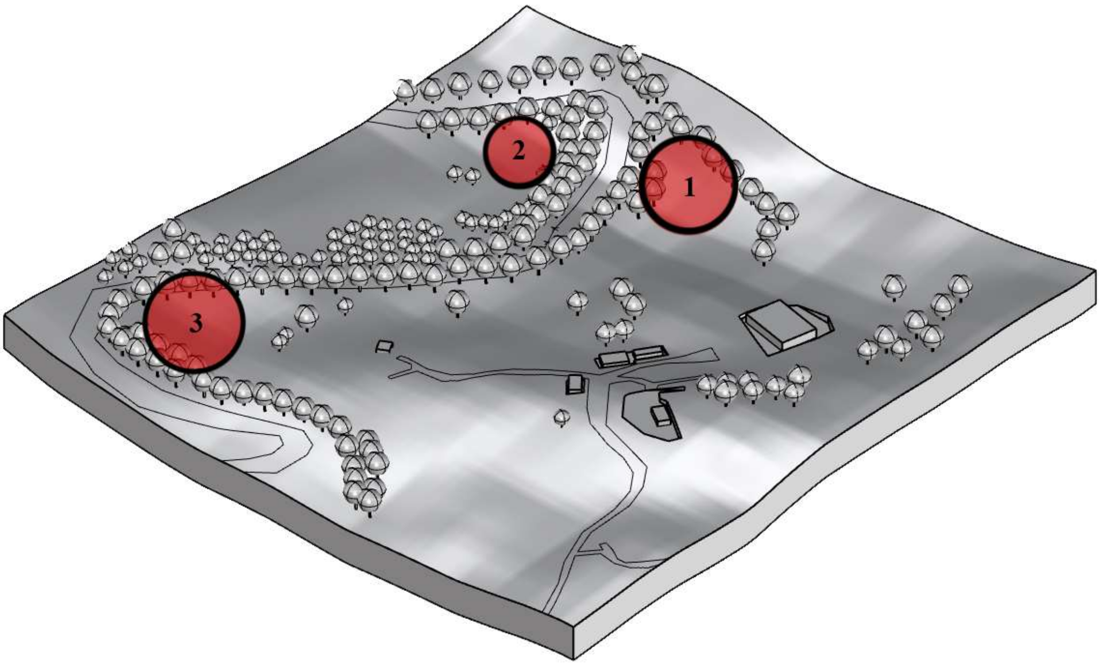


Figure 7.27. Suitable plots from the analysis.

In both conditions such as the hottest and coldest days, vegetation and context figured out with positive effects on the site, even at the night it produces heat to the site, and also it helps to decrease the temperature during the day. From the coldest day analysis, it is observed that even the minimum temperature will be in thermal comfort for cattle range between -5 to 20 (Waggoner, 2015) so, the main focus must be to decrease the temperature on the site. The existence slope doesn't show remarkable effects but, some dug places showed lower temperatures in UTCI analysis.

From the final output, 3 points near to the stream executed high performance in the location that the highest comfort area represents in the figure above with the red circles. İt is observed that designing those plots will be an advantage in decreasing temperature in the microclimate for cattle. Moreover, it is observed that the points' advantages are provided by the trees and water surface around the area so, increasing trees may create more advantages with a suitable design. On the other hand, elevation difference is providing an advantage on the general analysis by blocking as much solar radiation on the points 1 and 2. So, those points have shown more advantages. Additionally, It is observed that the wind is taken from the east side so, creating obstacles on this site is not preferable, the wind must pass easily around the area to increase ventilation and cooling effects the area. Under these conditions, only one point (1) was figured out as suitable for the design, considering its more advantages.

PART 3: DESİGN

8. Proposal

8.1. The site

The farm's name is Progresso Olaria approximately 26km away from Lavras and the owner of the site is Edson Wander Alves who already has one compost barn model which is for 100 cows and a small wooden barn for the 15 calves. As a service building, he has a milking unit, a storage unit for cow feed, and silage under the earth's surface. Moreover, his house is close to these units and it is also on the site. He has a total of 95 cows and 9 calves at the moment and he wants to increase capacity.

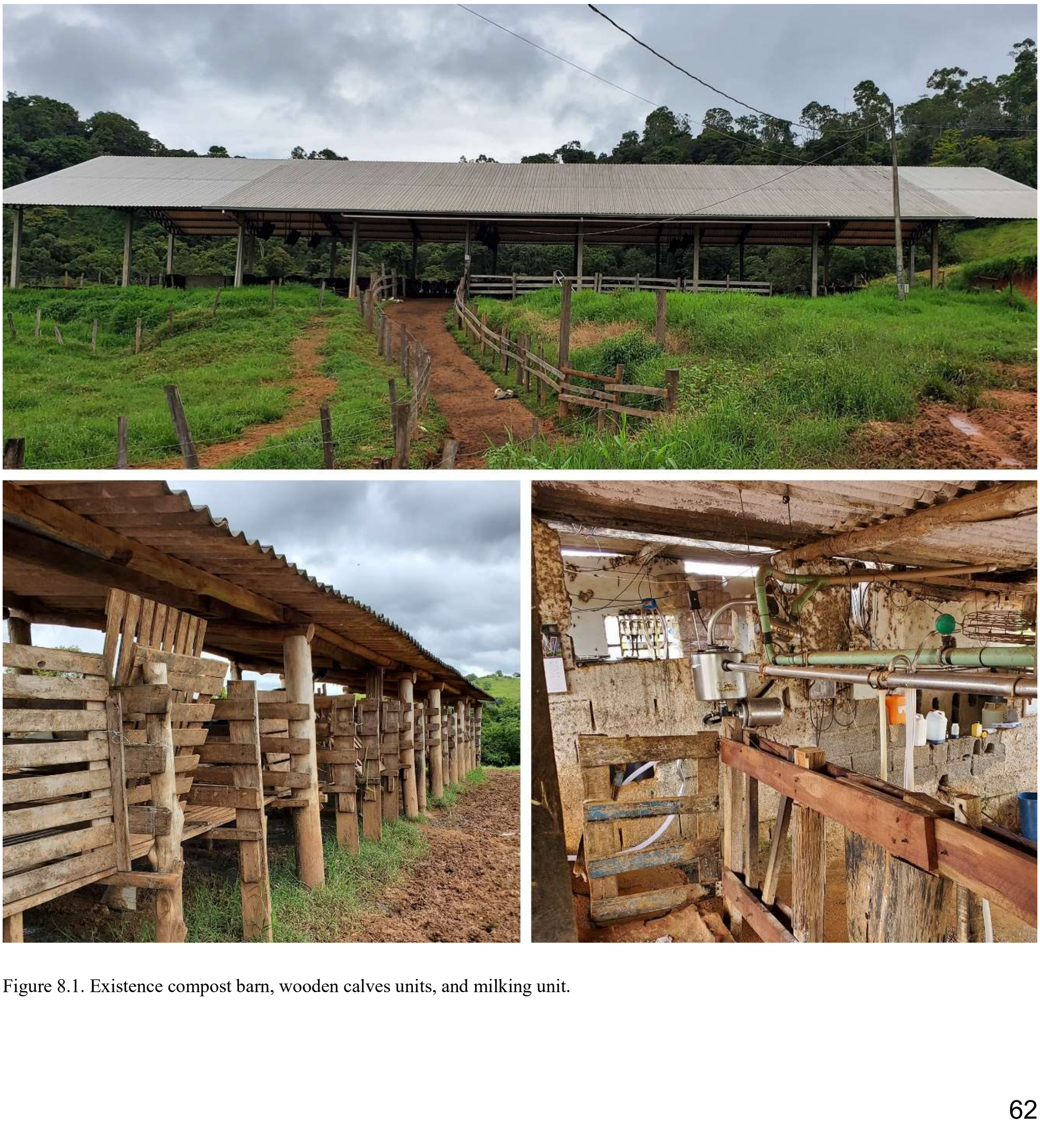


Figure 8.1. Existence compost barn, wooden calves units, and milking unit.

