# Development of Passive Cooling at the Gobabeb Research & Training Centre and Surrounding Communities



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# Development of Passive Cooling at the Gobabeb Research & Training Centre and Surrounding Communities

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# Abstract

The Gobabeb Research and Training Centre of the Namib Desert, Namibia has technology rooms that overheat. We were tasked to passively cool these rooms. We acquired contextual information and collected temperature data to determine major heat sources to develop a solution. We concluded that the sun and internal technology were the major sources of heat gain. Based on prototyping, we recommend the GRTC implement evaporative cooling, shading, reflective paints, insulation, and ventilation methods to best cool their buildings. Additionally, we generalized this process for use in surrounding communities.

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# Executive Summary

Air conditioning worldwide has been estimated to consume 300 billion kWh annually (Henley, 2015). Current trends forecast this cooling energy will increase by five times worldwide by 2050 (University of Birmingham, 2018). Considering the implications of these two statistics, it is imperative that an effective measure to reduce the magnitude of cooling energy usage is developed. An identified means for reducing this usage is through passive cooling. This is the method of reducing interior temperatures by manipulating Earth's fundamental qualities such as the sun, wind soil, and humidity (Cook, 1989).

Passive cooling methods can be applied to in two manners, new construction and modifications to existing buildings, known as retrofits. Yet, there is a substantial investment in new construction, and not all communities can afford to do this. Retrofits can address this issue. Examples include solar shades and reflective materials, which can be added to nearly every structure without major economic implications (Taleb, 2014). Our team was tasked with overcoming environmental constraints in order to retrofit passive cooling systems to buildings at the Gobabeb Research and Training Centre (GRTC), an off-grid ecology research station located in the Namib Desert, Namibia. This was to reduce heat buildup in their battery, inverter and server rooms. Based on our results, we generalized this process to enable constituents of local communities to implement retrofits effectively as well.

To address the cooling needs of the GRTC, we identified four objectives to accomplish:

1. Gaining context of passive cooling in Namibia.
2. Collecting data to determine passive cooling solutions for the GRTC.
3. Testing prototypes and solutions at the GRTC.
4. Generalizing our methods to enable local communities to assess and apply their own passive cooling solutions.

We determined that to best understand how to apply passive cooling strategies to the GRTC, it was necessary to observe the types of passive cooling methods are currently in use. This was accomplished by conducting interviews, and performing observations at the Habitat Research and Development Centre of Namibia. Additionally, we considered economic feasibility of implementing passive cooling retrofits by identifying the availability of local materials at Pupkewitz Megabuild. Following this, we traveled to the GRTC to collect two types data: pre-existing data such as floor

plans, weather patterns, and current passive cooling methods in use, as well as our own collected data, such as temperature distribution and sun orientation data. Analyzing the pre-existing data provided crucial context for how our passive cooling solutions could be integrating into the Centre appropriately. Temperature data was collected using various instruments to determine a thermal profile of the GRTC's battery, server, and inverter rooms. Following our data collection, we also interviewed industry professionals to validate our data collection. Collected data helped us determine which passive cooling solutions would be worth prototyping for further data collection.

The following solutions were tested:

1. Various roof and wall shading techniques
2. Evaporative cooling
3. Insulation
4. Reflective paints
5. Ventilation

Data was collected on each passive cooling solution by tracking ambient temperatures of rooms, as well as taking spot measurements to quantify direct localized temperature reductions. Trends were then analyzed to determine effectiveness in temperature reduction. Following this, a comparative cost benefit analysis was completed to produce our recommendations for the GRTC. Lastly, it was possible to generalize our methods and results to enable residents of local communities to effectively implement retrofits with solutions that are proven to work in that environment. We produced a rapid assessment protocol brochure that explains how to identify building inefficiencies and determine the major heat sources that contribute to a building, so that constituents can apply appropriate passive cooling retrofits.

### *Findings and Recommendations*

We identified that both solar radiation and heat exhaust from technology were major heat sources for these rooms. Based on these findings, we tested passive cooling prototypes that both reduced solar input and increased airflow in targeted rooms. We ranked solutions from most beneficial to least beneficial by comparing cooling effectiveness and costs incurred for each.

Evaporative coolers were determined to be the most beneficial passive cooling solution for the GRTC. Specifically, we recommend purchasing at least two evaporative coolers for installation in battery and inverter rooms. The passive units we suggest for implementation channel the air through funnels as opposed to drawing it in through a fan. The various roof and wall shading prototypes were determined to be the second most beneficial passive cooling solution for the GRTC. Specifically, we recommend installing solar panels onto the roof of the battery/inverter building as a dual-purpose method of shading and harnessing solar energy. In between these solar panels, there should also be a double-roof shading mechanism installed to account for the solar radiation that is not reflected. These recommendations are partly due to the GRTC's plans to install solar panels in these locations. Furthermore, we recommend the GRTC invest in shade cloth wall shades for the server tower. From analyzing the comparison of the different shading materials tested, it was determined that shade cloth was the most beneficial.

### *Rapid Assessment Protocol*

The team recognized that passive cooling has broader implications outside of the GRTC. Specifically, we identified there are cooling needs in developing Topnaar communities located in similar arid environments. We designed a rapid assessment protocol that would effectively enable locals to assess their own buildings and implement passive cooling retrofits for a minimal economic investment. To create these materials, our methodology was generalized into steps that reach similar conclusions. Acquiring climate data, determining current passive cooling methods, and collecting temperature data are crucial for conducting such an assessment. We recommend that the GRTC distributes this rapid assessment protocol to the traditional authority of the Topnaar community. Based on our analysis of their buildings coupled with the results from testing passive cooling prototypes at the GRTC, we found it is possible to retrofit these buildings and improve the comfort. We recommend that the Topnaar communities apply this protocol to identify the cooling inefficiencies of their community hall and agricultural building and retrofit them with the appropriate passive cooling solutions.

*Summary*

The goal of our project was to determine passive cooling retrofits that could decrease the temperatures of the GRTC's battery, inverter and server room. Using this as a case study, the team generalized our methods to create a rapid assessment protocol that enabled constituents from local communities to effectively implement retrofits. By completing the objectives illustrated in our methodology, we identified that shading, evaporative cooling, reflective paints, ventilation, and insulation would have a beneficial effect. These five different passive cooling methods were recommended for the GRTC to implement. Furthermore, these results were used to create a rapid assessment protocol brochure that will be distributed to the Topnaar community so that they can implement their own passive cooling retrofits. The results of this project directly helped the GRTC solve their cooling needs as well as addressed the broader problem of cooling exemplified by the Topnaar communities.

# Authorship

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| 4.4 "Enabling Local Communities to Assess and Apply their own Passive Cooling Solution" Analysis | Neel Dhanaraj | Jackson Bradin, Zachary Powers, Douglas Theberge |
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# 1.0 INTRODUCTION

Maintaining cool temperatures indoors during warm periods has been a goal of societies all over the world for centuries. In the precolonial United States, the indigenous Pueblo people used thick adobe walls in their structures (Janzen, 2010). These walls utilized the effect of thermal mass, which kept the buildings cool during the day and warm during the night. In the 20th century, the traditional air conditioner was invented, providing another tool for maintaining building temperatures (Housh, 2015). Cooling is essential for a range of industries (data storage, home refrigeration, medication storage, etc.), and has become fundamental to our global society (CVS Pharmacy, 2018; Joch, n.d.; United States Association of Home Appliance Manufacturers, 2018). Due to the widespread availability of electricity, the use of this technology is becoming increasingly common throughout the world. For example, now 87% of homes in the United States are equipped with air conditioning (EIA, 2011). However, the average residential air conditioning system consumes more than 2000 kilowatt-hours of electricity annually and is therefore relatively energy inefficient (DOE, n.d.). One way to address this is through passive cooling, is the method of harnessing Earth's fundamental processes to cool a building with as small of an external energy input as possible (Cook, 1989). When applied correctly, passive cooling methods can drastically improve the energy efficiency of buildings and work to reduce global energy demands.

As the need for cooling increases around the world, so does the challenge of adapting countless buildings and homes that were designed with the intention of using AC or simply without accounting for heat buildup (EIA, 2011). For example, American homes have adopted many similarities that focus on aesthetics and traditional architecture while having less of a consideration for how to best manage the localized climate (Alter, 2015). This phenomenon can be seen in communities around the world, which increases the challenge of implementing various passive cooling techniques to these existing buildings. The expense and environmental effects of AC have focused certain communities' attention on passive methods, and must then account for the minimal investment of time and resources (Larsen, 2011). Integrating passive cooling into the new construction of buildings can be bring benefits such as a 95.6% reduction in cooling energy usage, however, it is not economically feasible for many communities to reconstruct all buildings (Eugene Marais, Personal Communication, 9/3/2018; NPS, 2015).

This is where retrofits can make passive cooling possible. In Denmark, residential homes were outfitted with various kinds of solar shading devices that overhang windows and doors. These homes experienced a substantial decrease in interior temperatures after the installation of these shades (Larsen, 2011). Though passive cooling is possible throughout the world, there are certain methods that are more feasible in certain environments than others. In Dubai, where the import and installation of shading devices would be possible, it would not be feasible to grow trees for shading (Taleb, 2014). In structures that house sophisticated technology, it is impractical to open windows due to particulate buildup in the technology (Cleaver, 2016). Cost considerations and maintenance of any proposed passive cooling designs must also be considered to ensure efficient implementation (Torcellini, Judkoff & Hayter, 2002).

One location that must account for both of these factors is, the Gobabeb Research and Training Centre (GRTC), located in the unforgiving environment of the Namib Desert (Lancaster, J., Lancaster, N., & Seely, M.K., 1984). The GRTC is limited by its off-grid energy generation capacity due to the use of solar panels. Furthermore, local communities native to the Namib Desert, known as the Topnaar, face problems with building design and construction coupled with significant economic limitations. To address the cooling needs of such an extreme environment passively while including these considerations has not been effectively implemented to date in the Namib Desert by the GRTC or other local residents (Eugene Marais, Research Manager at GRTC, Personal Communication, September 3, 2018).

Our team was tasked with retrofitting buildings at the GRTC with passive cooling systems to reduce heat buildup in their battery, inverter and server rooms. We generalized this process to enable constituents of local communities to implement retrofits effectively as well. We sought to gain context for passive cooling in Namibia, determine passive cooling solutions for the GRTC, to test these solutions/prototypes at the GRTC, and determine how surrounding communities can apply these solutions. Through various methods of data collection from thermal imaging to informal interviews with key informants, we determined a system that has a minimal capital investment and upkeep, while also providing a solution that allows the GRTC to decrease the temperatures sufficiently in their battery, inverter, and server storage rooms. Our assessment of a local Topnaar community helped us to create a protocol to rapidly assess unique cooling needs and identify general ways to retrofit Topnaar community buildings based on our conclusions made at the GRTC.

# 2.0 BACKGROUND

This broad use of cooling causes a large load on electrical grids; one way to decrease this load is through passive cooling. In the following sections we discuss how energy for cooling is inefficiently used on a global level, then we focus on how the implementation of passive cooling retrofits can be carried out to successfully reduce this inefficiency. Our team will observe and analyze passive cooling implementation in current research that exists today, as well as the limitations of geographical locations. Finally, we will look at how this all ties into implementing passive cooling at the GRTC and how a generalized process can be applied to local communities.

## 2.1 Inefficient Cooling Energy Usage in the World

Energy availability is an enormous problem for both developed and developing nations (Jardine, 2011; Lindeman, 2015; World Energy Council, 2017). However, energy is more stable and available in developed nations due to a variety of factors. For example, in Dubai, plentiful oil supplies are burned to produce the required energy, while parts of Europe and the United States possess the capital and technological means to construct nuclear power plants to supplement their already robust electrical grids (DiPaola, 2011; Embassy of The United Arab Emirates, n.d.; World Nuclear Association, 2018). Conversely, in developing nations such as most of sub-Saharan Africa, those who do have access to electricity face an unreliable supply and frequent power outages (Ouedraogo, 2017). Over the next 20 years, according to the U.S. Energy Information Administration (2016), it is anticipated that world energy consumption will increase by 48%; This pattern of increasing energy use is not sustainable and it is paramount to find a solution (World Economic Forum, 2015).

### 2.1.1 Traditional Cooling Methods

Traditional heating, ventilation, and air conditioning (HVAC) requires a very large amount of input energy, and is used broadly across the world (IBISWorld, 2014). It cools sufficiently but is not energy efficient (Harrington, n.d.). Over the past century, many countries have transitioned from passive cooling to active cooling methods due to increased technological knowledge and availability of electricity (Raunekk, 2009). Active cooling is responsible for 6.2% of United States residential energy usage each year (EIA, 2013). Worldwide, it has been estimated to consume 300 billion kWh annually (Henley, 2015). These large energy demands of active cooling incentivize the development of robust passive cooling methods in areas where capacity for electrical generation is limited.

### 2.1.2 Expansion of Cooling

Cooling is an essential facet of life in the world today. Everything from data storage, computing technology and food preservation, to medicine and overall quality of life is dependent on cooling (California Department of Education, 2000; Neudorfer, 2016; WHO, 2003). In Britain, according to Chalabi (2013) "36 million Brits 'are' online every day", and each time one of these people goes online, he/she is accessing central data servers (Strickland, n.d.). It is essential that these server banks are maintained at a constant temperature near 20°C (Neudorfer, 2016). If these servers are left uncooled, they will overheat and data will be lost (Storage Craft, n.d.). Additionally, refrigeration is an essential factor that accompanies the transition from small-scale agriculture to modern farming. While food products can be produced at home and preserved by canning, the world is transitioning to modern, large scale farming (Belaya & Gagalyuk, 2017; NCHFP, 2017). Accompanying this transition, a significant proportion of food consumed is likely produced hundreds if not thousands of miles away (Barrett, 2013).

Implementation of cooling not only allows for the improvement of various industries but improves quality of life. Proper thermal comfort not only improves the mood and productivity of an individual, but it also allows one to remain healthy (Health and Safety Executive, n.d.). Living in consistently hot conditions can lead to conditions such as heat stress (Department of Health & Human Services, 2015). Heat stress aggravates chronic conditions as well as prevents the body from successfully cooling itself. In extreme cases, excessive heat exposure can cause death. (EPA, 2017). Cooling allows for the improvement of general human comfort levels as well as prevention of heat related deaths.

## 2.2 Examples of Passive Cooling Methods

The fiscal and environmental concerns associated with air conditioning (AC) have resulted in a surge in research and action in recent years to make passive cooling a relevant practice (Oropeza & Ostergaard, 2018). For this reason, researchers and professionals have been vigorously looking for ways to minimize energy consumption by considering these passive methods (Henley, 2015). The most popular areas of focus in current research today involve earth coupling, ventilation, shading, evaporative techniques, and radiative techniques (Kamal, 2012). Earth coupling is a technique that utilizes the constant cool temperature of Earth's soil found approximately 5 meters below the ground. At this depth, soil is not subject to the varying climate conditions that exist above ground, making earth coupling an easily and widely applicable method in many circumstances. Ventilation works by capturing the cooler outside air, and then dispersing it throughout the building at times that satisfy the building's cooling needs. This dispersion can occur through air vents around the building or by other structural features of the building that induce convection currents (Kamal, 2012). For an overview of passive cooling solutions, refer to **Appendix A.**

It is important to note that the method used within a building is largely affected factors including: climate conditions, location/orientation of the building, and access to resources (Oropeza & Ostergaard, 2018). Additionally, the approach to implementing passive cooling is also dependent on whether it is a retrofit or part of a new building design (Torcellini, Judkoff & Hayter, 2002). To examine and identify current progress in passive cooling more closely, an example of each alternative is provided.

### 2.2.1 Passive Cooling in New Construction

The most effective way known to adequately implement passive cooling into buildings involves designing the building with passive cooling in mind. At the Zion National Park Visitor Center, this has been successfully achieved (Torcellini, Judkoff & Hayter, 2002). The most prominent feature on display there is the cooling towers created around the building. Water is sprayed onto pads at the top of the towers which then evaporates, generating a cool, dense air that sinks down to the bottom of the towers and into the lobbies surrounding them (NREL, 2000). Other structural features include thermal insulators within the walls of the center, as well as clerestory windows. The thermal insulation, which was worked into the design of the walls and roofing of the building, reduces energy usage up to 70% by keeping out the hot, desert air surrounding the building. These design features did no incur more expenses than it normally would take to construct the center (NREL, 2000). The clerestory windows are located in lower locations of rooms exposed to the outside air to allow a natural ventilation of cool air to be drawn in and warmer air to leave through vents at the top of the rooms (NREL, 2000). The success the Zion National Park Visitor Center has experienced by considering sustainability when drafting the structural design concepts, is largely due to its cost-effectiveness. While some features such as the cooling towers may be large additional costs during initial construction, the investment eventually becomes worthwhile when accounting for the money saved on electricity-based air conditioning (Torcellini, Judkoff & Hayter, 2002). However, designing a building with passive cooling in mind is not always feasible.

### 2.2.2 Retrofits

When considering environmental and economic circumstances, justifying new construction can be unrealistic (Santamouris, Pavlou, Niachou & Kolokosta, 2007). To account for this, one must examine the possibility of retrofits to currently existing infrastructures. According to Taleb (2014), simulation software has been used to test the capabilities of various passive cooling retrofits to residential buildings in the United Arab Eremites, which include shading devices, insulation, and solar reflective roofing. It is important to note that these implementations are specifically geared towards accounting for the local climate, as any effective passive cooling method must do (Henley, 2015).

The idea behind retrofitting passive cooling designs is that they can be applied to currently existing buildings without spending large amounts of time and money to restructure the building itself. Shading is incorporated by a simple attachment to outside windows of buildings in the hot, dry climate of Dubai, UAE (Taleb, 2014). These attachments consisted of panels tilted at a 45-degree angle to effectively block the solar heat from entering through the window, but still allowing the light to pass. The properties of the material used in these panels allow for this heat absorption. Taleb (2014) also noted in these passive cooling simulations that windows are the primary cause of the internal temperature level variation. Depending on the local climate, one must consider factors such as humidity, solar exposure, and outside temperature to determine the magnitude of internal heat gain insulated areas such as windows have on the building. Researchers designed double paneled windows with Argon gas compressed between them to act as an insulator to the elements of the outdoor air from entering the building. These windows can easily replace current windows without having to change building infrastructure (Kamal, 2012).

Retrofits have also been used by architects and interior designers in Australia to layer modern residential houses with condensed earth material (Wang, 2017). This process uses a combination of insulation and earth coupling techniques by placing sections of this material around the exterior of the house while drawing on the Earth's natural ability to cool. The material is created from locally available resources such as sand and timber and requires no maintenance for continual use. The success seen in these projects based on retrofits is promising evidence for how the world can become less dependent on electrical energy to achieve optimal internal temperatures in buildings.

## 2.3 Passive Cooling Limitations

Passive cooling has been established as a viable solution for decreasing energy consumption. Many methods of passive cooling have been studied and integrated in both smaller residential and larger facility buildings. Each site of implementation shares one or more characteristics that have helped facilitate a successful application of passive cooling. These characteristics are a mild environment, functional requirements, and high resource availability. For example, an engineering team designed and created a large passively cooled and naturally ventilated building for the City College of San Francisco (Janssens, 2013). This learning center in San Francisco is located in an environment that does not put a large strain upon the cooling system. Furthermore, as a 10,000 square meter college building, it has access to both material and monetary resources. Lastly, the only functional restrictions are to keep the occupants comfortable. This passive cooling system decreased energy use by over 40%. San Francisco, Dubai and Zion show that passive cooling can be effectively used in areas with mild climate patterns, resource availability and/or minimum building functionality requirements. The next step in furthering the decrease of energy use for cooling is to conduct research and design methods of passive cooling for locations within harsh environments, low resource availability and/or specific building requirements. To allow for this research to have the greatest impact, retrofitting existing buildings must be especially considered.

### 2.3.1 Environmental Limitations

As the need for cooling is increasing, more regions with harsh climates will require passive cooling. Regions in the equatorial zones, such as Southeast Asia, experience a harsh climate with "a large amount of solar radiation, high temperature, high level of relative humidity and long periods of sunny days" (Al-Obaidi, Ismail & Rahman, 2014, P. 284). Many of these countries also experience rainy seasons. Furthermore, countries such as Malaysia, Singapore and Indonesia are experiencing large amounts of urbanization, which increases cooling needs due to the urban heat island phenomenon. These environmental conditions increase difficulty in implementation of certain passive cooling techniques. Researchers have only recently recommended special roofing technologies that are able to deal with the environmental restrictions of the region.

Deserts experience large temperature swings between day and night, which make it hard to maintain a constant internal temperature for buildings. This causes an increase in energy loads making it more difficult to cool buildings (Etzion, Pearlmutter, Erell & Meir 1997; Taleb, 2014).

### 2.3.2 Functional Limitations

More countries around the world are developing and using sophisticated technology. Adegoke (2017) asserts that Africa's internet economy needs more servers for optimal internet use. However, hardware such as servers cannot be exposed to the harsh desert climates found in some regions of Africa (Ruiz, 2015). Another example of a place with functional restrictions is the Desert Research Institute (DRI) (n.d.), which hosts the Frits Went Laboratory, located in Nevada USA. This laboratory has strict technological building requirements. The air temperature, humidity and air flow rate are controlled with precision. Variables such as temperature and air flow are controlled with great thought on how condensation may affect the instruments and area. This research lab shows the strict requirements that are needed for both machine precision as well as research conditions, reflecting functional limitations that are important to consider when implementing passive cooling.

### 2.3.3 Resource Limitations

A significant change in the building materials used in developing nations is the transition from traditional to modern materials. Malaysia is one country that has transitioned from traditional materials such as clay, wood, and bamboo, to concrete, steel, and glass (Al-Obaidi, Ismail &

Rahman, 2014). The implications of such a change are that affordable houses with these materials have high levels of heat gain. Solutions to decrease the heating load need to be cost effective. Economic circumstances can make new construction unrealistic. Therefore, buildings in these climates will need to be retrofitted with low cost passive cooling technologies. Multiple passive cooling studies have been done that have applied simple solutions such as painting walls with a reflective white color and providing internal shade (Etzion, Pearlmutter, Erell & Meir, 1997; Taleb, 2014). These methods have the potential to be cost effective applications for already constructed residential buildings.

## 2.4 The Gobabeb Research and Training Centre and Surrounding Communities

The Gobabeb Research and Training Centre is located in the Namib Desert, 120 km by road to the southeast of Walvis Bay which can be seen in **Figure 1**.


**Figure 1.** *Geographical relationship between the GRTC and Walvis Bay*

The location of the facility restricts access to municipal utilities such as electricity and water. Due to this lack of connections, electricity must be generated on site, and water must be taken from a well that taps into the ephemeral Kuiseb River aquifer. There are also surrounding Topnaar communities that are settled along the Kuiseb River. They experience the same environmental and resource restrictions as the GRTC, as well as their own economic challenges (Eugene Marais, Research Manager at GRTC, Personal Communication, September 3, 2018). In communities such as these, the quality of life can be seriously affected by high temperatures (Health and Safety Executive, n.d.). Within the Namib Desert, the temperature can reach as high as 40°C and as low as 0°C (Namibia Weather, n.d.). These large temperature swings present a unique challenge for both the Centre and the Topnaar, which is keeping cool during the day and warm at night. The yearly rainfall for the Namib Desert is 89.4 millimeters, and due to this minimal rainfall the area surrounding the Centre is arid.

