

Designing Transit Systems in Desert Cities

by

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ABSTRACT

Public transportation is considered a solution to congestion and a tool for reducing greenhouse gas emissions. It is becoming popular even in cities with the harshest climate conditions as these cities grow rapidly and are trying to provide sustainable alternatives for their vehicle-oriented communities. A lot must be taken into consideration when designing transit systems to reduce riders' vulnerability to heat in cities with high temperatures averaging 40°C during the summer and humidity levels reaching 90 percent. Using transit systems in Dubai, United Arab Emirates, and Phoenix Metropolitan, United States, as case studies, this paper focuses on both qualitative and quantitative research methods to observe the built environment around public transit stations and measure the temperatures and humidity levels to compare with the experienced temperatures and the built environment observations. The results show that the design of transit stations and the public realm significantly impacts a rider's experience. The findings show that passive cooling, shading, and vegetation as the best practices in the two case studies. Both transit systems have certain elements that work efficiently and other elements that need improvement to provide a better rider experience. Identifying these best practices helps develop recommendations for the future of designing transit systems in desert cities worldwide.

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Introduction

As cities worldwide are trying to transition from being vehicle-oriented by investing in new transit systems, they need to understand the impacts of the built environment and public realm on the rider's experience when designing these transit systems. Public transportation is a solution to ease congestion and has positive environmental impacts by reducing emissions, especially with higher ridership. Desert cities with harsh summer climate conditions have recently started investing in advanced public transit systems, such as commuter rail, metros, and light rail, which are considered relatively new compared to colder cities that have been using such systems for over a century. Urban planners and designers need to understand the best practices for designing transit systems in desert cities to provide transit riders with a reliable and comfortable transportation method. Therefore, this study will focus on current transit systems in cities with extreme hot climate conditions to determine best practices and avoidable mistakes when designing similar systems in other desert cities.

The study focuses on both qualitative and quantitative research methods, first by observing the experienced temperature and effectiveness of the surrounding built environment. Second, by measuring temperatures and humidity levels at ten different stations in two transit systems around the world, one of which is the Dubai Metro in Dubai, United Arab Emirates, and the second is Valley Metro Rail in Phoenix Metropolitan, United States. We are focusing on these two cities and their transit systems as they are both located in warmer climates and have high temperatures during the summer. Their transit systems are relatively new compared to other cities, and they have used two different approaches when designing and developing their new transit systems. They also have different humidity levels due to their different geographies; Dubai is extremely humid compared to Phoenix.

Since we are looking at two different transportation systems, we need to develop a research protocol that applies to both systems. The research includes both qualitative and quantitative research methods covering ten stations in each transit system. This study relies on field research observations of the experienced temperature and effectiveness of the built environment and the measurements of temperature and humidity levels to compare and contrast

the findings and develop the final results. Observations include photographs of the stations' surrounding areas and field notes reflecting the experienced temperatures and identifying whether different built environment elements are adequate in improving the rider's experience. The measurements include temperature, humidity levels, and pavement temperature. The results will integrate the quantitative and qualitative data to determine the findings and use them to answer our research questions:

- How can we incorporate heat when designing new transit systems in desert cities?
- How is the built environment affected by the introduction of a new transit system?

Considering that there are not many similar transit systems in desert cities around the world, one would suppose that the two cities, Dubai, and Phoenix, have not had many previous experiences to rely on when it comes to incorporating heat when designing their transit systems. Therefore, expectations include having disintegrated stations, increased riders' vulnerability to heat, and disconnected transit networks. Having highly vehicle-oriented cities supports this hypothesis at first, especially with minimal previous global experiences. However, introducing new transit systems in desert cities may positively impact the public realm by turning these cities into becoming more pedestrian-oriented. Assuming that the transit systems will encourage more transit-oriented development, pedestrianized public realm, improve the built environment around transit stations, and ensure safer neighborhoods.

Due to the limited research on this specific topic, designing transit in desert cities, this research study aims to find evidence of whether these hypotheses will turn out to be true or not. By focusing on two case studies, Dubai and Phoenix, we try to determine how they have considered their extreme weather conditions when designing the new transit systems. The research will analyze the findings gained from the mixed research method by comparing the weather measurements and field observations around transit stations. The analysis will help develop a set of recommendations of best practices and avoidable design flaws for future transit systems in desert cities.

Literature Review

Transportation planning literature has greatly emphasized the importance of transit walkability. Scholars have focused solely on the proximity of riders to transit stations, studying buffer zones around possible station locations in distances varying from 400 to 1600 meters (Alawadi, Khanal, Doudin, & Abdelghani, 2021) (Credit, 2018) (Stojanovski, 2020). In the last couple of decades, scholars have channeled their attention towards transit-oriented developments (TODs); however, they mainly focused on the buildings' uses and characteristics but not much on the entire built environment or the public realm when researching TODs. There has been a slight focus on other components of TODs in efforts to improve transit riders' and pedestrians' experiences, such as their comfort in the public realm and their vulnerability to heat (Alawadi et al., 2021) (Fahed, Kinab, Ginestet, & Adolphe, 2020) (Markolf, Hoehne, Fraser, Chester, & Underwood, 2017) (Chester & Fraser, 2017) especially after noticing the impacts of urban heat islands and climate change on our communities. However, with transit now becoming part of transportation systems in the hottest cities around the world, these studies are insufficient for desert cities to rely on when planning and developing transit systems that account for the riders' experiences in cities suffering from scorching heat for several months a year.

Climate change and transit

Understanding climate change and its impacts on riders are crucial given the growing frequency and magnitude of extreme events in recent years and the increasing number of days of sweltering heat. We build transit systems to function for decades; therefore, those systems need to be more resilient and sustainable than ever before. To ensure the development of long-term reliable transit systems in our cities, we must consider the climate change impacts specific to each city and their recent extreme events (Fahed et al., 2020) (Markolf et al., 2017) (Chester & Fraser, 2017). There is plenty of recent literature focusing on climate change in recent decades. Most of them agree on the urgency of adaptation and mitigation to avoid future catastrophic events and costly damages to our transit systems and, most importantly, harm to our communities. Markolf et al. have developed a model that identifies the transportation systems' vulnerabilities in four different

ways, as depicted in the figure below (2017). Markolf et al. have also used this same concept in a different article that looked at “what direct and indirect pathways lead to “failure” of the transportation system during extreme events?”; however, determining the direct and indirect physical and non-physical impacts of climate change is not limited to transit systems but also other relatable topics such as rider’s health as Salimi and Al-Ghamdi depicted in their research on urban infrastructure in the Middle East (2020). Scholars discuss how climate change impacts human health as it raises temperatures in hot cities; therefore, transit systems are affected by several aspects; the infrastructure, human health, energy sources, urban design, and many more factors that affect the reliability and safety of these systems (Chester & Fraser, 2017) (Fahed et al., 2020) (Salami, & Al-Ghamdi, 2020).

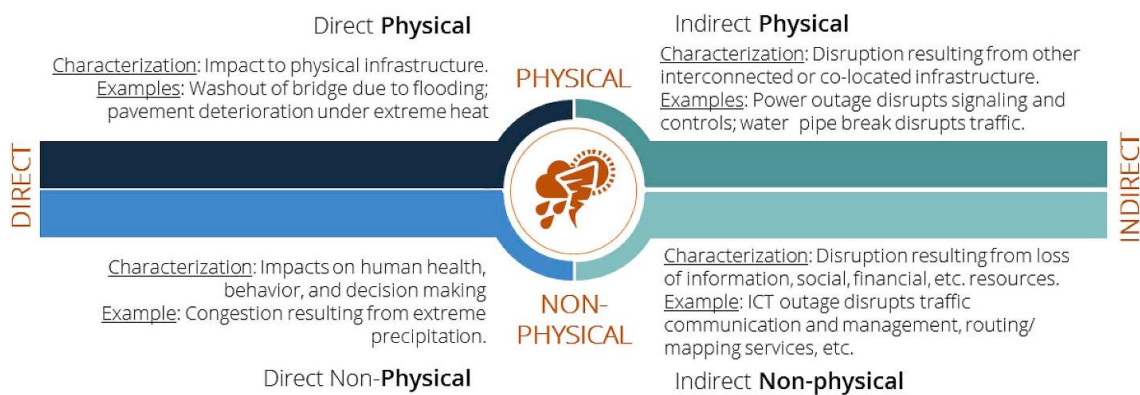


Figure 1 - Transportation system’s vulnerabilities (Markolf et al., 2017)

Furthermore, climate change has also forced governments and organizations to change their agendas and policies over the past couple of decades (United Nations, 2015). One of the main reasons for this push for mass transit is governments trying to reduce greenhouse gas emissions in their cities to help reduce the impacts of climate change. For instance, the Federal Transit Administration in the United States now understands how effective highly utilized public transit systems are in reducing emissions in the transportation sector (Fraser & Chester, 2016). We have also noticed that several articles are encouraging and demanding governments and entities to start reacting to climate change by changing design codes and zoning to reflect the future of our cities

with climate change impacts and develop cities that are resilient and sustainable (Chester & Fraser, 2017) (Fahed et al., 2020) (Markolf et al., 2017). This, of course, includes the design of transportation systems such as light rails and metros worldwide and the design of the public realm surrounding these transit systems. For instance, (Allan, & Taha, 2020) (Fahed et al., 2020) (Salimi & Al-Ghamdi, 2020) are proposing that cities in the Middle East with high temperatures and extreme heat events should include thermal resiliency requirements in their future building codes and urban/public realm design codes. Even on the other side of the world, scholars mention that cities in the southwestern region of the United States, such as Los Angeles and Phoenix, should start including heat mitigation strategies in their general plans, zoning, and design codes to avoid severe effects of heating (Pincetl, Chester, & Eisenman, 2016). They believe that changing the ways and methods used to build our cities will help reduce the impacts of climate change and make it more comfortable for our communities to live healthily and comfortably, hence improving the public transit riders' experiences.

Transit and urban design affect riders' experiences

Planners encourage cities to change their codes and plans because they have realized how different design components affect our daily lives. There is not a lot of literature focusing directly on how urban design and the public realm affect the transit riders' experiences, as many focus on a broader perspective of either the pedestrians' experience or the sufficiency of the built environment in general. For instance, scholars concluded that TODs encourage more people to stop using/owning private vehicles and start using other transportation modes, especially when TODs are providing solutions such as alleyways that make trips shorter and more comfortable (Alawadi et al., 2021) (Atkinson-Palombo, & Kubly, 2011) (Kamruzzaman, Deilami, & Yigitcanlar, 2018). Stojanovski also mentions how important visual proximity is to the rider's experience; particular transit and urban design strategies can make walking trips to transit stations feel shorter, more desirable, and more comfortable (2020). Some researchers suggest that using TODs as a strategy to reduce and mitigate greenhouse gas emissions has been successful; therefore, it can help improve the riders' experience around the transit system by reducing their vulnerability to heat

(Ali, Nawaz, Iqbal, Basheer, Hameed, Albasher, Shah, & Bai, 2021). However, some scholars note that there have not been many intensive studies on how TODs can reduce the effects of climate change effects on our cities and how transit design can reduce heat vulnerability (Alawadi et al., 2021) (Kamruzzaman, Deilami, & Yigitcanlar, 2018) (Stojanovski, 2020). Therefore, we need more research on designing transit that complements our urban design efforts and integrates all systems for a better experience.

Urban design elements and strategies

Even though TODs have not been studied intensively with regard to climate change and heat vulnerability, there are many articles celebrating how successful TOD is as an urban design strategy. Planners are focusing on TODs as they encourage many urban design elements that promote pedestrian-oriented cities rather than vehicle-oriented cities, as it aims to improve the public realm around transit systems. This includes improved connectivity, mixed uses, and making cities friendlier for pedestrians and cyclists (Ibraeva, Correia, Silva, & Antunes, 2020) (The World Bank, 2022) (Xu, Guthrie, Fan, & Li, 2017). The World Bank determines successful TODs through three variables: upscaling transit connectivity, improving the quality of the urban built environment, and market potential from growth and development (The World Bank, 2022). Lang categorizes transit systems into two types of urban design, a transit system can be built for developers to plug into, or the system itself is plugged into the city's infrastructure. Therefore, a transit system can become a catalyst for the redevelopment of older parts of the city or the development of new parts of the city (Lang, 2005). Therefore, as a catalyst, it affects several elements such as mix-use, densifying neighborhoods, connectivity, and walkability of an area (Ibraeva, Correia, Silva, & Antunes, 2020) (Lang, 2005) (The World Bank, 2022). These design elements help us understand how impactful a transit system has been on the surrounding public realm and allow us to use them as variables to measure and compare how different transit stations have been impacting their surrounding since their launch.

Vegetation used to mitigate heat effects

One of the critical heat mitigation strategies is vegetation, as it helps reduce experienced heat in several ways if implemented correctly. Many planners today highly recommend using an extensive tree canopy. They believe that it provides ample shading during the day, making it more comfortable for pedestrians to use sidewalks as they avoid discomforts from being exposed to direct sunlight. Cooling is not only limited to adding trees but is also achievable through increasing the vegetative cover in urban areas. This is possible through different vegetation strategies, such as having green roofs on top of buildings (Fahed et al., 2020) (Kim, Gu, & Kim, 2018). Rosheidat comes with an interesting conclusion that having an extensive tree canopy is not always beneficial to reducing the urban heat island effects because they have determined that it might reduce the sky-view factor of the pavement during the night (2010). Bigger tree canopies block some of the heat radiated from pavements to the sky during the night (Rosheidat, 2010). Therefore, they believe it is better to have vegetation that is not high or big on the sides of the road to not reduce the sky view factor, or else the urban surface nighttime radiation will be reduced as they do not have enough space to escape (Rosheidat, 2010). However, vegetation remains the best shading element to use; some scholars have concluded that the most severe heat impacts occur in densely populated neighborhoods that lack high-rise buildings and/or bigger trees that act as shading elements for pedestrians (Fahed et al., 2020) (Xiaoxiao et al., 2016). Therefore, it is essential to understand the uses and impacts of different types of vegetation and where to locate them in the public realm; better landscape architecture and planning should be included in the process of designing transit systems as they help with cooling when designed correctly.

Building materials and their heat effects

Climate change and extreme weather events have made many planners and engineers rethink the materials they use in their buildings and reconsider how they are paving roads to reduce UHI effects. For instance, when it comes to selecting the pavement material, the color and roughness of the material will all have different impacts on UHI depending on how much energy the materials absorb during the day and release at night (Fahed et al., 2020) (Kim, Gu, & Kim,

2018) (Rosheidat, 2010). Pavement and building materials are also impacted by vegetation, and different vegetation characteristics vary in their UHI effects as they affect the experienced temperatures (Fahed et al., 2020). According to Xiaoxiao et al., vegetation can decrease the land surface temperature; however, soil and impervious surface, on the other hand, increase it (2016). Therefore, it is crucial to determine the proper way to design our sidewalks and choose suitable pavement materials for our transit stations and their surrounding areas. It impacts the UHI effects and the transit riders' experiences throughout the day.

Transit infrastructure vulnerability to extreme heat

Choosing the suitable material when designing transit does not only help reduce the UHI effects it also helps in building a resilient and reliable infrastructure that is not vulnerable to extreme heat events. When the weather starts reaching extreme temperatures, materials react differently depending on how durable they are against severe climate (Markolf et al., 2017). For instance, in extreme heat events, some materials tend to expand; therefore, we might notice rail tracks start buckling and distorting the railway (Salimi & Al-Ghamdi, 2020). This can be solved by either mitigation, reducing the impacts of climate change to avoid reaching high temperatures where railways start buckling, or adaptation, using more durable materials and keeping the track well maintained. There are also other ways that extreme weather events can affect the infrastructure; these include asphalt softening/rutting, asphalt cracking, accelerated aging/oxidation of asphalt, and failure of thermal expansion joints on bridges and roads (Markolf et al., 2017). Current literature has shed light on the different material types and their characteristics. They play a crucial role when designing transit in desert cities as they affect the transit system's vulnerability and impact the riders' experiences.

Riders' vulnerability to extreme heat

Riders are highly vulnerable to heat events. After all, transit riders are humans and can be easily affected by any external element causing them discomfort or even harming their health and wellbeing. Unfortunately, extreme heat events impacts can reach the point of causing death and increasing mortality rates (Eisenman et al., 2016) (Fahed et al., 2020) (Fraser, & Chester, 2016).

As the frequency of climate change events increase, and the severity of extreme heat events reaches unprecedented levels, it is crucial to determine the most vulnerable demographics and where they are generally situated in our cities (Eisenman et al., 2016). Determining the most vulnerable sites allows us to supplement these sites with improved design and extended safety measures. As planners, we need to determine ways to mitigate the risk of heat-related death and illnesses (Eisenman et al., 2016) (Salimi & Al-Ghamdi, 2020). Extreme heat events also impact transit ridership as it forces riders to change their preferred transportation mode because of the severity of the weather conditions. For instance, elevated stations have higher impacts from natural weather events than underground stations as they are exposed to heavy rain, high wind speeds, and hot days that have higher negative effects on riders and station components compared to underground stations. Therefore, riders using elevated stations are more vulnerable to extreme weather conditions, affecting the ridership at these stations during extreme events (Singhal, Kamga, & Yazici, 2014). Elevated stations in hot cities suffer from harsh climates as they are directly exposed to the sun, and underground stations are vulnerable to occasional flooding due to high precipitation caused by climate change. Scholars have concluded that elevated stations are more sensitive to extreme weather conditions even though underground stations are exposing riders to extreme weather conditions such as flooding, causing closures or delays, which has disrupted subway services in New York several times over the past couple of decades (Singhal et al., 2014) (Stojanovski, 2020). Thus, each city should rely on studies specifically related to climate conditions. Unfortunately, there is no comprehensive set of studies dedicated to cities in hotter climates as the main focus was on cities in cooler climates which are usually more urbanized than their counterparts and also utilized transit systems sooner.

Lack of comprehensive literature

Current literature covers several aspects contributing to transit planning but there is no comprehensive literature yet that provides a set of best practices or recommendations for designing transit systems in hot desert cities. Literature has mainly focused on certain aspects influencing the design process in general, including studies on urban heat islands, the built environment,

increasing ridership, climate change, and urban design. There are few studies done on transit systems in areas impacted by extreme weather conditions or events and they are mainly covering cities in cooler climates, such as New York (Singhal, Kamga, & Yazici, 2014). We are currently at a stage where it is crucial to start determining the best practices for designing transit systems in desert cities as we see more and more cities developing mass transit systems despite their extreme weather conditions. In developing these transit systems, planners and engineers mainly rely on research based on the past experiences of cooler cities. Previous knowledge is not very useful in predicting future climate conditions, especially when considering climate change effects (Salimi, & Al-Ghamdi, 2020). Extreme weather events are occurring more frequently, and damages are costly; therefore, it is not safe to rely only on old data but instead start considering future trends. As more hot cities start developing transit, it is necessary to have a set of best practices from relevant experiences and that is why we need more literature to cover all the different aspects contributing to improving riders' experience.

Case Studies

Since we are trying to determine best practices for designing in desert cities, and in pursuit to answer the research questions we had to focus on cities that have already developed new transit lines in their extremely hot cities. Not looking for recently launched systems or currently developing systems but want to look at systems that have been serving the public for at least ten years. Our search has fallen on two cities that we can relate to as researchers as we have experienced their transit systems, those cities are Dubai, United Arab Emirates, and Phoenix Metropolitan, Arizona, United States. Both cities have launched their transit system more than ten years ago, Valley Metro's light rail was launched to the public in December 2008 and Dubai's Metro launched shortly after that in September 2009. Both transit systems have been running for more than a decade now and there have been several expansion projects since then, covering new areas and introducing new design features in the new extension lines.

As mentioned above, Dubai and Phoenix share the same extremely hot summer weather but have different humidity levels. Dubai lies on the Arabian Gulf and has significantly higher humidity levels compared to the landlocked Phoenix Metro. Weather conditions are not the only factors that the cities share similarities or differences in, there are other factors that we will be looking at such as population growth, public realm design, riders' demographics, ridership, and technologies used in the transit systems. Being cities that witnessed significant growth over the last fifty years in size and population, both had to adapt to challenges related to their highly vehicle-oriented infrastructures, and public transit seemed a viable option to improve their infrastructures and provide a new reliable service for the community. Understanding the background of the cities and the initiation of the transit system is essential to analyzing and determining how they have considered heat when designing the new transit systems and how they have impacted the surrounding public realm around them.

Dubai, United Arab Emirates

The city of Dubai is currently the second most populated city in the United Arab Emirates. Dubai was an important stop in the historical silk route for centuries making it a meeting point for many cultures. Historically, the city of Dubai was growing on both sides of Dubai Creek which can be seen in the eastern part of the figure below. That is where old Dubai now stands and continues to prosper. Dubai's population back fifty years ago (1970) was 73,000 only, and it is currently expected to surpass the 3-million-mark next year (2023) according to the U.N. projections (macrotrends, 2022). That is the population of Dubai alone, not including its neighboring cities Sharjah and Ajman where many of Dubai's workers reside. The city started witnessing growth in population and development since the 1990s, and as they entered the new millennium they set the goal to attract millions of visitors and residents over the next two decades. To cope with the city's rapid growth they realized that they will need to introduce a new transit system that will expand the city's public transportation network, help ease congestion, and most importantly set bases for future development alongside the metro lines. In 2005, they started construction on the Dubai Metro, which was at the time divided into two phases, the Red Line that goes from east of the creek all the way to Dubai ports, in far most left of the map below, was launched in September 2009.

Two years later in September 2011, the Green Line was launched making Dubai Metro the longest automated transit system in the world at the time. Most recently, in 2021, Route 2020 was launched to allow transit riders to reach the Expo 2020 site easily. The cost of all three lines, Red Line, Green Line, and Route 2020, comes to a total of approximately \$10 billion for the 90 km long network (Harnan, 2009)(Badam, 2016). One of the several reasons for the high cost is investing in DESMI's district cooling system that consists of underground piping that reduces energy consumption between 30-50% and eliminates noise and vibration that usually occurs when having rooftop air conditioning systems. By reducing energy consumption this system reduces the carbon footprint of the project (DESMI, 2020). The Red and Green lines share the same design language, Red line stations are mostly overground while several stations on the Green Line are underground given that they are in the older parts of Dubai where streets are narrower and do not allow for huge structures to be developed alongside them. The new Route 2020 has a new design and architecture, even the interior architecture of the stations is completely different from the older metro stations. There is a mix of overground and underground stations in the new Route 2020 that terminates at the Expo 2020 site. Therefore, we will be looking at stations from all three phases to better understand how heat was considered when designing the new transit system and how it has affected the surrounding public realm.



Figure 2 – Map of Dubai, United Arab Emirates (Source: Google Earth)

Phoenix Metropolitan, Arizona, United States of America

More than 8000 miles away from Dubai, lies our second case study in the United States, it is in Phoenix Metropolitan, Arizona. Phoenix Metro experienced a rapid growth phase of its own, causing endless urban sprawl that keeps on attracting people from all around the country to come and settle in an affordable single-family home in the middle of the desert. Phoenix Metro's population increased from 874,000 in 1970 to 4,511,000 in 2020 and is expected to surpass the 5 million mark by 2029. Phoenix's history goes back to the late 1800s when it was an agricultural community before becoming the capital of Arizona before the turn of the century. Affected by the same growth trends in major U.S. cities that were fueled by the adaptation of private vehicles as the main mode of transportation and the urban sprawl trend that creates all these suburbs spreading out around Phoenix as shown in the figure below. Compared to Dubai, Phoenix has less densely populated areas as it is more spread out and more people are occupying single-family homes and fewer apartment buildings and complexes are found in the suburbs. Densely populated areas are mainly found in downtown areas of the city of Phoenix and Tempe.

Being in a country where transit systems are common in populous cities, Phoenix Metro had many great examples to learn from and be encouraged to develop their own transit line to provide a reliable and affordable transit system that will give people the opportunity to choose between transportation modes. The transit system will also help cities develop and prosper, which is why we continue to see new extensions being added around Phoenix Metro since the launch of the first phase of the light rail in 2008. The line currently runs from 19th Ave/Dunlap in north Phoenix to Gilbert/Main St in Mesa making a total of 45 km which is half the distance the Dubai Metro runs, with a total cost of more than \$3 billion considering the new upcoming extensions (Collom, 2019). Valley Metro decided to have the light rail running on street level and in place of the middle island for several reasons, one of which is being more feasible financially with minimum infrastructure transformations. Since the light rail was built in different phases, we will be looking to identify any changes in design and observe any impacts on the surrounding public realm. Lastly, we are on the verge of witnessing the launch of the Tempe Streetcar that will be supporting the light rail in the city

of Tempe and soon enough will see other extensions such as the most anticipated extension line to South Phoenix to be completed by 2024.

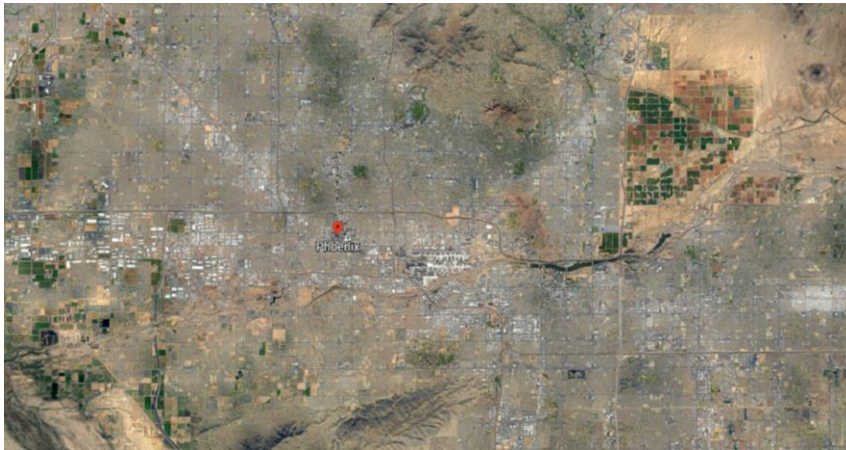


Figure 3 – Map of Phoenix Metropolitan, Arizona, United States (Source: Google Earth)

Methods

In this study, we rely on both qualitative and quantitative methods to collect data and observations during our fieldwork. We are seeking to measure the temperatures, humidity levels, and ground temperatures at different times of the day for all the ten stations selected from each transit system. This qualitative data will then be analyzed to determine the best and worst stations when it comes to these three variables, identifying which stations have the highest and lowest recorded temperatures and humidity levels. This data will also help us identify how useful the public realm is in cooling down temperatures around the stations which can be determined through the recorded temperatures and also the ground temperatures of shaded and unshaded areas. Furthermore, we will be noting and observing the public realm around these stations. We will be looking at the different built environment elements that may affect the riders' experiences as they use the transit stations. Once we have completed the field research, the quantitative data will be analyzed separately to discover the findings of this study and then relate it with the qualitative data by comparing analyzed data to notes and observations. We are hoping that a mixed data collection method will help us best reflect our observations and support the findings with our experiences.

After all, we are trying to determine how these stations have been designed to deal with heat and whether or not they have influenced the surrounding public realm to improve the rider's experience.

Network Stations Selection

For each transit system, ten stations are selected from the 56 stations of Dubai Metro, and ten stations are selected from the 38 stations of Valley Metro Light Rail. The stations are selected based on several factors including their location, design, supporting facilities, years of service, and be inclusive of the different lines that the transit lines go through in Dubai or the different cities the light rail passes through in Phoenix Metro to reflect the differences and similarities that stations have with each other for each transit system. Therefore, we will rely on a selective analysis based on stations around popular areas such as downtowns areas (higher population density), transit hubs (multiple transit systems or transit lines intersections), and potentially higher ridership areas (park-and-rides and event destinations). Having different station criteria and a spread-out selection of stations allows us to see how weather conditions differ from one place to another and how the public realm has been affected by the introduction of the transit system. For this research study we will be looking at a total of 20 stations, 10 in each city divided based on the criteria above and including all-new line extensions and jurisdictions the transit system goes through.

Dubai Metro Stations

Figure 4 below shows the current route map of Dubai Metro. The Red Line covers a bigger part of the city as it stretches from district 5 to 1 mainly on Sheikh Zayed Road, it also includes the recently launched line extension to the Expo 2020 site which is called Route 2020. On the other hand, the Green Line covers mostly the older part of Dubai and a smaller area in comparison to the Red Line; however, these areas have a higher population density compared to many areas served by the Red Line. The figure below shows an orange line which represents the Dubai Tram system that serves the Dubai Marina district and connects Dubai Metro to the Palm Monorail which is the blue line shown in the figure below. In this study, we are only focusing on Dubai Metro as we want to focus on one method of public transit for a better understanding of this specific transit system.

