Façade & Atmospheric Temperature Relationship

A Brick Façade Research Study

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Abstract

An urban environment is impacted by the urban heat island effect and as such has a higher temperature than that of surrounding rural areas, this is caused by the use of human construction materials such as concrete and bricks causing differences in albedo, emissivity and heat capacity as well as differences in vegetation cover. One aspect of this which is lacking in research is the connection between the temperature of the façades of buildings and the atmospheric temperature. This report will therefore be studying how a brick façade interacts and is connected to the atmospheric conditions and see which aspects have the greatest effect. This was achieved by measuring the properties of the façade and comparing them to downloaded weather data. The results show that while in shaded conditions there is a very strong correlation between façade and air temperature, with other factors such as solar radiation having a minimal impact. In sunlit conditions, the air temperature does still have an impact, but it is vastly outweighed by the impact of solar radiation which is the main factor behind the façade temperature, on the sunny side there are also other factors such as wind which causes thermal convection from the ground which has a noticeable impact on the façade temperature rather than being dominated entirely by a single factor. It was also found that the albedo of the façade was quite low at 0.38 which gives it a low reflective ability and makes the solar radiation more impactful. The emissivity was also calculated and found to be rather high at 0.81 causing a noticeable emission of energy from the façade which can lead to a quick drop in temperature in the evening unless outweighed by other factors such as heat storage.

Keywords: *façade, temperature, emissivity, albedo, solar-radiation, IR-camera*

1. Introduction

As the human population continues to grow, so too does the cities of the world (Ritchie & Roser, 2018). More and more people are moving towards urban regions thus making them more densely populated which in turn causes several problems such as higher resource demands, local climate fluctuations, air pollution, and traffic jams (Yin et al. 2018).

A major consequence of growing cities is the land surface temperature increase in urban areas called the Urban Heat Island Effect (UHI). The UHI effect is a phenomenon that increases the thermal heat of cities in comparison to suburban and rural areas due to anthropogenic causes (Oke, 1980). The UHI is determined by a diverse range of factors such as decrease of evapotranspiration, increase of anthropogenic heat, low air circulation, pollution, topography, size of city, solar radiation, albedo and building form, geometry, and building materials (Loh, 2019; Madina et al. 2019; Morini et al. 2017).

Of the factors behind the UHI, the two most important of these are anthropogenic heat and building materials. With the ever-increasing energy demands of growing cities causing more anthropogenic heat as a by-product and the use of human building materials which retain a larger amount of heat, the need to counteract these effects grows (Mohajerani. 2017). One solution to mitigate the UHI is to implement green spaces or vegetation in urban areas that can act as cooling zones. Cooling the areas that are near-by and/or shaded by the vegetation (Park et al. 2017). Another solution which mitigates the UHI impact on humans is the usage of air-conditioning that maintains a cool temperature in human living spaces, this unfortunately has the side effect of further raising the outdoor temperature and boosting the UHI, making this an important problematic measure to solve in the future. Air-conditioning is also relatively new in many countries and thus will be used for a long time to come (Salamanca. 2014).

1.1. Background

As mentioned above the UHI effect is influenced by the surface properties of façades on buildings such as what material the walls are made of. Depending on the characteristics of the material of walls, the cooling rate can either increase or decrease, hence contributing to the UHI negatively or positively respectively (Loh, 2019). The properties of the material to handle heat depends on four parameters, these are albedo, emissivity, specific heat, and thermal conductivity which will be discussed in detail below.

One of the many causes that influences the façades' cooling and heating is the albedo properties of the building material (Morini et al. 2017). Albedo is measured on a scale from 0 to 1 that indicates on a surface's reflectivity ability of all incoming short-wave light. A material that has an albedo of 0 absorbs all the radiation while an albedo of 1 reflects all radiation. The albedo of a surface depends on the color and roughness of the material. A darker colored surface thus absorbs the heat from the sun and becomes warmer than a lighter surface. This gives materials with high albedo lower cooling loads and light materials higher cooling loads (Madina et al. 2019).

According to the American Environmental Protection Agency (2008), another possible influence of the cooling and heating effect of façades is the property of thermal emissivity of a building's material. Emissivity is the ability of a material to emit or absorb radiation (W/m^2). It scales between 0 and 1 as albedo. A material of emissivity 1 tends to emit thermal radiation easier, while a material closer to 0 will emit thermal radiation much worse, thus having a higher threshold.

Two other parameters that influence the heat characteristic of building materials are the specific heat capacity and thermal conductivity (Wonorahardjo et al. 2020). Specific heat capacity (KJ/(kg K)) is the amount of heat that is able to be stored in a material for every one degree rise in temperature (^oC). Thermal conductivity (W/(m K)) is the rate of heat transfer inside a material. Furthermore, the larger the density (kg/m^3) of a material the lower specific heat it has compared to a more aerated material with less density.

Façades are usually built out of a few different materials, the most common of these in swedish residential buildings since the post-war period would be variants of concrete, metal, wood, and brick (Berggren, B. 2019). Of these wood heats up and reaches peak temperature fastest, followed by concrete and bricks trailing behind. Brick and concrete however have a considerably higher thermal capacity and are as such believed to be the main factor behind the UHI (Wonorahardjo et al, 2020).

1.2. Previous Research

Previous research has found that the orientation, building form, fenestration and building materials used have a considerable contribution to how much energy the building absorbs (Fathi, El Bakkush, Bondinuba, Harris, 2015). As such the temperature of the façade of a building will depend heavily on what material it is made of as well as how it has been positioned in relation to the sun and to surrounding structures.

Dietrich (2018) showed that air temperature without solar radiation, in a clear cold sky, has good correlation with the material of a building's surface temperature, which decreases in time together with air. This is true for many of today's building materials where the lightest materials i.e. plaster, cladding, and wood receive the smallest impact and heavier materials i.e. concrete, pavement, and bricks are impacted the most by temperature decrease. With the impact of radiation from the sun, brick façades in particular rise above air temperature during the sun-touched hours and decrease accordingly with the lack of sun. Furthermore, the ground temperature if made of tarmac, increases drastically compared to air temperatures, with up to 20 degrees.

According to Nazarian & Kleissl (2015), wind speed can have a cooling effect in the early mornings during sunrise depending on the angle, particularly on the east side of buildings when a rise in contrast between air and wall temperature happens. This phenomenon gets smaller when dominated by the buoyancy effect and solar radiation during the rest of the day. On a calm sunlit day, the solar radiation alone can cause a thermal convection flow, both from the façade and the ground, to rise along the wall which can increase the façade wall temperature in higher elevation further (Mu, Gao & Zhu, 2018; Nazarian & Kleissl, 2015).