### 2.4.1 Context for the GRTC

At the GRTC there is a collection of routers and a computer server that are all located within the same room in a tower, shown in **Figure 2**. One issue with this is that as the servers and routers run, they produce heat. This factor, compounded with the fact that the Namib Desert can experience temperatures over 40°C, puts a large strain the technology. This explains the necessity to keep the room within an appropriate temperature range. The optimal temperature for the operation of server rooms is 20-22°C (Geist, 2013). Furthermore, the Centre is powered by its solar panel arrays, which are supplemented by a diesel generator. The electricity that is produced by the arrays is stored within a series of batteries for use when the arrays are no longer producing power, i.e. after dusk, battery banks are shown in **Figure 2**. The batteries and inverters are housed in adjacent rooms within one building. These inverters convert the direct current from the batteries to the alternating current that is used to power electrical devices at the GRTC, inverters are shown in **Figure 2**. As shown in **Figure 3** the ideal conditions for batteries is about 20°C, with higher temperatures reducing battery longevity (Battery University, 2018).

**Figure 2.** *Photos of the Inverter Room (top left), Battery Room (bottom left), and Server Tower (right)*

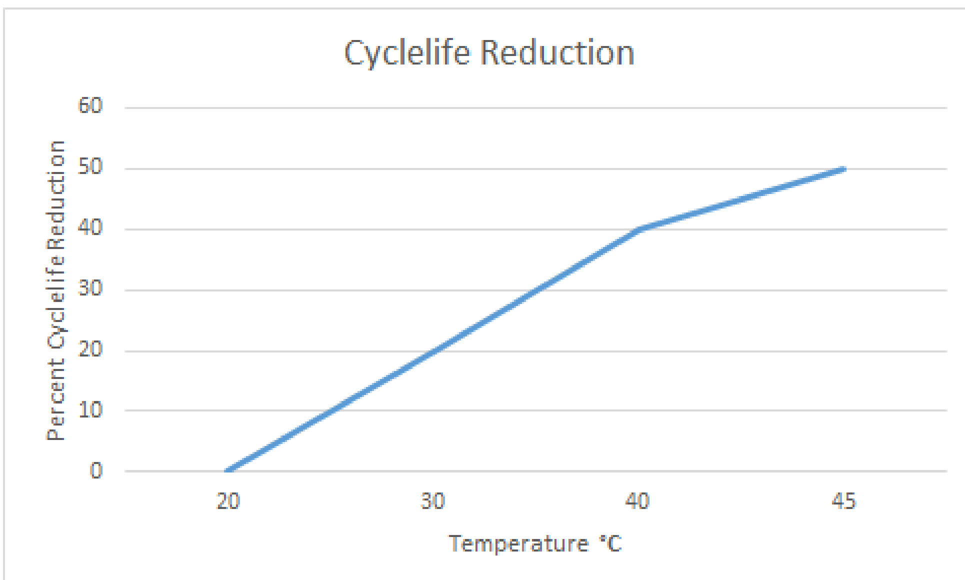


**Figure 3.** *Cyclelife reduction due to temperature (Adapted from Battery University, 2018)*

### 2.4.2 Context for Topnaar Communities

There are many developing communities in Namibia with unmet cooling needs, similar to the GRTC. An example of this includes various Topnaar settlements, which are located along the Kuiseb River. The Topnaar live in small homesteads commonly built out of corrugated metal sheets and other thin, locally-available materials. About 60 km away from the GRTC in the Topnaar community of Utiseb, there is a newly constructed community meeting hall, agricultural ministry building, and a hospital. Considerations for passive cooling was not prioritized when these buildings were designed and constructed; these community buildings tend to get very hot, especially when they are occupied by larger numbers of people (Eugene Marais, Personal Communication, September 3, 2018). Due to the limited access of electricity along with economic constraints, it is not feasible to use air conditioning or reconstruct these buildings to utilize passive cooling. The Topnaar people are just one example of the many Namibian communities that must consider passive cooling retrofits to improve quality of life.

## 2.5 Summary

In order to satisfy the ever increasing societal and technical needs for regulated temperatures in building infrastructure, the world must redefine how cooling is approached (Henley, 2015). Unfortunately, the inefficient consumption of energy around the world can be largely connected to the electrical demands required to operate HVAC units. This suggests a solution exists by using passive techniques (Oropeza & Ostergaard, 2018; Santamouris, 2007). While there is plenty of research on various passive cooling methods around the world, very little attention has been on the low-cost, low-maintenance needs of buildings with specific environmental circumstances. Furthermore, there is a lack of focus on retrofitting buildings in these environments. In desert climates, where local resources are limited, specific methods of passive cooling such as Earth coupling, shading, or ventilation are often viable solutions (Artmann, Hanz & Heislberg, 2007). We are studying the GRTC, which has restrictions on the exposure of its technology to outside elements combined with a need to cool the buildings that house this equipment.

# 3.0 METHODOLOGY

The goal of our project was to overcome environmental constraints in order to recommend passive cooling retrofits for the GRTC's battery, inverter, and server rooms. We aimed to create a rapid assessment protocol that would enable constituents of local communities to implement retrofits effectively. In order to reach this goal, we developed the following research objectives:

1. Gaining context of passive cooling in Namibia.

2. Collecting data to determine passive cooling solutions for the GRTC.
3. Testing prototypes and solutions at the GRTC.
4. Generalizing our methods to enable local communities to assess and apply their own passive cooling solutions.

## 3.1 Objective 1 - Gaining Context of Passive Cooling in Namibia

It was essential that we deepen our context of passive cooling in Namibia. This included understanding what types of different environments exist in Namibia, and which types of passive cooling address each of those environments best. Additionally, we determined what types of building materials were locally available to utilize for passive cooling solutions. Completing interviews and performing observational research around Windhoek further deepened our understanding.

### 3.1.1 Informal Interviews with Industry Professionals and Inventory Observation of Hardware Suppliers

We began our feasibility assessment at the Habitat Research & Development Centre of Namibia to understand methods currently implemented across the nation. Following these informal interviews conducted at the Habitat Centre on 8/22/2018, notes were transferred into a Microsoft Word document, and were subsequently analyzed by comparing our knowledge of general passive cooling solutions to what is feasible in Namibia. We also identified potential hardware suppliers to determine the availability of building materials in Namibia. We browsed Pupkewitz MegaBuild, a local building supply/hardware vendor in Windhoek, looking for different types of materials that could be used for passive cooling solutions such as: reflective paints, Mylar blankets, roof insulation and cloth.

## 3.2 Objective 2 - Collecting Data for Determining Passive Cooling Solutions for the GRTC

We identified two types of data that was crucial to collect at the GRTC: 1. Pre-existing data necessary to obtain for providing context and 2. Temperature data necessary to collect for determining major heat sources. This information was pertinent for developing a passive cooling solution that catered towards the GRTC's specific needs. We also validated this data and acquired specific prototype recommendations by conducting semi-structured interviews with industry professionals in Windhoek. The goal of this objective was to provide the Centre with an assortment of passive cooling solutions that simultaneously considered our analyses of this data as well as the factors identified in **Section 3.1**.

### 3.2.1 Archiving Pre-Existing Data

Upon initial arrival at the GRTC, it was crucial to identify and gather pre-existing data and materials. This helped us to fully understand the scope and constraints of the passive cooling design that was to be implemented at the facility. To structure technical data collection and design a prototype, we needed to obtain the following:

- A GRTC facility floor plan that explicitly displays room locations and interior ventilation
- Climate data from prior research and nearby weather stations
- Information on what passive methods have been already implemented or considered at the Centre

#### *GRTC Floor Plan*

The GRTC's floor plans, were obtained from the building manager, and were used to identify the following: the location of the battery, inverter and server rooms within the facility, their location relative to ventilation systems and exterior walls, the direction of these walls relative to the sun's orientation throughout the year, and the materials that compose the walls. Additionally, these plans were used as a map to record the placement of thermal measurement points.

Possible methods and areas of design implementation were identified by observing: the open spaces between rooms, locations of windows and doors, locations of heat extractors, and locations of the batteries and inverters. This data was stored as PDFs for further use.

#### *Climate Data*

Understanding general climate and weather trends in the surrounding environment of the Namib Desert is necessary to understand local climate variability and its effects on passive cooling (Artmann, Hanz & Heiselberg, 2007). Hourly logged climate data was retrieved from the local SASSCAL WeatherNet Station (n.d.), located at the GRTC, and was recorded in Microsoft Excel. This included temperature, relative humidity, and wind speed/direction data for the years of 2016-2018 for the purpose of understanding annual weather trends. Additionally, we retrieved hourly data for days during our initial data collection and when passive cooling solutions were tested. This was to compare how the weather, over a 24-hour cycle, correlated to the temperature data the team collected.

#### *Current Passive Cooling Methods*

Gathering information on the current methods of passive cooling incorporated into the structural design of the GRTC provided insight into what methods would be most effectively retrofitted. Engineers and architects have employed some passive concepts into the structural design of the buildings at the Centre. Through informal interviews with the building manager and facility staff, as well as personal observations, we documented all current passive cooling implementations and determined their effectiveness. The documentation of this data involved taking field notes and then storing them in a Microsoft PowerPoint slide. The efficacy of current passive cooling methods was determined by comparing the current average temperature of the technology with the technology's ideal temperature range. It is important to note that this initial collection of pre-existing data helped to identify gaps in what other technical information needed to be acquired to compare and validate present data.

### 3.2.2 Measurement Equipment Validation

To ensure that our temperature data collection methods were accurate, we verified each measurement tool was working properly. Once these tools were programmed and installed, they were validated using a calibrated IR Thermometer. Each button was tested at 3 specific data points of 8:00, 14:30, and 20:00 on 8/30/2018 to reflect the different temperature ranges that would be experienced during data collection. The 8:00 data point represents the colder morning temperatures, the 14:30 data point represents the hotter daytime temperatures, and the 20:00 data point represents the colder evening temperatures. Once this data was collected, it was analyzed by comparing the difference between the IR Thermometer and button measurements. A temperature deviation of ± 2°C between measurement tools was set as our acceptable limit.

### 3.2.3 Preliminary Data Collection

Once information was gathered and organized for use towards understanding the confines of possible cooling method designs, a series of data collections on various elements were required to further identify the most feasible solution. These elements include solar exposure and sun orientation relative to building faces throughout the day, interior wall/ambient air temperatures of key rooms, and the temperature of the technology itself. This quantitative and qualitative data was used to establish a thermal profile for the battery, inverter and server room.

#### *Solar Exposure*

The amount of direct exposure from the sun on exterior walls helped us to identify the times of day and precise locations of major solar heat transfer. This knowledge aided in determining optimal locations for passive cooling retrofits. For example, an overhanging solar shading device works by absorbing and/or reflecting direct solar radiation from the sun to prevent heat gain within the structure that is protected (Oropeza-Perez & Ostergaard, 2018).

To accurately and consistently collect sun exposure data for the battery, inverter and server rooms, data points were set up along the external facing walls to make observations on whether or not that specified part of the wall was exposed to sunlight. This data was taken hourly between sunrise and sunset. Coupling this information with temperature readings of the walls/windows of collection locations provided insight on the correlation between exposure to solar radiation and its thermal effect on the room (Thomas, n.d.).

#### *Temperature Distribution*

Finding the temperature variations allowed the team to determine where the insulation inefficiencies were located. This helped in choosing passive cooling methods that could mitigate these insufficiencies. For example, by finding the qualitative temperature distribution of a building it can be concluded that there is heat entering the interior through the roof (Plowright, 2016). Temperature measurement devices were used for quantitative and qualitative measurements. The exact measurement equipment is described in **Appendix B**.

These pieces of equipment were used in conjunction with each other to develop a comprehensive analysis of the temperature distributions of both the ambient environment as well as surface temperatures in each building.

- A general temperature data logger gave an accurate depiction of the ambient temperature of the room. The data logger was hung in the middle of the room and programmed to record temperature in 30-minute time intervals for the duration of the data collection period.
- A thermal imaging camera gave a qualitative temperature distribution map of the targeted room. Observational analysis of the live thermal imaging helped determine important areas of the room to take pictures incrementally. The position and direction to take photos were then marked in each room.
- An infrared (IR) thermometer gave quantitative temperature values of all the walls and roof in each room. The spots for measurement were marked and labeled. A grid of data points was taken for walls and roofs exposed to the sun. For other interior walls, one general temperature was taken.
- iButtons are self-recording temperature data loggers that recorded the local temperature of areas of interest. The iButtons are programmed to record temperature in 30 minutes' time intervals and were attached to surfaces in places that could not be accurately characterized by the IR thermometer. This included areas of convection and areas of heat pooling near different technology. Twelve iButtons were used.

The placement of the iButtons and temperature data loggers as well as the spots where measurements and images were taken are marked in **Figure 4**.

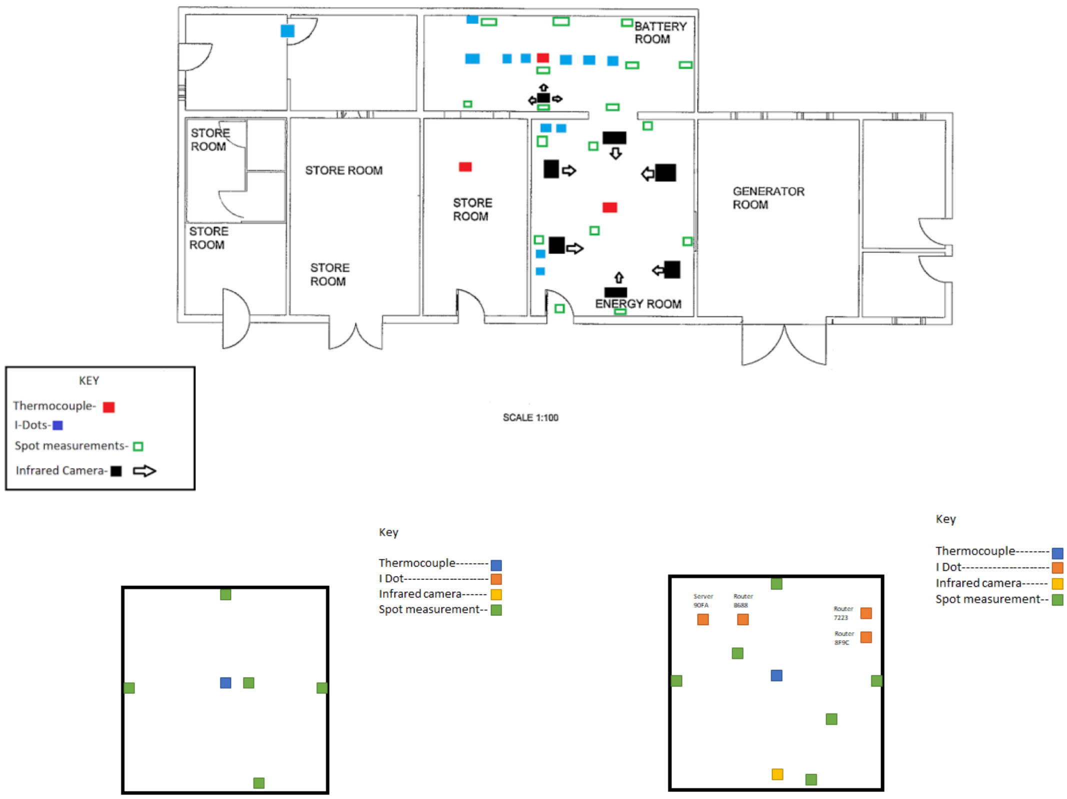


**Figure 4.** *Layout of targeted rooms, with key denoting types of measurements taken*

An IR thermometer and thermal imaging camera measurements were taken each hour throughout the day for three days in the battery, inverter and server tower rooms. This gave a broad coverage of what the room temperature was throughout time. Data loggers (Easylogs) were placed in the rooms of interest as well as in rooms adjacent of the battery and inverter room and the bottom of the server tower to act as a control. These data loggers operated continuously throughout the data collection period. The goal was to measure experimental control rooms so that the team could compare the targeted server and battery rooms to rooms without high heat producing appliances. The control rooms were exposed to similar environmental conditions as the rooms that housed technology, so therefore a temperature analysis of these rooms gave a baseline of how much heat was being emitted into the battery and inverter rooms from the technology. The iButtons were placed near each battery, inverter, and the server to assess how much heat was generated from them.

They were also placed near vents and all whirlybirds to help characterize the convection of the room.

The explicit procedure that was used to obtain an accurate temperature distribution profile of each room was as follows.

The thermal imaging camera was used to obtain a temperature distribution of each interior wall and the room appliances from each determined direction. The relevant temperatures for each wall and roof were measured using the IR thermometer. The temperature data logger recorded the average room temperature. The iButtons recorded the localized temperatures of areas of interest and acted as support measurements to validate other temperature readings. The data from the iButtons and temperature data loggers were recorded in 30-minute intervals and were downloaded after each 24-hour cycle. Thermal images were recorded hourly on 8/31/2018. The IR Thermometer measurements were recorded every hour for three days, which provided an accurate characterization of the temperature distribution and how the intensity changes throughout the day (Nahar, Sharma & Purohit, 1999). This data was collected on: 8/31/18, 9/4/18 and 9/5/18. The data was all archived in Microsoft Excel sheets.

### 3.2.5 Preliminary Data Analysis

Quantitative data was analyzed by compiling raw data into graphs for identification of relevant trends and differentials. Content and observational analysis was done to draw conclusions from thermal images.

#### *Temperature Distribution Analysis*

Thermal images were taken at hourly intervals for a 24-hour cycle, and were downloaded and organized chronologically on a computer hard drive. Observational analysis was completed to determine where heat builds up in the target and control rooms, as well as to understand distribution changes over the course of the day. Average room temperature data was correlated with time to establish which regions experienced the highest temperatures and the most heat gain throughout the day. The use of this data in conjunction with the archived data helped us draw conclusions regarding what mechanisms contributed to substantial heat gain in the buildings.

### *Heat Source Analysis*

The environmental and technology temperature data was analyzed to find which source contributes more to heat in the room at a given time of day. Comparing average air temperatures of the designated control rooms with the rooms that housed technology served as a basis for understanding the heat produced by technology. Furthermore, we assessed when significant heat input occurred within a day by identifying the biggest differential between the temperature of the control and targeted rooms. The environmental heat input was analyzed by considering the solar exposure data in conjunction with the interior wall and ceiling temperatures throughout the day. Specifically, we looked at when certain sections of wall or roof were in direct sunlight, and compared this to the corresponding wall and ceiling temperatures to understand the impact of direct sun exposure.

## 3.2.6 Interviews with Industry Professionals

Following the completion of our initial data collection, we conducting semi-structured interviews with local passive cooling experts in Windhoek. The purpose of these interviews were to provide validation for our preliminary data collection and to receive input on possible passive cooling solutions for further testing. The primary interviewees were referred to us by Dr. Gillian Maggs-Kölling - Director of the GRTC, and consisted of Mr. Glenn Howard - Consulting Engineer of Emcon Consulting Group, Ms. Gloria Gachiku – Head Architect of Gachiku Kamau Architecture Firm, and Ms. Nina Martiz – Head Architect of Nina Maritz Architects. These interviews were conducted between 9/10/2018 to 9/13/2018 at the respective office of each interviewee. The interview plan can be found in **Appendix C**. The notes from each interview were archived into Microsoft Word. The data was coded by solution type, such as: “Shading” or “Evaporative Cooling”. The results of each query were put into a list to identify commonalities between input from interviewees. Based on the opinions and insights of the participants, we determined which passive cooling solutions would be best fit for further testing at the GRTC as prototypes.

## 3.3 Objective 3 - Testing Solutions and Prototypes at the GRTC

Once a series of passive cooling solutions and prototypes were identified to be most effective for the GRTC, the team began implementing and testing each one. Based on the nature of each solution, some were applied as prototypes for proof of concept while others were applied permanently. The process of testing each solution involved acquiring materials necessary for construction, fixturing to targeted buildings, and collecting temperature data. Analysis of the previously obtained data in **Section 3.2** was crucial for identifying how certain solutions should be applied to ensure optimal effectiveness. The proposed solutions could be categorized as the following: Solar shading, ventilation, insulation, reflective paints, and evaporative cooling.

### 3.3.1 Creating and Implementing Prototypes/Permanent Solutions

We worked with the Centre's research manager, Eugene Marais, to determine an explicit list of what materials were necessary for effectively implementing each proposed solution. It was important to consider cost and availability of each material at this step. Some additional materials in consideration for use were already available at the Centre. Following this, the team traveled to Walvis Bay to obtain these materials from a variety of suppliers. Locally available woods and metals were used as the primary structure for most of the prototypes. Using the workshop at the Centre, the team constructed the prototypes with the aid of facilities workers staffed on site.

Implementation of prototypes was completed so that only one solution for a targeted room was in operation at a time. This was done to conclusively determine the effects of a given solution by minimizing other factors and establishing a controlled area of study. The prototypes that could easily be removed from the targeted buildings were tested first, and then the permanent solutions were applied last. Due to the permanent nature of these solutions, they could not be tested individually.

### 3.3.2 Collecting Temperature Data for Assessment of Solution Effectiveness

Once a specific passive cooling solution was implemented for a targeted room, we assessed the efficacy of the solution using equivalent methods to the preliminary data collection. The same instruments that were used in our initial data collection process were also used here and can be reviewed in **Appendix B**. This data was collected for comparison with control points taken on the day of testing. Control points consisted of temperature measurements of an unaffected area of the targeted room and were used to analyze the effect a given prototype had on that localized area. This data was also compared to our previously archived temperature data. The comparison with our preliminary data sets helped to identify relationships between a given day's weather conditions and the interior temperature of the targeted room, and then we compared this relationship again after prototype implementation. The temperature measurements of the technology were also compared with these data sets to understand how heat exhaust had an impact on the interior ambient air temperature as well.

The process of collecting temperature data for each solution differed depending on the nature of each solution. For example, assessing a shade that is fixed on the roof of a building would involve incrementally obtaining temperature measurements of the roof and ceiling where the shade was in effect, while acquiring data for an evaporative cooler would involve obtaining temperature measurements of the air flowing into the room. Average air temperature was recorded in conjunction with localized temperature measurements within the targeted room for each potential solution. This was done to understand how the reduction of heat gain from a given solution decreased the overall ambient air temperature for the targeted room. This information was archived on Microsoft Excel for further analyses, consistent with how the initial temperature data was archived.