The ten stations observed in this study include 4 stations on the Red Line as it covers the longer part of the transit network, 3 stations on the Green Line, and 3 stations on Route 2020. The stations have been color-coded in the quantitative datasets below (tables 1, 2, and 3) to reflect their different lines; Green Line stations have a green shade, Red Line stations have a red shade, and Route 2020 have a blue shade. Given that several Red Line stations are located near highly visited stations, we have to pick and choose those that meet several variables of our search criteria. Al Rigga Station is selected because it continues to have the highest ridership on the Red Line station, mostly because of its location in a densely populated area of mixed-use development in the older part of Dubai (Gulf News, 2022). The Dubai Mall Station is selected because it serves the most visited attractions in Dubai, one of the biggest shopping malls in the world, the Dubai Mall, the tallest building in the world, Burj Khalifa, and the new Downtown Dubai area in general. The third station selected on the Red Line is DMCC Station which connects Dubai Metro to Dubai Tram serving the densely populated districts of Dubai Marina and Jumeirah Lake Towers, it is a transit intersection station. The last station included from the Red Line is the Ibn Battuta Station, which lies farther away from Downtown Dubai and serves Ibn Battuta Mall, Jebel Ali industrial area, and the residential communities surrounding the mall.

Moreover, on the Green Line, we have selected Burjuman Station which is where the Red and Green Lines intersect, and it has the highest ridership figure for Dubai Metro of nearly 8.8 million riders in 2021 (Gulf News, 2022). The second station is Baniyas Square Station which has the largest ridership for a station serving the Green Line alone as it falls in one of the busiest squares in the older part of Dubai, and it is surrounded by mixed-use high-rise buildings. The last station on the Green line is the Stadium Station, which is farther away from the other stations and serves a different purpose as it can be considered a transit intersection as many bus riders change the mode of transportation here, and it is also serving an event destination which is the football stadium beside it.

Lastly, we select three stations on the recently opened Route 2020 that serves different areas on the way to its final destination the Expo 2020 station. At the time of the field research Expo, 2020 was not yet opened, as it opened in October of 2021, but the station itself has been

launched and serving the teams working in the Expo 2020 site at that time preparing for the event or working in the surrounding area. The next station is the Dubai Investment Park station, which is a mixed-use development district, it is one of the outlying districts of Dubai which is neighboring and supporting the Expo 2020 site that will be repurposed after the end of the event in March 2022 and 80% of the structure will continue to be used creating a new city on Dubai's outskirts. The last station of Route 2020 and our Dubai Metro selection is Jebel Ali stations, which is where Route 2020 intersects with the main Red Line, and it is considered as one of the biggest park-and-ride stations in the network with a parking structure with 3000 parking spaces.



Figure 4 - Dubai Metro route map (Source: Dubai Roads and Transport Authority)

Valley Metro Light Rail Stations

Figure 5 shows the Valley Metro Rail route map which consists of one line that goes through the three cities of Phoenix, Tempe, and Mesa. The rail goes through the main parts of the three cities, stopping at downtowns, event destinations, the airport, and Arizona State University. Given the different variables we are considering for selecting rail stations we first divide the ten stations to include four stations in Phoenix, three in Tempe, and three in Mesa. Due to Phoenix Metro's grid system which the rail follows as it goes along its streets, we notice how many stations are going east/west while others are north/south; therefore, are exposed to sunlight differently making it an important factor in the selection of stations for this study.

Starting off with Phoenix, we have selected the 7th Avenue/Camelback Station to the north of Phoenix which lies on the outskirts of the downtown area and is mainly surrounded by single-family homes. Next on the list is Roosevelt/Central Street Station, positioned in one of the revitalized areas of Phoenix and surrounded by mixed-use developments supported by the transit-oriented development overlay. The third station is 3rd St/Jefferson Station is selected because of its main purpose of serving event destinations around it including Chase field, Footprint Center, and Phoenix Convention Center. Even though this station is barely used during the summer due to the lack of events in the summer it is still one of the important stations to study due to the increase in ridership that occurs on event days. The last station selected in Phoenix is 44th St/Washington Station which is mainly serving riders connecting with Phoenix Sky Harbor International Airport using the PHX Sky Train making it the third-highest ridership ranked station in the boarding category and fifth in de-boarding according to the 2020 rankings (Valley Metro, 2021).

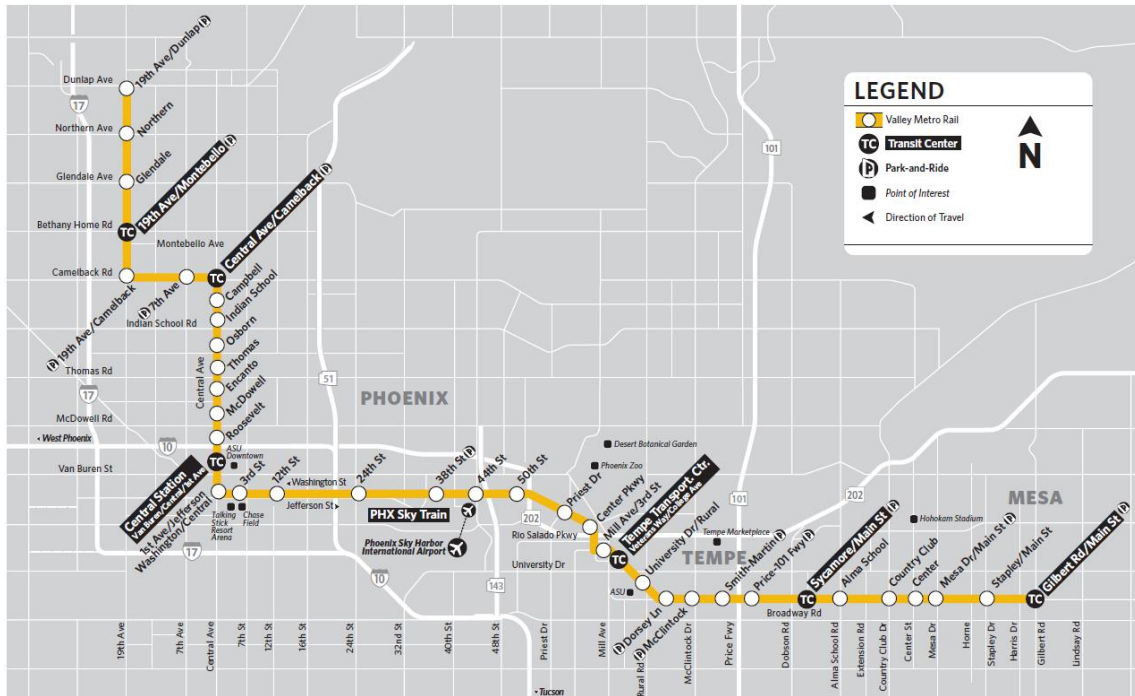


Figure 5 - Valley Metro Rail route map (Source: Valley Metro)

Moving to Tempe, there are three stations selected for this study. Mill Ave/3rd Street is selected due to its proximity to Mill Ave and Downtown Tempe in general. Since Arizona State University plays a major role in the population density and ridership in several rail stations in Tempe, the University Dr/Rural Station is selected as it serves ASU’s main campus and has the seventh-highest ridership ranked station in the boarding category and eighth in de-boarding according to the 2020 rankings (Valley Metro, 2021). Lastly, McClintock/Apache Blvd Station is selected due to its location on Apache and being surrounded by multiple apartment complexes and residential neighborhoods in general.

Moreover, Mesa has added several new stations since the rail launch back in 2008 and this is interesting to determine how station design and the public realm have changed over the years. Sycamore/Main Street Station is selected because it is considered a transit center and a park-and-ride station, serving different types of riders, and having a bigger station area compared to many other stations included in this study. Sycamore/Main Street Station is selected because of its location in Mesa’s historical downtown area making it convenient for riders to visit that vibrant part of the city. Last but not least, Gilbert Rd/Main St Station is selected because it is the second-

highest ridership ranked station in both boarding and de-boarding in the 2020 ranking for three main reasons; it is an end of line station, a transit center, and the newest addition to the park-and-ride stations serving the rail system.

Tools and Protocols

After identifying the ten stations we started working on developing a research protocol and determining the tools that will be used during the field research. We are looking to reflect the experienced temperature by riders using the transit system; however, we are not interested in the experience during the ride as both transit systems are relatively new and are air-conditioned to provide a fair ride experience for the riders traveling in their transit vehicles. We will be focusing on the rider's experience as they head to their nearest station and wait at the station; therefore, we will focus on measuring and observing the experienced temperature around the stations and in the waiting areas. The three main aspects of this field research are measuring the temperature and humidity levels around the stations, observing the experienced temperature, and capturing the effectiveness of the public realm elements around the transit stations.

Furthermore, the field research will be conducted by visiting the transit stations on three different days and during three distinct periods each day. The timeframe for collecting the data in the two case studies must be limited to a certain period of the summer; in this case, it is in August and September to cover a relatively similar period for both case studies. The three time periods to visit stations are the morning, afternoon, and evening shifts. On two occasions, these shifts will reflect the workday hours, and on the third occasion, it will reflect the weekend timings as people tend to head/stay out later in the day/night. This precise specification captures the rider's experiences at different times of the day based on their daily routines and measures the weather conditions around the stations in several time slots for a better analysis of the stations' effectiveness throughout the day. The three shifts are also constrained by a two-hour limit to have measurements taken closer to each other and allow for a better comparison between stations when it comes to measured and experienced temperatures.

Certain tools are required to conduct field research and take measurements. A thermometer is needed to measure the outdoor temperature, a hygrometer to measure the humidity levels, a digital infrared thermometer to measure the ground temperatures, and a camera to take pictures of the public realm elements that work and those that do not work as sufficient as anticipated. Therefore, we pick the following tools: to measure the temperature and humidity level we use a manual “Presitge” Thermometer, to measure the ground temperature we use a “LyfTrack” Digital Infrared Thermometer, and a smartphone to take the photographs. The next step is making sure each tool is tested prior to research and effective in extreme weather conditions as temperatures are anticipated to reach 45°C and humidity levels to reach above 90%, especially in Dubai.

Based on the demo runs of the tools to be used in the field research, we determined that 5-7 minutes are needed on any station site to collect the measurements and photographs. We then need to determine how many stations can we cover in the limited two-hour window we have to measure and collect data. Therefore, we study current schedules and waiting times for the transit system to be studied to make the choice of whether to rely on that system or not when conducting the research. Given the short measuring windows we decide to rely on a private vehicle for both case studies to travel faster between stations and avoid losing time waiting at the station. This decision seems to be reasonable since we are only focusing on the experienced temperature at the stations and their surrounding areas in this study and not the rider’s experience inside the vehicle. Keeping in mind that we have and will continue to experience riding both transit systems on a regular basis outside the course of this field research and are not outsiders to the concept of relying on both transit systems in our daily lives. Furthermore, the research is conducted in August and September since we are covering two cities in two different parts of the world. We want to keep the field research timeframe as short as possible, to conduct the field research in times closer to each other since we have two cities, and for temperatures to be high reflecting the extreme heat conditions these two cities go through during the summer.

The research protocol for Dubai goes as follows, since Dubai Metro is spread out in the city and covers the entire city from east to west, we decide on dividing the stations into two groups.

Therefore, we have five stations to cover in the 2-hour time span for each time slot of the day. As depicted in the Dubai Metro route map above in figure 4, stations fall into different districts; therefore, we divide the ten stations based on these districts. The first group of five stations is from districts 5 and 6, which includes all three stations from the Green Line and two stations from the Red Line. The other group of five stations is from district 1 and 2, which includes all three stations from Route 2020 and the remaining two stations from the Red Line. We then set the days to visit these stations and start with the first group of stations in districts 5 and 6. We start the field research on the third of August and completed the first group of Dubai Metro stations by the ninth of August. The field research for the second group of Dubai Metro stations on the tenth and was scheduled to be completed by the sixteenth. Unfortunately, due to unforeseen circumstances, we only completed one out of the three days dedicated to the second group of stations, and there was not enough time to reschedule the field research as we must travel back to Phoenix for the fall semester. Therefore, this becomes one of the limitations of this field research as our data is comprehensive only for one group of stations and limited for the second group of stations as reflected later in the results section.

Meanwhile, in Phoenix, the field research protocol is slightly different since the Valley Metro Rail consists of one line and covers a smaller area than Dubai Metro, we are able to fit all ten stations in the two-hour timeframe for collecting data for each time slot of the day. We complete a demo practice run considering the time it takes to measure and photograph in each station before starting the field research since we are planning to include all ten stations and not divide them into two groups. Therefore, we schedule three days to complete the field research data starting on the 27th of August and completing it on the 11th of September. Fortunately, unlike the situation that happened with the second group of Dubai Metro stations, here we did not have to suffer from any circumstance that could potentially prevent us from collecting a comprehensive dataset.

Furthermore, another important aspect of the field research is deciding the start and end stations for each timeslot. To be inclusive of all timings we had to switch our starting and ending points for each timeslot and day. For example, if on the first slot, the morning shift, you start in Gilbert Rd/ Main St Station in Mesa and end the shift in 7th Ave/Camelback in Phoenix, you will then have to reverse that on the next timeslot, which is the afternoon shift. And then switch the

starting points on the next field visit so that you start the morning shift in Phoenix rather than Mesa. This method allows you to collect data from all stations at different times and is helpful when comparing temperatures and humidity levels between stations. This is reflected in the results tables shown in the results section below and has been followed in both case studies. You will notice how the stations are visited at different times of the day during the field research days for each transit system.

Field Research Notes and Observations

Furthermore, another essential aspect of the field research is taking notes of the observations while collecting data on each transit system. This includes reflecting on the experience of the weather conditions and the surrounding public realm. We are looking at many different aspects here, the experienced temperature, the exposure to direct sunlight, and all design elements available or missing from the public realm. Specifically, the design elements observed in this field research are the following: land uses around the station, streets width and types (boulevards, narrow streets, and alleyways), station integration with the surrounding, shading adequacy, and available seating. Determining the land uses helps observe if specific uses are more effective in improving the rider's experience when heading to a station. Street widths and types reflect whether streets are vehicle or pedestrian-oriented; narrower streets have better chances for passive cooling and more shade to be provided. Station integration with the surrounding reflects on the level of connectivity of a station and how well it is integrated with the surrounding public realm and other transit modes. Shading adequacy is crucial to riders' heat vulnerability around a station and is highly effective in improving their experience. Last but not least, the availability of seating around transit stations is important to enhance the rider's experience. Observe if ample seating is available around transit stations. Determine whether it is primary or secondary seating and if air-conditioned or well-shaded open air waiting areas are provided around the station for the observed transit system and other transit modes. These are the design elements the field observations will focus on and are reflected in the observational notes provided in the results section and more in-depth in appendices C and D below for the two case studies.

Therefore, the notes found below in the appendices will show how a rider experiences walking towards the selected stations and observing the surrounding public realm, including shading, passive cooling, seating, and how supportive the urban design is in general in the surrounding area of the station. These design elements are similar to TODs elements, which is something we are also trying to observe to determine whether developments around transit stations are transit-oriented or transit adjacent. The field researcher needs to either use a notepad or collect the notes digitally on an electronic device to complete this task. For this research, we used Google Docs to collect and organize the notes on the phone as it allows for voice dictation which is an essential tool as it saves time and can be completed while on the move. Using Google phone apps also enables you to add the measurements collected during the field research into Google Sheets without the hassle of carrying a laptop or recording measurements on notepads and then adding them to an excel spreadsheet. The field notes reflect the experienced temperature and observation of all the public realm elements mentioned above surrounding each station site.

As shown in appendices C and D below, we have collected field notes for all time slots and stations during the field research. Each time we visit a station, we make sure that we approach it from a different perspective by walking towards it from a new location when applicable. For instance, Dubai Metro's Burjuman station has four different entrances. Even though the station is underground, all the station entrances are above it on street level, on four different corners of the intersection. Each time we visit the station, we park at a different block and walk towards the station from within that area as if we were any regular rider working/residing in that area and are using the metro. Therefore, we cover all the different perspectives as much as possible to better understand the experienced temperatures from all the different areas. This allows us to observe the public realm in the whole vicinity around the stations. Therefore, help to better understand how the experienced temperature may differ as design elements change from one corner to the other. These notes and observations will then be compared with the analytical results to support any findings or recommendations.

Results

Collecting data qualitatively and quantitatively allows us to reflect on factual data based on measurements and on observations based on human interpretation from their experiences using the transit systems and the surrounding public realm. Therefore, at first, we will be looking at the quantitative dataset results of each case study separately to analyze the measurements solely and compare transit stations to each other and between the two cities. Then we will be reflecting on the qualitative data and supporting it with results from the analysis of the quantitative datasets. It is crucial to combine both datasets to have a better understanding of how both transit systems have considered heat in their design and their effects on the surrounding public realm.

Temperatures

Temperatures around Dubai Metro stations average above 40°C during the summer months and humidity reaches the highest levels compared to the rest of the year. This combination of heat and humidity results in a harsh experience for everyone in the city, many are fortunate enough to avoid being exposed to these temperatures for longer periods of time as they do not have to use public transit where trips constitute of sections where riders are exposed to direct sunlight and harsh weather conditions till they reach their air-conditioned transit stations. The results below are a good representation of these harsh conditions as it is evident that both measured and recorded temperatures from The Weather Channel (weather.com) fall between 35-45°C during the day, which is even applicable to some stations early in the morning or later in the night.

Looking first at the temperatures during the morning shift from 7-9 am on Monday and Tuesday as shown in table 1. We notice how the stations from group 2 of stations (DMCC, Ibn Battuta, Jebel Ali, DIP, and Expo 2020) have higher temperatures as they fall in district 1 and 2 of the metro map shown in figure 4, which is farther away from the downtown area and closer to the desert and all of the stations except to DMCC are in open spaces exposed to direct sunlight and no passive cooling. When looking at the stations from group 1 (Stadium, Baniyas Square, Burjuman, Al Rigga, and Dubai Mall) we notice how temperatures rise during the afternoon. Moreover, during the weekend the morning shift changes to 10-11:59 am, and here we notice how

Dubai Mall which is a station situated in close proximity to the gulf and adjacent to a 14 lane highway has the highest temperature as we are getting closer to 12 pm measuring at 44°C and the recorded temperature [weather.com] is also the highest at 39°C, it is a station built to connect people through a pedestrian bridge to the mall and not focused on riders walking out to the surrounding area which is not very pedestrian-oriented like the other stations in group 1.

The afternoon shift shows the highest recorded temperature at 46°C at Al Rigga Station. The stations that stand out as with the highest temperatures on all three days in group 1 are Stadium, Al Rigga, and Jebel Ali. The station that stands out to have the lowest temperatures in all three days during the afternoon is Baniyas Square while the remaining stations have temperatures that fluctuate between high and low temperatures. Finally, when it comes to the evening shift, we see Dubai Mall and Burjuman stations have the highest temperatures after 5 pm. This is a reflection of the surrounding built environment and effects of urban heat islands because even at the weekend shift, between 10-11:59 pm they have the highest temperatures compared to the other stations in group 1 of Dubai Metro station. Remembering that circumstances have prevented us from completing the field research and collecting data for group 2 of stations affects our analysis regarding temperatures and humidity levels but does not affect our observations and notes as much. Overall, Al Rigga and Stadium stations appear to have the worst cooling conditions in their surrounding areas as they appear to have the highest average temperatures all week and for all three timings. Meanwhile, the Baniyas station has the lowest average temperatures for all timings of the day over the three days.

Table 1

Measured and recorded temperatures - Dubai Metro

Station	Tuesday, August 3, 2021 and Tuesday, August 10, 2021			Friday, August 6, 2021			Monday, August 9, 2021		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Exact time of measurement			Exact time of measurement			Exact time of measurement		
Stadium	7:00	1:45	5:00	10:20	4:10	10:15	8:50	3:25	6:30
Baniyas Square	7:42	1:00	5:37	11:00	4:45	10:55	8:10	2:35	5:40
Burjuman	8:12	12:31	5:54	11:15	5:10	11:10	7:50	2:10	5:20
Al Rigga	7:26	1:15	5:22	10:40	4:20	10:40	8:30	3:00	5:55
Dubai Mall	8:45	12:00	6:30	11:45	5:35	11:30	7:25	1:35	5:00
DMCC	9:20	1:55	5:55 -	-	-	-	-	-	-
Ibn Battuta	9:00	1:20	5:20 -	-	-	-	-	-	-
Jebel Ali	8:45	1:35	5:40 -	-	-	-	-	-	-
Dubai Investment Park	7:45	12:15	4:30 -	-	-	-	-	-	-
Expo 2020	8:15	12:35	4:50 -	-	-	-	-	-	-
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Measured Temperature (°C)			Measured Temperature (°C)			Measured Temperature (°C)		
Stadium	33	45	41	41	37	32	36	42	34
Baniyas Square	35	44	36	36	36	32	36	38	35
Burjuman	35	42	36	38	37	34	35	39	36
Al Rigga	34	46	40	39	38	33	38	37	35
Dubai Mall	34	42	34	44	35	34	33	40	36
DMCC	36	39	34 -	-	-	-	-	-	-
Ibn Battuta	34	40	33 -	-	-	-	-	-	-
Jebel Ali	35	41	33 -	-	-	-	-	-	-
Dubai Investment Park	34	39	34 -	-	-	-	-	-	-
Expo 2020	33	38	33 -	-	-	-	-	-	-
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)		
Stadium	32	39	37	37	38	36	38	42	42
Baniyas Square	32	39	36	37	38	37	37	42	41
Burjuman	32	39	37	38	38	36	35	43	41
Al Rigga	32	39	37	37	38	36	37	43	40
Dubai Mall	30	40	36	39	37	36	29	43	41
DMCC	39	42	38 -	-	-	-	-	-	-
Ibn Battuta	38	43	39 -	-	-	-	-	-	-
Jebel Ali	38	44	39 -	-	-	-	-	-	-
Dubai Investment Park	33	44	41 -	-	-	-	-	-	-
Expo 2020	37	44	41 -	-	-	-	-	-	-

Temperatures around Valley Metro Rail stations are generally above 40°C in the afternoon shift during August and drops a couple of degrees during September to fall between 35-40°C. As we measure temperatures in a two-hour window it is understood that temperature will rise as you get to the hotter part of the day; however, some stations show a significant increase in temperatures compared to other stations. Starting with the morning shift we have certain stations that always have the highest temperatures during all measurement timings, which includes the Roosevelt/Central Ave station, 3rd St/Jefferson, and Sycamore/Main St. stations. Two of them are in the Phoenix downtown area. Moving on to the afternoon shift, we see a similar trend with the hottest stations, on average of three days, Roosevelt/Central Ave station, 3rd St/Jefferson, and Sycamore/Main St stations have the same average highest temperature of 41°C, and this time Center/Main St and McClintock/Apache Blvd make it to the list as they have the same three-day average. Here again, we notice that the highest measured temperatures are found mostly in stations in Phoenix and Mesa.

However, during the evening shift, we see a new station appearing on the list of average highest temperature and that is the University/Rural station alongside Roosevelt/Central Ave station and Gilbert Rd/Main St. stations. We also notice that some stations even at the late evening shift, from 8-10 pm, still have high temperatures and this includes University/Rural station, Gilbert Rd/Main St., 44th St/Washington which can be an indicator of urban heat effects on the surrounding of these stations. Overall, the Roosevelt/Central Ave station appears to have the worst cooling conditions as it appears to have the highest average temperatures during all three timings of the day. Meanwhile, Mill Ave station has the lowest average temperatures for all three timings of the day.

Table 2

Measured and recorded temperatures - Valley Metro Light Rail

Station	Friday, August 27, 2021			Sunday, August 29, 2021			Saturday, September 11, 2021		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Exact time of measurement			Exact time of measurement			Exact time of measurement		
7th Ave/Camelback	6:45	2:30	4:15	12:20	2:45	9:00	9:50	2:00	7:05
Roosevelt/Central Ave	7:00	2:15	4:30	12:05	3:05	8:40	10:10	1:45	6:50
3rd St/Jefferson	7:15	2:00	4:45	11:50	3:20	8:30	9:35	1:35	6:40
44th St/Washington	7:30	1:40	5:00	11:30	3:40	8:20	9:20	1:20	6:25
Mill Ave/3rd St	7:45	1:20	5:25	11:15	3:55	8:10	9:10	1:10	6:10
University Dr/Rural	8:00	1:00	7:05	10:55	4:10	8:00	9:00	1:00	6:00
McIntock/Apache Blvd	8:20	12:45	6:55	10:45	4:20	7:50	8:50	12:45	5:50
Sycamore/Main St.	8:35	12:30	6:40	10:25	4:30	7:40	8:40	12:35	5:40
Center/Main St	8:45	12:10	6:25	10:10	4:40	7:25	8:25	12:20	5:25
Gilbert Road/Main St	9:00	11:55	6:10	9:55	4:55	7:10	8:10	12:00	5:10
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Measured Temperature (°C)			Measured Temperature (°C)			Measured Temperature (°C)		
7th Ave/Camelback	32	42	44	40	42	32	32	37	33
Roosevelt/Central Ave	33	46	46	41	39	35	34	37	33
3rd St/Jefferson	32	43	42	42	40	32	33	39	32
44th St/Washington	32	43	38	40	42	38	34	36	33
Mill Ave/3rd St	33	38	38	39	39	35	32	35	32
University Dr/Rural	34	40	42	39	42	37	33	38	34
McIntock/Apache Blvd	35	43	35	38	44	33	32	37	35
Sycamore/Main St.	35	43	38	41	42	34	32	38	36
Center/Main St	36	42	40	38	43	36	31	38	36
Gilbert Road/Main St	37	39	39	34	40	37	31	37	39
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)		
7th Ave/Camelback	31	44	44	39	42	37	34	40	38
Roosevelt/Central Ave	31	44	44	39	42	37	35	40	39
3rd St/Jefferson	31	44	43	39	42	37	34	39	40
44th St/Washington	32	43	44	38	41	39	33	38	40
Mill Ave/3rd St	32	43	43	38	42	38	32	38	40
University Dr/Rural	32	43	42	38	42	38	32	38	41
McIntock/Apache Blvd	33	42	41	38	42	38	32	38	41
Sycamore/Main St.	34	42	42	37	42	39	32	38	41
Center/Main St	34	41	42	36	42	39	31	38	41
Gilbert Road/Main St	34	42	42	36	42	39	30	38	42

Humidity Levels

Observing humidity levels around Dubai Metro Stations as depicted in Table 3 shows how humidity levels during the first half of August average between 50-70% and is the highest as it gets late in the evening. Dubai Mall, Expo 2020, and Burjuman stations have the highest average humidity levels during the morning shift, all had average humidity levels slightly above the 60% mark. the Dubai Mall station is one of the closest stations to the Arabian Gulf while Burjuman station is the closest to Dubai Creek and both have huge open areas where they are directly exposed to the waters. Meanwhile, Expo 2020 station is far away from the Gulf but still recorded a high humidity level in the morning; however, this station is amongst group 2 stations that have been only visited one out of three scheduled times. Therefore, the results are not reflective of the three-day average and only represent one-day measurements.

Moreover, the three-day average humidity levels drop during the afternoon shift. Burjuman and Dubai Mall stations remain amongst the higher humidity stations, but Stadium and Baniyas Square surpass them during this shift with higher average humidity levels reaching a maximum of 60% while the remaining stations had humidity levels as low as 35%. Those stations with the highest humidity levels all fall in districts 5 and 6 east of Dubai Creek.

As mentioned earlier, humidity levels are the highest later in the evening, especially during the weekend night shift, 10-11:59 pm, as they have a minimum humidity level of 80% which is significantly high compared to the other timings. Dubai Mall and Al Rigga station are amongst the top highest average humidity level with 69% and 70% respectively during the evening shift. However, two other stations surpass them during this shift, which is Ibn Battuta at 72% and Burjuman at 75% making it the highest average of all stations and all times. Overall, two metro stations stand out in the humidity level measurements, the Dubai Mall and Burjuman stations, as they have the highest average humidity levels during all measurement shifts. Meanwhile, Al Rigga station has the lowest average humidity levels for all three days and shifts.