A study by Yu et al (2008) has shown that the albedo of a façade can have a major impact on how much heat energy a façade can absorb, with it being able to lower the summer temperature by a noticeable amount if the albedo is increased. For this reason, the albedo of a façade will play a role in how the temperature façade is connected to the temperature of the air and solar radiation.

According to Zinzi (2016), the emissivity of the most common building materials do not vary greatly and are relatively high, around 0.9 (except metallic surfaces) and thus are very effective at re-emitting the absorbed radiation which makes these surfaces good cooling materials for buildings.

Wonorahardjo et al. (2020) found that the surface temperature of wooden walls, when exposed to radiation, increased much faster and became warmest compared to material with higher density, like brick. When it comes to cooling, wood tends to cool faster than bricks due to the higher thermal conductivity of bricks that transfers the heat to the centre and stores it there. While the lower thermal conductivity of wood prevents the heat from storing deep into the material and hence the cooling is faster.

1.3. Purpose and Aim of Study

The purpose of this research study is to compare the measured temperature of the University of Gothenburg's Earth Science Department buildings' façade with an infrared camera and the air temperature of the atmosphere surrounding it. Additionally, to see how incoming solar radiation has an effect on the building façade and calculate albedo and emissivity of the façade material. The aim is the following:

- Find out the relation between the observed temperature of the building façade compared to the temperature in the atmosphere.

- Find out the relation between the observed temperature change of the building façade compared to the incoming solar radiation.

- Find out the albedo, emissivity, and the heating rate of the building façade.

2. Method & Materials

2.1. Site Description

Geovetarcentrum (GVC) is situated in Gothenburg, Sweden's second largest city. It is located on the outskirts, south of the city center, and is elevated up on a hill (*figure 1*). In general, the area where GVC is situated is relatively open and is not likely to be affected by the UHI as much as the city centre. We took measurements on all sides of the building and they will be referred to by their geographic orientation. The South East side points towards an open pavement that is paralleled to a traffic road, creating a relatively broad open area before encountering a large rock formation covered with vegetation and another building on the other side. The South West is neighbouring with an open area with mostly low vegetation and some trees, the North East is secluded by a rock and an elevated small parking lot with a few trees. While the North West is met with an open area with a parking lot and some low vegetation before encountering apartment buildings.The façade of GVC is built out of yellow/beige tinted bricks which has small gaps between each one filled with mortar (*figure 2*).

Figure 1. A top view of the GVC building and the respective points where the measurements were taken.

2.2. IR Camera

To take temperature measurements a FLIR infra-red camera of the model *FLIR E6 Wifi* was used. The following settings were selected for the temperature measurements in order to be accurate for our selected surface and measurement conditions, Reflected temperature: 20°C, Distance 2m (*section 3.5*) and an Emissivity of 0.81 which was calculated later in the emissivity method section.

2.3. Façade Temperature Measurements

Measurements were taken from each of the four sides of the GVC building (*figure 1*) with the IR camera. They were taken once every 15 minutes on each side for 3 hours. A specific brick was selected on each side at about 2.45 m height and measured from 2 m away. Three measurements were taken on each brick and used to calculate an average to take into account the local variance. One of the sides (*figure 2B*) had alternating layers of bricks sticking out further than the rest, as such for this side 3 measurements were taken on the ordinary bricks as well as the ones poking out to calculate an average once again to account for possible differences. The raw data was initially written down in a notebook and later compiled in Excel and saved as a *.csv* file for further analysis in MATLAB © *1994-2021 The MathWorks, Inc.*

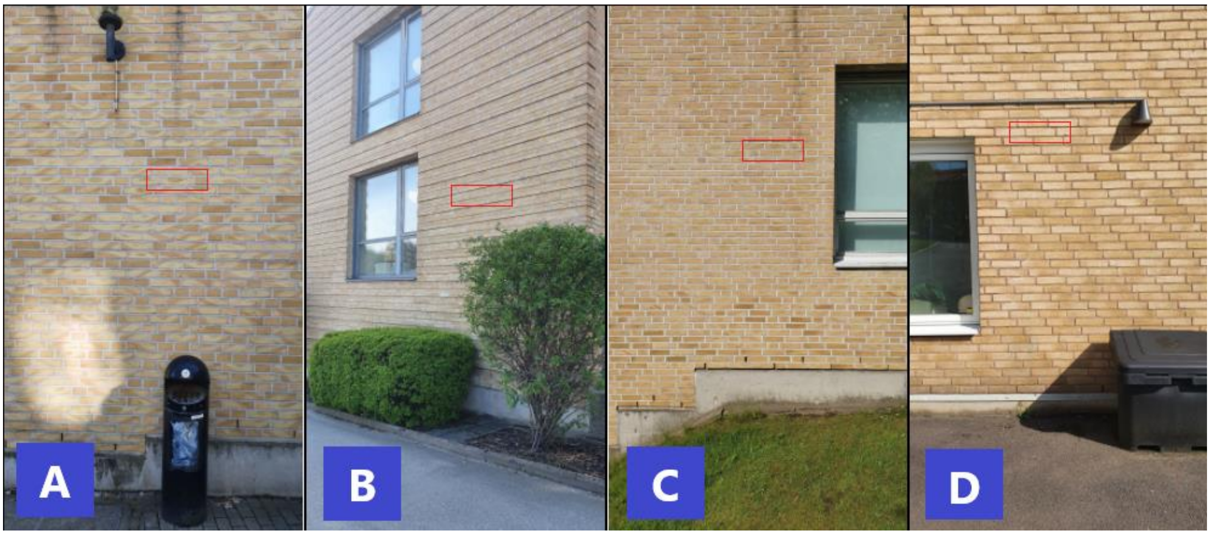

Figure 2. Pictures showing the four sides of GVC where A is the North East side, B the South East side, C the South West side, and D the North West side, with the respective points on the wall marked with red where the measurements were taken.

2.4. Observed Temperature Measurements, Solar Radiation & Wind Speed

Observed and incoming Solar Radiation (short-wave) data were gathered from the Swedish Meteorological and Hydrological Institution (SMHIa, 2021), with hourly measurements of both the temperatures and radiation, from the stations *Göteborg A,* which is located to the northeast of the city centre, and *Göteborg Sol,* located in Chalmers University relatively near to GVC, respectively. The radiation data downloaded from SMHI is called "*global solar radiation*" which is according to SMHI a combination of direct radiation from the sun and scattered radiation from the clouds and sky (SMHIb, 2021). The data was edited in Excel and saved as a *csv*. file for further analysis in MATLAB © *1994-2021 The MathWorks, Inc,* (*section 2.6*). The wind speed data was also gathered from SMHI with hourly measurements from the station *Göteborg A.* This data was then edited in excel and used in MATLAB to create a figure which was inserted into the wind section of the results (*figure 10*).