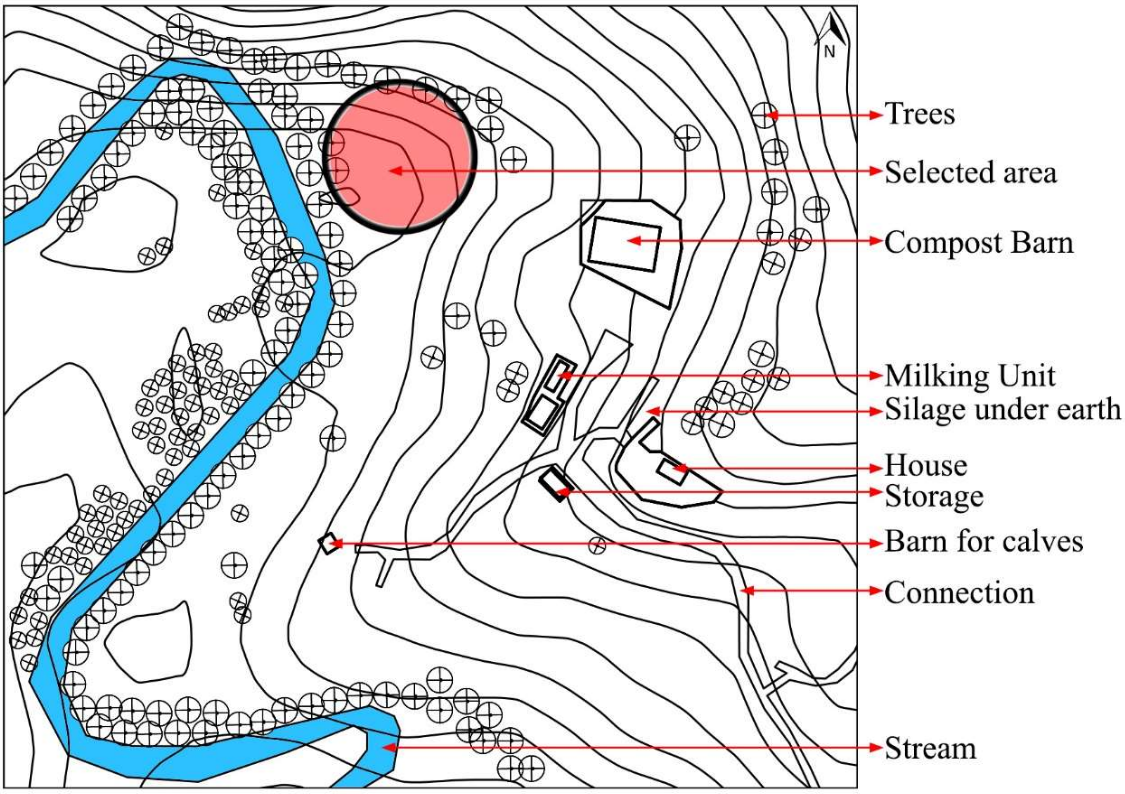


Figure 8.2. Existence site and the selected area. Contour lines:5m and Scale: 1/500

8.2. Architectural program and scenario

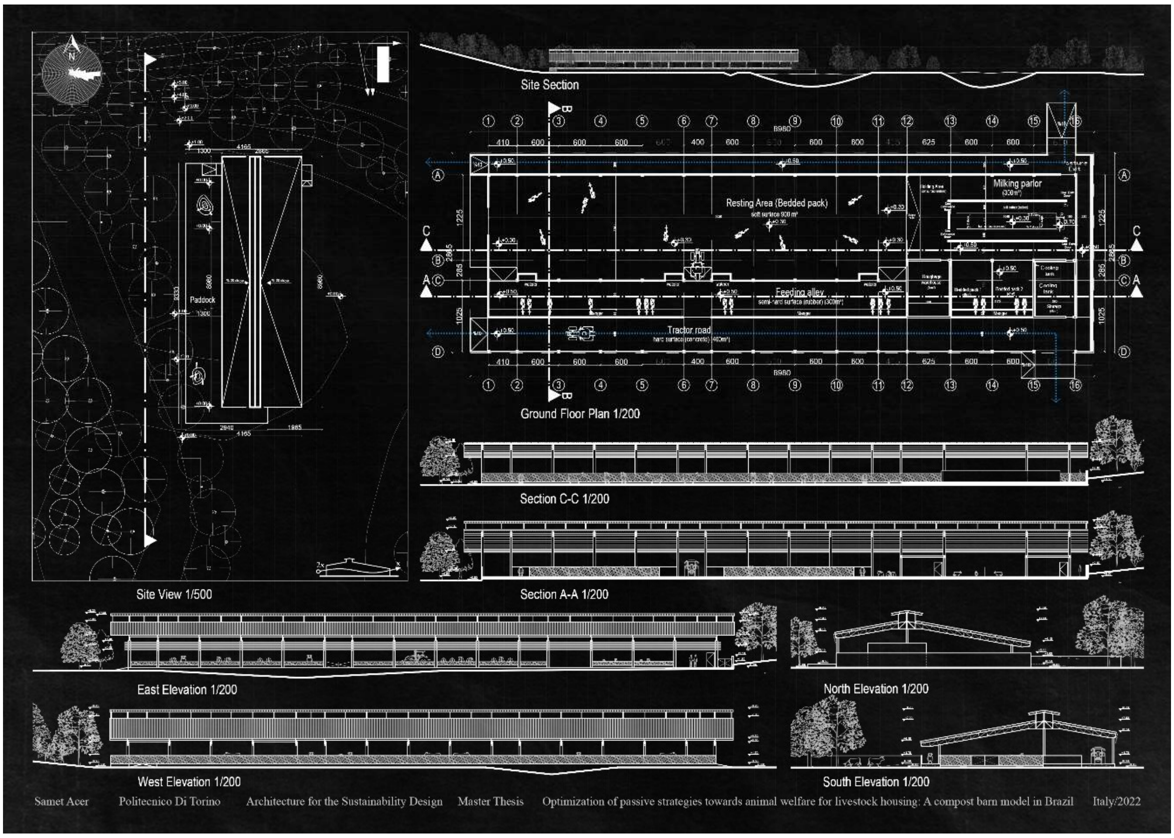
Edson Wander Alves wants to build a new compost barn model which is for approximately 80 cows and a milking unit to support it. One of his considerations was the closer milking unit to the compost barn for easy accessibility because he had problems on existence unit so, creating easy management was a consideration for the farmer. He prefers to strive for the farm's long-term viability and increase productivity as much as possible as an entrepreneur and he knows that he can achieve it by increasing animal comfort and welfare. He is keeping a little more budget for the subject but, he also wants to reduce unnecessary expenditures and to build as cheap as possible. So, he likes a cattle barn with little investment and lower healthcare costs as much as possible with the correct design. On the other hand, he would like to have cold storage for milk and one roughage storage as a support unit.