### 3.3.3 Comparative Cost-Benefit Analysis

We constructed a cost-benefit chart in order to aid the Centre in choosing the most appropriate solution. This chart compared the cost of a given permanent solution and its cooling effectiveness versus that of the other solutions that were tested. The cost was determined by considering the prices of locally sourced materials, assembly, and upkeep. The effectiveness of each solution was ranked on a scale from 1-3; 1 being not effective, 2 being effective, 3 being very effective. The breakdown of what is included in the chart is as follows.

- Cost of materials were determined through consulting with hardware suppliers and personal observation.
- Cost of transporting materials were determined through semi-structured interviews with GRTC staff and suppliers
- Assembly cost was based upon the pay rate of the GRTC employees or the contractors that would install the cooling system.
- Upkeep cost was based upon the annually incurred maintenance cost.
- Solutions ranked 1-3 based on cooling effectiveness

Once the cost and effectiveness for each passive cooling solution was identified, they were then ranked from most beneficial to least beneficial by considering both of these factors. This analysis resulted in our final passive cooling solution recommendations for the GRTC to apply in their battery, inverter and server rooms.

## 3.4 Objective 4 - Enabling Local Communities to Assess and Apply their own Passive Cooling Solutions.

There are numerous communities all across the world that also experience cooling problems along with the GRTC. We gained context as to why passive cooling retrofits are important to implement in Namibian communities, and how they could apply them through their own building assessments. We completed a series of interviews, and observational analysis to understand deeper context of cooling problems. Furthermore, we generalized our methodology to create a rapid assessment protocol.

### 3.4.1 Gaining an Understanding of the Cooling Needs in Surrounding Communities

We visited Utiseb, a Topnaar village approximately 60 kilometers away from the GRTC, to contextualize how passive cooling solutions could benefit communities in similar environments. An abbreviated temperature data collection method was carried out and informal interviews with users of the community hall and agricultural ministry buildings. This increased our understanding of passive cooling needs in the community.

#### *Simplified Data Collection of Community Building*

In-depth data collection and analysis of the GRTC allowed the team to identify variables contributing to the accumulation of unwanted heat energy. An abbreviated version of this method was executed at Utiseb. This involved taking one set of temperature measurements opposed to identifying trends over time. Based on the trends identified in our previous data collection at the GRTC, we could extrapolate how the building's thermal profile would develop over time. Our methods were divided into two parts: observational data and temperature data collection.

The goal of this observational data collection was to identify different kinds of information regarding the design of the building. This included the following:

- Materials of both the walls and ceilings
- Size estimation of walls, wall thickness, roofs, and roof thickness.
- Placement of windows, vents, and doors
- Functionality of the room

The goal of temperature data collection was to quickly and quantitatively characterize the temperature of the walls and ambient air of the buildings as well as establish thermal hotspots. The method was conducted for each building using manual measurement devices (thermal imaging camera, and IR thermometer) similar to **Section 3.3.2**. This method established a basic thermal profile of the buildings of interest, and identified causes for substantial heat gain.

#### *Informal Interviews with building users*

Informal interviews were conducted during the visit with local residents who used buildings of interest. The goal of the interviews was to answer one general question: What temperature conditions do local people experience in their buildings?

Upon visiting Utiseb, the team identified English-speaking informants who had experienced the inside temperatures of the buildings. For example, the agricultural ministry representative was a key informant for describing the temperature experience in the agricultural building. The informal interview method was the same as in **Section 3.1.1**.

### 3.4.2 Simplified Thermal Building Analysis and Rapid Assessment Protocol

We analyzed our methodology to create a rapid assessment protocol that could be used by local communities. This protocol consisted of a generalized version of the original methodology and was designed to identify the cooling needs of a desired building for application of a passive cooling retrofit. This generalization of the methodology was done so that an individual with limited access to tools and resources could effectively apply it. From the analysis, the team created protocol steps that could effectively reach the same relevant conclusions about the cooling inefficiencies of a building as the original technical data collection.

### *Analysis of Original Methodology for Protocol Development*

The analysis of the methodology involved reviewing each section and identifying pertinent aspects that could be simplified or altered while still obtaining an appropriate solution. The criteria for this assessment accounted for the ease of use by local constituents by minimizing quantitative data collection. The original methodology was first assessed through a rubric. Each step of the methodology was rated between 1 and 3 based on the scale below.

1. Necessary to determine relevant conclusions.
2. Helpful to determine relevant conclusions
3. Redundant in determining relevant conclusions

The methodology sections that were rated between 1 and 2 were then analyzed for ease of implementation by local constituents. Theses sections would undergo the simplification of reducing extensive documentation and quantitative data collection. For example, it would be unlikely for an individual to have access to a thermal imaging camera to determine heat sources and distribution. Therefore, this step was replaced by the qualitative method of placing a hand on surfaces to determine the heat sources in a building. The complete rubric and analysis form can be found in **Appendix D.** The team was able to create a rapid assessment protocol that could effectively assess a building's cooling needs and recommend solutions that local constituents could implement with the consideration of environmental and economic circumstances.

## 3.5 Summary

The completion of each objective identified within our methodology allowed us to adequately provide the GRTC with appropriate passive cooling retrofits that accounted for environmental and economic constraints. Furthermore, we produced a rapid assessment protocol to enable local communities to implement passive cooling solutions.

# 4.0 Results and Analysis

Based on our analysis, the key findings for each objective are:

1. Shading and thermal mass are the most prominent passive cooling methods used in Namibia.
2. There are two major sources of heat gain for the targeted rooms at the GRTC:
    a. Solar radiation
    b. Heat exhaust internal technology
3. There are 5 beneficial passive cooling solutions for implementation at the GRTC:
    a. Evaporative cooling
    b. Solar shading on roofs and external walls
    c. Reflective paints
    d. Insulation
    e. Ventilation
4. Our methods can be simplified to apply effective passive cooling retrofits in surrounding communities.

## 4.1 "Gaining Context of Passive Cooling in Namibia" Analysis

It was important to get an understanding of what feasible methods of passive cooling are currently practiced. This was achieved through our interviews with the professionals and observations at the Habitat Centre, as well as observations at Pupkewitz Megabuild. This helped to better understand how retrofits could be effectively implemented. Through analysis of our collected data, we determined that:

1. The most prominent methods of passive cooling in the Namibian environment are thermal mass, shading, and use of reflective materials
2. The broadly available and commonly used building materials are clay, brick, cement, sand, rocks, rammed earth, wood, and thatch.
3. There are also many commercially available materials such as dimensional lumber, Sisalation insulation, and heat reflective paint.

The most available and apparent passive cooling methods used in Namibia's arid environments are the use of thermal mass, shading, and reflective materials. Namibian sustainable development experts constructed the Habitat Resource and Development Centre, which specializes in improving quality of life by implementing sustainable building design. The Habitat Centre researches the most effective passive cooling methods, and additionally searches for locally available building materials for each region of Namibia.

In Namibian architecture, walls are often 25-26 cm thick concrete or another substitute material. According to our tour-guide at the Habitat Centre, large thermal walls work like a wave; the heat will hit the exterior of the wall, and slowly reach the interior. Meanwhile, once the energy reaches the interior, the exterior is being exposed to the cooler night air, and creates a "cold" wave, and this cycle repeats throughout the year. This is extremely important because it emphasizes that this type of wall is perfect for the arid Namibian environments. Additionally, walls with thermal mass work well in the Namibia because they are often sealed, which prevents the accumulation of particulate matter from the outside environment. This solution suits the restrictions of both the localized environment of the Namib desert, as well as the many other arid regions of Namibia that have strong winds and similar topography.

Another widespread passive cooling solution across all of Namibia's environments is shading. We found that there are many different types of shades that can be used in the Namibian climate. There are shades that are made out of solar panels, thatch, wood, and cloth. All of these options have different benefits when used for passive cooling. The solar panels allow for the generation of electricity. Materials such as wood and thatch can be harvested locally and then constructed cheaply as retrofits. One exceptional option for the Namib desert especially is cloth shades. Due to the highly variable wind in the desert, it is actually possible that roofs can be torn off of buildings if they have too much overhang (Nina Maritz, Architect, Personal Communication, 9/13/2018). Cloth combats this issue by not restricting airflow nor channeling it in a direction that could cause major structural damage.

Additionally, it is possible to greatly reduce heat transfer through solar radiation by using reflective materials. We conducted informal interviews with the Habitat Centre's engineering staff. When we asked them what type of solutions work most effectively in the hot seasons, they responded that maximizing solar radiation reflection back into the atmosphere and preventing the structure from being exposed to heat are the most important factors to consider for passive cooling.

The experts of the Habitat Centre identified numerous building materials that are available for each region of Namibia that align with the properties that we are seeking for our passive cooling solutions. Each of the materials found in **Appendix E** can be found locally, processed in a very simple manner and used to increase the thermal mass of walls in buildings around Namibia. We took a trip to Pupkewitz Megabuild (Windhoek) to identify modern building materials for prototype creation at the GRTC. We found materials that include: dimensional lumber, reflective paints, and Sisalation insulation.

## 4.2 “Collecting Data for Determining Passive Cooling Solutions for the GRTC” Analysis

To determine what passive cooling prototypes would be most effective for testing in the GRTC’s battery, inverter, and server rooms, we analyzed the pre-existing data available at the Centre, our own collection of temperature data, and our consultations with industry professionals. We established:

1. Climatic conditions such as wind, low humidity, and high air temperature follow consistent yearly trends, and passive cooling solutions must account for these trends.
2. The most prominent passive cooling solutions currently implemented at the GRTC include ventilation, and thermal mass.
3. Solar exposure is a major source of heat gain for the targeted rooms and primarily occurs through radiation and conduction through the buildings’ roofs.
4. Heat exhaust from technology is causing major heat pooling in areas of the targeted rooms and currently existing convective methods are not relieving this heat effectively.
5. Our initial technical data collection properly identified major heat gain sources from the environment and technology while accounting for the current passive methods in place at the GRTC
6. A series of passive cooling solutions that involve shading, evaporative cooling, insulating, reflective paints, and ventilation were the most suitable for testing at the Centre.

### 4.2.1 Pre-Existing Data Analysis

The major pieces of data we obtained for initial analysis of the GRTC included a floor plan of the targeted rooms, current passive cooling considerations within the targeted rooms and climate data from the SASSCAL weather station on base. Extrapolating from this information helped to determine the following:

1. The most prominent passive cooling solutions currently implemented at the GRTC include convective currents induced through heat extractors and thermal mass from the thick cemented walls.
2. The walls, ceilings and doors are especially important to consider for temperature data collection.
3. Climatic conditions such as wind, low humidity, and high air temperature follow consistent yearly trends.

*GRTC Floor Plan and Observation of Current Passive Cooling Methods*

The floor plan found in **Figure 5** of the battery and inverter rooms was used in conjunction with our observational analysis to establish a general understanding of the orientation of the rooms relative to each other and how this effected the distribution of heat.

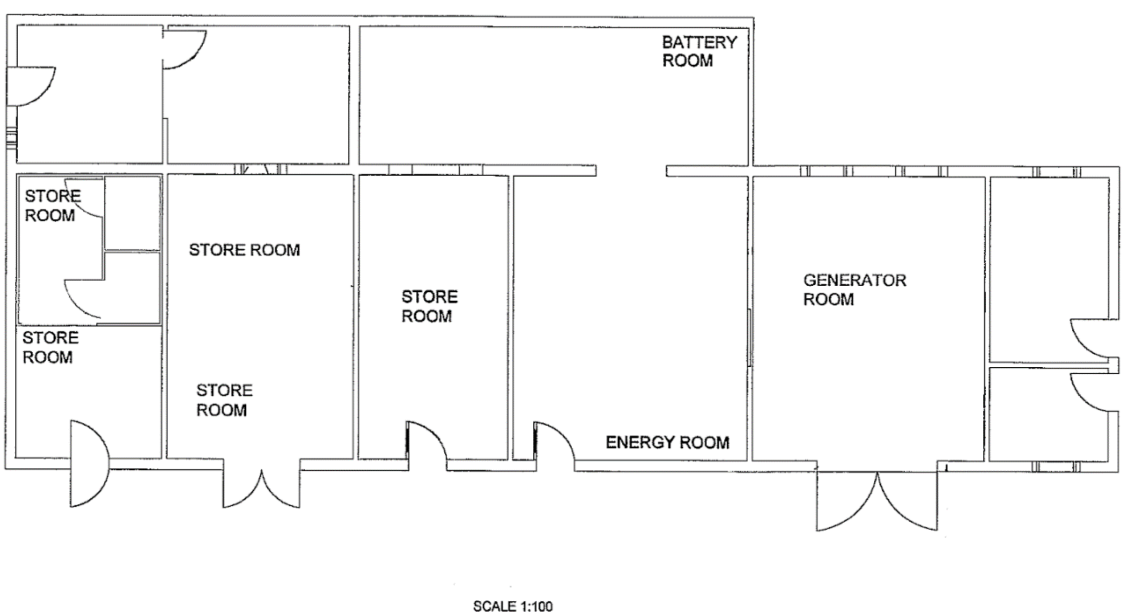


**Figure 5.** *Battery and inverter rooms w/ adjacent storage rooms*

The battery and inverter "energy" rooms share a wall with a large door opening between them, raising the concern that heat could transfer in between these two rooms as both house technology with significant heat exhaust. Additionally, there are storage rooms adjacent to both the battery and inverter rooms. The adjacent rooms were subject to similar environmental factors as the battery and inverter rooms because of how they shared the same external wall on each side of the building, as well as the same roof. This allowed us to use these adjacent rooms as control rooms for acquiring comparable air temperature data that showed how much hotter the rooms with technology become due to the technology's heat exhaust.

Passive heat extractors, known as "WhirlyBirds", are located along the roof of both the battery and inverter rooms. Specifically, there are four WhirlyBirds along the battery room, and four located in the corners of the inverter room. These heat extractors are meant to work with exterior vents to induce airflow throughout the rooms and exhaust the hot air outside. In the battery room, there are two 36 x 36 cm vent holes cut near the top of the external wall on the East side. The issue with the location of these holes is that air coming into the room gets immediately pulled through the heat extractor, which does not effectively induce a current throughout the room or the batteries (Eugene Marais, Personal Communication, 9/4/2018).

The roofing for this building consists of thin metal and insulating foam boarding for the ceilings. Between these materials, there is an air gap to prevent additional heat transfer through conduction. The exterior and interior walls of this building were constructed with plastered brick and cement and are ~ 26 cm thick. There are two sets of wooden doors that connect the inverter and battery rooms to each other and connect the inverter room to the outside. These building features offer a wide range in thermal mass capabilities and were identified as key locations for temperature data collection to understand each material's effectiveness.

The server room is a stand-alone tower with four exterior walls. This tower has no exterior ventilation but has pipes that connect the top and bottom floor of the building. This lack of ventilation was a major factor when considering passive cooling solutions to implement. This tower, similar to the battery/inverter building, was also created with dense thick walls. Like the battery and server rooms, we identified that the walls, ceilings and doors were key features to consider for temperature data collection.

*Climate Data*

The climate data we obtained from the local SASSCAL weather station shows that wind, air temperature and humidity follow consistent yearly trends, as shown in **Figures 6 and 7**. Thus, passive cooling methods would be useful year round in this environment. Additionally, obtaining a weather report on the days we collected our preliminary temperature data was useful to understand how our measurements were affected by environmental conditions.

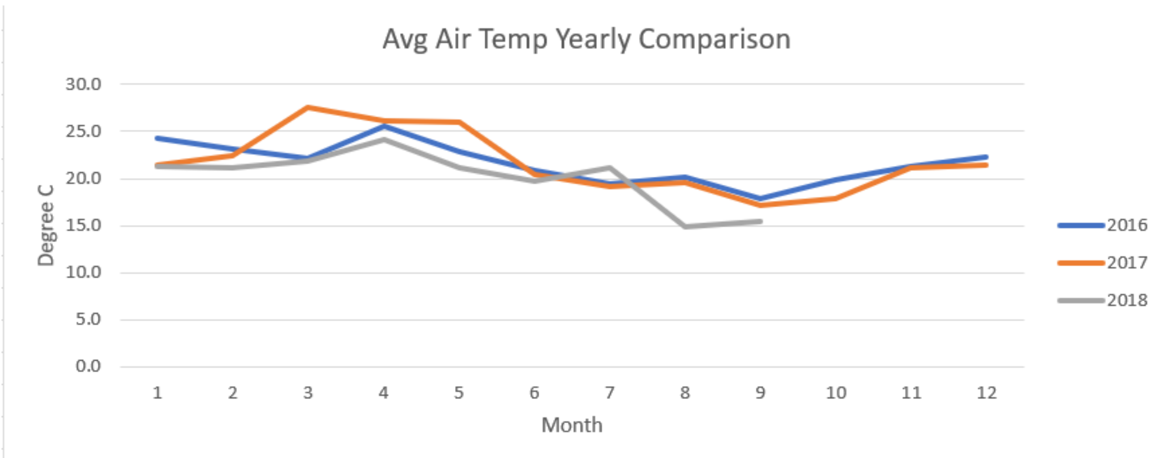


**Figure 6.** *Comparison of yearly trends for the average ambient temperature of each month*

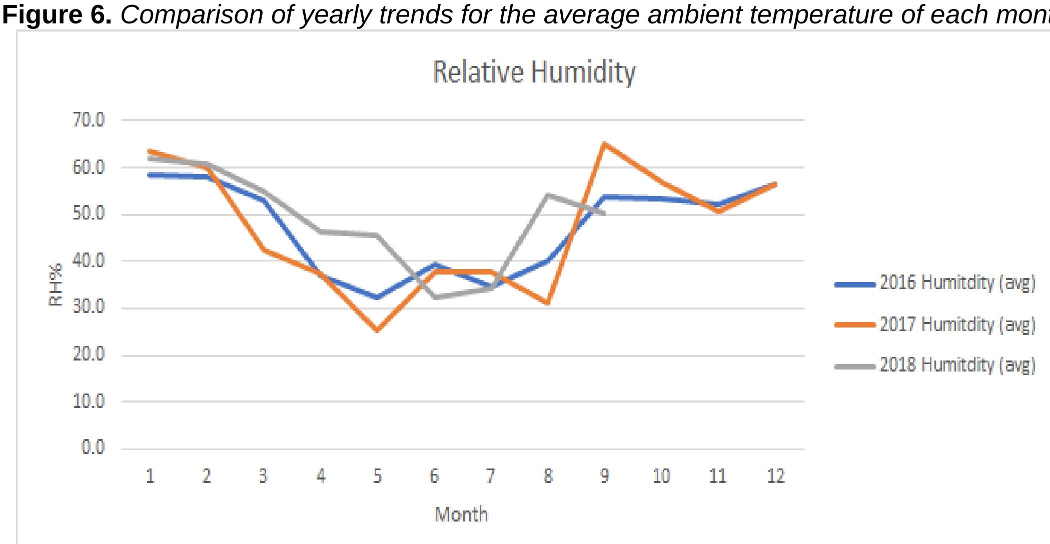


**Figure 7.** *Comparison of yearly trends for the relative humidity of each month*

As we collected our data in early September, it was important to note that the heat from the environment was at a minimum and that it would become even more of a factor in the hotter months between February and May. These conclusions caused us to focus on roof and wall shading techniques when brainstorming our prototypes. The trends of average yearly wind speed suggest that while certain months bring faster winds, the currents in the air are consistent enough to consider ventilation passive cooling methods as a year round solution.

The trends in average yearly humidity suggest that there is a consistent dip in humidity levels between the months of May-August, where the relative humidity ranges from 25-40 %. We determined that an evaporative cooling method was worth testing as a solution for the drier times in the year. Additionally, the data obtained regarding wind direction aided in determining how to orient the wind funnels of the evaporative cooling prototype to most effectively capture the wind. There are two general directions that winds go through the area surrounding the GRTC. These directions are approximately from the northeast and the southwest.

### 4.2.2 Temperature Data Analysis

This section presents the results from the temperature data collection which was used to identify solar radiation and technology as the two primary heat sources into targeted rooms.

#### *Heat gain from solar radiation*

Temperature data collected for the walls, roofs and doors on 8/31/2018 indicated that solar radiation exposure is a major source of heat gain for the targeted rooms and primarily occurs through radiation and conduction through the buildings' roofs. **Figure 8** shows the outside temperatures of the roofs for each room throughout the day. All three roofs quickly rise in temperature as the sun rises in the day and reaches a maximum temperature of 35°C. This is 10°C hotter than the outside ambient temperature.

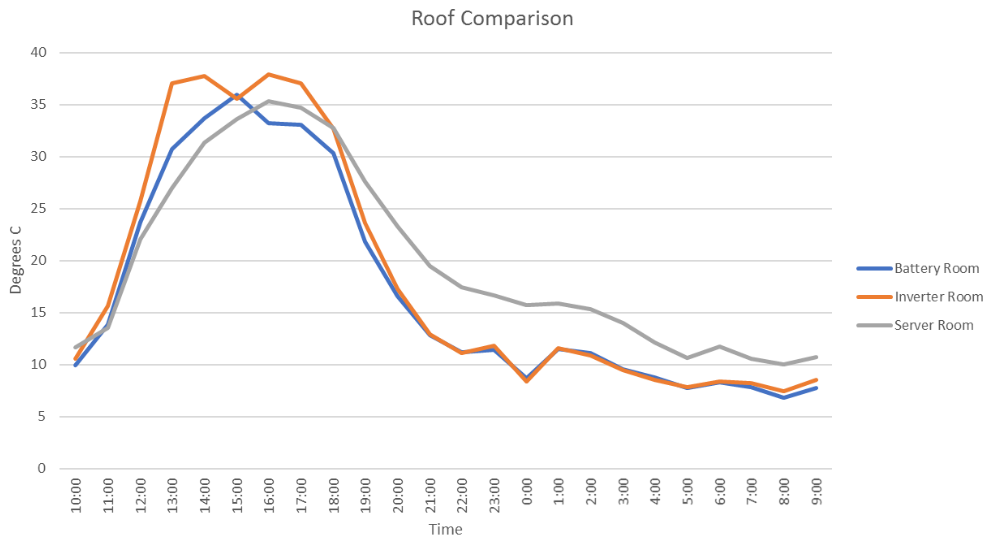


**Figure 8.** *Comparison of average roof temperature collected from an IR Thermometer*

We characterized the heat transfer rate between the roof and the ceiling as differentials in **Figure 9.** A roof that is an efficient thermal barrier would have a larger temperature difference with the corresponding ceiling. The data demonstrates that in the middle of the day, the roof-ceiling differential for the inverter and battery room roof remains relatively small with a peak of 13°C, which is an indication that heat is quickly transferring into the ceiling and therefore the room. In comparison, the server room differential is relatively large throughout the middle of the day with a peak of 22°C which means that heat transfers into the ceiling at a much slower rate. This means that the inverter and battery room ceilings are not as effective in insulating the room from the heat in comparison to the server room. The server room is more efficient due to the concrete ceiling which acts as thermal mass.

