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Comparative Study of Green and Concrete Roofs for Urban Heat Island Mitigation in Urban Pockets of Kathmandu Valley in Winter

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ADARSHA MAHARJAN

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DECLARATION

I hereby declare that the thesis entitled "**Comparative Study of Green and Concrete Roofs for Urban Heat Island Mitigation in Urban Pockets of Kathmandu Valley in winter**" submitted to the Department of Architecture in partial fulfilment of the requirement for the degree of Master of Science in Energy Efficient Buildings, is a record of an original work done under the guidance of Associate Prof. Dr. Sanjaya Uprety and Dr. Ashim Ratna Bajracharya, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Comparative Study of Green and Concrete Roofs for Urban Heat Island Mitigation in Urban Pockets of Kathmandu Valley in winter**" submitted by Adarsha Maharjan in partial fulfillment of the requirements for the degree of Master of Science in Energy Efficient Building.

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Abstract

This study examines the effectiveness of green roofs in mitigating the Urban Heat Island (UHI) effect in Kathmandu Valley, Nepal, during winter, comparing their performance against conventional concrete roofs. The exploration highlights the thermal advantages and environmental benefits of green roofs, emphasizing their role in sustainable urban design. Key findings reveal that green roofs maintained significantly lower surface temperatures than concrete roofs, with an average reduction of 4.84 °C, peaking at 9.74 °C during the day. At night, green roofs displayed faster cooling, reaching temperatures as low as 7 – 9 °C, whereas concrete roofs retained heat, rarely dropping below 13 °C. In terms of heat mitigation efficiency, green roofs outperformed concrete roofs by 32%. Indoor thermal regulation was also notably improved, as rooms beneath green roofs experienced more stable temperatures. Correlation analysis indicated weaker dependence on HVAC usage ($r = 0.137$) compared to concrete roofs ($r = 0.655$), demonstrating superior insulation properties. Without HVAC, green roofs reduced inner temperature fluctuations by 5.1 °C. Simulations using the Urban Weather Generator (UWG) further verified the broader civic impact, showing that green roofs reduced ambient temperatures by 3 – 5 °C in localized urban environments, effectively mitigating UHI goods.

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1 CHAPTER ONE: INTRODUCTION

1.1 Background

The Urban Heat Island (UHI) effect is a miracle of heat accumulation within civic areas, primarily driven by civic development and mortal conditioning. It's extensively regarded as one of the most prominent features of civic climates. The rise in land face temperatures caused by the UHI effect significantly impacts material and energy overflows within civic ecosystems, altering their structure and functionality. This leads to colorful ecological and environmental consequences, affecting civic climates, hydrological conditions, soil characteristics, air quality, natural patterns, material cycles, energy dynamics, and the health of civic residents(Akbari & Kolokotsa, 2016; Buchin et al., 2016; Santamouris et al., 2011; L. Yang et al., 2016).

The rise in peak and energy demand during the cooling season, alongside the intensification of the Urban Heat Island (UHI) effect, has come to a pressing concern. The structure sector plays a crucial part in diving energy and environmental challenges, with roofs offering significant eventuality for enhancement. Green roofs use soil sequestration and evapotranspiration to reduce heat gain(Zinzi & Agnoli, 2012).

Green roofs, also known as eco-roofs, use factory leafage to shield structures from thermal loads caused by solar radiation and air temperature. The foliage subcaste absorbs solar energy for processes like photosynthesis, evapotranspiration, and respiration, reducing heat penetration. Also, the soil subcaste provides redundant sequestration, while its water content increases the roof's thermal indolence. Foliage characteristics farther influence convective and radiative heat transfer through the roof face (Cascone et al., 2019; Zinzi & Agnoli, 2012).

Green roofs serve as a sustainable volition to civic green spaces, mollifying Urban Heat Island (UHI) goods while perfecting air quality, reducing temperatures, saving energy, and enhancing adaptability. Recent exploration highlights their eventuality to address UHI through wide relinquishment on flat or graded rooftops (Akbari & Kolokotsa, 2016; Baniya et al., 2018; Kolokotroni et al., 2016; Zinzi & Agnoli, 2012).

The Urban Heat Island (UHI) impacts millions of people worldwide, as civic areas constantly witness advanced temperatures than their pastoral surroundings. This temperature difference has significant counteraccusations for the health and well-being of megacity residents. The primary contributors to UHI are the expansive use of artificial accoutrements and increased heat generated by mortal conditioning. As urbanization continues to expand, it has become apparent that it plays a major part in enhancing the UHI effect. This miracle not only increases energy demands, aggravating civic heating, but also brings about environmental and public health challenges. Civic shells, similar as pavements and roofs, which are heavily exposed to solar radiation, further amplify this issue(Akbari & Kolokotsa, 2016; Baniya et al., 2018; Mohajerani et al., 2017).

Kathmandu Valley, Nepal's most vibrant and citified region, gests elevated air and land face temperatures. From 2000 to 2016, the face temperature rose significantly at a rate of 0.04 °C per time. During the same period, outside and minimal temperatures also showed notable increases of 0.06 °C per time and 0.03 °C per time, independently (Baniya et al., 2018). The civic areas of the vale parade a low regularized difference foliage indicator (NDVI) and a high regularized difference erected- up indicator (NDBI), reflecting a dramatic expansion of urbanization (Baniya et al., 2018; Mishra et al., 2019).

Rapid urbanization leads to the metamorphosis of agrarian land, timbers, and other natural shells into erected- up areas. The expansion of erected surroundings, along with increased transportation and artificial conditioning, significantly contributes to rising temperatures in civic areas compared to pastoral regions. This growing civic heat poses serious pitfalls to the health of people living in metropolises, particularly in developing countries, where the issue of raising temperatures is getting an adding concern (Chaudhary et al., 2021; Chidi et al., 2021).

Nepal, a fleetly developing country, is passing nippy urbanization, with Kathmandu Valley arising as the largest and swift- growing megacity in recent decades. Several studies have linked the factors contributing to the development of the Urban Heat Island (UHI) effect in Kathmandu. As a mountainous nation, Nepal’s Kathmandu Valley is in the mid-hills, characterized by significant elevation variations that impact the temperature lapse rate. Still, former exploration has largely overlooked this aspect. The main civic area of

Kathmandu is positioned on the low- altitude vale bottom, encircled by advanced hills (Chidi et al., 2021).

Although the miracle has been studied largely throughout the world, it's less understood for Kathmandu, Nepal (Mishra et al., 2019). It's reasonable to assume that Kathmandu, as a decreasingly citified area, is passing analogous challenges. Given the rapid-fire urbanization and limited vacuity of ground- position space for civic forestry and green premises, indispensable mitigation strategies must be prioritized. In densely erected metropolises like Kathmandu, where open space is constrained, roofs being the most exposed part of the structure, present a significant occasion for UHI mitigation. Cool roofs and green roofs crop as promising results in this environment, offering multiple benefits. These roof types can effectively reduce the UHI effect by lowering face temperatures, thereby reducing the cooling and heating loads of structures, which contributes to energy effectiveness. Also, they ameliorate air quality and enhance thermal comfort for residents. The perpetration of similar strategies in Kathmandu could play a pivotal part in addressing the civic heat challenges and promoting sustainable civic development.

1.2 Importance of research

Rising temperatures hamper the body's capability to regulate heat, leading to health pitfalls similar as heat rash, cramps, prostration, heat stroke, and indeed death. Pre-existing conditions like heart or lung conditions may worsen, putting the senior at threat (Basu & Samet, 2002; cited by Buchin et al., 2016). The study highlights a threat conception distinguishing heat- stress hazards in inner and out-of-door surroundings, emphasizing the need for targeted mitigation strategies. Analysis of mortality data for Berlin’s 65 age group, paired with inner temperature modeling, revealed that relative threat doubles with each 1 K rise in ambient temperature. In areas with high air-exertion content, UHI countermeasures offer minimum threat reduction. Still, in regions with limited air-exertion, unresistant cooling measures like shadowing and cool roofs effectively alleviate overheating and reduce inner pitfalls. The unborn relinquishment of air-exertion can reduce pitfalls but should minimize fresh energy consumption, immaculately counting on renewable sources. Priority should be given to unresistant cooling measures at the room position in civic planning and policy. A combined approach, integrating passively cooled structure designs with civic- scale countermeasures, is likely essential to maintain inner temperatures below critical thresholds(Buchin et al., 2016).

A green roof lowers face temperature by transubstantiating solar radiation into idle heat, whereas a largely reflective cool roof achieves the same by bouncing further solar radiation back into the atmosphere (Imran et al., 2018). Green roofs can act as a cover for ground-position civic green spaces, helping to combat civic heat and ameliorate mortal comfort by bringing nature near to megacity residents. Numerous compact metropolises suffer from a lack of green space due to limited land for planting, leaving residents in concrete areas without access to natural verdure. This contributes to severe civic heat islet goods. Greening rooftops offers a promising result to reduce heat and alleviate climate change in metropolises(Baniya et al., 2018).

1.3 Problem Statement

Kathmandu Valley, Nepal's most vibrant civic center, has endured significant face temperature increases, with land face temperatures rising by 0.04 °C per time between 2000 and 2016. During this time, outside and minimal temperatures also rose by 0.06 °C and 0.03 °C per time, independently. The civic areas of the valley show low foliage (NDVI) and high erected- up indicators (NDBI), reflecting rapid-fire civic expansion. This trend poses a growing threat of civic heat islet goods. Rising civic temperatures, driven by reduced verdure and increased erected- up areas, punctuate the need for effective results. Green roofs are cost-effective technology that can restore civic verdure and promote a healthier terrain. exploration shows that replacing traditional roofs with green roofs significantly lowers summer temperatures, perfecting thermal performance. Civic conditioning heavily contributes to increased energy consumption and hothouse gas emigration. contemporaneously, inordinate use of natural coffers for civic development has lowered adaptability capacities. Green roof ways can help alleviate civic heat islet goods and environmental challenges in Kathmandu, contributing to a smart, eco-friendly, flexible, and sustainable megacity. still, detailed studies on green roofs, erecting designs, and policy interventions are necessary for their effective perpetration (Baniya et al., 2018).

The rise in land face temperature is primarily due to adding roads, vehicles, and erected-up areas, along with a decline in open spaces, cultivated land, and timbers. Thermal analysis shows inner- megacity areas are hotter than external megacity areas, which, in turn, are warmer than forested regions. This demonstrates that lesser urbanization leads to advanced temperatures and a stronger UHI effect. The UHI effect shows that rising temperatures in megacity areas are driven by adding erected- up shells and civic conditioning, unlike recently rural areas. However, the ecological condition in Kathmandu Valley may deteriorate further, if this trend continues. Unplanned urbanization and inadequate open spaces punctuate a critical future, taking significant time and trouble to manage domestic areas and civic growth to address UHI goods effectively (Chidi et al., 2021).

Quality design for the erected terrain should ensure comfortable thermal conditions in both inner and out-of-door spaces while promoting low energy structures. Cool roof technology offers significant benefits, including advanced thermal comfort, energy conservation, and enhanced civic spaces. Still, integrating assessments across structure, neighborhood, and megacity scales is grueling and demands a multidisciplinary approach. Many studies have explored the full counter accusations of cool roofs at both the structure and civic scales. utmost being exploration at the structure position focuses hardly on cool roofs as a thermal sequestration result, primarily examining their impact on energy consumption or inner temperatures. There's a lack of consideration for microclimate factors in cool roof studies, as utmost structure energy simulation (BES) programs calculate on pre-defined hourly rainfall biographies to calculate heating and cooling loads. These biographies are generally grounded on rainfall stations located outside civic areas, where they aren't told by civic heat island (UHI) goods. This results in high query in simulation data, leading to inaccurate hypotheticals about energy demands for inner thermal comfort (Elnabawi et al., 2022).

Green roofs are told by numerous factors, making it essential to conduct detailed analyses for a comprehensive comparison with other ways. These analyses should consider not only energy effectiveness but also water operation, life cycle costs, environmental impacts, civic comfort, and their part in mollifying the civic heat island effect(Zinzi & Agnoli, 2012).

1.4 Research objectives

The primary objective of this research is to evaluate the mitigation of urban heat island (UHI) effects through roofing design.

- To investigate the UHI phenomenon mitigation on the selected neighborhood with concrete roof and green roof using Urban weather generator and morphing the weather file particularly in winter.
- To assess the effectiveness of concrete roofs versus green roofs.
- To assess the relationship between internal air temperature and Surface temperature of roof.

1.5 Topic Validity

The concept of green roofs is relatively new in Nepal, despite being widely practiced in major cities globally. While intensive green roofs have been implemented, extensive green roofs have not yet been adopted. Both communities and policymakers lack scientific awareness of green roofs and their environmental benefits. In urban areas, surface and air temperatures are rising, with low NDVI and high NDBI, reflecting rapid urban growth. Dust and air pollution are significantly impacting the environment and public health. However, there is growing interest from government, private, and public sectors to develop smart, eco-friendly cities. Key aspects of green roof design, such as roof assembly, plant selection, use of polymers, drainage layers, growing media, and maintenance, are not well understood or widely practiced in Nepal(Baniya et al., 2018). This lack of awareness and the research specifically in Nepal makes it utmost important research as much research have proved that green roofs and cool roofs have performed well in similar climatic condition to that of Kathmandu. This research can act as a reference point for future policy makers and designers as well as provide the required attention to the mitigation strategies for UHI.

Rapid urbanization in Kathmandu Valley from 1999 to 2017 has significantly increased land surface temperatures. Key factors include the growth of roads, vehicles, and built-up areas, along with the decline of open spaces like cultivated land and forests. Thermal analysis shows that inner-city areas are hotter than the outer city, which in turn is hotter than forested regions. This indicates that greater urbanization leads to higher temperatures and a stronger urban heat island (UHI) effect(Chidi et al., 2021). building level interventions play an important role in the mitigation of the UHI in highly compact regions(Kotharkar et al., 2020). Most common approaches have failed to adequately assess or explain the performance of cool roofs at various levels, including individual buildings and urban communities. Few studies have explored the full implications of cool roofs at both the building and urban scales(Elnabawi et al., 2022). Since there are very few studies of green roof and cool roofs in urban scale this fact points the dire need for this research.

Uninsulated houses may experience a significant increase in heating demand. However, cool roofs can help reduce the need for cooling systems due to their very low cooling energy demand(Zinzi & Agnoli, 2012). This backs up the fact that Uninsulated buildings and concrete buildings which are common sites in the Kathmandu valley which are high contributors of the UHI indeed require immediate intervention.

Indoor hazards can be estimated based on outdoor climate using a simple building model. In cities with low air-conditioning coverage, traditional UHI countermeasures and passive cooling strategies, such as shading and cool roofs, are more effective in reducing overheating and associated indoor risks. The future spread of air-conditioning could reduce these risks, but it should be avoided or powered by renewable sources to prevent additional energy consumption(Buchin et al., 2016). Parametric studies using ENVI-met demonstrate that effective greening can significantly enhance the urban microclimate and reduce summer air temperatures at ground level. In high-rise, high-density areas like urban Hong Kong, planting trees or grass on rooftops or the ground has limited cooling effects on the pedestrian environment. However, these measures can help by not exacerbating urban heat compared to artificial materials(Ng et al., 2012). While roofing is not only a major part of building but also part that is highly exposed to the solar radiation and environmental factors that affect the building overall. Since buildings are constantly re-roofed applying or suggesting green roofs, surfaces can be deemed liable option for the future integration of the more sustainable approach in the valley.

The suitability of using Typical Meteorological Year (TMY) data in building energy simulations heavily depends on roof design, as it can lead to significant overestimation or underestimation of energy savings. Other roof design parameters, such as thermal emittance and roof membrane roughness, can be analyzed through sensitivity studies to evaluate their impact on energy performance(Hosseini et al., 2017). This statement suggest that Roofs are one of the most important factors while considering building energy use.

1.6 Methodology

1.6.1 Research Paradigm

This study adopts a **post-positivist paradigm**, acknowledging that while absolute objectivity may not be achievable, scientific methods can provide reliable and reproducible insights. Post-positivism aligns with the study's aim to quantify the impact of green roofs on UHI mitigation and energy efficiency.

1.6.2 Ontology

The ontological stance of this research is **critical realism**, which posits that phenomena such as urban heat island (UHI) effects and energy efficiency exist independently of our perceptions. These phenomena are measurable through modeling and simulations, reflecting an underlying reality that can be observed and analyzed.

1.6.3 Epistemology

The epistemological foundation is **empiricism**, emphasizing the collection and interpretation of quantitative data. Knowledge is derived through simulations and analysis of variables such as temperature and energy consumption using validated tools and techniques.

1.6.4 Axiology

The research acknowledges the societal and environmental value of mitigating UHI effects and enhancing energy efficiency in buildings. It prioritizes practical and sustainable solutions that contribute to urban resilience and thermal comfort.

1.7 Methods

1.7.1 Simulation Modeling:

Tools: **Rhino** will be used to model the building typology and urban pocket using data from cad mapper. **Grasshopper** with plugins like **Ladybug, Dragonfly** and **Honeybee** for UHI and energy efficiency.

Process: Rhino will be used to create the model of both urban landscape and the buildings. Weather data from Tribhuvan International Airport (TIA) will be retrieved which will be morphed accordingly using dragonfly. Research aims to leverage **Dragonfly**, a Grasshopper plugin within the Ladybug Tools suite, to evaluate the comparative effectiveness of green roofs and concrete roofs in mitigating urban heat island (UHI) effects, enhancing energy efficiency. Dragonfly's robust urban-scale modeling capabilities will be utilized to simulate environmental conditions across a representative section of the Kathmandu Valley. The study will develop scenarios with green roofs focusing on their impact on surface temperatures, energy consumption for cooling, and outdoor thermal comfort. Dragonfly's integration with urban climate models, such as Energy Plus and UWG (Urban Weather Generator), will enable the study to account for microclimatic interactions and provide high-fidelity data for analysis.

1.7.2 Data Collection and Analysis:

Variables: Surface temperature, energy usage, indoor temperature profiles.

Analysis: Statistical comparison to determine the relative effectiveness of the two roof types.

Primary Data

Surface temperature and Relative Humidity will be measured by green roof study using data loggers and required tools.

Secondary Data

Meteorological Data:

Hourly weather data, including air temperature, humidity, wind speed, and solar radiation, will be sourced from reliable databases online. These datasets will serve as inputs for Dragonfly's integration with the Urban Weather Generator (UWG).

Urban and Building Data:

GIS datasets of the Kathmandu Valley will provide information on urban morphology, including building footprints, heights, and land use distribution. These inputs are critical for modeling the urban context and understanding spatial variations.

Material Properties:

Properties such as albedo, emissivity, thermal conductivity, and vegetation characteristics (for green roofs) will be obtained from scientific literature, material databases, or manufacturers' specifications.

UHI Intensity Map:

The existing UHI intensity map of Kathmandu Valley will be used to calibrate the simulation model, ensuring alignment with real-world urban thermal conditions (Using GIS).

1.7.3 Validation:

Calibration of Model Outputs:

Simulated outputs, such as surface temperatures and energy consumption, will be validated against the UHI intensity map and local weather data to ensure accuracy and reliability.

Cross-Validation with Literature:

Results will be compared with findings from similar studies to establish the credibility and transferability of the findings to the local context.

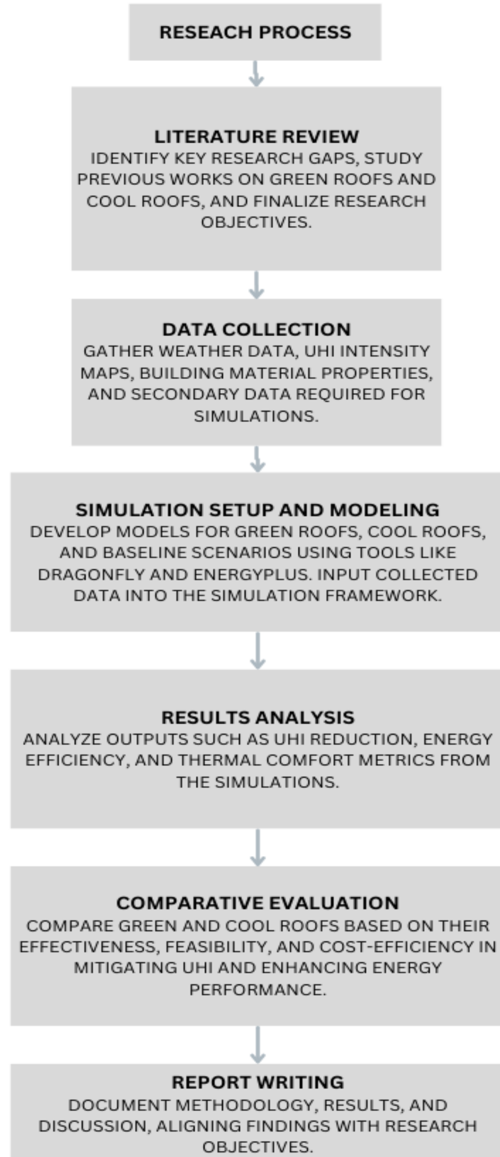
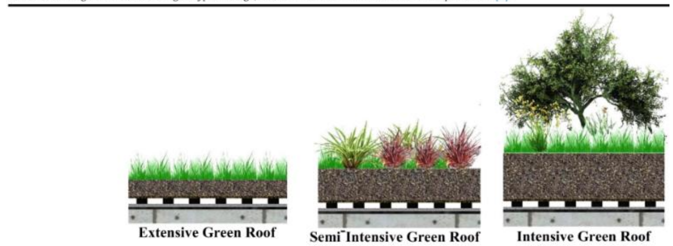


Figure 1 RESEACH PROCESS

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Green roofs

The implementation of foliage on rooftops, frequently referred to as green roofs, is getting a decreasingly popular approach to enhancing environmental well-being. Green roofs offer a practical result to combat the civic heat island (UHI) effect. They provide multitudinous benefits, including lowering civic temperatures, perfecting air quality, and conserving energy (Baniya et al., 2018). Modern green roofs consist of various types of layers for proper functioning of the roof system.



Classification of green roofs according to type of usage, construction factors and maintenance requirements [8].

	Extensive Green Roof	Semi-Intensive Green Roof	Intensive Green Roof
Maintenance	Low	Periodically	High
Irrigation	No	Periodically	Regularly
Plant communities	Moss-Sedum-Herbs and Grasses	Grass-Herbs and Shrubs	Lawn or Perennials, Shrubs and Trees
System build-up height	60 - 200 mm	120 - 250 mm	150 - 400 mm on underground garages > 1000 mm
Weight	60 - 150 kg/m^2	120 - 200 kg/m^2	180 - 500 kg/m^2
Costs	Low	Middle	High
Use	Ecological protection layer	Designed Green Roof	Park like garden

Figure 2 Extensive vs Intensive Green roof type

The green roof design must incorporate a root barrier, drainage layer, filter layer, water retention, growing medium, and foliage layer (Baniya et al., 2018), as depicted in Figure 1. There are two distinct types of green roofs i.e. intensive and extensive green roofs. Both roofs have distinct features which are mentioned in the table below.

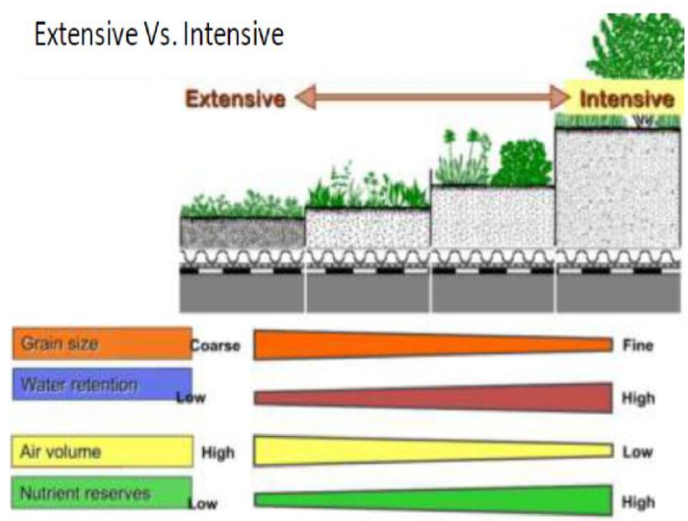


Figure 3 Green Roof Classification

Extensive green roofs feature a relatively thin layer of growing medium, typically 6–20 cm thick, and support vegetation such as moss, sedums, herbs, and grass with minimal maintenance requirements. In contrast, intensive green roofs have a deeper growing medium, ranging from 20–100 cm, and require regular irrigation and ongoing maintenance. Semi-intensive green roofs blend characteristics of both types but are designed so that the extensive portion comprises no more than 25% of the total roof area as shown in figure 3 below.

The thermal performance of green roofs is influenced by colorful factors related to foliage, including its form, type, diversity, content ratio (CR), splint area indicator (LAI), leafage height, and natural processes similar as photosynthesis, respiration, and transpiration. Additionally, the physical parcels of the growing medium, similar as its consistence, water content, and viscosity, along with point-specific conditions like climate and roof sequestration, play a pivotal part in determining the effect of green roofs on temperature regulation and heat flux (Raji et al., 2015).

The green roofs and cool roofs not only alter the surface energy balance and reduce the UHI effects but also impact the boundary layer up to 2.5 km. The decrease in sensible flux due to the green and cool roofs reduces perpendicular mixing and PBLH (Planetary Boundary Layer Height), and accordingly, reduces the air temperature. Still, the changes in wind speed and relative humidity are not substantial in the lower boundary layer during the day. Green and cool roofs drop the sensible heat flux and accordingly reduce perpendicular mixing, the depth of boundary layer and temperatures over urban areas in the lower atmosphere, which reduces UHI effects. Cool roofs reflect the incoming solar radiation, and accordingly, decrease the sensible heat flux and reduce UHI effects(Imran et al., 2018).

2.1.1 The impact of green roofs on temperature and heat flux

The thermal performance of green roofs is influenced by various factors related to vegetation and site conditions. Key vegetation parameters include the form, type, and diversity of plants, coverage ratio (CR), leaf area index (LAI), foliage height, and biological processes such as photosynthesis, respiration, and transpiration. Additionally, physical characteristics of the growing medium—such as its thickness, water content, and density—play a crucial role. Site-specific conditions, including climatic factors and the insulation value of the roof, further contribute to the effectiveness of green roofs in regulating temperature and heat flux(Raji et al., 2015).

2.1.2 Evapo-transpiratory effect

Evapotranspiration, a key factor in the cooling efficiency of green roofs, combines two processes: evaporation and transpiration. Together, these phenomena significantly enhance the roof's ability to regulate temperature(Raji et al., 2015). Of the total heat dissipated, **58.4%** was removed through evapotranspiration from the plant-soil system, **30.9%** was lost through long-wave radiation between the canopy and atmosphere, and **9.5%** was used in plant photosynthesis. Only **1.2%** of the heat was retained in the plants and soil or transferred to the room below(Feng et al., 2010).

According to (Lazzarin et al., 2005) cited by (Raji et al., 2015) field experiment, when the substrate was dry and evapotranspiration was minimal, the green roof reduced heat gain by 60%, primarily through solar reflection and heat absorption by the canopy and soil layer. However, when the substrate was wet, the increased evapotranspiration rate caused a slight amount of heat to flow outward from the building, rather than 40% of the heat entering as in the dry case.

2.1.3 Thermal insulation

Numerous researchers have studied how various parameters of the growing medium influence the thermal efficiency of green roofs, focusing on factors such as thickness, density, and moisture content(Raji et al., 2015). A study comparing green roofs with soil depths of 10 cm and 20 cm to a bare roof revealed notable differences. The 10 cm and 20 cm green roofs reduced heat transfer by **59%** and **96%**, respectively, and decreased energy consumption by **31%** and **37%**, highlighting the impact of soil thickness on thermal performance. This study shows that soil depth affects heat transfer.

2.2 Effects of plants

Green roofs enhance buildings through both direct and circular thermal influences. Direct effects involve structural elements of the building itself, similar as shadowing that lowers exterior surface temperatures. Indirect effects improve the surrounding terrain by mollifying outdoor heat conditions, thereby contributing to a cooler microclimate(Saadatian et al., 2013).

2.2.1 Leaf Area Index

The LAI is an indicator representing the plan- form area of coverage of the leaves and depends on the plant species. It's typically in the range of 0.5 – 5.0. For example, if the average parcel of a given roof surface is beneath two leaves, its leaf area index would be considered as two(Saadatian et al., 2013). LAI is estimated by picking leaves (destructive evaluation), but optic techniques can also be used to estimate LAI. These techniques measure the transmittance of photosynthetically active radiation (PAR, wavelength of 400 – 700 nm) by a canopy and provide approximate values of LAI. PAR can be intercepted by leaves but also other plant components including stems, leading to biases in estimates. Therefore, an approximate value of LAI attained by optic ways is referred to as the plant area index (PAI)(Johnson et al., 2023).

2.2.2 Fractional coverage

The fractional vegetative cover is another indicator which is related to LAI and calculated bit of the green roof surface that's directly covered by plants' leaves. Fractional coverage is considered significant, since it determines the number of radiative characteristics of the soil media in the surface energy balances(Saadatian et al., 2013).

2.2.3 The role of plants and water scarcity issue

Recognizing the role of plants in shielding a roof from direct sunlight, absorbing some precipitation water, and cooling off the roof surface, it may be concluded that the use of plants on a roof improves its functionality, aesthetics, and the buildings surroundings. Green Roofs are living systems, and the selection criteria for plant species play a pivotal role in their effective function, even if the selection isn't typically driven by ecological criteria or made according to the structural characteristics of the plants.