2.5. Albedo

To calculate the albedo of our brick surfaces we used a simple method inspired by Gilchrist (n.d.). Three digital photographs were taken on the brick wall on the South East side of the building with a white A4 office paper taped to it (*figure 3*). The photos were taken from two different mobile phones with the same CMOS sensor, whereas two photos from *Samsung Galaxy S10* and the third from *Samsung Galaxy S10 Plus*. The images were later analysed using a free image software program called *ImageJ* (2021). The software program is available for download or used directly through the browser. Histograms were created for the paper and the brick wall separately where the mean brightness values were taken (*figure 3*). Because the brick wall had gaps between the individual bricks, four separate values were gathered of four different bricks in one image and an average was calculated amongst them. The recorded mean values of the paper and bricks were put in an equation to calculate the *relative albedo,* by calculating the ratio between the unknown surface (brick) and the referenced surface (paper):

$$\mathbf{Albedo_{rel} = B_{unknown} / B_{reference}} \qquad \text{Equation 1}$$

Where; $\mathbf{B_{unknown}}$ is the mean brightness of the unknown surface and $\mathbf{B_{reference}}$ the mean brightness of the known surface. To calculate the *absolute albedo* of the brick the *relative* *albedo* was multiplied by 0.65; which is the known absolute albedo of an A4 office paper (Gilchrist, n.d.):

$$\mathbf{Albedo_{abs} = 0.65 \times Albedo_{rel}} \quad \text{Equation 2}$$

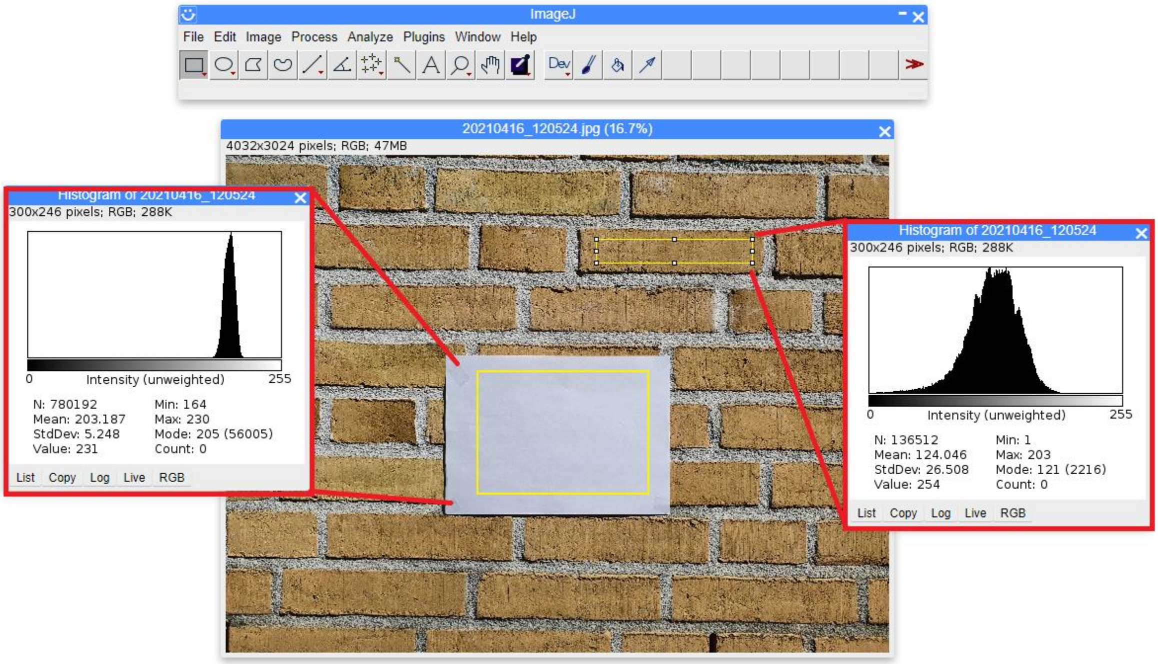

Figure 3. Histograms of the brightness levels from the A4 office paper and from one of the bricks, shown in ImageJ. (Figure is only an illustration and the values were not used).

2.6. Emissivity

In order to calculate the emissivity of the wall, we followed the instructions from *Crimson Industrial Vision* (2017) to get a good estimate. Firstly, we calculated the emissivity of black electrical tape which was done by placing the tape on a stainless steel pot filled with boiling water, after waiting 5 minutes to give the tape time to absorb the temperature from the water the IR-camera was used to measure the temperature of the tape (*figure 4*). Since we know that boiling water is 100°C and that the tape should have nearly the same temperature we could then adjust the emissivity setting on the camera until it showed a temperature of 100°C on the tape. After calculating the tape emissivity we went to the GVC building and placed the tape on the brick façade (*figure 4*) and waited approximately 15 minutes to give the tape time to exchange temperature with the wall behind it. As we then knew that the wall behind the tape should have nearly the same temperature as the tape itself we could measure the tape temperature using its known emissivity for the settings, after that to get the wall emissivity we removed the tape and adjusted the emissivity value immediately before it had time to cool down until the IR-camera showed the same temperature for the wall as it did before for the tape giving us the correct value for the wall.

Figure 4. The methodology of measuring emissivity of the electrical tape (left) and the brick wall (right).

2.7. MATLAB analysis

Façade temperature and atmospheric temperature combined with solar radiation for each day (*figure 7*) show the trend of the different types of temperature and their correlation to the trend in solar radiation. In addition to this, the façade temperature during every day on each side of the building (*figure 5*) shows how the temperature develops over the measuring period for each of the sides. Lastly, we also have the change in façade temperature between each hour of the day combined with the current solar radiation (*figure 8*) which shows in which direction and how quickly the temperature is moving at a given hour and how it is connected to the incoming solar radiation.

2.8. Risk Assessment

Before we started our research study, we submitted a risk plan detailing precautions to the university in order to get approval for the project. This study was conducted during spring of 2021, as such precautions had to be made to take into consideration the ongoing COVID-19 pandemic as well. The precautions were:

- To be aware of incoming traffic and follow regulations.
- To always wear a face mask and to keep as large of a distance from people as possible while conducting the fieldwork for the project.
- To travel privately to and from the fieldwork by foot or car instead of public transport.

- To have all cooperative report work done remotely over zoom instead of in person at the GVC building.
- To have remote contact with our advisor over zoom and e-mail.