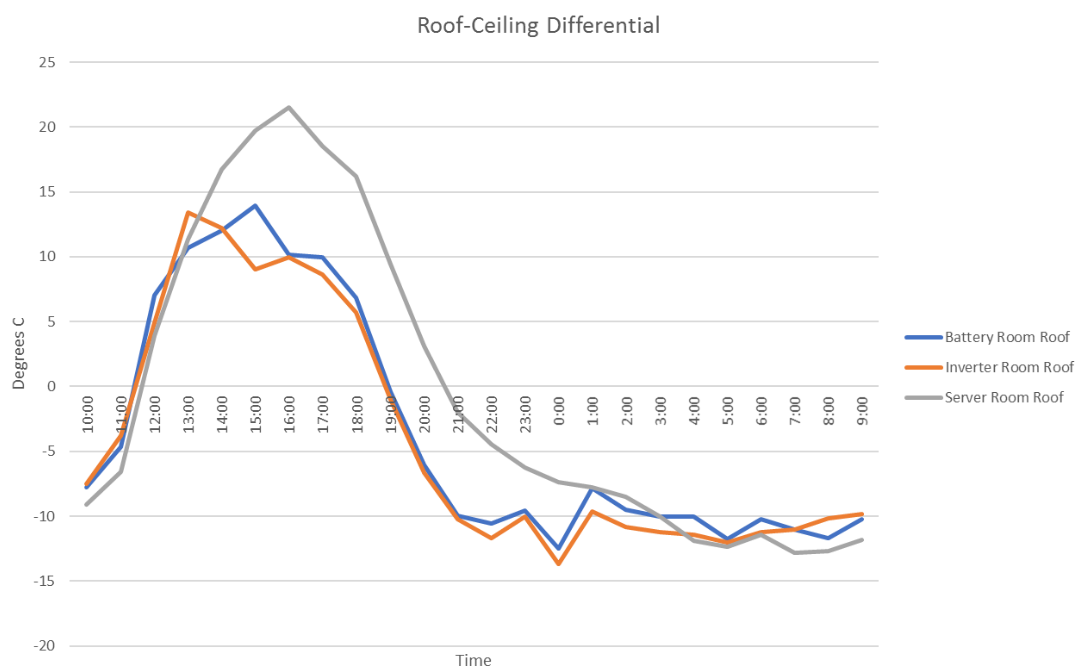


**Figure 9.** *Differential between Roof-Ceiling for targeted rooms*

Like the roofs, the exposed battery external walls were also examined to determine their effectiveness as heat barriers. **Figure 10** compares the external battery wall with the interior wall temperature. The external wall quickly heats up to a high temperature during the day, but the inside wall slowly heats up throughout the day. This indicates a more efficient wall that has a slower heat transfer rate which is most likely due to the thermal mass in the walls. It is interesting to note that the inside wall remains at a higher temperature into the night while the external wall cools off. This implies that the wall stores the heat energy and slowly releases it throughout the night.

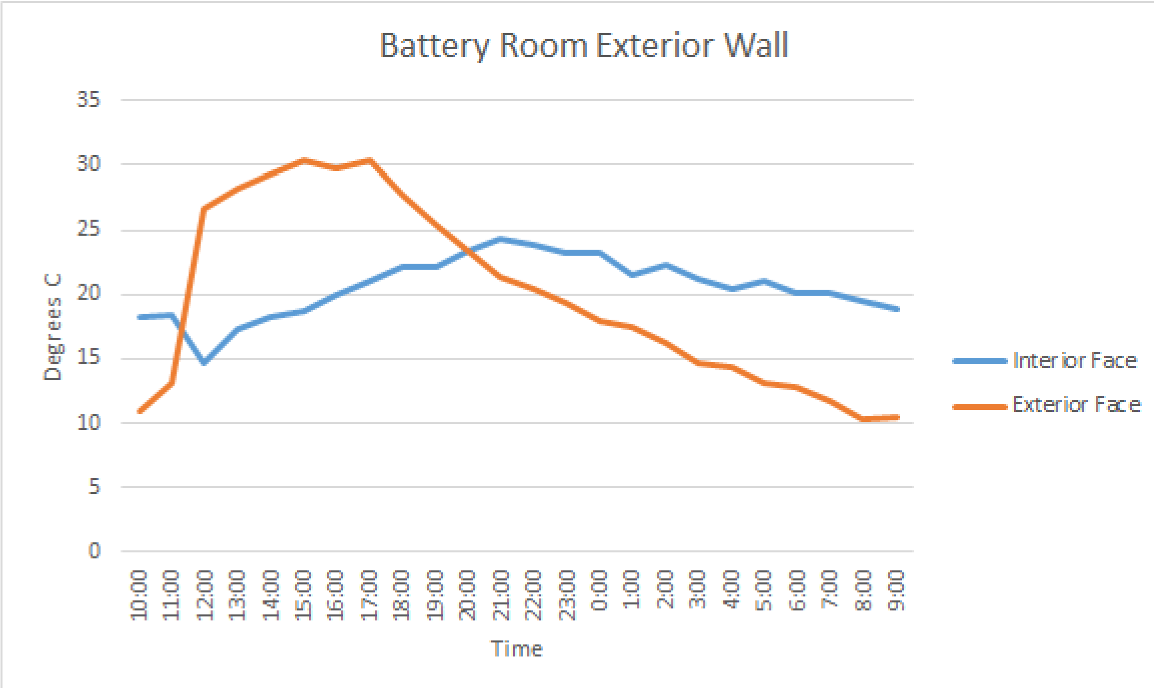


**Figure 10.** *Comparison between the faces of the battery room exterior wall*

Solar radiation is the primary cause for heat gain through exterior building surfaces. Understanding the orientation of these surfaces relative to the sun's path is crucial to identify where the most heat gain from solar radiation occurs. **Figure 11** displays the sun's path over the course of a day, as well as how it changes throughout the year. It can be seen that in the winter months, the sun's path flattens to the Northwest, while in the summer, it travels higher over the sky. **Figure 12** depicts the temperatures of the four walls of the server tower. It is important to note that each wall faces a cardinal direction and the temperatures of these walls peak at different times of the day. This is a clear indication that the orientation of the walls relative to the sun's path determines where the most heat gain from solar radiation occurs. Our data collected on solar exposure of targeted walls correlates with these peaks and can be seen in **Figure 13.**

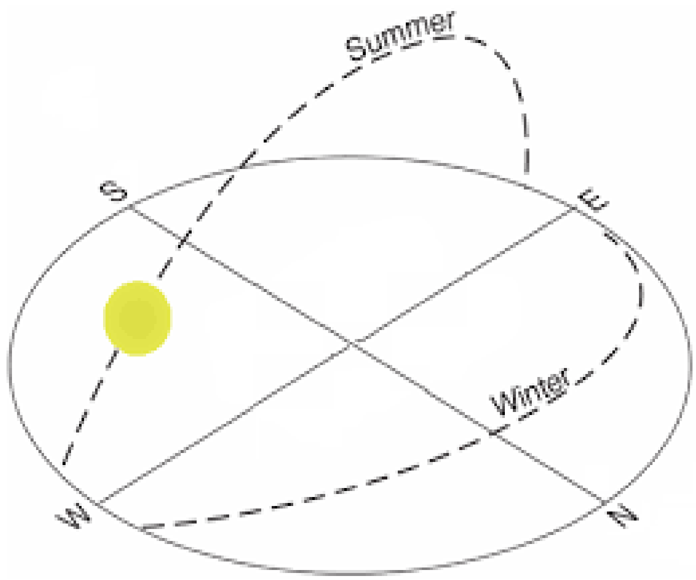


**Figure 11.** *The sun's path throughout seasons.*

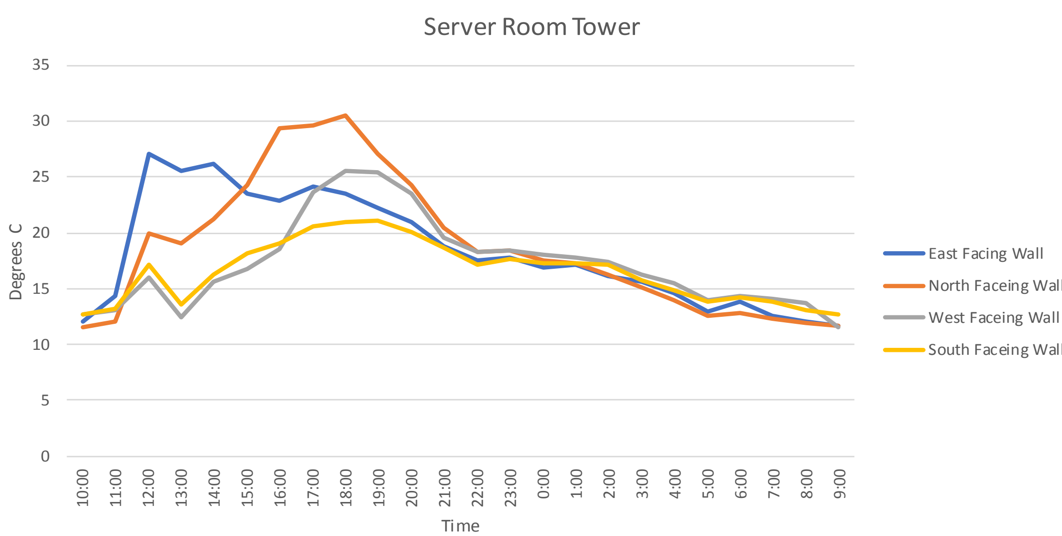


**Figure 12.** *Comparison of temperature readings for each face of the server tower*

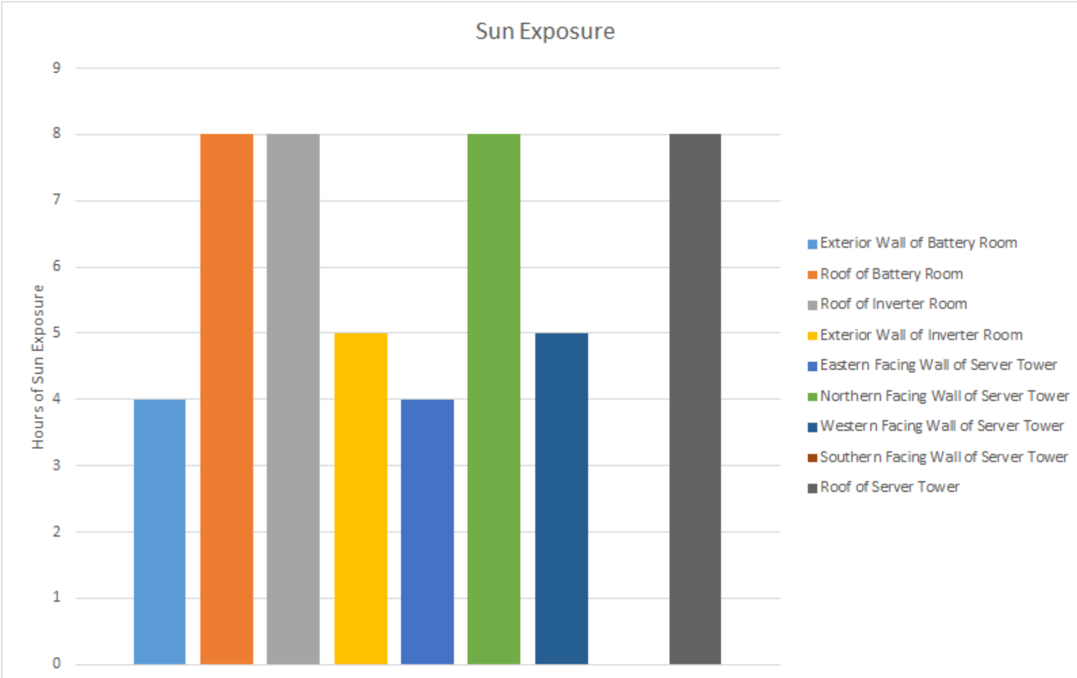


**Figure 13.** *Comparison of hours of direct sun exposure*

Qualitative analysis of thermal images taken in each room identifies specific building inefficiencies that increases solar heat transfer. **Figures 14** show a painted black strip on the exterior wall of the battery room. Qualitative analysis indicates that this is a significant area of absorption. **Figure 15** shows that there is a red band of heat on the inside of the wall. This supports the result that the black color of the strip absorbs a significant amount of solar radiation and transfers it into the room. A similar building quality inefficiency was observed with the exterior doors. **Figure 16** shows that qualitatively the dark brown door is significantly hotter than the surrounding wall, which is an indication of an increased transfer of solar heat. Overall these inefficiencies can be characterized by their darker paints which causes solar radiation to be absorbed rather than reflected at these locations.

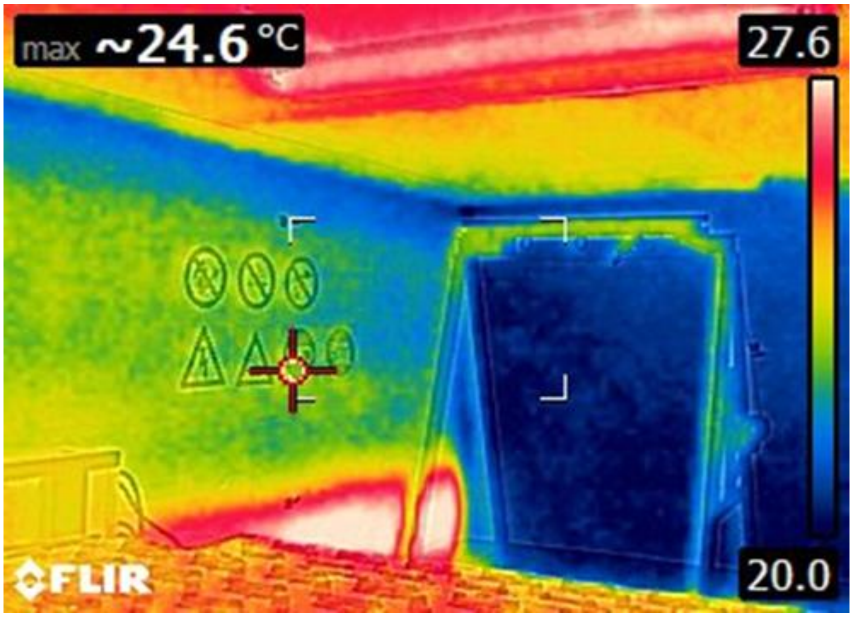


**Figure 14.** *Effects of a painted black strip on the interior wall in the battery room.*

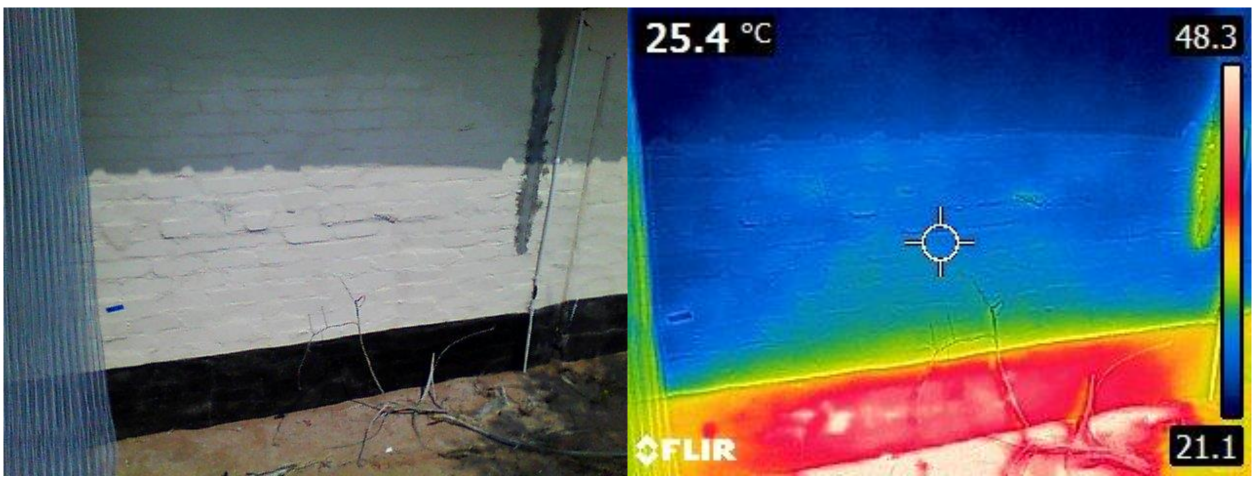


**Figure 15.** *Images of battery external wall ball strip in color and as thermal image*

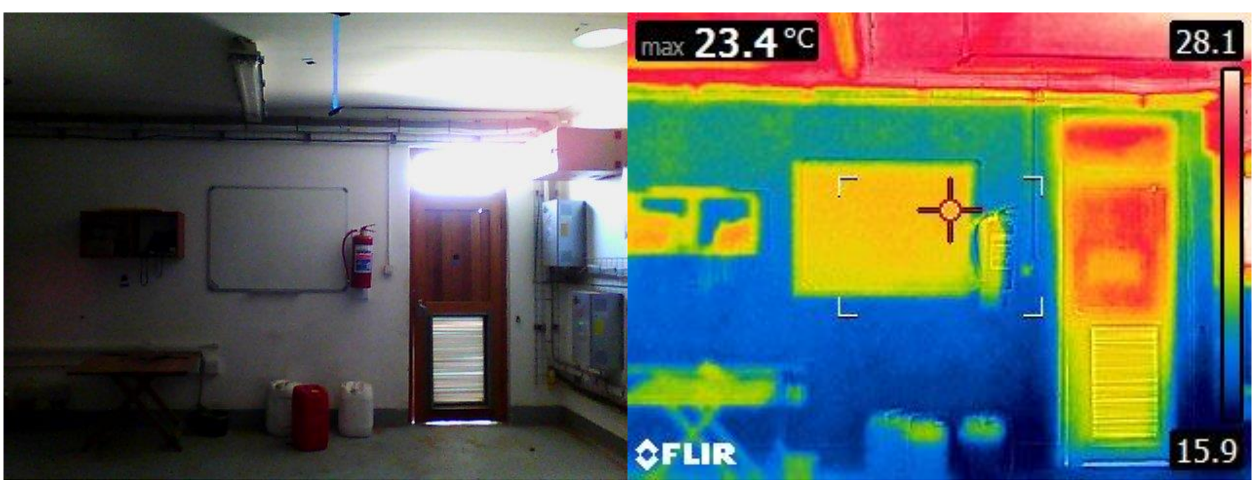


**Figure 16.** *Images of inverter room door in color and as thermal image*

The sun is the major source of heat gain through the roofs and exterior walls, especially when in direct sunlight. Examining the differential of the roof and ceiling indicates that the battery and inverter room roofs have insulation inefficiencies which allow the heat to transfer into the rooms. It was important to consider passive cooling solutions that work to reduce the high external surface temperatures. Furthermore, insulation can reduce the heat transfer rate between the roof and ceiling. This would limit the amount of solar heat gain into the room which would keep the room at a lower ambient temperature.

### *Heat gain from technology*

Heat exhaust from technology is the other major source of heat gain in these rooms. Specifically, it causes major heat pooling in targeted areas of the rooms and currently ventilation methods are not relieving this heat effectively. **Figures 17, 18 and 19** show the comparison of the ambient temperature of the room with the temperatures of the technology throughout the day. Note that the server equipment and inverters operate at a much higher temperature than the ambient temperature. The batteries also operate under a similar yet less pronounced manner