Calculating compost bedded pack barn dimensions (Bewley, 2012)				
Step	**Calculation**	**Formula**	**Inputs**	**Result**
1	Required Pack Area	RCxNC	16x100	1600 m2
2	Barn Length	(MC x NC)/12	(8x100)/12	66 m
3	Pack Width	RPA/BL	1600/66	24 m
4	Total Barn Width	PW + FAW + EW	24+4+0.5	28.5 m
5	Total Barn Area	TBW X BL	28.5x66	1800 m2
Key: BL= barn length; EW = exterior walls; FAW = feed alley width; MC = manger space/cow; NC = number of cows; PW = pack width; RC = resting space/cow; RPA = required pack area; TBW =total barn width				
Recommendations: RC = 24 m2/cow (Macitelli et al., 2020) and range from 10 to 30 m2(Klopčič & Kuipers, n.d.), MC = 8 in/row, FAW = 4 m, EW = 0.25m				

Table 8.1. Calculating compost bedded pack barn dimensions (Bewley, 2012)

The information above was collected from the literature to optimize necessary areas for the compost barn model. The calculation had made based on that information before the design and the optimal decision made by those data.

8.3. Overview of the proposal



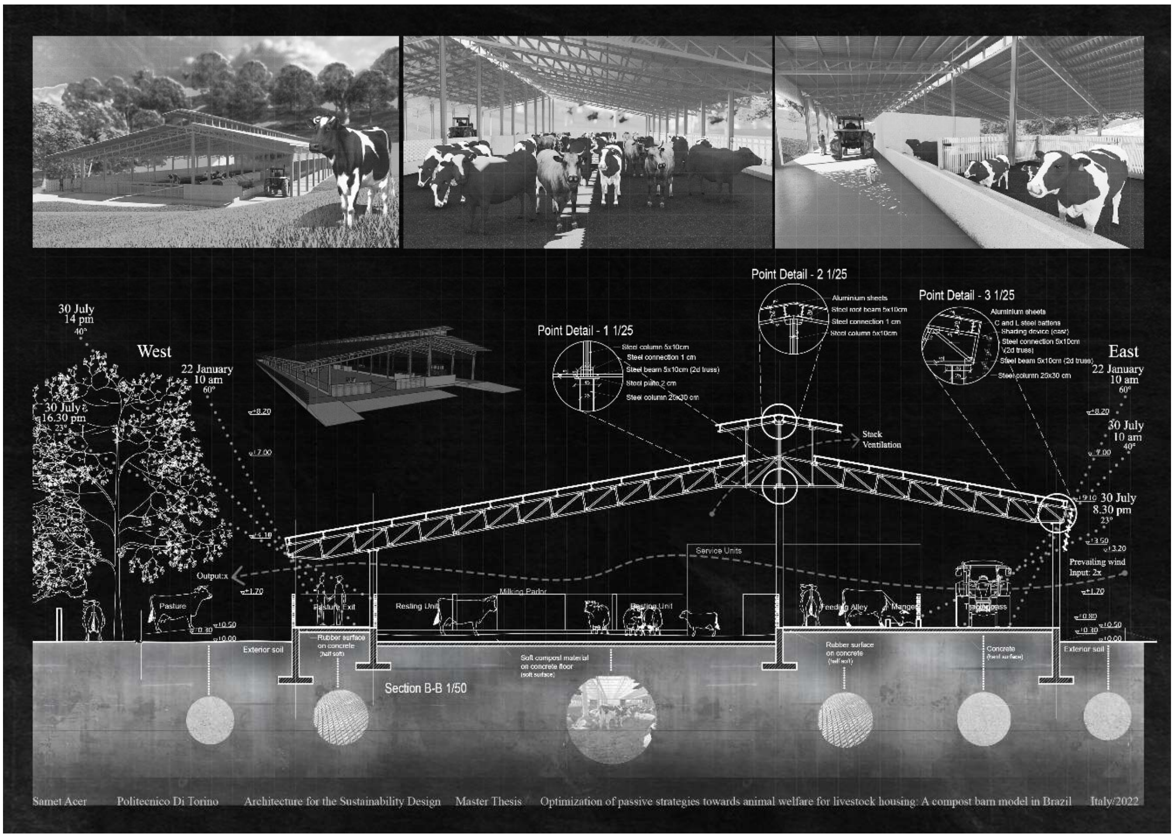


Figure 8.3. Sustainable compost barn design through animal welfare with optimized architectural passive strategies.

The design was located based on analysis with considering advantages of the trees, slope, and stream in the location. And, the paddock is located on the west side to decrease solar radiation by getting shadows from the trees and getting passive cooling from the stream. Passive strategies helped to optimize them on the site. Orientation is generally from east and west in the Minas Gerais but, we preferred reverse to get more ventilation from the east side and, disadvantages are blocked with using architectural strategies in a correct way. Moreover, the linear shapes provide a narrow space which creates fast air cleaning when considering the prevailing wind side as compared with bigger dimensions. So, one of the reasons to prefer a simple rectangular shape instead of a complex form is the increased ventilation and cooling effect in the space below the roof. The other reason is that application and construction techniques are easier and more affordable so it was more suitable for the people in the region and also for the owner. The form supports the design to gather necessary units on the roof without any functional problems and provides easy control of natural sources such as solar control or wind. Basically, all design decisions such as unit locations and size under the roof, dimension of the spaces or highs, roof hangings, or shading devices all are defined based on the controlling natural sources for animal thermal comfort and animal welfare.