Table 3

Measured and recorded humidity levels - Dubai Metro

Station	Tuesday, August 3, 2021 and Tuesday, August 10, 2021			Friday, August 6, 2021			Monday, August 9, 2021		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Exact time of measurement			Exact time of measurement			Exact time of measurement		
Stadium	7:00	1:45	5:00	10:20	4:10	10:15	8:50	3:25	6:30
Baniyas Square	7:42	1:00	5:37	11:00	4:45	10:55	8:10	2:35	5:40
Burjuman	8:12	12:31	5:54	11:15	5:10	11:10	7:50	2:10	5:20
Al Rigga	7:26	1:15	5:22	10:40	4:20	10:40	8:30	3:00	5:55
Dubai Mall	8:45	12:00	6:30	11:45	5:35	11:30	7:25	1:35	5:00
DMCC	9:20	1:55	5:55 -	-	-	-	-	-	-
Ibn Battuta	9:00	1:20	5:20 -	-	-	-	-	-	-
Jebel Ali	8:45	1:35	5:40 -	-	-	-	-	-	-
Dubai Investment Park	7:45	12:15	4:30 -	-	-	-	-	-	-
Expo 2020	8:15	12:35	4:50 -	-	-	-	-	-	-
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Measured Humidity (%)			Measured Humidity (%)			Measured Humidity (%)		
Stadium	78	64	52	32	66	85	57	50	65
Baniyas Square	57	52	68	52	71	82	54	55	56
Burjuman	50	53	72	72	72	92	63	48	60
Al Rigga	64	30	52	60	51	83	43	60	76
Dubai Mall	52	55	70	70	76	91	60	40	47
DMCC	54	35	72 -	-	-	-	-	-	-
Ibn Battuta	52	36	66 -	-	-	-	-	-	-
Jebel Ali	51	40	64 -	-	-	-	-	-	-
Dubai Investment Park	57	40	52 -	-	-	-	-	-	-
Expo 2020	64	42	46 -	-	-	-	-	-	-
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)		
Stadium	66	45	64	48	50	60	36	39	26
Baniyas Square	64	49	61	48	53	64	43	28	29
Burjuman	61	45	60	44	54	63	46	28	30
Al Rigga	62	47	59	50	51	63	40	26	29
Dubai Mall	67	38	63	44	54	63	63	27	34
DMCC	30	28	40 -	-	-	-	-	-	-
Ibn Battuta	30	25	37 -	-	-	-	-	-	-
Jebel Ali	32	26	39 -	-	-	-	-	-	-
Dubai Investment Park	47	19	30 -	-	-	-	-	-	-
Expo 2020	31	19	28 -	-	-	-	-	-	-

When it comes to Phoenix Metro, we notice a significant decrease in humidity levels compared to the city of Dubai as shown in table 4. The highest recorded humidity level here is 50% during the month of August. Similar to humidity levels around the Dubai Metro stations the humidity levels around Valley Metro Rail are the lowest during the afternoon. However, humidity levels in Phoenix Metro are higher in the morning shift than they are in the evening shift which is opposite to the situation in the city of Dubai. During the morning shift, 44th S/Washington and Gilbert/Main St at 48% and 50% respectively, have the highest average humidity levels amongst the selection of ten stations in this study. Gilbert/Main St. is one of the three stations alongside Sycamore/Main St. and Mill Ave stations with a 40% average humidity level during the afternoon shift. Lastly, during the evening shift, University Rd/Rural and 3rd St/Jefferson have the highest average humidity levels at 44% and 43% respectively. Those two stations are also amongst the highest average temperatures during the night shift as shown in table 2 above. Overall, Gilbert is the only one that appears twice with the highest average humidity levels. Meanwhile, McClintock/Apache Blvd. and 7th Ave/Camelback have the lowest average humidity levels at an average of 40% for all three days and shifts.

Table 4

Measured and recorded humidity levels - Valley Metro Light Rail

Station	Friday, August 27, 2021			Sunday, August 29, 2021			Saturday, September 11, 2021		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Exact time of measurement			Exact time of measurement			Exact time of measurement		
7th Ave/Camelback	6:45	2:30	4:15	12:20	2:45		9:00	2:00	7:05
Roosevelt/Central Ave	7:00	2:15	4:30	12:05	3:05		8:40	10:10	1:45
3rd St/Jefferson	7:15	2:00	4:45	11:50	3:20		8:30	9:35	1:35
44th St/Washington	7:30	1:40	5:00	11:30	3:40		8:20	9:20	1:20
Mill Ave/3rd St	7:45	1:20	5:25	11:15	3:55		8:10	9:10	1:10
University Dr/Rural	8:00	1:00	7:05	10:55	4:10		8:00	9:00	1:00
McIntock/Apache Blvd	8:20	12:45	6:55	10:45	4:20		7:50	8:50	12:45
Sycamore/Main St.	8:35	12:30	6:40	10:25	4:30		7:40	8:40	12:35
Center/Main St	8:45	12:10	6:25	10:10	4:40		7:25	8:25	12:20
Gilbert Road/Main St	9:00	11:55	6:10	9:55	4:55		7:10	8:10	12:00
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Measured Humidity (%)			Measured Humidity (%)			Measured Humidity (%)		
7th Ave/Camelback	38	22	20	38	35		51	55	48
Roosevelt/Central Ave	37	23	22	39	37		51	52	51
3rd St/Jefferson	40	24	23	42	38		52	56	48
44th St/Washington	41	25	28	45	35		48	59	53
Mill Ave/3rd St	38	27	27	40	40		48	55	52
University Dr/Rural	42	28	36	39	36		47	53	54
McIntock/Apache Blvd	38	23	31	38	35		46	54	51
Sycamore/Main St.	36	30	30	37	38		48	56	53
Center/Main St	40	26	28	38	36		48	59	52
Gilbert Road/Main St	36	28	30	48	38		47	67	53
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)		
7th Ave/Camelback	33	15	13	22	19		24	34	23
Roosevelt/Central Ave	32	15	13	22	18		22	33	23
3rd St/Jefferson	33	15	12	22	18		22	35	24
44th St/Washington	35	16	12	23	18		21	35	24
Mill Ave/3rd St	36	17	13	24	18		22	39	25
University Dr/Rural	38	17	15	25	17		23	39	25
McIntock/Apache Blvd	36	18	15	26	17		22	40	25
Sycamore/Main St.	34	19	14	27	17		21	40	25
Center/Main St	34	20	15	28	17		20	43	26
Gilbert Road/Main St	33	20	15	31	17		20	43	28

Pavement temperatures

The last measurement conducted at the transit station is measuring the temperature of the shaded and unshaded pavement that surrounds the transit stations. Making sure to measure the same spot every time and the same pavement material to have the best representation of temperature levels as they vary from shaded to unshaded pavement throughout the day. Since Dubai Metro stations are closed air-conditioned structures, we will be measuring the pavement temperatures in the surrounding areas of both transit systems even though Valley Metro Rail has open-air stations. Lastly, as shown in tables 5 and 6, for the night shift during the weekend measurement times are after sunset; therefore, only one pavement measurement is taken, and the other slots are left blank.

Looking at the measurements of pavement temperatures around Dubai Metro stations, shown in table 5, we notice that the average temperatures are the highest during the afternoon shift. The degree Celsius difference between the average pavement temperature of shaded and unshaded pavements is 22°C for the afternoon shift and the difference decrease to 13°C at the

evening shift and 7°C at the morning shift. These findings are reasonable given that pavement is mostly exposed to direct sunlight during the afternoon where it is also the hottest temperature. That heat is absorbed by the pavement and is not released quickly which is evident as the pavement temperatures are higher in the evening and later in the night than they are early in the morning.

When it comes to stations with the highest average pavement temperatures, looking closely at group 1 stations, we notice that Burjuman, Al Rigga, and Dubai Mall stations have the highest average unshaded pavement temperatures during the morning shift. During the afternoon shift, Stadium and Al Rigga station have the highest average values. The same two stations, Stadium and Al Rigga continue to have the highest average values during the evening shift. Therefore, the Al Rigga station can be considered to have the worst pavement cooling elements as it has the highest average unshaded pavement temperatures for all times of the day. Meanwhile, Baniyas Square has the lowest three shifts average at 51°C, this is the average of all three days and three shifts for the unshaded pavements temperatures.

Meanwhile, when looking at the shaded pavement temperatures we see some changes in the trends. During the morning shift, the Al Rigga station leads with the highest average shaded pavement temperature at 38°C. However, during the afternoon shift, we see that three stations have the highest value at 44°C, which are Al Rigga, Burjuman, and Baniyas Square stations. During the evening shift, we no longer see Al Rigga in the top list, its Burjuman and Stadium stations with the highest values at 41°C for shaded pavement temperatures. Meanwhile, the Dubai Mall station has the lowest three shifts average at 37°C, this is the average of all three days and three shifts for the shaded pavements temperatures.

These results help us understand how the public realm and cooling techniques can have an impact in reducing pavement temperatures for shaded and unshaded temperatures. This can also be measured by taking a further step of calculating the difference between the average unshaded pavement temperature and the average shaded pavement temperature around a certain station at a specific shift. As the difference grows, it can be an indicator of how effective the shading elements are around the station. For instance, the Al Rigga station which usually has the highest values for pavement temperature also has the highest difference between unshaded and shaded

pavement temperatures; therefore, we recommend that this station can have more of these shading elements in exposed areas and those same elements can be implemented in other stations.

Table 5

Difference in Pavement temperatures - Dubai Metro

Station	Tuesday, August 3, 2021 and Tuesday, August 10, 2021			Friday, August 6, 2021			Monday, August 9, 2021		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Exact time of measurement			Exact time of measurement			Exact time of measurement		
Stadium	7:00	1:45	5:00	10:20	4:10	10:15	8:50	3:25	6:30
Baniyas Square	7:42	1:00	5:37	11:00	4:45	10:55	8:10	2:35	5:40
Burjuman	8:12	12:31	5:54	11:15	5:10	11:10	7:50	2:10	5:20
Al Rigga	7:26	1:15	5:22	10:40	4:20	10:40	8:30	3:00	5:55
Dubai Mall	8:45	12:00	6:30	11:45	5:35	11:30	7:25	1:35	5:00
DMCC	9:20	1:55	5:55 -	-	-	-	-	-	-
Ibn Battuta	9:00	1:20	5:20 -	-	-	-	-	-	-
Jebel Ali	8:45	1:35	5:40 -	-	-	-	-	-	-
Dubai Investment Park	7:45	12:15	4:30 -	-	-	-	-	-	-
Expo 2020	8:15	12:35	4:50 -	-	-	-	-	-	-
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Difference Between Unshaded and Shaded Pavement Temperatures								
Stadium	0.80	20.50	17.00	12.50	25.20	-	7.30	21.50	11.30
Baniyas Square	6.00	30.40	10.00	8.30	7.10	-	1.80	21.10	7.50
Burjuman	2.60	25.10	7.30	23.80	8.10	-	1.80	22.40	7.70
Al Rigga	0.90	20.00	18.00	18.60	22.20	-	8.00	28.80	11.80
Dubai Mall	11.40	28.90	4.70	20.20	12.10	-	2.90	30.00	6.20
DMCC	15.40	21.90	6.50 -	-	-	-	-	-	-
Ibn Battuta	4.00	24.00	17.30 -	-	-	-	-	-	-
Jebel Ali	4.10	21.70	15.90 -	-	-	-	-	-	-
Dubai Investment Park	3.50	22.10	13.30 -	-	-	-	-	-	-
Expo 2020	5.60	22.70	14.50 -	-	-	-	-	-	-

As mentioned earlier, Valley Metro Rail stations are not closed like Dubai Metro; therefore, for consistency, we have measured pavement around the stations rather than on the waiting areas of the stations. After all, we are looking for how the public realm can help reduce the heat experienced by transit riders using these stations and are coming from the surrounding areas. At the first glimpse at table 6, we notice how stations in the city of Phoenix have the highest unshaded pavement temperatures. Similar to Dubai Metro stations we observe that pavement temperatures are the highest during the afternoon, they slightly decrease later in the evening and reach their minimum values in the morning. The highest recorded temperature of an unshaded pavement is 73.8°C at 3rd St/Jefferson station in Phoenix, this is the highest pavement temperature recorded in both transit systems.

During the morning shift, the stations in Phoenix have the highest average unshaded and shaded temperatures at 52°C and 37°C respectively. There is a slight change during the afternoon, as Mill Ave station joins Phoenix’s stations on top of the list for highest unshaded temperatures and we see that stations in Tempe and Mesa have the highest average shaded pavement temperatures during the afternoon. However, as it gets later in the day, the Phoenix stations are back on top of the list with the highest average shaded and unshaded pavement temperatures at 47°C and 49°C

respectively. We can conclude that based on the three-day/three shifts average, 3rd st/Jefferson and Roosevelt have the highest average temperatures for shaded and unshaded pavement. This is also a reflection of the air temperatures mentioned above, both stations had the highest average temperatures as well. Meanwhile, Mill Ave and 7th Ave/Camelback stations had the lowest temperatures for shaded pavement at 37°C average value and Center/Main St had the lowest temperatures for unshaded pavement at a 50°C average value. Lastly, Mill Ave has the best performance when it comes to calculating the difference between shaded and unshaded pavement temperatures, an indicator that the public realm elements are effective here in reducing temperatures.

Table 6

Difference in Pavement temperatures - Valley Metro Light Rail

Station	Friday, August 27, 2021			Sunday, August 29, 2021			Saturday, September 11, 2021		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Exact time of measurement			Exact time of measurement			Exact time of measurement		
7th Ave/Camelback	6:45	2:30	4:15	12:20	2:45	9:00	9:50	2:00	7:05
Roosevelt/Central Ave	7:00	2:15	4:30	12:05	3:05	8:40	10:10	1:45	6:50
3rd St/Jefferson	7:15	2:00	4:45	11:50	3:20	8:30	9:35	1:35	6:40
44th St/Washington	7:30	1:40	5:00	11:30	3:40	8:20	9:20	1:20	6:25
Mill Ave/3rd St	7:45	1:20	5:25	11:15	3:55	8:10	9:10	1:10	6:10
University Dr/Rural	8:00	1:00	7:05	10:55	4:10	8:00	9:00	1:00	6:00
McIntock/Apache Blvd	8:20	12:45	6:55	10:45	4:20	7:50	8:50	12:45	5:50
Sycamore/Main St.	8:35	12:30	6:40	10:25	4:30	7:40	8:40	12:35	5:40
Center/Main St	8:45	12:10	6:25	10:10	4:40	7:25	8:25	12:20	5:25
Gilbert Road/Main St	9:00	11:55	6:10	9:55	4:55	7:10	8:10	12:00	5:10
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
	Difference Between Unshaded and Shaded Pavement Temperatures								
7th Ave/Camelback	6	22	24	23	23	--	12	14	2
Roosevelt/Central Ave	6	25	10	22	22	--	19	22	2
3rd St/Jefferson	4	40	14	27	26	--	10	22	4
44th St/Washington	6	31	15	25	25	--	10	21	8
Mill Ave/3rd St	5	34	20	19	29	--	11	23	12
University Dr/Rural	5	26	11	18	20	--	8	17	11
McIntock/Apache Blvd	4	22	3	17	17	--	5	14	10
Sycamore/Main St.	8	24	10	19	16	--	6	19	7
Center/Main St	9	21	4	20	25	--	8	25	16
Gilbert Road/Main St	9	20	12	19	15	--	5	16	6

Experiences and Observations

This section will focus on certain observations that stand out in the observational notes found in appendices C and D below and will showcase each station’s satellite imagery with a buffer zone of 600 m radius. Therefore, we will cover the most important observations noted for each station in both transit systems. We will be sharing our experiences and observations from around all the stations. Further distinctive findings and observations will be mentioned in the following discussion section, where we will be comparing stations and discussing future recommendations.

Dubai Metro Observations (A mix of underground and overground stations)

Stadium Station (Overground)

The stadium station acts as a transit center, it connects the metro with many other bus networks as there are numerous bus stops around it. Its main goal is to provide access to the surrounding neighborhoods, Rashid Stadium, and the huge hypermarket store which are all shown in the figure below. The area to the east of the stadium has a mixed-use zoning ordinance, while the northwest corner is Dubai's police headquarters and to the southwest, we have single-family homes. An air-conditioned pedestrian bridge is available for riders to cross the street. Visiting the station regularly, one would notice that most riders are coming from the bus stops under the metro station or to its east, transiting from one public transit system to another. The huge parking lot and the low-rise stadium deny riders any shade as they head towards the station. The other bus stops are either shaded by the metro station or have a small waiting area which is not always enough for the number of people waiting under the sun as there are not enough shading elements around the station. Temperatures are usually hot, especially under the sun, and the humidity level is low, however, on certain days humidity levels are unbearable. The experienced temperature under the shade is significantly better than when exposed to direct sunlight. Overall, the station needs more shading elements and greenery around it to improve the experienced temperature.



Figure 6 - Stadium Station (Source: Google Earth)

Al Rigga Station (Underground)

Al Rigga station is an underground station with two overground entrances one at each side of Al Rigga street. There are bus stops located close to the station on street level allowing pedestrians to reach them quickly, but those stops do not have any shading structures and rely completely on the public realm around them. Al Rigga station is surrounded with low rise mixed-use buildings creating a highly densely populated area as seen in the figure below. These are the older parts of Dubai where streets are narrower and buildings are closer to each other, that is why the stations had to be built underground as there is not enough space to have them overground. Rider waiting for the bus stops have no proper shading and are exposed to direct sunlight during the afternoon due to being surrounded by low-rise buildings that are not providing shade and because there is no trees or other shading elements in that area. However, there is plenty of shade in other parts of the street as there are plenty of trees. There is plenty of primary and secondary seating near the station. The overall experienced temperature is usually hot around the station and that could be from the urban heat effects in the area.



Figure 7 - Al Rigga Station (Source: Google Earth)

Baniyas Station (Underground)

Similar to Al Rigga station, Baniyas station is an underground station in the middle of the older parts of Dubai. It is situated under the square which contains a park with plenty of trees and seating. It is surrounded by high-rise mixed-use buildings that are very close to each other and are separated by narrow alleyways that provide passive cooling for pedestrians passing through or by them. The area is amongst the highest densely populated areas in Dubai. Temperatures are significantly high and humidity reaches high levels on certain days due to the proximity to Dubai Creek and the Arabian Gulf. However, the narrow alleyways and streets help create passive cooling systems in the area, improving the experienced temperature for people passing through or by them. The closer the buildings are to each other the more shading they provide throughout the day. This area of Dubai is one of the most pedestrian-oriented parts of the city. These narrow alleyways and streets are one of the best practices found in the city of Dubai as they do not require any additional elements to be added to provide shade or cool down the weather.

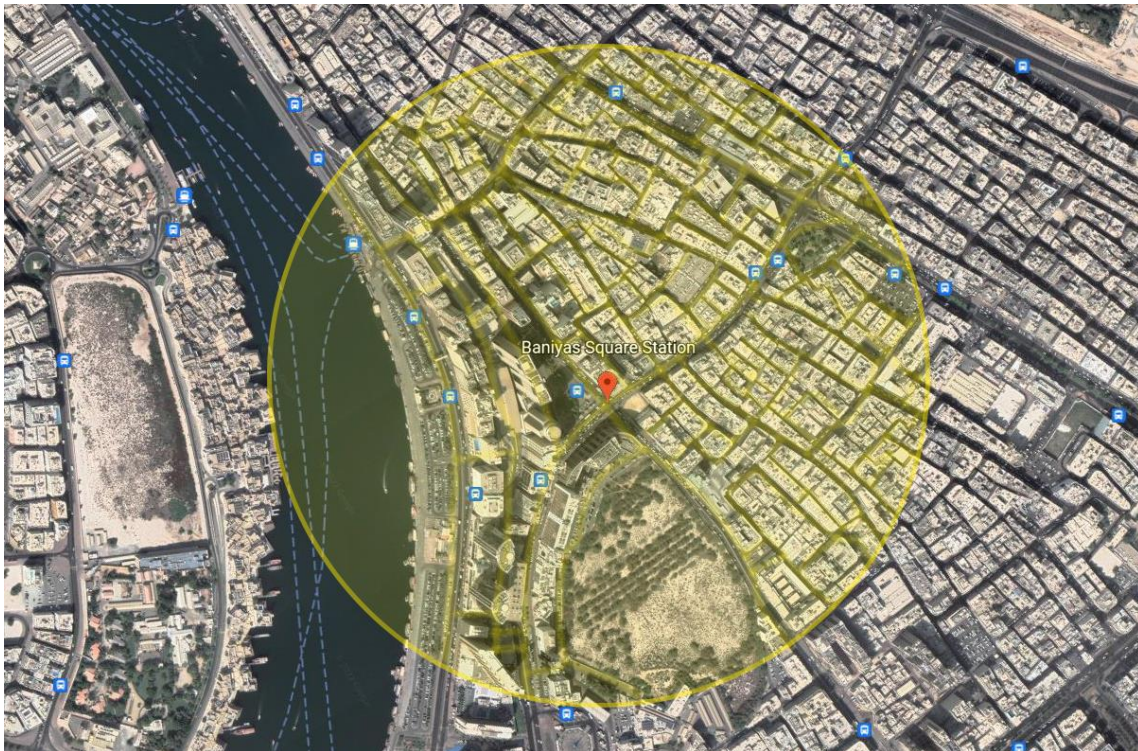


Figure 8 - Baniyas station (Source: Google Earth)

Burjuman Station (Underground)

The Burjuman station even though is in the older parts of Dubai, west of the creek, is not as cool as the stations mentioned earlier, Al Rigga and Baniyas, from east of the creek. Burjuman station is under the intersection shown in the figure below and has four entrances from each corner of the intersection. The densely populated area has a huge boulevard cut through it, a very wide intersection exposing the area to direct sunlight, mixed-use low-rise buildings providing shade occasionally and huge buildings, such as Burjuman shopping mall on the northwest corner of the intersection, are blocking any airflow created by passive cooling systems of the narrow alleyways and streets behind it. Therefore, the experienced temperature here is hotter than the previous stations and after five minutes it gets uncomfortable to walk around the station or wait for a bus. Bus stops are spread out farther away from the metro station which might be due to how busy the intersection gets during peak hours, forcing riders to walk for long distances in the scorching heat and often high humidity levels.

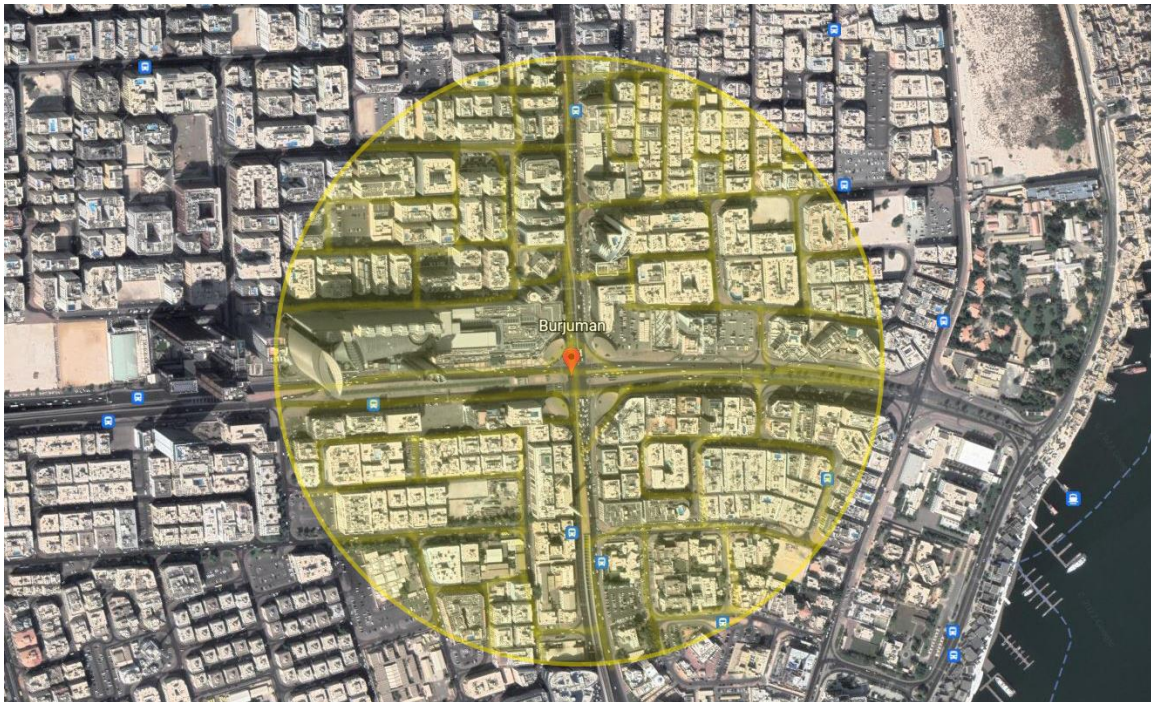


Figure 9 - Burjuman station (Source: Google Earth)

Dubai Mall Station (Overground)

This station's surrounding area is one of the least pedestrian-oriented areas in the city of Dubai as seen from the gigantic intersection, wide highway, and spread-out buildings seen in the figure below. The main purpose of this station is to connect Dubai Metro riders with the new downtown area that is home to the Dubai Mall and Burj Khalifa. Metro riders heading to these attractions have a dedicated 820 m long pedestrian bridge connecting them directly to the Dubai Mall; therefore, avoiding being exposed to the extreme heat and humidity outside the station. There is also another pedestrian bridge for riders to cross the Sheikh Zayed Road to go to the other side but is rarely used in this highly vehicle-oriented part of the city. The temperature outside the station is hot and humid, the unshaded pavement temperatures here are one of the highest recorded temperatures. Buildings on the downtown side are high-rise buildings that are spread out from each other as the area is fairly new and not yet fully developed; therefore, there is no ample shading provided for pedestrians walking in that area. On the other side of the Sheikh Zayed Road are low-rise buildings to the left of the gigantic intersection and high-rise buildings to the right as seen in the figure below, meanwhile the areas behind them are a mixture of mixed-use low-rise developments and single-family homes. The station is doing a good job serving the riders heading to the mall by keeping them cool but has not helped improve the public realm to become more pedestrian-friendly.

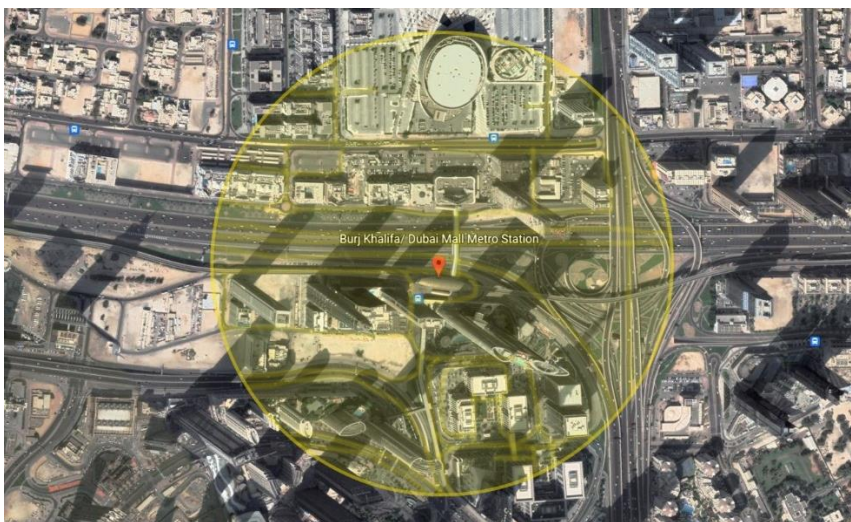


Figure 10 - Dubai Mall station (Source: Google Earth)

DMCC Station (Overground)

From this station onward we enter the second group of stations, our experiences here at these five stations are limited compared to the previous five stations due to unforeseen circumstances. However, experiencing these stations for three shifts in a single day allows us to have better observations than what we can analyze from the limited quantitative data collected. The DMCC station is 21 km west of the Dubai Mall station, on the same wide Sheikh Zayed Road with its gigantic intersections. This station is serving mainly two high-rise mixed-use developments which are Dubai Marina to the north and Jumeirah Lake Towers to the south as seen in the figure below. We have learned from the Dubai Mall station that skyscrapers are not good for shading if they are separated and spread out far from each other. However, these two areas around DMCC are dense and buildings are close to each other causing some passive cooling in certain areas. This station is considered a transit center as it connects Dubai Metro to Dubai Tram which serves Dubai Marina and connects to the Palm Monorail. There is also a pedestrian bridge provided for pedestrians to cross Sheikh Zayed Road easily in air-conditioned hallways. The public realm in the surrounding area is designed to make it easy for pedestrians to get around but is not very successful in providing them with a comfortable experience with regards to the experienced temperature. Even though it is mostly hot around the station but the narrow alleyways between buildings cool you off as you pass by or through them.

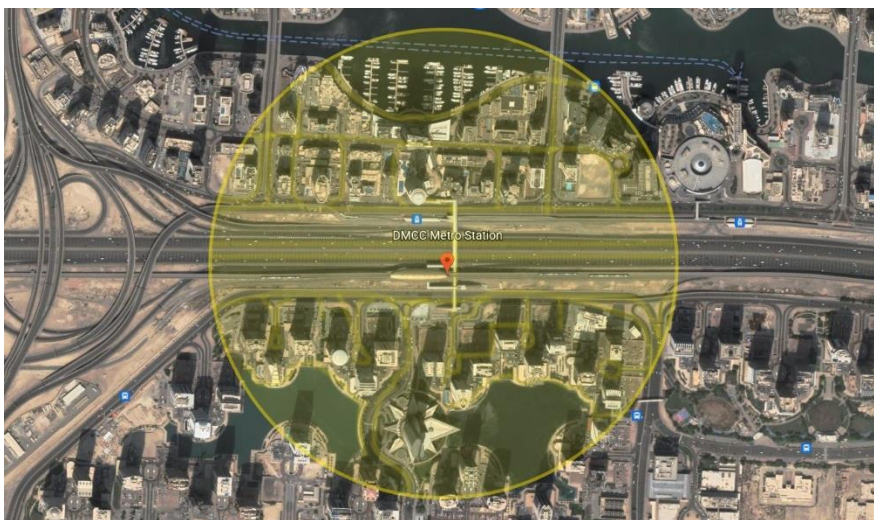


Figure 11 - DMCC station (Source: Google Earth)

Ibn Battuta Station (Overground)

As we head out from the urban areas of the city center, we start seeing a trend of stations that are developed for the sole purpose of serving one or a maximum of two types of riders. Here at Ibn Battuta's station, we have riders who will be heading to the Ibn Battuta Mall through the pedestrian bridge and the other riders will be traveling to nearby locations who will rely on the bus stops and taxi stops available outside of the metro station. Nearby destinations include a couple of hotels and plenty of residential communities south of the mall. The experienced temperature here is mostly hot and slightly humid. Bus stops are shaded and there is plenty of primary seating for riders waiting at this transit center. However, during the afternoon it is extremely hot, and the heading elements provided are inadequate. The surrounding area could make use of more vegetation to cool down the weather and trees to provide ample shading throughout the day.