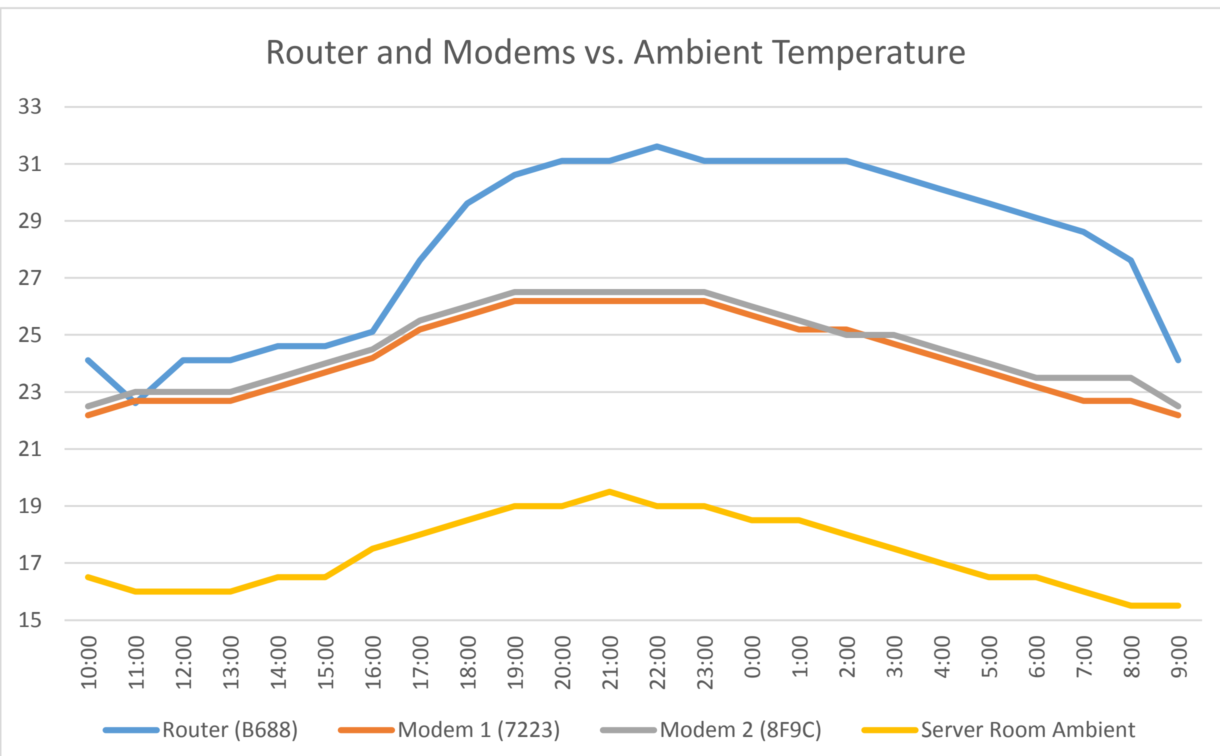


**Figure 17.** *Comparing of temperature measurements of various technology vs. the ambient temperature of the room.*

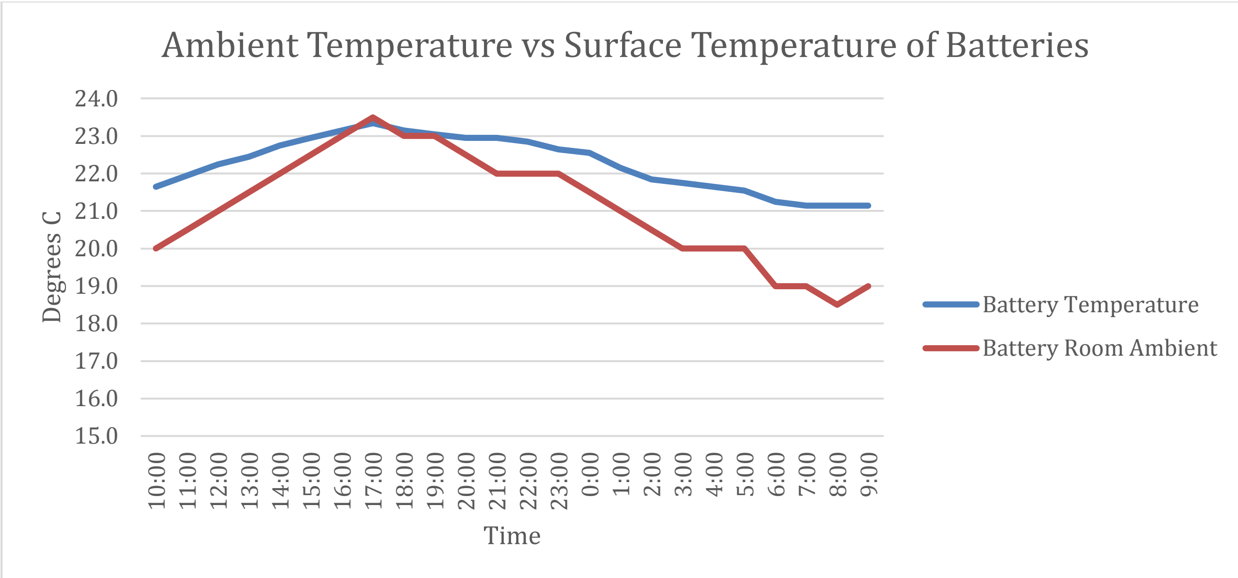


**Figure 18.** *Comparison of the temperature of the batteries vs the ambient temperature of the battery room.*

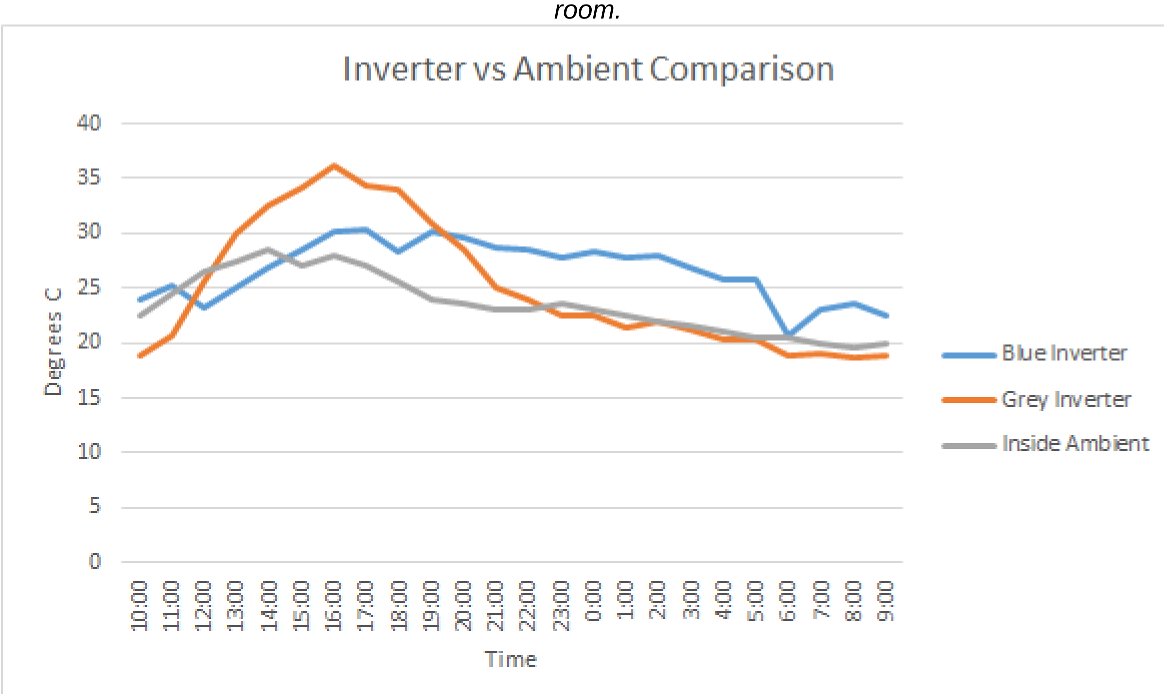


**Figure 19.** *Comparison of the two different types of inverters and the ambient temperature of the room.*

The thermal images of the inverter and battery rooms in **Figure 20** show the thermal gradients focused directly on this technology. A qualitative analysis of these images further indicates a significant difference in temperature between the technology and the ambient area. It is also important to note that the heat produced from inverters and batteries pool in localized regions, which increase the temperatures that the batteries and inverters operate. We did not observe heat pooling in the server room thermal images **(Appendix F).**

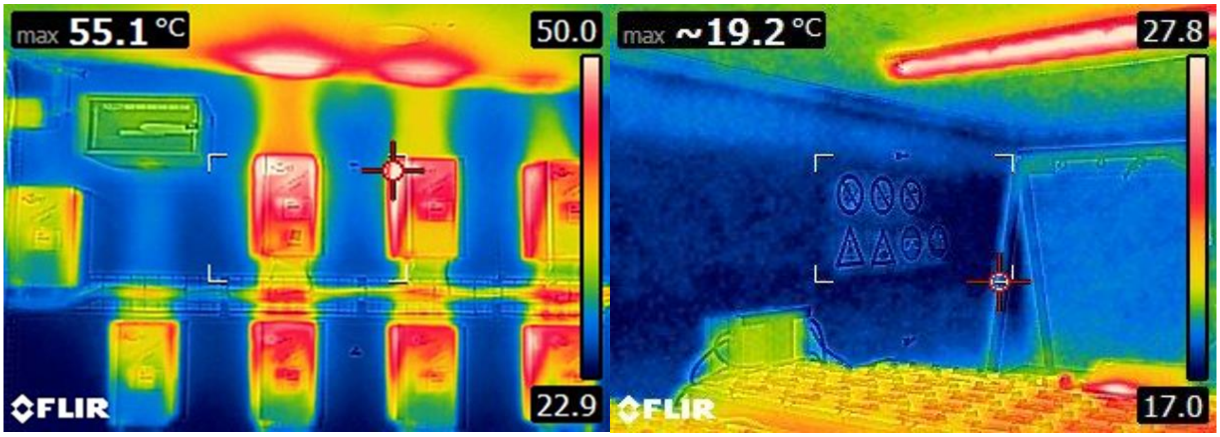


**Figure 20.** *Heat pooling due to Grey Inverters and Batteries*

Lastly, the technology in these rooms was found to have a significant effect on the rooms themselves. The graphs in **Figures 21 and 22** compare the ambient temperature between the inverter and battery rooms with similar adjacent rooms that experience the same environmental heat input but do not house technology. The ambient temperatures of these rooms were 2-4°C higher than the adjacent control rooms during the middle of the day. It is also important to note the target rooms continue to operate at higher temperatures compared to the control rooms throughout the night.

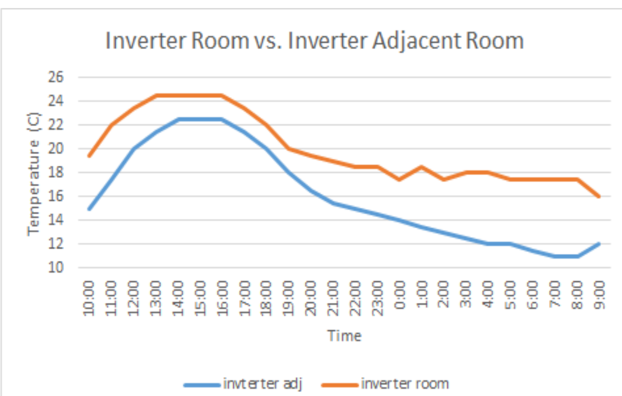


**Figure 21.** *Comparison of the ambient temperatures of the inverter room and a room adjacent to it*

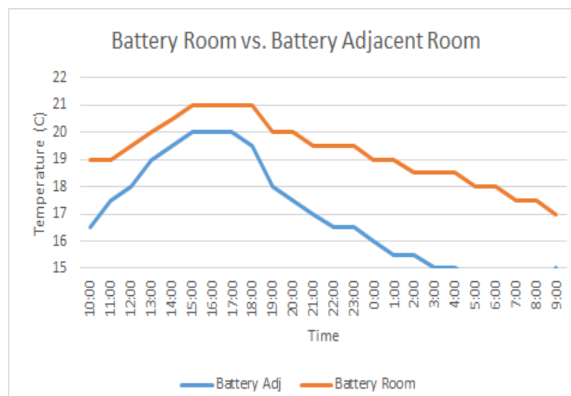


**Figure 22.** *Comparison of the ambient temperatures of the battery room and a room adjacent to it.*

Overall, we found that the technology in each room outputs a significant amount of heat which causes them to operate at a much higher temperature than the ambient room temperature. This is most likely because the current cooling mechanisms in place are inefficient. Next, putting the inverters and batteries in close proximity to each other causes significant heat pooling that further increases the operating temperatures, which can reduce their life and efficiency. Lastly, these technology rooms have significantly higher ambient temperatures compared to the control rooms, which indicates that technology is a significant heat contributor. Thus, passive cooling methods need to be designed to move heat away from the technology and also introduce cool air to further reduce the room temperature.

### 4.2.3 Validation of Data Collection and Methods Analysis

The methods of data collection explained in **Section 3.2**, produced reliable data that fell within the operating tolerances of based on two major factors: our validation of the measurement equipment and the confirmation from our semi-structured interviews with industry professionals.

#### *Measurement Equipment Validation Analysis*

iButtons and USB Data-Loggers that did not possess an active calibration sticker were tested following the protocol established in **Section 3.2.2**. We found that the measurement equipment was operating inside of our ± 2°C tolerance in 2 of the 3 data points collected. The data point outside of this range was due to user error during handling and setup.

#### *Semi-Structured Interviews with Industry Professionals*

Semi-structured interviews with industry professionals supported our data collection methods. We reviewed our data collection methods during these interviews. Mr. Glenn Howard said, "In general, here in Namibia, the external atmosphere is the biggest influence on building temperatures" (Mr. Glenn Howard, Consulting Engineer of Emcon Consulting Group, Personal Communication, 9/11/2018). This was the consensus across all interviews, validating one of our key findings. Additionally, we presented our conclusions on how the heat exhaust from the technology was another major contributor to the inside ambient air temperature of the targeted rooms at the Centre. Our methods for arriving at this conclusion were confirmed by their expertise. After this validation, we began to identify the most applicable passive cooling solutions for testing at the GRTC.

#### *Identification of Prototype/Solution Candidates*

To address the excessive heat in the server and battery/inverter rooms at the GRTC, we determined to test shading, evaporative cooling, reflective paints, ceiling insulation, and ventilation passive cooling prototypes. Shading was identified as the primary method to test because of the significant amount of heat gain into the rooms due to solar radiation and recommendations from the industry professionals. During our interview with Nina Maritz, she informed us that shading works not by cooling the air, but by reducing the amount of solar radiation that a targeted surface is exposed to (Nina Maritz, Architect, Personal Communication, 9/13/2018). This knowledge was coupled with the fact that the walls of the battery room were identified to be cavity walls, which implies that conduction is significantly reduced (Glenn Howard, Consulting Engineer, Personal Communication, 9/11/2018). There are numerous methods of shading (see **Section 4.1).** Gloria Gachiku of Gachiku-Kamau Architects recommended that we look more extensively into the invasive woods, as she utilizes them on her office due to its aesthetic nature. Additionally, our observations in Windhoek highlighted that shading cloth is widely used as well. Based on observations at Pupkewitz Megabuild, we identified a prominent insulation material used across Namibia known as Sisalation, which can also be used for a reflective solar shade. These three methods of shading were identified for further prototype testing.

The second passive cooling method we identified for further testing was evaporative cooling. Low relative humidity (RH) values throughout most of the year **(Section 3.2.1)** suggested that evaporative cooling may be a viable option. Notably, the GRTC's batteries are sealed and therefore are not susceptible to humidity which would increase with evaporative cooling. This was coupled with the information acquired from Glenn Howard that evaporative coolers can be harness wind through funnels passively (Consulting Engineer, Personal Communication, 9/11/2018). Furthermore, Nina Maritz explained to us a phenomenon called second stage cooling, which is utilized by modern evaporative cooling technology (Architect, Personal Communication, 9/13/2018). This phenomenon involves using the excess water that is not utilized in the initial evaporative cooling step, but was significantly cooled by being exposed to cooler air. Then is recycled back into the system to provide a more effective cooling method due to a larger temperature differential. This benefits the GRTC in two ways, water would be conserved and recycled, and the energy requirement is very low compared to that of a traditional air conditioner. The Habitat Centre utilizes an evaporative cooler, which works by spraying water on cloth in a tall tower, and letting the cool air sink into targeted rooms. Due to its passive nature, we decided to model our future prototype off of this type of cooler.

Our third method consisted of researching reflective paints, following advice from the Habitat Centre Engineers. Who recommended coating the walls and ceilings with reflective paint will decrease the overall building temperatures, by decreasing the total amount of solar radiation permeating the surfaces. The thermal image of a black strip of paint on the battery room external wall highlights the amount of radiation that can be absorbed by a non-reflective paint, and is emphasized by the visible red stripe depicted in **Figure 14**. Reflective paint would reduce the amount of absorption in this particular area. We determined a feasible way to reduce the overall radiation absorbed by the structure would be to use reflective paint on the doors and darker regions of the exterior walls.

Our fourth method identified for further testing was increasing ceiling insulation inside of the battery and inverter rooms. During our interview with Glenn Howard, he informed us that there was no reflective barrier inside of the ceiling/roof gap of the battery and inverter rooms. Coupled with our observations of these rooms, we determined that utilizing a reflective barrier as ceiling insulation could decreased heat transfer from radiation. Sisalation was the material we decided to use given its availability across Namibia.

Our final method identified for further testing was ventilation. This method addresses the heat exhausted from technology (i.e. significant heat pooling as seen in **Figure 23**). We found that there needed to be increased ventilation to induce a more effective convective current to exhaust the heat into the atmosphere. The Whirlybirds in the technology rooms were installed to generate convection currents that exhaust the heat from the inverters into the battery room and out of the Whirlybird (Glenn Howard, Consulting Engineer, Personal Communication, 9/11/2018). However, our temperature data suggests these currents are not sufficiently cooling the rooms. Furthermore, analysis of the GRTC floor plans helped us to identify adjacent rooms that do not house technology **(Figure 5)**. Utilizing these rooms for ventilation would be beneficial because of the lack of heat exhaust. Thus, we proposed that inducing additional convection currents through the battery and inverter room would be worth testing as a passive cooling solution at the GRTC.


**Figure 23.** *Substantial heat pooling due to inverter heat exhaust*

## 4.3 "Testing Solutions and Prototypes at the GRTC" Analysis

Following the implementation of our passive cooling prototypes, the temperature data collected for each potential solution was analyzed through comparison of control points on the given testing days, as well as with our preliminary data sets. This was crucial to quantify and understand the effectiveness each solution had on the targeted rooms. Each passive cooling solution was assessed by considering the effectiveness level (1-3) and cost to determine the most beneficial solutions for retrofit implementation. The passive cooling prototypes we tested at the GRTC were: roof/wall shades, evaporative coolers, reflective paint, ceiling insulation, and cutting holes in the rooms to induce convection currents. We found:

1. Roof/wall shades were effective (2) as a passive cooling solution
2. Evaporative coolers were very effective (3) as a passive cooling solution
3. Reflective paint was found to be effective (2) as a passive cooling solution
4. Ceiling insulation was found to be effective (2) as a passive cooling solution
5. Cutting holes to induce convection currents was found to be minimally effective (1) as a passive cooling solution.

6. Based on total cost incurred for each prototype/solution, evaporative cooling and shading would be the most appropriate to implement as passive cooling retrofit(s) at the GRTC.

### 4.3.1 Roof/Wall Shading Analysis

Shading was found to be an effective (2) passive cooling method. The shading prototypes we tested on the targeted rooms at the GRTC were projected to effectively reduce the amount of thermal energy from the sun that was transferred into the rooms. Solar radiation would be reflected or absorbed by the shades (Nina Maritz, Architect, Personal Communication, 9/13/2018). This passive cooling concept was applied through the following prototypes: Solar geyser roof shades, a double roof, and wall shades of various materials. Each of these designs were tested individually on each room. An analysis of the effectiveness of each is provided below.

#### *Solar Geyser Shades*

The purpose for considering the solar geysers as shading devices was because of the GRTC's plan to implement solar panels on the roof of the battery/inverter building. The solar geysers act as mock solar panels to give an accurate representation of using solar panels as shades. This shading technique proved to reduce the amount of solar radiation transferred into the part of the roof that the shade covered by as much as 7°C, as seen in **Figure 24**. Our initial data collection showed that the inside ambient temperature of the battery room steadily increases over the course of the day, while the outside temperature has a typical daily trend, as seen in **Figure 25**. On the day we tested the solar geyser shades, the ambient air temperature of the battery room compared to outside shows a 6°C difference at the hottest time of the day, as seen in **Figure 26**. While, the preliminary data collection day only shows a 2°C difference between the inside and outside ambient temperatures at the hottest time.

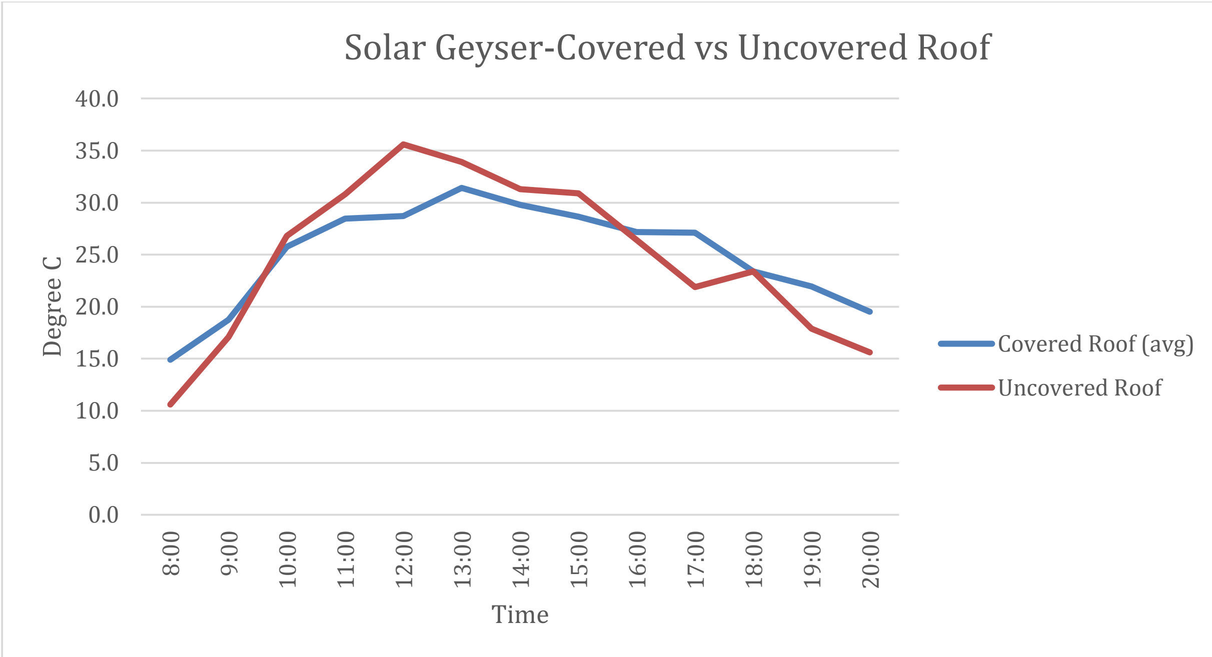


**Figure 24.** *Temperature trends of the area of roof covered by geyser shades vs a control area that was uncovered*

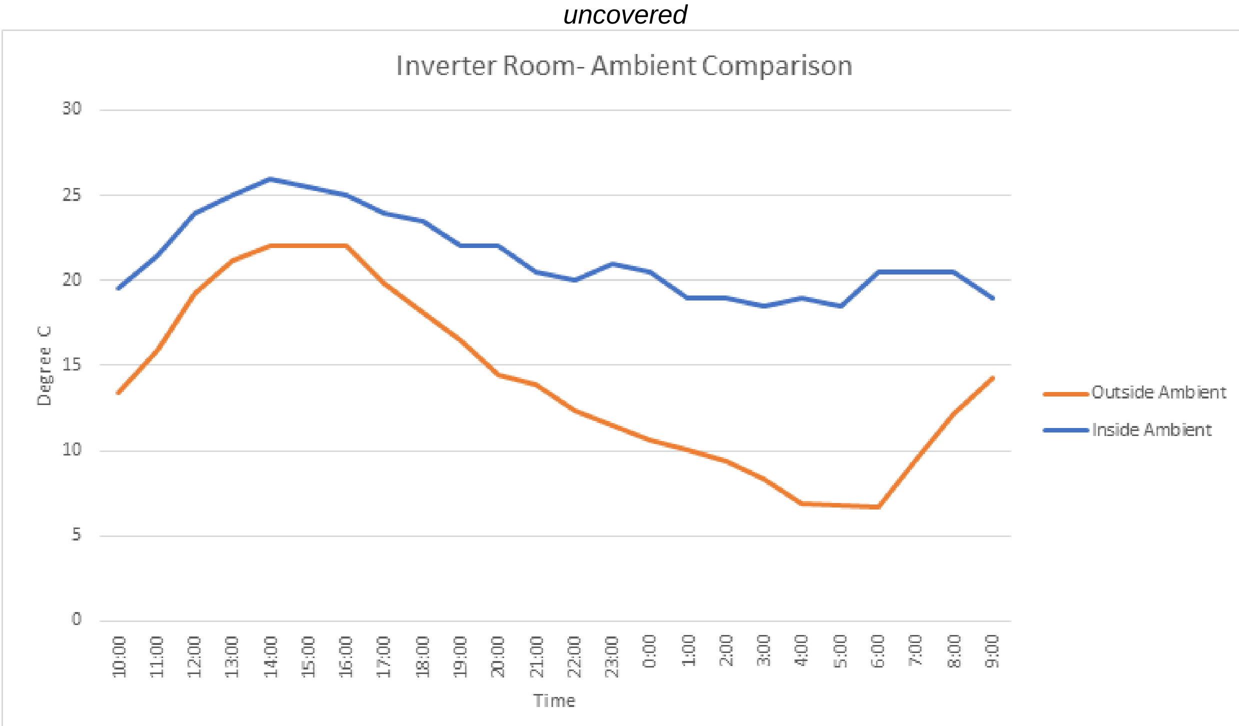


**Figure 25.** *Comparison between daily temperature trends*

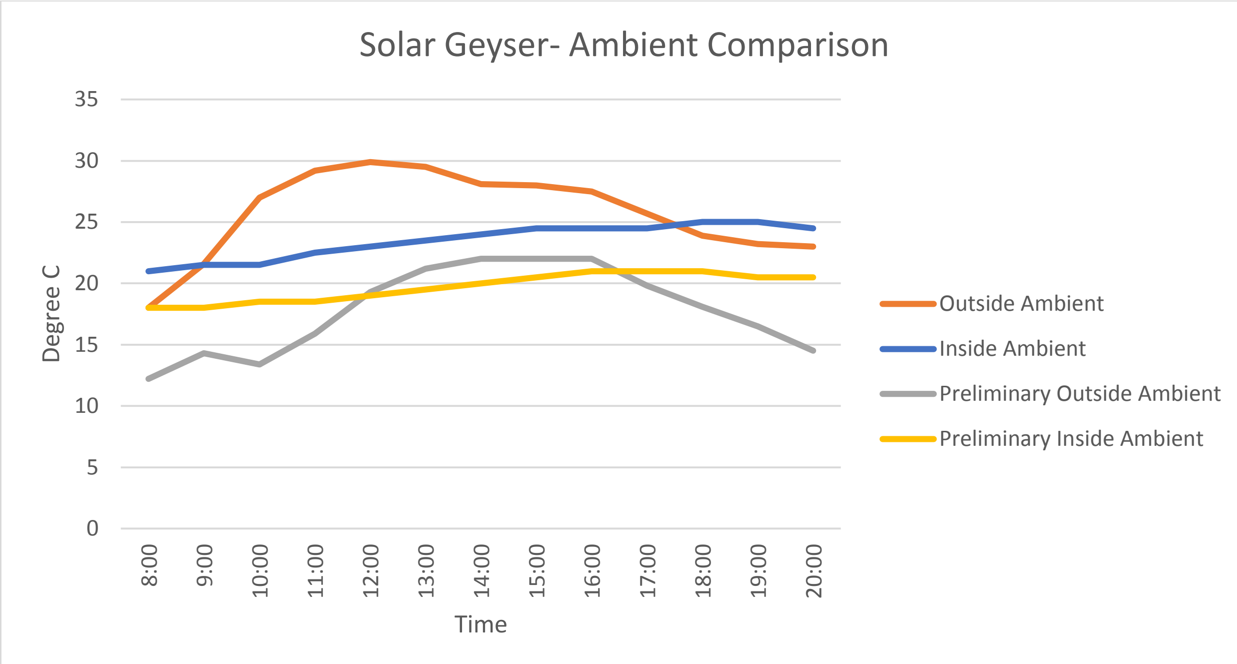


**Figure 26.** *Comparison of the outside vs inside ambient temperature comparison for the day of testing and control day*

As the trends in differentials remained consistent for the hours of the day when the sun was at its peak, we can infer that the geyser shades contributed to the decrease of inside air temperature for the battery room.