8.4. Planning

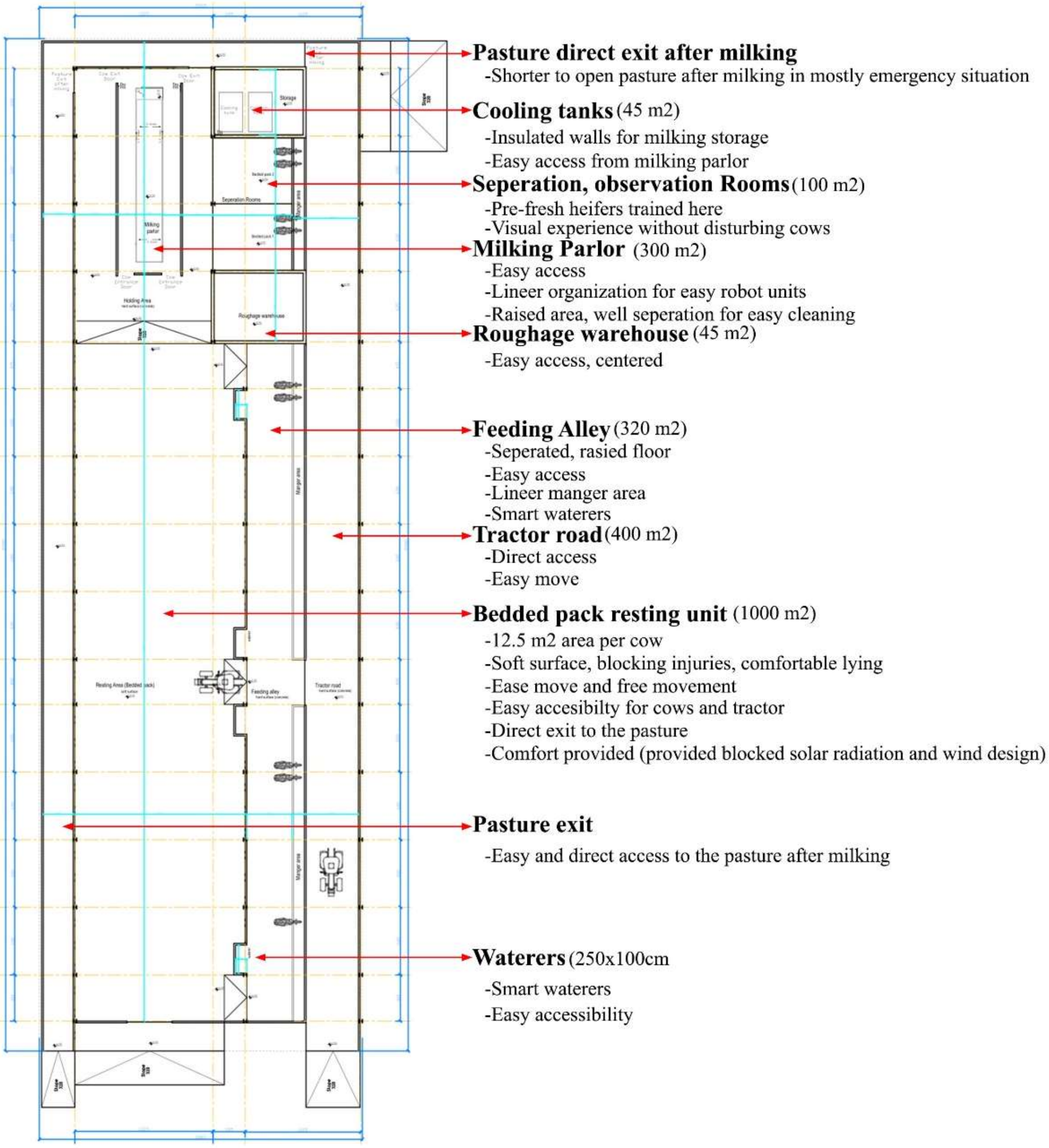


Figure 8.4. Ground floor plan.

The layout shown in this article's design features a bedded pack with grazing access and a linear milking parlor. This layout is relatively straightforward because everything is protected by a single rectangular roof, yet it enables automation that is simple for cows to understand and for producers to handle. Robots can be successfully integrated into a grazing dairy enterprise with the correct mix of management strategies, a strong support network, and an ideal barn layout. Designing the barn to make it simple for cows to access the robot and the grazing field is the basis of it all. Cows enter the milking area from one side and exit on the opposite side, either to the resting area or immediately to the pasture. To prevent the mixing of milked and unmilked cows, which can cause congestion, the cows first leave the milking parlor in the opposite direction. As a result, sorting cows is made simpler. A free-flow arrangement should be chosen to optimize capacity (time milking). On the other side, in milk-first, proposal is maximizing capacity by only allowing cows with milk permission into the robots. The quality of the bedded pack is retained when cows returning to the barn do not enter the pack instantly at one location. Cows with milk permission go to the robot immediately while those without milk permission are sorted to the resting unit or pasture. Interaction is provided between cows to keep their natural behavior so, a separation room is provided for necessary conditions.

8.5. Solar control, ventilation and cooling design

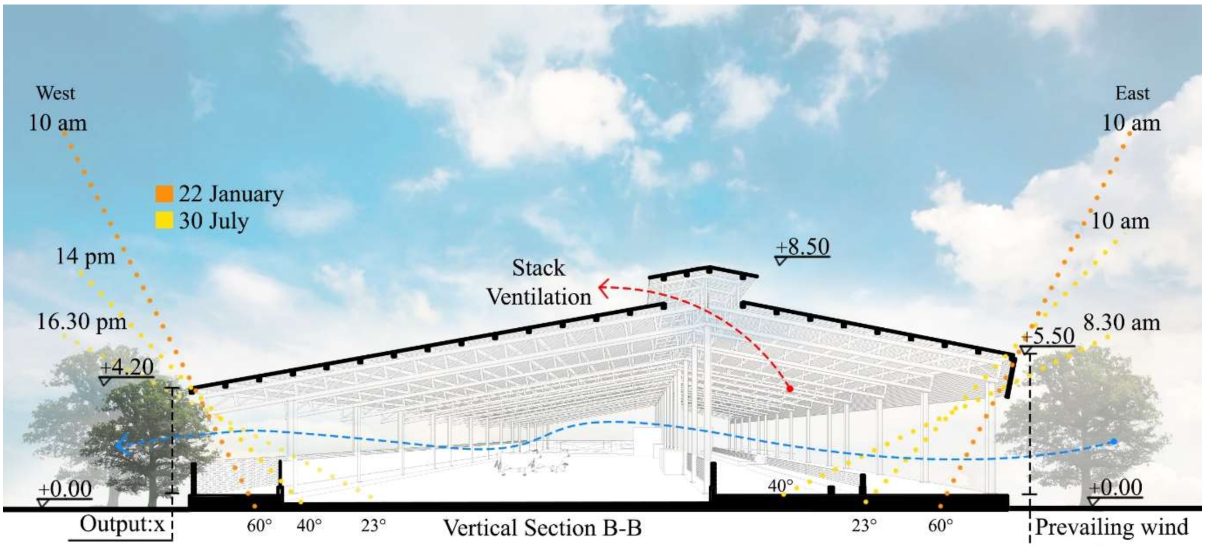


Figure 8.5. Vertical Section.

On the coldest day and the most horizontal sunbeam on 30 July, every hour had been calculated before design to arrange interior units and block solar radiation as much as possible in the spaces under the roof. So, the roof is designed to block solar radiation even on a winter day to decrease heat stress. Meanwhile, there were no direct solar radiation problems on other days because of the rising angle with this calculation method. West had lots of big trees on the site which provides shadow so, the advantage was helpful to block solar radiation from the west side with also accurately using the roof's angle, high, and overhang. On the other hand, the east was playing important role in the design which has a prevailing wind direction. So, it was not logical to reduce the roof's high because it was also blocking the wind. The design was created, when blocking east solar radiation by creating suitable roof and shading devices, the design provides wind to enter directly into the proposal. For this purpose, by creating input of the wind 2x from the prevailing side, and creating x on the other side, cool effects are upgraded as much as possible, and also stack ventilation is provided to increase ventilation effects under the roof. Support units such as the milking parlor and storage are placed on the north side to block the sun's highest angles of radiation. All design elements such as walls, shading devices, roofs, or even interior orientation are provided to decrease solar radiation and provide ventilation and cooling effects on the proposal as much as possible. Finally, the lake cooling effect was also considered.