Figure 12 - Ibn Battuta station (Source: Google Earth)

Jabal Ali Station (Overground)

This is the biggest park-and-ride metro station out of the three currently available with 3000 parking spaces. This is also a transit station, it is part of the original Red Line and a year ago became the starting point for Route 2020. A new station has been added to host the new line heading to Expo 2020 site. This station was built for the sole purpose of being a park-and-ride station serving the people coming from the capital city of Abu Dhabi who want to avoid paying any tolls or waste time looking for a parking spot in the busy areas of the city of Dubai. This station recently became a transit center for riders using the newly launched route. It is hot and humid throughout the day but the riders do not have to deal with the surrounding built environment as all three buildings are connected together with air conditioning. There are also shaded bus stops available between the metro station and the parking building, it is shaded most of the time for riders waiting for their shuttle buses.



Figure 13 - Jabal Ali station (Source: Google Earth)

Dubai Investment Park Station (Underground)

Dubai Investment Park is what they call a city within a city, it consists of mixed-use zoning ordinances including industrial, recreational, and most importantly residential developments. All these three uses are depicted in the image below, as you can see the single-family homes in the center, surrounded by mixed-use development, and then we have industrial units on the outer skirts of the city. It is located near the Expo 2020 site, which in itself will become a 15-minute city after the end of the event in March 2022 as planned by the city of Dubai. Therefore, it was crucial to connect these smaller cities to the inner city and downtown areas by extending the metro. The station here is an underground station located to mainly serve the mixed-use development more than the single-family homes that will mostly be relying on their private vehicles. The surrounding area has not yet been fully developed, there are a lot of empty lots exposing pedestrians to direct sunlight and heat. The experienced temperature here is extremely hot but not as humid as it is in the inner parts of the city that are closer to the gulf. The surrounding public realm is more pedestrian-friendly compared to older metro stations. Bus stops are available right outside the overground entrances of the station, but waiting areas are not shaded which could turn into a terrible experience during the summer if there were any delays.



Figure 14 - Dubai Investment Park station (Source: Google Earth)

Expo 2020 Station (Overground)

This is the most promising station in the new route. It is an example of how efficient the transit system can be as it has shown during the last 6 months over the period of the Expo 2020 event. Even though there are plenty of parking spaces available around the city as seen in the figure below, the metro riders are provided with a more convenient and comfortable experience as they leave the metro station and directly enter the site without having to rely on a shuttle bus to carry them from the parking to the site entrances as car owners have to do. The station has a centralized location to what is going to become District 2020 after the completion of the event, you see the site to the south where many pavilions and buildings will become mixed-use developments, and to the north, we have apartment complexes, convention center, and facilities such as a hospital, shopping malls, and schools that will transform this event site into a smaller city of its own. Dubai is hoping that District 2020 will become a 15-minute city where everything is nearby and within walking distance. These visions are reflected in their implementation and design processes. As the site offers many of the urban design components missing from the nearby station at Dubai Investment Park. For most of the surrounding areas, there are plenty of natural and structural shading elements provided for pedestrians walking around and riders waiting at bus stops. However, some walkways here are too wide so many parts are not shaded during the afternoon. It also needs more trees that provide shading instead of beautifying the area. The experienced temperature is slightly better compared to other stations in group 2 of Dubai Metro stations, it is hot but not humid.

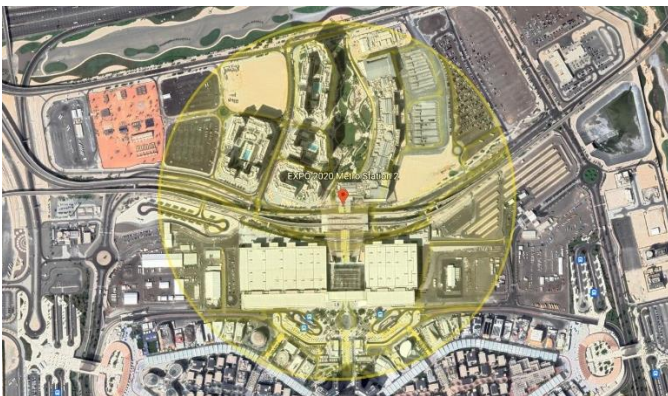


Figure 15 - Expo 2020 station (Source: Google Earth)

Valley Metro Rail Observations (All stations are street-level stations)

Gilbert Rd/Main St Station

This is one of the several park-and-ride Valley Metro stations, it is located at the end of the line in the city of Mesa. This transit center has a huge parking lot dedicated to transit riders, several buses shaded bus stops, a resting area serving transit riders, and of course rail station waiting area. Park-and-rides are supposed to attract commuters and riders heading to big events where parking is usually an issue. The station is surrounded by several industrial/commercial lots on Main St. and mostly single-family homes behind them with a few apartment complexes to the northeast corner of the station. The resting area beside the parking lot provides ample seating, but poor shading because of the design and height of structures. The same could be said for the waiting area on the station's platform, the side facing south is exposed to direct sunlight throughout the day. This issue of exposure on the south-facing waiting area is experienced on all stations moving east/westbound during the summer as the sun is always shining on their side of the platform and the shading structure is too high to provide shade for most of the day. When it comes to the experienced temperature, the overall experience is hotter compared to stations in downtown Mesa and downtown Tempe.

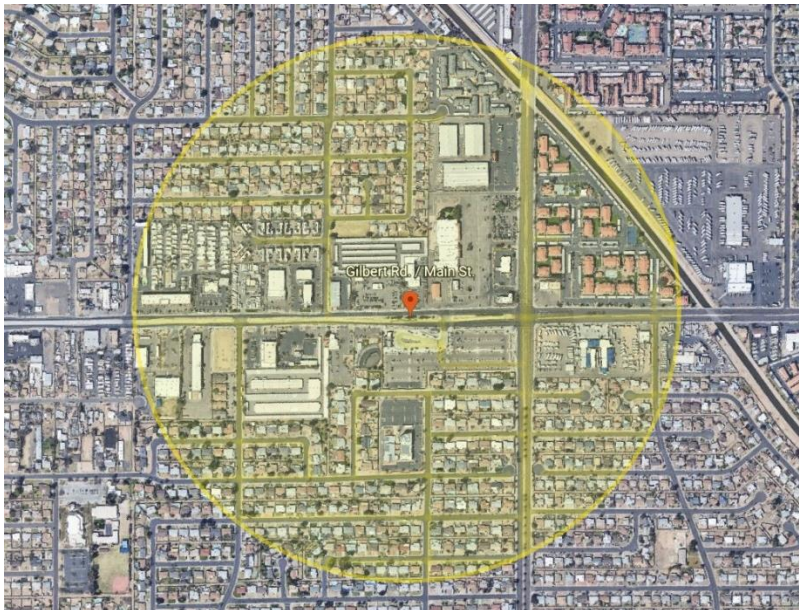


Figure 16 - Gilbert/Main St station (Source: Google Earth)

Center/Main St Station

This station serves the historic downtown of the city of Mesa. located in front of the Arts Center and surrounded mostly by mixed-use mostly low-rise buildings in the buffer zone of 600 m. Yet again, the south waiting area on the platform is exposed to direct sunlight for most of the day due to the height of the shading elements. This part of the city is pedestrian-oriented as street lanes are reduced to one for each direction to preserve the historic design of narrower streets and allow for wider sidewalks. The building on the southwest corner of the intersection has a great arcade feature that provides shading for pedestrians walking through it all day and is a good passive cooling technique. The experienced temperature is hot and gets uncomfortable when waiting for longer times no matter what time of the day it is due to urban heat effects. The lighting around the station is successful in providing a sense of comfort and safety. The public realm could benefit from having more trees to cool the weather and provide more shade.



Figure 17 - Center/Main St station (Source: Google Earth)

Sycamore/Main St Station

This is the second park-and-ride station in the city of Mesa, it is the last station before entering Tempe. Therefore, it is a transit center, has a dedicated parking lot and numerous shaded bus stops for riders to wait comfortably. The station is surrounded by huge and empty parking lots, commercial developments, business parks all on Main St and then plenty of single-family homes behind them to the north as seen in the figure below. The experienced temperature here is worse than the other two stations we visit in Mesa as it is hotter. The waiting areas could benefit from having better shading structures, either trees or functional shading structures. The area in general could benefit from reducing the number of parking spaces available in this block as they negatively impact the weather by worsening the urban heat effects.

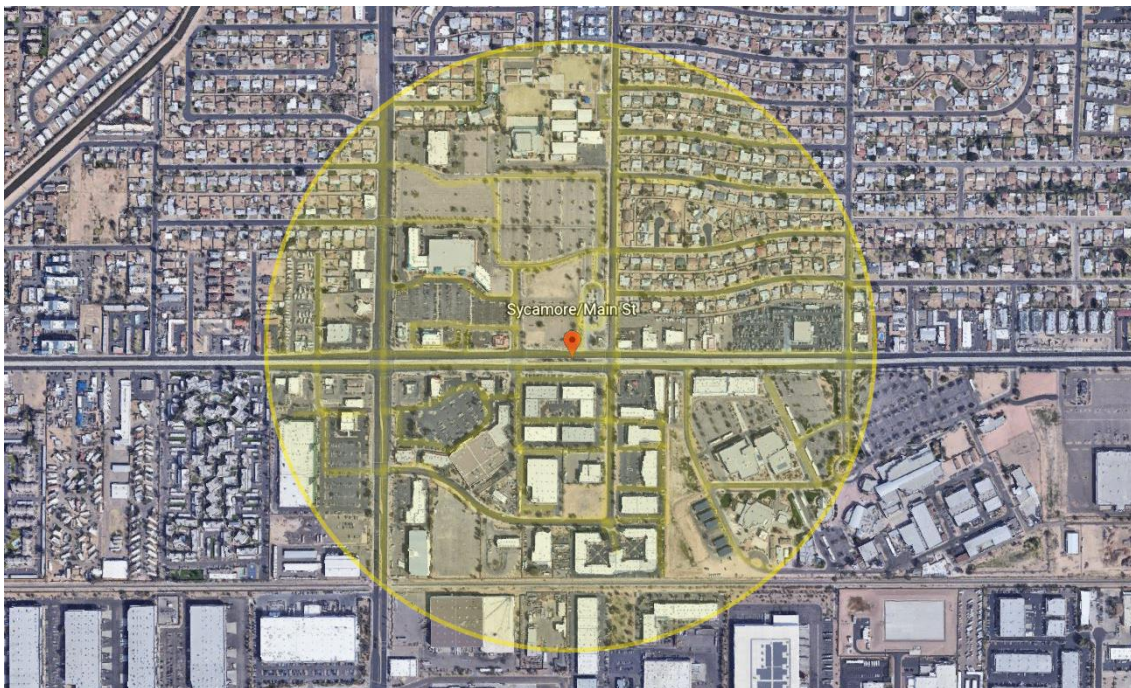


Figure 18 - Sycamore/Main St station (Source: Google Earth)

McClintock/Apache Blvd Station

The intersection at McClintock and Apache Blvd. is surrounded by mixed-use developments including commercial uses and apartment complexes. This station serves plenty of apartment complexes and single-family homes as can be seen in the figure below. The apartment complex on Apache Blvd does a good job in providing ample shading for pedestrians on the sidewalk throughout the day and for short time intervals, it provides shade for the station where the south waiting area would usually suffer from being exposed to direct sunlight. However, that is the only high-rise building while the majority of other buildings are low-rise consisting of one to two floors and unfortunately do not provide adequate shading. This is a busy intersection, and vehicles are often waiting at the intersection for long periods of time; therefore, more emissions are released to the surrounding area contributing to urban heat and impacting the experienced temperature of riders waiting at the station which is very close to the intersection. The temperature in the surrounding area remains high even after sunset. Overall, the experienced temperature here is better compared to the experiences at the park-and-ride stations in Mesa.



Figure 19 - McClintock/Apache Blvd station (Source: Google Earth)

University Dr/Rural Station

During the summer of 2021, the University Dr and Rural intersection was under renovation, and it was always congested during peak hours. As more vehicles are waiting at the intersection more emissions are being released into the air; therefore, influencing the experienced temperatures and increasing urban heat effects in the area. Even though the station is pushed back slightly away from the intersection you still feel the impacts of the congestion, especially after sunset. The surrounding public realm has plenty of trees and shaded areas around the station making it a more pleasant experience, we noticed that the shading structures are doing a better job at this station because of the positioning of the structures. However, that does not seem to help in decreasing the temperature as indicated in the measurements above which is experienced when waiting at the rail station and the bus stops. The temperature remains high even at later hours of the evening, making it hotter than other parts of the city.

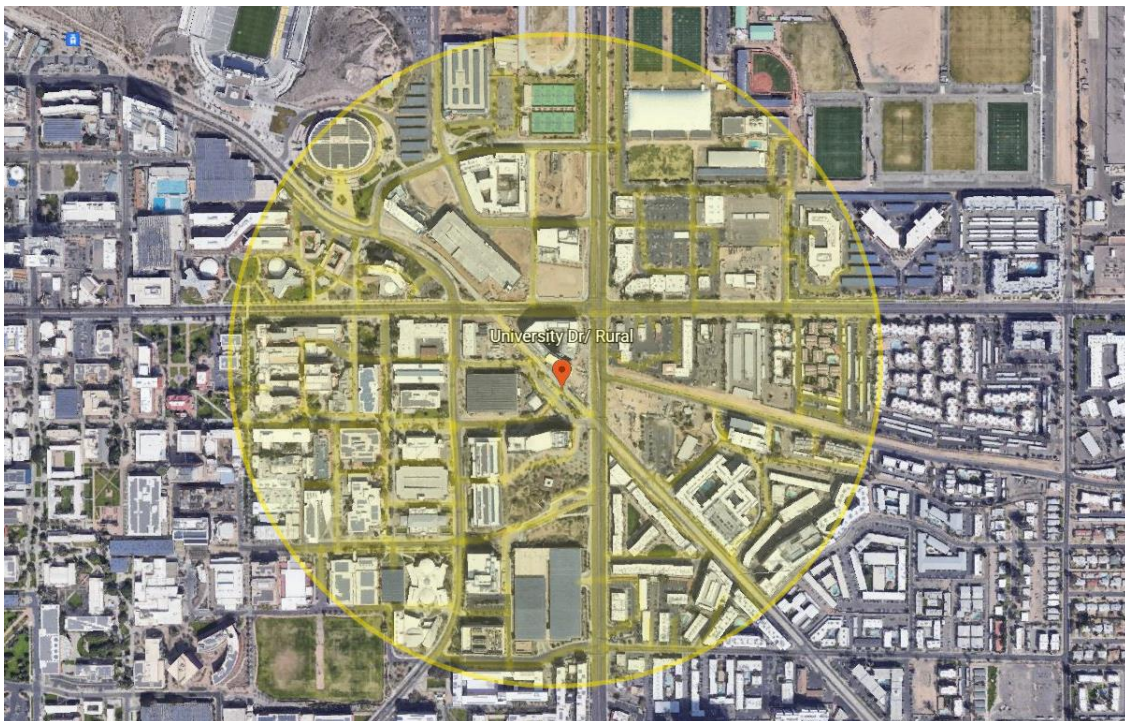


Figure 20 - University Rd/Rural station (Source: Google Earth)

Mill Ave/3rd St Station

This is one of the best-experienced rail stations in Tempe because of the tunnel-shaped shading structure on the platform. The metallic structure is infused with plants in the middle provides a safe haven during the hottest hours in the afternoon. It provides ample shading and has a cooling effect on riders waiting in these areas. Furthermore, Mill Ave is also different from other areas as the street has narrower streets as it has only one lane for each direction, there are plenty of trees alongside Mill Ave and 3rd St providing ample shading and cooling effects in addition to beautification of the area. We have noticed that this station is always at least 1°C cooler than the station at University/Rural and it is an indication that having different public realm elements can actually improve the experienced temperatures. Even though the summer heat is still felt around the station, it is by far the coolest experienced temperature amongst all rail stations in Phoenix Metro.



Figure 21 - Mill Ave/3rd St station (Source: Google Earth)

44th St/Washington Station

The main purpose of this station is to connect Phoenix Sky Harbor International Airport with the rest of Phoenix Metro. Travelers can use the PHX Sky Train to get to this rail station from the airport and finally walk through the pedestrian bridge leading to the rail station platform. There is a bus stop on the other side of the road that is well shaded. The rail station platform is also shaded with plenty of seating. Since the pedestrian bridge and PHX Sky train station are all closed air-conditioned structures this rail station could have also been closed to provide travelers with a better experience when arriving in Phoenix Metro. It would have been very helpful as this station has one of the worst experienced temperatures and it is not even surrounded by a supporting public realm to enhance riders' experiences.

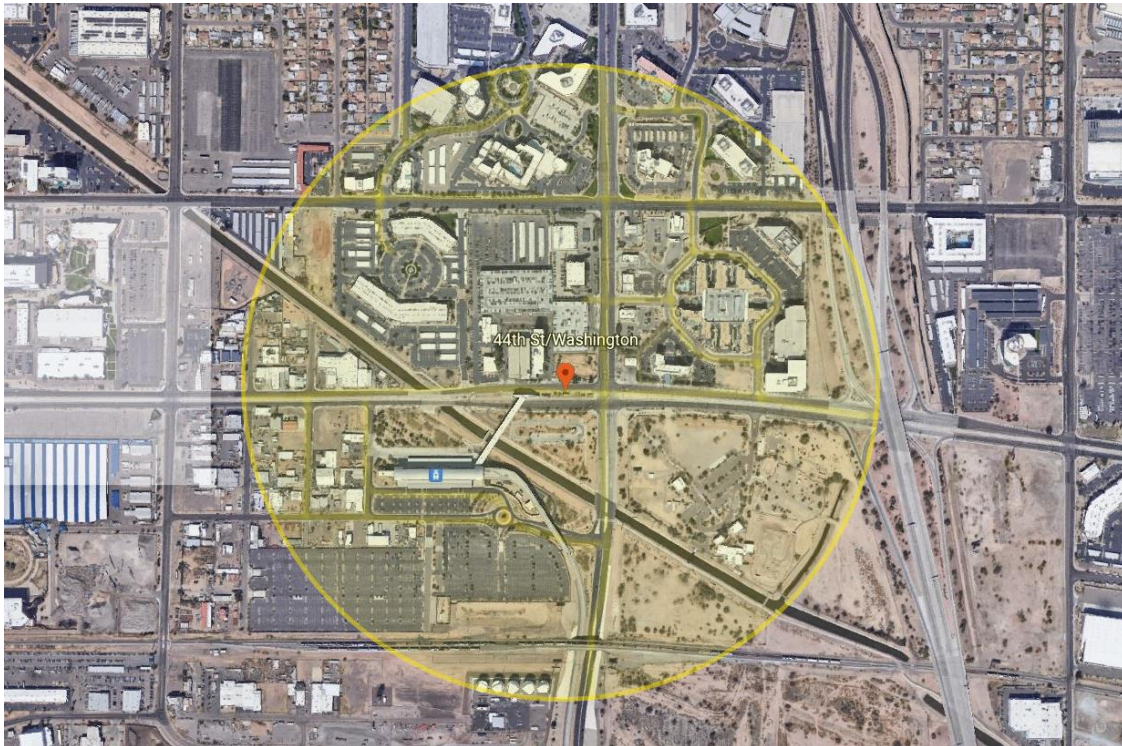


Figure 22 - 44th St/Washington station (Source: Google Earth)

3rd St/Jefferson Station

Similar to the previous station, the experienced temperature here is higher than stations in Tempe and Mesa. During the summer months, the rail station on Jefferson has the lowest ridership as there are no events occurring in the surrounding arenas or the convention center. It is rare to see someone waiting at the station. The building behind the station regularly provides shade for riders waiting on the platform, which is also applicable to the other massive buildings around the station that do a good job of providing shade at certain hours of the day. However, the experienced temperature remains hot and that could be due to urban heat effects that are the highest in Phoenix compared to other included parts in Tempe and Mesa. Heat differs significantly between shaded and unshaded areas, pavement temperatures have a 30°C between shaded and unshaded pavements at noon. The public realm lack any trees positioned in areas to provide ample shading for pedestrians who are currently exposed to direct sunlight in most parts of the station's surrounding area as seen in the figure below. Downtown Phoenix in general needs more vegetation and greenery.



Figure 23 - 3rd St/Jefferson station (Source: Google Earth)

Roosevelt/Central Ave Station

This station falls in Roosevelt row and plays a huge role in the revitalization project of this area. The station is now surrounded by numerous apartment buildings and complexes in an effort to revitalize downtown Phoenix by promoting mixed-use development. Unlike other stations, two streets unite at this intersection creating a bigger waiting area for the station, which means more ground exposed to direct sunlight and less shade from surrounding buildings. The shading elements used here are similar to all the other rail stations where structures are not providing adequate shading for riders waiting at this station and allowing them to experience the highest temperatures compared to all other stations included in this study. The revitalization project is helping improve the public realm around the station but the station itself also needs more improvement, The area in general lacks shading trees and greenery, they could transform the area to look more like Portland Parkway Park on Portland Street. It is not only about planting trees for shade but also about replacing the heat-absorbing pavements with more greenery or better pavement material to reduce urban heat effects in this area.

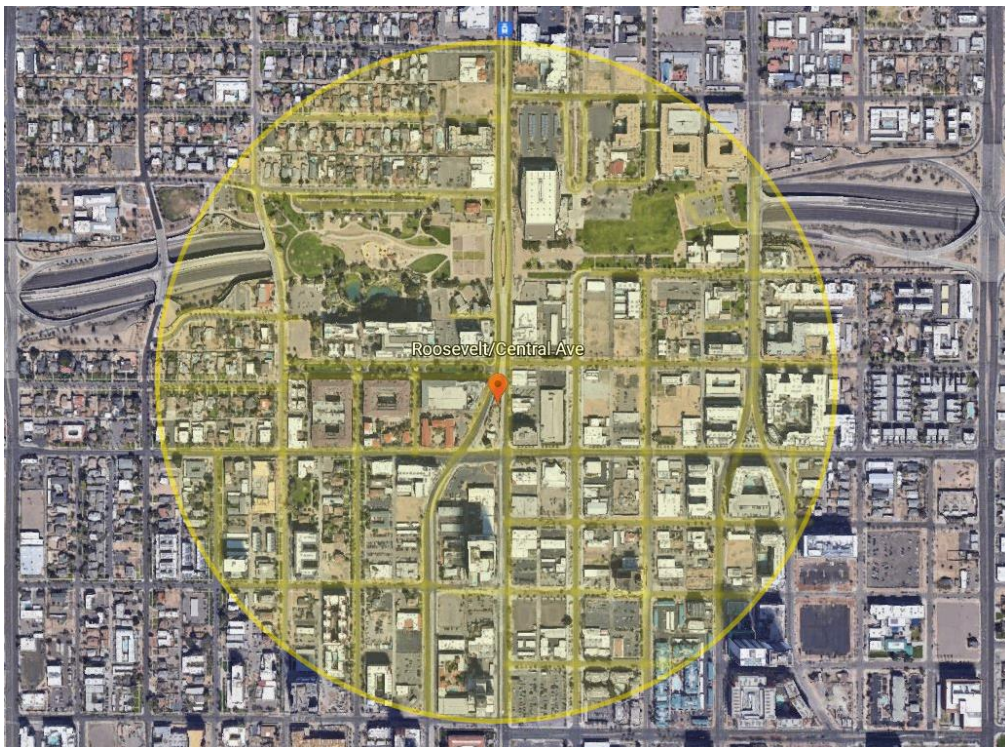


Figure 24 - Roosevelt/Central Ave station (Source: Google Earth)

7th Ave/Camelback Station

Last but not least, this Camelback station has the best-experienced temperature compared to the other three stations in Phoenix that are included in this study. The station's platform and both sidewalks are covered with trees providing more shade throughout the day and cooler temperatures compared to Roosevelt and Jefferson rail stations. The bus stop is also shaded but is exposed to direct sunlight for many hours during the day as it is facing the south, creating a similar situation to what is experienced when waiting on the southern side of the rail station platform. Even though this station is surrounded by huge parking lots it still had better-experienced temperatures than the previous two stations. Furthermore, this station is surrounded by commercial uses on Camelback and then mostly single-family homes around the area. Overall, the experienced temperature here is better than the other three stations in the city of Phoenix.



Figure 25 - 7th Ave/Camelback station (Source: Google Earth)

Discussion

Designing a new transit system in a desert city is challenging when there are not many similar experiences around you that you can learn from. Even the literature has been mainly focused on cities with different climate conditions, much cooler than the experienced temperatures in Dubai and Phoenix Metro. Although some design implementations might be useful to observe from these transit systems in cooler areas, a public transit system in a hot desert city should be designed specifically for the environment it is going to be serving in. Therefore, we studied the Dubai Metro and Valley Metro Rail to determine how successful these two systems have been in designing a transit system that is adaptable to the extremely hot summer months. There are several practices that can be recommended or avoided from our findings in the two case studies.

When designing the Dubai Metro, they ensured to have all transit stations closed and air-conditioned to make the rider's experience more comfortable. The air-conditioning system used is the DESMI district cooling system that has all piping and components fitted underground in a system that reduces energy consumption by up to 50% and also avoids having any components on the rooftops that usually cause noise and vibration. It is all hidden underground and helps reduce the carbon footprint of the transit system. However, the stations themselves are now huge structures and take large amounts of area in the city as they have numerous facilities included in these stations from elevators, escalators, information desks, mini-marts, and restrooms to enhance the rider's experience. Due to the number of facilities and how big the stations are, there are numerous underground stations, especially in the older parts of Dubai such as the Baniyas Square station as depicted in figure 26 below where the surrounding streets are narrower and do not allow for such structures to be erected overground. However, in newer parts of Dubai this is not an issue and most Dubai Metro stations are overground as depicted in figure 27 below of the DMCC station.

Meanwhile, the Valley Metro had a different approach to its rail system. They have decided to go with a street-level light rail that goes through the current roads of Phoenix Metro without having the need of building big structures or going underground as shown in figures 28 and 29. However, by doing so the stations are now smaller and have limited facilities available, they are open stations that provide shading and seating structures on the platforms and kiosks for tickets.

Since the open-air stations are located in the traffic island of main streets they are exposed directly to the built environment, inhaling the emissions from the passing vehicles and dealing with the harsh weather conditions while waiting for the light rail to arrive. Having the stations in the middle of the road denies it from shading provided by buildings on either side of the street, especially when the line goes through main low-rise neighborhoods there is not enough shade provided by those buildings to reach the stations' platforms. However, the implications at the time of designing the light rail did not allow it to be on either side of the road but instead take advantage of the traffic island in the middle of the streets. Both cities have considered heat when designing their new transit systems but had to deal with certain limitations specific to each circumstance. There is still room for improvement in both transit systems, which is evident when we start looking at the qualitative and quantitative data and how riders' experience differ depending on the surrounding public realm.



Figures 26 and 27 – Baniyas Square station (underground) and DMCC station (overground)
(Sources: Alamy and OneClickDrive)



Figures 28 and 29 - Sycamore/Main St. Station and Center/Main St. Station
(Sources: Dreamstime and PhoenixNewTimes)

There are several best practices and implementation from which the public realm has improved the experienced temperature around transit stations. It is important to showcase how supportive the public realm can be to transit riders even if it was not influenced or improved since the introduction of the public transit system. One of the significant trends we see is the difference between the experienced temperatures from older downtown areas in comparison to new downtown areas and suburbs. Old downtown areas tend to have narrower streets and dense mixed-use developments with alleyways separating them rather than roads which are effective techniques for passive cooling. This is evident around transit stations such as Baniyas Square station in Dubai and Mill Ave station in Tempe shown in figures 30 and 31 below, both stations have the lowest average temperature records amongst their transit systems at 36°C for the three days and three shift averages during the month of August. Both have an average of 1-2°C lower temperature compared to other stations in nearby areas. Mill Ave also has the best average difference in pavement temperatures of 17°C between shaded and unshaded pavement, which is an indicator of how effective the public realm is in cooling down the area. Both stations are located in older areas of their cities and have narrower streets around them creating a more vibrant place and a better-experienced temperature. Buildings are closer to each other providing more shade, there is plenty of vegetation and trees cooling down the weather and providing ample shade too, and most importantly their surrounding areas are significantly more pedestrianized compared to many other areas around the other transit stations which are highly vehicle oriented.