### *Double Roof*

The double roof shading prototype consisted of Sisalation and was designed to lay flay across the inverter room roof to reflect the greatest amount of solar energy. This design was projected to be especially effective in the summer months due to the orientation of the sun being directly overhead, as depicted in **Figure 11**. For the portion of the roof that was covered by the double roof, it was about 11°C cooler than the uncovered roof at the hottest part of the day, as shown in **Figure 27**. At about 15:30, the covered roof cools off slower than the uncovered roof which is due to the Sisalation acting as a radiation barrier for the heat trapped underneath. This is important to consider for rooms that need to cool off quickly later in the day.

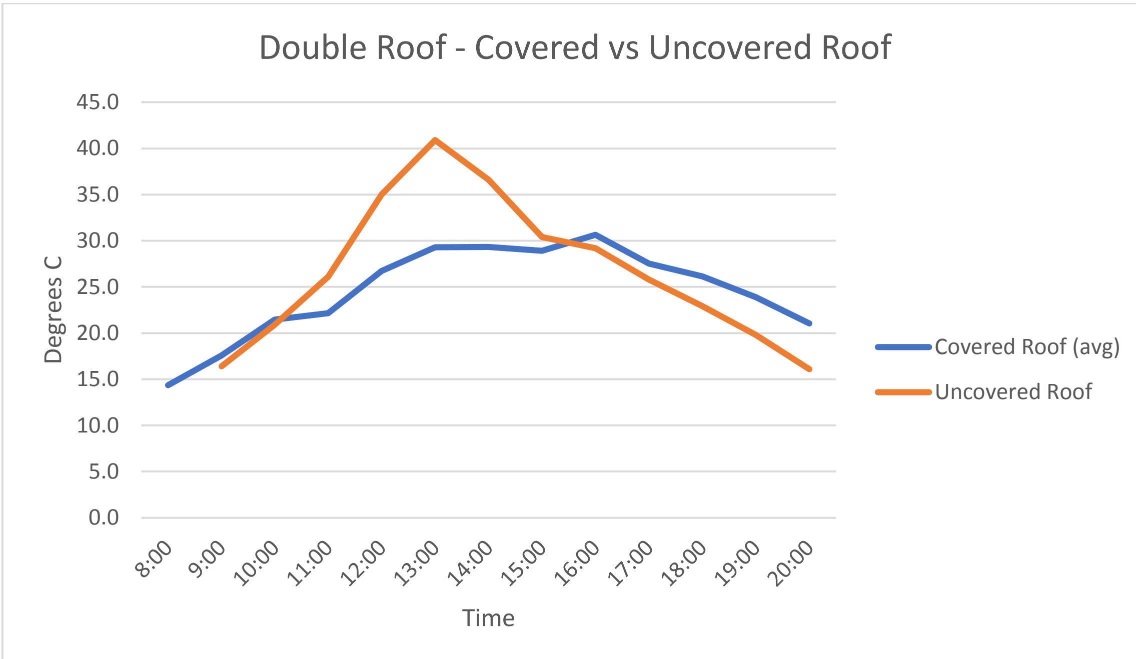


**Figure 27.** *Comparison of the area of roof covered vs the control area that was not covered*

To understand the effect on the inside ambient air temperature for the inverter room, we looked at the relationship between the outside/inside ambient air temperatures on a preliminary data collection day to the same relationship on the day we tested the double roof shown in **Figure 28**.

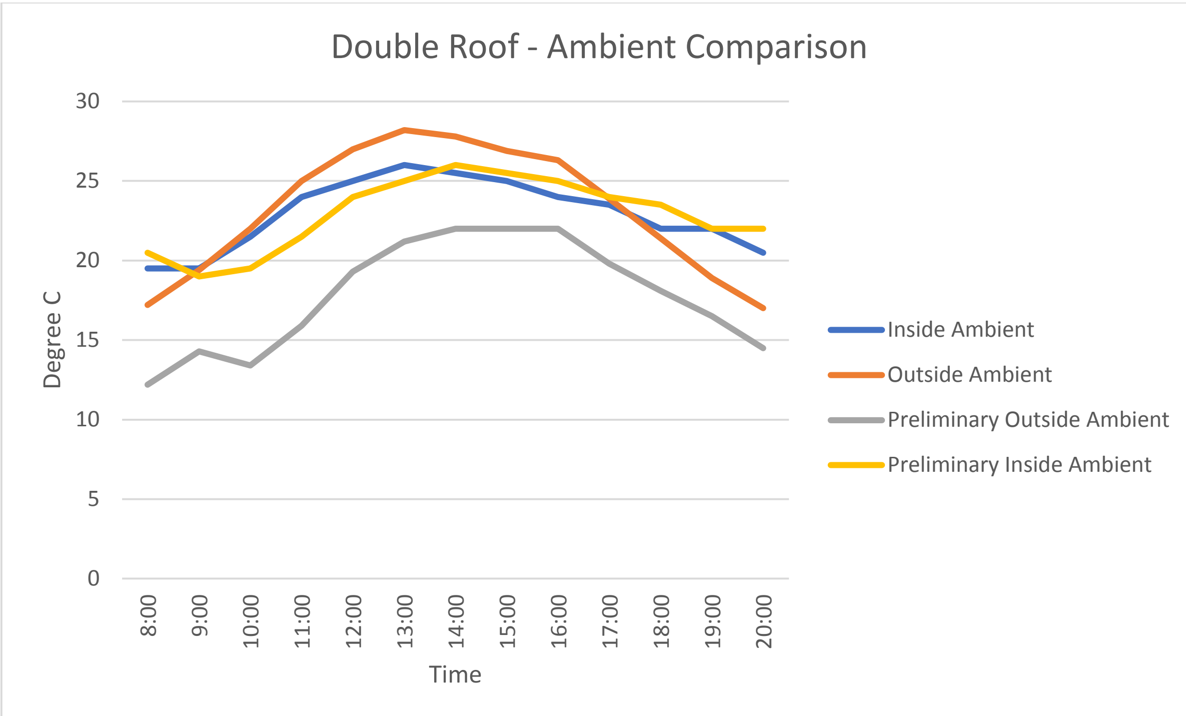


**Figure 28.** *Comparison the inside vs outside ambient temperature on the day the double roof was tested vs the control day.*

It can be seen from comparing these relationships that the inside ambient air temperature for the day we tested the double roof has decreased by as much as 6°C relative to the outside temperature. While this is a dramatic improvement, it is important to identify that the inside ambient air temperature for the inverter room on both of these days was almost the same. This could be a result of the heat exhausting from the inverters being the main contributor to the inside ambient air temperature.

### *Wall Shades*

The wall shades were designed to reduce the amount of solar radiation that would be transferred into the exterior walls of the battery room. To test the effectiveness of different materials available in Namibia, four different wall shades were created. Each one consisted of a different material; general sun shade cloth, invasive wood spars, and Sisalation. The sun shade cloth, invasive wood spars, and Sisalation shades were all tested along the battery room wall simultaneously to understand individual effectiveness, while also getting an overall effectiveness of shading that wall. The server tower shade was placed on the north face because it was identified through sun orientation data the north face receives the most sun during the Winter.

For the battery room wall shades, it can be seen that the Sisalation shade and the cloth shade were most effective in reducing exterior wall temperatures compared to the invasive wood spar shade as seen in **Figure 29**.

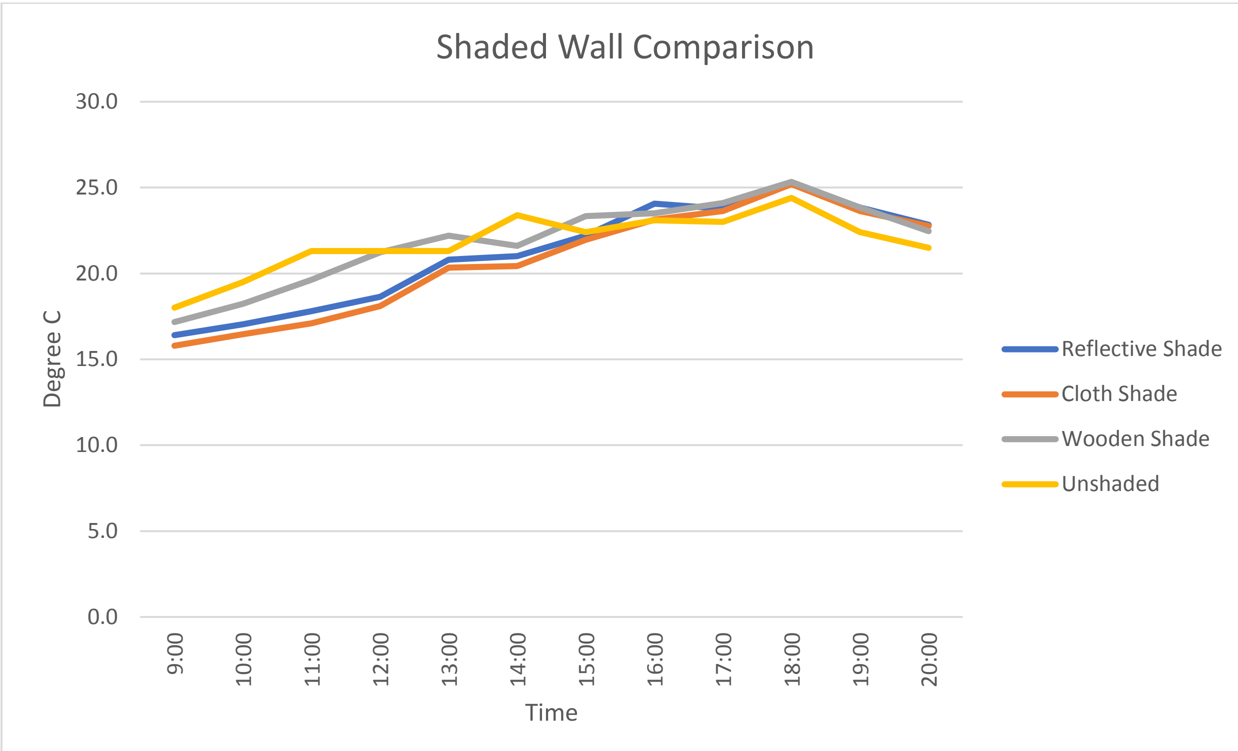


**Figure 29.** *Comparison of the shaded area of the wall for each type of shade and an unshaded control point.*

When we analyzed the wall shades, it was shown that the they did not have a significant effect on the battery room's ambient air temperature overall. Comparing the relationship of outside/inside ambient air temperatures on the day we tested the wall shades to the preliminary temperature data, as seen in **Figure 30**. It can be seen that the inside ambient air temperature increases at the same rate. While the wall shades effectively cooled the walls by reducing solar radiation, the ambient air temperature for the battery room remained unaffected, which could be due to the heat being given off from the technology inside.

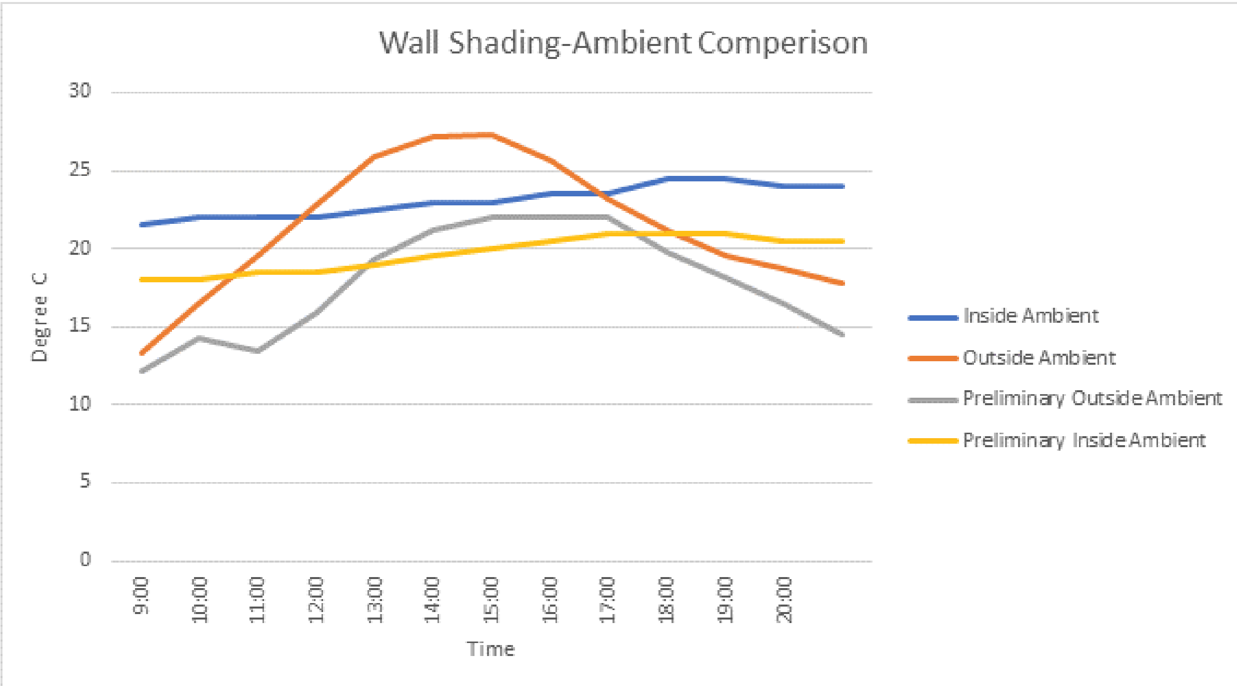


**Figure 30.** *Comparison of the inside vs outside ambient temperature of the battery room on the day the wall shading was tested.*

A Sisalation wall shade was tested on the north face of the server tower. The north face was selected for testing because it was found to receive the most direct sun exposure. As seen in **Figure 31**, the wall shade reduced the temperature of the wall by as much as 5°C compared to the area of that was not covered by the shade. This shows the shade was successful in reducing heat from solar radiation. To understand how shading the server tower would reduce the inside ambient air temperature, shading would need to be implemented on all walls of the tower that received direct sun exposure.

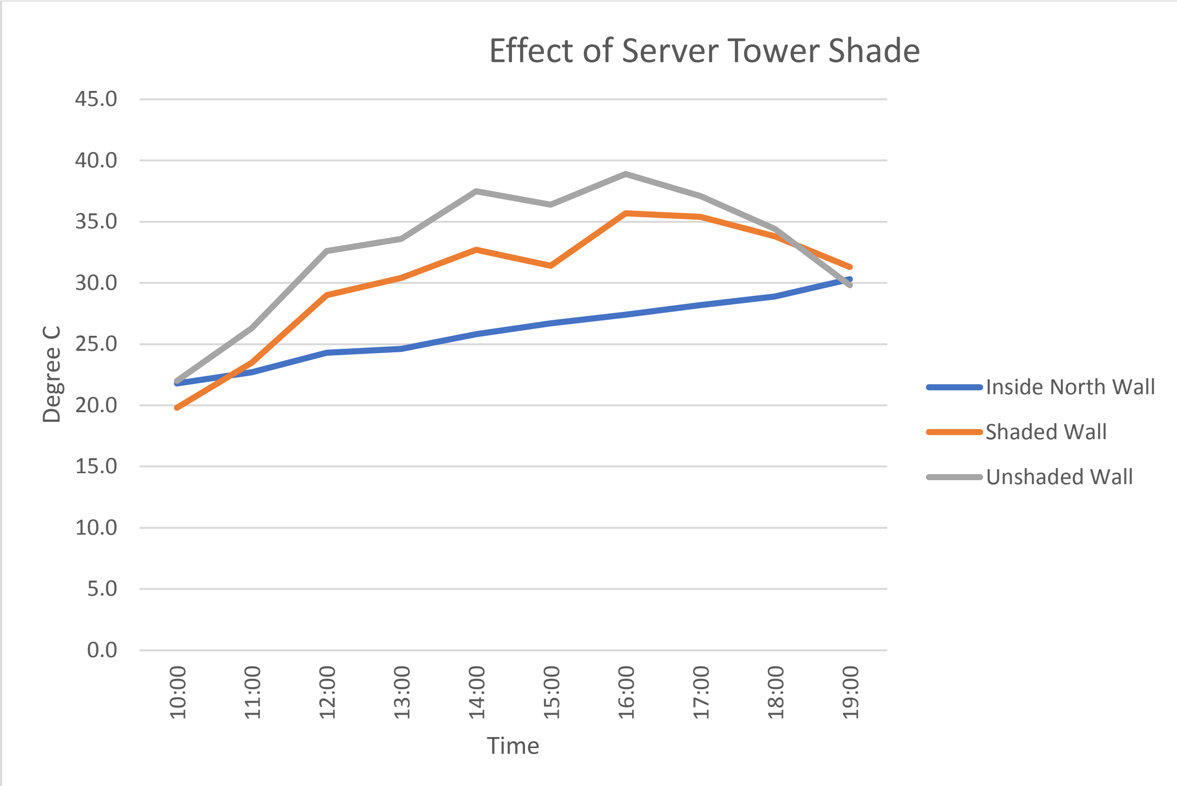


**Figure 31.** *Comparison of the shaded vs unshaded wall with the internal wall*

Shading as an overall solution was found to be effective (2) because of each prototypes effectiveness in reducing the thermal energy transferred into the targeted rooms. Shading for the server tower was especially effective because of how much of an impact solar radiation had on inside ambient air temperatures compared to the battery and inverter rooms. Roof shading, such as the solar geyser and doubles roofs, for the battery and inverter rooms were found to be more effective than the wall shades based on the amount of direct solar exposure the roofs received compared to the exterior walls of the building throughout the day.

### 4.3.2 Evaporative Cooling Analysis

The evaporative coolers were found to be very effective (3). The team constructed two evaporative cooler prototypes that were placed on WhirlyBird ducts on either end of the battery room. These evaporative cooling prototypes are depicted in **Figure 32**. The idea was that cooler air brought in from the evaporative coolers would fall into the battery room and would displace the hotter air that is being extracted by the two WhirlyBird's located in the middle of the room.

**Figure 32.** *Evaporative cooler prototype*

Both evaporative cooling prototypes showed a reduction in temperature in the air that traveled through the ducts. Not only did the air flowing into the room become cooler, the ambient air temperature of the battery room remained within a consistent 22-24°C temperature range throughout the entire 12-hour data collection period as seen in **Figure 33**. When comparing these trends, it can be seen that there is a substantial reduction in the increase of inside ambient air temperature for the day we tested the evaporative coolers. This is especially striking when we identify the outdoor ambient air temperature to peak at 28°C on this day, while the peak of the outside ambient temperature during preliminary data collection data was 22°C.

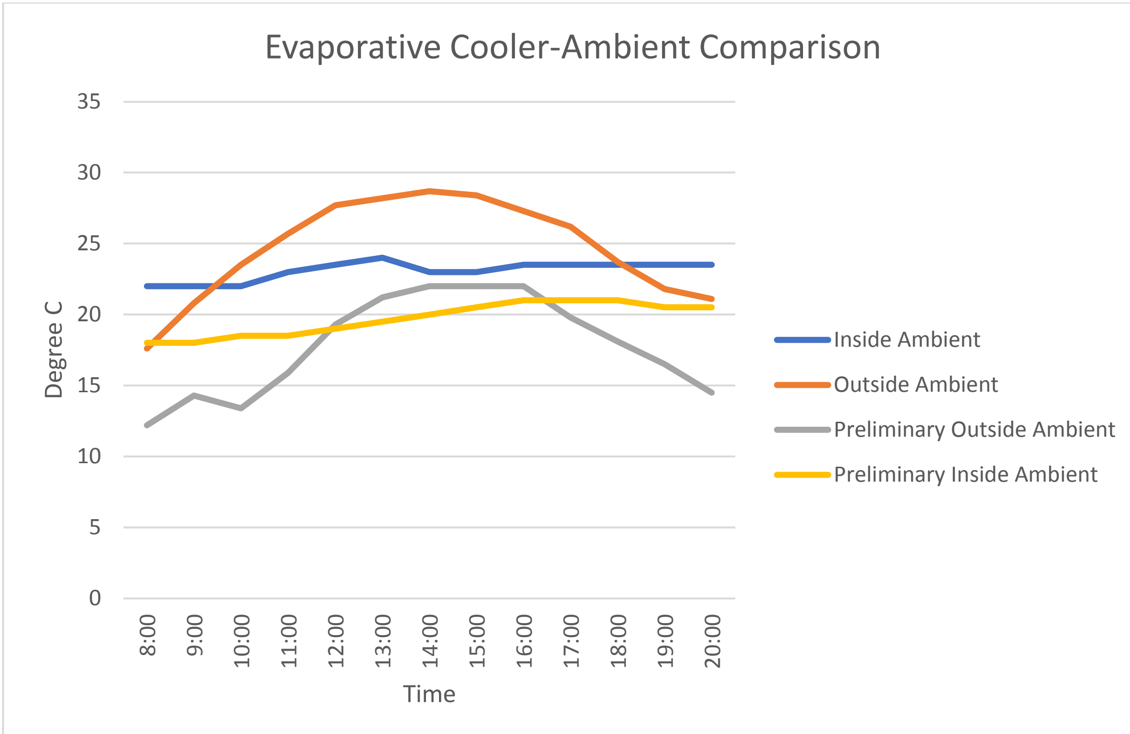


**Figure 33.** *Comparison of the inside vs ambient temperature of that battery room on the day that the Evaporative cooler was tested.*

### 4.3.3 Reflective Paints Analysis

For the following three passive cooling solutions, each had to be implemented in a permanent manner to accurately assess effectiveness. To understand individual effectiveness of each solution, localized temperature data collection and thermal image comparison was completed in the areas of implementation.