2.3 Green roof Benefits compared to other solutions

GRs are nature- based solutions that are designed and implemented as artificial ecosystems to reduce energy consumption, ameliorate air quality, and promote civic sustainability. Parametric studies Several system parameters were considered similar as LAI, soil layer thickness, insulation thickness, irrigation, foliage height and density, type of planted roof, plant coverage, etc. Among them, LAI was found to be the parameter affecting further considerably the thermal behavior of the GR system. Energy benefits of green roofs contribute to a significant reduction of cooling load reaching up to 70 as well as to a decrease of inner temperature up to 15 °C. Environmental benefits of green roofs and environmental benefits include air pollutants concentration reduction PM 2.5, PM10, O_3, SO_2, NO_2. Carbon sequestration through photosynthesis and evapotranspi-ration; runoff water quality improvement; and urban noise reduction. Experiments and observations showed 7 – 33 reduction of PM 2.5, and significant reduction in PM10, O_3, NO_2, while GRs showed an excellent contribution to carbon sequestration (Mihalakakou et al., 2023).

2.4 Urban Heat Island

2.4.1 Characteristics of heat islands

“Heat islands exhibit five common characteristics:

1 When compared to undeveloped, rural areas, a heat island is warmer in general, with distinct daily patterns of behavior. Heat islands are often warmest, relative to rural surroundings, after the sun goes down, and coolest after the sun rises. Urban air in the ‘canopy layer, below the tops of trees and buildings, can be as much as 6°C (10°F) warmer than the air in rural areas.

2 Air temperatures are driven by the heating of urban surfaces, since many man-made surfaces absorb more of the sun’s heat than natural vegetation does.

3 These differences in air and surface temperatures are enhanced when the weather is calm and clear.

4 Areas with the least vegetation and greatest development tend to be hottest, and heat islands tend to become more intense as cities grow larger.

5 Heat islands also display warmer air in the ‘boundary layer’, a layer of air up to 2000 meters (6500 feet) high. Heat islands often create large plumes of warmer air over cities, and temperature inversions (warmer air over cooler air) caused by heat islands are not uncommon(Gartland, 2008).”

2.4.2 Effects of UHI According to weather

The urban heat island effect is most pronounced on clear, calm days and is the least noticeable during cloudy, windy conditions. This is because clear weather allows for greater solar energy absorption, and lighter winds slow down the heat dissipation process, intensifying the heat island effect. On cloudy and windy nights, the temperature difference between urban and rural areas is relatively small, around 1°C (1.8°F). However, during calm and clear conditions, the intensity of the heat island effect is significantly higher, reaching up to 3.6°C (6.5°F)(Gartland, 2008).

2.5 Article review

2.5.1 "A Review of Green Roofs to Mitigate Urban Heat Island and Kathmandu Valley in Nepal" by (Baniya et al., 2018)

It explores the potential of green roofs to address urban heat island (UHI) effects in the Kathmandu Valley. The study highlights the role of urbanization in exacerbating UHI and evaluates green roofs as a sustainable intervention. Using a comprehensive review methodology, the authors examine historical temperature trends, the environmental benefits of green roofs, and their feasibility in Nepal's urban context. This article is particularly relevant given the increasing urbanization and environmental challenges faced by developing nations.

Summary

1. **Urban Heat Island and its Causes**
    - The authors define UHI as the temperature difference between urban and rural areas, driven by factors such as impervious surfaces, reduced vegetation, and urban geometry. They emphasize that urbanization has significantly increased surface temperatures in Kathmandu, with an average annual increase of 0.04°C.
2. **Green Roofs as a Mitigation Strategy**

- Green roofs, comprising vegetation layers on rooftops, are presented as a cost-effective and sustainable solution to UHI. The article reviews global practices, emphasizing the thermal performance of green roofs and their ability to lower both surface and air temperatures through shading, evapotranspiration, and insulation.

3. **Environmental Benefits**
   - Beyond temperature regulation, green roofs enhance biodiversity, improve air quality, sequester carbon, and provide aesthetic value. The authors cite studies demonstrating that green roofs can reduce roof temperatures by 5–7°C and contribute to energy savings of 10–80% in air conditioning needs.

4. **Kathmandu Valley Context**
   - The study highlights the rapid urbanization of Kathmandu Valley, where the built-up area has increased dramatically, leading to a significant decline in green spaces. The authors underscore the valley's vulnerability to climate change and advocate for green roofs as a feasible intervention, given limited ground-level space for greenery.

5. **Recommendations**
   - The authors recommend policy interventions, public awareness campaigns, and technical capacity building to promote green roof adoption in Nepal.

Critical Analysis

Strengths:

- **Comprehensive Review:** The article effectively synthesizes global and local perspectives, providing a robust foundation for understanding green roofs' potential in Kathmandu.
- **Data-Driven Insights:** The use of temperature trends and land-use data strengthens the argument for green roof implementation.

- **Contextual Relevance:** The authors tailor their recommendations to Nepal's unique challenges, such as rapid urbanization and limited resources.

Weaknesses:

- **Limited Empirical Evidence:** The study relies heavily on secondary data and lacks field-based research specific to Kathmandu.
- **Feasibility Concerns:** While the authors discuss the benefits of green roofs, there is limited analysis of the economic and technical barriers to implementation in Nepal.
- **Policy Gap Analysis:** Although the article emphasizes the need for policy interventions, it does not provide a detailed roadmap or examples from similar contexts.

Conclusion

(Baniya et al., 2018) make a compelling case for the adoption of green roofs as a strategy to mitigate UHI effects in Kathmandu Valley. The article provides valuable insights into the environmental and socio-economic benefits of green roofs, while also highlighting the urgency of addressing urban heat challenges. However, future studies should focus on field-based experiments and cost-benefit analyses to strengthen the practical applicability of the proposed interventions. Policymakers and urban planners can leverage the findings to integrate green roofs into Kathmandu's urban development strategies.

2.5.2 "Cooling Benefits of an Extensive Green Roof and Sensitivity Analysis of Its Parameters in Subtropical Areas" by (Zhang et al., 2019)

The article investigates the thermal and energy-saving advantages of extensive green roofs (EGRs) in subtropical climates. The authors conduct both onsite measurements and numerical simulations to assess the cooling potential of EGRs and identify the key factors affecting their performance. The study's relevance is underscored by its focus on sustainable building practices aimed at reducing energy consumption and mitigating urban heat challenges in hot and humid regions.

Summary

1. Objectives and Methodology: The study aims to:

- Quantify the cooling benefits of EGRs under sunny and rainy conditions.
- Validate the accuracy of the Green Roof Module (GRM) in EnergyPlus simulations.
- Perform a sensitivity analysis to identify critical design parameters influencing EGR performance.

Onsite measurements were conducted on a rooftop experimental system in Guangzhou, China. The setup included a bare roof, and a green roof test chamber equipped with sensors for temperature and heat flux monitoring. Data collected during sunny and rainy days were used to evaluate the thermal performance of the EGR. The GRM in EnergyPlus was validated against these measurements, and a fractional factorial simulation with 16 green roof parameters was performed to determine the sensitivity of each parameter.

Key Findings:

- **Cooling Benefits:**
    - EGRs significantly reduced peak air temperatures by 4.0°C on sunny days and 1.9°C on rainy days compared to bare roofs.
    - The daily electricity consumption for air conditioning was reduced by 16.7% on sunny days and 6.7% on rainy days.

- **Sensitivity Analysis:**
    - Parameters such as the R-value of roof construction, substrate thickness, thermal conductivity of the dry substrate, leaf area index, leaf emissivity, and solar absorptance of the substrate contributed 90.8% to EGR performance.
    - Substrate and vegetation properties played a crucial role in optimizing the cooling efficiency of green roofs.

- **Validation of GRM:**
    - Simulations using the GRM in EnergyPlus showed mean bias errors and cumulative variation of root mean square errors within acceptable limits, confirming the model's accuracy for subtropical climates.

Critical Analysis

Strengths:

- **Comprehensive Approach:** The integration of experimental data and numerical simulations provides robust evidence for the cooling benefits of EGRs.
- **Relevance to Subtropical Climates:** The study's focus on subtropical conditions fills a significant research gap, offering practical insights for regions with similar climates.
- **Detailed Sensitivity Analysis:** The identification of key design parameters offers actionable guidance for optimizing green roof systems.

Weaknesses:

- **Limited Scope of Validation:** While the GRM was validated for a specific experimental setup, its applicability to diverse building types and climates could be further explored.
- **Economic Feasibility:** The study does not address the cost implications of implementing EGRs, which is critical for widespread adoption.
- **Nighttime Insulation Effects:** The observation that EGRs act as insulation layers during the night, hindering heat dissipation, warrants further investigation and potential solutions.

Conclusion

(Zhang et al., 2019) provide compelling evidence for the effectiveness of extensive green roofs in reducing energy consumption and enhancing thermal comfort in subtropical areas. Their findings highlight the importance of substrate and vegetation properties in optimizing green roof performance. However, future research should focus on economic analyses, long-term performance evaluations, and strategies to address nighttime insulation challenges. Policymakers and architects can utilize these insights to promote sustainable urban development in hot and humid regions.

2.5.3 "Comparison of thermal performance between green roofs and conventional roofs" by (Polo-Labarrios et al., 2020)

The article explores the thermal efficiency of green roofs in comparison to traditional roofing systems. As urbanization increases and climate change poses significant challenges, the need for sustainable building practices has become paramount. This study aims to provide empirical data on the thermal performance of green roofs, highlighting their potential benefits in urban environments.

Summary

The authors conducted a comprehensive analysis of two types of roofing systems: conventional roofs and green roofs. The study utilized a model that incorporates various climatic variables, such as ambient temperature, wind speed, and solar radiation, to assess the thermal performance of each roofing type. The research was grounded in the premise that green roofs can mitigate urban heat effects and contribute to energy efficiency in buildings. The findings are based on simulations and empirical data, providing a robust framework for understanding the thermal dynamics involved.

Key Findings

1. **Thermal Performance**: The study found that green roofs significantly outperform conventional roofs in terms of thermal insulation and energy efficiency. The green roofs maintained lower internal temperatures during peak heat periods, which can lead to reduced energy consumption for cooling.

2. **Climatic Variables**: The model developed in the study requires easily obtainable climatic data, making it accessible for implementation in various regions. The authors emphasized that the model's accuracy is acceptable, providing a reliable tool for future assessments.

3. **Heat Transfer Dynamics**: The research examined two scenarios: one neglecting heat transfer through walls and another considering it. The results indicated that accounting for heat transfer through walls is crucial for accurate thermal performance assessments.

4. **Environmental Benefits**: Beyond thermal performance, the study briefly touches on the broader environmental benefits of green roofs, including stormwater management and biodiversity enhancement.

Critical Analysis

While the study presents compelling evidence supporting the advantages of green roofs, there are areas that warrant further exploration. The authors could have expanded on the long-term sustainability of green roofs, including maintenance requirements and potential challenges such as plant selection and irrigation needs. Additionally, the economic implications of installing green roofs versus conventional roofs could provide a more comprehensive understanding of their feasibility for widespread adoption.

Moreover, the study primarily focuses on thermal performance without delving deeply into other factors such as aesthetic value, noise reduction, and air quality improvement, which are also critical in evaluating the overall benefits of green roofs.

Conclusions

The article by (Polo-Labarrios et al., 2020) contributes significantly to the discourse on sustainable building practices by providing empirical evidence of the thermal advantages of green roofs over conventional roofing systems. The findings underscore the potential of green roofs to enhance energy efficiency and mitigate urban heat effects, making them a viable option for modern urban architecture. However, further research is needed to address the long-term sustainability and economic viability of green roofs to encourage their adoption in urban planning and development.

2.5.4 "Toward the practicability of a heat transfer model for green roofs" by (Chen et al., 2015a)

The article by (Chen et al., 2015a) presents a simplified one-dimensional heat transfer model designed to assess the thermal effects of green roofs during the design stage. As urbanization increases, the need for sustainable building practices becomes more critical, and green roofs are recognized for their potential to mitigate urban heat islands and improve energy efficiency. This study aims to provide a practical tool for architects and engineers to evaluate the thermal performance of green roofs without requiring extensive prior knowledge of their thermal properties.

Summary

The authors developed a heat transfer model that simulates the thermal behavior of green roofs by partitioning heat transfer into two main stages: the heat budget of the plant layer and the substrate surface, followed by heat conduction through the substrate. The model was calibrated and validated using temperature data collected from a small-scale green roof experiment conducted at National Taiwan University. The study emphasizes the importance of using reasonable assumptions for unknown parameters, particularly the temperature at the substrate bottom, which is often not available during the design phase.

Key Findings

1. **Model Development**: The proposed model effectively simulates the thermal effects of green roofs, providing insights into temperature and heat flux dynamics.
2. **Calibration and Validation**: The model was calibrated using data from specific periods and validated with independent datasets, demonstrating its predictive accuracy.
3. **Performance Metrics**: The model achieved a root mean square error (RMSE) of 3.87 °C and a Nash–Sutcliffe efficiency index of 0.38, indicating a reasonable fit between observed and predicted temperatures.

4. **Thermal Benefits**: The results suggest that green roofs can significantly regulate temperature and heat flux compared to conventional roofing systems, highlighting their potential for energy savings and urban heat mitigation.

Critical Analysis

While the study provides a valuable contribution to the field of green roof modeling, several aspects warrant further consideration. The simplification of the model, while beneficial for ease of use, may overlook complex interactions within the green roof system, such as variations in plant species, substrate composition, and moisture content. Additionally, the reliance on literature values for parameter estimation may introduce uncertainties, as these values can vary significantly based on local conditions. Future research could benefit from incorporating more detailed models that account for these variables and conducting in-field experiments to validate the model under diverse environmental conditions.

Conclusions

The research by (Chen et al., 2015a) offers a practical and simplified approach to modeling the thermal effects of green roofs, making it a useful tool for designers and engineers. The findings underscore the potential of green roofs to enhance urban sustainability by regulating temperatures and reducing energy consumption. However, the study also highlights the need for further exploration of the model's limitations and the incorporation of more complex interactions within green roof systems. Overall, this work lays the groundwork for future advancements in green roof modeling and encourages the adoption of sustainable building practices.

2.5.5 "Theoretical Evaluation of Thermal and Energy Performance of Tropical Green Roofs" by (Tsang & Jim, 2011)

Article presents a comprehensive study on the benefits of green roofs in urban environments, particularly in the context of Hong Kong. As urban areas face increasing challenges related to heat retention and energy consumption, the authors explore how green roofs can serve as a sustainable solution to mitigate these issues. The study aims to establish a theoretical basis for understanding the thermal performance of green roofs and to provide practical recommendations for their implementation in densely populated cities.

Summary

The research focuses on an experimental green roof site set up in Hong Kong to assess the environmental benefits of roof greening. The authors employ a theoretical model to evaluate the thermal performance of green roofs compared to conventional bare roofs. The study utilizes various metrics, including air and soil temperatures, moisture levels, and solar radiation, to analyze the effectiveness of green roofs in reducing energy consumption, particularly during the hot summer months. The findings are intended to inform urban planning and building design, promoting energy-efficient technologies in compact urban areas.

Key Findings

1. **Thermal Performance**: The study reveals that green roofs exhibit superior thermal performance compared to bare roofs, primarily due to enhanced latent heat dissipation. This efficiency is particularly pronounced in humid-tropical climates, where green roofs can be twice as effective as their temperate counterparts.

2. **Energy Savings**: The research estimates that green roofs can prevent significant solar energy penetration into buildings, leading to substantial energy savings during peak air-conditioning periods. The theoretical calculations suggest that a considerable amount of solar energy (43.9 TJ) was mitigated in one summer.

3. **Impact of Roof Properties**: The authors highlight the importance of roof albedo and heat storage characteristics. Green roofs, with a higher albedo (0.30) compared to bare roofs (0.15), result in lower heat storage and reduced sensible heat accumulation.

4. **Microclimatic Benefits**: Beyond energy efficiency, green roofs contribute to urban biodiversity, provide habitats for wildlife, and help mitigate noise pollution, enhancing the overall quality of urban life.

Critical Analysis

The article presents a well-structured and methodologically sound investigation into the thermal and energy performance of green roofs. The use of a theoretical model, combined with empirical data from the experimental site, strengthens the validity of the findings. However, while the study provides valuable insights, it could benefit from a broader range of case studies across different urban settings to enhance the generalizability of the results. Additionally, the long-term sustainability and maintenance of green roofs, as well as their economic implications, warrant further exploration.

2.6 Systematic Review

It involves accumulation of existing research on the effectiveness of green roofs compared to contemporary roofs in mitigating UHI, focusing on temperature reduction and energy savings.

2.6.1 Databases

- Elsevier
- ResearchGate
- MDPI

2.6.2 Keywords

- "Green roofs"
- "Urban heat island"
- "Temperature reduction"

2.6.3 Review

author	Year	Location	Roof Type	Methodology	Sample Size	Metrics Measured	Key Findings
(Y. Yang et al., 2021)	2021	Onondaga County Convention Center, Syracuse, NY	Extensive Green Roof	Experimental validation and numerical simulations using the CHAMPS-BES model	1 green roof (5550 m^2)	Thermal performance, heat flux, temperature profiles, water balance, albedo effect	The green roof significantly reduced heat flux by 40% compared to a traditional roof, demonstrating benefits in passive cooling and energy savings. The insulation layer was crucial for maintaining stable temperatures.
(Polo-Labarrios et al., 2020)	2020	Mexico City	Green and conventional	Numerical modeling validated through field experiment	Not specified	Internal temperature, heat transfer, solar radiation, ambient temperature, wind speed	Green roofs reduced internal temperature fluctuations by up to **14°C** and decreased internal temperature by up to **12°C**, improving thermal comfort.
(He et al., 2020)	2020	Shanghai, China	Green Roofs, Cool Roofs, Conventional Roofs		9 test chambers	Temperature reduction, heat flux, cooling and heating loads	Green roofs and cool roofs significantly reduce indoor temperatures; cooling load lower for green

							roofs in summer.
(Zhang et al., 2019)	2019	Subtropical China	Extensive Green Roof and bare roof	Onsite measurements, energy consumption analysis, validation of the Green Roof Module (GRM) in EnergyPlus, sensitivity analysis of 16 factors, and statistical analysis of results.	Not specified	Temperature, energy consumption, solar radiation	extensive green roofs (EGR) significantly reduce roof internal surface temperatures, chamber air temperatures, and daily air-conditioning electricity consumption, with reductions of up to 12.5°C, 4.9°C, and 16.7%, respectively, compared to bare roofs in subtropical climates
(Coma et al., 2016)	2016	Puigverd de Lleida, Spain	green roof	Experimental setup with three house-like cubicles; measurements taken for free floating and controlled temperature	3 cubicles	Internal and external temperatures, humidity, electrical consumption of HVAC systems	Green roofs can significantly mitigate UHI effects, with varying effectiveness based on media type and depth.
(Chen et al., 2015b)	2015	National Taiwan University	Extensive Green Roof	Simulation using Energy plus and experimental data collection	1 m x 1 m	Temperature, Heat Flux	The green roof significantly reduced surface and air temperatures compared to bare

							roofs, enhancing cooling performance.
(Saadatian et al., 2013)	2013	Midwestern U.S.	Extensive Green Roof	Field experiment	325.2 m^2	Ambient weather conditions, heat flux, soil moisture, temperature	Green roofs can reduce temperatures by 5°C in autumn and significantly lower cumulative heat flux compared to gravel roofs.
(Jim & Peng, 2012)	2012	Hong Kong	Extensive Green Roof	The study involved monitoring environmental parameters before and after green roof installation using various sensors to collect data on temperature, humidity, and other fact	Not specified	Surface temperature, air temperature (10 cm and 160 cm), relative humidity, soil moisture, solar radiation, wind speed	Green roofs significantly reduce roof temperatures in summer and help manage heat loss in winter. The presence of vegetation and soil alters heat flux and indoor climate.
(Jaffal et al., 2012)	2012	La Rochelle, France	Green Roof	The study utilized a green roof model integrated into a building thermal program to evaluate energy performance. Simulations were conducted for different climates (Athens, La Rochelle, Stockholm) and various parameters were analyzed.	Single-family house (96 m^2)	Roof temperature, indoor air temperature, heating and cooling demand	Planted roofs (green and sod) maintained lower and more stable temperatures compared to conventional roofs, especially in summer. The sod roof was warmer than the green roof in autumn.

(Teemusk & Mander, 2010)	2010	Estonia (Tartu, Tallinn)	Green Roof, Sod Roof, SBS Roof, Steel Roof	Temperature measurements were taken every 15 minutes using Pt1000TG8/E sensors, with data recorded by a data logger. Statistical analysis included non-parametric tests (Spearman Rank Order Correlation, Mann–Whitney U-test).	Various (3 types of each roof)	Surface tempera ture, tempera ture at various depths (50 mm, 100 mm, 150 mm), air tempera ture	Green roof combined with solar thermal shading reduced indoor air temperature by 5.1°C. The green roof provided a cooling potential of 3.02 kWh per day, which is adequate for the building's needs.

2.6.4 Discussion

Temperature is a pivotal metric in assessing green roofs' efficacy in energy conservation and UHI mitigation. While field experiments capture real-world variability, computational models enable scalable scenario testing—their integration ensures robust insights. Despite regional disparities in climate and design parameters, green roofs consistently demonstrate cooling benefits, underscoring their adaptability. Future research must address socio-technical barriers (e.g., retrofit costs, policy gaps) and expand longitudinal datasets to optimize designs for extreme climates, ensuring equitable, climate-resilient urban transitions.

2.7 Land use pattern of Kathmandu

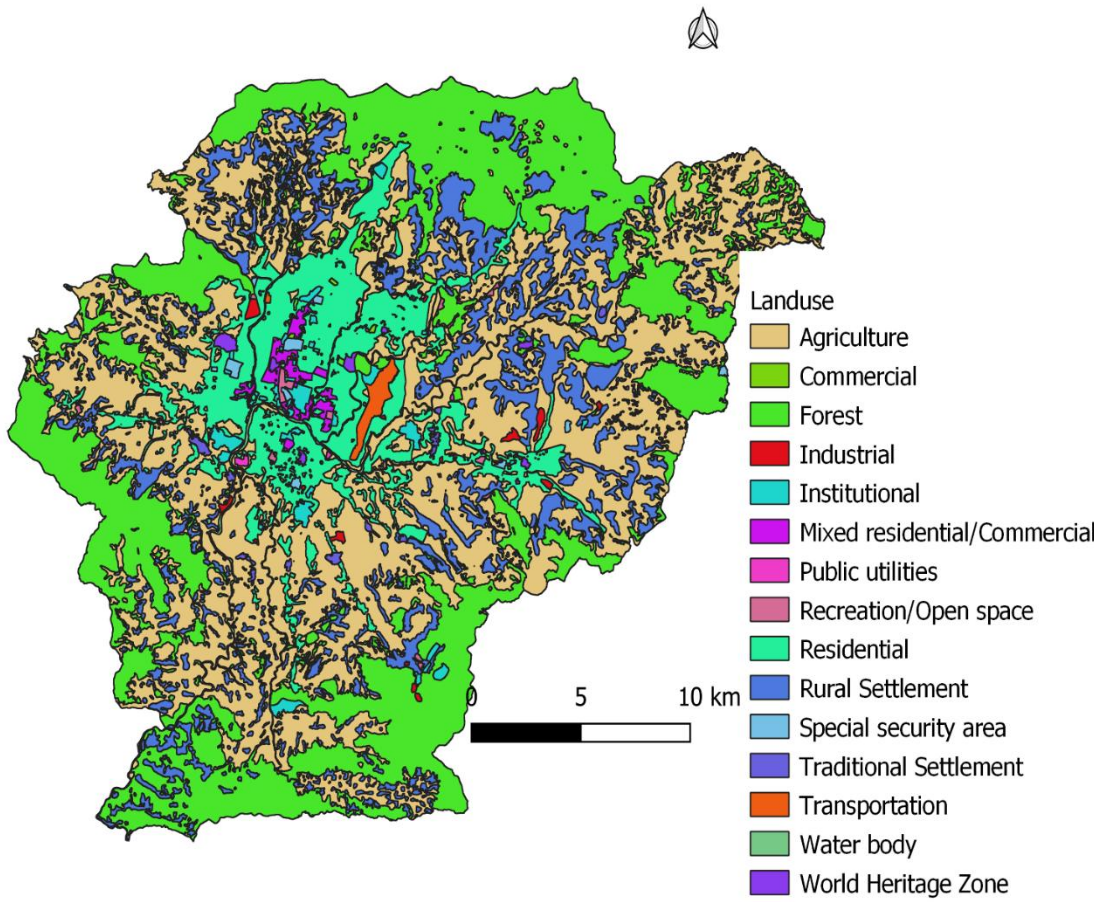


Figure 4 Land use of kathmandu (KVDA Dataset)

The spatial distribution depicted in the diagram reveals Kathmandu Valley's urban core as a mosaic of institutional hubs, mixed residential-commercial developments, and fragmented industrial zones. This dense aggregation of built infrastructure prioritizes economic and administrative functions, leaving minimal room for green or open spaces critical oversight in urban planning. The dominance of impervious surfaces like concrete, asphalt, and metal rooftops exacerbates the Urban Heat Island (UHI) effect, as these materials possess high thermal mass, absorbing and re-radiating solar energy throughout the day and night. With limited vegetation to facilitate evapotranspiration or shade, the core area experiences reduced albedo and diminished natural cooling, resulting in ambient temperatures 3–6°C higher than the valley's rural peripheries.

In contrast, rural settlements on the outskirts retain permeable soils, agricultural plots, and tree cover, which collectively moderate temperatures through evaporative cooling and shade. This stark thermal disparity underscores land use patterns as a key driver of UHI intensity. The urban core's lack of green corridors, parks, or rooftop gardens further isolates heat within its dense urban canyons, trapping pollutants and elevating health risks such as heat stress and respiratory illnesses. Meanwhile, rural zones benefit from lower building densities and proximity to natural landscapes, which act as thermal buffers.

The findings highlight an urgent need to recalibrate Kathmandu's urban development strategies. Integrating nature-based solutions such as mandatory green roofs, urban forestry, and pedestrian-friendly greenways could counteract heat retention in the core. Policymakers must prioritize mixed-use zoning that balances infrastructure growth with ecological preservation, ensuring equitable thermal comfort across urban and rural landscapes.

2.8 Conceptual framework

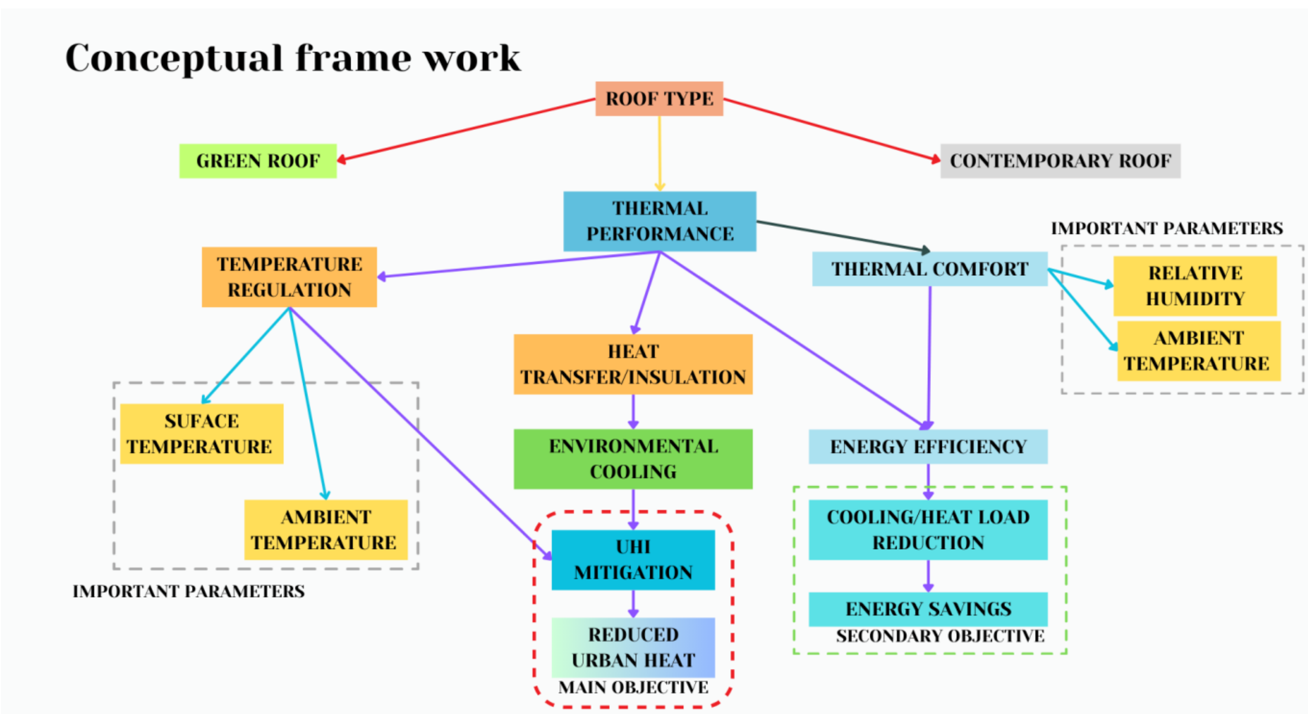


Figure 5 Conceptual Framework

3 CHAPTER THREE: DATA COLLECTION

3.1 Field Data collection

3.1.1 Equipment and tools

Different tools and devices are used to measure the required data.