Figures 30 and 31 – Baniyas Square station and Mill Ave/3rd St station (Source: Google Earth)

On the other hand, stations in highly vehicle-oriented areas or are developed as park-and-ride stations have the highest average temperature records in both cities resulting in uncomfortable experienced temperatures. For instance, Gilbert and Sycamore stations in Mesa are park-and-ride stations that are surrounded by huge parking lots which leave the public realm extremely exposed to direct sunlight, shading structures are not sufficient, and urban heat effects keep temperatures high even late at night. This is evident from our field observations of the station designs and their impacts on the public realm and from the measured temperatures. Gilbert station has the highest average temperature during the evening shift, shading structures are too high to provide adequate shade in both the transit center resting area and the station's platform. Shading structures adequacy is an issue in all eastbound stations on Apache Blvd and Main St as riders waiting for the eastbound rail are exposed to direct sunlight for many hours of the day even when waiting under the shading structures. Lack of adequate shading is also an issue experienced around several stations in Dubai, such as the Burjuman station depicted below with vast open areas exposing riders to direct sunlight. Longer exposure to direct sunlight and wider unshaded areas have also been reflected on measured temperatures as Burjuman station has higher temperatures than Baniyas Square station, even though both are in the older parts of Dubai. There should be better-designed structures or more trees planted on the platform to improve shading.



Figures 32 and 33 – Sycamore/Main St Station and Burjuman Station (Source: Google Earth)

Furthermore, urban heat effects are evident in stations in Phoenix and Dubai that are surrounded by certain types of development, public realm design, and/or vast mostly empty parking lots. This is evident when looking at the recorded temperatures in Roosevelt/Central, 3rd

St/Jefferson, and University/Rural stations in Phoenix Metro and in Al Rigga, Stadium, and Burjuman stations in Dubai. Those stations regularly have the highest temperatures measured on any certain day or time. Extreme heat continues to be experienced even during the later hours of the night, and that was observed during the 10-11:59 pm shift in Dubai, where it was uncomfortably hot till midnight. It is also noticeable when looking at the pavement temperature records of these stations at all times of the day as they always have the highest values. Furthermore, given the proximity of the University/Rural station to Mill Ave station, it is surprising to see that there is a constant 1°C difference in temperatures between them on any given day. That is because of how the surrounding areas public realm differs from one station to another. As mentioned earlier, Mill Ave station has one of the best public realms practices; however, University/Rural station, on the other hand, is in close proximity to one of the busiest intersections in Tempe which at the time of measurements was under construction and most congested during peak hours. Therefore, riders at this station are exposed to all the emissions released by vehicles waiting at the wide intersection. That was evident in our observation during the field research as the experienced temperature always felt hotter when around this station compared to other stations in Tempe even late at night. A similar situation is noticeable in Roosevelt/Central and 3rd St/Jefferson stations in the city of Phoenix. The transit systems here do not seem to improve the public realm around them, instead, the transit riders are negatively impacted by the surrounding public realm.

Launching these transit systems has positively impacted the public realm around several stations, improving the transit riders' experiences. First of all, we see a growing trend of transit-oriented development appearing around many stations in Dubai and Phoenix Metro. Comparing Google Earth Street view images from before and after the launching of Valley Metro Rail, there is an evident increase in the number of apartment complexes appearing around many transit stations in the Phoenix metro area. Having TOD overlays improves the public realm and enhances the transit rider experience by making it more accessible and desirable to rely on transit rather than a private vehicle. It is astonishing that many people can now choose to live in such vehicle-oriented cities without owning a personal vehicle, especially with Dubai's extreme heat and humidity levels. It is not only limited to buildings but also the public realm, in general, has become more pedestrian-

friendly in many areas such as Dubai Investment Park and District 2020, where it is highly pedestrianized compared to other surrounding regions of multiple Dubai Metro stations. This includes having better pedestrian-oriented infrastructure, such as pavement material that reduces urban heat effects, organized vegetation, proper lighting, and most importantly, shading from different elements during the scorching heat summers.

As mentioned earlier in the methodology section, we note different design elements when observing the areas around transit stations. Land uses seem to have been one of the most significant contributors to improving riders' experience around transit stations. This is evident in areas with mixed-use zonings, such as Burjuman and Al Rigga in Dubai and Mill Ave/3rd St. in Tempe. All these stations are in the older parts of their respective cities; they are surrounded by mixed-use developments that are usually mid to high rise buildings and, therefore, denser than any other parts of those two cities, as seen in figures 30 and 31 above. On the other hand, in areas where land uses are limited to single uses, we see the surrounding areas are filled with single-story buildings no matter the use. We see an abundance of parking spaces and broader streets; this is more common in Phoenix Metro, as seen in Sycamore/Main St., Gilbert/Main St., and 7th Ave/Camelback stations. Therefore, it is essential to encourage more TODs when designing transit in desert cities as they promote mix-use land uses that seem to impact rider's experiences positively.

TODs also promote pedestrian-oriented streets by reducing the number of vehicles on the roads resulting in narrower streets and wider sidewalks. Narrower streets and alleyways are typical in older parts of Dubai; even before the introduction of the Dubai Metro, this is where we have seen lower heat vulnerabilities. Narrower streets provide more shade as buildings get closer to each other; this design also allows for better passive cooling, which is evident in stations like Baniyas Square and Al Rigga in older Dubai. This is also applicable to Mill Ave/3rd St station in Tempe, where we have narrower streets that allow for better shade amplified by the abundance of vegetation and bigger trees compared to many other Phoenix stations that lack these elements. Therefore, narrower streets and alleyways are highly recommended around transit stations in desert cities.

Another essential element of urban design to consider is integrating transit stations with their surroundings. Whether the stations are plugged into the current city infrastructure or built for new developments to be plugged into them, integrating the stations with the public realm is crucial. It improves the rider's experience and perception of heat when heading to the station. Better integration with the public realm affects riders' perspectives and perceptions of how far stations are from their final destinations. Underground stations in Dubai are well integrated with the surroundings as they do not disrupt the public realm above them and provide several access points for riders without taking significant areas of the built environment.

Lastly, seating availability around transit stations also helps in improving riders' experiences and allows for a more comfortable trip. Most stations in both case studies provide seating for transit riders in and around the stations. Some stations in Dubai provide air-conditioned waiting areas for the bus stops around the Dubai Metro stations; meanwhile, all bus stops in Phoenix are shaded open-air waiting areas. Primary and secondary seating elements increase in denser regions of the two cities; this is evident in more socially active squares and streets such as Baniyas Square station and Mill Ave/3rd St station.

However, we see more room for improvement when it comes to shading elements. All Valley Metro rail stations use the same design language and inadequate shading structures. During the summer, transit riders heading east suffer from direct sun exposure throughout the day as the shading structures are minimal and are positioned too high above the waiting areas. They are also denied shade provided by the built environment as most stations are located on traffic islands farther away from the surrounding buildings. However, Mill Ave/3rd St station offers a great example of a well-shaded waiting area, as shown in figure 18 in appendix B below; it is a vegetation-covered shading structure that allows for better passive cooling resulting in a better experience. In Dubai, shading adequacy differs between older and newer parts of the city. As discussed earlier, narrower streets and alleyways provide more shading throughout the day and better passive cooling experiences, reducing rider's heat vulnerabilities. Meanwhile, in newer parts of Dubai with spread-out skyscrapers and urban sprawl effects, we see a decrease in shading adequacy and a

demand for more shading structures to be integrated for a better experience. In general, shading elements improve the rider's experience and are highly recommended in desert cities.

Study Limitations and Recommendations

Completing field research in two different countries around the world requires ensuring enough time is dedicated for each case study. It is highly recommended to have extra time allocated for unforeseen circumstances such as the ones we faced during this research where we had to miss two field research days without having the option to reschedule due to limited time at that case study country. The COVID-19 pandemic has decreased transit ridership around the world, fortunately, Dubai Metro's ridership in summer 2021 has got very close to ridership numbers from before the pandemic (GulfNews, 2022). However, Valley Metro Rail's ridership numbers have decreased by nearly 50% in 2021 compared to 2020 and are not recovering as fast as they did in Dubai (Valley Metro, 2022). Therefore, having fewer riders relying on the transit system affects waiting times and impacts our observations of the transit system and its riders' vulnerability to heat. Furthermore, another recommendation for future studies is to collect data on more than three days and to include a more spread-out schedule over the summer months for a more comprehensive datasets resulting in more reliable results.

Conclusions

This paper identifies how some aspects of the built environment effectively impact the transit rider's experience. It analyzes how Dubai and Phoenix Metropolitan have considered heat when designing their new transit systems. This includes how the station design provides factors such as shading, passive cooling, and integration with the built environment. This is observed in the field research when visiting the ten stations for each transit system. The results show how several stations have successfully provided a comfortable rider experience given the harsh weather conditions and vehicle-oriented built environments. Shading elements are only practical when used sufficiently and when developers appropriately distribute them around the station. Passive cooling has played a huge role in improving the experienced temperature at different stations.

Most importantly, some stations integrate adequately with the built environment, such as Dubai Metro's Baniyas Square station and Valley Metro's Mill Ave station. A well-designed and integrated transit station significantly improves the experience of transit riders and encourages many more to consider public transit instead of relying on their private vehicles. Moreover, the quantitative data is essential to support our field research observations. Temperatures, humidity levels, and pavement temperatures have all been measured at each station to better understand how the built environment has impacted the weather conditions around the stations. For instance, we have seen how Mill Ave/3rd St station always has lower temperatures than other nearby stations. That is also applicable to Baniyas Square station, which has always had better weather conditions than Burjuman station. These measurements reflect the experienced temperatures and are a good indicator of how some stations perform better than others because they are adequately integrated with their surroundings and ensure a more pedestrian-oriented built environment.

However, not all stations have successfully integrated with their surroundings or provided a comfortable rider experience. The park-and-ride stations have failed to create a pedestrian-oriented public realm. It mainly focuses on providing parking spaces and the infrastructure that supports them, resulting in higher temperatures and exposure to direct sunlight due to the open parking spaces and infrastructure. Heat vulnerability is not limited to park-and-ride stations but includes stations that suffer from urban heat effects due to the surrounding built environment, such as the Roosevelt station in Phoenix and Burjuman station in Dubai. These stations have unusually higher pavement temperatures than other nearby stations. This recommends enhancing the built environment to improve the rider's experience when designing transit.

Therefore, when designing new transit systems in desert cities, all built environment aspects should be considered and rely on best practices based on similar weather conditions to provide a comfortable experience even in the warmest months of the year. The surrounding built environment plays a massive role in improving the rider experience and transforming an area from vehicle-oriented to pedestrian-oriented, ensuring a better experience and reducing the weather impacts. Lastly, we recommend that there should be further intensive research on this topic to cover extended periods of the summer months and allow for more stations to be included in the study.

REFERENCES

- Alawadi, K., Khanal, A., Doudin, A., & Abdelghani, R. (2021). Revisiting transit-oriented development: Alleys as critical walking infrastructure. *Transport Policy*, 100, 187–202.
<https://doi.org/10.1016/j.tranpol.2020.11.007>
- Ali, L., Nawaz, A., Iqbal, S., Basheer, M., Hameed, J., Albasher, G., Shah, S. A. R., & Bai, Y. (2021). Dynamics of Transit Oriented Development, Role of Greenhouse Gases and Urban Environment: A Study for Management and Policy. *Sustainability*, 13, 2536.
<https://doi.org/10.3390/su13052536>
- Allan, A. & Taha, B. (2020). Hosting Mega Event - Drive towards Sustainable Planning for Public Transport - Case Study: Metro Line Route 2020. *Transportation Research Procedia*, 2176–2186. ScienceDirect.
<http://creativecommons.org/licenses/by-nc-nd/4.0/>
- Atkinson-Palombo, C. & Kuby, M. (2011). The geography of advance transit-oriented development in metropolitan Phoenix, Arizona, 2000–2007. *Journal of Transport Geography*, 19, 189–199.
<http://dx.doi.org/10.1016/j.jtrangeo.2010.03.014>
- Badam, R. T. (2016). Contract awarded for Dubai Metro's Route 2020 project to Expo site. *The National*.
<https://www.thenationalnews.com/business/travel-and-tourism/contract-awarded-for-dubai-metros-route-2020-project-to-expo-site-1.189256>
- Chester, M. & Fraser, A. (2017). Transit Planning and Climate Change: Reducing Rider's Vulnerability to Heat. *International Conference on Sustainable Infrastructure 2017*.
<https://doi.org/10.1016/j.tranpol.2018.11.003>
- Cho, A. (2017). A New Era of Transit. *Engineering News-Record*.
<https://www.enr.com/articles/41427-a-new-era-of-transit>
- Credit, K. (2018). Transit-oriented economic development: The impact of light rail on new business starts in the Phoenix, AZ Region, USA. *Urban Studies* 2018, Vol. 55(13) 2838–2862.
<https://doi.org/10.1177%2F0042098017724119>
- Collom, L. (2019). Light rail to reach eastern end of the line with opening of Mesa extension. *The Arizona Republic*.
<https://www.azcentral.com/story/news/local/mesa/2019/05/17/newest-light-rail-track-expands-farther-into-mesa-gilbert-road/3698341002/>
- DESMI (2020). Dubai Metro - District Cooling, UAE.
<https://www.desmi.com/customer-stories/dubai-metro-district-cooling-uae/>
- Eisenman, Wilhalme, H., Tseng, C.-H., Chester, M., English, P., Pincetl, S., Fraser, A., Vangala, S., & Dhaliwal, S. K. (2016). Heat Death Associations with the built environment, social vulnerability, and their interactions with rising temperature. *Health & Place*, 41, 89–99.
<https://doi.org/10.1016/j.healthplace.2016.08.007>
- Fahed, J., Kinab, E., Ginestet, S., & Adolphe, L. (2020). Impact of urban heat island mitigation measures on microclimate and pedestrian comfort in a dense urban district of Lebanon.
<https://doi.org/10.1016/j.scs.2020.102375>

Fraser, A. M., & Chester, M. V. (2017). Transit system design and vulnerability of riders to heat. *Journal of Transport & Health*, 4, 216–225.
<https://doi.org/10.1016/j.jth.2016.07.005>

Gulf News Report (2022). Watch: 461 million riders used public transport, taxis and shared transport in Dubai in 2021. Gulf News.
<https://gulfnews.com/uae/transport/watch-461-million-riders-used-public-transport-taxis-and-shared-transport-in-dubai-in-2021-1.85881789>

Harna, E. (2009). Changes to Metro put cost up by Dh12bn. *The National*.
<https://www.thenationalnews.com/uae/transport/changes-to-metro-put-cost-up-by-dh12bn-1.562126/>

Ibraeva, A., Correia, G., Silva, C., & Antunes, A. P. (2020). Transit-oriented development: A review of research achievements and challenges, *Transportation Research Part A: Policy and Practice*, 132, 110-130.
<https://doi.org/10.1016/j.tra.2019.10.018>

Kamruzzaman, Deilami, K., & Yigitcanlar, T. (2018). Investigating the urban heat island effect of transit-oriented development in Brisbane. *Journal of Transport Geography*, 66, 116–124.
<https://doi.org/10.1016/j.jtrangeo.2017.11.016>

Ketcherside, C. & Menon, M. (2014). Valley Metro Organizational Integration: Advancing the Future of Transportation in the Metropolitan Area of Phoenix, Arizona. *Transportation Research Record*, 2420 (1), 55-61.
<https://doi.org/10.3141/2420-06>

Kim, H., Gu, D., & Kim, H. Y. (2018). Effects of Urban Heat Island Mitigation in Various Climate Zones in the United States. *Sustainable Cities and Society*, 41, 841–852.
<https://doi.org/10.1016/j.scs.2018.06.021>

Kuby, M. & Upchurch, C. (2013). Evaluating light rail sketch planning: actual versus predicted station boardings in Phoenix. *Transportation*, 41:173–192.
<http://dx.doi.org/10.1007/s11116-013-9499-9>

Lang, J. (2005). *Urban design: A typology of procedures and products*. Routledge.
<https://ebookcentral-proquest-com.ezproxy1.lib.asu.edu/lib/asulib-ebooks/reader.action?docID=270149>

MacroTrends (2022). Phoenix Metro Area Population 1950-2022.
<https://www.macrotrends.net/cities/23099/phenix/population>

MacroTrends (2022). Dubai, UAE Metro Area Population 1950-2022.
<https://www.macrotrends.net/cities/22635/dubai/population>

Markolf, S. A., Hoehne, C., Fraser, A., & Chester, M. (2017). Maintaining Reliability of Transportation Systems and Interconnected Infrastructure under Climate Change. In *International Conference on Sustainable Infrastructure 2017* (pp. 219–230).
<https://doi.org/10.1061/9780784481196.020>

Markolf, S. A., Hoehne, C., Fraser, A., Chester, M. V, & Underwood, B. S. (2017). Transportation resilience to climate change and extreme weather events – Beyond risk and robustness. *Transport Policy*, 74, 174–186.
<http://doi.org/10.1016/j.tranpol.2018.11.003>

- Pincetl, S., Chester, M., & Eisenman, D. (2016). Urban Heat Stress Vulnerability in the U.S. Southwest: The Role of Sociotechnical Systems. *Sustainability*, 8(9), 842.
<https://doi.org/10.3390/su8090842>
- Rosheidat. (2010). Optimizing the Effect of Vegetation for Pedestrian Thermal Comfort and Urban Heat Island Mitigation in a Hot Arid Urban Environment. ProQuest Dissertations Publishing.
https://keep.lib.asu.edu/flysystem/fedora/c7/114007/Rosheidat_asu_0010E_13958.pdf
- Salimi, & Al-Ghamdi, S. G. (2020). Climate change impacts on critical urban infrastructure and urban resiliency strategies for the Middle East. *Sustainable Cities and Society*, 54, 101948–.
<https://doi.org/10.1016/j.scs.2019.101948>
- Singhal, Kamga, C., & Yazici, A. (2014). Impact of weather on urban transit ridership. *Transportation Research. Part A, Policy and Practice*, 69, 379–391.
<https://doi.org/10.1016/j.tra.2014.09.008>
- Stojanovski, T. (2020). Urban design and public transportation – public spaces, visual proximity and Transit-Oriented Development (TOD). *Journal of Urban Design*. 25:1, 134-154.
<https://doi.org/10.1080/13574809.2019.1592665>
- Sunnucks, M. (2016). Phoenix Rises Again. *Planning*, 82, 1, 21-27.
<http://login.ezproxy1.lib.asu.edu/login?url=https://www.proquest.com/trade-journals/phoenix-rises-again/docview/1759327270/se-2?accountid=4485>
- The World Bank (2022). Transforming the Urban Space Through Transit-Oriented Development: The 3V Approach.
<https://tinyurl.com/yc2nasjx>
- Xiaoxiao, L., Wenwen, L., Middel, A., Harlan, S.L., Brazel, A.J., Turner, B.L. (2016). Remote sensing of the surface urban heat island and land architecture in Phoenix, Arizona: Combined effects of land composition and configuration and cadastral–demographic-economic factors. *Remote Sensing of Environment*, 174, 233–243.
<https://doi.org/10.1016/j.rse.2015.12.022>
- Xu, W. (Ato), Guthrie, A., Fan, Y., & Li, Y. (2017). Transit-oriented development in China: Literature review and evaluation of TOD potential across 50 Chinese cities. *Journal of Transport and Land Use*, 10, 743–762.
<http://www.jstor.org/stable/26211754>
- United Nations (2015). Transforming our World: The 2030 Agenda for Sustainable Development.
<https://sdgs.un.org/publications/transforming-our-world-2030-agenda-sustainable-development-17981>
- Valley Metro (2022). Ridership Reports.
<https://www.valleymetro.org/about/agency/transit-performance/ridership-reports>
- Valley Metro (2021). Annual Rail Station Ridership Report FY 2020.
https://drupal-space.nyc3.cdn.digitaloceanspaces.com/s3fs-public/uploads/event-resources/fy20_yearly_ridership_by_station-online.xlsx

APPENDIX A
FIELD RESEARCH MEASUREMENT TABLES

Table 1
Measured and recorded temperatures - Dubai Metro

Station	Tuesday, August 3, 2021 and Tuesday, August 10, 2021			Friday, August 6, 2021			Monday, August 9, 2021			Morning	Midday	End of day
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM			
	Exact time of measurement			Exact time of measurement			Exact time of measurement					
Stadium	7:00	1:45	5:00	10:20	4:10	10:15	8:50	3:25	6:30			
Baniyas Square	7:42	1:00	5:37	11:00	4:45	10:55	8:10	2:35	5:40			
Burjuman	8:12	12:31	5:54	11:15	5:10	11:10	7:50	2:10	5:20			
Al Rigga	7:26	1:15	5:22	10:40	4:20	10:40	8:30	3:00	5:55			
Dubai Mall	8:45	12:00	6:30	11:45	5:35	11:30	7:25	1:35	5:00			
DMCC	9:20	1:55	5:55 -	-	-	-	-	-	-			
Ibn Battuta	9:00	1:20	5:20 -	-	-	-	-	-	-			
Jebel Ali	8:45	1:35	5:40 -	-	-	-	-	-	-			
Dubai Investment Park	7:45	12:15	4:30 -	-	-	-	-	-	-			
Expo 2020	8:15	12:35	4:50 -	-	-	-	-	-	-			
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day
	Measured Temperature (°C)			Measured Temperature (°C)			Measured Temperature (°C)			Average Measured Temperature (°C)		
Stadium	33	45	41	41	37	32	36	42	34	37	41	36
Baniyas Square	35	44	36	36	36	32	36	38	35	36	39	34
Burjuman	35	42	36	38	37	34	35	39	36	36	39	35
Al Rigga	34	46	40	39	38	33	38	37	35	37	40	36
Dubai Mall	34	42	34	44	35	34	33	40	36	37	39	35
DMCC	36	39	34 -	-	-	-	-	-	-	36	39	34
Ibn Battuta	34	40	33 -	-	-	-	-	-	-	34	40	33
Jebel Ali	35	41	33 -	-	-	-	-	-	-	35	41	33
Dubai Investment Park	34	39	34 -	-	-	-	-	-	-	34	39	34
Expo 2020	33	38	33 -	-	-	-	-	-	-	33	38	33
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 A	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day
	Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)					
Stadium	32	39	37	37	36	36	36	42	42	41	41	41
Baniyas Square	32	39	36	37	38	37	37	42	41	41	41	41
Burjuman	32	39	37	38	38	36	36	43	41	41	41	41
Al Rigga	32	39	37	37	38	36	37	43	40	40	40	40
Dubai Mall	30	40	36	39	37	36	29	43	41	41	41	41
DMCC	39	42	36 -	-	-	-	-	-	-	-	-	-
Ibn Battuta	38	43	39 -	-	-	-	-	-	-	-	-	-
Jebel Ali	38	44	39 -	-	-	-	-	-	-	-	-	-
Dubai Investment Park	33	44	41 -	-	-	-	-	-	-	-	-	-
Expo 2020	37	44	41 -	-	-	-	-	-	-	-	-	-

Table 2
Measured and recorded temperatures - Valley Metro Light Rail

Station	Friday, August 27, 2021			Sunday, August 29, 2021			Saturday, September 11, 2021			Morning	Midday	End of day	All Day Average
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM				
	Exact time of measurement			Exact time of measurement			Exact time of measurement						
7th Ave/Camelback	6:45	2:30	4:15	12:20	2:45	9:00	9:50	2:00	7:05				
Roosevelt/Central Ave	7:00	2:15	4:30	12:05	3:05	8:40	10:10	1:45	6:50				
3rd St/Jefferson	7:15	2:00	4:45	11:50	3:20	8:30	9:35	1:35	6:40				
44th St/Washington	7:30	1:40	5:00	11:30	3:40	8:20	9:20	1:20	6:25				
Mill Ave/3rd St	7:45	1:20	5:25	11:15	3:55	8:10	9:10	1:10	6:10				
University Dr/Rural	8:00	1:00	7:05	10:55	4:10	8:00	9:00	1:00	6:00				
McIntock/Apache Blvd	8:20	12:45	6:55	10:45	4:20	7:50	8:50	12:45	5:50				
Sycamore/Main St	8:35	12:30	6:40	10:25	4:30	7:40	8:40	12:35	5:40				
Center/Main St	8:45	12:10	6:25	10:10	4:40	7:25	8:25	12:20	5:25				
Gilbert Road/Main St	9:00	11:55	6:10	9:55	4:55	7:10	8:10	12:00	5:10				
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day	All Day Average
	Measured Temperature (°C)			Measured Temperature (°C)			Measured Temperature (°C)			Average Measured Temperature (°C)			All Day Average
7th Ave/Camelback	32	42	44	40	42	32	32	37	33	35	40	36	37
Roosevelt/Central Ave	33	46	46	41	39	35	34	37	33	36	41	38	38
3rd St/Jefferson	32	43	42	42	40	32	33	39	32	36	41	35	37
44th St/Washington	32	43	38	40	42	38	34	36	33	35	40	36	37
Mill Ave/3rd St	33	38	38	39	39	35	32	35	32	35	37	35	36
University Dr/Rural	34	40	42	39	42	37	33	38	34	35	40	38	38
McIntock/Apache Blvd	35	43	35	38	44	33	32	37	35	35	41	34	37
Sycamore/Main St	35	43	38	41	42	34	32	38	36	36	41	36	38
Center/Main St	36	42	40	38	43	36	31	38	36	35	41	37	38
Gilbert Road/Main St	37	39	39	34	40	37	31	37	34	34	39	38	37
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day	All Day Average
	Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)			Recorded Temperature - weather.com (°C)						
7th Ave/Camelback	31	44	44	39	42	37	34	40	38				
Roosevelt/Central Ave	31	44	44	39	42	37	35	40	39				
3rd St/Jefferson	31	44	43	39	42	37	34	39	40				
44th St/Washington	32	43	44	38	41	39	33	38	40				
Mill Ave/3rd St	32	43	43	38	42	38	32	38	40				
University Dr/Rural	32	43	42	38	42	38	32	38	41				
McIntock/Apache Blvd	33	42	41	38	42	38	32	38	41				
Sycamore/Main St	34	42	42	37	42	38	32	38	41				
Center/Main St	34	41	42	36	42	39	31	38	41				
Gilbert Road/Main St	34	42	42	36	42	39	30	38	42				

Table 3
Measured and recorded humidity levels - Dubai Metro

Station	Tuesday, August 3, 2021 and Tuesday, August 10, 2021			Friday, August 6, 2021			Monday, August 9, 2021					
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM			
	Exact time of measurement			Exact time of measurement			Exact time of measurement					
Stadium	7:00	1:45	5:00	10:20	4:10	10:15	8:50	3:25	6:30			
Baniyas Square	7:42	1:00	5:37	11:00	4:45	10:55	8:10	2:35	5:40			
Burjuman	8:12	12:31	5:54	11:15	5:10	11:10	7:50	2:10	5:20			
Al Rigga	7:25	1:15	5:22	10:40	4:20	10:40	8:30	3:00	5:55			
Dubai Mall	8:45	12:00	6:30	11:45	5:35	11:30	7:25	1:35	5:00			
DMCC	9:20	1:55	5:55	-	-	-	-	-	-			
Ibn Battuta	9:00	1:20	5:20	-	-	-	-	-	-			
Jebel Ali	8:45	1:35	5:40	-	-	-	-	-	-			
Dubai Investment Park	7:45	12:15	4:30	-	-	-	-	-	-			
Expo 2020	8:15	12:35	4:50	-	-	-	-	-	-			
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day
	Measured Humidity (%)			Measured Humidity (%)			Measured Humidity (%)			Average Measured Humidity (%)		
Stadium	78	64	52	32	66	85	57	50	65	56	60	67
Baniyas Square	57	52	68	52	71	82	54	55	56	54	59	69
Burjuman	50	53	72	72	72	92	63	48	60	62	58	75
Al Rigga	64	30	52	60	51	83	43	60	76	56	47	70
Dubai Mall	52	55	70	70	76	91	60	40	47	61	57	69
DMCC	54	35	72	-	-	-	-	-	-	54	35	72
Ibn Battuta	52	36	66	-	-	-	-	-	-	52	36	66
Jebel Ali	51	40	64	-	-	-	-	-	-	51	40	64
Dubai Investment Park	57	40	52	-	-	-	-	-	-	57	40	52
Expo 2020	64	42	46	-	-	-	-	-	-	64	42	46
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Recorded Humidity - weather.com (%)		
	Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)					
Stadium	66	45	64	48	50	60	36	39	26			
Baniyas Square	64	49	61	48	53	64	43	28	29			
Burjuman	61	45	60	44	54	81	46	28	30			
Al Rigga	62	47	59	50	51	63	40	26	29			
Dubai Mall	67	38	63	44	54	63	63	27	34			
DMCC	30	28	40	-	-	-	-	-	-			
Ibn Battuta	30	25	37	-	-	-	-	-	-			
Jebel Ali	32	26	39	-	-	-	-	-	-			
Dubai Investment Park	47	19	30	-	-	-	-	-	-			
Expo 2020	31	19	28	-	-	-	-	-	-			