8.6. Roof structure

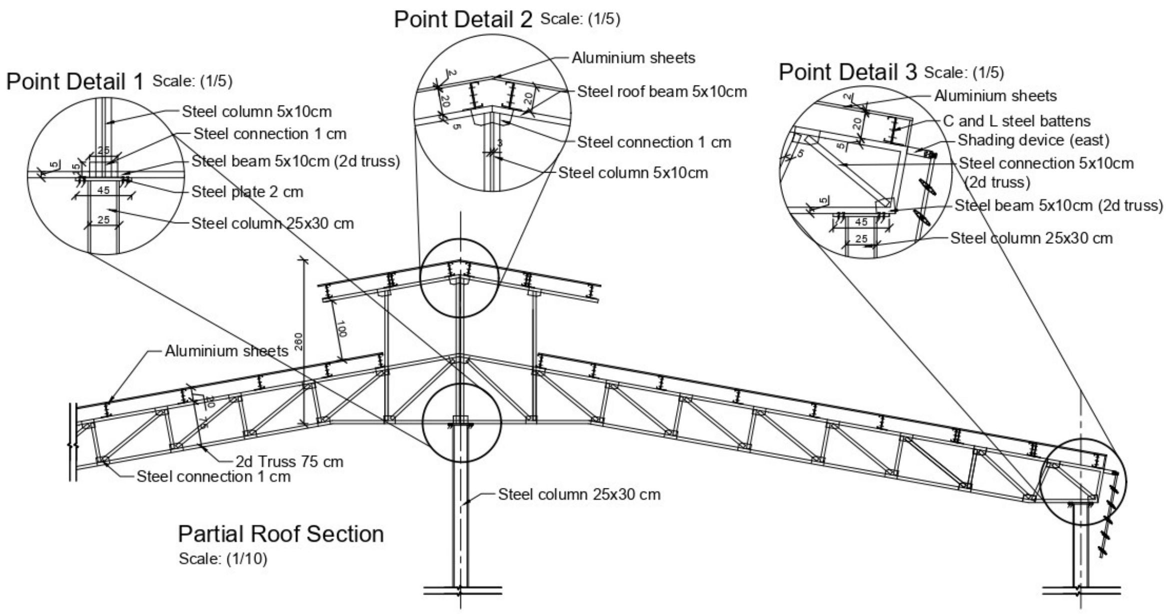


Figure 8.6. Roof structure detail.

As construction material on the roof, steel was selected. The reason is not only the bigger span, it makes it possible to reuse or recycle. Steel is one of the world’s most sustainable materials. The material provides an advantage for reliability with it is durability so, it is a long-lived construction material that requires very little maintenance and leaves a smaller footprint. It provides safer construction work, and is deconstructed just as easily as constructed (Bhatnagar, 2021).

8.7. Floor and materials

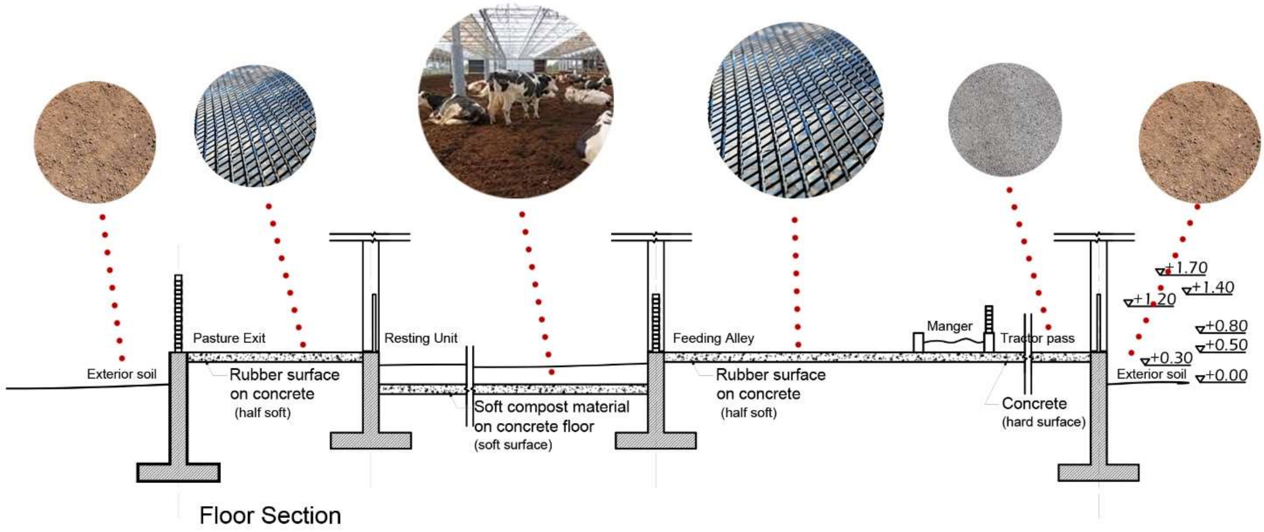


Figure 8.7. Floor section details.

When designing hard and soft surfaces and finding the correct material, the maximum welfare conditions are observed for health problems such as injuries, breast and foot problems, or even comfort conditions. Rubber is used to create a half-soft surface on the pasture exit way, milking parlor, and feeding alley. Resting units have a totally soft surface using compost. The only hard surface exists on the tractor road and cows can not use this surface. So, their natural behavior and their living are considered in the material selection and design decisions. They are in their natural living life and the problems defined above are mostly solved.

Figure 8.8. Interior views.

9. THESIS RESULTS

9.1. Discussions

The objective of this study is to increase production as much as possible while also boosting the welfare of the cows and the thermal conditions in their dwelling quarters because there is a dearth of research on livestock housing construction under animal welfare. However, one of the main considerations was the meaning of animal welfare, standards, and also finding a livestock housing model which can provide the highest welfare conditions. Based on several institutions that are working on animal welfare, data collected from those institutions and also from the papers, journals, and books directly forwarded us to one of the barn models that have more advantages on welfare when compare with other types of livestock housings. The model has also disadvantages such as ventilation and cooling having problems which was an issue, especially in a tropical climate, the research has been focused on the feasibility and adaptability and, the solving the disadvantages. For this purpose, regional research is made to understand, if it applies to the region from the eyes of farmers, vets, or agricultural engineers. The research showed that it is applicable and preferable in the region so, the project focused on the disadvantage of the compost barn model as much as possible. So, architectural passive strategies were figured out from the literature and worked on applicable to this climate as a solution. Thanks to climate data from EPW, within this thesis work, models were created within the various software to simulate the current state and subsequently the project state and to adapt the solution to the climate, several analysis methods had been carried out with starting an understanding of general climate conditions and continuing with micro-climate analyses such as UTCI, incident radiation, direct radiation, direct sun hours, and wind analyses by creating 2750 analysis points on the site. From this analysis, the exact area for the compost barn was figured out, and every single day and time was calculated to block solar radiation on the design face. On the other hand, wind design was the most important issue to provide higher ventilation and cooling effect. Relating to, organizations generally must be east-west to decrease solar radiation as much as possible in tropical climates but, our proposal is the reverse. The reason for that is the prevailing wind direction. So, the wind is playing a very important role and for solar radiation, every date and hour must be a consideration when calculating it accurately and design must be affected by this in real life, it is a very important issue for sustainability that carried out on the design phase in the thesis.