Data loggers

Datalogger for Surface temperature of Green Roof

Manufacturer: Onset Computer Corporation

Product: MX2304

Serial Number: 20516813

Firmware Version: 48.100

Metrics: Temperature (±5°C)

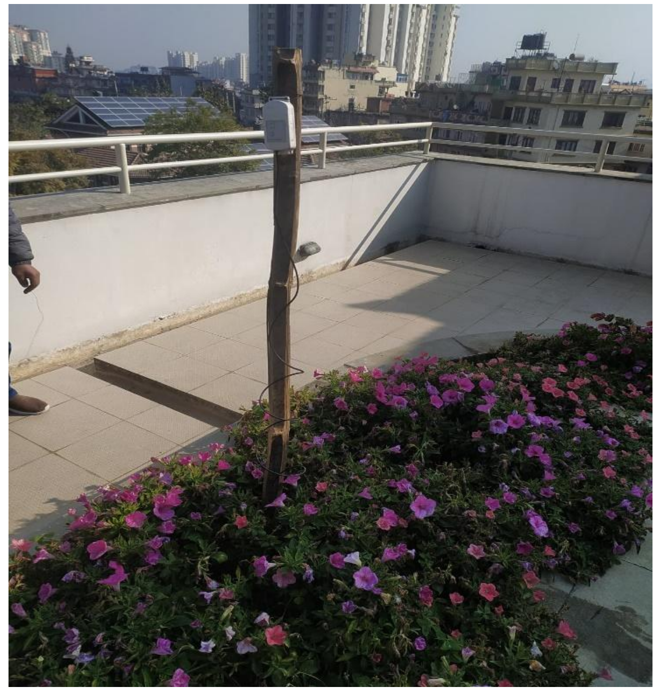


Figure 6 Data logger measuring ST of Green roof

Datalogger for Surface temperature of Concrete Roof

Manufacturer: Onset Computer Corporation

Product: MX2304

Serial Number: 20516816

Firmware Version: 48.100

Metrics: Temperature (±5°C)

Figure 7 Data logger measuring ST of Concrete roof

3.1.2 ICIMOD

The International Centre for Integrated Mountain Development, a regional intergovernmental organization established in 1983. In Nepal it is in khumaltar. Kailash Bhawan named after the Kailash Hall, contains green roof which will the field experiment area.

Figure 8 Kailash Bhawan,IICMOD,Khumaltar

3.2 Floor plan of the rooms

Below the floor plans of the rooms are given.

3.2.1 Green roof Area

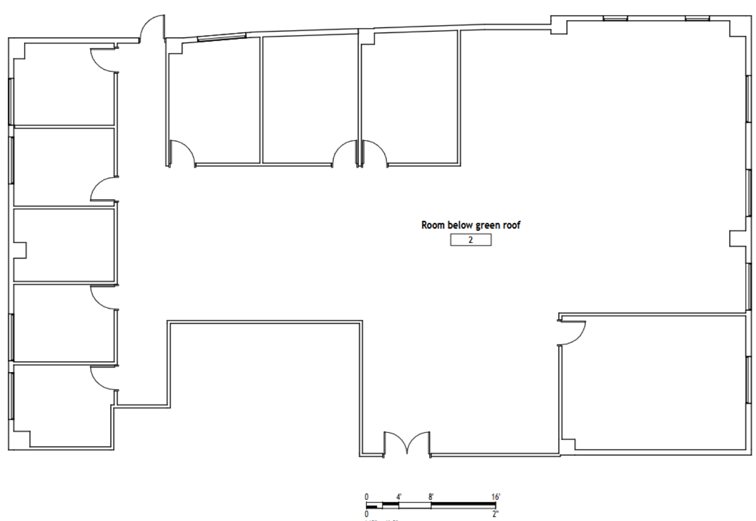


Figure 9 Room below green roof

Room height – 2.81 m (clear height),

Wall composition – 9”-12” brick wall with 12 mm plaster

Internal wall composition – 8 mm gypsum board with rock wool inside

Floor – RCC slab 6”-8”

Ceiling – 6”-8” RCC slab with false ceiling

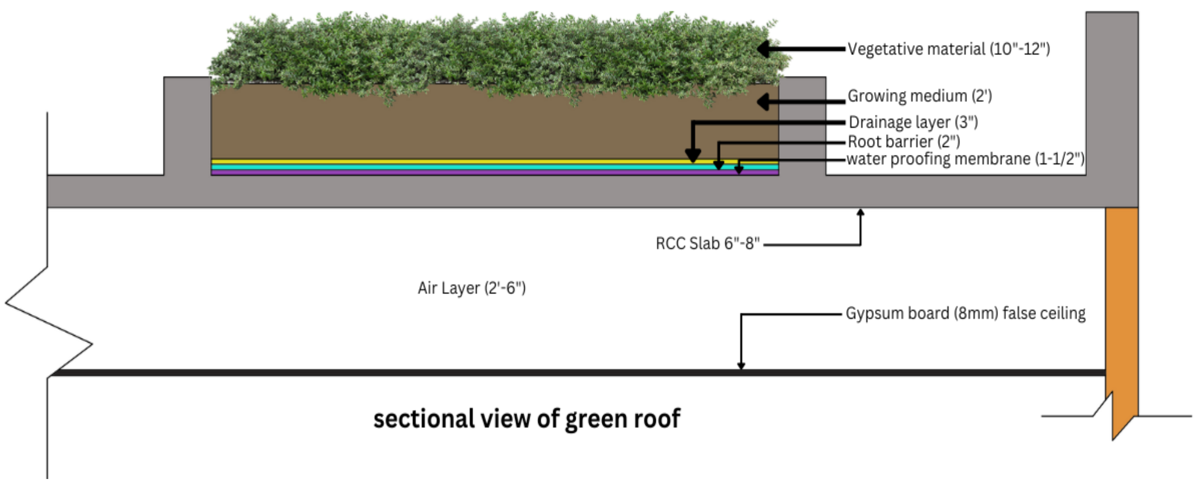


Figure 10 Sectional view of green roof

Green roof Information

Type of green roof: Partial semi-Intensive

Depth (Approx): 2’6”

Slab depth (Approx): 6”-8”

False ceiling depth (Approx): 2’6”

Area (Approx): 70 m^2

Room below green roof Information

Use: Office

HVAC: Yes (Except for Saturday and Sunday)

Wall construction

Windows: Full height

Wall: Brick wall with plaster

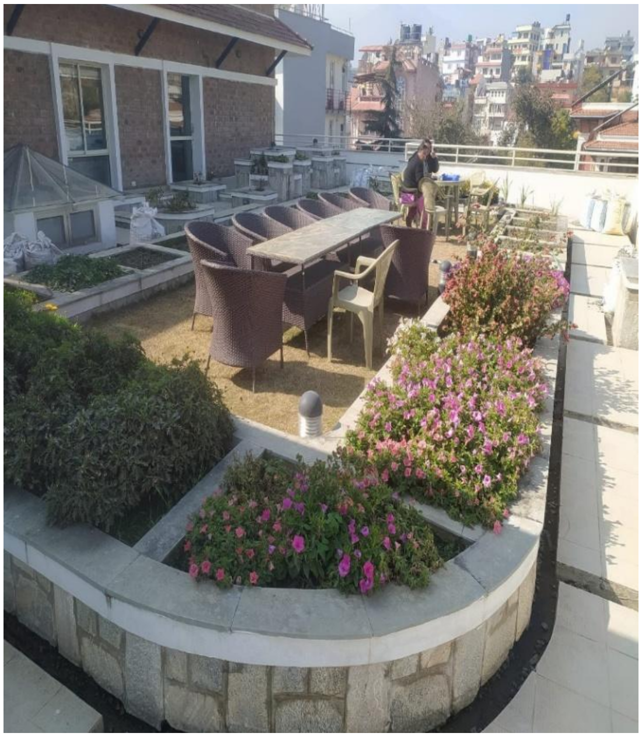


Figure 11 Semi-Intensive Green roof

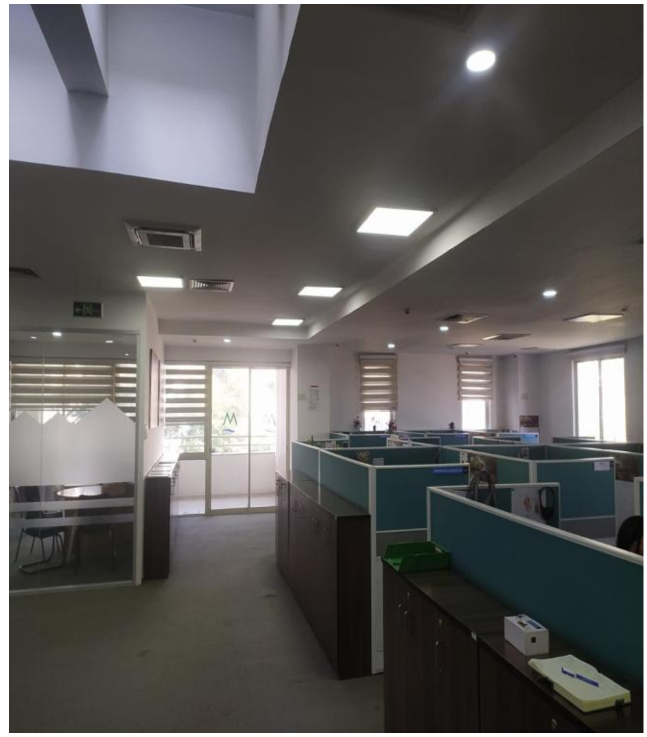


Figure 12 Room Below Green roof

Concrete roof Information

Slab depth (Approx): 6“-8”

False ceiling depth (Approx): 2’6”

Area (Approx): 690 m^2

Room below green roof Information

Use: Meeting

HVAC: Yes (Except for Saturday and Sunday)

Wall construction

Windows: Full height

Wall: Brick wall with plaster

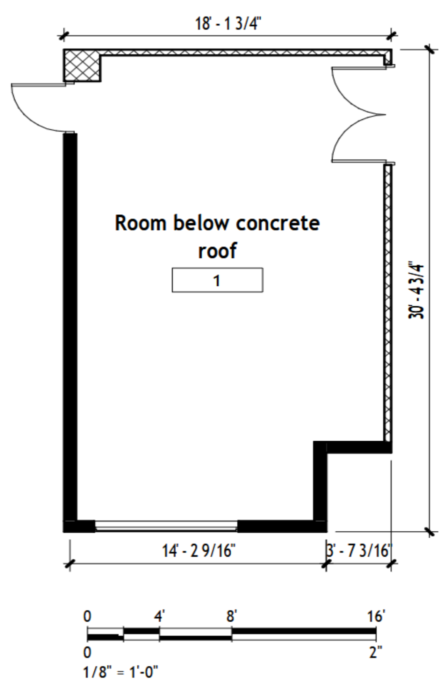


Figure 13 Room below Concrete Roof

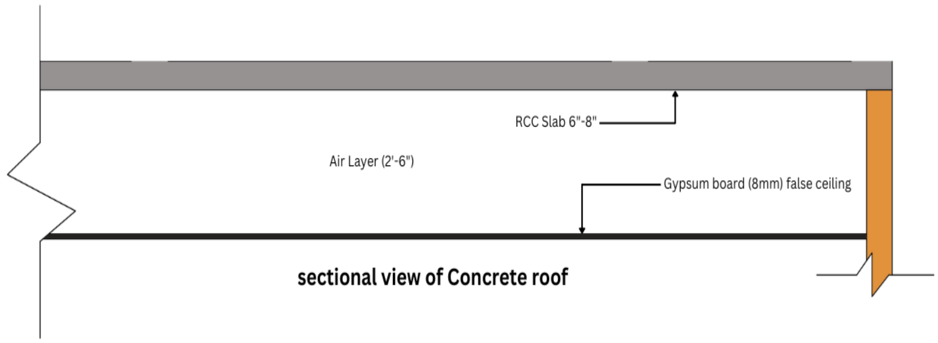


Figure 14 Sectional view of concrete roof

Figure 15 Room below Concrete roof

Figure 16 Concrete Roof with solar Panels

3.2.2 Measurements details

Surface temperature

Surface temperature of Both Green roof and concrete roof are measured using HOBO ONSET data loggers with an interval of 1 hour for 3 weeks continuously.

Ambient Temperature

Ambient temperature for green roof, Room below green, Concrete roof as well as the room Below the concrete roof is measured once a day at height of 1.5m due to limited permission.

Relative Humidity

Relative Humidity for Green roof, Room below green, Concrete roof as well as the room Below the concrete roof is measure once a day at height of 1.5m due to limited permission.

3.3 Study Area

The study area is selected based on GIS mapping of Higher Surface temperature, NDVI and UHI intensity. Data was extracted from USGS earth explorer.

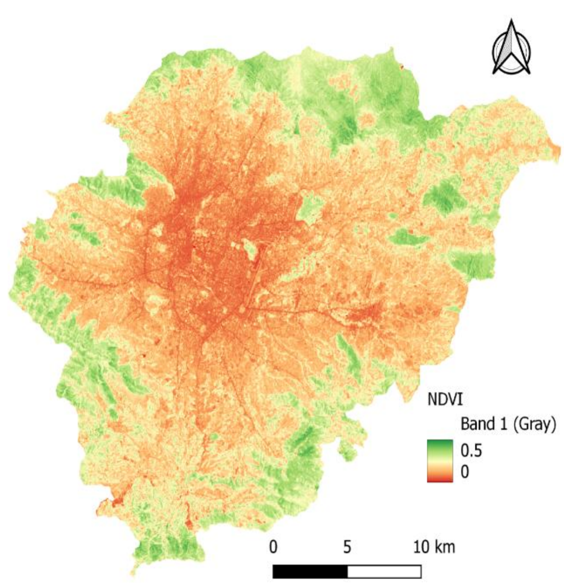


Figure 18 NDVI Kathmandu valley 2024

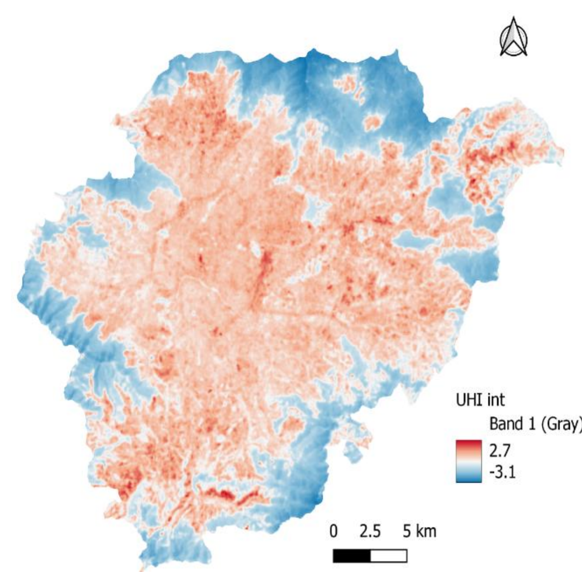


Figure 17 UHI intensity Kathmandu valley 2024

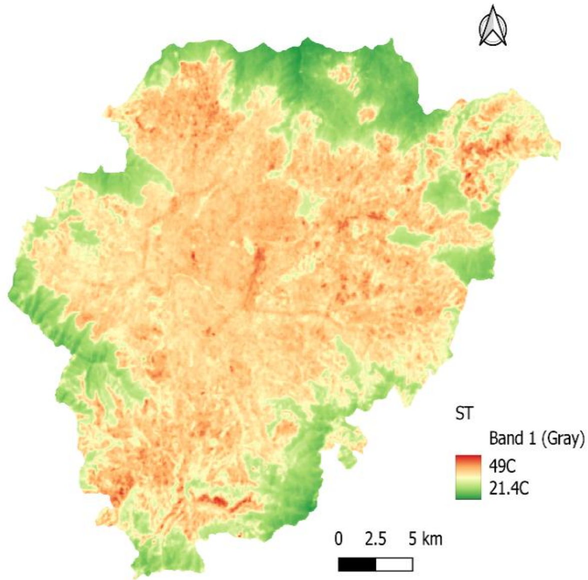


Figure 19 Surface temperature kathmandu valley 2024

The data clearly indicates that the urban core of Kathmandu Valley exhibits significantly higher Urban Heat Island (UHI) intensity compared to its sub-rural peripheries, underscoring the necessity of prioritizing the core area as the focal study site for UHI mitigation research. This thermal disparity stems from the core's dense concentration of impervious surfaces—concrete buildings, asphalt roads, and industrial zones—which absorb and retain solar radiation, coupled with a near-total absence of green spaces to facilitate cooling through evapotranspiration or shade. The urban morphology of the core, characterized by tightly packed mid-rise structures, further exacerbates heat retention by limiting airflow and creating "urban canyons" that trap warm air. In contrast, sub-rural areas benefit from lower building densities, agricultural land, and vegetative cover, which naturally regulate temperatures through soil permeability and transpiration.

Selecting the core as the study site is critical to understanding the drivers of extreme UHI effects in high-density urban environments. Focusing research here allows for granular analysis of heat-generating variables, such as anthropogenic activity (e.g., vehicular emissions, industrial operations), thermal properties, and microclimatic feedback loops. It also provides actionable insights for designing targeted interventions—such as retrofitting buildings with green roofs, expanding urban forestry, or introducing cool pavements—that directly address the unique challenges of densely populated urban centers.

3.4 Workflow

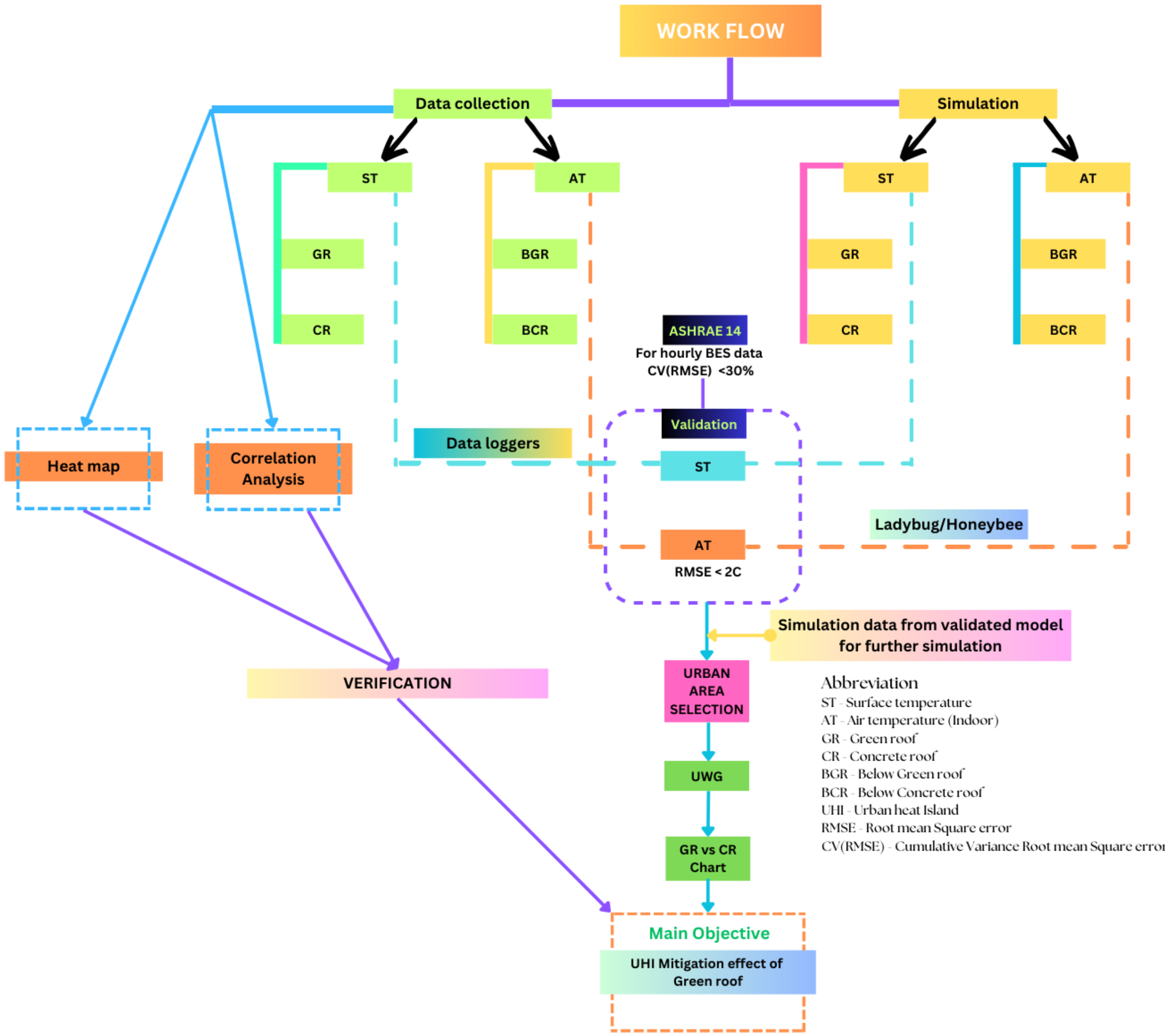


Figure 20Work flow

4 CHAPTER FOUR: SCOPES AND LIMITATIONS

The Study Limitations and scopes are mentioned below:

1. Limited Study Period Data collection lasted only two weeks, which may not reflect seasonal variations and long-term thermal performance.
2. The Studied Green Roof Covers the roof partially while during the study it is considered to cover the roof fully.
3. The study area consists of Semi-Extensive roofs, thus is likewise considered in design while other forms of green roof are not properly analyzed in this study.
4. Single Study Location Findings are grounded on one site and may not completely represent the variability across Kathmandu, especially in different building typologies.
5. Foliage Type Influence Different plant species and soil compositions could impact green roof performance but weren't extensively analyzed in this study.
6. While both Relative humidity and temperatures were measured, only temperature parameters are used.
7. Lack of Long-Term Analysis Structural integrity, waterproofing concerns, and maintenance challenges weren’t part of this study and should be explored in future exploration.
8. ASHRAE Fundamentals 2021 was used as reference for materials data properties which may vary from the material properties of Nepal as there is no specific material properties guide for Nepal.
9. ASHRAE 14-2014 is used to validate simulation model and field data.
10. While Relationship between roofs and internal rooms are studied, Relative humidity was not considered during the analysis of data.
11. While the Study area is far from Tribhuvan International Airport (TIA) the EPW file is taken from TIA which was later morphed for study site accordingly for simulation analysis.
12. Since the study was specifically done in winter season the insights and results were predicted based on the winter data even for other seasons.

5 CHAPTER FIVE: DATA ANALYSIS AND DISCUSSIONS

5.1 Surface temperature

The data from the loggers shows that green roofs are significantly cooler than concrete roofs. The average difference between concrete surface and green surface is found to be about **4.84** °C, maximum of **9.74** °C and minimum of **-3.43** °C. Below is the Chart showing the Surface temperature comparison between Concrete roof and green roof.

The graph presents a comparative analysis of **Concrete Surface Temperature (CST)** and **Green Surface Temperature (GST)** from **January 20 to February 4, 2025**. Each data point represents 24-hour surface temperature variations, with minor axis ticks marking intervals of **2 hours and 24 minutes**.

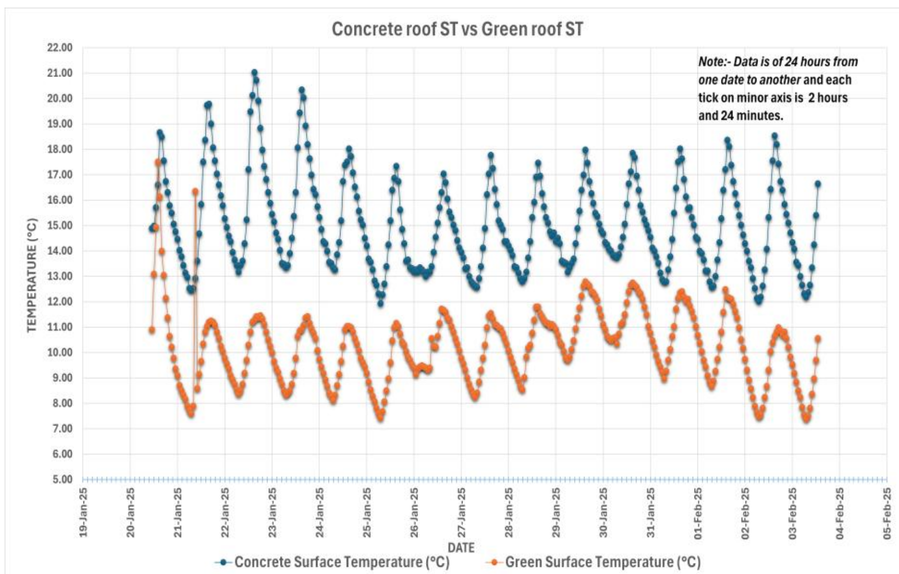


Figure 21 Surface temperature comparison of green roof vs concrete for 2 weeks

Temperature Fluctuation Patterns

Concrete Roof

- Exhibits advanced peak temperatures during the day, reaching around 19 °C to 21 °C.
- Retains heat longer, cooling down gradually at night but rarely dropping below 13 °C.

- It shows a strong diurnal variation, with significant temperature differences between day and night.

Green Roof

- Maintains a much lower peak temperature, around 10 °C to 12 °C during the day.
- Cools down quickly at night, reaching as low as 7 °C to 9 °C.
- Displays a more stable temperature profile, indicating better thermal regulation.

Heat Absorption and Dissipation

- The concrete roof absorbs and retains further heat during the daytime, making it susceptible to the civic heat island effect.
- The **green roof has a natural cooling effect**, preventing excessive heat accumulation and allowing for faster heat dissipation at night.

Figure 23 and Figure 24 indicates that ST of green roof is significantly cooler compared to that of concrete roof. Even during day and night the ST of green roof is cooler than that of concrete roof to green roof can cool the urban microclimate significantly reducing UHI and Heat waves effect.

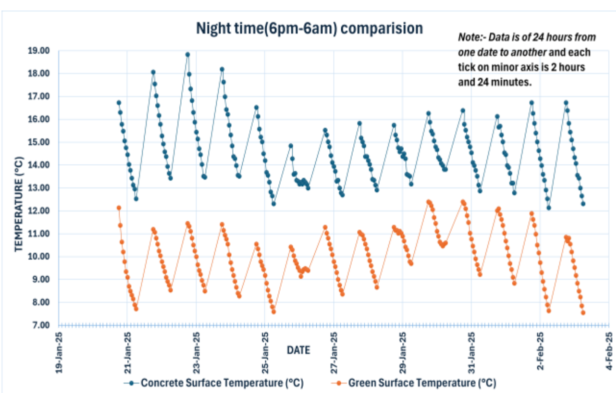


Figure 22 Surface temperature comparison for green roof vs concrete roof at night

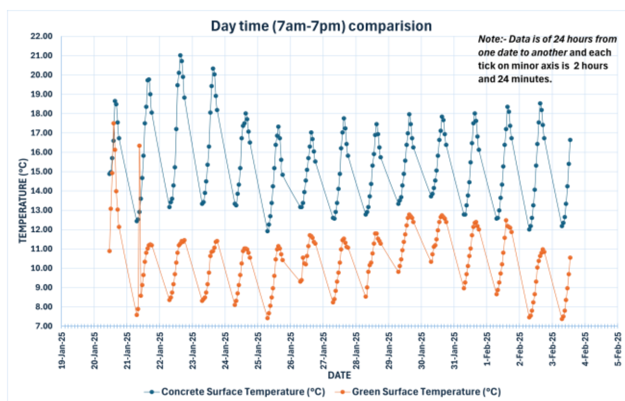


Figure 23 Surface temperature comparison for green roof vs concrete roof at daytime

The analysis of surface temperature variations between concrete and green surfaces during both nighttime (6 PM – 6 AM) and daytime (7 AM – 7 PM) provides precious insights into thermal performance, heat retention, and implicit energy savings.

The data indicates that concrete surfaces exhibit consistently advanced temperatures than green surfaces during both day and night. still, the magnitude of the difference varies

At night, concrete retains heat for an extended duration, with surface temperatures ranging from approximately 13 °C to 18 °C, while green surfaces remain significantly cooler, fluctuating between 8 °C and 12 °C. During the day, concrete temperatures peak around 20 °C – 21 °C, whereas green surfaces remain within the 10 °C – 14 °C range.

This trend highlights the high heat retention capacity of concrete compared to vegetated surfaces, contributing to the Urban Heat Island (UHI) effect and increased energy demand in civic areas.

Heat Loss and Retention Analysis: Concrete Surfaces The thermal inertia of concrete allows it to absorb and store heat during the day, which it also gradationally releases at night. This results in sustained advanced night temperatures, delaying cooling processes and increasing heat stress in civic surroundings.

Green Surfaces The vegetated surfaces exhibit a lower heat retention capacity, allowing them to cool down fleetly after evening. This indicates a reduced heat storage effect, making them salutary in mitigating nighttime UHI goods.

A crucial observation is that concrete surfaces witness a slower rate of heat loss at night, maintaining temperatures well above green surfaces. This implies that buildings and pavements made of concrete contribute to prolonged night heat retention, challenging increased cooling energy operation in conterminous inner spaces.