The reflective painting solution was found to be effective (2). Painting the targeted doors, as well as the black strip on the exterior battery room wall, showed a substantial reduction in heat transferring into the rooms through those areas. However, those areas only accounted for a minimal area of heat transfer for those rooms. **Figure 34** shows how hot the inverter room door was after being painted compared to the walls. This is evident given the bluish color of the door, demonstrating a cooler temperature distribution than the red walls. When comparing this to the temperature of the door from preliminary data collection in **Figure 15**, it can be seen that there is a decrease in the amount heat being transferred into the room by the door. The gradients between these two photos are different, which explains why the wall appears hotter in the second picture even though they are relatively the same temperature.

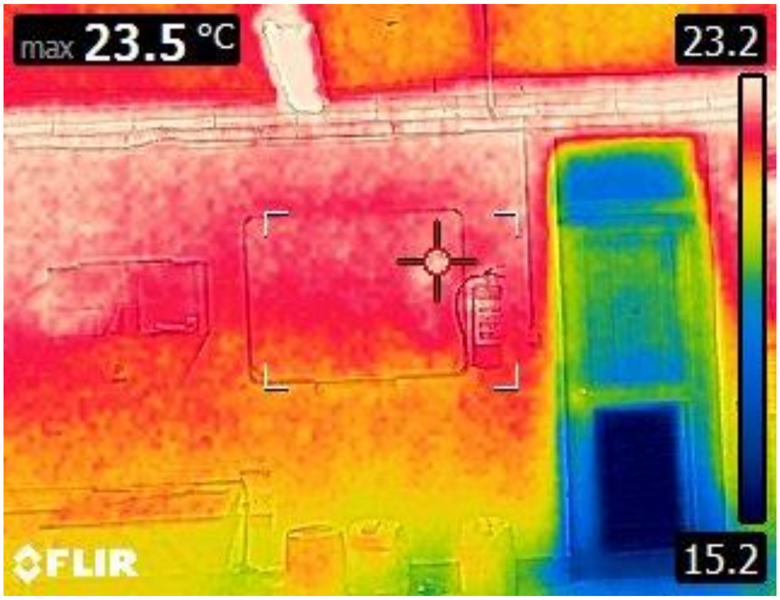


**Figure 34.** *Painted Inverter room external door temperature gradient*

Furthermore, the black strip along the bottom of the exterior battery room wall showed a reduction in heat absorption as supported by **Figure 35.** When comparing this thermal image to the one of the same wall in preliminary data collection found in **Figure 14**, it can be seen that the color of the strip becomes similar to that of the rest of wall.

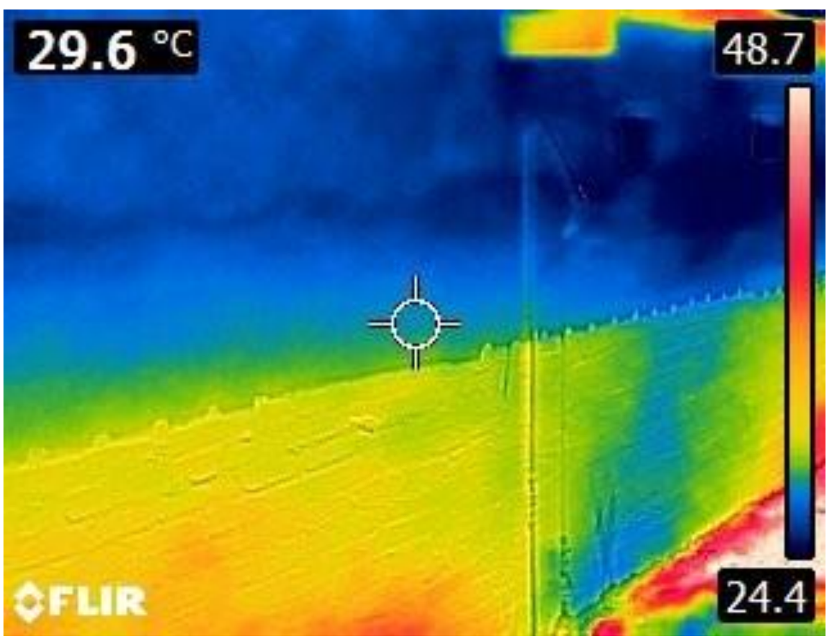


**Figure 35.** *Depiction of the temperature gradients on the battery room external wall after being painted with heat reflective paint*

While this evidence shows that painting darker regions of building successfully reduces the heat absorbed by them, these regions only accounted for a minimal amount of the total area of the targeted rooms. Because of this, painting these regions with reflective paints were determined to be effective (2) as a passive solution for the GRTC.

### 4.3.4 Ceiling Insulation Analysis

The addition of ceiling insulation to the roof of the battery room was determined to be effective (2). The insulation was only able to be installed to cover half of the battery room, this allowed for the effect to be measured through spot measurements over the course of 12 hours. Optimally the room would have had the insulation installed for the whole room. However due to installation of the insulation covering only half of the battery room, the comparison between outside/inside ambient air differentials from preliminary data collection to the day we tested the insulation was inconclusive. Comparison between the spot measurements of the ceiling and roof were used to evaluate the insulation.

The insulation caused the roof to be 2-3 °C hotter than the control, this was due to the heat being reflected back rather than transferring into the room. The difference between the uninsulated and the insulated ceiling peaked at 1°C, as seen in **Figure 36**. This difference was determined to be inconclusive due to it being small. The limited nature of the installation, caused the effects on inside ambient air temperature to not be fully demonstrated.

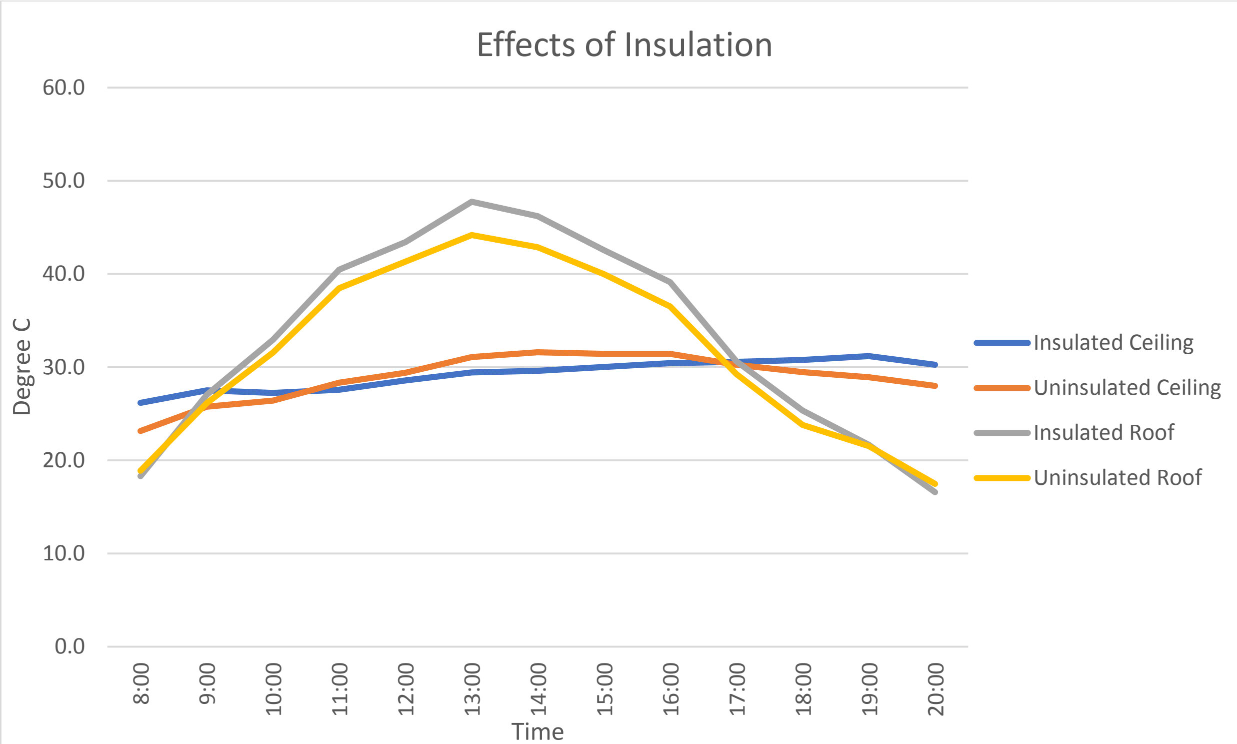


**Figure 36.** *Comparison between insulated roof and uninsulated roof*

### 4.3.5 Convection Currents Analysis

Inducing convection currents by cutting holes underneath the inverters was found to be minimally effective (1). While ventilation methods have been proven to be an effective means of reducing heat build-up in buildings in prior research, our implementation of holes leading into the adjacent rooms did not induce a noticeable change. The goal was to alleviate the heat pooling around this technology by inducing a current of cool air from the adjacent rooms that did not house technology. As seen in **Figure 37**, there was no substantial reduction in heat pooling after the implementation of the vent holes when compared to the thermal image taken at the same time of day from preliminary data collection, seen in **Figure 23**.


**Figure 37.** *Thermal image of inverters after the hole had been cut*

The inability to reduce the heat build-up around these targeted areas could be due to the lack of airflow entering the adjacent room. Without this airflow from the environment, the air contained in the adjacent room was unable to flow through the holes we cut.

### 4.3.6 Comparative Cost-Effectiveness Analysis

Based upon the effectiveness ratings, the evaporative cooler was deemed to be to the most effective solution. The least effective solution was the holes cut to induce a convection current. Insulation, shading, and reflective paints were all determined to be relatively effective. For these solutions, cost became the deciding factor in determining overall benefit. The costs were calculated based upon the factors outlined in **Section 3.3.3**. The cost of materials was based on the unit prices from Pupkewitz Megabuild and projected cost ranges from Fixr (n.d.), a website that provided estimated cost for a variety of products.

- Cost of labor was determined by the hourly pay rate of the facilities workers at the Centre. The labor cost for the solar panel was based off an average of contractor cost. Hours of labor was based on a projected time for the solution to be constructed and installed.

- Cost of transport was based upon the cost of gas for a round-trip from the Centre to Walvis Bay.
- Cost of assembly was based the cost of needed construction for the solution to be implemented.
- Cost of upkeep was based upon the annual maintenance cost. All of these factors were combined to give the total cost of the solution.

| Solution | Cost of Material (N$) | Cost of Labor (N$) | Hours of Labor | Cost of Transport (N$) | Assembly Cost (N$) | Upkeep Cost (N$) | Total Cost (N$) |
|---|---|---|---|---|---|---|---|
| Evaporative Cooling | 8,000 | 20 | 6 | 400 | 100 | 400 | 9,020 |
| Shading-Solar Panels | 266,150 | 650 | 24 | 400 | 1000 | 500 | 283,150 |
| Shading-Server Tower Exterior Wall Shade | 2,240 | 20 | 18 | 400 | 500 | x | 3,500 |
| Painting | 800 | 20 | 10 | 400 | x | x | 1,400 |
| Insulation | 1,798 | 20 | 16 | 400 | x | x | 2,518 |
| Convection Currents | x | 20 | 4 | x | x | x | 80 |

**Table 1.** *Breakdown of the various cost for each solution*

The comprehensive cost benefit analysis resulted in a benefit ranking that took both the cost and effectiveness rankings into account. The effectiveness was the primary factor in the determination, while the cost helped to distinguish between solutions that were equal in effectiveness. Table 2 shown below contains the rankings for effectiveness, cost and benefit. This benefit ranking was then used to determine which recommendations should be prioritized for the GRTC.

| Solution | Cost (N$) | Effectiveness (1-3) | Cost (1-5) | Benefit Ranking (1-5) |
|---|---|---|---|---|
| Evaporative Cooling | 9020 | 3 | 2 | 1 |
| Shading | 286,650* | 2 | 1 | 2 |
| Painting | 1,400 | 2 | 4 | 3 |
| Insulation | 2518 | 2 | 3 | 4 |
| Convection currents | 80 | 1 | 5 | 5 |

**Table 2.** *Projected cost along with effectiveness ratings and an overall ranking*

*This solution is ranked second due to the GRTC's preconceived plans to implement a solar array on the roof of their battery/inverter rooms.

## 4.4 "Enabling Local Communities to Assess and Apply their own Passive Cooling Solutions" Analysis

Examining the characteristics of the Topnaar community buildings helped contextualize the cooling needs of developing Namibian communities and establish the relevancy of passive cooling outside of the GRTC. To enable passive cooling to be implemented in such communities, we followed the procedure outlined in **Section 3.4**. This allowed us to effectively simplify pertinent sections of our methodology for development of a rapid assessment protocol. This rapid assessment protocol is intended for use by these communities to analyze building design and to recommend passive cooling retrofits. We established:

1. The Topnaar have poorly designed buildings that are uncomfortable to occupy. These buildings could benefit from the implementation of passive cooling retrofits.
2. The methodology can be simplified into steps that reach similar conclusions on determining effective passive cooling retrofits. This was the guiding principles in developing our rapid assessment protocol.

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### 4.4.1 Gaining an Understanding of the Cooling Needs in Surrounding Communities Analysis

Using observational analysis and informal interviews, we found that Topnaar community buildings, including the community hall and agricultural ministry building, were poorly designed for the climate. This could be due to these buildings being contracted out to foreign architects (Eugene Marais, Personal Communication, 9/3/18). These buildings were described to be uncomfortably hot, and a temperature distribution data collection procedure further substantiated such claims. We completed an observational analysis of Utiseb, the location of the traditional authority for the Topnaar, to assess the cooling needs of two community buildings.

#### *Community Hall Building*

We observed that the community hall's building walls were made from a quartz stone with cement placed at the base as well as near roof structure. Multiple windows and clear doors were incorporated into all the walls as well. It was noted that each window could be opened to let in a draft, but did not have any shades. The windows and doors were hypothesized to be a major a source of heat radiation into the room. **Figure 38** depicts an image of the structure and the building temperature measurements taken of the various building materials that comprised the community hall. These measurements were compared to the ambient temperatures to quantify how much heat the building was absorbing and transferring into the room. Based on the temperature differentials of the quartz and the roof, it was clear that the quartz was an efficient insulator/had greater thermal mass while the roof absorbed significantly more heat. Furthermore, **Figure 39** shows that the cement was not as efficient at reflecting heat as the quartz due to its color. Lastly our temperature measurements show that due to the sun, as well as poor reflectivity, the roof absorbs a lot of the solar radiation.


**Figure 38.** *Topnaar Community Hall and the relevant data collected about the building.*


**Figure 39.** *Community Hall temperature gradient showing how different materials affect heat gain to the building*

We were not able to establish a thermal profile for the inside of the building; therefore, we were unable to absolutely determine which building design features contributed to the interior heat input. However, we were able to conduct an informal interview with the Gobabeb Research Manager, Eugene Marais, who had visited the community hall for different events and meetings. He informed us that during those times, the building would become unbearably hot for the occupants. Based on this interview, we infer that the roof, cement and the unshaded windows are primary sources of heat for the community center. Lastly, because the function of this building is to host large amounts of people, we speculate that this may be another source of heat that is not effectively released out of the building.

### *Agricultural Building*

We also examined the Topnaar Agricultural Ministry building. We found that the walls were 26 cm thick and made out of cement that was painted green. It appeared that the building was designed with thermal mass to help regulate the temperature. Furthermore, we observed some shading on the long sides of the walls. However, when we conducted an informal interview with one of the ministry officials who works in this building, she informed us that the office can get very hot while working. She emphasized this by saying "sometimes, it is difficult to breathe". **Figure 41** shows an image that summarizes the relevant data collected at the agricultural building. The walls facing the sun were experienced elevated temperatures, and a door which was made of iron and can be seen in **Figure 42**, was 55°C. The interior of this wall was measured to be 36°C. **Figure 42** also indicates that the sun is a major heat source in this building and the walls easily absorb the sun's radiation. This is most likely because of lack of shading for two of the walls as well as the fact that the walls are painted green, which absorbs more light than it reflects (Nina Maritz, Personal Communication, 9/13/2018). Because no roof data was collected we cannot draw conclusions to whether the roof is another method for heat input. However, its similarity in design to the community hall roof suggests that it easily absorbs heat from the sun throughout the day.


**Figure 40.** *The Topnaar Agricultural Building and the relevant data collected about the building*

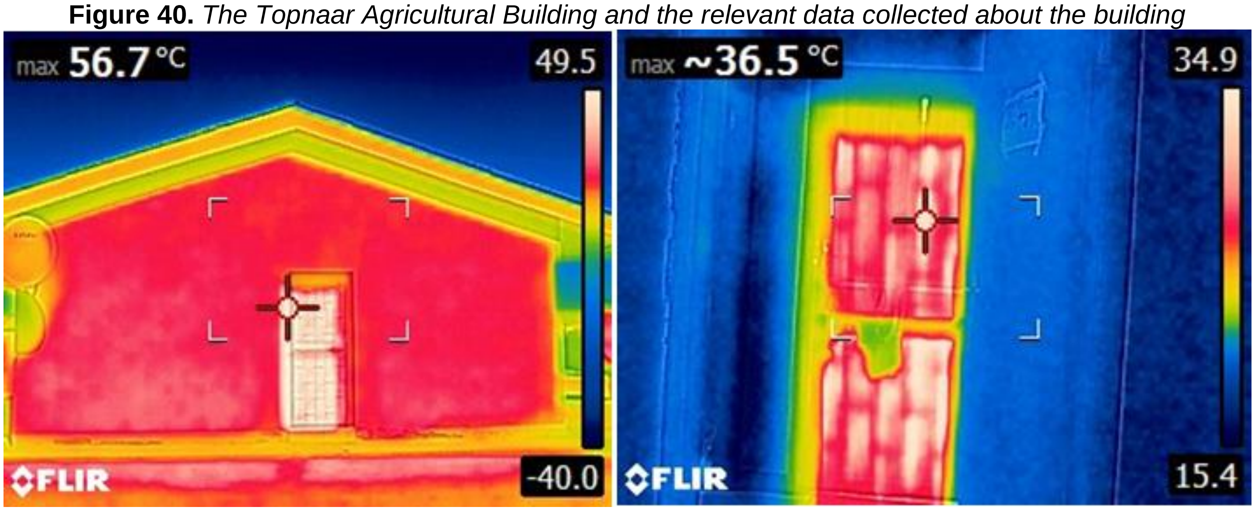



**Figure 41.** *Thermal gradient of side of Agricultural Buildings and interior face of the door*

Thus, we found that the agricultural building's interior temperatures are not cool enough to comfortably occupy. The temperature data further indicates that both the community and agricultural buildings are not designed efficiently to be cool in the arid environment. It is not feasible for the Topnaar community to reconstruct these buildings, nor do they have the electric generation capacity to implement AC. Thus, passive cooling retrofits could be effectively applied to improve comfort.

### 4.4.2 Rapid Assessment Protocol Analysis

We generalized our methodology into a version that could reach similar conclusions on determining effective passive cooling retrofits. We also created a rapid assessment protocol that would enable community members to analyze their buildings for cooling inefficiencies and implement recommended retrofits in a similar manner.

The rubric attached in **Appendix D** shows the sections of the methodology that we rated as crucial or helpful to conduct a building assessment and determine passive cooling solutions. The steps for completing Objective 2 in our methodology were determined to be the most relevant. The methodology to achieve Objective 1 was only necessary for us to get context of passive cooling in Namibia and so was not necessary as steps for someone lives in the country. Instead, our findings of Objective 1 can be included as background for the rapid assessment protocol to give the reader context. We also determined that the steps in Objective 3 were redundant for developing a rapid assessment protocol because our analysis involved testing our passive cooling prototypes at the GRTC. Therefore, we decided the results of our Objective 3 findings could be included in the rapid assessment protocol as suggestions of potential solutions for retrofitting to address their cooling needs.

Once the methodology was examined, the team used the results found from the rubric in **Appendix D** as a guide to create a set of questions that accomplished the same goals as the original relevant identified methodology steps. These questions and methods we designed to be simple to use yet still determine the necessary data to conduct a building assessment. Based on the analysis of our original methodology, we identified crucial steps needed to assess a building for passive cooling. Furthermore, the steps were redesigned to be simpler and qualitative, yet still accomplish the same goal. From this analysis we were able to create a rapid assessment protocol that enables the Topnaar people to assess their community buildings. The rapid assessment protocol brochure can be found in **Appendix G.**

# 5.0 Conclusions and Recommendations

We assessed the potential to develop passive cooling of specific buildings at the Gobabeb Research and Training Centre and in surrounding Topnaar communities, and established recommendations based on our key findings. For the GRTC, we were able to determine suitable passive cooling solutions for retrofitting of their battery, inverter, and server rooms. Additionally, we generalized these methods for determining suitable passive cooling solutions in the form of a rapid assessment protocol, so that surrounding Topnaar communities could apply appropriate retrofits to their community buildings using a similar methodology. Our findings show that retrofits are an ideal method of implementing passive cooling in a cost effective manner. Retrofits must consider environmental, functional and economic factors, and our results demonstrate that retrofitting is effective in areas such as the GRTC. Lastly, we provide recommendations for how future studies could build on our work to further understand how passive cooling can benefit the GRTC and be applied throughout Namibia.