3. Results

3.1. Façade Temperature Measurements

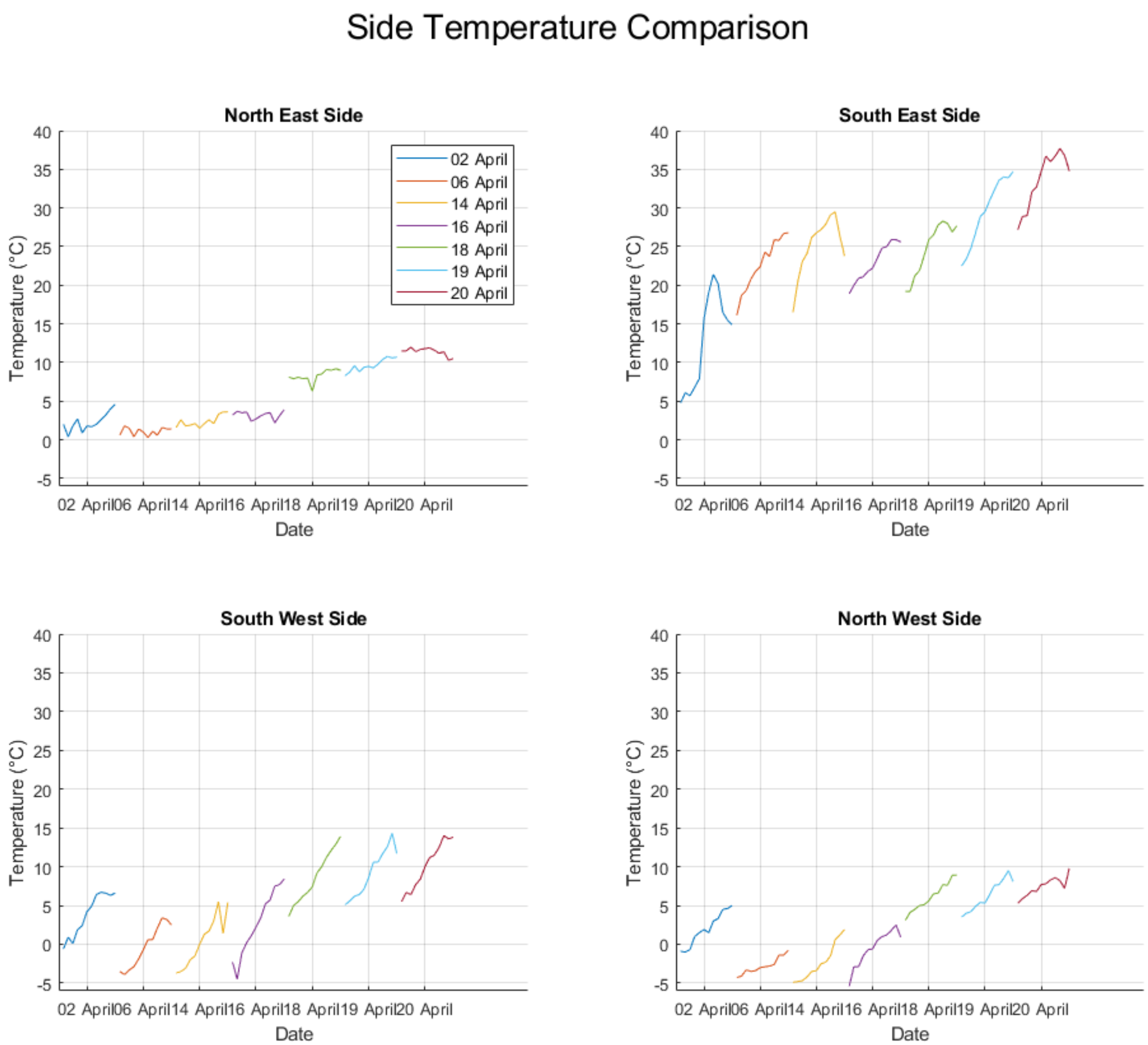

Figure 5. Comparison of façade temperature measurements from day to day for each side of the GVC building.

The result from our temperature measurements (*figure 5*) showed a general increase in temperature as the day went on and a frequent drop at the end of the day, but with certain sides such as the North East being more gradual while others such as the South East/West had a more sharp increase. It also showed an increase in temperature as the month progressed where later dates generally had higher temperatures, albeit with a few exceptions such as the 2nd of April on the North West side or the 14th of April on the South East sides where they were higher than some later dates.