Energy Efficiency Implications: The temperature differences between the two surface types have direct consequences on energy demand for heating and cooling. In urban areas dominated by concrete, advanced night temperatures reduce the natural cooling effect, leading to increased reliance on air conditioning systems, which elevates energy consumption and electricity costs.

If integrated on a larger scale, green roofs and vegetated landscapes could provide passive cooling benefits, reducing overall energy consumption and mitigating urban temperature extremes.

5.2 Room ambient temperature

Rooms below the green roof and concrete rooms were measured respectively with CO2 Recorder data loggers for 14 days. The rooms have HVAC units which is used mostly during office hours thus for analysis of data it is divided into Temperature with HVAC and Without HVAC.

5.3 Without HVAC

The graph below shows the temperature data without HVAC. It can be deduced that the insulation properties of concrete are significantly lower than that of the green roof which is indicated by the sharp rise of temperature during hotter days while reduction during colder days. The temperature of the room below the green roof is comparatively stable compared to the temperature of the room below concrete roof.

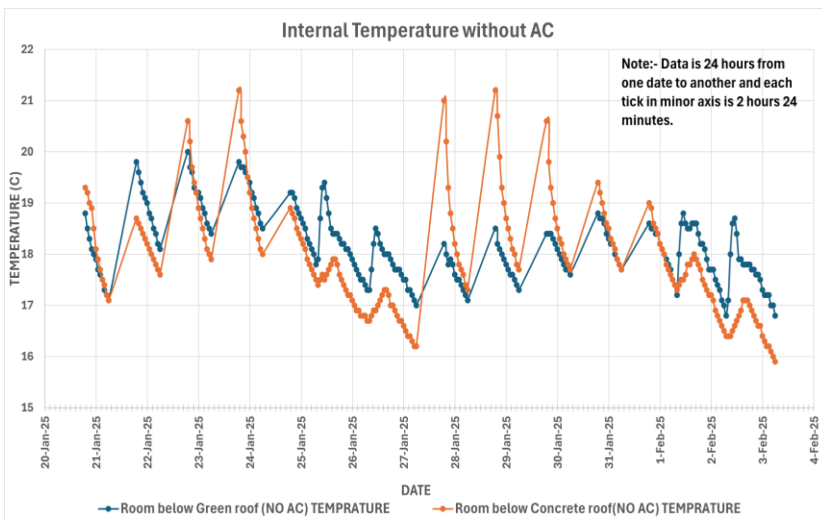


Figure 24 Internal temperature comparison between room below green roof and concrete roof without HVAC

Figure 25, which represents the indoor ambient temperature of rooms just below the green and concrete roof without HVAC reveals the temperature spikes in rooms just below the concrete roof whereas the room below green roof is quite stable all around. This suggests that concrete has poor insulation compared to that of concrete roof which in turn indicates that the high temperature peaks at the peak hours as in the chart above.

5.4 With HVAC

The graph below shows the temperature data with HVAC which indicates high temperatures in the room below concrete roof suggesting high energy consumption by HVAC units to maintain stable internal temperatures.

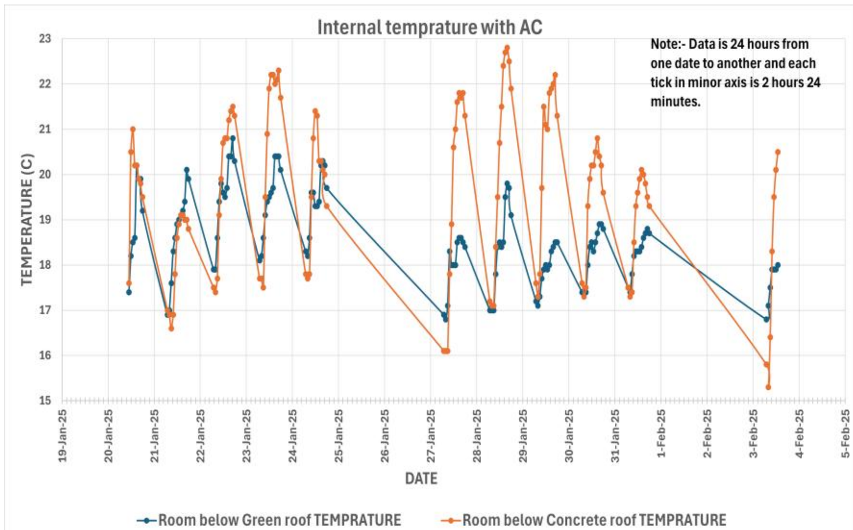


Figure 25 Internal temperature comparison between room below green roof and concrete roof with HVAC

Figure 26, which represents the indoor ambient temperature of rooms just below the green and concrete roof with HVAC shows high temperature spikes in room just below the concrete roof whereas the room below green roof has small temperature spikes compared to that of room below concrete roof. This again solidifies the fact that concrete has poor insulation compared to concrete roofs and it also reveals how rooms below green roofs require less energy to maintain optimal room temperature while rooms below concrete roof require high energy to maintain the same optimal temperature.

5.5 Correlation between Concrete roof surface temperature and room below internal temperature

While performing correlation analysis between concrete roof and internal temperature of the roof below.

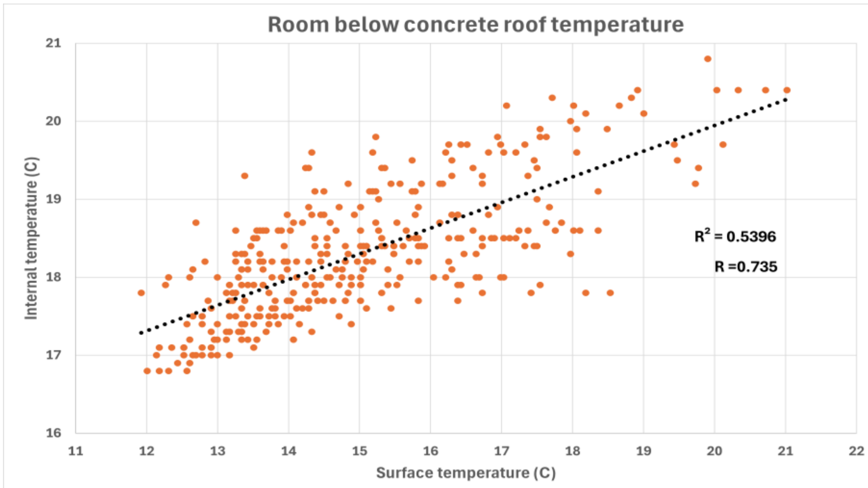


Figure 26 Correlation graph between internal temperature and Surface temperature in concrete roof

Figure 27's correlation coefficient (r) of **0.735** indicates a **moderately strong positive** relationship between the concrete roof's surface temperature (ST) and the room's internal temperature (IT).

Discussion

Thermal Mass Effect: Concrete has high thermal mass, meaning it absorbs and retains heat effectively. This leads to a strong, predictable relationship between surface temperature and internal temperature. The heat transfer is more harmonious, resulting in a advanced correlation.

Direct Heat Transfer: Concrete roofs lack insulating layers, so superficial temperature changes are more directly transmitted to the room below. This creates a direct and stronger dependency between the two variables.

5.6 Correlation between Green roof surface temperature and room below internal temperature

While performing correlation analysis between concrete roof and internal temperature of the roof below.

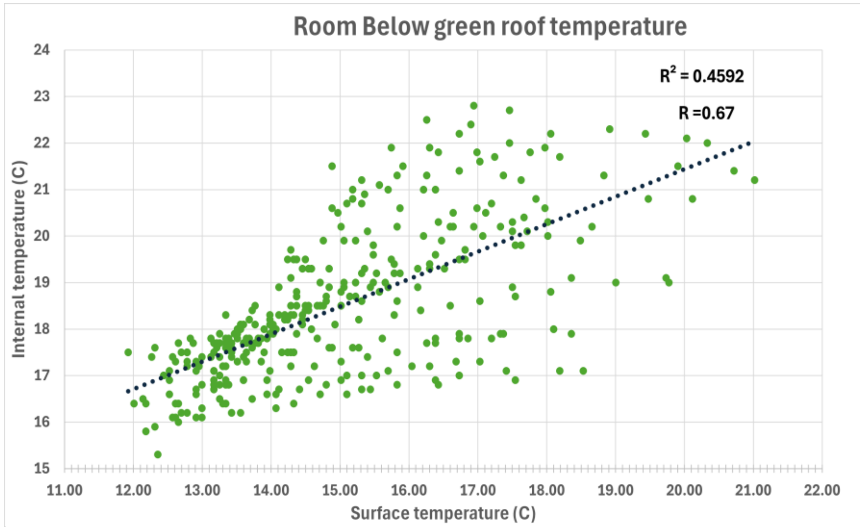


Figure 27 Correlation graph between internal temperature and Surface temperature in green roof

A Pearson correlation coefficient (r) of **0.677** suggests a **moderately strong positive** relationship between surface temperature (ST) and internal temperature (IT).

Discussion

Insulation and Buffering: Green roofs include soil and foliage, which act as natural insulators. These layers dampen temperature fluctuations, reducing the direct impact of face temperature on internal conditions.

Evapotranspiration: Plants release humidity, which cools the surface through evaporation. This dynamic process adds variability, weakening the direct relationship between surface and internal temperatures.

Variable Conditions: Factors like soil humidity, plant health, and weather (e.g., rain) introduce fresh variability, further reducing the correlation compared to concrete.

5.7 Correlation between Green roof surface temperature and room below internal temperature without HVAC

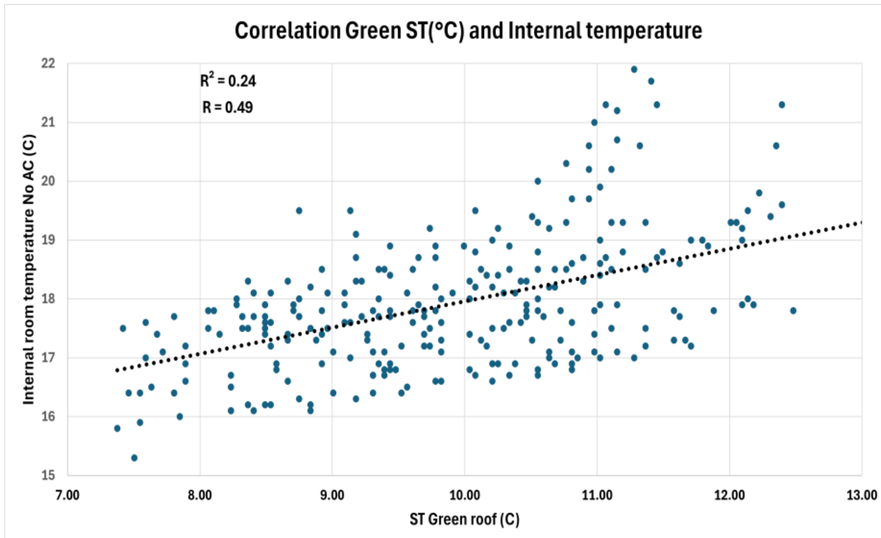


Figure 28 Correlation between green roof ST and Internal room temperature with No AC

The correlation between internal room temperature and the green roof, without air conditioning, showed a **moderate positive** correlation coefficient of **0.49**.

Discussion

Natural Insulation: Soil and vegetation act as thermal buffers, reducing the direct impact of surface temperature on the room below.

Evapotranspiration Cooling: Plants release moisture, which absorbs heat and lowers surface temperature, adding variability to the relationship.

Variable Factors: Soil moisture, plant coverage, and weather conditions (e.g., rain, shade) introduce unpredictability, weakening the correlation.

5.8 Correlation between Concrete roof surface temperature and room below internal temperature without HVAC

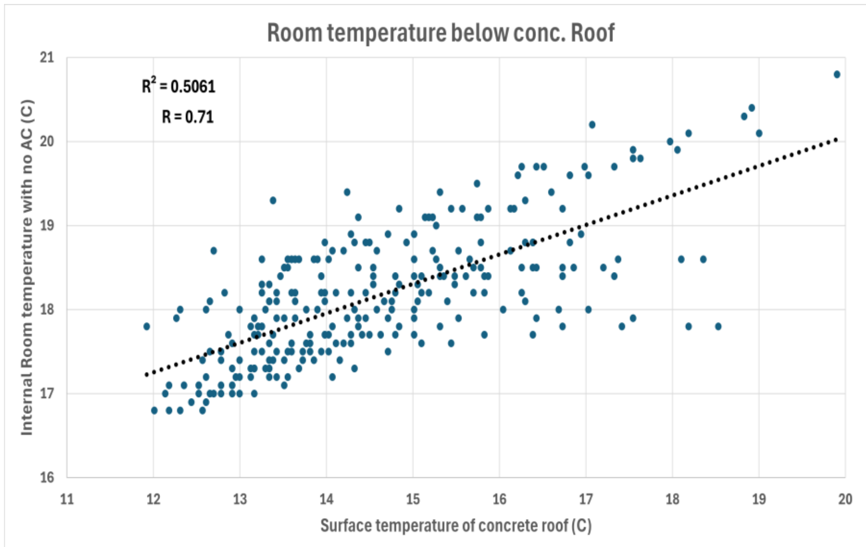


Figure 29 Correlation between green roof ST and Internal room temperature with No AC

A Pearson correlation coefficient (r) of **0.71** suggests a **moderately strong** relationship between surface temperature (ST) of concrete roof and internal temperature (IT).

Discussion

- **High Thermal Conductivity**: Concrete readily absorbs and transfers heat, creating a strong linear relationship between surface temperature (ST) and internal room temperature.
- **No Insulation**: Without air conditioning (AC), heat flows directly into the room, leading to predictable temperature changes and a higher correlation.
- **Thermal Lag Still Present**: While concrete stores heat, its slow release still causes some delay, but the overall trend remains strongly correlated.

5.9 Correlation between Green roof surface temperature and room below internal temperature with HVAC

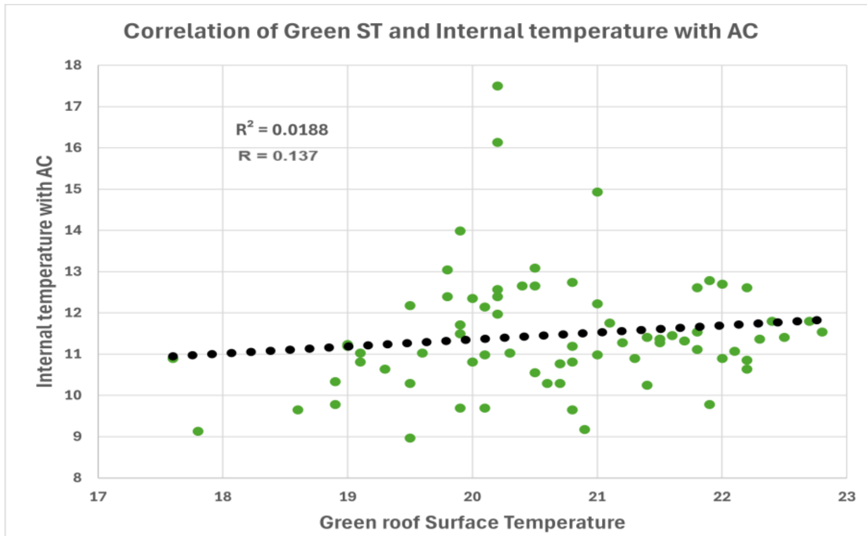


Figure 30 Correlation between green roof ST and Internal room temperature with AC

The correlation between internal room temperature and the green roof, without air conditioning, showed a **Weak** correlation coefficient of **0.137**.

Discussion

Very Weak Correlation: The green roof's natural insulation and evapotranspiration already stabilize temperatures, making the AC's influence dominant.

AC Overrides Natural Effects: Since the green roof already buffers temperature changes, the AC further decouples the internal temperature from the roof's surface temperature.

Minimal Direct Influence: The internal temperature is now mostly governed by the AC system rather than the roof's thermal properties.

5.10 Correlation between Concrete roof surface temperature and room below internal temperature with HVAC

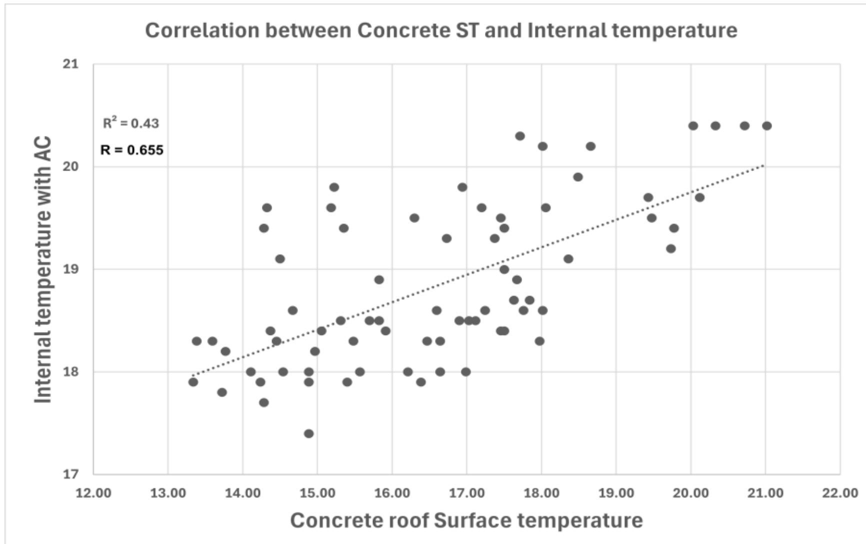


Figure 31 Correlation between green roof ST and Internal room temperature with AC

A Pearson correlation coefficient (r) of **0.655** suggests a **moderately strong posit**ive relationship between surface temperature (ST) of concrete roof and internal temperature (IT).

Discussion

Moderate Correlation: The presence of air conditioning (AC) disrupts the natural heat transfer from the concrete roof, weakening the correlation compared to the no-AC scenario.

AC Regulation: The cooling system actively counteracts heat from the roof, reducing the direct influence of surface temperature (ST) on internal temperature.

Thermal Mass Still Relevant: Concrete's heat retention still has some effect, but the correlation is weaker because AC introduces external control.

5.11 Heat map of Concrete roof and green roof surface temperature

The heat maps you provided compare surface temperatures for two different types of roofs a concrete roof and a green roof over a period of days in January 20 and February 4. Below is a detailed analysis based on time of day and seasonal impact.

HEAT MAP FROM GREEN SURFACE

Average of Green Surface Temperature (°C) — Column Labels

Row Labels	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM	Averages
20-Jan												10.89	13.08	14.93	17.50	16.13	13.98	13.04	12.14	11.37	10.64	10.21	9.78	9.35	12.54
21-Jan	9.09	8.71	8.49	8.32	8.15	7.89	7.72	7.59	7.89	16.34	8.58	9.14	9.65	10.34	10.81	11.02	11.19	11.24	11.19	11.07	10.81	10.55	10.25	10.04	9.84
22-Jan	9.78	9.56	9.35	9.09	8.92	8.75	8.53	8.36	8.49	8.75	9.18	9.69	10.29	10.81	11.19	11.28	11.41	11.37	11.45	11.32	11.11	10.81	10.51	10.25	10.01
23-Jan	9.99	9.65	9.39	9.22	8.96	8.75	8.49	8.32	8.41	8.49	8.75	9.18	9.78	10.64	10.85	10.89	11.07	11.37	11.41	11.15	10.94	10.77	10.55	10.08	9.88
24-Jan	9.74	9.44	9.18	8.92	8.66	8.41	8.28	8.11	8.32	8.71	9.14	9.65	10.25	10.89	11.02	11.02	10.98	10.81	10.55	10.34	10.08	9.78	9.61	9.44	9.64
25-Jan	9.18	8.83	8.53	8.28	8.06	7.81	7.59	7.42	7.68	8.06	8.49	8.96	9.61	10.46	10.98	11.15	11.02	10.72	10.42	10.29	10.04	9.82	9.69	9.52	9.28
26-Jan	9.39	9.14	9.35	9.44	9.48	9.44	9.39	9.31	9.39	10.55	10.25	10.21	10.64	11.15	11.71	11.67	11.58	11.37	11.28	11.02	10.81	10.55	10.34	10.08	10.31
27-Jan	9.78	9.56	9.31	9.01	8.75	8.53	8.36	8.23	8.41	8.83	9.31	9.78	10.29	10.98	11.45	11.54	11.32	11.11	11.07	10.98	10.94	10.77	10.55	10.34	9.97
28-Jan	10.08	9.82	9.61	9.35	9.14	8.92	8.66	8.53	9.01	9.82	10.16	10.29	10.77	11.28	11.79	11.79	11.54	11.41	11.28	11.15	11.15	11.02	11.11	11.02	10.36
29-Jan	10.89	10.68	10.42	10.29	10.04	9.78	9.69	9.82	10.12	10.46	10.94	11.37	11.75	12.22	12.61	12.78	12.70	12.61	12.40	12.35	12.22	12.05	11.71	11.45	11.31
30-Jan	11.11	10.89	10.64	10.55	10.46	10.55	10.59	10.34	10.72	11.11	11.19	11.49	11.97	12.40	12.65	12.74	12.65	12.57	12.40	12.31	12.10	11.79	11.49	11.02	11.49
31-Jan	10.77	10.46	10.21	9.91	9.65	9.44	9.22	8.96	9.26	9.69	10.12	10.64	11.02	11.71	12.14	12.35	12.40	12.18	12.01	12.10	11.84	11.62	11.37	11.02	10.84
1-Feb	10.68	10.38	10.04	9.69	9.44	9.09	8.83	8.66	8.88	9.26	9.74	10.21	10.81	11.58	12.48	12.18	12.14	12.10	11.88	11.62	11.37	10.98	10.51	10.16	10.53
2-Feb	9.74	9.31	8.92	8.58	8.23	7.89	7.63	7.46	7.55	7.81	8.23	8.66	9.31	10.04	10.38	10.64	10.81	10.98	10.85	10.68	10.81	10.55	10.21	9.82	9.38
3-Feb	9.52	9.18	8.83	8.49	8.23	7.85	7.55	7.38	7.50	7.81	8.36	8.96	9.69	10.55											8.57
Averages	9.98	9.69	9.45	9.22	9.01	8.79	8.61	8.46	8.69	9.69	9.46	9.94	10.59	11.33	11.97	11.94	11.77	11.63	11.45	11.27	11.06	10.81	10.55	10.26	10.24

Figure 33 Heat map of green roof

HEAT MAP FOR CONCRETE ROOF

Average of Concrete Surface Temperature (°C) — Column Labels

Row Labels	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM	Averages
20-Jan												14.88	14.97	15.70	16.60	18.66	18.49	17.54	16.73	16.30	15.78	15.48	15.06	14.75	16.23
21-Jan	14.45	14.03	13.77	13.43	13.12	12.95	12.52	12.44	12.52	12.91	13.60	14.67	15.83	17.50	18.36	19.73	19.77	19.00	18.06	17.54	17.03	16.60	16.17	15.78	15.49
22-Jan	15.27	14.93	14.58	14.37	13.94	13.64	13.43	13.17	13.43	13.60	14.28	15.23	17.20	19.47	20.12	21.02	20.72	19.90	18.83	17.97	17.33	16.81	16.30	15.87	16.31
23-Jan	15.44	15.14	14.71	14.45	14.03	13.51	13.47	13.34	13.43	13.90	14.50	15.36	16.30	18.06	19.43	20.33	20.03	18.92	18.19	17.63	16.99	16.43	16.21	15.74	16.06
24-Jan	15.31	14.84	14.37	14.28	13.98	13.55	13.51	13.34	13.25	13.85	14.33	15.18	16.73	17.37	17.50	18.02	17.72	17.07	16.51	16.13	15.57	15.23	15.01	14.50	15.30
25-Jan	14.20	13.68	13.55	13.25	12.82	12.65	12.31	11.92	12.27	12.70	13.38	14.24	15.18	16.39	16.86	17.33	16.73	15.61	14.84	14.28	13.60	13.64	13.34	13.30	14.09
26-Jan	13.17	13.25	13.17	13.34	13.25	13.17	13.00	13.17	13.17	13.38	13.94	14.54	15.10	15.70	16.30	17.03	16.69	16.04	15.53	15.31	15.01	14.80	14.41	14.11	14.44
27-Jan	13.94	13.73	13.30	13.34	13.00	12.78	12.70	12.61	12.57	12.91	13.38	14.11	14.88	16.21	17.03	17.76	17.24	16.43	15.83	15.18	15.01	14.84	14.37	14.37	14.48
28-Jan	14.20	14.03	13.81	13.38	13.34	13.12	12.91	12.78	12.91	13.17	13.73	14.37	15.31	15.91	16.90	17.46	16.94	16.26	15.74	15.31	15.10	14.75	14.58	14.71	14.61
29-Jan	14.37	14.50	14.28	13.60	13.55	13.51	13.17	13.34	13.51	13.68	14.28	14.88	15.57	16.39	16.99	17.97	17.46	16.73	16.26	15.87	15.48	15.36	15.06	14.80	15.02
30-Jan	14.67	14.33	14.24	14.07	13.98	13.81	13.81	13.73	13.85	14.15	14.54	15.06	15.83	16.64	17.11	17.84	17.67	16.94	16.39	15.78	15.53	15.23	15.01	14.80	15.21
31-Jan	14.54	14.11	13.98	13.77	13.51	13.12	12.87	12.78	12.78	13.25	13.77	14.45	15.48	16.47	17.50	18.02	17.63	16.81	16.13	15.66	15.70	15.31	15.01	14.54	14.88
1-Feb	14.45	13.98	13.90	13.64	13.21	13.21	12.78	12.57	12.61	13.00	13.64	14.33	15.27	16.39	17.20	18.36	18.10	17.37	16.73	16.26	15.83	15.40	15.01	14.63	14.91
2-Feb	14.28	13.98	13.60	13.34	12.91	12.52	12.14	12.01	12.18	12.61	13.25	14.07	15.31	16.43	17.54	18.53	18.19	17.41	16.73	16.39	15.83	15.44	15.10	14.71	14.77
3-Feb	14.33	14.07	13.55	13.43	13.00	12.65	12.31	12.18	12.35	12.65	13.34	14.24	15.40	16.64											13.58
Averages	14.47	14.18	13.92	13.69	13.40	13.16	12.92	12.81	12.92	13.27	13.85	14.64	15.62	16.75	17.53	18.43	18.10	17.29	16.61	16.12	15.70	15.38	15.05	14.76	15.03

Figure 33 Heat map of concrete roof

Midnight to Early Morning (12 AM- 6 AM)

- The concrete roof maintains temperatures between 13 °C- 15 °C, with gradational cooling through the night.
- The green roof starts cooler, around 9 °C- 11 °C, showing better heat dissipation at night.
- This suggests that the green roof has an advanced thermal emissivity, meaning it releases heat more effectively, precluding heat retention.

Morning Hours (7 AM- 11 AM)

- The concrete roof experiences a slow temperature rise from about 12.5 °C to 15 °C.
- The green roof also increases but at a lower rate, remaining around 8 °C- 10 °C.
- The insulating effect of the green surface prevents rapid-fire temperature increases.

Afternoon (12 PM- 4 PM, Peak Sunlight Exposure)

- The concrete roof heats up significantly, reaching 18 °C- 21 °C, with some days exceeding 25 °C.
- The green roof remains significantly cooler, with temperatures around 12 °C- 16 °C, a difference of 5- 10 °C compared to the concrete surface.
- This demonstrates the heat island effect where non-vegetated surfaces absorb and retain further heat.
- The vegetation layer on the green roof absorbs solar radiation but prevents excessive heat buildup.

Evening to Night (5 PM- 11 PM, Heat Release Phase)

- The concrete roof retains heat for a longer period, cooling down slowly from 17 °C at 5 PM to about 14 °C at night.
- The green roof cools down much briskly, dropping to about 10 °C- 11 °C by night.
- This highlights the thermal pause in concrete roofs compared to green surfaces, which parade faster heat dissipation.

Seasonal and Daily Variations

The study period, spanning late January to early February, aligns with Kathmandu’s winter season, a time typically characterized by cooler ambient temperatures and reduced solar intensity compared to summer months. Despite these milder conditions, the thermal behavior of concrete roofs demonstrates a critical concern: even in winter, concrete exhibits significant heat absorption, likely due to its inherent material properties. Concrete’s high thermal mass allows it to efficiently store solar energy during daylight hours, releasing it gradually into the surrounding environment after sunset. This delayed heat release not only elevates nighttime temperatures in the immediate vicinity but also signals a troubling potential for amplified urban heat island (UHI) effects during summer. In warmer months, when solar radiation is more intense and prolonged, concrete's capacity to absorb and radiate heat could exacerbate surface and ambient temperatures, worsening thermal discomfort and energy demands for cooling.

In contrast, green roofs maintain consistently cooler surface temperatures across both seasons. During winter, the vegetation layer even in a dormant or slower growth phase acts as a natural insulator, reducing heat transfer between the building and the external environment. The soil substrate retains moisture, which moderates temperature fluctuations through latent heat processes, while the plant cover provides partial shading and reflects a portion of incoming solar radiation. This stability suggests that green roofs offer reliable, year-round UHI mitigation, countering the thermal extremes associated with conventional roofing materials.