The study focused on the improve milking cows' natural behavior, thermal comfort, and welfare to improve productivity which is an important aspect for animals under human control. There must be more research on this topic to decrease global warming and create animal welfare in a safer living environment and necessary time must have given for this purpose. Lack of time was the main limitation of this study and also during the Coronavirus, the study was carried out in an extraordinary situation so, the suggestion is that more time is necessary for that kind of project. On the other hand, the data is figured out based on EPW climate data in this thesis. If climate data can be collected on the micro-climate by the researcher, the data can be more accurate. Moreover, the project is not possible to reach the maximum level of comfort, without considering and quantifying the technology such as mechanical systems to help with cooling and ventilation but welfare conditions can be provided with suitable natural living design.

9.2. Conclusions

With the rapid population growth, necessities are increasing. It would be necessary to boost overall food production by 70% in 2050, which would necessitate major production increases so, using more methane gas, and increased usage of electricity and petrol that causes global warming (FAO 2009). Therefore, to provide those necessities, additional systems with use extra energy creates negative effects on humanity such as hotter temperatures, more severe storms, increased drought, rising ocean, loss of species, and health risks. The performance of agricultural goods must be improved without utilizing additional energy that contributes to global warming. So, sustainable production getting important and several institutions and researchers focusing on it to decrease those bad effects on humanity. Safe production and maximum efficiency, are the pillars of this aspect, especially in food production. The research on this subject shows that this is getting more important year by year and under this aim, the new solutions will going to provide so, the belief can be one of the solutions to livestock housing design (Galama et al., 2020). On this aim, using maximum natural sources in the barns and optimal solutions for animal welfare must be the main focus. More research and innovation are needed to maintain sustainable production while also improving the living environment of animals, comfort, and decreasing diseases or injuries with supporting the agricultural needs of our economy.

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APPENDIX

SketchUp

The site information was extracted using google map on the SketchUp program

1. Setted 'mm' from Windows/Model Info
2. Window/Model Info/Add Location/Coordinates/Select Region/Import
3. Click the map/Toggle Train
4. Saved As/SketchUp 7

Rhinoceros 7

The site was created as a mesh using information from SketchUp and google Maps and the buildings, plots and trees placed.

1. Open Template File/Largo Objects-Millimeters/Open
2. Command/Import(SkechUp file)/Open
3. Command/Drape(AutoSpacing=yes, Spacing=5, Auto Detect Max Depth=yes)/Select Boundery (Site created)
4. Command/ExtrudeSrf(Solid=yes)/Set thinkness/Enter

Drawed road and water surface with reference and placed on topography.

1. Command/Project/Select Road and Topography/Enter

Sites are created for each building's plot. Drew with polygon line and created a box on the topography.

2. Command/BooleanDiffrence/Select the topography/Enter/Select Boxes/Enter
3. The buildings are created and placed on the plots.
4. Some important trees are placed for the calculation.

EPW (EnergyPlus)

EPW (EnergyPlus Weather Format) is used for climate data.

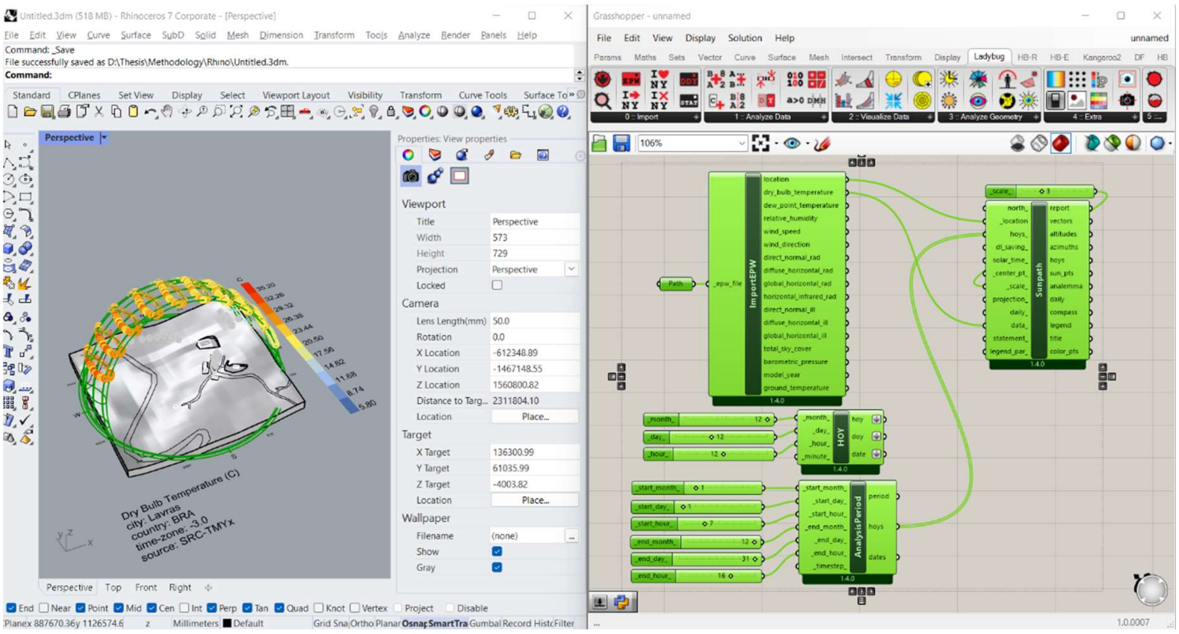
1. Go to https://www.ladybug.tools/epwmap/ or https://climate.onebuilding.org
2. Find the location (Lavras :: 836870 :: ISD-TMYx) /Click to download from ONEBUILDING.

After downloading epw. file, settings will be created in ladybug for microclimate calculation.

Ladybug analysis

Sun Path Matrix

1. Command/Grasshopper/ click ladybug
2. Placed Lb Import epw on the screen
3. Find Path (Double click on the screen and find filepath/Enter
4. Right-clickick on path/ Select one existing file/ add
5. Connect path with ImportEPW.
6. Added Lb sun path/ linked with the location to location.
7. Added Lb analysis period/ linked with the hoys to hoys.
8. Each month, day, and hour boxes are created and linked with the Lb analysis period.
9. Added Lb calculate hoy and linked with hoy to hoys (it is for calculation of one single day and hour)
10. ImportEpw(dry_bulp_temp.) linked with Sunpath(data_)



Sun path is created by showing dry bulb temperature and it disabled for the next calculation.

Incident Radiation

1. Download and install the version of Radiance listed in the Ladybug Tools compatibility matrix. (https://github.com/ladybug-tools/lbt-grasshopper/wiki/1.4-Compatibility-Matrix)

2. Add Lb cumulative sky matrix/linked ImportEPW matrix(location, direct_normal_rad, diffuze_horizantal_rad) to Lb cumulative sky matrix(location, direct_rad, diffuze_rad) and linked hoys.