## 5.1 Conclusions and Recommendations for the GRTC

From our analysis of the effectiveness and cost of each passive cooling solution, we concluded that each one tested at the GRTC would be beneficial to retrofit targeted rooms. We ranked solutions from most beneficial to least beneficial by comparing cooling effectiveness and costs incurred for each. This ranking is as follows:

1. Evaporative cooling
2. Shading
3. Reflective Painting
4. Insulation
5. Ventilation

### *Evaporative Cooler Recommendations*

Evaporative coolers were determined to be the most beneficial passive cooling solution for the GRTC. Specifically, we recommend purchasing at least two evaporative coolers for installation in both the battery and inverter rooms. Due to heat exhaust from the technology, displacing the hot air within these rooms with the cooler air drawn in from the evaporative coolers was found to be especially effective. The passive units we suggest for implementation channel the air through funnels as opposed to drawing it in through a fan. It is also important to note that there may need to be additional energy input to pump the water through the system for distribution. These evaporative coolers would work in conjunction with the Whirlybird heat extractors that are already installed onto the roofs of the battery and inverter rooms to displace the hot air pooling inside.

### *Roof/Wall Shading Recommendations*

The various roof and wall shading prototypes were determined to be the second most beneficial passive cooling solution for the GRTC. We recommend installing solar panels onto the roof of the battery/inverter building as a dual-purpose method of shading and harnessing solar energy. This is partly due to the GRTC's plans to install solar panels in these locations and is bolstered by the effectiveness of the solar geyser shading prototypes we tested. Additionally, we recommend the GRTC invest in a double roof shading mechanism to work in conjunction with the solar panel installation. This would account for the direct solar radiation that would hit the roof in between the solar panels.

Furthermore, we recommend the GRTC invest in shade cloth wall shades for the server tower, but not for the exterior walls of the battery/inverter building due to ineffectiveness in reducing the inside ambient air temperatures. From analyzing the comparison of the different shading materials, it was determined that shade cloth was the most beneficial. If aesthetics become a priority, we also suggest layering invasive wood spars over the shade cloth. With the server tower being a stand-alone building with all four walls exposed to the sun and housing minimal technology relative to the battery and inverter rooms, heat gain from solar radiation becomes more of a focus.

### *Reflective Paints Recommendations*

Painting the doors and exterior battery room wall with white reflective paint was determined to be the third most beneficial solution for the GRTC. The paint reduced the amount of heat absorbed into the targeted areas of the building based on the comparison between thermal images of painted and unpainted areas. Additionally, the cost of purchasing and applying the paint was relatively low compared to the implementation of the other passive cooling solutions. It is important to note that the white reflective paints were only applied to certain targeted areas to establish proof of concept as an effective passive cooling solution. Due to this, the painted areas were not large enough to have a substantial impact on the interior air temperature of the targeted rooms. From this, we recommend that the GRTC invest in additional paint for the remaining exterior walls of the targeted rooms as well as for the doors of the adjacent rooms.

### *Insulation Recommendations*

Installing insulation into the ceiling of the battery room was determined to be the fourth most beneficial solution for the GRTC. The Sisalation was only installed in half of the battery room ceiling, which made the solution's impact on the inside ambient air temperature difficult to assess. We recommend that the GRTC finish installation of the Sisalation in the battery room ceiling as well as for the ceiling of the inverter room. Localized temperature data was analyzed to find that heat from solar radiation was effectively being reflected away from the room due to the Sisalation. With this proof of concept confirmed, entirely covering the ceiling of the targeted rooms could reduce the amount of heat gain from the sun through the roof.

### *Ventilation Recommendations*

The ventilation holes cut below the inverters were determined to be the fifth most beneficial passive cooling solution for the GRTC. The holes that were cut were not successful in inducing a current to reduce the heat pooling around the technology. The concept behind implementation of these holes was that the cooler air within the adjacent room would flow through the holes decreasing the ambient temperatures of the inverter room. Our recommendation for the Centre would be to introduce additional airflow into the adjacent room from outside so that air can move throughout the room more easily. This could be done by adding more louvres on the door to that room, or by implementing a wind funnel onto the roof above the room.

Limitations surrounding this passive cooling solution involved a limited time-frame for experimenting with air flow, and the many uncontrollable variables that affected the heat pooling around the technology. These variables include performance levels of the WhirlyBirds due to wind conditions and heat exhaust from the technology differing across units. Because of these variables, it was difficult to identify conclusive evidence for the reduction in heat pooling compared to the preliminary data collection. If more time was allotted for collecting airflow data, the team may have been able to introduce an additional ventilation solution that would promote airflow from the outside into the adjacent rooms, which would be coupled with the vent holes.

*Summary*

Through testing the five most beneficial passive cooling solutions implemented at the GRTC, we determined that it is possible to effectively retrofit buildings located in harsh environments. This is an especially important concept for regions such as sub-Saharan Africa, where many developing countries are technologically advancing. The findings from our research identify certain methods of applying passive cooling retrofits that account for these environmental and functional limitations.

## 5.2 Conclusions and Recommendations for Rapid Assessment Protocol

We recognized that passive cooling has broader implications outside of the GRTC. Specifically, we identified there are cooling needs in developing Namibian communities located in similar arid environments. We contextualized this by examining the thermal profile and general design of the Topnaar community hall and agricultural building. We found that these two buildings were poorly designed for the climate which causes them to be uncomfortable when occupied. When we visited Utiseb to examine these buildings, it was clear that both buildings had applied some considerations for passive cooling such as thermal mass. However, we also observed many cooling inefficiencies that increased heat gain into the buildings. One example is that both buildings have large windows that allow solar radiation to enter the room. Furthermore, there are exposed walls that receive direct sunlight for parts of the day. Overall, our observations and temperature measurements aligned with informal interviews with individuals who utilize these buildings and described it as hot and uncomfortable. It is not practical to address this problem through reconstruction, nor can they implement AC, therefore passive cooling retrofits could effectively improve comfort of the buildings' occupants (Eugene Marais, GRTC Research Manager, Personal Communication, 9/3/2018).

It is important to note that a limitation of this data collection and analysis was that we were not able to conduct the same rigorous methodology that was conducted for the GRTC. Therefore, our conclusion was not supported by extensive data. However, by conducting our comprehensive analysis at the GRTC, we gained the necessary context and background needed to identify inefficiencies through observation and simplified data collection. We concluded that it is possible for anyone from these communities to make the same conclusions as we did, if they are given the right materials.

To create these materials, we determined the original technical passive cooling assessment could be generalized into steps that reach similar conclusions for identifying building cooling inefficiencies and determining effective passive cooling retrofits. We identified that the steps for acquiring climate data, determining current passive cooling methods, and collecting temperature data are important for conducting an assessment. The results from analyzing the current passive cooling methods in Namibia were identified to be essential as background, so that the user can gain a general understanding of passive cooling. Lastly, our analysis of prototypes tested at the GRTC was condensed to a list of potential solutions that address the cooling needs. These key findings were the guiding principles for creating a rapid protocol assessment that could be used by anyone to assess a building and identify building cooling flaws. Furthermore, it gives the information needed to enable someone to retrofit buildings with low cost, low maintenance solutions.

The team recommends that the GRTC distributes this rapid assessment protocol to the traditional authority of the Topnaar community. Based on our analysis of their buildings coupled with the results from testing passive cooling prototypes at the GRTC, we found it is possible to retrofit these buildings and improve comfort. The rapid assessment protocol is a stand-alone product that can enable the communities to address those cooling needs themselves. We recommend that the Topnaar communities apply this protocol to identify the cooling inefficiencies of their community hall and agricultural building retrofit them with the appropriate passive cooling solutions. There are many communities similar to the Topnaar that have transitioned from traditional architecture to modernized buildings that are not suitable for their environment. The rapid assessment protocol addresses resource limitations of such communities by suggesting a simplified assessment and low cost passive cooling retrofits

## 5.3 Recommendations for Future Studies

From the methods and major findings established through carrying out this project, we identified future studies that could investigate how passive cooling provides technological benefits at the GRTC, as well as how it can be further applied throughout Namibia.

### *Future Studies at the GRTC*

The results of this project indicate to the GRTC that certain passive cooling methods can be effective for cooling the three technology rooms. This was based on evidence collected from our tested passive cooling solutions to determine proof of concept. The next step for the Centre is to install the permanent solutions. We recommend to the Centre that this research can be furthered by collecting long term data to assess the benefits of passive cooling implementations on the technology. This future study could also have broader implications by answering whether it is feasible for passive cooling to replace air conditioning for modern buildings that house technology. Air conditioners are capable of keeping a room at an exact temperature which provides optimal operating conditions. It is important to investigate if passive cooling methods can achieve this as well. Factors to examine may include technology operating temperatures, efficiency, and life. The results from such future projects that use Centre as a case study can help guide other developing modern areas in efficiently cooling their technology through passive methods.

### *Future Studies for Implementing Passive Cooling in Namibia*

The team determined a broader context for passive cooling for Namibian communities by establishing that there are certain buildings that are inefficiently designed for cooling in the Topnaar community. This data led to the development of a rapid assessment protocol (R.A.P) that would enable the community members to address these problems. While the R.A.P was created to address the broader cooling problems in the Namibian arid environment, we recommend that further research is conducted in assessing the need and effectiveness of applying a rapid assessment protocol throughout communities in Namibia.

In our methodology to determine a R.A.P, we examined two community buildings for the Topnaar village in order to give us the necessary broader context. However, we also observed many Topnaar people owning homesteads that were built out of corrugated metal sheets. These initial observations indicate that these homes get very hot during the day. This may be a characteristic that is common with most homes in developing communities across Namibia. Further research needs to be conducted to identify if cooling inefficiencies are a systemic problem that is common in most buildings and homes found in Namibia. Additionally, it would be useful to identify the underlying reasons that contribute to this issue. This information is vital to developing and testing an effective solution such as the rapid assessment protocol.

We identified that providing information through a R.A.P could enable community members to solve their cooling problems. We further recommend that the R.A.P be tested with different communities to assess its effectiveness. Based on the data collected, the protocol can be revised and expanded to apply to all Namibian communities. We also recommend that both aspects discussed above be incorporated and conducted as one WPI interdisciplinary qualifying project. This can be partnered with the Habitat Research and Development Centre as well as Nina Maritz Architects. Both entities focus on sustainable and comfortable architecture development and would be ideal sponsors. Such a project would have the potential to provide an impact to local Namibian communities.

## 5.4 Conclusion

The goal of our project was to determine passive cooling retrofits that could decrease the temperatures of the GRTC's battery, inverter and server rooms. Using this as a case study, the team generalized our methods to create a rapid assessment protocol that enabled constituents from local communities to effectively implement retrofits. By completing the objectives illustrated in our methodology, we identified that evaporative cooling, shading, reflective paints, ventilation, and insulation would have a beneficial effect. These five passive cooling methods were recommended to implement at the GRTC. Furthermore, the rapid assessment protocol brochure will be distributed to the Topnaar community so that they can implement their own passive cooling retrofits to their own buildings. The results of this project directly helped the GRTC solve their cooling needs as well as addressed the broader problem of cooling exemplified by the Topnaar communities.

# Appendices:

## Appendix A - Sample Passive Cooling Solutions

1.) Shading: Shading is the process of implementing a barrier that reduces the amount of radiation from the sun that reaches a surface (Build it Solar, n.d.). By reducing the radiation, the temperature increase during daylight hours is immensely decreased. One example as how this method could be applied at the GRTC is to shade the side of the server room that is facing the sun most directly.
2.) Earth Coupling: Earth Coupling is a method of increasing the amount of surfaces in a room that are in contact with the Earth, and are therefore able to directly access the Earth as a heat sink (Anderson, 2015).
3.) Radiant Barriers: The implementation of Radiant Barriers is the process of shielding surfaces from radiation passing through, specifically reflecting this radiation back to its source (RadiantGuard, n.d.). This method could be implemented at the GRTC, by coating a building with Sisalation, and therefore reflecting the sun's rays back.
4.) Night-Purge Ventilation: This method includes opening windows during the night, and consequently closing them during the day, entrapping the cool night air in the building (Griffin, n.d.). This method would allow the team to trap the near freezing air at the GRTC, and offset the warmer daytime temperatures.

## Appendix B - List of Measurement Equipment

1.) DIGI-SENSE Infrared Laser Thermometer: An Infrared Laser Thermometer is a device that uses infrared radiation to measure the temperature of surfaces (Cole-Pramer, n.d.). This device is accurate to ±2% of the given measurement of any surface within the operating parameters.
2.) FLIR Thermal Imaging Camera: This device measures the infrared radiation of different surfaces and outputs a heat map display (FLIR, n.d.). This device is accurate to ±2°C.
3.) iButton: A device that measures the temperature of a specific point at programmed intervals of time (Maxim Integrated, n.d.). This device is accurate to ±0.5°C.
4.) EasyLog EL-USB-2: This device measures ambient temperatures and relative humidity at programmed intervals of time (Lascar Electronics, n.d.). This device is accurate to ±0.55°C.

## Appendix C - Industry Professional Interview Plan

1. Greet informant, and then say "We are Jackson Brandin, Neel Dhanaraj, Zachary Powers, and Douglas Theberge, a group of students from Worcester Polytechnic Institute in Massachusetts USA. We are conducting a survey with industry professionals to assess the feasibility of passive cooling in Namibia in connection with our work here. We strongly believe this kind of research will ultimately enhance the team's ability to implement passive cooling at the Gobabeb Research and Training Centre, located in the Namib Desert. Your participation in this interview is completely voluntary and you may withdraw your survey responses at any time. This is a collaborative project between the Gobabeb Research and Training Centre and WPI, and your participation is greatly appreciated. We may include your responses inside of our report, do we have your consent to publish your name? If interested, a copy of our results can be provided at the conclusion of the study.", then begin interview.
2. Explain our project and why we are here in Namibia
3. Explain how we visited the Habitat Centre upon arrival in Namibia, and then traveled to the Namib to acquire information and take data at the Station. Explain what kind of data was taken and how.
4. Show the interviewee some of our preliminary data, as well as analysis.
5. Ask interviewee if our data collection was adequate. (Did we miss anything)
    a. If we missed anything, what did we miss?
    b. If the interviewee does not see any problems, continue with interview
6. Present to the interviewee our prototype ideas
7. Ask interviewee if we missed any possible solutions, or if any would work better than others.
    a. If there are better solutions, ask why.
    b. If not, continue interview
8. Ask interviewee if there are any other professionals to speak to
9. Thank interviewee and terminate interview

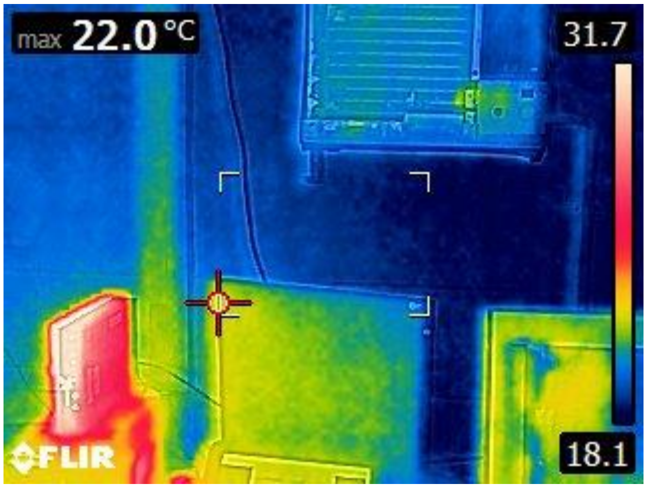
## Appendix D - Rapid Assessment Protocol Analysis Rubric

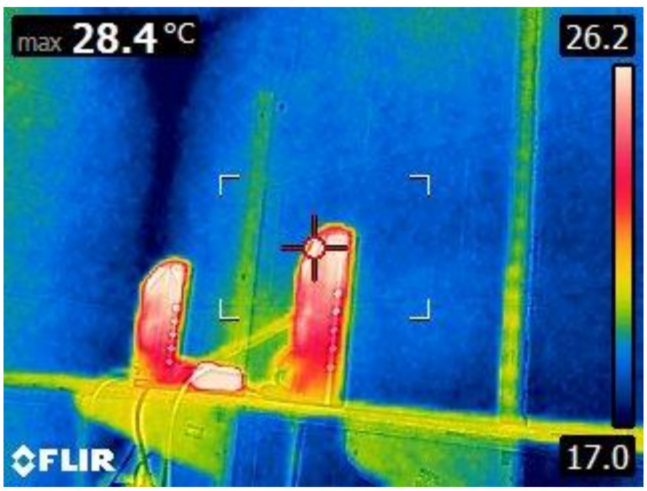
1: Crucial 2: Helpful 3: Redundant

| Method | Rating | Goal Accomplished | Convertible to Simplified Method |
|---|---|---|---|
| Acquire Pre-Archived Climate Data<br>(Wind, Temperature, Rain, Etc.) | 1 | This information is a factor in determining what passive cooling solutions can work in the area | Yes |
| Determine Current Passive Cooling Methods | 2 | This information is necessary to determine what has already been tried | No |
| Solar Exposure Data | 1 | This information is important for determining what surfaces absorb heat from the sun | Yes |
| Collect Ambient Interior and Exterior Temperature | 1 | Important for contextualizing the building cooling inefficiency and assessing a solution's effectiveness | Yes |
| Collect Temperature distribution Data Via Thermal Images and IR Spot Thermometer | 1 | This information is important for identifying areas of large heat input and seeing how it changes throughout the day. | Yes |
| Determine Heat Sources | 1 | Important for determining sources of heat and deciding what passive cooling solutions can address them. | Yes |

# Appendix E - Locally Available Building Materials

## Appendix F - Additional Technology Thermal Images in Server Tower



# Appendix G - Rapid Assessment Protocol

## Solution Recommendations

### Shading - Reflects/absorbs heat from the sun

**B.** Putting a material over your windows can greatly reduce the impact of heat from the sun.

**D.** You want to implement shading on the walls that receive the most sunlight. This is usually the case for the North face in the Winter. The East face can also get very hot in the morning as the sun is rising.

**E.** The inside of the walls that get the most sunlight tend to be the hottest. This correlation confirms the need for wall shading. It is especially important to shade the roof if the ceiling gets hot. The roof is exposed to the most direct sunlight throughout the year.

**F.** Shading is the primary solution to combat heat from the sun. General shade cloth is found to be very effective. If resources are limited, invasive wood spars can also be used to accomplish the same goal.

### Insulation – Reduces the transfer of heat through walls/roofs

**B.** Laying insulation in between your ceiling and roof, as well as in between your walls, will reduce the heat transfer into the building.

**E.** Darker colored parts of walls tend to absorb more heat from the sun. Painting these darker parts white can help to reflect this heat away from the building.

**F.** Insulation/painting is an appropriate solution for reducing heat from the sun. Sisalation is a thin reflective insulation that has been found to be effective for this purpose. This material, as well as white, heat reflective paints, can be found in local hardware stores across Namibia. These solutions are important to consider in conjunction with shading techniques.

## Solution Recommendations

### Evaporative Cooling - Cools the outside air using evaporation of water to be put in the building

**A.** Orienting the evaporative cooling tower towards the wind direction can increase the air that is captured and cooled for the building

**C.** To conserve water, you can use the evaporative cooler only during the times of the day when the building gets hot.

**F.** This solution is effective for displacing the hot air with cooled air. This makes it an ideal solution to address all three heat sources. A simple tower can be constructed with a large cloth to catch the wind. This cloth must continually be wet to be the most effective. The tower must be connected to the inside so that the cool air can fall into the room

### Inducing Convection Currents – Creating airflow to remove heat

**A.** Opposing windows can be opened to catch the wind. Vents can also be installed in the walls to capture this wind as well.

**C.** It is important to identify when the room gets hot in comparison to the outside temperature as this can determine when you should open your windows/vents. If the room is hot while the outside is cooler, you can open the windows/vents to take advantage of the cool winds. Do not open windows/vents if the outside air is the same or hotter than the inside.

**F.** Using Convection cooling is an effective solution for addressing all heat sources. You can cut small vent holes on the lower areas of the building wall to capture cooler winds, while cutting holes at the top will allow the hot air to leave. Opening windows at the right time can also effectively cool your building.

## Passive Cooling

## Rapid Assessment Protocol

*For retrofitting of buildings and homes*

By:

Jackson Brandin,
Neel Dhanaraj,
Zachary Powers,
and Douglas Theberge

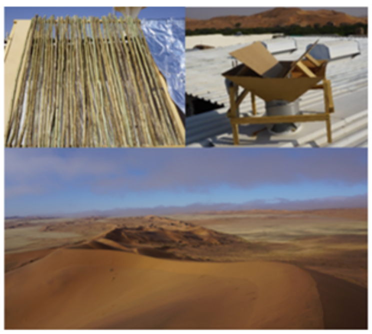
# Passive Cooling

## What is Passive Cooling?

Passive cooling is the practice of reducing interior air temperatures of buildings and homes by manipulating Earth's fundamental qualities such as the sun, wind, soil, and humidity. The concept of being "passive" suggests that these methods do NOT require the use of electrical energy. The build up of heat within a building can come from the sun, technology exhaust, or simply many people occupying the building at once. Passive cooling can effectively reduce uncomfortably heat from all of these sources.

## Why is it important?

Passive Cooling is incredibly important to implement for its financial and environmental benefits. Greatly reducing the need for electrical energy usage not only allows an individual to save money on their electrical bill, but is crucial for communities that have limited access to electricity in general. Additionally, Air Conditioning units can contribute to global warming if the chemicals housed inside them begin to leak. Passive cooling eliminates the use of these chemical entirely.



# Building Assessment

## In Namibia…

To effectively apply passive cooling retrofits to a targeted building, consistent factors such as Namibia's climate must be considered.

The desert regions of Namibia are generally very hot and dry throughout the year. The sun rises in the east and sets in the west every day throughout the year. However, it rises higher over the sky in the summer and flattens out to the north in the winter. This causes north faces of buildings to receive more direct sunlight in the winter.

These factors are important to consider when assessing a building/home for sources of heat gain, and determining what passive cooling solution(s) would be optimal to address these inefficiencies. The following questions will help you conduct this building assessment.

**A.** What direction does the wind blow?

**B.** Are there any unshaded windows?
How thick are the walls?
What is the roof made out of?

**C.** When does the building get hot? How long does it stay hot?

**D.** Which walls get direct sunlight? What time during the day?

**E.** Which walls become the hottest? What about the ceiling?

**F.** What are the main heat sources for the building?

An explanation for how to answer these questions are provided on the next page for the corresponding letters.

# Building Assessment

**A.** This may be something you already know. If not, it can be determined by sticking a pole with a lightweight fabric near the building to observe the trends in wind direction.

**B.** Observe these about your building. Sunlight can easily penetrate unshaded windows.
Walls that are about 25 cm thick are effective in reducing outside heat from entering the interior.
Metal roofs are more conductive, which means they heat up easily in the sun.

**C.** Make note of this throughout the day. Consider your comfort level when occupying the building.

**D.** Some walls can get significantly more sunlight than others. Consider how the position of the sun effects this.

**E.** Place your hand on each surface to determine this throughout the day. This can be directly correlated with **D.**

**F.** Is it heat from the sun?
Is it heat coming off of technology housed inside?
Is it heat from many people occupying the building at once?
Uncomfortable heat build up can be a combination of all three of these. It is important to identify these sources to determine an appropriate passive cooling solution.

The information obtained from this assessment will help guide you towards which passive cooling approach you should take based on the recommended solutions provided.

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