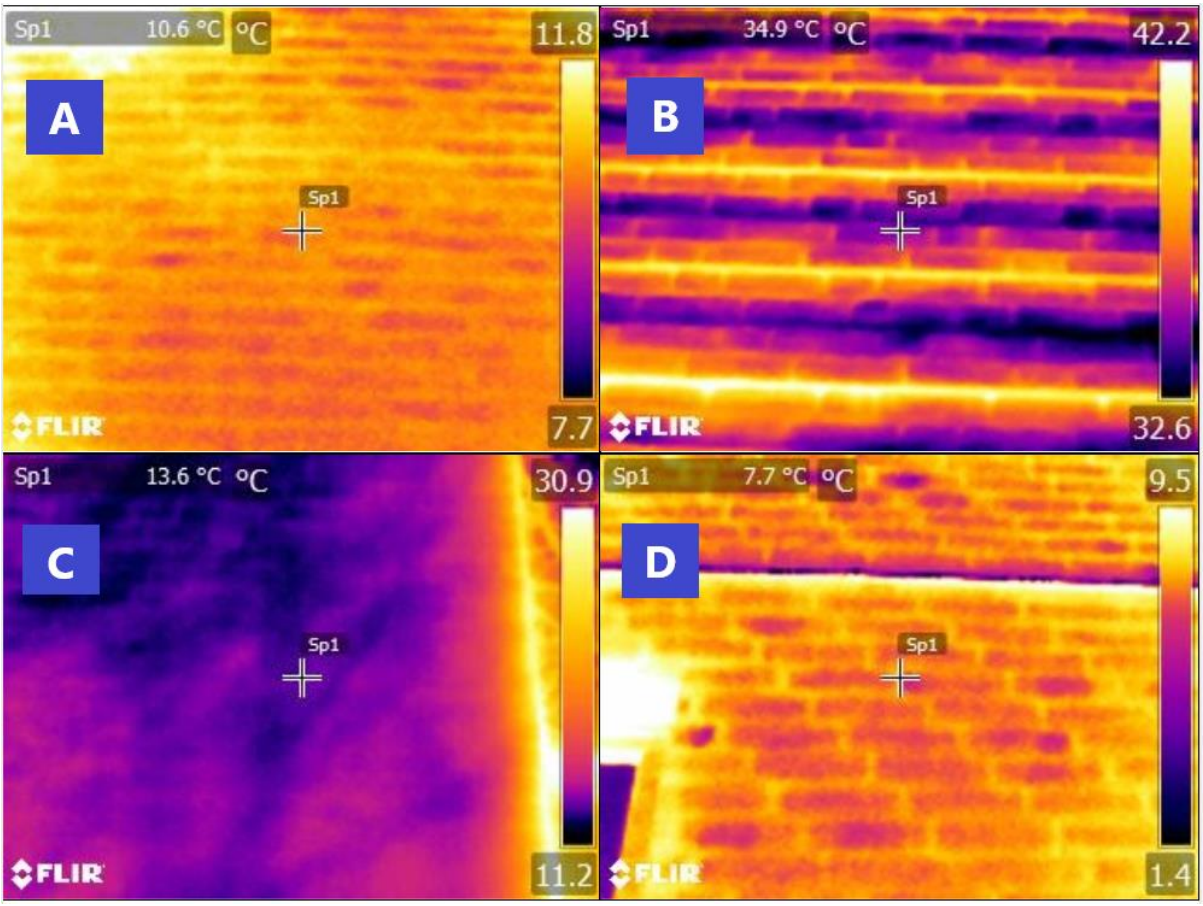

Figure 6. Example pure IR-images of the four sides where the measurements were taken. Where A; is North East, B; South East, C; South West and D; North West.

In *figure 6C*, there are pronounced shadows of tree branches that cover the sunshine from the wall around 11:30 on each day which may affect the temperature dynamics of that side. On the other sides there are no shadows covering the walls during the entire timespan of our measurements.

3.2. Observed vs. Façade Temperature Measurements

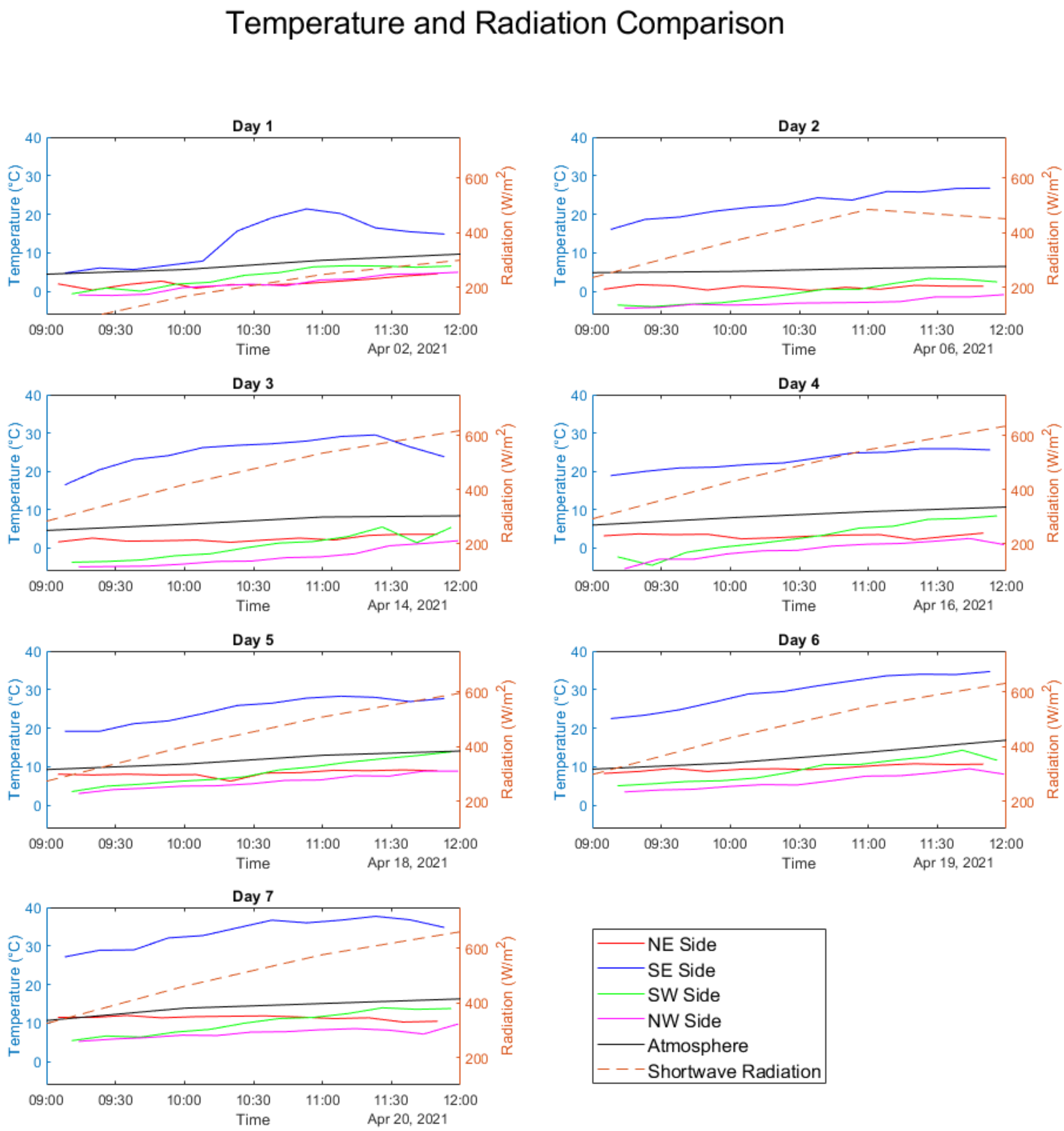

Figure 7. Comparison between façade temperature measurements of each side of the GVC building vs. observed temperature and shortwave solar radiation.

Our daily results generally showed a gradual temperature increase for all sides but with varying temperature levels for each side (*figure 7*). It also showed that the incoming solar radiation generally mirrored this but with a couple of exceptions. When comparing our façade temperature measurements to atmospheric data we could see that both clearly followed the same trend. We could however also see that although both the sunny and shaded sides of the building followed this trend it was noticeably more reliable on the shaded side while the sunny

South East side could diverge from this pattern as seen on April 02 where the sunny side increased and then dropped around 10°C in temperature despite no changes in air temperature or solar radiation.