5.12 Heat Mitigation Efficiency

HME can be calculated using the following formula:

$$Efficiency = \frac{Tconcrete - Tgreen}{Tconcrete} X100$$

Where:

$T_{concrete}$ = Surface temperature of concrete roof

T_{green} = Surface temperature of green roof

Analyzing data,

Average Surface temperature of concrete roof =15.03 C

Average Surface temperature of green roof =10.24 C

We get, Efficiency = 31.88 %

This shows that green roofs are around 32 % effective in Surface temperature reduction compared to concrete roofs.

6 CHAPTER SIX: SIMULATION ANALYSIS AND DISCUSSIONS

6.1 Simulation construction set

The construction set shows how the Flow of the simulations were run. While modelling was done in rhino 3D and Grasshopper plugins were used to generate the desired results as shown in the figure below.

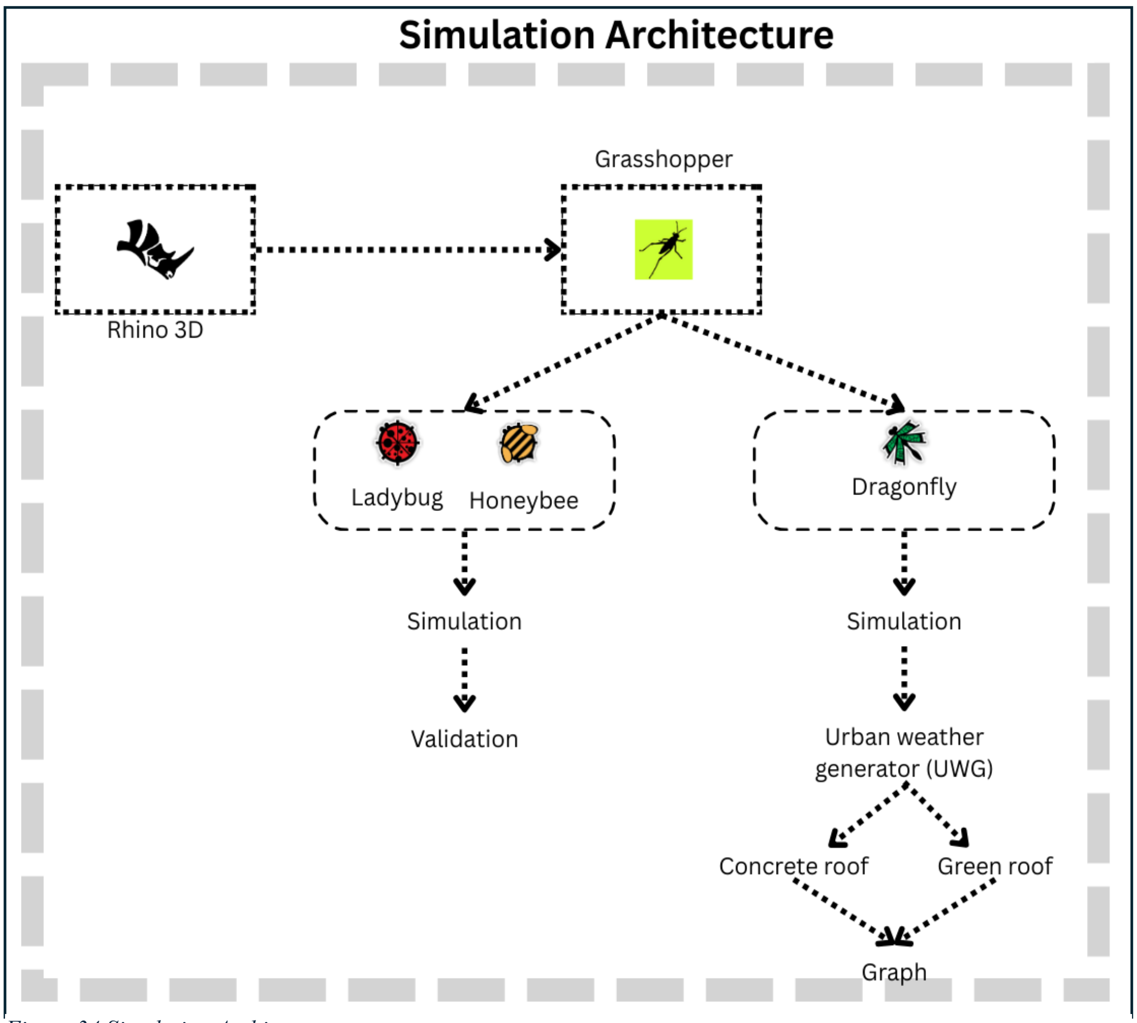


Figure 34 Simulation Architecture

6.1.1 3D model

The design utilizes Rhinoceros 3D(Rhino), a leading computer- aided design (CAD) software, to construct detailed 3D geometric models of buildings and interior spaces. Rhino's robust NURBS-based modeling engine enabled precise representation of architectural elements, including walls, roofs, windows, and spatial volumes, icing accuracy in scale and figure — a critical prerequisite for dependable simulations. These models were specifically designed to dissect environmental performance, similar as thermal dynamics, tailwind patterns, and energy efficiency, which are central to evaluating urban heat island (UHI) mitigation strategies like green roofs. Ladybug and Honeybee Ladybug and honeybee were plugins used to conduct simulations of rooms that were used to validate the model for neighborhood analysis.

Once the 3D modeling phase was complete, the workflow transitioned to *Grasshopper*, a visual programming plugin integrated with Rhino. Grasshopper's parametric design capabilities allowed for the automation of complex simulations by linking geometric inputs to environmental analysis algorithms. For instance, the software facilitated the assignment of material properties (e.g., concrete vs. vegetation), boundary conditions (e.g., solar exposure, ambient temperature), and temporal variables (e.g., diurnal temperature cycles) to the 3D models. This step was essential to simulate real-world scenarios, such as heat absorption by concrete roofs or evaporative cooling from green roofs, under controlled parameters.

The integration of Rhino and Grasshopper streamlined the iterative design process. Modifications to the models such as adjusting roof pitch, adding vegetation layers, or altering insulation thickness—could be tested rapidly within Grasshopper's parametric framework. Plugins like *Ladybug Tools* were employed to import localized climate data (e.g., Kathmandu's historical weather patterns) into the simulation, ensuring context-specific accuracy. By generating visual outputs such as heatmaps, temperature gradients, and time-series graphs, the software provided actionable insights into how design choices influence

6.1.2 Boundary conditions

3D models were created in such manner that they match real world scenarios as much as possible which in turn helps to generate accurate results thus generating less error. Walls (both interior and exterior), roofs, window construction, floor etc. data were taken from ASHRAE 2021 FUNDAMENTALS due to lack of reliable data for simulations.

6.1.3 Urban weather generator (UWG)

The urban microclimate analysis leveraged a multi-stage computational workflow to quantify the impact of green roofs versus concrete roofs on the Urban Heat Island (UHI) effect. First, a baseline *urban model* was generated using **Dragonfly**, a specialized urban design plugin for Rhino-Grasshopper tailored for environmental simulations. Dragonfly enabled the parametric creation of a 3D urban fabric representative of Kathmandu Valley's built environment, incorporating variables such as building density, street geometry, roof types, and land-use patterns. This model was spatially and geometrically calibrated to reflect real-world conditions, including building heights, surface materials, and vegetation cover, ensuring alignment with the region's urban morphology.

The Dragonfly model was then linked to the **Urban Weather Generator (UWG) Script**, an open-source tool designed to simulate urban-scale climatic conditions by modifying rural weather data to account for localized heat island effects. The UWG workflow involved two distinct scenarios:

1. **Green Roof Scenario**: All building roofs in the model were assigned vegetated surfaces with parameters such as soil depth, plant albedo (reflectivity), and evapotranspiration rates calibrated to subtropical vegetation typical of Kathmandu.
2. **Concrete Roof Scenario**: Roofs were modeled as conventional concrete surfaces with high thermal mass and low albedo, reflecting common construction practices in the valley.

For each scenario, the UWG Script generated **annual dry bulb temperature profiles**, simulating hourly temperature fluctuations over a full year.

6.2 Room below Concrete roofs

Rhino model was created which later integrated with grasshopper (Ladybug and honeybee tools). The conditions for simulations were highly focused on tallying the real-world situation as much as possible to receive highly accurate results.

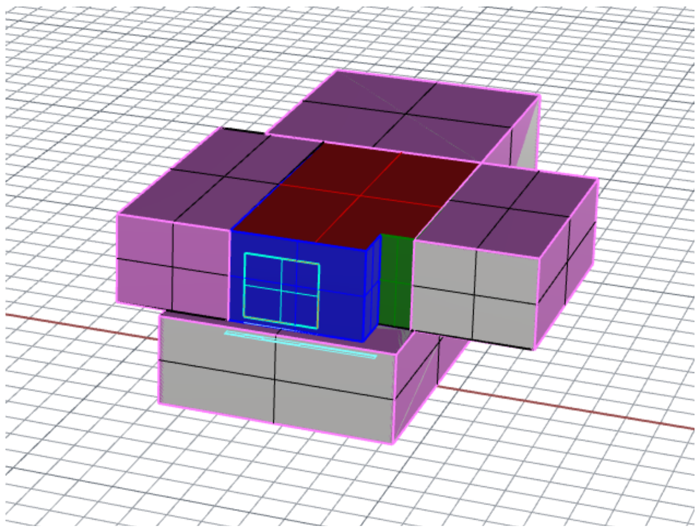


Figure 35 Concrete roof model

RMSE	1.94
CV(RMSE)	10.59

For Below Concrete roof

RMSE	1.82
CV(RMSE)	12.11

For ST of Concrete roof

The Root mean square error for both room below concrete roof and ST of concrete roof is Below 2°C and Cumulative variation Root mean square error is below 30% which is the tolerance for hourly data from Building energy simulation according to ASHRAE 14 2014. Data of building material properties were also retrieved from (*ASHRAE Handbook. Fundamentals*, 2021).

The building performance simulation result and the field measurement result should be between 10 - 20%, so that the difference of 8% is acceptable(Sedki et al., 2019).

The best empirical models of building energy use performance were only capable of producing CV(RMSE) in the 10% to 20% range for hourly comparisons(Measurement of Energy, Demand, and Water Savings, 2014).

6.3 Room below green roof

Rhino model was created which later integrated with grasshopper (Ladybug and honeybee tools). The conditions for simulations were highly focused on tallying the real-world situation as much as possible to receive highly accurate results.

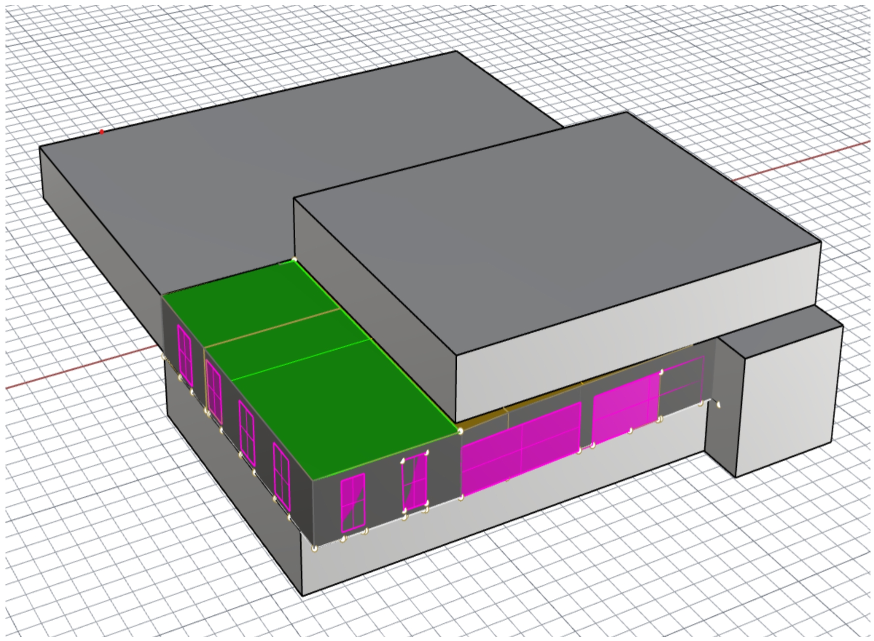


Figure 36 Green roof model

RMSE	1.74
CV(RMSE)	9.41

For Room below green roof

RMSE	1.06
CV(RMSE)	10.36

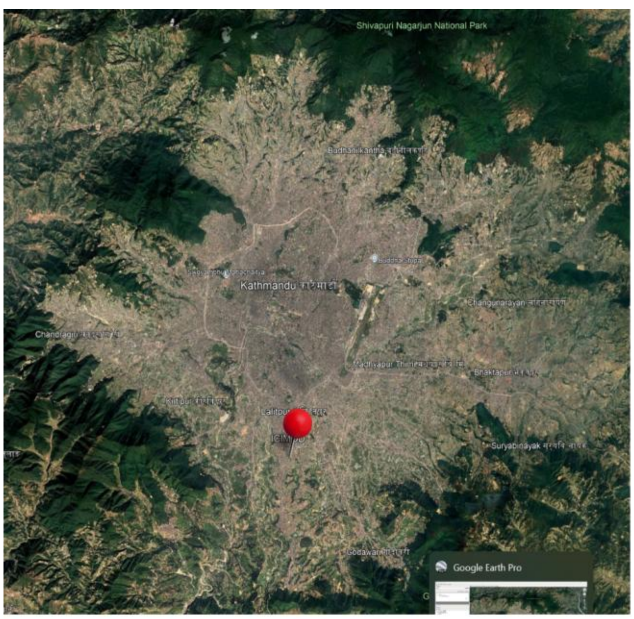
For ST of green roof

The Root mean square error for both room below concrete roof and ST of concrete roof is Below 2°C and Cumulative variation Root mean square error is below 20% which is the tolerance for hourly data from Building energy simulation according to ASHRAE 14 2014. Data of building material properties were also retrieved from (*ASHRAE Handbook. Fundamentals*, 2021).

6.4 Urban heat Island effect using Urban weather generator

The study focused on a site in Kathmandu Valley, Nepal, with geographic coordinates **27.646656°N, 85.325233°E**, an area emblematic of the region's rapid urbanization and intensifying Urban Heat Island (UHI) effects. To construct the base 3D model, **Cadmapper**—a tool that automates the conversion of geospatial data into CAD formats—was employed to generate a 2D urban layout. Cadmapper extracted OpenStreetMap (OSM) data, including road networks, building footprints, and land-use patterns, ensuring geometric accuracy for the site. This 2D map was imported into **Rhinoceros 3D** (Rhino), where it was extruded vertically to create 3D building masses.

Building Height Assumptions and Urban Morphology
All structures were modeled with a uniform height of **15 meters**, equivalent to a 5-story building, reflecting Kathmandu's prevalent mid-rise construction style. This height assumption aligns with municipal building codes and the valley's seismic risk mitigation guidelines, which discourage high-rises. The 3D model replicated the site's urban density, capturing the "urban canyon" effect a phenomenon where closely spaced buildings trap heat and reduce airflow, exacerbating UHI.



Satellite Map

Figure 38 Satellite map location

Figure 37 Arieal view of site

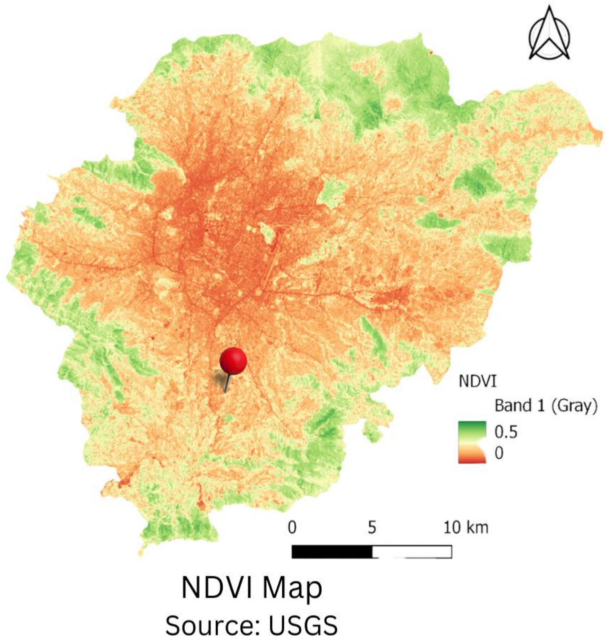


Figure 39 NDVI Map at location

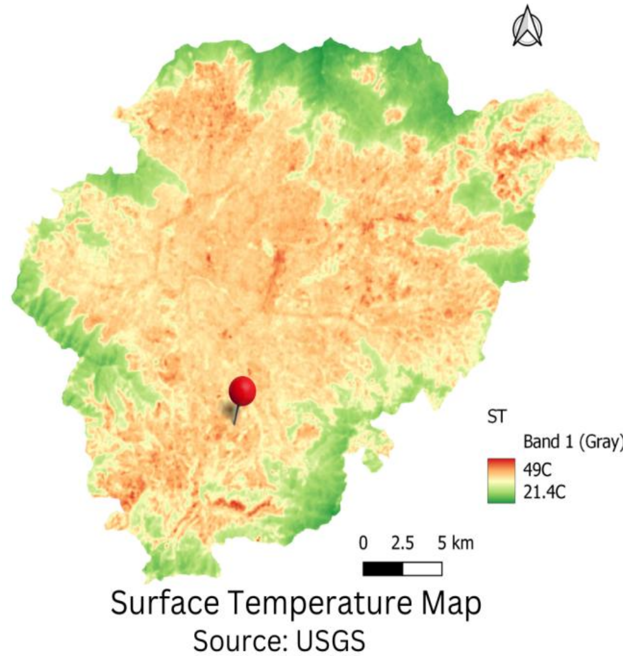


Figure 40 Surface temperature Map at site

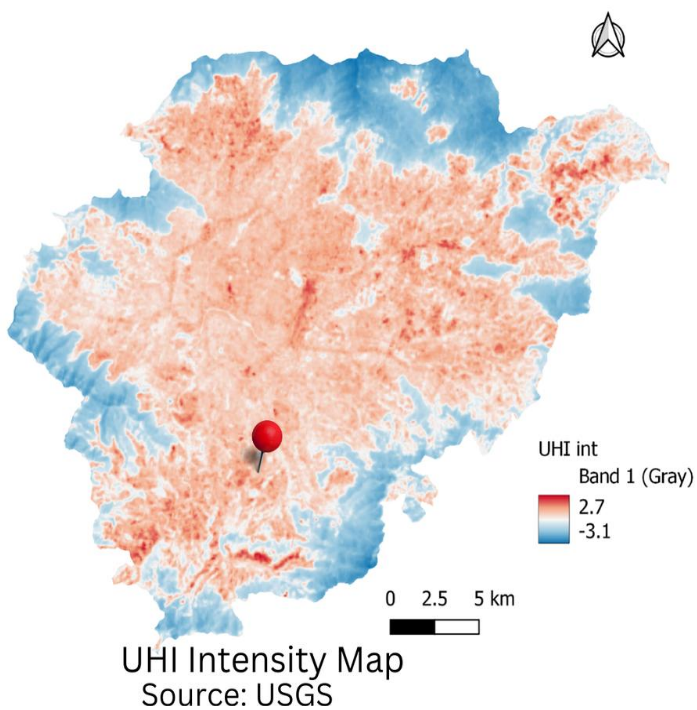


Figure 41 UHI intensity at site

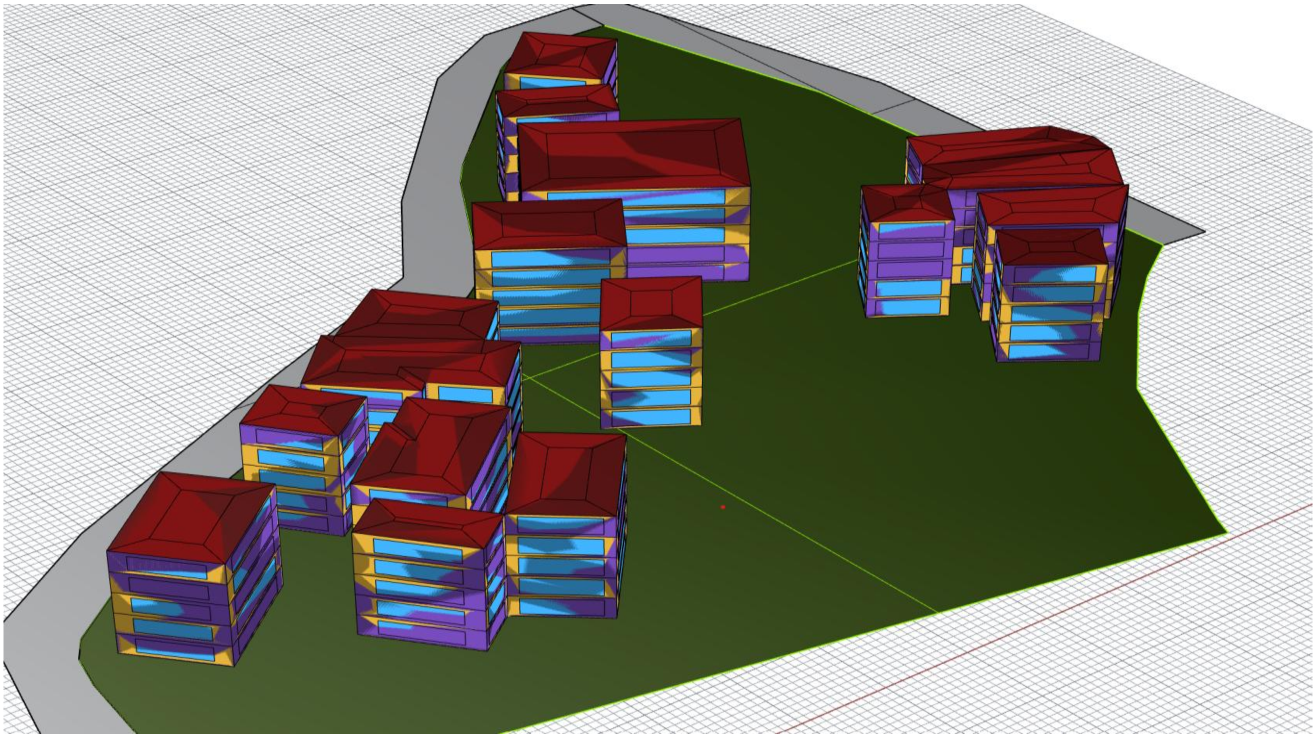


Figure 42 3d Site model generated by dragonfly

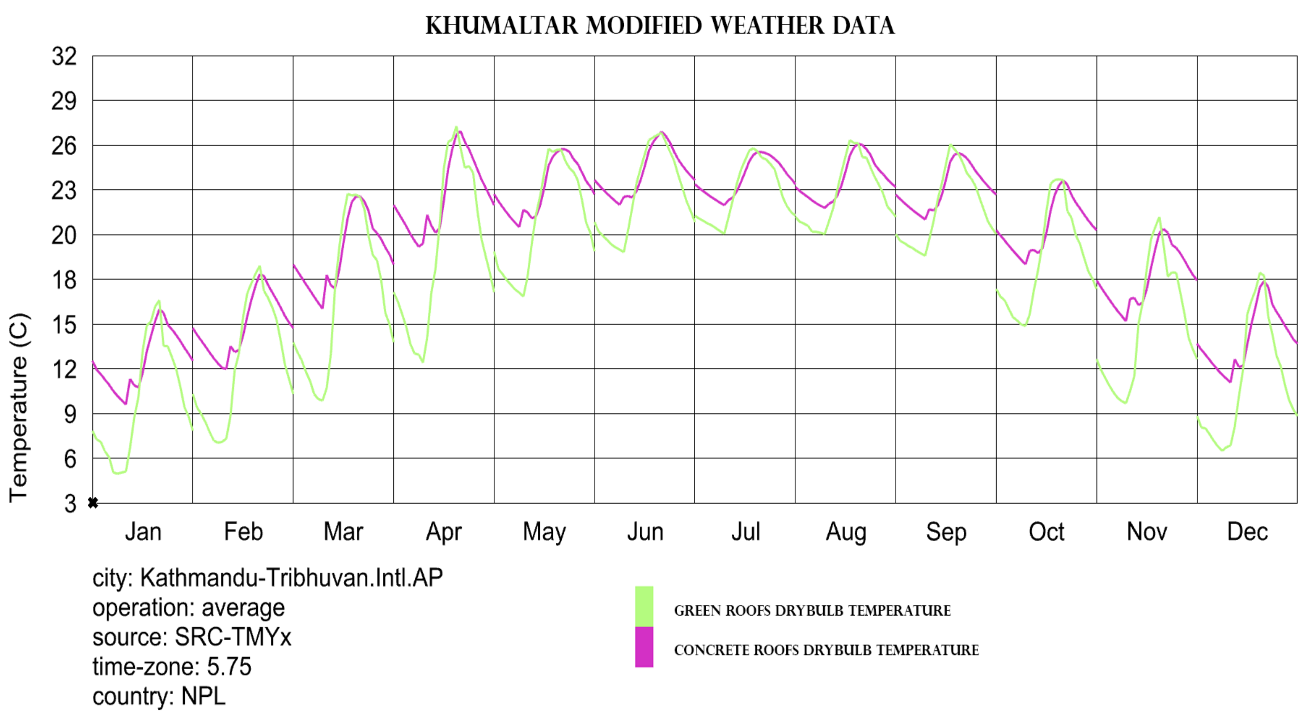


Figure 43 UHI effect Using UWG with green roof and concrete roof

Figure 43 presents the hourly temperature variations for green and concrete roofs in Khumaltar, Kathmandu, generated using the Urban Weather Generator (UWG). The dataset represents the monthly average of hourly temperatures recorded for each scenario. The green-colored plot represents the green roof temperature, while the purple plot represents the concrete roof temperature.

Seasonal Temperature Trends

Discussion of Results – Winter Season (December to February)

The results presented in the graph illustrate the relative dry bulb temperature trends between green roofs and concrete roofs in Khumaltar during the winter months (December – February). The data provides critical insights into the thermal behavior of both roof types and their implications for urban heat island (UHI) mitigation and inner thermal comfort.

1. Temperature Variation and Trends

1. **Diurnal Cyclic Pattern**:

   Both roofs follow daily temperature cycles tied to sunlight. Concrete heats rapidly under daytime sun due to its heat-absorbing properties, while green roofs moderate peaks through natural processes like plant transpiration and soil insulation. At night, concrete slowly releases stored heat, whereas green roofs cool faster.

2. **Lower Peak Temperatures on Green Roofs**:

   Green roofs consistently stay cooler during the day. Plants and soil dissipate heat via moisture release (evapotranspiration) and shade, reducing surface heat buildup. Concrete, lacking these mechanisms, absorb and radiating more solar energy, amplifying local warmth.

3. **Day-Night Thermal Gap**:

   The temperature difference between the two roofs peaks during daylight when solar exposure is highest. At night, the gap narrows as concrete's stored heat lingers, while green roofs cool efficiently. However, green roofs still maintain a slight thermal advantage after sunset.

Implications for Kathmandu:

In the valley's dense urban core, where concrete dominates, these patterns explain heightened UHI effects. Green roofs could break this cycle by lowering daytime heat retention and accelerating nighttime cooling, easing energy demands and heat stress. Prioritizing green infrastructure in commercial/residential zones would address both seasonal extremes and long-term climate resilience.

2. Thermal Performance of Green Roofs in Winter

Green roofs reduce temperature extremes by balancing heat absorption and release:

1. **Daytime Cooling**:

   Green roofs maintain lower surface temperatures than concrete roofs during daylight. Vegetation shades the surface, while evapotranspiration (moisture release from plants and soil) converts solar energy into cooling latent heat. The soil layer also acts as insulation, slowing heat transfer to the building. Concrete, lacking these features, absorbs and radiates solar energy freely, raising local temperatures.

2. **Nighttime Heat Retention**:

   At night, green roofs stay marginally warmer than concrete due to the soil's thermal mass, which stores daytime heat and releases it gradually. Concrete, despite its high thermal mass, cools rapidly once solar input ceases, as its stored heat dissipates quickly into the air.

This behavior confirms the **thermal buffering** effect of green roofs, which reduces extreme temperature variations and helps stabilize indoor temperatures in buildings beneath them.

implications for Urban Areas:

This dual behavior—daytime cooling and nighttime heat buffering—makes green roofs ideal for mitigating urban heat islands (UHI). In Kathmandu's dense core, replacing concrete roofs with green systems could stabilize indoor temperatures, lowering energy use for heating and cooling. Nighttime heat retention also reduces frost risk in cooler months, benefiting rooftop vegetation longevity.

3. Concrete Roofs and Their Limitations in Winter

Concrete roofs show advanced temperature peaks in the day, indicating advanced heat immersion due to their low albedo and high thermal conductivity. still

- They witness rapid-fire heat loss at night, leading to colder conditions, which could negatively impact inner thermal comfort in downtime.
- The advanced change between day and night temperatures makes structures with concrete roofs more prone to thermal discomfort and increased hotting demand.

4. Counteraccusations for Urban Heat Island (UHI) Effect

The data aligns with well- established findings that green roofs contribute to UHI mitigation by

- Reducing day heat immersion.
- furnishing sequestration and reducing heat loss at night.
- Maintaining a more stable thermal terrain compared to conventional concrete roofs.

During winter, while the UHI effect is less severe than in summer, the high day temperatures of concrete roofs still contribute to localized heating, whereas green roofs promote a more balanced microclimate by reducing axes.