Table 4
Measured and recorded humidity levels - Valley Metro Light Rail

Station	Friday, August 27, 2021			Sunday, August 29, 2021			Saturday, September 11, 2021						
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM				
	Exact time of measurement			Exact time of measurement			Exact time of measurement						
7th Ave/Camelback	6:45	2:30	4:15	12:20	2:45	9:00	9:50	2:00	7:05				
Roosevelt/Central Ave	7:00	2:15	4:30	12:05	3:05	8:40	10:10	1:45	6:50				
3rd St/Jefferson	7:15	2:00	4:45	11:50	3:20	8:30	9:35	1:35	6:40				
44th St/Washington	7:30	1:40	5:00	11:30	3:40	8:20	9:20	1:20	6:25				
Mill Ave/3rd St	7:45	1:20	5:25	11:15	3:55	8:10	9:10	1:10	6:10				
University Dr/Rural	8:00	1:00	5:50	10:55	4:10	8:00	9:00	1:00	6:00				
McIntock/Apache Blvd	8:20	12:45	6:55	10:45	4:20	7:50	8:50	12:45	5:50				
Sycamore/Main St	8:35	12:30	6:40	10:25	4:30	7:40	8:40	12:35	5:40				
Center/Main St	8:45	12:10	6:25	10:10	4:40	7:25	8:25	12:20	5:25				
Gilbert Road/Main St	9:00	11:55	6:10	9:55	4:55	7:10	8:10	12:00	5:10				
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day	All Day Average
	Measured Humidity (%)			Measured Humidity (%)			Measured Humidity (%)			Average Measured Humidity (%)			
7th Ave/Camelback	38	22	20	38	35	51	55	48	54	44	35	42	40
Roosevelt/Central Ave	37	23	22	39	37	51	52	51	53	43	37	42	41
3rd St/Jefferson	40	24	23	42	38	52	56	46	53	46	37	43	42
44th St/Washington	41	25	28	45	35	48	59	53	46	48	38	41	42
Mill Ave/3rd St	38	27	27	40	40	48	55	52	48	44	40	41	42
University Dr/Rural	42	28	36	39	36	47	53	54	49	45	39	44	43
McIntock/Apache Blvd	38	23	31	38	35	48	54	51	46	43	36	41	40
Sycamore/Main St	36	30	30	37	38	48	56	53	46	43	40	41	42
Center/Main St	40	26	28	38	36	48	59	52	45	46	38	40	41
Gilbert Road/Main St	36	28	30	48	38	47	67	53	46	50	40	41	44
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Recorded Humidity - weather.com (%)			
	Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)			Recorded Humidity - weather.com (%)						
7th Ave/Camelback	33	15	13	22	19	24	34	23	16				
Roosevelt/Central Ave	32	15	13	22	18	22	33	23	14				
3rd St/Jefferson	33	15	12	22	18	22	35	24	14				
44th St/Washington	35	16	12	23	18	21	35	24	14				
Mill Ave/3rd St	36	17	13	24	18	22	39	25	14				
University Dr/Rural	38	17	15	25	17	23	39	25	14				
McIntock/Apache Blvd	36	18	15	26	17	22	40	25	14				
Sycamore/Main St	34	19	14	27	17	21	40	25	13				
Center/Main St	34	20	15	28	17	20	43	26	13				
Gilbert Road/Main St	33	20	15	31	17	20	43	28	13				

Table 5
Difference in Pavement temperatures - Dubai Metro

Station	Tuesday, August 3, 2021 and Tuesday, August 10, 2021						Friday, August 6, 2021			Monday, August 9, 2021		
	Exact time of measurement			Exact time of measurement			Exact time of measurement			Exact time of measurement		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
Stadium	7:00	1:45	5:00	10:20	4:10	10:15	8:50	3:25	6:30			
Baniyas Square	7:42	1:00	5:37	11:00	4:45	10:55	8:10	2:35	6:40			
Burjuman	8:12	12:31	5:54	11:15	5:10	11:10	7:50	2:10	5:20			
Al Rigga	7:26	1:15	5:22	10:40	4:20	10:40	8:30	3:00	5:55			
Dubai Mall	8:45	12:00	6:30	11:45	5:35	11:30	7:25	1:35	5:00			
DMCC	9:20	1:55	5:55	-	-	-	-	-	-			
Ibn Battuta	9:00	1:20	5:20	-	-	-	-	-	-			
Jebel Ali	8:45	1:35	5:40	-	-	-	-	-	-			
Dubai Investment Park	7:45	12:15	4:30	-	-	-	-	-	-			
Expo 2020	8:15	12:35	4:50	-	-	-	-	-	-			
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day
Shaded Ground Temperature (°C)												
Stadium	35.3	48.2	41.2	35.5	37.5	39.5	41.1	43.6	41.3	37	43	41
Baniyas Square	34.5	37.8	35.6	37.3	45.2	36.1	36.1	48.4	46.2	36	44	39
Burjuman	38.1	41.9	41.3	37.8	46.8	36.3	36.4	42.8	46.7	37	44	41
Al Rigga	35.8	48	40.4	39.2	42.3	38.2	39.2	42.3	42.5	38	44	40
Dubai Mall	36.4	37.6	38	37.1	38.8	35.2	33.6	31.2	47.4	35	36	40
DMCC	39.5	45.5	48.3	-	-	-	-	-	-	40	46	44
Ibn Battuta	38.5	42	41.9	-	-	-	-	-	-	39	42	42
Jebel Ali	39.1	47.6	42.5	-	-	-	-	-	-	39	48	43
Dubai Investment Park	34.9	47.4	45.8	-	-	-	-	-	-	35	47	46
Expo 2020	33.8	45.6	42.2	-	-	-	-	-	-	34	46	42
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day
Unshaded Pavement Temperature (°C)												
Stadium	36.1	68.7	58.2	48	62.7	-	48.4	65.1	52.6	44	66	55
Baniyas Square	40.5	68.2	45.6	45.6	52.3	-	37.9	69.5	53.7	41	63	50
Burjuman	40.7	67	48.6	45.6	54.9	-	38.2	61.6	54.4	47	62	54
Al Rigga	36.7	68	58.4	57.8	64.5	-	47.2	71.1	54.3	47	68	56
Dubai Mall	46.8	66.5	42.7	57.3	50.9	-	36.5	61.2	53.6	47	60	48
DMCC	54.9	67.5	54.8	-	-	-	-	-	-	55	68	55
Ibn Battuta	42.5	66	53.2	-	-	-	-	-	-	46	66	59
Jebel Ali	43.2	69.3	58.4	-	-	-	-	-	-	43	69	58
Dubai Investment Park	38.4	69.5	59.1	-	-	-	-	-	-	38	70	59
Expo 2020	39.4	68.3	56.7	-	-	-	-	-	-	39	68	57

Table 6
Difference in Pavement temperatures - Valley Metro Light Rail

Station	Friday, August 27, 2021						Saturday, August 29, 2021			Saturday, September 11, 2021		
	Exact time of measurement			Exact time of measurement			Exact time of measurement			Exact time of measurement		
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM
7th Ave/Camelback	6:45	2:30	4:15	12:20	2:45	9:00	9:50	2:00	7:05			
Roosevelt/Central Ave	7:00	2:15	4:30	12:05	3:05	8:40	10:10	1:45	6:50			
3rd St/Jefferson	7:15	2:00	4:45	11:50	3:20	8:30	9:35	1:35	6:40			
44th St/Washington	7:30	1:40	5:00	11:30	3:40	8:20	9:20	1:20	6:25			
Mil Ave/3rd St	7:45	1:20	5:25	11:15	3:55	8:10	9:10	1:10	6:10			
University Dr/Rural	8:00	1:00	7:05	10:55	4:10	8:00	9:00	1:00	6:00			
McIntlock/Apache Blvd	8:20	12:45	6:55	10:45	4:20	7:50	8:50	12:45	5:50			
Sycamore/Main St	8:35	12:30	6:40	10:25	4:30	7:40	8:40	12:35	5:40			
Center/Main St	8:45	12:10	6:25	10:10	4:40	7:25	8:25	12:20	5:25			
Gilbert Road/Main St	9:00	11:55	6:10	9:55	4:55	7:10	8:10	12:00	5:10			
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day
Shaded Ground Temperature (°C)												
7th Ave/Camelback	31.1	41.1	37.3	42.8	49	34.7	35.7	36	37	37	37	37
Roosevelt/Central Ave	32.4	41.4	52.2	43.2	41.6	32.1	37.9	41.6	36	40	47	41
3rd St/Jefferson	34.5	34.2	52.2	36.3	39.7	36.3	42.1	37.8	36	39	45	40
44th St/Washington	33.8	37.8	40.3	37.1	38.9	34.1	38.1	40.1	35	38	40	38
Mil Ave/3rd St	31.5	38.6	39.7	36.9	40.1	32	36.8	41	33	39	40	37
University Dr/Rural	34.2	44.1	36.5	37.6	43	33.5	37.8	42.3	35	42	39	39
McIntlock/Apache Blvd	35.4	45.1	42.8	39.8	43.2	34.3	39.5	42.7	37	43	43	41
Sycamore/Main St	32	46.1	43.3	37.7	45.3	33.9	40.9	43.2	35	44	43	41
Center/Main St	34.5	38.8	38.8	34	38.2	31.8	33	38.2	33	36	39	36
Gilbert Road/Main St	35	39.4	41.3	30.6	41.9	31.2	38.2	41.4	32	40	41	38
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day
Unshaded Pavement Temperature (°C)												
7th Ave/Camelback	37.1	63	61.2	65.6	62.6	36.9	46.3	49.7	38	50	58	45
Roosevelt/Central Ave	37.9	66.2	62.2	65.3	63.6	41.8	51.5	59.4	43.2	52	63	49
3rd St/Jefferson	38.4	73.8	66.2	63	66	39.6	46.5	64.5	41.9	49	68	49
44th St/Washington	39.8	69.7	55.4	62.1	64.2	40.1	44.2	59.5	48.2	49	64	48
Mil Ave/3rd St	36.7	72.9	59.8	65.3	69.2	38.3	42.7	59.3	52.9	45	67	50
University Dr/Rural	38.8	69.9	47.8	55.2	62.7	41.2	41.1	54.8	53.1	45	62	47
McIntlock/Apache Blvd	39.7	67	45.8	56.7	60.2	40.6	39.7	53.8	52.6	45	60	46
Sycamore/Main St	40.4	69.7	52.8	56.3	60.9	41.3	40.1	59.9	50.1	46	64	48
Center/Main St	43	57.7	42.9	54	62.9	40.2	39.7	57.9	53.8	46	60	46
Gilbert Road/Main St	44	59.1	53.1	49.9	56.4	45.3	36	53.7	47.6	43	56	49

Table 7
Average Difference in Pavement temperatures – Dubai Metro

Station	Tuesday, August 3, 2021 and Tuesday, August 10, 2021			Friday, August 6, 2021			Monday, August 9, 2021						
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM				
	Exact time of measurement			Exact time of measurement			Exact time of measurement						
Stadium	7:00	1:45	5:00	10:20	4:10	10:16	8:50	3:25	6:30				
Baniyas Square	7:42	1:00	5:37	11:00	4:45	10:55	8:10	2:35	5:40				
Burjuman	8:12	12:31	5:54	11:15	5:10	11:10	7:50	2:10	5:20				
Al Rigga	7:26	1:15	5:22	10:40	4:20	10:40	8:30	3:00	5:55				
Dubai Mall	8:45	12:30	6:30	11:45	5:35	11:30	7:25	1:35	5:00				
DMCC	9:20	1:55	5:55	-	-	-	-	-	-				
Ibn Battuta	9:00	1:20	5:20	-	-	-	-	-	-				
Jebel Ali	8:45	1:35	5:40	-	-	-	-	-	-				
Dubai Investment Park	7:45	12:15	4:30	-	-	-	-	-	-				
Expo 2020	8:15	12:35	4:50	-	-	-	-	-	-				
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 10-11:59 AM	Midday 4-6 PM	End of day 10-11:59 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day	All Day Average
Difference Between Unshaded and Shaded Pavement Temperatures													
Stadium	0.80	20.50	17.00	12.50	25.20	-	7.30	21.50	11.30	7	22	15	15
Baniyas Square	6.80	30.40	10.00	8.30	7.10	-	1.80	21.10	7.50	5	20	10	12
Burjuman	2.60	25.10	7.30	23.80	8.10	-	1.80	22.40	7.70	9	19	10	13
Al Rigga	0.90	20.00	18.00	18.60	22.20	-	8.00	28.80	11.80	9	24	16	16
Dubai Mall	11.40	28.90	4.70	20.20	12.10	-	2.90	30.00	6.20	12	24	8	14
DMCC	15.40	21.90	6.50	-	-	-	-	-	-	15	22	7	-
Ibn Battuta	4.00	24.00	17.30	-	-	-	-	-	-	4	24	17	-
Jebel Ali	4.10	21.70	15.90	-	-	-	-	-	-	4	22	16	-
Dubai Investment Park	3.50	22.10	13.30	-	-	-	-	-	-	4	22	13	-
Expo 2020	5.80	22.70	14.50	-	-	-	-	-	-	6	23	15	-

Table 8
Average Difference in Pavement temperatures - Valley Metro Light Rail

Station	Friday, August 27, 2021			Sunday, August 29, 2021			Saturday, September 11, 2021						
	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM				
	Exact time of measurement			Exact time of measurement			Exact time of measurement						
7th Ave/Camelback	6:45	2:30	4:15	12:20	2:45	9:00	9:50	2:00	7:05				
Roosevelt/Central Ave	7:00	2:15	4:30	12:05	3:05	8:40	10:10	1:45	6:50				
3rd St/Jefferson	7:15	2:00	4:45	11:50	3:20	8:30	9:35	1:35	6:40				
44th St/Washington	7:30	1:40	5:00	11:30	3:40	8:20	9:20	1:20	6:25				
Mil Ave/3rd St	7:45	1:20	5:25	11:15	3:55	8:10	9:10	1:10	6:10				
University Dr/Rural	8:00	1:00	7:05	10:55	4:10	8:00	9:00	1:00	6:00				
McIntock/Apache Blvd	8:20	12:45	6:55	10:45	4:20	7:50	8:50	12:45	5:50				
Sycamore/Main St	8:35	12:30	6:40	10:25	4:30	7:40	8:40	12:35	5:40				
Center/Main St	8:45	12:10	6:25	10:10	4:40	7:25	8:25	12:20	5:25				
Gilbert Road/Main St	9:00	11:55	6:10	9:55	4:55	7:10	8:10	12:00	5:10				
Station	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning 9-11 AM	Midday 3-5 PM	End of day 8-10 PM	Morning 7-9 AM	Midday 12-2 PM	End of day 5-7 PM	Morning	Midday	End of day	All Day Average
Difference Between Unshaded and Shaded Pavement Temperatures													
7th Ave/Camelback	6	22	24	23	23	-	12	14	2	13	20	8	14
Roosevelt/Central Ave	6	25	10	22	22	-	19	22	2	16	23	2	14
3rd St/Jefferson	4	40	14	27	26	-	10	22	4	14	29	4	16
44th St/Washington	6	31	15	25	25	-	10	21	8	14	26	8	16
Mil Ave/3rd St	5	34	20	19	29	-	11	23	12	12	29	10	17
University Dr/Rural	5	26	11	18	20	-	8	17	11	10	21	8	13
McIntock/Apache Blvd	4	22	3	17	17	-	5	14	10	9	18	4	10
Sycamore/Main St	8	24	10	19	16	-	6	19	7	11	19	5	12
Center/Main St	9	21	4	20	25	-	8	25	16	12	24	7	14
Gilbert Road/Main St	9	20	12	19	15	-	5	16	6	11	17	7	12

APPENDIX B
FIELD RESEARCH PHOTOGRAPHS



Figure 1 - DMCC Station

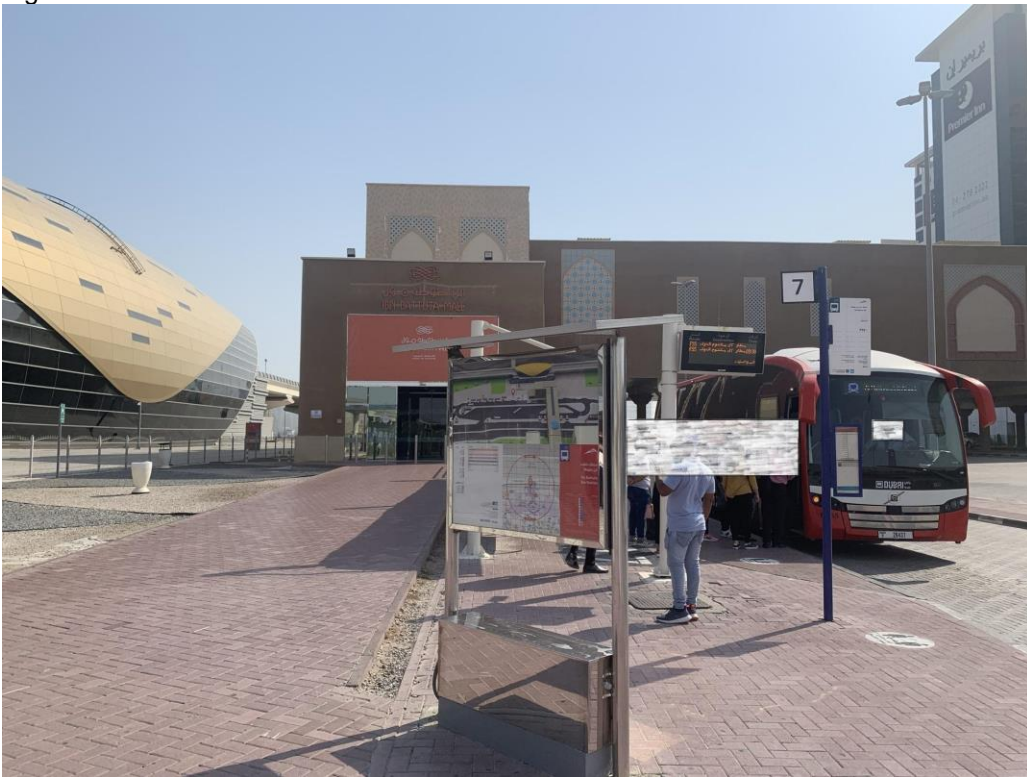


Figure 2 - Ibn Battuta Station (left) and bus stops (right)



Figure 3 - Jebel Ali Station (right) and parking structure (left)



Figure 4 - Dubai Investment Park Station and bus stop



Figure 5 - Expo 2020 Station and shuttle bus stops



Figure 6 - Baniyas Square Station



Figure 7 - Stadium Station and bus stop

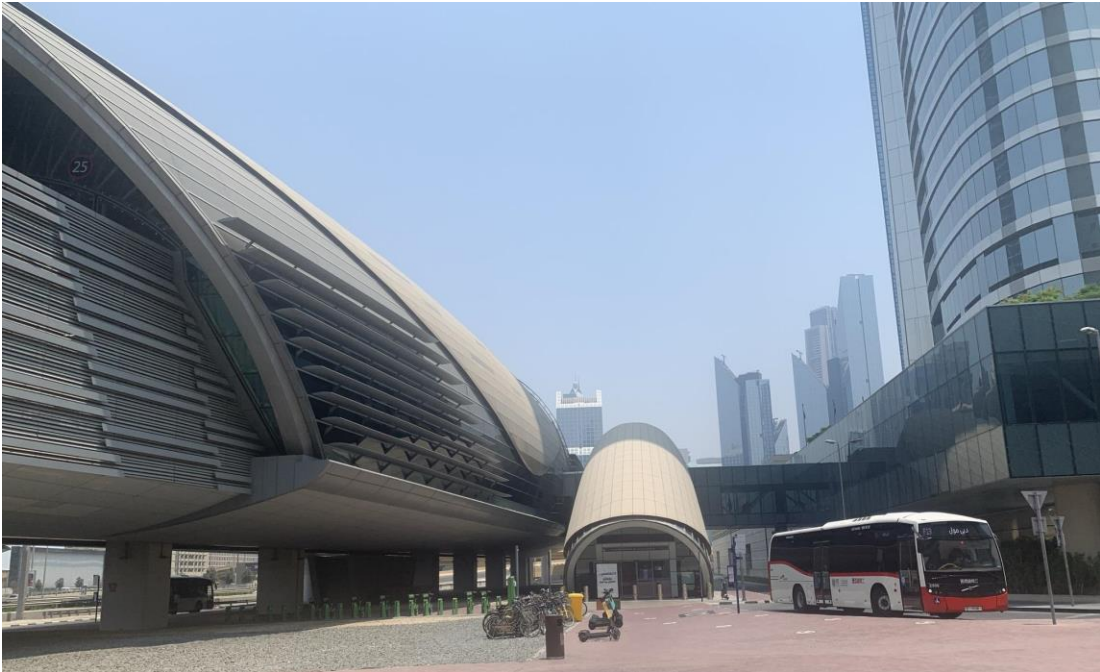


Figure 8 - Dubai Mall Station, bus stop, and pedestrian walkway



Figure 9 - Burjuman Station



Figure 10 - Al Rigga Station



Figure 11 - Gilbert/Main St Station



Figure 12 - Gilbert/Main St Station, transit center seating area



Figure 13 - Center/Main St Station



Figure 14 - Sycamore/Main St Station



Figure 15 - Sycamore/Main St Station, transit center's bus stops



Figure 16 - McClintock/Apache Blvd Station



Figure 17 - University Dr/Rural Station



Figure 18 - Mill Ave/3rd St Station



Figure 19 - 44th St/Washington Station



Figure 20 - 3rd St/Jefferson Station



Figure 21 - Roosevelt/Central Ave Station



Figure 22 - 7th Ave/Camelback Station

APPENDIX C
OBSERVATIONAL NOTES - DUBAI METRO

Dubai Metro - Field Research Notes

Tuesday, August 3, 2021 - Five Dubai Metro stations

(Sunrise 5:47 am - Sunset 7:03 pm)

(5 stations included today: 3 Greenline + 2 Redline)

(Stadium Station, Al Rigga Station, Baniyas Square Station, Burjuman Station, and Dubai Mall Station)

Stadium Station (overground)

7:00 am

Feels like 32°C - weather.com.

Direct sunlight but not sun rays as the sun is still low and harmless. Riders are entering the station walking from the surrounding area but mostly from the bus stop located under the metro station's building. Walking to the station via D93 is also well shaded as the sun is currently to the east behind the buildings. Humidity wasn't felt too much either at this time. There are two Bus stops, one is air-conditioned and the other is open but shaded all day. The area between the bus stops and metro station is well shaded, the space is pedestrian-oriented and there is a pedestrian bridge connecting to the other side of the main street, D93. However, there is not much seating available or trees to provide shade and cool down the weather. The shading is coming from buildings and the station itself. Inside the station, it is cooled and perfect. The overall experience at this time was great.

Al Rigga Station (underground)

7:25 am

Feels like 32.

Lacks a shaded/cooled waiting area for the bus stop (overground) serving the metro station (underground). There is great public primary and secondary seating. The area, in general, is well shaded at this time from the morning sun especially on the eastern side of the station, thanks to the surrounding buildings and the trees on some parts of the sidewalk. You can feel the weather is getting hotter as the sun goes up. The overall experience at this time was fair.

Baniyas Square Station (underground)

7:45 am

Feels like 32.

The station area is surrounded by high-rise buildings providing shading and passive cooling as the wind blows between them into the square over the metro station. Currently, there is no direct sunlight. The area is pedestrian-friendly which is common in older parts of Dubai. Some of the bus stops around the square are not shaded and rely on shade from surrounding structures, but there is a couple of bus stops around the square that is shaded and air-conditioned. The station is accessible from several entry points. It is getting hot here but the passive cooling is helpful to cool down a bit. The station itself is under the ground and well cooled. The station is serving a large number of riders. The overall experience at this time is great.

Burjuman Station (underground)

8:15 am

Feels like 32.

The Burjuman station serves both the Green and Red lines and acts as an interconnecting hub, where riders can easily change between the lines while remaining underground in the air-

conditioned station. Outside however is getting really hot, there is minimum shading around the station and zero trees to provide shade and to cool off the weather. The station is built under an intersection having four neighborhoods surrounding it, two of which have some form of passive cooling that helps reduce the impacts of the weather on riders heading to the metro. Bus stops around it aren't shaded.

Dubai Mall Station (overground)
8:45 am

Feels like 30.

The weather is fairly hot and slightly humid. This station is mainly serving the Dubai Mall, Burj Khalifa, and the new Downtown Dubai area in general. They are connected through pedestrian bridges and the bus stops in shade under the overground station. The bus stops are shaded depending on the time of the day as they are positioned in different spots around the metro station. However, there are no trees or seating surrounding the station or the other side of the pedestrian bridge on the opposite side of Sheikh Zayed Road. The pedestrian bridge over Sheikh Zayed road is cooled and has moving walkways/flat escalators to move you faster, there is also a cooled pedestrian walkway (820 meters) taking you to the Dubai mall. The station itself is also well cooled. The heat is felt surrounding the station as it's surrounded by a concrete jungle with barely any trees to cool down the place or provide shade. The ground temperature of an unshaded area is the highest until now compared to the previous stations. The tall buildings provide good shade for both sides of the street only during certain times of the day, there is a lot of unshaded spots as the area is not very dense with buildings, and pedestrians are easily exposed to the sun.

– End of the morning shift.

– Start of the afternoon shift:

Dubai Mall Station (overground)
12:00 pm

Feels like 48.

It feels very hot, even in the shade areas. There was some breeze from the narrow corridors and sidewalks between buildings but there are only a few of them around the station and not enough to cool down the area. The difference between shaded and unshaded areas was significant especially since it is noon, there are few shaded areas around and huge chunks of open land surrounding the station. Terrible experience for the pedestrians, it is a vehicle-oriented space.

Burjuman Station (underground)
12:30 pm

Feels like 51.

The weather is hot and there is a lot of open space that is affected by direct sunlight at this time. However, this area has many narrow corridors unlike the Dubai Mall area, therefore, it has some form of a passive cooling effect that brings an air breeze into these corridors as people head towards the station. The station's surrounding area lacks however ample shading for all entrances above the underground station. Some of the bus stops are unshaded and a couple are cooled and shaded; however, those are a bit far away from the metro station.

Baniyas Square Station (underground)
1:00 pm

Feels like 52.

The experienced weather is hot all around except when passing by/through narrow corridors that have a passive cooling effect or when walking under the many trees in the square itself. There is a sufficient amount of shade surrounding the station as it is under the square and surrounded by high-rise buildings. However, some of the supporting/feeder bus stations are located many meters away from the metro station without cooled or direct shaded waiting areas making it an unpleasant experience for riders connecting to the station and waiting for their bus to reach their destination.

Al Rigga Station (underground)
1:15 pm

Feels like 52.

The experienced weather here is not too hot because there is ample shading in the area and this could be by far the best public realm surrounding a metro station up until now. The station is underground, and there are very close bus stations above it. The bus stations don't have assigned shaded/cooled waiting areas; however, they do have ample shading from the nearby buildings and trees which provide a lot of shade as they are stacked beside each other. Another noticeable aspect is the abundance of seating areas around the station (primary and secondary). Overall it is a better experience when compared with the other stations included in this study at this time of day and year.

Stadium Station (overground)
1:30 pm

Feels like 51

The surrounding area of the stadium consists of low-rise buildings (including a stadium, department store, police department) that unfortunately do not provide any shade at noontime as the sun is up. The experienced weather is hot and there are few shaded areas surrounding the station where it is comfortable to walk at this time of the day. Fortunately, the bus stations are close and have closed/shaded waiting areas. There is also a cooled pedestrian bridge connecting the metro station to the other side. Many riders rely on the bus system to reach their final destination and its proximity to the metro station is helpful but doesn't save them from the scorching heat as they don't get any shade from the nearby buildings or from the lack of trees in the area.

°° Slight wind was blowing in the afternoon in certain areas today, cooling down riders.

– End of the afternoon shift.

– Start of the evening shift:

Stadium Station (overground)
5:00 pm

Feels like 52

As it is getting late in the evening the sun is slightly down, giving more shade to the surrounding area which is reflected in the measured ground temperature. Few winds but the humidity level is high. The place is now more active as people are heading from the metro station to the bus stops to reach their final destination or shopping in the area, as people are leaving work. The football/soccer league is off during the summer so no one is heading to the stadium. There are several buses waiting in line to go to the bus stations as many riders get off this metro station to get to their homes. The department store's parking lot is full at this time, which is mainly filled by people leaving work in their cars and stopping for some groceries on their way home.

Al Rigga Station (underground)
5:22 pm

Feels like 50.

There is a lot more shade now as the sun is partially hidden behind the buildings and trees around the station. It is slightly windy with a lot of shade to cool you down around the station, especially from the trees on both sides of the road where the entrance to the underground station is accessible.

Baniyas Square Station (underground)

5:37 pm

Feels like 49

It is very well shaded now, the square (above the station) is shaded from mostly all sides. There are few winds going through the square but it is slightly humid.