3.3. Temperature Change over Time

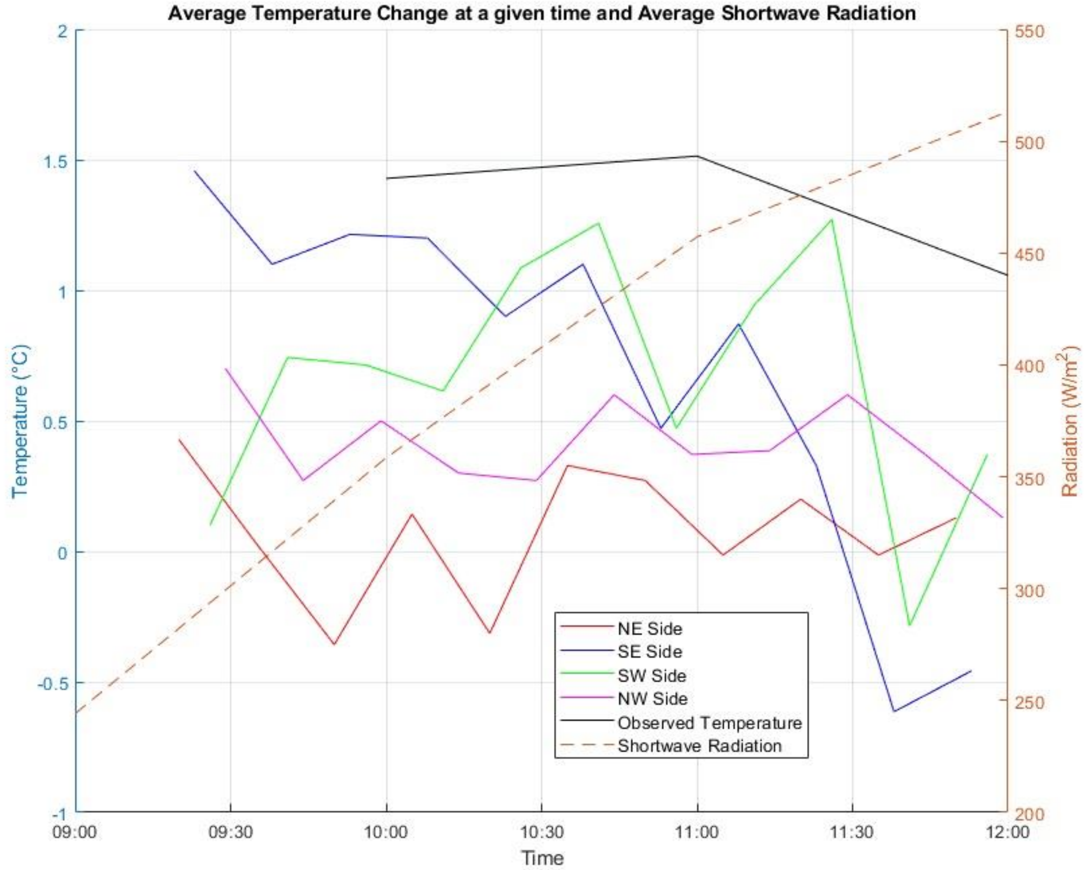

Figure 8. Change in façade temperature between 15-minute average temperatures showed at the later time (as in 'change for 9:05-09:20 placed at 09:20') for each measuring day compared to hourly average atmospheric temperature change and shortwave radiation. Note observational interval.

Our results (*figure 8*) showed that for all sides apart from the South East side there is a relatively even temperature change from 09-11 and then a drop later at 11-12, the South East side instead has a constant drop. We could also see that initially the temperature change and solar radiation were still matching up rather well, but that after 11 when the temperature change dropped the radiation continued rising every day.

3.4. Albedo

Table 1. The noted mean brightness values and the resulting relative and absolute albedo value of our brick wall. All three images were taken on the same day (2021-04-16).

Image (#)	Reference Value (Paper)	Unknown Value (Brick)	Relative Albedo	Absolute Albedo
1	203.208	121.310	0.507	~0.39
2	203.264	117.351	0.577	~0.38
3	201.142	118.709	0.590	~0.38
Mean				**~0.38**

The results from the albedo calculation showed a relative albedo hovering around 0.5 to 0.6 for the three images, it also showed that all three images had an absolute albedo of roughly 0.38 (*table 1*).

3.5. Emissivity

Our results show that the emissivity of the black electrical tape was roughly 0.93 when it reached 100°C on the pot of boiling water. When this emissivity was then used to calibrate the camera the tape placed on the brick wall gave a temperature of 38.6°C, when the tape then was removed and the temperature of the brick wall was measured it reached a similar temperature of 38.5°C when a emissivity setting of 0.81 was used which gave us a brick wall emissivity value of 0.81 (*figure 9*).

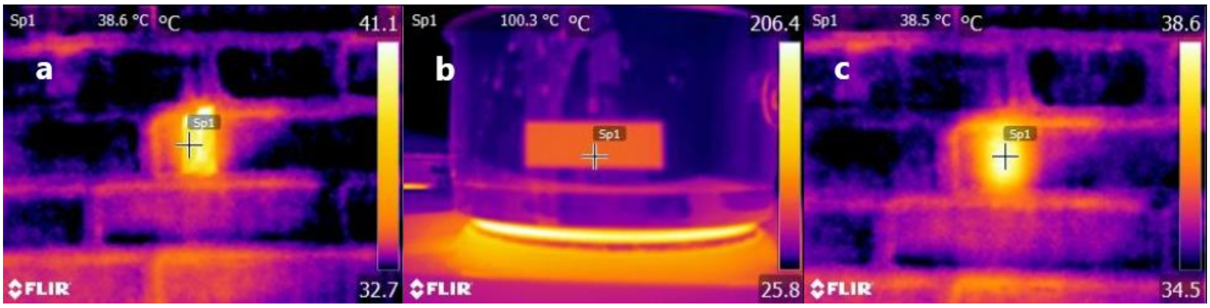

Figure 9. The pure IR-images of the emissivity measurements where a; is wall with tape, b; pot with tape and c; wall without tape.