5. Practical Counteraccusations for Kathmandu's Winter Climate

Given Kathmandu's moderate downtime conditions, the data suggests that

- Green roofs can help reduce inner heating demand by precluding inordinate heat loss at night.
- The reduced change in green roof temperatures makes them a more energy-effective option for maintaining inner thermal comfort in downtime.
- Structures with green roofs may bear lower heating compared to those with concrete roofs, leading to implicit energy savings.

Spring (March–May)

- Gradual increase in daytime temperatures, reaching 20°C–26°C by May.
- Concrete roofs heat up faster during the day, whereas green roofs maintain a more moderate temperature rise due to evapotranspiration effects.
- At night, green roofs cool down faster, whereas concrete roofs store residual heat, contributing to a higher nighttime UHI effect.
- The difference between the two roof types becomes more evident towards late spring, as temperatures start rising.

Summer (June–September)

- Peak temperatures exceed 26°C–29°C, with concrete roofs consistently recording higher values.
- Green roofs provide significant daytime cooling, reducing peak temperatures due to evapotranspiration and thermal mass effects.
- At night, concrete roofs release stored heat slowly, resulting in higher nighttime temperatures, whereas green roofs dissipate heat faster, improving urban thermal comfort.
- This season shows the largest temperature difference between green and concrete roofs, highlighting the potential of green roofs in mitigating heat stress.

Autumn (October–November)

- Gradual cooling trend, with temperatures stabilizing between 15°C–23°C.
- The temperature difference between green and concrete roofs is reduced, but green roofs still show lower daytime temperatures due to thermal buffering.
- Concrete roofs continue to retain heat at night, maintaining slightly higher temperatures compared to green roofs.
- The transition from summer to winter shows that green roofs remain effective in temperature regulation, though their impact is more visible in warmer months.

7 CHAPTER SEVEN: SCALABILITY AT URBAN LEVEL

The analysis of dry bulb temperature data, a standard metric for quantifying ambient air temperature, reveals significant differences in urban heat island (UHI) effects between green roofs and conventional concrete roofs. In scenarios simulating the thermal performance of these two roof types, green roofs demonstrated a measurable capacity to mitigate the UHI phenomenon. This cooling effect can be attributed to the natural processes essential to green roofs, similar as evapotranspiration from vegetation, improved albedo(reflectivity), and the insulation handed by soil and plant layers. These mechanisms collectively reduce heat absorption and release, lowering localized air temperatures. Again, concrete roofs which dominate urban landscapes due to their affordability and durability were set up to amplify UHI effects. Concrete's high thermal mass allows it to absorb and store solar radiation during the day, which is also gradually released as heat at night. This cycle elevates ambient temperatures, exacerbating heat stress in densely built environments.

The findings hold applicability for regions like Kathmandu Valley, a fleetly urbanizing basin in Nepal characterized by high population density, unplanned construction, and dwindling green spaces. The vale's unique geography is a bowl-shaped terrain girdled by hills traps pollutants and heat, enhancing UHI impacts. Concrete roofs, current across Kathmandu's domestic and marketable structures, probably contribute to the area's rising temperatures, which are farther exacerbated by deforestation and shrinking water bodies. By discrepancy, the wide relinquishment of green roofs could offset these trends. Their cooling implicitly aligns with Kathmandu's tropical climate, where seasonal monsoon rains could sustain vegetation without inordinate irrigation. Moreover, green roofs offer benefits similar as stormwater management, biodiversity support, and improved air quality critical advantages for a city grappling with pollution and climate resilience.

While the study's results are promising, scalability depends on addressing practical challenges. For instance, retrofitting existing concrete roofs with green infrastructure requires structural assessments, fiscal incentives, and public awareness campaigns. Still, pilot projects in Kathmandu's external areas, combined with policy reforms prioritizing sustainable Urban design, could pave the way for broader implementation. These efforts would not only combat UHI goods but also align with global climate adaptation goals, positioning Kathmandu Valley as a model for balancing urbanization with ecological stewardship.

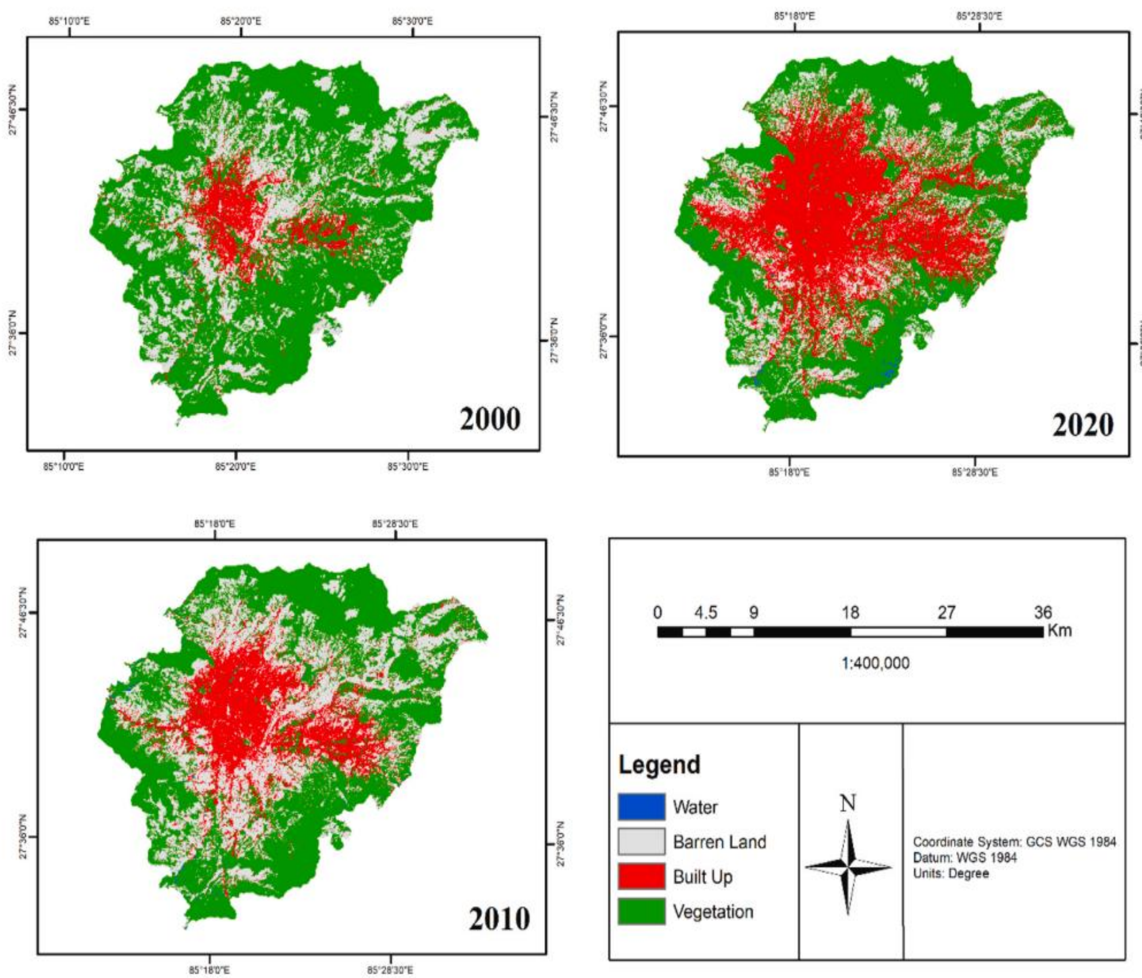


Fig. 9. Spatial dynamics of LULC in Kathmandu in 2000, 2010, 2020.

Figure 44Land use pattern in Kathmandu

Figure 44 shows Land use pattern in Kathmandu from 2000,2010 and 2020 which indicates massive urbanization increase within every decade. Most of the new constructions that are taking place in Kathmandu is mostly concrete buildings which have been a building norm in the valley as Municipality has developed codes for it while neglecting other building typologies.

Below in figure 44 we can see the predicted land use in 2030 in Kathmandu valley suggesting higher unplanned urbanization which covers mostly every flat and fertile land in Kathmandu valley.

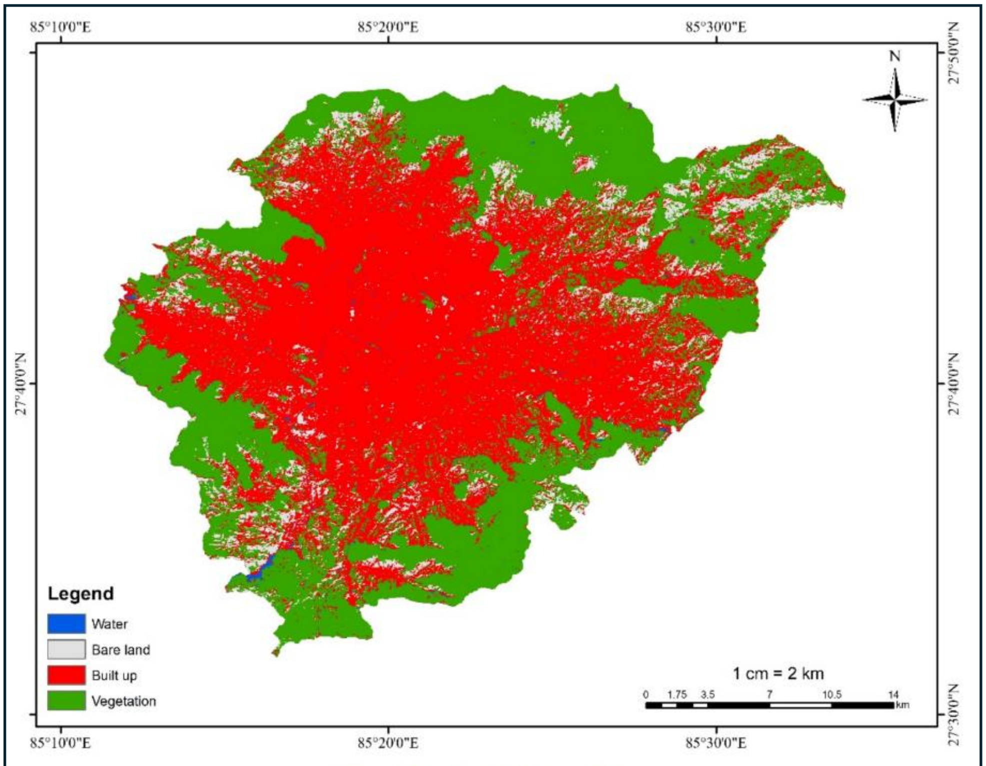


Fig. 19. Predicted LULC of 2030.

Figure 45 Predicted Land use pattern2030

While Land use further grows so do the Concrete roofs and structures which further amplify the UHI effect in the valley. As from our study above we can see that Concrete roofs do have amplifying effect which further increases the UHI within the valley in unison. Since most of the construction in the valley resembles that of ICIMOD despite it being an office building, it shows the profound effect of the green roof in reducing surface temperature within the valley as shown from the simulation. While Urban canyons might be different in various areas of the valley positive relation can be derived in every area of Kathmandu due to modern urban concrete architecture as well as From GIS maps it suggests the high growth of same level UHI effect which further suggests that green can create soothing effect in every dense area in Kathmandu.

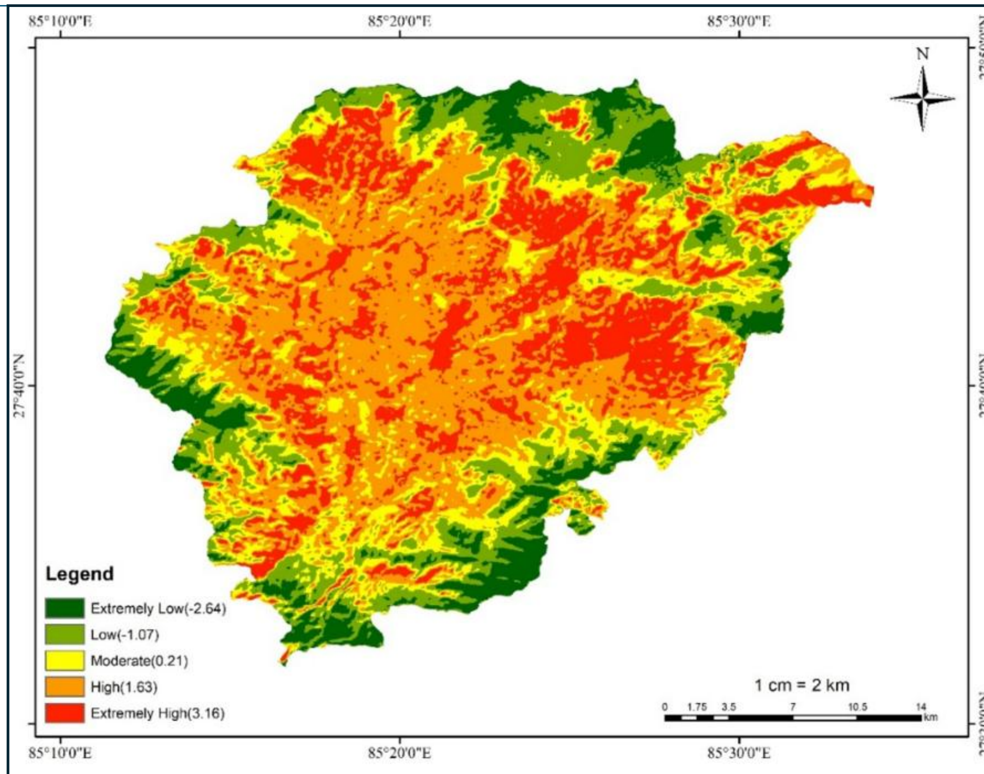


Fig. 23. Predicted UHI Winter 2030.

Figure 46 Predicted UHI winter 2030

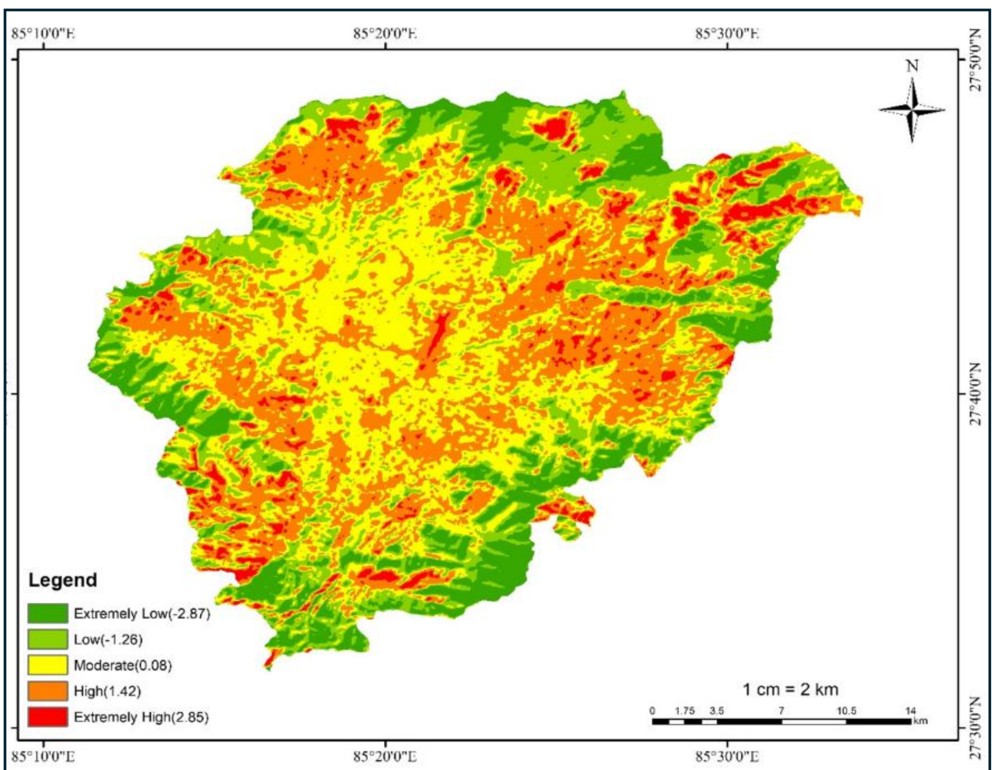


Fig. 16. UHI Winter 2020.

Figure 47 Winter UHI 2020

8 CHAPTER EIGHT: CONCLUSIONS

This study assessed how well both concrete and green roofs performed thermally and how they affected the interior room temperatures in metropolitan settings. In lowering surface temperatures and minimizing the Urban Heat Island (UHI) impact, the results highlight the value of green roofs. Further demonstrating the significance of roofing materials in controlling indoor climate was the examination of relationships between roof surface temperatures and interior room temperatures.

Important findings include:

1. Green roofs are 32% more successful at reducing surface temperatures than concrete roofs, which display far lower surface temperatures.
2. The concrete roof demonstrates stronger temperature regulation, likely due to its thermal mass properties, which allow it to absorb and release heat more effectively, influencing internal temperatures consistently both with and without HVAC. In contrast, the green roof, which offers better insulation through its vegetation and soil, shows weaker temperature influence when HVAC is in use, suggesting that the HVAC system's control over internal temperature reduces the green roof's insulating effect.
3. Concrete roofs exhibit high peak Surface temperature of 19 ℃ to 21 ℃ during daytime while green roof exhibits 10℃ to 12℃.
4. Concrete roof retains heat longer, cooling down gradually at night while rarely dropping below 13℃ whereas green roofs cools quickly at night reaching as low as 7℃ to 9℃.
5. The highest recorded Surface temperature on concrete roof reached 25.05℃ at 3 PM whereas green roof's peak was significantly lower at 17.5℃ demonstrating that green roofs absorb and retains heat less than concrete roofs during peak hours.
6. The concrete roof showed higher fluctuations with temperatures rising sharply from 13℃ in the morning at over 25℃ in the afternoon.
7. The results from simulation analysis clearly highlights the superior of green roofs over concrete roofs in winter by reducing daytime overheating and minimizing nighttime heat loss. This confirms green roofs are an effective passive strategy for

improving thermal comfort and reducing energy consumption in Kathmandu's built environment.

8. Khumaltar air temperature peaks around **19°C**, while the concrete roof surface reaches **~19°C** and the green roof **~12°C**, confirming that the concrete roof amplifies heat beyond ambient conditions, whereas the green roof maintains temperatures closer to air temperature, proving its effectiveness in mitigating urban heat.
9. Since the Urban typology of Kathmandu valley mostly consists of Concrete structure with concrete roofs, the data can be scaled in the various area of the Kathmandu valley with similar positive results.
10. With increase of the land use for construction of more new concrete structure the UHI is further amplified as shown from the figure 46 and 47 respectively suggesting that green roof can be a better solution compared to that of other options as it has more positive benefits for every on including as it is a natural solution which not only helps to deal with UHI effect but also with Climate change, Air pollution, Stormwater retention and less energy usage which are also some of the notable problems that exists within the modern urban areas.

9 CHAPTER NINE: RECOMMENDATIONS

- Concrete roofs demonstrate a harmonious relationship with internal temperature, making them effective for buildings with HVAC systems, where they help maintain stable inner temperatures by exercising thermal mass properties.
- Green roofs offer better insulation and thermal regulation, reducing heat gain and loss, and should be considered for buildings without HVAC systems or where unresistant cooling is preferred.
- Integrating green roofs with high- performance HVAC systems could optimize energy consumption by utilizing both unresistant cooling and HVAC regulation, especially in areas with mild climates or lower HVAC operation.
- Future exploration should explore different green roof configurations (soil depth, plant species) to assess their impact on internal temperatures and energy use, as well as the seasonal performance of green roofs, especially during hotter months.
- Building designs should incorporate a combination of thermal mass (e.g., concrete) and green roofs to balance energy effectiveness and sustainability, particularly in civic areas where heat mitigation is pivotal.
- Expanding temperature and humidity monitoring systems would give more accurate data for future comparisons, allowing a deeper understanding of surface temperature variations and their effect on building interiors.
- Policy frameworks should be developed to encourage the use of green roofs in urban environments to combat UHI effects and promote sustainability, with government incentives supporting these technologies.
- HVAC systems should be designed to work more synergistically with green roofs, adjusting based on external rainfall conditions to optimize energy use and maintain comfort levels while reducing consumption.
- Green roofs should be promoted as an effective UHI mitigation strategy in Kathmandu Valley and other urban areas, with urban planning policies encouraging or mandating their use to reduce temperature axes and improve livability.

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11 APPENDIX A: SITE VISIT PICTURES

12 APPENDIX B: SURFACE TEMPERATURE DATA (CONCRETE ROOF)

Concrete surface temperature field and simulation data from Jan 20-Feb 4.

#	Date-Time (Nepal Standard Time)	Temperature (°C)	simulation	Difference	Error squared
1	01/20/2025 11:08:00	14.88	13.98	0.90	0.82
2	01/20/2025 12:08:00	14.97	15.68	-0.71	0.50
3	01/20/2025 13:08:00	15.70	16.58	-0.88	0.78
4	01/20/2025 14:08:00	16.60	16.77	-0.17	0.03
5	01/20/2025 15:08:00	18.66	15.80	2.86	8.17
6	01/20/2025 16:08:00	18.49	16.49	2.00	3.99
7	01/20/2025 17:08:00	17.54	16.23	1.31	1.73
8	01/20/2025 18:08:00	16.73	15.54	1.19	1.41
9	01/20/2025 19:08:00	16.30	15.23	1.07	1.14
10	01/20/2025 20:08:00	15.78	15.45	0.33	0.11
11	01/20/2025 21:08:00	15.48	15.23	0.25	0.06
12	01/20/2025 22:08:00	15.06	15.80	-0.74	0.55
13	01/20/2025 23:08:00	14.75	15.73	-0.98	0.95
14	01/21/2025 00:08:00	14.45	15.55	-1.10	1.20
15	01/21/2025 01:08:00	14.03	15.23	-1.20	1.45
16	01/21/2025 02:08:00	13.77	15.14	-1.37	1.87
17	01/21/2025 03:08:00	13.43	14.87	-1.44	2.09
18	01/21/2025 04:08:00	13.12	14.98	-1.86	3.44
19	01/21/2025 05:08:00	12.95	13.78	-0.83	0.68
20	01/21/2025 06:08:00	12.52	13.57	-1.05	1.09
21	01/21/2025 07:08:00	12.44	13.53	-1.09	1.19
22	01/21/2025 08:08:00	12.52	13.27	-0.75	0.56
23	01/21/2025 09:08:00	12.91	14.57	-1.66	2.75
24	01/21/2025 10:08:00	13.60	14.83	-1.23	1.52
25	01/21/2025 11:08:00	14.67	15.27	-0.60	0.36
26	01/21/2025 12:08:00	15.83	17.34	-1.51	2.28
27	01/21/2025 13:08:00	17.50	18.56	-1.06	1.12
28	01/21/2025 14:08:00	18.36	18.87	-0.51	0.26
29	01/21/2025 15:08:00	19.73	18.45	1.28	1.64
30	01/21/2025 16:08:00	19.77	18.12	1.65	2.74
31	01/21/2025 17:08:00	19.00	17.54	1.46	2.14
32	01/21/2025 18:08:00	18.06	17.32	0.74	0.55
33	01/21/2025 19:08:00	17.54	16.89	0.65	0.43
34	01/21/2025 20:08:00	17.03	16.70	0.33	0.11
35	01/21/2025 21:08:00	16.60	15.84	0.76	0.58
36	01/21/2025 22:08:00	16.17	16.54	-0.37	0.14
37	01/21/2025 23:08:00	15.78	16.40	-0.62	0.38

38	01/22/2025 00:08:00	15.27	15.76	-0.49	0.24
39	01/22/2025 01:08:00	14.93	15.40	-0.47	0.22
40	01/22/2025 02:08:00	14.58	15.74	-1.16	1.34
41	01/22/2025 03:08:00	14.37	15.60	-1.23	1.52
42	01/22/2025 04:08:00	13.94	14.68	-0.74	0.55
43	01/22/2025 05:08:00	13.64	14.20	-0.56	0.31
44	01/22/2025 06:08:00	13.43	13.67	-0.24	0.06
45	01/22/2025 07:08:00	13.17	13.43	-0.26	0.07
46	01/22/2025 08:08:00	13.43	13.20	0.23	0.05
47	01/22/2025 09:08:00	13.60	13.45	0.15	0.02
48	01/22/2025 10:08:00	14.28	14.56	-0.28	0.08
49	01/22/2025 11:08:00	15.23	15.78	-0.55	0.31
50	01/22/2025 12:08:00	17.20	17.59	-0.39	0.15
51	01/22/2025 13:08:00	19.47	17.78	1.69	2.87
52	01/22/2025 14:08:00	20.12	15.60	4.52	20.40
53	01/22/2025 15:08:00	21.02	16.67	4.34	18.87
54	01/22/2025 16:08:00	20.72	17.21	3.51	12.30
55	01/22/2025 17:08:00	19.90	17.01	2.89	8.37
56	01/22/2025 18:08:00	18.83	16.43	2.40	5.77
57	01/22/2025 19:08:00	17.97	15.80	2.17	4.73
58	01/22/2025 20:08:00	17.33	15.15	2.17	4.73
59	01/22/2025 21:08:00	16.81	14.47	2.35	5.51
60	01/22/2025 22:08:00	16.30	13.72	2.58	6.64
61	01/22/2025 23:08:00	15.87	13.03	2.84	8.08
62	01/23/2025 00:08:00	15.44	12.36	3.08	9.48
63	01/23/2025 01:08:00	15.14	11.68	3.46	11.98
64	01/23/2025 02:08:00	14.71	11.05	3.66	13.40
65	01/23/2025 03:08:00	14.45	12.68	1.77	3.15
66	01/23/2025 04:08:00	14.03	13.59	0.44	0.19
67	01/23/2025 05:08:00	13.51	13.12	0.39	0.15
68	01/23/2025 06:08:00	13.47	13.23	0.24	0.06
69	01/23/2025 07:08:00	13.34	12.78	0.56	0.31
70	01/23/2025 08:08:00	13.43	12.32	1.11	1.22
71	01/23/2025 09:08:00	13.90	10.49	3.41	11.62
72	01/23/2025 10:08:00	14.50	13.41	1.08	1.18
73	01/23/2025 11:08:00	15.36	16.95	-1.59	2.54
74	01/23/2025 12:08:00	16.30	18.56	-2.26	5.11
75	01/23/2025 13:08:00	18.06	19.23	-1.17	1.37
76	01/23/2025 14:08:00	19.43	19.12	0.31	0.10
77	01/23/2025 15:08:00	20.33	20.40	-0.07	0.00
78	01/23/2025 16:08:00	20.03	20.87	-0.84	0.70
79	01/23/2025 17:08:00	18.92	19.30	-0.38	0.15

80	01/23/2025 18:08:00	18.19	19.23	-1.04	1.09
81	01/23/2025 19:08:00	17.63	18.78	-1.15	1.32
82	01/23/2025 20:08:00	16.99	18.21	-1.22	1.50
83	01/23/2025 21:08:00	16.43	17.65	-1.22	1.49
84	01/23/2025 22:08:00	16.21	17.53	-1.32	1.73
85	01/23/2025 23:08:00	15.74	16.87	-1.13	1.27
86	01/24/2025 00:08:00	15.31	16.59	-1.28	1.63
87	01/24/2025 01:08:00	14.84	16.23	-1.39	1.93
88	01/24/2025 02:08:00	14.37	15.70	-1.33	1.77
89	01/24/2025 03:08:00	14.28	16.56	-2.28	5.20
90	01/24/2025 04:08:00	13.98	15.65	-1.66	2.77
91	01/24/2025 05:08:00	13.55	14.79	-1.24	1.53
92	01/24/2025 06:08:00	13.51	13.97	-0.46	0.21
93	01/24/2025 07:08:00	13.34	13.23	0.11	0.01
94	01/24/2025 08:08:00	13.25	13.40	-0.15	0.02
95	01/24/2025 09:08:00	13.85	14.93	-1.07	1.15
96	01/24/2025 10:08:00	14.33	15.56	-1.23	1.52
97	01/24/2025 11:08:00	15.18	16.80	-1.62	2.61
98	01/24/2025 12:08:00	16.73	17.89	-1.16	1.35
99	01/24/2025 13:08:00	17.37	18.53	-1.16	1.34
100	01/24/2025 14:08:00	17.50	18.78	-1.28	1.64
101	01/24/2025 15:08:00	18.02	19.20	-1.18	1.40
102	01/24/2025 16:08:00	17.72	19.45	-1.73	3.01
103	01/24/2025 17:08:00	17.07	19.78	-2.71	7.34
104	01/24/2025 18:08:00	16.51	18.47	-1.96	3.83
105	01/24/2025 19:08:00	16.13	19.40	-3.27	10.71
106	01/24/2025 20:08:00	15.57	17.56	-1.99	3.96
107	01/24/2025 21:08:00	15.23	16.22	-0.99	0.99
108	01/24/2025 22:08:00	15.01	18.59	-3.58	12.80
109	01/24/2025 23:08:00	14.50	18.67	-4.17	17.41
110	01/25/2025 00:08:00	14.20	18.80	-4.60	21.19
111	01/25/2025 01:08:00	13.68	17.50	-3.82	14.57
112	01/25/2025 02:08:00	13.55	16.80	-3.25	10.54
113	01/25/2025 03:08:00	13.25	17.84	-4.59	21.07
114	01/25/2025 04:08:00	12.82	16.92	-4.09	16.76
115	01/25/2025 05:08:00	12.65	14.59	-1.94	3.75
116	01/25/2025 06:08:00	12.31	14.23	-1.92	3.69
117	01/25/2025 07:08:00	11.92	14.50	-2.57	6.62
118	01/25/2025 08:08:00	12.27	14.65	-2.39	5.70
119	01/25/2025 09:08:00	12.70	15.80	-3.10	9.64
120	01/25/2025 10:08:00	13.38	16.50	-3.12	9.72
121	01/25/2025 11:08:00	14.24	16.78	-2.54	6.45