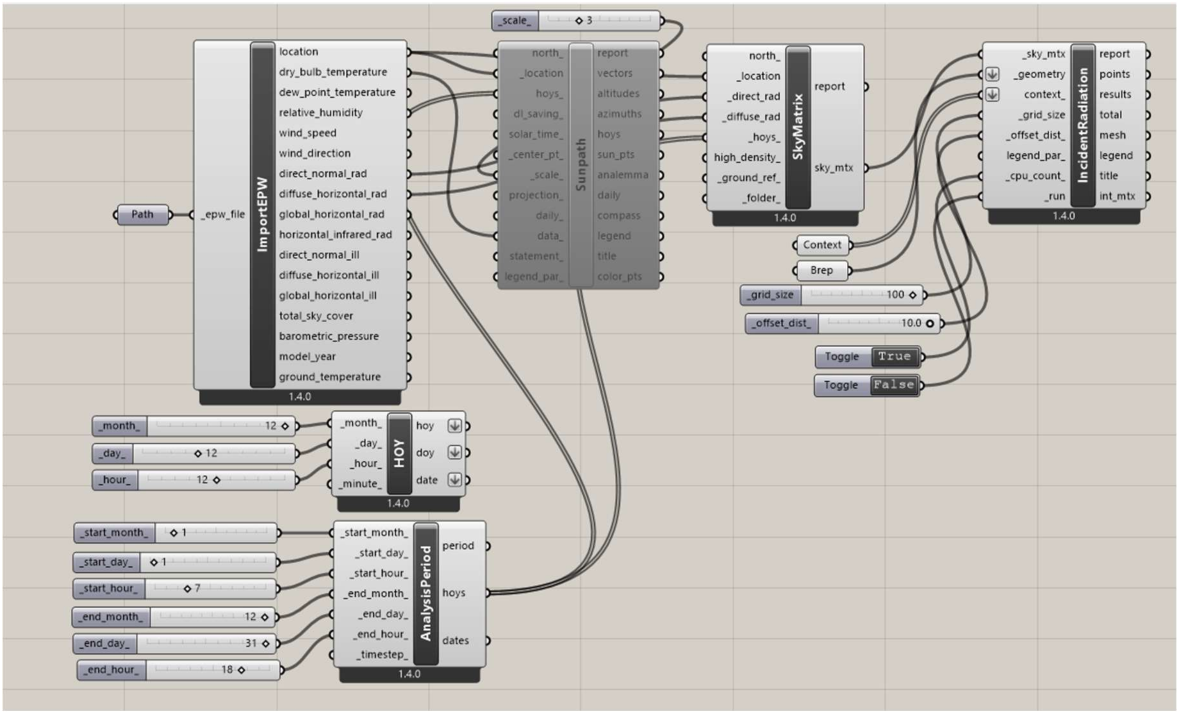
3. Added Lb incident radiation matrix/ linked skymatrix to skymatrix

4. Added brep matrix/ selected all context(buildings,trees/Right click to the brep matrix and click to set multiple breps/ linked with Lb incident radiation matrix(context).

5. Added brep matrix/selected topography/ linked with Lb incident radiation matrix(geo).

6. Added grid size 100, offset 10 and linked with Lb incident radiation matrix.

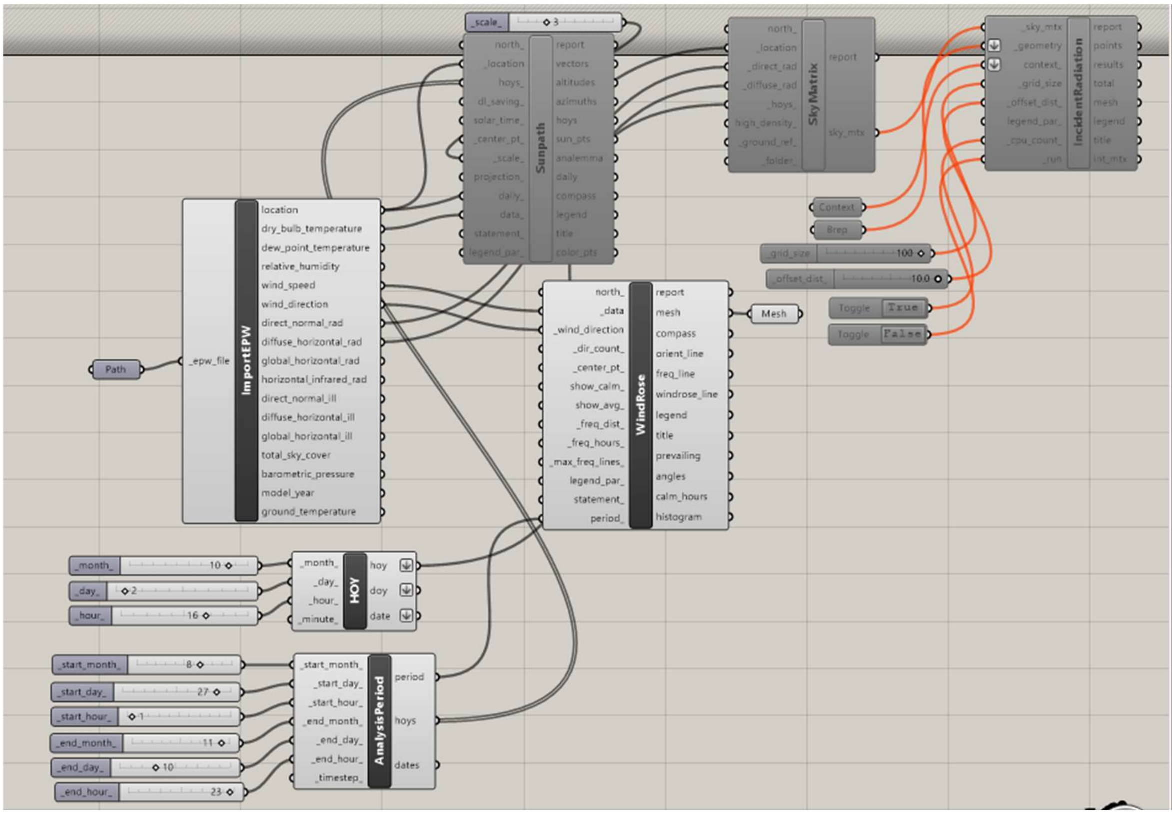
7. Added two boolean toggle and linked with Lb incident radiation matrix (_cpu_count, _run)



Disabled Sunpath, skymatrix and incident Radiation matrixes for next calculation.

Wind

1. Added Lb wind rose matrix.
2. Linked ImportEPW(wind_speed, wind_direction) to wind rose matrix(_data, wind_direction)
3. Created mesh and linked with output mesh matrix.
4. Added Lb analysis period and linked with wind rose matrix(_period).
5. Month, day, and hours are placed on the analysis period matrix.