Burjuman Station (underground)

5:54 pm

Feels like 49

It still feels hot and humid even though it is getting closer to sunset, however, there is a lot of shade as the sun is now down and behind the buildings around the station but since it's all concrete and pavement and no trees or vegetation it is still hot compared to Al Rigga and Baniyas Square stations. You feel the slight winds amplified by the narrow sidewalks, passive cooling systems due to the dense building formation around the station, but this is not felt around Burjuman shopping center as it takes a huge chunk of the land unlike the other three neighborhoods around the station.

Dubai Mall Station (overground)

6:30 pm

Feels like 49.

The sun is setting hidden behind the buildings and the area is fully shaded now. There is a nice cold breeze. And it is just great right now around the station, as it is not too hot or humid.

-End of day, Tuesday, August 3 (5 stations)

Friday Aug 6- Sunrise 5:48am Sunset 7:00pm

(5 stations included today: 3 Green + 2 Red)

(Stadium -> Al Rigga -> Baniyas Square -> Burjuman -> Dubai Mall)

Stadium Station (overground)

10:20 am

Feels like 46

It is hot and dry, the experienced weather is significantly cooler under the shade. There is shade on one side under the metro station while the other side is directly exposed to sunlight (two bus stations). There are very light winds in the area. The station was mostly used by people coming from the feeder buses, who are going to be the same people dropping off at this station later in the evening as they head back home.

Al Rigga Station (underground)

10:40 am

Feels like 46

It is hot and humid, it is evident how a station's proximity to Dubai Creek or the gulf affects the humidity levels felt around the station. The station's two entrances are positioned in a way that they are not providing any shade to their surrounding. There are few trees where people can be walking

and sitting under but in general, it is hot especially if you are waiting at the bus stops above the underground metro station.

Baniyas Square Station (underground)
11:00 am

Feels like 47

It is less hot and humid compared to Al Rigga station surrounding area, the passive cooling caused by buildings here is cooling down the place. Older parts of Dubai have better applications of urban design allowing for passive cooling, I think it is a reflection of how older generations had to deal with heat in such a region of the world and how cities were not as vehicle-oriented as they are today.

Burjuman Station (underground)
11:15 am

Feels like 47

Currently, at Burjuman, the weather is nicer than usual. Even though it is hot and very humid there is still winds coming from the creekside in addition to the winds created by the passive cooling caused by the narrow corridors between all the low/mid-rise buildings. Buildings here are mostly five-seven floors, there's a few higher buildings and they are all positioned in urban design patterns allowing for passive cooling to occur. However, the place is still poorly shaded there's not much shade around the station especially on the main streets, unless you go out and walk between the buildings there is shade but at this time which is 11:30 in the morning there's not much shade as the sun is up. The experienced temperature is hot when walking to the station using the main streets.

Dubai Mall Station (overground)
11:45 am

Feels like 48

Here it is hot and humid as well, however, there are light winds below the buildings which are cooling down riders as they head to the station or wait under it in the open air bus stops. In addition, the main reason for this station's location is to connect you directly to The Dubai mall which you can go to through an air-conditioned bridge so one might think that there's no need for a lot of investments around the station to improve the experienced weather but that is wrong as many riders aren't going to the Mall and are actually working in the surrounding area of Downtown Dubai.

– End of the morning shift.

– Start of the afternoon shift:

Stadium Station (overground)
4:10 pm

Feels like 51

The weather is amazing, the wind is actually cool. It is still hot under the sun and a bit humid. However, it is great in the shaded areas. More areas are shaded all around the station, you won't be sweating due to the cooler wind and low humidity. An interesting seen is the amount of people standing behind the bus stop near the stadium for its shade as the air-conditioned waiting area is full at this time of day.

Al Rigga Station (underground)
4:30 pm

Feels like 52

It was not too hot, but experienced higher humidity. Under the shade, the weather was cool, under the sun not as much. Light winds and air breeze hit you as you walk on Al Rigga street towards the station. The trees on Al Rigga Street give you shade and a sense of fresh air but there aren't any trees in the couple of meters surrounding the station entrances. One side of Al Rigga station is vulnerable to the sun but the other is shaded by the buildings. Both sides of the street have trees giving shade to pedestrians and benches under them but not in the close area around the station entrances.

Baniyas Square Station (underground)

4:45 pm

Feels like 51

The weather is cool in the shade and thankfully there is ample shade provided in the square and the surrounding area above the underground station. However, it is too humid here due to its proximity to the creek. You sweat instantly as you get out of the station even though it is not too hot. There is a lot of shade which is good, shade comes from the buildings surrounding the square and trees in the square itself.

Burjuman Station (underground)

5:10 pm

Feels like 50

It is hotter than the previous station and the humidity is high due to its proximity to the creek. You can feel a cool breeze sometimes but it is not too much to cool you down. The four entrances to the metro station at the intersection are now shaded because of the surrounding buildings and the lower position of the sun. The area around the station can be divided into two, one which is wide open and no wind is felt so it is really hot and humid, while the other part have passive cooling because of the buildings and narrow corridors. Highest humidity level felt during this shift by far.

Dubai Mall Station (overground)

5:35 pm

Feels like 49

It is very windy and cool, but the heat and humidity are immediately felt as the winds stops. The shade around the station is great at this time. The tunnel connecting to Dubai mall is highly used right now, it is congested, which makes sense since it is a Friday evening and people are going to the mall to enjoy the weekend. Thankfully, the air conditioning system in the metro station and the pedestrian walkway are working great.

– End of the afternoon shift.

– Start of the evening shift:

Stadium Station (overground)

10:15pm

Feels like 48.

It is extremely humid, your glasses become foggy instantly as you leave the station. It is strange how humid it is considering how far the station is from the creek of the gulf. It is not windy anymore either, but it is cool inside the station thanks to air conditioning. It is not comfortable outside because of the humidity and air quality as there are barely any trees in the vicinity of the station. The station is busy at this time as the supermarket is still welcoming shoppers even at 10 pm as it is the weekend.

Al Rigga Station (underground)
10:40 pm

Feels like 49

Humidity is high, same foggy glasses. Light winds, it is a better experience than at the stadium station. The place is busy and people are sitting outside in front of restaurants and cafes on this busy street.

Baniyas Square Station (underground)
10:55 pm

Feels like 49

Seems to be a humid night in Dubai, humidity is high here similar to all other areas visited earlier. The experienced heat and humidity is a little less here as more air because of passive cooling systems due to the amount of buildings and their positioning around the square. The square itself has some trees which cools the place down.

Burjuman Station (underground)
11:10 pm

Feels like 49

It is still humid and hot even at this time of the night. There is some cool air breezes especially when passing by narrow corridors. There is fewer people out and about compared to the previous stations as it is getting late in the night. The wide boulevard is bringing in the wind from the creek. It is hot, you will start sweating within 5 minutes from leaving the station and waiting for a bus or walking to your final destination. It is the most humid area of all five stations visited today.

Dubai Mall Station (overground)
11:30 pm

Feels like 48

Humidity is so high that is visible in the air especially since now we are in an open space around the Dubai Mall station. Your clothes will start getting wet and stick on you within a couple of minutes. It is terrible being out waiting for the buses, however, most people are either in the mall or using the closed walkways to get to the metro and are in complete comfort as they have an 800m air-cooled pedestrian walkway connecting them to the air conditioned station insulating them from the outside world, it is really amazing in here given the condition outside. They also have the moving walkways that speed up the trip of reaching the mall or the station.

Such a humid night!

°° Note about all stations: there are bike racks in all metro stations and some have electric scooters to rent parked outside the stations encouraging multi-modal transportation and avoiding cars/taxis.

Monday Aug 9 - Sunrise 5:49am Sunset 6:58pm
(5 stations included today: 3 Green + 2 Red)
(Stadium -> Al Rigga -> Baniyas Square -> Burjuman -> Dubai Mall)

Morning

Dubai Mall Station (overground)
7:25 am

Feels like 32

Since it is early in the morning it feels good and not too humid at this station which is usually has one of the highest temperatures. Some cool air coming through and there is shade in lots of areas

as the sun is still rising and it so not too hot. It is a good morning, you wont be sweating as quickly as other times. People waiting in the bus stops are currently in full shade created by the overground station itself.

Burjuman Station (underground)
7:50 am

Feels like 41

As people walk on the main boulevard heading to the station at this time of the day they are welcomed by the bright shining morning sun. It is still not too hot or humid, there is plenty of shade around 3 of the 4 station entrances, one of them is always exposed to the sun due to the parking lot right beside it. The passive cooling elements are not very active at the moment due to the lack of air coming from the creek? The experienced temperature starts getting uncomfortable after 5-7 minutes of walking in the area. People walking from the bus stops to the station might be fine but people from the surrounding area might feel uncomfortable as they head towards the station.

Baniyas Square Station (underground)
8:10 am

Feels like 43

There is a refreshing breeze but it is getting hot and humid. There is some shade from buildings and trees but the sun has gone over the buildings that provide shade for the square itself so it is really hot under it. Few passive cooling elements are functional at this time of day.

Al Rigga Station (underground)
8:30 am

Feels like 43

It is actually cool under the shade (trees), and passive cooling elements are functional here in most of Al Rigga Street. However, the unshaded areas directly around the station entrances are exposed to direct sunlight, making it really hot but the light air breeze keeps hitting you and cooling you down even though it is not a cool breeze. However, the other side of Al Rigga street is fully shaded due to the buildings and sun position at this time, so it is immediately felt how it is cooler to be on the other side and enter from the second station entrance, but this shaded half is only serving half of the transit riders who use/live on that side of the station.

Stadium Station (overground)
8:50 am

Feels like 43

The two bus station cooled waiting areas are small and get crowded easily, people are waiting behind it for shade as seen in the pictures. It is not humid, there is some air flowing but it is still hot. There is not much shade in the first 100 m radius except under the station itself. The pedestrian bridge taking you to the other side is well cooled and maintainet, it is important as it serves buses that go the other way of Alnahda street.

°° In general, all metro stations were used mostly by commuters. Those five stations were extremely busy and that was noticeable in the surrounding areas. Dubai Mall station busyness was noticed in the 800m walkway connecting to the mall unlike the other stations.

– End of the morning shift.

– Start of the afternoon shift:

Dubai Mall Station (overground)

1:35 pm

Feels like 49

It is too windy so the experienced weather is nice under the shaded areas given the high temperature. It is not humid as well. Actually, even under the sun it is bearable because of the winds that I assume are the aftermath of the rain showers from yesterday in the central region of the country. It is not bad at all, winds and low humidity can actually beat the heat, but the weather is still hot which is obvious from the ground temperature readings.

Burjuman Station (underground)

2:10 pm

Feels like 49

There is a breeze coming from the creekside, it is allowing passive cooling systems to function properly to the maximum. It is hot but not too humid like the previous days. The station entrances themselves are completely exposed to direct sunlight however the surrounding areas vary in shading levels. It is really hot in unshaded areas that aren't affected by winds.

Baniyas Square Station (underground)

2:35 pm

Feels like 48

It is hot and humid. However, the winds from the creek cools you down especially when you pass by the trees in the square. However, there is a lot of unshaded areas except for one side of the square at this time of the day.

Al Rigga Station (underground)

3:00 pm

Feels like 48

As the sun's position changed the shaded parts of the street have switched, now one side is shaded and the other is unshaded (opposite to the morning situation). It is hot and humid, and there is not much air flowing through the street. Few breezes here and there. Clouds are seen far away and this might be the cause of high winds today. Again, trees are effective when they are providing shade and cool down the experienced weather.

Stadium Station (overground)

3:25 pm

Feels like 52

It is windy as the rest of the city, a little humid and sunny! It is hot and there isn't much shade. Luckily two out of three of the bus stops around the metro station are air conditioned.

°° General thought: metro stations need more trees around them to provide more shade and cool down the weather.

– End of the afternoon shift.

– Start of the evening shift:

Dubai Mall Station (overground)

5:00 pm

Feels like 49

It is still windy which is great and the weather is cooler because there are only two hours left to sunset. The unshaded bus stop from the afternoon is now shaded and the other one is exposed. Weather is great, not humid. You wouldn't break a sweat for ten minutes at least.

Burjuman Station (underground)
5:20 pm

Feels like 46

It is windy but the air is a little bit hot but its still cooling you down from the sun's heat. Two of the entrances are fully shaded and well cooled now compared to the other two that are exposed. Burjuman center and the building opposite to it on Khalifa bin Zayed road are huge therefore arent allowing for any passive cooling features like the buildings behind them in the area. The areas behind the main streets leading to the intersection are well shaded now compared to the buildings on the main streets and feel cooler too, passive cooling is more functional here as buildings are separated by narrow corridors and buildings are not too wide.

Baniyas Square Station (underground)
5:40 pm

Feels like 46

Winds are cooling down the square especially that now most of it is shaded as the sun is setting down and hidden behind the mid-rise buildings around the square. A bit of heat and humidity, but nothing unbearable. The Square is alive, it is something I haven't seen during this field research, it is busy with people on all sides and shops and the metro entrances too. Felt great seeing this in the middle of a hot summer day during a pandemic. And everyone is wearing their masks.

Al Rigga Station (underground)
5:55 pm

Feels like 45

It is lovely, wind is going through, the street on both sides are fully shaded around the two station entrances providing some sense of comfort to transit riders. However, it is more humid here compared to the previous one but the air breeze compensates for that. It is beautiful but humid. Humidity is strangely higher here than in other places, it is making you sweat right away.

Stadium Station (overground)
6:30 pm

Feels like 46

It is not as windy as it was earlier, it is hot and humid. However, as the sun sets down the heat is relatively less than when it is up there. There is a lot of cars on the road as it is the main road that people use to leave Dubai after work without paying for tolls. The emissions from the thousands of vehicles passing through might be one of the main causes of this irregularity in climate compared to other previous stations that are even closer to the water bodies. Very hot air breeze as you wait at the bus stop or walk towards the metro station.

AUGUST 10 - The new shift, the next five stations
(DIP, DMCC, Ibn Battuta, Jebel Ali, Expo)

Dubai Investment Park Station (Underground)
7:45 am

Feels like 37

It is a new part of town, with new infrastructure, a new metro station design. It is hot as the sun is going up but it is not humid cause we are far away from the sea now. There are a lot of all sorts of businesses in DIP and riders differ from commuters and residents of the area. The area is still relatively new as the infrastructure is still looking brand new around the station. The DIP station is underground and has two entrances on the main road. There is some vegetation around it but not the type that'll provide shade. The public realm is more pedestrianized than the inner city as witnessed in the red and green lines of the metro. There are nice winds cooling the place and one of the entrances is actually fully shaded. Overall good experience at this time of the day.

Expo 2020 Station (overground)
8:15 am

Feels like 39

The purpose of this station is mainly to serve the Expo 2020 site and it does it well. It has direct access to the exhibition and also provides shuttle bus services for all the exhibition's entrances as it is a massive site. They took into consideration that the Expo 2020 site will be used for commercial/residential purposes once the exhibition is over in March 2022. There is plenty of vegetation around it to cool down riders, most areas are currently well shaded in the morning. There are some winds coming in the proximity of the station. The vegetation is mostly for landscaping purposes to make the place look beautiful and welcoming rather than providing ample shade. Currently, the station is mostly used by expo volunteers and workers who are finalizing the preparation steps for the opening of Expo 2020 in October 2021.

Jebel Ali Station (overground)
8:45 am

Feels like 41

It is hot and humid with some winds to cool off. There is plenty of shade in the vicinity of the station and for the bus stops. There is a cooled pedestrian bridge to the large covered parking structure serving this station. The two main functions of this station are the parking lot for people going into Dubai and the shuttle buses that take you inside of Jebel Ali (industrial free zone area). There is no infrastructure or commercial/residential facilities in the 600-meter range from the station, so you would not see anyone walking to the station.

Ibn Battuta Station (overground)
9:00 am

Feels like 42

The temperature is hot and a bit humid but there are winds cooling off people waiting in the shaded bus station areas. The shades are currently not shading the benches due to their position with accordance to the sun. The station mainly serves Ibn Battuta Mall and the huge bus stops area right outside the metro station. There are many busses that take you around the residential areas (mix of single family homes and multi family homes) around the shopping mall. There is a pedestrian bridge connecting directly to the mall but it is separated from the metro station.

DMCC Station (overground)
9:20 am

Feels like 42

Direct cooled connection to the tram (serving the Dubai marina area and connecting to Palm Jumeirah) with moving walkways to cross from Jumeirah Lake Towers side (metro station) to Dubai Marina side (Tram). While outside the experienced temperature is hot and many areas are unshaded, there are not many trees to provide shade in the vicinity of the station. The Marina area is highly reliant on the high-rise buildings to provide shade for the area, it is hot and humid due to its proximity to the sea. The public realm is designed for pedestrians but isn't providing them with a comfortable experience with regards to the experienced temperature, it is designed to help you get around but not to protect you from the sun or cool you down.

°° Expo was the least used station amongst all of the stations visited as nothing around it has opened yet (Next October) and then comes Jebel Ali station which is only serving riders changing lines and for the park and ride purpose. The other stations were highly used due to their importance and proximity to many working/living spaces.

– End of the morning shift.

– Start of the afternoon shift:

Dubai Investment Park Station (Underground)
12:15 pm

Feels like 47

It is extremely hot but it is not humid. There is barely any shade in the surrounding area as the sun is on the top of our heads. There are few winds blowing but it is still hot and unbearable if you had to walk to your destination for more than 5 minutes. Bike racks are shaded but bus stops are not. You would not sweat immediately as there is no humidity but eventually you would not be able to handle the heat.

Expo 2020 Station (overground)
12:15 pm

Feels like 47

Some winds under the station due to passive cooling systems. It is hot but it is not humid, so it is not easily sweaty but the sun is over your head. You could easily get a headache waiting in the sun or even feel dizzy after a while which is applicable to any other part of the city at this time of the day. The bus stops are shaded by structures rather than vegetation. Large bus stop areas to pick up the riders heading to Expo 2020 different entrances and later on for people that will be living/working in this area. Easy access to shopping mall, park, exhibition center which are located in a walking distance from the station. Shaded area for bike racks and electric scooter stands. Huge shading structures. This is a unique station compared to all the other metro stations, and we are excited to see it running in full capacity when the exhibition starts in October 2021 and being utilized even after the end of the exhibition in March 2022 when the site is repurposed for continuous use.

Ibn Battuta Station (overground)
1:20 pm

Feels like 47

It is extremely hot but it is not too humid. Barely any wind or shade in the vicinity of the station. Riders are exposed to direct sunlight walking around it, except when sitting on the bus stops benches that are shaded and the mall entrance of course, but it is still hot. This reflects the differences in urban design between older and newer parts of Dubai, denser areas that are less vehicle oriented seem to have better experienced temperatures.

Jebel Ali Station (overground)

1:35 pm

Feels like 48

It is hot, however, the station is mainly used by park and ride metro riders and others changing between the red line and the new Expo 2020 extension line. So, they are not affected by the heat as they are spending most of their time inside the air conditioned station.

DMCC Station (overground)

1:55 pm

Feels like 48

It is hot and slightly humid, but there is a lot of winds. The winds are hot in exposed areas and cooler in the shaded areas or between buildings around the station because of passive cooling. The public realm has been enhanced to allow for pedestrian and cyclists to be comfortable and prioritize them over vehicles. The tram also stops in an air conditioned station, so transit riders can exit the metro station and only walk around twenty steps in the sun before entering the tram waiting station which is shaded and cooled. Heat during the summer is the same in Dubai wherever you are in the city, humidity differs from one place to another, and this field research has shown me that urban design allowing for passive cooling can improve your experience walking in the city and relying on public transportation.

– End of the afternoon shift.

– Start of the evening shift:

Dubai Investment Park Station (Underground)

4:30 pm

Feels like 46

It is hot but not too humid. There are more winds than in the afternoon. There is more shade around the most used entrance to the underground station. It is cooler in the shaded areas as the winds cool down and hit you while you wait for the bus in the bus stop area or walk towards the metro station from the surrounding area. There are not many buildings built yet in the area so some areas are still exposed to direct sunlight as you walk on the road.

Expo 2020 Station (overground)

4:50 pm

Feels like 46

The experienced temperature in this station's surrounding area is similar to Dubai Investment Park (DIP) station as they are in the same part of the city and are newly constructed, it is hot but not too humid. However, there is more shaded areas here than in DIP so it feels cooler and the bus stops are shaded and the fact that it is surrounded with buildings from all sides and shading structures also helps reduce heat in this area. It needs more bigger and taller trees other than palm trees to provide more shading and have a cooling effect on pedestrians using the station.

Ibn Battuta Station (overground)

5:20 pm

Feels like 47

There is a nice cold air breeze when under the shade, waiting at the bus stops. It is less hotter than the afternoon but seems to be more humid. The sun is in the golden hour period so it is not too hot at the moment. Most of the area is now shaded by the metro station itself as the sun is behind it, and all the bus stops waiting areas are shaded too. Walking directly under the sun and being exposed to it might not feel comfortable especially given the humidity level and the tiredness after a busy work day.

Jebel Ali Station (overground)

5:40 pm

Feels like 46

Due to the design and the usage of this station, it is comfortable even though it is hot and humid, and that is because all services are situated so close to the station and no buildings around it to walk to. Therefore, users of this station will always be either taking a bus from the shaded waiting areas or their cars out of the shaded car park and not get too uncomfortable no matter the weather. There is passive cooling because of the placement of the buildings all in parallel to each other and it also creates enough shade to get between the spaces around it.

DMCC Station (overground)

5:55 pm

Feels like 46

It is extremely humid, but not too hot at this time of the day. But the surrounding areas are mostly shaded now so when the breeze comes in it is cool and cools you down but the humidity is just too much to handle, it is uncomfortable. There are barely any trees to clear the climate and make it fresher and reduce temperatures during the summer. Trees would be a great shading source too. However, the entire area is shaded thanks to the station itself and the surrounding towers of Dubai Marina but that is partial shading as it depends on the time of the day and it is from structures that are releasing heat instead of cooling down the weather.

°° There is no heat felt from any air conditioning system around the metro stations as it is all underground and not releasing any emissions above ground. We will be focusing more on this topic in the thesis as Dubai RTA have used an underground cooling system for Dubai Metro.

APPENDIX D
OBSERVATIONAL NOTES – VALLEY METRO RAIL

Valley Metro Rail - Field Research Notes

Friday, August 27, 2021 - All ten Valley Metro Rail stations

(Sunrise 5:59 am - Sunset 7:00 pm)

(All 10 stations included today)

(7th Ave/Camelback Station, Roosevelt/Central Ave Station, 3rd St/Jefferson Station, 44th St/Washington Station, Mill Ave/3rd St Station, University Dr/Rural Station, McClintock/Apache Blvd Station, Sycamore/Main St Station, Center/Main St Station, and Gilbert Rd/Main St Station) - *All stations are overground stations.*

Morning shift

7th Ave/Camelback Station

6:45 am

Feels like 31°C - weather.com.

It is not hot yet as it is still early in the morning. There are more trees to the north of the station, on the commercial side where all the shops are. There is a shaded bus stop but currently, riders sitting in it will be exposed to direct sunlight at this time of the day. This station runs on Camelback road in Phoenix which goes from east to west, therefore, I believe there will always be direct sunlight on the south part of the station for those heading east. The ecliptic differs from summer to winter.

Roosevelt/Central Ave Station

7:00 am

Feels like 31.

It is not that hot at this time of day, there is more shading provided by the buildings around the station compared to the shade provided around the previous station. This cools you down as you are heading to the station from the surrounding area, walking under the many buildings in the area. This station goes through Central Ave heading from south to north, and currently, there is not enough shade for those waiting in the northbound waiting areas of the station. The southbound waiting area is well shaded now.

3rd St/Jefferson Station

7:15 am

Feels like 31.

There is ample shading from the building behind the station, the experienced temperature is not that high. This station currently has few to zero riders using it because its main purpose is to serve riders going to watch a game/event in one of the fields or convention centers around it. It goes through Jefferson street from west to east, this is one of the few one-way light rail stations.

44th St/Washington Station

7:30 am

Feels like 32.

You can start noticing that the experienced temperature is getting hotter, especially since this is one of the most exposed stations up until now as it falls on Washington with barely any buildings surrounding it. Most of the users are those connecting to the Phoenix Sky train, while some are connecting with the feeder buses and a few going to the several business parks to the north of the station. Riders are expected to direct sunlight walking to the station, but there is ample shading at

the station itself thanks to the numerous planted trees and shading structures. There is additional seating provided under the trees which are not very common in previous stations.

Mill Ave/3rd St Station
7:45 am

Feels like 32.

There is ample shading in the waiting area of the station, it is getting hotter as the sun is rising but you can cool off in the shaded structure in the middle of the station. Mill Ave's characteristics help improve the experienced temperature by riders using the light rail. The number of buildings and trees providing shade in the surrounding area of the station is higher than most of the other stations visited today. Everything is closer together and streets are narrower with fewer lanes.

University Dr/Rural Station
8:00 am

Feels like 33.

Good shading structures and trees, however, the eastbound waiting area (to Mesa) is totally exposed to the sun at this time of day. Trees do make it more comfortable and improve the experienced temperature around this station. This is one of the unique stations that are not positioned in the middle of a street as it goes through the ASU campus and it also has one of the highest ridership numbers experienced until now in this field research.

McClintock/Apache Blvd Station
8:20 am

Feels like 33.

Not as many trees in the surrounding area compared to the previous station. The Tempe Metro apartment building is doing a great job in providing shade for riders in the light rail's waiting area and pedestrians walking by it. It is getting hotter but the shade helps cool you down as you are waiting for the light rail to arrive. Other than the apartment buildings the area does not have any other characteristics to provide shade for pedestrians walking to the station from the surrounding area.

Sycamore/Main St Station
8:35 am

Feels like 35.

The experienced temperature here is worse than at any other previous station. There are not many shaded areas around it, it is all open areas (parking lots) and small one-floor buildings (offices and commercial). This is one of the park-and-ride light rail stations, which has a designated parking lot for the light rail and bus riders. However, there is only a couple of cars utilizing this parking lot. The pandemic might have reduced the ridership numbers and the number of park-and-ride users. The bus stops have shading structures but are not providing proper shade at this time as the trees scattered around is doing. There should be more trees in the waiting areas supporting the shading structures.

Center/Main St Station
8:45

feels like 34

There is only one high-rise building here as they are preserving the historic buildings in this area. Therefore, the area is exposed to the rising sun, not much shade in the surrounded areas except when walking under the arcade of one of the buildings. It is the most pedestrianized part of Main street in Mesa as streets are narrower and there are more commercial uses attracting more people to the area, and encouraging more people to use the light rail.

Gilbert Rd/Main St Station
9:00 am

feels like 36

This station is extremely exposed to direct sunlight, and it seems like the main purpose of this station is to serve the park-and-ride and feeder bus users. There are several bus stops in this light rail station with designated shaded waiting areas. The parking lot is huge but empty, few users similar to the Sycamore station. All waiting areas are shaded, and there is an additional shaded waiting area/art feature? for both the light rail and bus stops. Even though they are shaded they are not very well shaded because of the design of the shading structures and their positioning. Overall, the experienced temperature is hotter than the stations in downtown areas.

– End of the morning shift.

– Start of the afternoon shift:

Gilbert Rd/Main St Station
11:55 am

Feels like 43.

The sun is up! The weather is hot and dry but there are a few winds here and there. The waiting areas are shaded as the sun is right above it so it's getting full shade better than the shade that was provided earlier today in the morning, this is most experienced in bus stops beside the light rail station. The light rail station is also shaded especially the seating areas, so the seats are fully shaded in the waiting area. Other than that the station is exposed to the sun right now. The area could also be improved by adding some vegetation and trees that will provide shade and cool down the weather on this very hot day.

Center/Main St Station
12:10 pm

Feels like 42.

It is really hot now in this area as the place is exposed to direct sunlight and there is a huge open area in front of the museum. The station is similar to the previous station, it has a seating area that is well shaded as they have special shading elements for riders waiting for the light rail. However, standing around the station will be hot as not the entire place is shaded well. The surrounding area on the Main streets has some form of passive cooling because of the tight buildings beside each other and the arcades too which bring in some of the wind through the walkways.

Sycamore/Main St Station
12:30 pm

Feels like 43.

Sycamore Station also has a park-and-ride option where you could park your car in a huge parking lot and then go to one of the bus stops or to the light rail station, both have designated waiting areas that are shaded. Some waiting areas are well shaded compared to other areas because of the positioning of the sun and whether there is shade on the available seating or not. The entire area would be better if it was provided with more trees for better shade than the current metallic shading structures. Currently, there is a cool breeze but the sun is really hot and the breeze is not cooling down the experience weather.

McClintock/Apache Blvd Station
12:45 pm

Feels like 43.

This station has ample shading thanks to the huge apartment complex behind it. However, there is not much shading provided around other parts of the area which is common in many of the light rail stations. Downtown areas usually have better shading due to the numerous high-rise buildings, narrower streets, and more trees. Light rail stations need more trees and vegetation to improve air quality for the riders waiting in the stations. Stations are usually located in the middle of the roads where riders are constantly exposed to vehicle emissions and are also away from the shade provided by the nearby buildings.