122	01/25/2025 12:08:00	15.18	17.30	-2.12	4.48
123	01/25/2025 13:08:00	16.39	18.40	-2.01	4.06
124	01/25/2025 14:08:00	16.86	18.56	-1.70	2.90
125	01/25/2025 15:08:00	17.33	19.20	-1.87	3.50
126	01/25/2025 16:08:00	16.73	19.42	-2.69	7.24
127	01/25/2025 17:08:00	15.61	17.56	-1.95	3.79
128	01/25/2025 18:08:00	14.84	15.62	-0.78	0.61
129	01/25/2025 19:08:00	14.28	15.88	-1.60	2.55
130	01/25/2025 20:08:00	13.60	13.84	-0.24	0.06
131	01/25/2025 21:08:00	13.64	14.13	-0.49	0.24
132	01/25/2025 22:08:00	13.34	14.23	-0.89	0.79
133	01/25/2025 23:08:00	13.30	14.33	-1.03	1.07
134	01/26/2025 00:08:00	13.17	14.20	-1.03	1.07
135	01/26/2025 01:08:00	13.25	13.84	-0.59	0.34
136	01/26/2025 02:08:00	13.17	13.95	-0.78	0.61
137	01/26/2025 03:08:00	13.34	14.87	-1.53	2.34
138	01/26/2025 04:08:00	13.25	14.85	-1.60	2.55
139	01/26/2025 05:08:00	13.17	15.38	-2.21	4.89
140	01/26/2025 06:08:00	13.00	15.92	-2.92	8.52
141	01/26/2025 07:08:00	13.17	15.14	-1.97	3.88
142	01/26/2025 08:08:00	13.17	15.29	-2.12	4.50
143	01/26/2025 09:08:00	13.38	16.78	-3.40	11.53
144	01/26/2025 10:08:00	13.94	17.56	-3.62	13.11
145	01/26/2025 11:08:00	14.54	17.68	-3.14	9.86
146	01/26/2025 12:08:00	15.10	17.95	-2.85	8.13
147	01/26/2025 13:08:00	15.70	18.12	-2.42	5.86
148	01/26/2025 14:08:00	16.30	18.25	-1.95	3.80
149	01/26/2025 15:08:00	17.03	18.56	-1.53	2.34
150	01/26/2025 16:08:00	16.69	18.23	-1.54	2.39
151	01/26/2025 17:08:00	16.04	17.23	-1.19	1.41
152	01/26/2025 18:08:00	15.53	16.56	-1.03	1.07
153	01/26/2025 19:08:00	15.31	16.25	-0.94	0.88
154	01/26/2025 20:08:00	15.01	15.87	-0.86	0.74
155	01/26/2025 21:08:00	14.80	14.58	0.22	0.05
156	01/26/2025 22:08:00	14.41	14.23	0.18	0.03
157	01/26/2025 23:08:00	14.11	13.54	0.57	0.33
158	01/27/2025 00:08:00	13.94	13.23	0.71	0.50
159	01/27/2025 01:08:00	13.73	12.56	1.17	1.36
160	01/27/2025 02:08:00	13.30	13.87	-0.57	0.33
161	01/27/2025 03:08:00	13.34	17.34	-4.00	16.02
162	01/27/2025 04:08:00	13.00	16.42	-3.43	11.75
163	01/27/2025 05:08:00	12.78	15.55	-2.77	7.68

164	01/27/2025 06:08:00	12.70	14.79	-2.09	4.37
165	01/27/2025 07:08:00	12.61	14.13	-1.52	2.30
166	01/27/2025 08:08:00	12.57	14.29	-1.72	2.97
167	01/27/2025 09:08:00	12.91	15.12	-2.21	4.88
168	01/27/2025 10:08:00	13.38	15.87	-2.49	6.19
169	01/27/2025 11:08:00	14.11	16.42	-2.31	5.33
170	01/27/2025 12:08:00	14.88	16.78	-1.90	3.60
171	01/27/2025 13:08:00	16.21	16.60	-0.39	0.15
172	01/27/2025 14:08:00	17.03	16.58	0.45	0.20
173	01/27/2025 15:08:00	17.76	17.20	0.56	0.31
174	01/27/2025 16:08:00	17.24	17.56	-0.32	0.10
175	01/27/2025 17:08:00	16.43	16.58	-0.15	0.02
176	01/27/2025 18:08:00	15.83	15.80	0.03	0.00
177	01/27/2025 19:08:00	15.18	15.73	-0.55	0.30
178	01/27/2025 20:08:00	15.01	15.30	-0.29	0.08
179	01/27/2025 21:08:00	14.84	15.21	-0.37	0.14
180	01/27/2025 22:08:00	14.37	14.87	-0.50	0.25
181	01/27/2025 23:08:00	14.37	14.40	-0.03	0.00
182	01/28/2025 00:08:00	14.20	14.32	-0.12	0.02
183	01/28/2025 01:08:00	14.03	14.27	-0.24	0.06
184	01/28/2025 02:08:00	13.81	13.89	-0.08	0.01
185	01/28/2025 03:08:00	13.38	13.40	-0.02	0.00
186	01/28/2025 04:08:00	13.34	13.21	0.13	0.02
187	01/28/2025 05:08:00	13.12	12.68	0.44	0.20
188	01/28/2025 06:08:00	12.91	12.42	0.49	0.24
189	01/28/2025 07:08:00	12.78	13.12	-0.34	0.11
190	01/28/2025 08:08:00	12.91	13.40	-0.49	0.24
191	01/28/2025 09:08:00	13.17	13.56	-0.39	0.15
192	01/28/2025 10:08:00	13.73	13.87	-0.14	0.02
193	01/28/2025 11:08:00	14.37	14.56	-0.19	0.04
194	01/28/2025 12:08:00	15.31	15.88	-0.57	0.32
195	01/28/2025 13:08:00	15.91	16.23	-0.32	0.10
196	01/28/2025 14:08:00	16.90	16.78	0.12	0.01
197	01/28/2025 15:08:00	17.46	16.89	0.57	0.32
198	01/28/2025 16:08:00	16.94	17.56	-0.62	0.38
199	01/28/2025 17:08:00	16.26	17.23	-0.97	0.95
200	01/28/2025 18:08:00	15.74	16.25	-0.51	0.26
201	01/28/2025 19:08:00	15.31	16.13	-0.82	0.67
202	01/28/2025 20:08:00	15.10	15.67	-0.57	0.33
203	01/28/2025 21:08:00	14.75	15.57	-0.82	0.66
204	01/28/2025 22:08:00	14.58	14.80	-0.22	0.05
205	01/28/2025 23:08:00	14.71	14.76	-0.05	0.00

206	01/29/2025 00:08:00	14.37	14.23	0.14	0.02
207	01/29/2025 01:08:00	14.50	14.68	-0.18	0.03
208	01/29/2025 02:08:00	14.28	15.21	-0.93	0.86
209	01/29/2025 03:08:00	13.60	15.54	-1.94	3.78
210	01/29/2025 04:08:00	13.55	15.24	-1.69	2.84
211	01/29/2025 05:08:00	13.51	15.80	-2.29	5.24
212	01/29/2025 06:08:00	13.17	14.20	-1.03	1.07
213	01/29/2025 07:08:00	13.34	14.10	-0.76	0.58
214	01/29/2025 08:08:00	13.51	14.21	-0.70	0.49
215	01/29/2025 09:08:00	13.68	15.44	-1.76	3.08
216	01/29/2025 10:08:00	14.28	15.20	-0.92	0.84
217	01/29/2025 11:08:00	14.88	15.70	-0.82	0.67
218	01/29/2025 12:08:00	15.57	15.79	-0.22	0.05
219	01/29/2025 13:08:00	16.39	16.78	-0.39	0.16
220	01/29/2025 14:08:00	16.99	17.84	-0.85	0.73
221	01/29/2025 15:08:00	17.97	18.50	-0.53	0.28
222	01/29/2025 16:08:00	17.46	18.75	-1.29	1.67
223	01/29/2025 17:08:00	16.73	17.23	-0.50	0.25
224	01/29/2025 18:08:00	16.26	17.10	-0.84	0.71
225	01/29/2025 19:08:00	15.87	17.71	-1.84	3.37
226	01/29/2025 20:08:00	15.48	17.03	-1.54	2.39
227	01/29/2025 21:08:00	15.36	16.33	-0.98	0.96
228	01/29/2025 22:08:00	15.06	15.63	-0.58	0.33
229	01/29/2025 23:08:00	14.80	14.93	-0.13	0.02
230	01/30/2025 00:08:00	14.67	14.22	0.45	0.21
231	01/30/2025 01:08:00	14.33	13.51	0.82	0.67
232	01/30/2025 02:08:00	14.24	12.80	1.44	2.07
233	01/30/2025 03:08:00	14.07	12.11	1.96	3.83
234	01/30/2025 04:08:00	13.98	11.44	2.54	6.45
235	01/30/2025 05:08:00	13.81	10.81	3.01	9.04
236	01/30/2025 06:08:00	13.81	11.50	2.31	5.34
237	01/30/2025 07:08:00	13.73	11.40	2.33	5.41
238	01/30/2025 08:08:00	13.85	12.23	1.62	2.64
239	01/30/2025 09:08:00	14.15	12.56	1.59	2.54
240	01/30/2025 10:08:00	14.54	14.88	-0.34	0.12
241	01/30/2025 11:08:00	15.06	15.98	-0.92	0.86
242	01/30/2025 12:08:00	15.83	16.24	-0.41	0.17
243	01/30/2025 13:08:00	16.64	16.78	-0.14	0.02
244	01/30/2025 14:08:00	17.11	17.80	-0.69	0.47
245	01/30/2025 15:08:00	17.84	18.23	-0.39	0.15
246	01/30/2025 16:08:00	17.67	18.68	-1.01	1.02
247	01/30/2025 17:08:00	16.94	18.40	-1.46	2.12

248	01/30/2025 18:08:00	16.39	17.84	-1.45	2.12
249	01/30/2025 19:08:00	15.78	17.42	-1.64	2.67
250	01/30/2025 20:08:00	15.53	17.40	-1.87	3.51
251	01/30/2025 21:08:00	15.23	16.76	-1.53	2.35
252	01/30/2025 22:08:00	15.01	16.40	-1.39	1.93
253	01/30/2025 23:08:00	14.80	15.84	-1.04	1.09
254	01/31/2025 00:08:00	14.54	14.87	-0.33	0.11
255	01/31/2025 01:08:00	14.11	14.56	-0.45	0.20
256	01/31/2025 02:08:00	13.98	13.70	0.28	0.08
257	01/31/2025 03:08:00	13.77	13.87	-0.10	0.01
258	01/31/2025 04:08:00	13.51	14.20	-0.69	0.47
259	01/31/2025 05:08:00	13.12	13.80	-0.68	0.46
260	01/31/2025 06:08:00	12.87	13.50	-0.63	0.40
261	01/31/2025 07:08:00	12.78	13.56	-0.78	0.61
262	01/31/2025 08:08:00	12.78	14.09	-1.30	1.70
263	01/31/2025 09:08:00	13.25	15.73	-2.48	6.13
264	01/31/2025 10:08:00	13.77	17.50	-3.73	13.93
265	01/31/2025 11:08:00	14.45	17.87	-3.42	11.66
266	01/31/2025 12:08:00	15.48	18.60	-3.12	9.71
267	01/31/2025 13:08:00	16.47	19.40	-2.93	8.58
268	01/31/2025 14:08:00	17.50	19.87	-2.37	5.61
269	01/31/2025 15:08:00	18.02	19.50	-1.48	2.20
270	01/31/2025 16:08:00	17.63	18.40	-0.77	0.59
271	01/31/2025 17:08:00	16.81	17.84	-1.03	1.05
272	01/31/2025 18:08:00	16.13	17.40	-1.27	1.62
273	01/31/2025 19:08:00	15.66	15.40	0.26	0.07
274	01/31/2025 20:08:00	15.70	16.10	-0.40	0.16
275	01/31/2025 21:08:00	15.31	15.98	-0.67	0.45
276	01/31/2025 22:08:00	15.01	15.40	-0.39	0.15
277	01/31/2025 23:08:00	14.54	14.84	-0.30	0.09
278	02/01/2025 00:08:00	14.45	14.54	-0.09	0.01
279	02/01/2025 01:08:00	13.98	13.85	0.13	0.02
280	02/01/2025 02:08:00	13.90	14.23	-0.33	0.11
281	02/01/2025 03:08:00	13.64	14.80	-1.16	1.35
282	02/01/2025 04:08:00	13.21	14.50	-1.29	1.66
283	02/01/2025 05:08:00	13.21	13.87	-0.66	0.43
284	02/01/2025 06:08:00	12.78	14.23	-1.45	2.10
285	02/01/2025 07:08:00	12.57	14.50	-1.93	3.74
286	02/01/2025 08:08:00	12.61	15.25	-2.64	6.98
287	02/01/2025 09:08:00	13.00	16.73	-3.73	13.93
288	02/01/2025 10:08:00	13.64	17.40	-3.76	14.14
289	02/01/2025 11:08:00	14.33	17.56	-3.23	10.46

290	02/01/2025 12:08:00	15.27	18.46	-3.19	10.18
291	02/01/2025 13:08:00	16.39	19.54	-3.15	9.95
292	02/01/2025 14:08:00	17.20	19.78	-2.58	6.65
293	02/01/2025 15:08:00	18.36	19.87	-1.51	2.28
294	02/01/2025 16:08:00	18.10	20.15	-2.05	4.20
295	02/01/2025 17:08:00	17.37	19.45	-2.08	4.32
296	02/01/2025 18:08:00	16.73	19.80	-3.07	9.43
297	02/01/2025 19:08:00	16.26	18.46	-2.20	4.86
298	02/01/2025 20:08:00	15.83	17.58	-1.75	3.07
299	02/01/2025 21:08:00	15.40	16.89	-1.49	2.22
300	02/01/2025 22:08:00	15.01	16.60	-1.59	2.52
301	02/01/2025 23:08:00	14.63	15.45	-0.82	0.68
302	02/02/2025 00:08:00	14.28	15.12	-0.84	0.70
303	02/02/2025 01:08:00	13.98	14.74	-0.76	0.57
304	02/02/2025 02:08:00	13.60	14.50	-0.90	0.82
305	02/02/2025 03:08:00	13.34	14.30	-0.96	0.92
306	02/02/2025 04:08:00	12.91	13.40	-0.49	0.24
307	02/02/2025 05:08:00	12.52	14.20	-1.68	2.81
308	02/02/2025 06:08:00	12.14	14.25	-2.11	4.46
309	02/02/2025 07:08:00	12.01	15.12	-3.11	9.68
310	02/02/2025 08:08:00	12.18	15.32	-3.14	9.83
311	02/02/2025 09:08:00	12.61	16.85	-4.24	18.00
312	02/02/2025 10:08:00	13.25	17.50	-4.25	18.03
313	02/02/2025 11:08:00	14.07	17.87	-3.80	14.45
314	02/02/2025 12:08:00	15.31	18.12	-2.81	7.88
315	02/02/2025 13:08:00	16.43	18.56	-2.13	4.55
316	02/02/2025 14:08:00	17.54	19.20	-1.66	2.74
317	02/02/2025 15:08:00	18.53	19.45	-0.92	0.85
318	02/02/2025 16:08:00	18.19	20.40	-2.21	4.90
319	02/02/2025 17:08:00	17.41	18.80	-1.39	1.92
320	02/02/2025 18:08:00	16.73	18.40	-1.67	2.79
321	02/02/2025 19:08:00	16.39	17.23	-0.84	0.71
322	02/02/2025 20:08:00	15.83	17.21	-1.38	1.91
323	02/02/2025 21:08:00	15.44	16.70	-1.26	1.58
324	02/02/2025 22:08:00	15.10	16.45	-1.35	1.83
325	02/02/2025 23:08:00	14.71	15.80	-1.09	1.18
326	02/03/2025 00:08:00	14.33	15.68	-1.35	1.83
327	02/03/2025 01:08:00	14.07	16.10	-2.03	4.13
328	02/03/2025 02:08:00	13.55	15.40	-1.85	3.41
329	02/03/2025 03:08:00	13.43	14.84	-1.41	2.00
330	02/03/2025 04:08:00	13.00	15.21	-2.21	4.90
331	02/03/2025 05:08:00	12.65	15.46	-2.81	7.88

332	02/03/2025 06:08:00	12.31	15.63	-3.32	10.99
333	02/03/2025 07:08:00	12.18	14.86	-2.68	7.16
334	02/03/2025 08:08:00	12.35	14.99	-2.63	6.94
335	02/03/2025 09:08:00	12.65	15.87	-3.22	10.35
336	02/03/2025 10:08:00	13.34	17.80	-4.46	19.90
337	02/03/2025 11:08:00	14.24	18.21	-3.97	15.76
338	02/03/2025 12:08:00	15.40	18.46	-3.06	9.37
339	02/03/2025 13:08:00	16.64	18.89	-2.25	5.05

13 APPENDIX C: SURFACE TEMPERATURE DATA (BELOW CONCRETE ROOF)

Temperature below concrete roof from field and Simulation Jan 20-Feb 5.

sn	Date/Time	Temperature field	Simulation	Error	SQ error
1	1/20/2025 10:54	17.4	16.80	0.60	0.36
2	1/20/2025 11:54	18.2	18.54	-0.34	0.12
3	1/20/2025 12:54	18.5	20.16	-1.66	2.77
4	1/20/2025 13:54	18.6	21.20	-2.60	6.77
5	1/20/2025 14:54	20.2	21.40	-1.20	1.45
6	1/20/2025 15:54	19.9	20.71	-0.81	0.66
7	1/20/2025 16:54	19.9	19.70	0.20	0.04
8	1/20/2025 17:54	19.2	18.87	0.33	0.11
9	1/20/2025 18:54	18.8	18.45	0.35	0.12
10	1/20/2025 19:54	18.5	17.57	0.93	0.86
11	1/20/2025 20:54	18.3	17.20	1.10	1.21
12	1/20/2025 21:54	18.1	16.55	1.55	2.39
13	1/20/2025 22:54	18	14.58	3.42	11.70
14	1/20/2025 23:54	17.9	14.52	3.38	11.42
15	1/21/2025 0:54	17.7	15.20	2.50	6.25
16	1/21/2025 1:54	17.6	15.88	1.72	2.96
17	1/21/2025 2:54	17.5	15.87	1.63	2.66
18	1/21/2025 3:54	17.3	15.53	1.77	3.13
19	1/21/2025 4:54	17.2	15.25	1.95	3.82
20	1/21/2025 5:54	17.1	15.12	1.98	3.92
21	1/21/2025 6:54	16.9	14.85	2.05	4.20
22	1/21/2025 7:54	17	12.90	4.10	16.85
23	1/21/2025 8:54	17.6	14.06	3.54	12.56
24	1/21/2025 9:54	18.3	15.66	2.64	6.98
25	1/21/2025 10:54	18.6	18.03	0.57	0.33
26	1/21/2025 11:54	18.9	19.98	-1.08	1.17

27	1/21/2025 12:54	19	20.79	-1.79	3.19
28	1/21/2025 13:54	19.1	20.80	-1.70	2.89
29	1/21/2025 14:54	19.2	20.97	-1.77	3.13
30	1/21/2025 15:54	19.4	21.12	-1.72	2.96
31	1/21/2025 16:54	20.1	20.25	-0.15	0.02
32	1/21/2025 17:54	19.9	19.54	0.36	0.13
33	1/21/2025 18:54	19.8	19.12	0.68	0.46
34	1/21/2025 19:54	19.6	18.87	0.73	0.53
35	1/21/2025 20:54	19.4	17.56	1.84	3.39
36	1/21/2025 21:54	19.2	17.23	1.97	3.88
37	1/21/2025 22:54	19.1	18.13	0.97	0.94
38	1/21/2025 23:54	19	17.52	1.48	2.19
39	1/22/2025 0:54	18.8	17.12	1.68	2.82
40	1/22/2025 1:54	18.7	16.86	1.84	3.37
41	1/22/2025 2:54	18.5	16.87	1.63	2.66
42	1/22/2025 3:54	18.4	16.57	1.83	3.35
43	1/22/2025 4:54	18.2	17.50	0.70	0.49
44	1/22/2025 5:54	18.1	17.52	0.58	0.34
45	1/22/2025 6:54	17.9	17.80	0.10	0.01
46	1/22/2025 7:54	17.9	17.65	0.25	0.06
47	1/22/2025 8:54	18.6	18.80	-0.20	0.04
48	1/22/2025 9:54	19.4	18.24	1.16	1.35
49	1/22/2025 10:54	19.8	18.69	1.11	1.23
50	1/22/2025 11:54	19.6	18.78	0.82	0.67
51	1/22/2025 12:54	19.5	18.75	0.75	0.56
52	1/22/2025 13:54	19.7	17.28	2.42	5.87
53	1/22/2025 14:54	20.4	17.71	2.69	7.24
54	1/22/2025 15:54	20.4	17.66	2.74	7.51
55	1/22/2025 16:54	20.8	17.55	3.25	10.55
56	1/22/2025 17:54	20.3	17.75	2.55	6.50
57	1/22/2025 18:54	20	17.66	2.34	5.48
58	1/22/2025 19:54	19.7	17.17	2.53	6.40
59	1/22/2025 20:54	19.6	16.35	3.25	10.54
60	1/22/2025 21:54	19.3	16.80	2.50	6.25
61	1/22/2025 22:54	19.2	16.78	2.42	5.86
62	1/22/2025 23:54	19.2	16.40	2.80	7.84
63	1/23/2025 0:54	19.1	15.98	3.12	9.73
64	1/23/2025 1:54	18.9	15.89	3.01	9.06
65	1/23/2025 2:54	18.8	15.45	3.35	11.22
66	1/23/2025 3:54	18.6	15.25	3.35	11.22
67	1/23/2025 4:54	18.5	15.26	3.24	10.50
68	1/23/2025 5:54	18.4	15.12	3.28	10.76

69	1/23/2025 6:54	18.1	15.45	2.65	7.02
70	1/23/2025 7:54	18.2	15.87	2.33	5.43
71	1/23/2025 8:54	18.6	15.89	2.71	7.34
72	1/23/2025 9:54	19.1	17.08	2.02	4.08
73	1/23/2025 10:54	19.4	19.33	0.07	0.00
74	1/23/2025 11:54	19.5	21.05	-1.55	2.40
75	1/23/2025 12:54	19.6	21.50	-1.90	3.61
76	1/23/2025 13:54	19.7	21.23	-1.53	2.34
77	1/23/2025 14:54	20.4	21.25	-0.85	0.72
78	1/23/2025 15:54	20.4	20.10	0.30	0.09
79	1/23/2025 16:54	20.4	22.55	-2.15	4.62
80	1/23/2025 17:54	20.1	21.85	-1.75	3.06
81	1/23/2025 18:54	19.8	20.70	-0.90	0.82
82	1/23/2025 19:54	19.7	19.76	-0.06	0.00
83	1/23/2025 20:54	19.7	18.86	0.84	0.71
84	1/23/2025 21:54	19.6	17.99	1.61	2.58
85	1/23/2025 22:54	19.5	16.98	2.52	6.33
86	1/23/2025 23:54	19.4	16.45	2.95	8.68
87	1/24/2025 0:54	19.2	16.65	2.55	6.50
88	1/24/2025 1:54	19.1	16.85	2.25	5.06
89	1/24/2025 2:54	18.9	16.54	2.36	5.56
90	1/24/2025 3:54	18.8	16.25	2.56	6.53
91	1/24/2025 4:54	18.6	17.54	1.06	1.12
92	1/24/2025 5:54	18.5	17.54	0.96	0.92
93	1/24/2025 6:54	18.3	17.56	0.74	0.54
94	1/24/2025 7:54	18.2	16.57	1.63	2.66
95	1/24/2025 8:54	18.6	16.82	1.78	3.17
96	1/24/2025 9:54	19.6	17.68	1.92	3.70
97	1/24/2025 10:54	19.6	19.70	-0.10	0.01
98	1/24/2025 11:54	19.3	21.86	-2.56	6.57
99	1/24/2025 12:54	19.3	21.25	-1.95	3.80
100	1/24/2025 13:54	19.4	21.45	-2.05	4.21
101	1/24/2025 14:54	20.2	21.35	-1.15	1.32
102	1/24/2025 15:54	20.3	21.45	-1.15	1.32
103	1/24/2025 16:54	20.2	21.54	-1.34	1.80
104	1/24/2025 17:54	19.7	22.24	-2.54	6.43
105	1/24/2025 18:54	19.2	21.22	-2.02	4.10
106	1/24/2025 19:54	19.2	20.20	-1.00	1.00
107	1/24/2025 20:54	19.1	19.25	-0.15	0.02
108	1/24/2025 21:54	18.9	18.34	0.56	0.31
109	1/24/2025 22:54	18.8	17.25	1.55	2.40
110	1/24/2025 23:54	18.7	16.68	2.02	4.09

111	1/25/2025 0:54	18.6	16.07	2.53	6.42
112	1/25/2025 1:54	18.5	15.55	2.95	8.70
113	1/25/2025 2:54	18.3	15.58	2.72	7.41
114	1/25/2025 3:54	18.2	15.87	2.33	5.43
115	1/25/2025 4:54	18.1	16.24	1.86	3.46
116	1/25/2025 5:54	18	15.09	2.91	8.46
117	1/25/2025 6:54	17.8	15.03	2.77	7.66
118	1/25/2025 7:54	17.9	15.68	2.22	4.93
119	1/25/2025 8:54	18.7	16.64	2.06	4.26
120	1/25/2025 9:54	19.3	17.69	1.61	2.59
121	1/25/2025 10:54	19.4	19.49	-0.09	0.01
122	1/25/2025 11:54	19.1	21.53	-2.43	5.91
123	1/25/2025 12:54	18.8	21.54	-2.74	7.51
124	1/25/2025 13:54	18.5	21.10	-2.60	6.76
125	1/25/2025 14:54	18.4	21.25	-2.85	8.09
126	1/25/2025 15:54	18.4	21.54	-3.14	9.86
127	1/25/2025 16:54	18.4	21.24	-2.84	8.07
128	1/25/2025 17:54	18.3	21.23	-2.93	8.58
129	1/25/2025 18:54	18.2	21.54	-3.34	11.16
130	1/25/2025 19:54	18.2	21.07	-2.87	8.23
131	1/25/2025 20:54	18.1	20.01	-1.91	3.65
132	1/25/2025 21:54	18.1	19.01	-0.91	0.83
133	1/25/2025 22:54	18	17.73	0.27	0.08
134	1/25/2025 23:54	17.9	17.00	0.90	0.81
135	1/26/2025 0:54	17.8	16.33	1.47	2.16
136	1/26/2025 1:54	17.7	15.86	1.84	3.38
137	1/26/2025 2:54	17.6	15.42	2.18	4.74
138	1/26/2025 3:54	17.5	15.02	2.48	6.14
139	1/26/2025 4:54	17.5	14.65	2.85	8.15
140	1/26/2025 5:54	17.4	14.72	2.68	7.17
141	1/26/2025 6:54	17.3	14.89	2.41	5.81
142	1/26/2025 7:54	17.3	15.76	1.54	2.36
143	1/26/2025 8:54	17.7	17.04	0.66	0.43
144	1/26/2025 9:54	18.2	18.68	-0.48	0.23
145	1/26/2025 10:54	18.5	20.10	-1.60	2.57
146	1/26/2025 11:54	18.4	21.31	-2.91	8.46
147	1/26/2025 12:54	18.2	21.24	-3.04	9.24
148	1/26/2025 13:54	18.1	21.54	-3.44	11.83
149	1/26/2025 14:54	18	21.23	-3.23	10.43
150	1/26/2025 15:54	18	21.35	-3.35	11.22
151	1/26/2025 16:54	18	21.20	-3.20	10.24
152	1/26/2025 17:54	17.9	21.46	-3.56	12.64