3.6. Wind

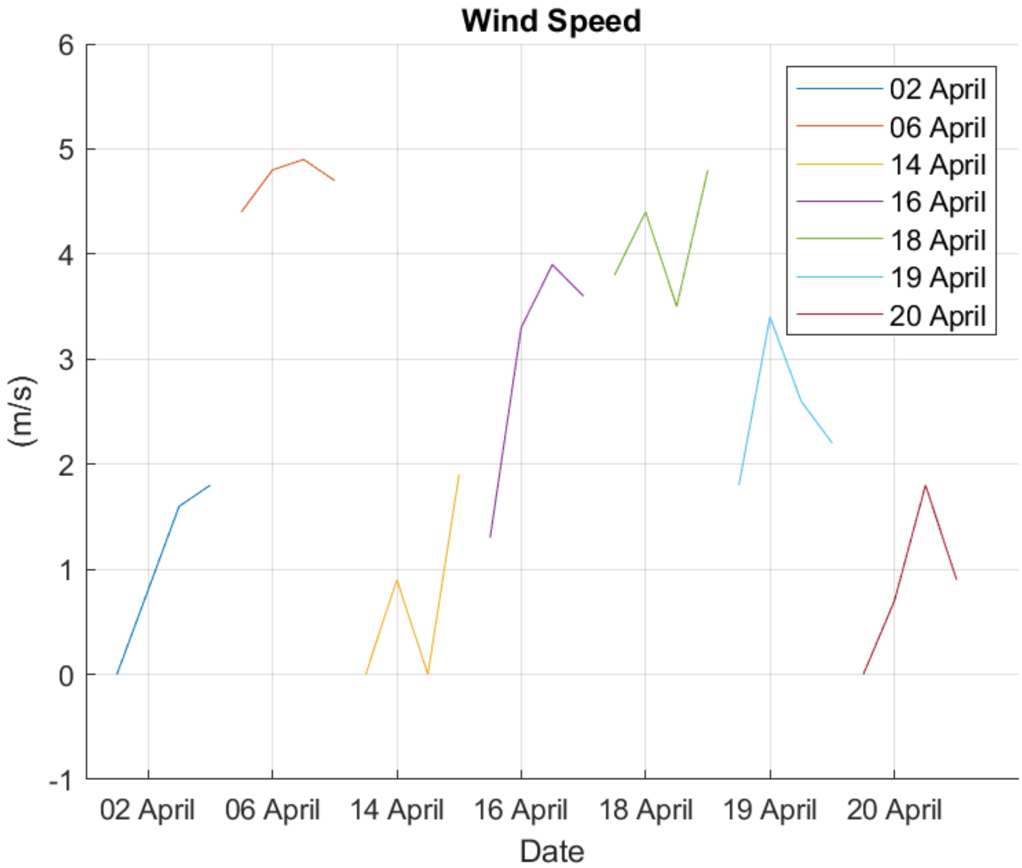

Figure 10. Observed wind (m/s) measurements for our timespan with dates. (Downloaded from SMHI).

The wind data obtained from SMHI showed that the wind speed alternates between low and comparatively high speeds for the measured days, with April 02, 14 and 20 having low wind speeds and April 06, 16, 18 and 19 having higher wind speeds (*figure 10*).

4. Discussion

4.1. Temperature Measurements

As we can see in *figure 5* the temperature of the façade generally rises throughout the day but on certain days, particularly on the South East side but also the North/South West sides, there is a drop in temperature come noon. This drop in temperature at that time seems strange as the sun doesn't reach its zenith until roughly 13:00 (Meteogram, 2020) and we can also clearly see in *figure 7* that despite this drop the solar radiation does still continue to rise after 10:00/11:00 with only a single exception on April 06 which means that the heating of the façade shouldn't slow down. The explanation for that is most likely that although the sun is still rising, the angle with which it hits our façade becomes less perpendicular and as such less solar heating will occur (Fathi et al. 2015). This in combination with an emissivity value of 0.8-0.9 generally being seen as high (Zinzi, 2016) and our emissivity value of 0.81 for the bricks, makes it a possible explanation that the emitted heat at this time simply starts to overtake the incoming solar radiation causing the drop in temperature. The fact that certain days earlier in the month have higher façade temperatures than certain later days, despite the trend being an increase in temperature later in the month could be due to temporary atmospheric differences. This could be conditions such as occasional clouds blocking some solar radiation on the cooler days or the local atmospheric temperature differing from the trend of always rising temperatures. It could also partially be explained by differences in wind speed, but according to Nazarian (2015) wind speed only has a noticeable cooling effect in the early morning during sunrise. When the solar radiation gets higher as it does during our measurement period, this phenomenon gets smaller and the radiation is what dominates the façade temperature. As such we believe that the reason for the façade temperature going against the trend is due to the local atmospheric temperature also having daily anomalies rather than following the trend and getting warmer exactly every day. In *figure 6C*, there were shadows from branches covering the wall around 11, which could impact the results. However, there was only one day you could see a sudden dip on the South West wall on *figures 5 and 7*, April 14th. Around 11:30 there was a sharp decrease followed by a sudden increase, which could be explained by this shadow cover. Although this could only be seen on one day, which makes it an uncertain correlation.

4.2. Observed vs. Façade Temperature Measurements

Looking at the graph (*figure 7*) of the atmospheric versus the façade temperature, the sunny side (South East) was the warmest and surpassed the atmospheric temperature, which is of no surprise since it is facing the sun. This follows Dietrich (2018) statement, that brick walls when exposed to solar radiation, surpassess air temperature. On days 3, 4, and 5 the South East side levels off at around 11:00 while the radiation still increases, which is odd but can be due to the angle between the sun and wall according to Fathi et al. (2015). With the decrease in radiation on day 2 at 11:00, a local cloud could be covering the station, while the façade temperature keeps on rising. This could be due to the thermal properties of the brick material; according to Wonorahardjo et al. (2020), bricks and concrete are materials with high density, which stores heat for longer compared to other materials and therefore prevents it from decreasing quickly together with radiation if incoming radiation is lower than the emittance. On day 1 looking at the sunny side temperature change, it stays low together with the atmospheric temperature but then increases drastically at 10:15 and decreases at 10:45, this could be due to the low radiation levels compared to the other days early in the morning, which then rises until the sun's angle becomes too steep and the temperature drops. The other sides do not increase dramatically and do not surpass the atmospheric temperature at all on all 7 days within our timespan. This could be due to the fact that there is not enough radiation to store and heat the bricks on these sides. However, you can see a small increase in temperature on the South West side and a decrease on the North East side when they eventually cross around 10:30 and 11:00. This is due to the sun touching the North East side before it moves and starts touching the South West side. The back side (North West) or shade side, is perpetually covered in shade and never sees the sun in our timespan, thus is the coldest and has temperatures below the other sides. This being said these sides are following the atmospheric temperature with the same trend despite not having the full attention from the sun which is in line with Dietrich (2018) as mentioned in section 1.2, stating that air temperature correlates well with the temperature of façade materials in a non-radiative clear sky. Another strange result is that in *figure 7* we can see that the 14th of April has a slightly warmer South East side than the 16th of April, despite them having nearly the same incoming solar radiation and the 16th actually having higher atmospheric temperature. One possible explanation for this could be the more windy conditions seen in *figure 10* on the 16th cooling the façade down more than what occurs on the 14th. This could also be due to the global radiation data of SMHI, which incorporates not only the direct solar radiation but also the scattered radiation from clouds and sky (see section 2.4). This could explain the lower temperature on the 14th as the direct radiation from the sun is slightly lower that day compared to 16th despite the global (total) radiation being the same. However, this could further be due to residual temperature from a previous day remaining on the 14th raising its temperature more than the conditions of the day would normally permit. This however is a limitation of the study as we do not have data for the previous day and as such can't know for certain which is the definitive explanation.