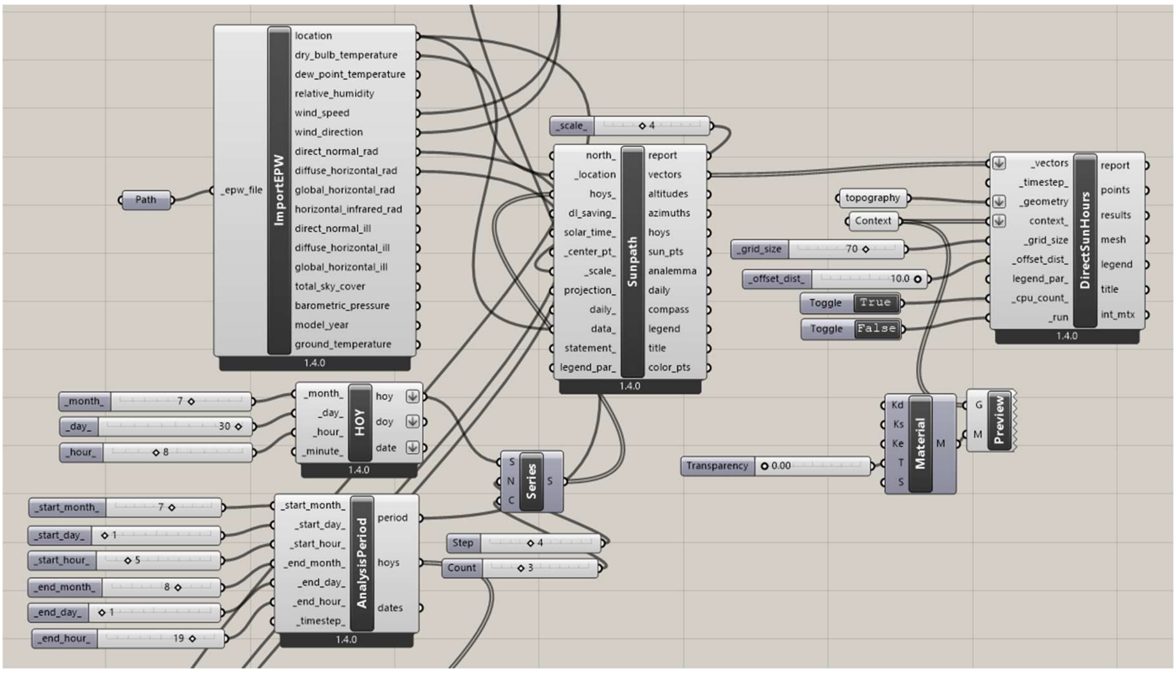


Direct Sun Hours

1. Added Lb direct sun hours
2. Enabled sun path that was created before.
3. Added brep matrix/ selected all context(buildings, trees/Right-click to the brep matrix and click to set multiple breps/ linked with Lb direct sun hours matrix(context).
4. Added brep matrix/selected topography/ linked with Lb direct sun hours matrix (geo).

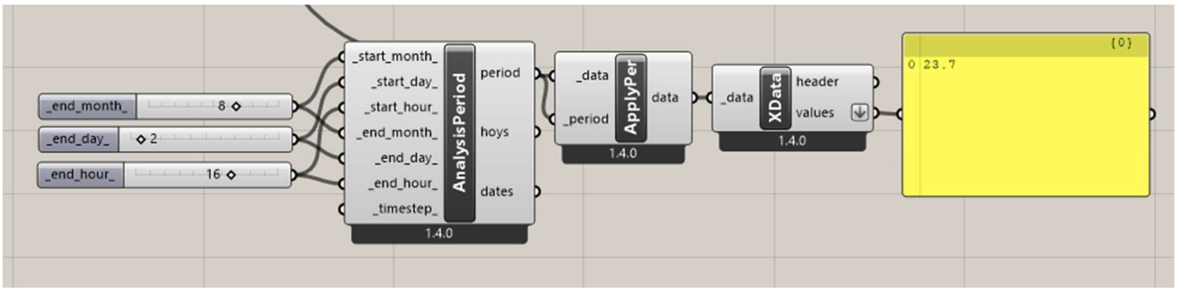
5. Connect Lb sun path (vectors) to Lb direct sun hours (vectors)
6. Connect Lb analysis period (hoys) to Lb sun path (hoys). This makes it possible to analyze every single hour, date, or time even all periods.
7. Added grid size 70, offset 10, and linked with Lb direct sun hours matrix.
8. Added two boolean toggle and linked with Lb direct sun hours matrix (_cpu_count, _run)

With a click boolean toggle makes it 'true' which means starting the calculation. The Lb material had been added for changing context or topography presentation.



A hottest week and coldest week calculation

1. Added Data path matrix and right-click on it. Select an existing file (on the climate data epw. file added).
2. Added a panel (By connecting extreme cold week output or extreme hot week output with the empty panel, the calculation started and the result was figured out).



UTCI calculation

1. Added Lb UTCI comfort matrix, Lb epwmap, Lb downloadepw and one boolean toggle.
2. Connect toggle with Lb epwmap.
3. Double click to toggle and find the location. Copied the climate information on the clipboard.
4. Added a panel and pasted information from clipboard.
5. Added Lb Importepw and Lb analysis period.
6. Connect numbers of hours, months, and days with Lb analysis period.
7. Connected panel with Lb downloadepw (wheather_URL).
8. Connected Lb downloadepw (epw_file) to Lb importepw (epw_file). For the climate data.
9. Added 6 times Lb apply analysis period and connected with Lb analysis period (period) to Lb analysis period (period).
10. Connected each Lb apply analysis period seperatly (data section) with Lb importepw (dry_bulp_temp, relative_humidity, wind_speed, direct_normal_rad, diffuse_horizental_rad, horizantal_infrared_rad).
11. Added Lb outdoorsolarMRT to provide information base for UTCI analysis.
12. Connected 1.Lb apply analysis period matrix (dry_bulp_temp) with Lb outdoorsolarMRT (surface_temp).
13. Connected 2. Lb apply analysis period matrix (rel_humid) with Lb UTCI matrix (rel_humid).
14. Connected 3. Lb apply analysis period matrix (wind_speed) with Lb UTCI matrix (wind_velocity).
15. Connected 4.Lb apply analysis period matrix (direct_normal_rad) with Lb outdoorsolarMRT (dir_normal_rad).
16. Connected 5.Lb apply analysis period matrix (diffuse_horizental_rad) with Lb outdoorsolarMRT (diff_horiz_rad).

17. Connected 6.Lb apply analysis period matrix (horizantal_infrared_rad) with Lb outdoorsolarMRT (horiz_infrared).
18. Connected Lb importepw (location) with the Lb outdoorsolarMRT (location).
19. Added Lb humantosky matrix as data provider to Lb outdoorsolarMRT.
20. Added genpts, surface, 2 boolean toggles, material, preview, apply analsis period and xdata matrixes for Lb humantosky matrix calculation.
21. Surface selected and added in surface matrix. Connected with Lb genpts (geometry).
22. Gridsize number of 1000 added and connected with Lb genpts (grid_size).
23. Genpts outputs (points) connected with Lb humantosky (position).
24. Context selected to another surface matrix and connected with Lb humantosky (context).
25. Context connected with Lb preview (G).
26. Lb preview (M) connected with Lb material (M). Material settings are done.
27. Added number 0.25 for Lb outdoorsolarMRT (ground_ref).
28. Added boolean toggle for Lb outdoorsolarMRT (run) and clicked twice to make it true for starting the calculation.
29. Connected Lb outdoorsolarMRT (mrt output) with Lb UTCI (mrt). Data provided.
30. Lb importepw matrix (location) connected with Lb humantosky matrix (location).
31. Output of Lb humantosky (fract_body_exp) connected with Lb apply analsis period.
32. Lb apply analsis period (data) connected with Xdata matrix.
33. The final values of the Xdata matrix connected with Outdoorsolarmrt (fract_body_exp).
34. Added one boolean toggle for UTCI (run) and Xdata matrix for converting data.
35. For the presentation, Lb heatmap added and connected (mesh) with Lb genpts (mesh output).
36. Lb heatmap (values) connected with UTCI Lb xdata (values).
37. With twice click on toogle UTCI calculation started and map created.

On the other hand, the values of each period can be visible with adding a panal and connecting it UTCI Lb xdata (values).