University Dr/Rural Station

1:00 pm

Feels like 43.

It is extremely hot right now as the temperature rises to 44. There is some shading in the area especially on the side going to Mesa (eastbound), there are more trees on that side providing better shade. There is some passive cooling from the surrounding buildings but the station area is wide open and the cooling effect is sometimes lost. Overall, it is hot and there isn't sufficient shading or cooling elements around the station especially on Rural road.

Mill Ave/3rd St Station

1:20 pm

feels like 43

This is by far the best station design wise because the waiting area has passive cooling by the tunnel shaped waiting areas with plants on both sides. It is providing shade and cooling effects. Mill Avenue in general is well shaded because of the buildings being closer together and have plenty of trees that are cooling down the weather which can be seen as well in the temperature measurements.

44th St/Washington Station

1:40 pm

feels like 43

This is the light rail station that connects to the Phoenix Sky Harbor Airport and there's a pedestrian bridge that is air-conditioned. The station itself however is exposed to the scorching heat. The trees might be helping in cooling down but it can't be felt in the experienced weather at this time of the day. Riders are exposed to direct sunlight in the surrounding area of the station as there are not many shading elements around.

3rd St/Jefferson Station

2:00 pm

Feels like 44.

This station has been included in the field research because it is serving riders heading to the nearby arenas and the convention center. The shading structures in the station are like all the other stations, it is only providing shade for the people who are sitting in the waiting area. It is also hot and dry, lowest humidity level. There is some shading provided by the building behind the station but there isn't any vegetation or trees that provide shade. So, it is hot at this time of day, however, this area is mostly used after 5 PM on weekends for attending games and going to indoor events so will not be exposed to the heat for long periods of time.

Roosevelt/Central Ave Station

2:15 pm

Feels like 44.

Well since it's the afternoon, 2 pm, it is extremely hot. However, because of the high-rise buildings surrounding the Roosevelt station, there is more passive cooling compared to the wide-open areas surrounding some other stations. There are more winds coming through between these buildings, so it is cooling down the area as an experienced temperature, not as a measured temperature. When you are in the shaded areas which are ample because of the high-rise buildings there's more shade around the station and when walking to the station. However, the station needs more vegetation similar to some other parts of Central Avenue.

7th Ave/Camelback Station
2:30 pm

Feels like 45.

This station was similar to most of the other visited light rail stations. They all have the same structures for shading and design elements. However, this one is similar to the ones on Apache and Main street because of its east/west direction affecting the shading provided in the station. The eastbound waiting area is not very well shaded, while the other side was shaded perfectly which is going to the west of Camelback Road. The surrounding area is sort of fully shaded as there are many trees within the surrounding residential units and the sidewalks. Trees also have a cooling down effect however there are no passive cooling elements as this is basically a suburb with low-rise buildings and wide streets.

– End of the afternoon shift.

– Start of the evening shift:

7th Ave/Camelback Station
4:15 pm

Feels like 44.

The shading is good on both sides of the station now. Both waiting areas (eastbound and westbound) provide good shading for the people sitting and waiting under the shading structure at this time of the day. However, the weather is it still hot and dry. There are not many winds to cool you down while you wait for the light rail to arrive.

Roosevelt/Central Ave Station
4:30 pm

Feels like 44.

It is still hot and there's actually no more shade for people waiting in the northbound seating area and there's little shade provided for people waiting in the southbound area. There is a flaw in the shading structure's design because it has different panels instead of one structure. Sunlight passes through it and cuts the shade and also heats the seats. There should be more trees and vegetation to cool down and provide more natural shade as well.

3rd St/Jefferson Station
4:45 pm

Feels like 43.

This station is currently highly exposed to direct sunlight. The sun is now at a place where it is directly affecting the area due to the high exposure of sunlight in the waiting areas. There are barely any shaded areas in the vicinity of the station except on the chairs where people would wait for the light rail. Furthermore, walking to the station through Jefferson Street is not shaded but on the other streets going north or south, you could get a lot of shade behind the buildings and some passive cooling as well which is good while walking towards the light rail station but once you get near to the station you'll be exposed to the sun.

44th St/Washington Station
5:00 pm

Feels like 43.

Minimum exposure to direct sunlight as we are getting closer to sunset. In general, the experienced temperature is good now compared to earlier in the afternoon and the morning as there is no more direct sunlight in most parts of the station.

Mill Ave/3rd St Station
5:25 pm

Feels like 43.

The effect of the shaded tunnels is very noticeable here compared to other stations and other waiting areas of the light rail because it has a passive cooling effect on riders waiting for the train. The experienced weather is cooler here because of the shading from the surrounding buildings and the number of trees in the area which is very nice for the people walking around compared to other stations in areas like Mesa where there are not many buildings providing shade for pedestrians walking along Main street.

Gilbert Rd/Main St Station
6:10 pm

Feels like 42.

The weather is now much nicer since the sun is setting. It's the golden hour right now, however, the temperature is still high. There are some few winds coming through the shaded and it is a better-experienced temperature from earlier in the day, more comfortable in the waiting areas.

Center/Main St Station
6:25 pm

feels like 42

It is cooler now as the sun is setting and more areas are shaded. It is still fairly hot but it is getting more comfortable to wait for the light rail compared to the afternoon.

Sycamore/Main St Station
6:40 pm

feels like 42

No more direct sunlight in the waiting area. It's still hot but it is not uncomfortable anymore. A general point is that when visiting the stations after 6 PM, more mosquitoes are out around the station because I guess it is their time of the year after the recent rainfall.

McClintock/Apache Blvd Station
6:55 pm

feels like 41

The entire area is now shaded as you can barely see the sun. However, the heat is still there and humidity is very low but you do get a cool breeze while you're in the shade. The experienced temperature is no longer uncomfortable.

University Dr/Rural Station
7:05 pm

feels like 42

It is now past sunset time but it is not yet dark. It is still hot but the entire station is now shaded because there's no more direct sunlight. However, you can notice the heat from the difference between the pavements that have been shaded for longer times by measuring the temperatures at two different points. It is getting more humid in this area, could it be because of the recent rainfalls?

SUNDAY
AUGUST 29

Morning Shift

Gilbert Rd/Main St Station
9:55 am

Feels like 36.

The shaded area doesn't fully cover the sidewalks and riders dropping off at this final station in Mesa will instantly be exposed to direct sunlight as they get off. However, the ones heading west are well shaded because of the positioning of the sun and they have more shade compared to the other side of the waiting area. Even the shaded area that's provided between the park-and-ride, bus stops and the light rail station is entirely ineffective at this time of day as it is highly exposed to the sun because of its very high shading structures. A general comment for all three stations here in the region there should be lower shading structures. They should be lowered down cause having them so high gives them a bigger opening to get through and expose people to direct sunlight.

Center/Main St Station
10:10 am

Feels like 37.

The sitting area on both sides of the waiting area of the light rail station are currently both shaded at this time of day. The shading structures are well-positioned to cover the seating areas and provide them with shade at this time of day which is in better shape than the one at Gilbert which is a newer station. A good practice in such hot areas is having arcades alongside/under buildings, so that people could go through during the day without being exposed to direct sunlight. It also provides passive cooling as well which is really required in these places at this time of day.

Sycamore/Main St Station
10:25 am

feels like 38

One recommendation for this park-and-ride station is reducing the number of parking spots provided because the parking lot is massive. Having more wasted pavement and asphalt on the ground increases the urban heat effect around the stations. The shading here is not that good as half of the seating areas are exposed to direct sunlight and when measuring the temperatures of the exposed seats and shaded seats you observe a 20°C difference between them. A positive point for the Sycamore station is that they have a lot of vegetation and trees scattered around the waiting areas for the buses, for the park-and-ride and for the light rail station itself as well. However, those trees should have been arranged in a manner that provides more shade for people waiting rather than being scattered in random spots.

McClintock/Apache Blvd Station
10:45 am

Feels like 38.

There are some winds coming through at this time of day, it is cooling people off while waiting at the McClintock light rail station. The shading areas for the people going west is excellent however for the people going east it's a little bit exposed.

University Dr/Rural Station
10:55 am

feels like 39

The light rail station has better shading and better pass of cooling systems because of all the buildings on campus. There are trees here around the station which is cooling down the weather and helping it to cool down and help reduce urban heat effects caused by the streets around it and surrounding the station itself. We also noticed that the shading structures are doing a better job at this station because of the positioning of the structures.

Mill Ave/3rd St Station
11:15 am

Feels like 39.

The tunnel shading structures aren't working as well as at other times of the day because the sun is now at a position where it's able to go through the tunnel. There's some form of passive calling, however, you still feel the heat.

44th St/Washington Station
11:30 am

Feels like 39.

The shading structure is positioned well for the seating areas but the rest of the light rail station is exposed to direct sunlight. Scorching heat at the moment. The experienced temperature is unbearable if you had to wait for more than the regular 15 minutes. This station's main focus is to help and serve the Phoenix sky Harbor international airport so it could have been a closed station to provide shade and air conditioning for travelers. It could have been connected with the pedestrian bridge.

3rd St/Jefferson Station
11:50 am

Feels like 39.

It is extremely hot right now at this time of day, it's nearly 12 PM in the afternoon. There is a nearly 30°C difference between shaded and unshaded pavement in the station. Walking around the public realm in this area you will notice there's not much vegetation providing any shade. The trees around chase field are for beautification/landscaping purposes and not for providing shade. Therefore, the place needs more shade especially on Jefferson Street where people are going to be walking and waiting at the station. It is terribly hot here and currently there are not any people around the area because it's surrounded by empty arenas. The light rail station isn't used at all because there isn't any games or events that are happening. The restaurants and bars behind the station would also benefit from having more trees and shading.

Roosevelt/Central Ave Station
12:05 pm

Feels like 40.

This place at this time of the day is extremely hot. The temperature is over 40 and you can experience it instantly. It is dry too. There isn't much shade even though the sun is now at a position that with proper shading elements it would be completely shaded. Unfortunately, most of the light rail stations have the same design elements including the shading structures that are useless many

hours of the day because of how they are built and configured. Furthermore, there isn't many trees in the stations. The light rail stations are in the middle of the street and there are usually two lanes on each side so they are further away from the buildings, so they are barely getting any shade from those buildings so they aren't providing any shade except for those walking within a couple of meters around them.

7th Ave/Camelback Station
12:20 pm

feels like 40

It's in the afternoon and it is extremely hot here. There is shading for the sitting areas but not for the entire station. Fortunately, Camelback Road has many trees providing shading for those using the sidewalks and the bus stop opposite of the light rail station. There is ample shading from the trees which is nice at this time of day as they cool down the weather a little bit and bring in a cool breeze.

– End of the morning shift.

– Start of the afternoon shift:

7th Ave/Camelback Station
2:45 pm

Feels like 42.

Even though there's a high temperature since it is 3 pm in the evening, however, because of the trees around the station itself the experienced temperature isn't that high even though the numbers are high because you're still cooled off by the winds that come through while you're under the shade of the trees or even under the shade in the seating areas of the light rail station itself. However, one side of the light rail station is highly exposed to sunlight at this time of the day. Some parts of the surrounding public realm have ample shading from the big trees by the sidewalks.

Roosevelt/Central Ave Station
3:05 pm

Feels like 42.

This place needs a lot of shading due to the positioning of the light rail station in the middle of the avenue. It's terrible because it's in an open area and open space and there's no shading from the surrounding buildings as will be seen in the photos. The southbound seating areas have zero shade at this moment and even though there are shading structures provided above the seating areas they are not effective because you're highly exposed to sunlight at this moment of the day. The only shaded area provided on the waiting area for the light rail station is behind the art structure by Roosevelt Street but the seating areas by the light rail tracks are not giving any shade at all.

3rd St/Jefferson Station
3:20 pm

Feels like 42.

This station provides ample shading areas for people waiting for the light rail especially under the seating areas the chairs at this time because of the shading structures. However, right on the back of the station where they have the restaurants there is no shading at all so walking by that area wouldn't be comfortable.

44th St/Washington Station
3:40 pm

Feels like 41.

The station is in serious need of more shading elements especially for the side that is going east. The experienced temperature is a bit high just like the other places, however, there could be more space for improvement here because it has more trees than other stations. Since it is serving mostly people traveling through the airport, the station could have been a closed station as well since you have already built the skywalk you could have also built a closed air conditioned or the public realm could be improved slightly through better design and vegetation.

Mill Ave/3rd St Station

3:55 pm

Feels like 42.

This has got to be my most favorable station in the Phoenix metro because it is located in a densely populated area and it's always busy, day and night, weekend or not, so every day of the week every time of the week the place is busy even though people here aren't highly reliant on light rail. The station is one of the best stations when it comes to providing appropriate shading and seating. The shaded waiting areas where you have vegetation planted within these walls it's cooling down the place specially when the winds are coming through they cool you down as you wait for your light rail to arrive. The passive cooling elements and features that are available to people who are waiting on for the light rail is one of the greatest features and best practices that could be duplicated in other stations. to arrive. Another good thing about the station is that is located in this mixed use development area around Mill Avenue.

University Dr/Rural Station

4:10 pm

Feels like 42.

At this time of the day with this hot weather, it's highly experienced how hot it is here in the area of the Rural station. Half of the station is completely exposed to sunlight right now, even the other half that is shaded is also suffering from exposure to direct sunlight because of the way the trees has been planted and the light rail station has been designed. The congestion on Rural road seems to be increasing pollution in the area and affecting the experienced temperature in this station.

McClintock/Apache Blvd Station

4:20 pm

Feels like 42.

The seating areas on both sides of this station are well shaded, however, the public realm around the station is not shaded and riders walking to the station are directly exposed to heat and sunlight. It's hot even though it's nearly 4:30 PM and the high temperature can be easily experienced as you wait for the light rail.

Sycamore/Main St Station

4:30 pm

Feels like 42.

There are some light winds, so the experienced temperature is not bad especially when you're sitting in the seating areas which are now completely shaded. The surrounding sidewalks are partially shaded by trees and you could still be exposed to heat when walking by and going through the station's waiting areas.

Center/Main St Station

4:40 pm

Feels like 42.

Having more shade structures added around this station is very important as it is currently fully exposed to direct sunlight except in certain areas such as the arcade. This affects the experienced weather and pushes riders away from using the light rail. The place could use more tree shading.

Gilbert Rd/Main St Station
4:55 pm

Feels like 42.

At this time of the day in the evening, it's extremely hot as the temperature goes up to 40° in direct sunlight. Even though the seats in the waiting area are shaded completely, standing in the station or walking to it a rider is still exposed to direct sunlight. There's no ample shading at this moment of the day but it's not that bad, it's manageable as you wait for the light rail to arrive.

– End of the afternoon shift.

– Start of the evening shift:

Gilbert Rd/Main St Station
7:10 pm

Feels like 39.

Tonight's night shift starts from Gilbert Station in Mesa at 7:10 PM, a few minutes after sunset. The lights have been turned on in the stations. Having ample lighting provides a sense of safety and security which is important when designing the public realm around a transit station. Riders can still experience it even though it's dark. The pavement's temperature is now at 45°C which is a bit high, however, the air's temperature has decreased and the experience has improved.

Center/Main St Station
7:25 pm

Feels like 39.

The weather is kind of still hot. There's not too much wind or air flowing through the station or the arcade nearby. No more direct sunlight so there's no more heat as much as it was during the day, however, the heat is still experienced because of the urban heat effect. The lighting is good providing a sense of safety and security.

Sycamore/Main St Station
7:40 pm

Feels like 39.

I guess now we will start having similar experiences from one station to another because the sun has set and the weather is stable, the heat is still felt while walking around the station but there's no more direct sunlight which is good. Here around Sycamore station, there are more trees around so I think they are helping reduce urban heat effects compared to the previous station even though this is a park-and-ride station. I would like to remind you that the park-and-ride parking spaces are a lot and they can be reduced or they can add more trees in those areas because having too much asphalt that isn't even being used is another huge effect on the experienced heat even during the night.

McClintock/Apache Blvd Station
7:50 pm

Feels like 38.

Currently at McClintock and there aren't any air breezes. However, the weather is nice & bearable but you can still feel the heat even after sunset by approximately an hour.

University Dr/Rural Station
8:00 pm

Feels like 38.

Now that it is 8 pm, the experience is nice because of all the winds here and they are passing through the bus stop area because of all the buildings so it's better than the other parts that we have visited previously in Mesa. However, the air that is touching you while you are waiting is hot and it is caused by too many reasons one of which is the emissions coming from all the cars that are congested on Rural road and that's why the air quality is not good. This station up until now has been one of the hottest station experiences in the night shift because of all the emissions around it and the urban heat effects in general.

Mill Ave/3rd St Station
8:10 pm

Feels like 38.

The experience here is better than what we experienced at Rural, however, the air was still a little bit hot causing some discomfort as the wind blows. In general, it is fine as an overall experience. Mills Avenue is noticeably cooler compared to previous stations and it might be from the different design characteristics or that we are 1 hour into our night shift.

44th St/Washington Station
8:20 pm

Feels like 39.

The abundance of office buildings and lack of trees in the surrounding areas of this light rail station has magnified the urban heat effects. The experienced temperature here is hotter than what we have experienced earlier in other parts of Tempe and Mesa.

3rd St/Jefferson Station
8:30 pm

Feels like 37.

This time at this station was actually nicer than previous experiences. There was a lot of wind and air flowing through Jefferson Street actually the hotness of the air wasn't as much as it was felt at Rural road back in Tempe. I think one of the main reasons for that uncomfortable experience on Rural road was because of the car emissions. There aren't many cars here driving by at Jefferson Street and I think that's one of the main reasons why the temperature is slightly cooler, this experience was strange given how this area is usually hot and lacks any trees. It could be that we are getting late into the night compared to where we were an hour ago and that heat is reduced over time.

Roosevelt/Central Ave Station
8:40 pm

Feels like 37.

Luckily here as well at Roosevelt station it was a more comfortable experience because of the winds and the breeze i actually cool and not hot anymore. Again, this might be because it is now nearly 9 pm so the temperatures have decreased compared to earlier at 7 pm. It is not cold but it's a bit cooler, could this be because of not having many cars driving or parked in downtown Phoenix as many people are still working from home and there are no minor congestions like the ones occurring in Tempe. Walking around Roosevelt Street and towards the station feels very nice considering that we are still in August and that it was very hot in the afternoon earlier today.

7th Ave/Camelback Station
9:00 pm

Feels like 37.

This area is until now the coolest area amongst all the stations in the city of Phoenix and I think that's because of all the trees on the sidewalks on both sides of Camelback road. Those trees slightly help in cooling down temperatures and improve the overall experience of riders waiting at the light rail station or the bus stop.

°° Another side note to keep in mind is the idea that having the light rail go through the middle of the street can increase the experienced temperature. Having at least four lanes of asphalt surrounding it also increases the urban heat effects on the stations' waiting areas and what people feel during the day and especially at night. The heat is still here at 9 pm because of how asphalt absorbs the heat during the day and starts releasing it after sunset.

Saturday
September 11, 2021
Morning shift

Gilbert Rd/Main St Station
8:10 am

Feels like 31.

The weather is better today as it has been two weeks since the last field day and we are near mid-September. There are also a few clouds in the sky providing shade for certain areas and cooling them down. The overall experienced temperature is better than previous experiences here at Gilbert.

Center/Main St Station
8:25 am

Feels like 31.

The cloudy weather today has improved the experience as it is providing some shade but not completely as they pass by over the light rail stations. It also has a psychological effect on riders as the sky looks nicer than regular sunny days and gives the sense that it is colder and there is a slight chance of rain. They sure help with providing shade, especially in stations like this one that lacked ample shading on sunny days.

Sycamore/Main St Station
8:40 am

Feels like 33.

There are a few breezes and they're cooling down the weather but as mentioned earlier it is partially cloudy so currently this station is completely exposed to direct sunlight. Previous experiences have shown us how this station needs more trees to provide shade and freshness in the air which is reassured in today's visit.

McClintock/Apache Blvd Station
8:50 am

Feels like 33.

As we enter Tempe we see more apartment buildings appearing that go up to five stories so they provide more shade for the people who are walking to and from the light rail stations near them. For instance, here at McClintock, the Metro apartment complex provides really good in the morning which helps in cooling down the experienced temperature in the area a bit. It is providing shade for

pedestrians on the sidewalk and riders waiting for the light rail going east to Mesa, however, the seating area on the westbound track is not shaded at the moment.

University Dr/Rural Station
9:00 am

Feels like 33.

The trees here in the vicinity of the station and on-campus are providing some cooling effects which is good, however, it's still exposed to the sun. Overall the experienced temperature here is better than those in light rail stations in Mesa.

Mill Ave/3rd St Station
9:10 am

Feels like 33.

this is one of my favorite waiting stations here in the valley because it's the only one that has the tunnel experience what do you have the waiting area covered from the top and the two sides and it's really providing passive cooling and ultimate sheeting for the place it's really good

44th St/Washington Station
9:20 am

Feels like 34.

Unfortunately, this station is the least favorite station included in this field research. It usually has the highest experienced temperatures due to the lack of proper public realm elements around it, from the lack of trees around it and buildings that could potentially be providing shade for pedestrians walking by. However, it is mostly serving riders heading to the airport or the bus stop nearby, which might be the reason why it is sort of ignored in comparison to other stations.

3rd St/Jefferson Station
9:35 am

Feels like 34.

This is also a station that lacks proper public realm elements given the scorching heat of the summer months here in Phoenix. There should be more shading elements and they can surely have more trees in this area. After all, this area is highly used by pedestrians on certain days and events. This area has more potential given the surrounding land uses, but it does not seem too attractive at the moment. The overall experience in this station has barely improved since the August visits and the experienced temperatures here are higher than what has been experienced earlier in Tempe.

Roosevelt/Central Ave Station
10:10 am

Feels like 37.

Strangely the experienced temperature here is currently worse than what it was at Washington street station. There could be several explanations for this, such as it being surrounded by more buildings, therefore, more heat is being released from air conditioning systems around it. It could be because the buildings are far away from the station because of the position of the station in the middle of the avenue so riders are not getting enough shade. Another reason could be the lack of trees, the Washington station had more trees providing shade in the seating areas.

7th Ave/Camelback Station
9:50 am

Feels like 34.

This station does a good job of providing trees on both sidewalks of the street. Cooling down the area and helping provide more shade for pedestrians and light rail riders. One of the setbacks of having the light rail route going in the middle of streets and avenues is that they are farther away from the sidewalks and any shading elements that are available. Therefore, you need to have proper shading structures and plant more trees on the station platform to have a better-experienced temperature. The experience here is better than on Roosevelt street.

– End of the morning shift.

– Start of the afternoon shift:

Gilbert Rd/Main St Station

12:00 pm

Feels like 39.

It's extremely hot now in the afternoon. There are fewer winds blowing compared to earlier in the day but it is still sort of cool when waiting/sitting under the shade. However, as soon you get out in an unshaded area and get hit with direct sunlight the experience worsens immediately.

Center/Main St Station

12:20 pm

Feels like 39.

You feel the heat instantly when getting out and while walking around the station. The station provides shade on one side while the other side is exposed to the sun. One-floor buildings don't provide any shading to their surroundings, so there is barely any shade around this station.

Sycamore/Main St Station

12:35 pm

Feels like 39.

It is still extremely hot, however, since it's partially cloudy today and the clouds are sometimes covering the sun riders feel relieved especially when a little cool breeze hits them while waiting at the station. The overall experience has improved over the past two weeks.

McClintock/Apache Blvd Station

12:45 pm

Feels like 39.

Currently, the entire area is shaded by the clouds which slightly improves the experienced weather. The area is cooler compared to previous experiences and by measuring the pavement's temperature we notice an improvement in the temperature differences between shaded and unshaded areas.

University Dr/Rural Station

1:00 pm

Feels like 39.

One thing that I have noticed quite often with light rail stations such as the one on Rural Road is that due to their proximity to a very busy intersection the weather is always at least 1°C higher than the other stations around the area such as McClintock and Mill Road in this example. This might be due to the fact that there is the ongoing construction and the intersections on Rural road are

often congested; therefore, increasing emission levels in the area and affecting the temperatures here. Therefore, we should be looking into solutions to reduce these heating impacts.

Mill Ave/3rd St Station
1:10 pm

Feels like 39.

I am starting to think that the Mill Avenue light rail station is the best amongst this selected group of stations. IT provides an innovative solution for shading and passive cooling by having a unique structure on the waiting area platform. The tunnel-shaped structure provides a unique experience, unlike any other station. Furthermore, the public realm of the surrounding area and Mills Avenue also help in improving the experience of riders using this station even on hot summer days.

44th St/Washington Station
1:20 pm

Feels like 39.

As usual, this station has a significantly higher experienced temperature compared to some other stations that have better urban design characteristics and properties. As a traveler coming from the airport, one would really wish to have a closed air-conditioned station especially after long flights and while carrying several bags or items. It might also be encouraging for airport employees to start using the light rail when having a better experience.

3rd St/Jefferson Station
1:35 pm

Feels like 39.

It is evident that some parts of Phoenix have higher temperatures compared to other cities in the metropolitan. The entire area around the Jefferson station is completely exposed to direct sunlight except for the shaded areas in the station platform. Pedestrians are being exposed directly to sunlight when walking around the station. Visiting this station in the afternoon you feel like you are in an abandoned city, there's barely any people here due to the lack of events and the afternoon timing.

Roosevelt/Central Ave Station
1:45 pm

Feels like 41.

It is extremely hot now in the afternoon specially that the sun is right above your head. The temperature I believe will be around 40°C, the experienced temperature would be even higher due to the dry climate of Phoenix. Waiting areas aren't completely shaded so half of the seats are exposed to direct sunlight so it's hot even when you are trying to sit and wait for the light rail to arrive. This station needs some improvements in shading.

7th Ave/Camelback Station
2:00 pm

Feels like 41.

This is the best station in Phoenix because of all the trees around it and how it is usually a better experience here compared to other stations in the city of Phoenix. It is amazing even though it is really hot and you can feel the heat when you are directly exposed to the sun but once you're in the shaded areas and sidewalks, the cool breeze improves your experience using this station.

– End of the afternoon shift.

– Start of the evening shift:

Gilbert Rd/Main St Station

5:10 pm

Feels like 42.

This light rail station is a park-and-ride parking area and tonight is the first time I have seen it busy on a weekend. Today is game night for the Sun Devils who would be playing in Tempe so people are coming here from different parts of Mesa or even further cities/towns to park their cars and go use the light rail to get to the stadium. Parking here is free of charge unlike the paid parking lots in downtown Tempe that will be full tonight. The weather is still hot even though we are getting closer to sunset. There is enough shading for the riders so it's a more comfortable experience today compared to previous data collection days.

Center/Main St Station

5:25 pm

Feels like 41.

It's a bit cooler than the previous station as there's more wind flowing around the station. There is more shade now but the experienced weather is still hot, it is nearly 40°C. One more thing I have noticed is that there are a lot of people using the light rail station now compared to other times. It seems to be busier than any other day, could it be because of the Sun Devils game? This is interesting.

Sycamore/Main St Station

5:40 pm

Feels like 41.

This station is also a park-and-ride station there are more cars now than there were in the morning. This one had more people riding the light rail and waiting at the bus stops. The weather here is not that nice, it's still hot around 40°C so you need to be in a shaded area below a tree or shading structure while waiting.

McClintock/Apache Blvd Station

5:50 pm

Feels like 41.

The experienced temperature here is a bit better than what I have experienced at the park-and-ride stations due to the number of buildings in the area providing shade. The waiting areas are fully shaded now since the sun is setting down.

University Dr/Rural Station

6:00 pm

Feels like 41.

The experienced temperature at Rural is hotter than in other parts of the city as usual. With the intersection being congested more than usual because of the game tonight, it shows how car emissions can directly affect the experienced temperature in the surrounding area. There's a lot of shade now considering that the sun is setting down. It is slightly better than what it was two weeks ago.

Mill Ave/3rd St Station

6:10 pm

Feels like 40.

Yet again, Mill Ave station has the best experienced temperature and conditions compared to the other stations. It is hot but still cooler than the other stations.

44th St/Washington Station
6:30 pm

Feels like 40.

Getting closer to sunset, it is slowly cooling down but still hotter than Mill ave.

3rd St/Jefferson Station
6:40 pm
Feels like 40.

The sun is not visible anymore, it's hidden behind the high-rise buildings as it is sitting down here in Phoenix. However, you could still feel the heat effects by measuring the difference between the pavement that was shaded and the parts that were not. The experienced temperature has improved relatively compared to the afternoon, there is a cool breeze.

Roosevelt/Central Ave Station
6:50 pm

Feels like 40.

The area is now shaded as it is sunset time but you can still experience the heat in the surrounding area. This area needs some improvement in the public realm around it and supporting it.

7th Ave/Camelback Station
7:05 pm

Feels like 38.

So now that the sun has set and it's 7:05 PM here in Phoenix Arizona the heat is still there but it's lower than in other parts of the city especially since we have more trees here compared to previous stations visited today.