4.3. Temperature Change over Time

As you can see on the results of our graph (*figure 8*) there is as mentioned an initial stable trend for temperature change for all 7 days but with a drop in temperature change for the last hour of the day which is strongest on the sunlit sides, there are also occasional decreases such as the South West side at 10:40 that go against that which is indicated by the solar radiation trend. One possible explanation for the anomalies could be the thermal convection caused by heated façades varying depending on the wind conditions (Mu, Gao & Zhu 2018). According to Mu et al. (2018) on windless sunny days the heating of the façade and near ground cause upward convection flows near the wall, this thermal plume will then bring heated air upwards along the façade causing the air which interacts with the façade to have a higher temperature than that which atmospheric observations indicate. The alternate scenario connected to this phenomenon is that on windy days this heated air will get blown away instead of migrating upward along the wall and bringing in regular cooler air. This phenomenon can for this reason explain the temperature change over time data varying without a correlated change in solar radiation, with temperature increase despite no increase in solar radiation or air temperature being caused by windless days amplifying the convection flows, and temperature decreases not explained by a lower solar radiation or air temperature being due to windy conditions limiting the warming from convection. The explanation for the general drop in temperature after 11 could instead be explained by the change in the angle of incidence of the sun and the façade, since although the sun is rising the less perpendicular angle means that less heating of the wall will occur (Fathi et al. 2015). This would also explain why this drop is strongest on the sunlit sides as those sides would be most impacted by the change.

4.4. Albedo

According to previous studies, our particular brick wall's albedo (*section 3.3*) is very similar to Oke's (1987) data which is around 0.2-0.4. This puts our *absolute albedo* measurement of

0.38 perfectly inside this interval. Thus making the simple method inspired by Gilchrist (n.d.) a reliable one to use for future albedo studies of different urban surfaces. The albedo value of 0.38 of our brick wall indicates a relatively low reflectivity ability, which compels the radiation from the sun to get more absorbed hence the brick wall can become much warmer in comparison to the atmospheric temperature on a sunny lit day, which is in line with Dietrich (2018) as previously mentioned. This is clearly seen on the results in *figure 7* of the sunny (South East) side of GVC. This seems quite natural as the air has to get warmed up from below by the solar heated land surface, while the façade gets warmed directly by the radiation without it needing to transfer from another material/surface.

4.5. Emissivity

The emissivity values of 0.93 for the tape and 0.81 for the wall we received during our measurements were very comparable to values given for the same types of surfaces by other sources, this gives us greater confidence that they are accurate. The brick emissivity of 0.81 lies between 0.8 and 0.9 indicates that it has a fairly high emissivity (Zinzi, 2016), this means that it will emit stored heat relatively quickly and as such cool down at a fairly high rate when it's no longer being heated. As such the temperature of the façade will likely drop rather quickly in the evening and night causing the building as a whole to cool down. This however is also reliant on the heat capacity and thermal conductivity, as such there might not be a fast drop in temperature in the evening if the brick has stored a large amount of heat during the day since it will have to emit heat for a longer period of time to deplete the stored heat.

4.6. Limitations

The observed temperature data were first decided to be collected from GVC's own temperature station situated on the roof of the building. However, the station had a malfunction in the middle of the month of April where only data of half of the month were measured. Thus we had to use another source of data for our observed data and settled with SMHI. GVC has measurements for every 5 minutes while the data collected from SMHI had only hourly data, which was not as accurate as we wanted but it was the only reliable source we could find that has a station in Gothenburg for both temperature and radiation.

Another limitation of our study was that our measurements required clear and sunny conditions and during our project we had a lack of sunny days for our measuring period (April), which prevented us from gathering as many days of data as would have been preferred, giving us an incomplete picture and preventing us from seeing possible impacts of previous days on our measured days.

4.7. Future Improvements

In order to improve this study in the future a number of changes could be made. One thing which could be improved would be the timeframe of the temperature measurements, our study only measured from 09-12 on days with measurements, this could in all likelihood be improved by starting at or just before sunrise and ending in the early afternoon to incorporate the changing daily scenarios. Another option would be to do the project in a period or location with more reliable clear sunny days to have access to more days of measuring. Yet another option would be to measure on buildings which have uniform conditions on each side, to minimize the impact the surrounding areas (buildings, trees, etc) have on the measurements. When it comes to the emissivity the measuring could probably be made more thorough as for this study we only calculated an estimate due to lack of more specialized tools and as such could be made more accurate with better equipment. The measuring of emissivity could also probably be improved by doing more measurements and creating an average to avoid any local errors as we only had one measurement which was used for the study. To get a better understanding of the results a future study could also include more in depth wind and cloud condition examinations as our study found that the wind would not have a particularly noticeable impact on façade temperatures and did not have any exact data for cloud conditions apart from the days of measurements being mostly cloud free. In addition to this, a future study could also include non-clear days with different weather conditions to be able to see how the other weather conditions would impact the results and compare them to the clear days.

5. Conclusion

For this report, a study was made where the temperature of a building's façade was measured for 3 hours a day 7 times over a month and the façade albedo and emissivity were calculated. This was then compared to downloaded temperature, shortwave radiation, and wind data from SMHI to see relevant connections. This gave the following results:

- The temperature of the façade generally rises between 09:00 and 12:00 but frequently has a minor drop shortly before 12:00, caused by local anomalies in daily atmospheric temperature and due to the angle of incidence from the sun.
- Atmospheric temperature and our façade temperature measurements follow a similar trend in a non solar radiation presence, with atmospheric temperature being slightly higher.
- Façade temperatures rise significantly higher than atmospheric temperature in the presence of solar radiation and act accordingly to the thermal properties of bricks.
- The change rate of our façade measurements follows the radiation change rate initially in the morning (9-10) and drops suddenly at 11-12 for all the measured days, this was attributed to wind conditions amplifying thermal convection bringing warmer air to the wall early in the day and changes in the wind conditions reducing this effect later in the day.
- The wind speed can have a noticeable effect on the temperature of the façade, particularly on the sides exposed to the sun with higher wind speeds causing a decrease in temperature.
- The albedo of our brick wall was calculated to be 0.38 which gives us a high absorption of solar radiation at our given façade and as such makes solar radiation a major contributor to our façade temperature.
- The emissivity of our brick wall was calculated to be 0.81 which indicates that our façade has a quite high emissivity, as such it will radiate out heat rather efficiently and as such drop in temperature in the absence of incoming radiation if no heat has been stored.
- The lack of sunny days during April gave us less data to work with and prevented us from seeing possible connections with adjacent days. With the malfunction of the GVC temperature station, we had no choice but to find alternative data and hence limited our accuracy of the atmospheric temperature from 5 minutes to hourly.

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