153	1/26/2025 18:54	17.8	20.68	-2.88	8.28
154	1/26/2025 19:54	17.7	19.60	-1.90	3.62
155	1/26/2025 20:54	17.7	18.56	-0.86	0.74
156	1/26/2025 21:54	17.7	17.75	-0.05	0.00
157	1/26/2025 22:54	17.6	16.94	0.66	0.43
158	1/26/2025 23:54	17.5	16.61	0.89	0.79
159	1/27/2025 0:54	17.5	16.16	1.34	1.78
160	1/27/2025 1:54	17.3	15.73	1.57	2.46
161	1/27/2025 2:54	17.3	15.33	1.97	3.89
162	1/27/2025 3:54	17.2	14.96	2.24	5.02
163	1/27/2025 4:54	17.1	14.97	2.13	4.52
164	1/27/2025 5:54	17	15.15	1.85	3.42
165	1/27/2025 6:54	16.9	15.08	1.82	3.31
166	1/27/2025 7:54	16.8	15.67	1.13	1.27
167	1/27/2025 8:54	17.1	16.72	0.38	0.15
168	1/27/2025 9:54	18.3	17.56	0.74	0.55
169	1/27/2025 10:54	18	18.84	-0.84	0.70
170	1/27/2025 11:54	18	20.64	-2.64	6.99
171	1/27/2025 12:54	18	20.12	-2.12	4.49
172	1/27/2025 13:54	18.5	19.62	-1.12	1.26
173	1/27/2025 14:54	18.6	18.57	0.03	0.00
174	1/27/2025 15:54	18.6	17.09	1.51	2.27
175	1/27/2025 16:54	18.5	17.00	1.50	2.25
176	1/27/2025 17:54	18.4	17.41	0.99	0.98
177	1/27/2025 18:54	18.2	17.59	0.61	0.37
178	1/27/2025 19:54	18	17.11	0.89	0.79
179	1/27/2025 20:54	17.8	16.63	1.17	1.38
180	1/27/2025 21:54	17.9	16.12	1.78	3.16
181	1/27/2025 22:54	17.8	15.55	2.25	5.05
182	1/27/2025 23:54	17.6	15.48	2.12	4.49
183	1/28/2025 0:54	17.5	15.43	2.07	4.28
184	1/28/2025 1:54	17.5	15.21	2.29	5.24
185	1/28/2025 2:54	17.4	15.58	1.82	3.31
186	1/28/2025 3:54	17.3	15.34	1.96	3.84
187	1/28/2025 4:54	17.2	16.21	0.99	0.98
188	1/28/2025 5:54	17.1	16.24	0.86	0.74
189	1/28/2025 6:54	17	15.85	1.15	1.32
190	1/28/2025 7:54	17	15.85	1.15	1.32
191	1/28/2025 8:54	17	15.00	2.00	3.99
192	1/28/2025 9:54	17.8	16.69	1.11	1.23
193	1/28/2025 10:54	18.4	18.93	-0.53	0.28
194	1/28/2025 11:54	18.5	21.03	-2.53	6.39

195	1/28/2025 12:54	18.4	21.30	-2.90	8.41
196	1/28/2025 13:54	18.5	21.50	-3.00	9.00
197	1/28/2025 14:54	19.5	21.27	-1.77	3.13
198	1/28/2025 15:54	19.8	20.58	-0.78	0.61
199	1/28/2025 16:54	19.7	21.59	-1.89	3.56
200	1/28/2025 17:54	19.1	20.12	-1.02	1.04
201	1/28/2025 18:54	18.5	19.54	-1.04	1.08
202	1/28/2025 19:54	18.2	19.24	-1.04	1.08
203	1/28/2025 20:54	18.1	18.98	-0.88	0.77
204	1/28/2025 21:54	18	18.58	-0.58	0.34
205	1/28/2025 22:54	17.9	18.66	-0.76	0.58
206	1/28/2025 23:54	17.8	17.98	-0.18	0.03
207	1/29/2025 0:54	17.7	17.42	0.28	0.08
208	1/29/2025 1:54	17.6	16.98	0.62	0.38
209	1/29/2025 2:54	17.6	16.57	1.03	1.06
210	1/29/2025 3:54	17.5	16.16	1.34	1.79
211	1/29/2025 4:54	17.4	15.78	1.62	2.62
212	1/29/2025 5:54	17.3	15.10	2.20	4.83
213	1/29/2025 6:54	17.2	14.98	2.22	4.91
214	1/29/2025 7:54	17.1	15.23	1.87	3.49
215	1/29/2025 8:54	17.3	15.80	1.50	2.25
216	1/29/2025 9:54	17.7	17.03	0.67	0.45
217	1/29/2025 10:54	17.9	19.12	-1.22	1.50
218	1/29/2025 11:54	18	20.12	-2.12	4.49
219	1/29/2025 12:54	17.9	20.52	-2.62	6.86
220	1/29/2025 13:54	18	20.89	-2.89	8.35
221	1/29/2025 14:54	18.3	20.25	-1.95	3.80
222	1/29/2025 15:54	18.4	21.40	-3.00	9.00
223	1/29/2025 16:54	18.5	21.09	-2.59	6.70
224	1/29/2025 17:54	18.5	19.74	-1.24	1.55
225	1/29/2025 18:54	18.4	19.15	-0.75	0.56
226	1/29/2025 19:54	18.4	18.47	-0.07	0.00
227	1/29/2025 20:54	18.4	17.82	0.58	0.34
228	1/29/2025 21:54	18.3	17.24	1.06	1.13
229	1/29/2025 22:54	18.2	16.70	1.50	2.26
230	1/29/2025 23:54	18.1	15.75	2.35	5.50
231	1/30/2025 0:54	18	15.22	2.78	7.72
232	1/30/2025 1:54	17.9	16.57	1.33	1.77
233	1/30/2025 2:54	17.8	15.85	1.95	3.80
234	1/30/2025 3:54	17.7	15.45	2.25	5.06
235	1/30/2025 4:54	17.7	16.23	1.47	2.16
236	1/30/2025 5:54	17.6	16.42	1.18	1.39

237	1/30/2025 6:54	17.4	16.50	0.90	0.81
238	1/30/2025 7:54	17.4	16.27	1.13	1.28
239	1/30/2025 8:54	17.4	16.42	0.98	0.96
240	1/30/2025 9:54	18	18.10	-0.10	0.01
241	1/30/2025 10:54	18.4	19.60	-1.20	1.44
242	1/30/2025 11:54	18.5	20.12	-1.62	2.62
243	1/30/2025 12:54	18.3	20.75	-2.45	6.00
244	1/30/2025 13:54	18.5	21.20	-2.70	7.29
245	1/30/2025 14:54	18.7	21.50	-2.80	7.84
246	1/30/2025 15:54	18.9	21.24	-2.34	5.48
247	1/30/2025 16:54	18.9	21.72	-2.82	7.95
248	1/30/2025 17:54	18.8	19.58	-0.78	0.61
249	1/30/2025 18:54	18.8	20.45	-1.65	2.72
250	1/30/2025 19:54	18.7	20.40	-1.70	2.88
251	1/30/2025 20:54	18.7	19.28	-0.58	0.34
252	1/30/2025 21:54	18.6	18.29	0.31	0.10
253	1/30/2025 22:54	18.4	17.15	1.25	1.55
254	1/30/2025 23:54	18.3	16.57	1.73	3.00
255	1/31/2025 0:54	18.2	15.98	2.22	4.94
256	1/31/2025 1:54	18.2	15.50	2.70	7.30
257	1/31/2025 2:54	18	15.05	2.95	8.69
258	1/31/2025 3:54	17.9	15.56	2.34	5.48
259	1/31/2025 4:54	17.8	15.85	1.95	3.80
260	1/31/2025 5:54	17.7	15.86	1.84	3.40
261	1/31/2025 6:54	17.5	15.75	1.75	3.06
262	1/31/2025 7:54	17.4	15.64	1.76	3.08
263	1/31/2025 8:54	17.8	16.76	1.04	1.08
264	1/31/2025 9:54	18.2	18.36	-0.16	0.03
265	1/31/2025 10:54	18.3	20.14	-1.84	3.38
266	1/31/2025 11:54	18.3	20.85	-2.55	6.50
267	1/31/2025 12:54	18.3	20.86	-2.56	6.54
268	1/31/2025 13:54	18.4	21.42	-3.02	9.12
269	1/31/2025 14:54	18.6	21.50	-2.90	8.41
270	1/31/2025 15:54	18.7	19.58	-0.88	0.77
271	1/31/2025 16:54	18.8	18.54	0.26	0.07
272	1/31/2025 17:54	18.7	18.20	0.50	0.25
273	1/31/2025 18:54	18.6	17.54	1.06	1.12
274	1/31/2025 19:54	18.5	17.59	0.91	0.83
275	1/31/2025 20:54	18.5	17.59	0.91	0.83
276	1/31/2025 21:54	18.4	17.75	0.65	0.42
277	1/31/2025 22:54	18.4	16.91	1.49	2.21
278	1/31/2025 23:54	18.2	16.73	1.47	2.17

279	2/1/2025 0:54	18.1	16.46	1.64	2.69
280	2/1/2025 1:54	18	16.24	1.76	3.10
281	2/1/2025 2:54	17.9	16.09	1.81	3.29
282	2/1/2025 3:54	17.8	15.96	1.84	3.38
283	2/1/2025 4:54	17.7	15.84	1.86	3.45
284	2/1/2025 5:54	17.5	15.83	1.67	2.79
285	2/1/2025 6:54	17.4	15.74	1.66	2.75
286	2/1/2025 7:54	17.2	16.26	0.94	0.88
287	2/1/2025 8:54	18	17.77	0.23	0.05
288	2/1/2025 9:54	18.6	20.06	-1.46	2.12
289	2/1/2025 10:54	18.8	20.15	-1.35	1.82
290	2/1/2025 11:54	18.6	20.24	-1.64	2.69
291	2/1/2025 12:54	18.5	20.78	-2.28	5.20
292	2/1/2025 13:54	18.5	20.84	-2.34	5.48
293	2/1/2025 14:54	18.6	21.25	-2.65	7.02
294	2/1/2025 15:54	18.6	21.24	-2.64	6.97
295	2/1/2025 16:54	18.6	21.54	-2.94	8.64
296	2/1/2025 17:54	18.4	20.58	-2.18	4.75
297	2/1/2025 18:54	18.2	19.85	-1.65	2.72
298	2/1/2025 19:54	18.2	19.85	-1.65	2.72
299	2/1/2025 20:54	18.1	18.98	-0.88	0.77
300	2/1/2025 21:54	17.9	17.95	-0.05	0.00
301	2/1/2025 22:54	17.7	17.23	0.47	0.22
302	2/1/2025 23:54	17.7	17.16	0.54	0.30
303	2/2/2025 0:54	17.7	16.97	0.73	0.54
304	2/2/2025 1:54	17.5	16.74	0.76	0.58
305	2/2/2025 2:54	17.4	16.23	1.17	1.38
306	2/2/2025 3:54	17.3	15.55	1.75	3.05
307	2/2/2025 4:54	17.1	15.07	2.03	4.12
308	2/2/2025 5:54	17	14.80	2.20	4.86
309	2/2/2025 6:54	16.8	14.65	2.15	4.62
310	2/2/2025 7:54	17.1	15.55	1.55	2.40
311	2/2/2025 8:54	18	17.14	0.86	0.74
312	2/2/2025 9:54	18.6	18.64	-0.04	0.00
313	2/2/2025 10:54	18.7	20.41	-1.71	2.92
314	2/2/2025 11:54	18.4	21.12	-2.72	7.40
315	2/2/2025 12:54	17.9	21.24	-3.34	11.16
316	2/2/2025 13:54	17.9	21.25	-3.35	11.19
317	2/2/2025 14:54	17.8	21.52	-3.72	13.84
318	2/2/2025 15:54	17.8	20.15	-2.35	5.52
319	2/2/2025 16:54	17.8	20.75	-2.95	8.70
320	2/2/2025 17:54	17.8	20.15	-2.35	5.52

321	2/2/2025 18:54	17.7	20.50	-2.80	7.84
322	2/2/2025 19:54	17.7	20.40	-2.70	7.27
323	2/2/2025 20:54	17.6	18.93	-1.33	1.76
324	2/2/2025 21:54	17.6	17.90	-0.30	0.09
325	2/2/2025 22:54	17.5	17.15	0.35	0.13
326	2/2/2025 23:54	17.3	16.81	0.49	0.24
327	2/3/2025 0:54	17.2	16.34	0.86	0.74
328	2/3/2025 1:54	17.2	15.94	1.26	1.60
329	2/3/2025 2:54	17.2	15.43	1.77	3.14
330	2/3/2025 3:54	17	15.15	1.85	3.41
331	2/3/2025 4:54	17	15.03	1.97	3.86
332	2/3/2025 5:54	16.8	14.98	1.82	3.30
333	2/3/2025 6:54	16.8	15.05	1.75	3.05
334	2/3/2025 7:54	17.1	15.88	1.22	1.48
335	2/3/2025 8:54	17.5	17.21	0.29	0.08
336	2/3/2025 9:54	17.9	18.56	-0.66	0.44
337	2/3/2025 10:54	17.9	20.79	-2.89	8.33
338	2/3/2025 11:54	17.9	21.27	-3.37	11.36
339	2/3/2025 12:54	18	21.40	-3.40	11.56

14 APPENDIX D: SURFACE TEMPERATURE DATA (GREEN ROOF)

Green Roof surface temperature from field and simulation Jan 20- Feb 5.

	Date-Time (Nepal Standard Time)	Temperature (°C)	Simulation	Error	Squared Error
1	01/20/2025 10:25:00	9.39	11.57	-2.18	4.74
2	01/20/2025 11:25:00	10.89	12.78	-1.89	3.56
3	01/20/2025 12:25:00	13.08	12.87	0.21	0.04
4	01/20/2025 13:25:00	14.93	13.89	1.04	1.07
5	01/20/2025 14:25:00	17.50	14.43	3.07	9.43
6	01/20/2025 15:25:00	16.13	15.40	0.73	0.53
7	01/20/2025 16:25:00	13.98	14.23	-0.24	0.06
8	01/20/2025 17:25:00	13.04	13.04	-0.01	0.00
9	01/20/2025 18:25:00	12.14	12.25	-0.11	0.01
10	01/20/2025 19:25:00	11.37	11.78	-0.41	0.17
11	01/20/2025 20:25:00	10.64	11.33	-0.69	0.48
12	01/20/2025 21:25:00	10.21	10.73	-0.52	0.27
13	01/20/2025 22:25:00	9.78	10.21	-0.43	0.19
14	01/20/2025 23:25:00	9.35	9.77	-0.42	0.18
15	01/21/2025 00:25:00	9.09	9.41	-0.32	0.10

16	01/21/2025 01:25:00	8.71	9.17	-0.46	0.21
17	01/21/2025 02:25:00	8.49	8.96	-0.47	0.22
18	01/21/2025 03:25:00	8.32	8.74	-0.42	0.17
19	01/21/2025 04:25:00	8.15	8.42	-0.28	0.08
20	01/21/2025 05:25:00	7.89	8.13	-0.23	0.06
21	01/21/2025 06:25:00	7.72	7.88	-0.16	0.03
22	01/21/2025 07:25:00	7.59	7.79	-0.20	0.04
23	01/21/2025 08:25:00	7.89	8.92	-1.03	1.06
24	01/21/2025 09:25:00	16.34	10.96	5.38	28.99
25	01/21/2025 10:25:00	8.58	11.23	-2.65	7.04
26	01/21/2025 11:25:00	9.14	11.40	-2.26	5.13
27	01/21/2025 12:25:00	9.65	11.53	-1.88	3.54
28	01/21/2025 13:25:00	10.34	10.80	-0.46	0.22
29	01/21/2025 14:25:00	10.81	10.40	0.41	0.17
30	01/21/2025 15:25:00	11.02	9.98	1.04	1.09
31	01/21/2025 16:25:00	11.19	9.86	1.33	1.78
32	01/21/2025 17:25:00	11.24	10.20	1.04	1.08
33	01/21/2025 18:25:00	11.19	10.43	0.76	0.58
34	01/21/2025 19:25:00	11.07	10.58	0.49	0.24
35	01/21/2025 20:25:00	10.81	12.55	-1.74	3.03
36	01/21/2025 21:25:00	10.55	11.93	-1.38	1.91
37	01/21/2025 22:25:00	10.25	11.59	-1.34	1.80
38	01/21/2025 23:25:00	10.04	11.35	-1.31	1.72
39	01/22/2025 00:25:00	9.78	11.11	-1.33	1.78
40	01/22/2025 01:25:00	9.56	10.93	-1.37	1.87
41	01/22/2025 02:25:00	9.35	10.79	-1.44	2.07
42	01/22/2025 03:25:00	9.09	10.12	-1.03	1.06
43	01/22/2025 04:25:00	8.92	9.56	-0.64	0.41
44	01/22/2025 05:25:00	8.75	9.40	-0.65	0.42
45	01/22/2025 06:25:00	8.53	8.87	-0.34	0.11
46	01/22/2025 07:25:00	8.36	8.43	-0.07	0.00
47	01/22/2025 08:25:00	8.49	7.89	0.60	0.36
48	01/22/2025 09:25:00	8.75	8.78	-0.03	0.00
49	01/22/2025 10:25:00	9.18	9.45	-0.27	0.07
50	01/22/2025 11:25:00	9.69	9.89	-0.20	0.04
51	01/22/2025 12:25:00	10.29	10.32	-0.03	0.00
52	01/22/2025 13:25:00	10.81	10.85	-0.04	0.00
53	01/22/2025 14:25:00	11.19	11.45	-0.26	0.07
54	01/22/2025 15:25:00	11.28	12.20	-0.92	0.85
55	01/22/2025 16:25:00	11.41	12.23	-0.82	0.67
56	01/22/2025 17:25:00	11.37	12.01	-0.64	0.41
57	01/22/2025 18:25:00	11.45	11.54	-0.09	0.01

58	01/22/2025 19:25:00	11.32	11.17	0.16	0.02
59	01/22/2025 20:25:00	11.11	10.79	0.32	0.10
60	01/22/2025 21:25:00	10.81	10.22	0.59	0.34
61	01/22/2025 22:25:00	10.51	9.73	0.78	0.60
62	01/22/2025 23:25:00	10.25	9.48	0.77	0.59
63	01/23/2025 00:25:00	9.99	9.13	0.86	0.74
64	01/23/2025 01:25:00	9.65	8.76	0.89	0.80
65	01/23/2025 02:25:00	9.39	8.55	0.84	0.70
66	01/23/2025 03:25:00	9.22	8.31	0.91	0.84
67	01/23/2025 04:25:00	8.96	7.99	0.97	0.94
68	01/23/2025 05:25:00	8.75	7.72	1.03	1.05
69	01/23/2025 06:25:00	8.49	7.51	0.98	0.96
70	01/23/2025 07:25:00	8.32	7.47	0.85	0.73
71	01/23/2025 08:25:00	8.41	8.76	-0.35	0.12
72	01/23/2025 09:25:00	8.49	8.87	-0.38	0.14
73	01/23/2025 10:25:00	8.75	9.78	-1.03	1.06
74	01/23/2025 11:25:00	9.18	11.32	-2.14	4.59
75	01/23/2025 12:25:00	9.78	11.56	-1.78	3.17
76	01/23/2025 13:25:00	10.64	10.98	-0.34	0.12
77	01/23/2025 14:25:00	10.85	11.23	-0.38	0.14
78	01/23/2025 15:25:00	10.89	11.78	-0.89	0.79
79	01/23/2025 16:25:00	11.07	11.90	-0.83	0.69
80	01/23/2025 17:25:00	11.37	12.23	-0.86	0.75
81	01/23/2025 18:25:00	11.41	12.30	-0.89	0.79
82	01/23/2025 19:25:00	11.15	12.43	-1.28	1.64
83	01/23/2025 20:25:00	10.94	11.87	-0.93	0.87
84	01/23/2025 21:25:00	10.77	11.58	-0.81	0.66
85	01/23/2025 22:25:00	10.55	10.89	-0.34	0.12
86	01/23/2025 23:25:00	10.08	10.58	-0.50	0.25
87	01/24/2025 00:25:00	9.74	10.23	-0.49	0.24
88	01/24/2025 01:25:00	9.44	9.87	-0.43	0.19
89	01/24/2025 02:25:00	9.18	9.58	-0.40	0.16
90	01/24/2025 03:25:00	8.92	9.77	-0.85	0.72
91	01/24/2025 04:25:00	8.66	9.44	-0.78	0.60
92	01/24/2025 05:25:00	8.41	9.15	-0.75	0.56
93	01/24/2025 06:25:00	8.28	8.85	-0.57	0.32
94	01/24/2025 07:25:00	8.11	8.74	-0.64	0.41
95	01/24/2025 08:25:00	8.32	9.88	-1.56	2.42
96	01/24/2025 09:25:00	8.71	10.57	-1.86	3.47
97	01/24/2025 10:25:00	9.14	10.87	-1.73	3.01
98	01/24/2025 11:25:00	9.65	11.23	-1.58	2.50
99	01/24/2025 12:25:00	10.25	11.43	-1.18	1.39

100	01/24/2025 13:25:00	10.89	11.56	-0.67	0.44
101	01/24/2025 14:25:00	11.02	11.43	-0.41	0.17
102	01/24/2025 15:25:00	11.02	10.80	0.22	0.05
103	01/24/2025 16:25:00	10.98	10.68	0.30	0.09
104	01/24/2025 17:25:00	10.81	10.40	0.41	0.17
105	01/24/2025 18:25:00	10.55	9.87	0.68	0.46
106	01/24/2025 19:25:00	10.34	10.20	0.14	0.02
107	01/24/2025 20:25:00	10.08	10.23	-0.15	0.02
108	01/24/2025 21:25:00	9.78	10.50	-0.72	0.52
109	01/24/2025 22:25:00	9.61	9.23	0.38	0.14
110	01/24/2025 23:25:00	9.44	9.43	0.01	0.00
111	01/25/2025 00:25:00	9.18	9.56	-0.38	0.15
112	01/25/2025 01:25:00	8.83	9.20	-0.37	0.13
113	01/25/2025 02:25:00	8.53	8.89	-0.36	0.13
114	01/25/2025 03:25:00	8.28	9.12	-0.84	0.71
115	01/25/2025 04:25:00	8.06	8.98	-0.92	0.84
116	01/25/2025 05:25:00	7.81	8.56	-0.75	0.57
117	01/25/2025 06:25:00	7.59	8.23	-0.64	0.41
118	01/25/2025 07:25:00	7.42	8.45	-1.03	1.06
119	01/25/2025 08:25:00	7.68	8.56	-0.88	0.78
120	01/25/2025 09:25:00	8.06	8.87	-0.81	0.65
121	01/25/2025 10:25:00	8.49	9.26	-0.77	0.59
122	01/25/2025 11:25:00	8.96	9.42	-0.46	0.21
123	01/25/2025 12:25:00	9.61	9.89	-0.28	0.08
124	01/25/2025 13:25:00	10.46	10.54	-0.08	0.01
125	01/25/2025 14:25:00	10.98	11.20	-0.22	0.05
126	01/25/2025 15:25:00	11.15	11.56	-0.41	0.17
127	01/25/2025 16:25:00	11.02	11.67	-0.65	0.42
128	01/25/2025 17:25:00	10.72	10.85	-0.13	0.02
129	01/25/2025 18:25:00	10.42	10.23	0.19	0.04
130	01/25/2025 19:25:00	10.29	10.87	-0.58	0.33
131	01/25/2025 20:25:00	10.04	9.76	0.28	0.08
132	01/25/2025 21:25:00	9.82	9.52	0.30	0.09
133	01/25/2025 22:25:00	9.69	9.23	0.46	0.21
134	01/25/2025 23:25:00	9.52	9.38	0.14	0.02
135	01/26/2025 00:25:00	9.39	9.76	-0.37	0.14
136	01/26/2025 01:25:00	9.14	10.43	-1.29	1.68
137	01/26/2025 02:25:00	9.35	10.68	-1.34	1.78
138	01/26/2025 03:25:00	9.44	10.35	-0.91	0.83
139	01/26/2025 04:25:00	9.48	10.00	-0.52	0.27
140	01/26/2025 05:25:00	9.44	9.69	-0.25	0.06
141	01/26/2025 06:25:00	9.39	9.48	-0.09	0.01

142	01/26/2025 07:25:00	9.31	9.47	-0.16	0.03
143	01/26/2025 08:25:00	9.39	10.63	-1.24	1.54
144	01/26/2025 09:25:00	10.55	11.23	-0.68	0.46
145	01/26/2025 10:25:00	10.25	11.56	-1.31	1.71
146	01/26/2025 11:25:00	10.21	11.46	-1.25	1.57
147	01/26/2025 12:25:00	10.64	11.67	-1.03	1.07
148	01/26/2025 13:25:00	11.15	11.78	-0.63	0.40
149	01/26/2025 14:25:00	11.71	11.87	-0.16	0.03
150	01/26/2025 15:25:00	11.67	12.23	-0.56	0.32
151	01/26/2025 16:25:00	11.58	12.28	-0.70	0.49
152	01/26/2025 17:25:00	11.37	12.58	-1.21	1.47
153	01/26/2025 18:25:00	11.28	11.47	-0.19	0.04
154	01/26/2025 19:25:00	11.02	11.11	-0.09	0.01
155	01/26/2025 20:25:00	10.81	10.85	-0.04	0.00
156	01/26/2025 21:25:00	10.55	13.54	-2.99	8.94
157	01/26/2025 22:25:00	10.34	12.85	-2.51	6.32
158	01/26/2025 23:25:00	10.08	10.24	-0.16	0.03
159	01/27/2025 00:25:00	9.78	9.87	-0.09	0.01
160	01/27/2025 01:25:00	9.56	9.85	-0.29	0.08
161	01/27/2025 02:25:00	9.31	9.65	-0.34	0.12
162	01/27/2025 03:25:00	9.01	9.25	-0.24	0.06
163	01/27/2025 04:25:00	8.75	9.85	-1.10	1.20
164	01/27/2025 05:25:00	8.53	9.67	-1.14	1.29
165	01/27/2025 06:25:00	8.36	9.56	-1.20	1.44
166	01/27/2025 07:25:00	8.23	9.58	-1.35	1.82
167	01/27/2025 08:25:00	8.41	10.24	-1.83	3.36
168	01/27/2025 09:25:00	8.83	10.58	-1.75	3.05
169	01/27/2025 10:25:00	9.31	10.78	-1.47	2.17
170	01/27/2025 11:25:00	9.78	10.89	-1.11	1.24
171	01/27/2025 12:25:00	10.29	10.79	-0.50	0.25
172	01/27/2025 13:25:00	10.98	11.24	-0.26	0.07
173	01/27/2025 14:25:00	11.45	11.68	-0.23	0.05
174	01/27/2025 15:25:00	11.54	11.78	-0.24	0.06
175	01/27/2025 16:25:00	11.32	12.20	-0.88	0.77
176	01/27/2025 17:25:00	11.11	11.56	-0.45	0.20
177	01/27/2025 18:25:00	11.07	11.42	-0.35	0.13
178	01/27/2025 19:25:00	10.98	10.85	0.13	0.02
179	01/27/2025 20:25:00	10.94	10.45	0.49	0.24
180	01/27/2025 21:25:00	10.77	10.25	0.52	0.27
181	01/27/2025 22:25:00	10.55	10.12	0.43	0.19
182	01/27/2025 23:25:00	10.34	9.87	0.47	0.22
183	01/28/2025 00:25:00	10.08	9.56	0.52	0.27

184	01/28/2025 01:25:00	9.82	10.85	-1.03	1.06
185	01/28/2025 02:25:00	9.61	10.47	-0.86	0.74
186	01/28/2025 03:25:00	9.35	10.07	-0.72	0.51
187	01/28/2025 04:25:00	9.14	9.68	-0.55	0.30
188	01/28/2025 05:25:00	8.92	9.29	-0.37	0.14
189	01/28/2025 06:25:00	8.66	8.92	-0.26	0.07
190	01/28/2025 07:25:00	8.53	8.82	-0.28	0.08
191	01/28/2025 08:25:00	9.01	10.05	-1.04	1.09
192	01/28/2025 09:25:00	9.82	10.56	-0.74	0.55
193	01/28/2025 10:25:00	10.16	10.72	-0.56	0.31
194	01/28/2025 11:25:00	10.29	11.23	-0.94	0.88
195	01/28/2025 12:25:00	10.77	11.42	-0.65	0.43
196	01/28/2025 13:25:00	11.28	11.45	-0.17	0.03
197	01/28/2025 14:25:00	11.79	11.85	-0.06	0.00
198	01/28/2025 15:25:00	11.79	11.78	0.01	0.00
199	01/28/2025 16:25:00	11.54	12.65	-1.11	1.24
200	01/28/2025 17:25:00	11.41	12.87	-1.46	2.14
201	01/28/2025 18:25:00	11.28	12.98	-1.70	2.89
202	01/28/2025 19:25:00	11.15	11.88	-0.73	0.53
203	01/28/2025 20:25:00	11.15	10.75	0.40	0.16
204	01/28/2025 21:25:00	11.02	10.70	0.32	0.10
205	01/28/2025 22:25:00	11.11	10.57	0.54	0.29
206	01/28/2025 23:25:00	11.02	10.87	0.15	0.02
207	01/29/2025 00:25:00	10.89	10.45	0.44	0.20
208	01/29/2025 01:25:00	10.68	10.21	0.47	0.22
209	01/29/2025 02:25:00	10.42	9.98	0.44	0.20
210	01/29/2025 03:25:00	10.29	9.87	0.42	0.18
211	01/29/2025 04:25:00	10.04	9.76	0.28	0.08
212	01/29/2025 05:25:00	9.78	9.58	0.20	0.04
213	01/29/2025 06:25:00	9.69	10.07	-0.37	0.14
214	01/29/2025 07:25:00	9.82	9.99	-0.17	0.03
215	01/29/2025 08:25:00	10.12	10.91	-0.79	0.62
216	01/29/2025 09:25:00	10.46	11.23	-0.77	0.59
217	01/29/2025 10:25:00	10.94	11.46	-0.52	0.27
218	01/29/2025 11:25:00	11.37	11.56	-0.19	0.04
219	01/29/2025 12:25:00	11.75	11.58	0.17	0.03
220	01/29/2025 13:25:00	12.22	11.89	0.33	0.11
221	01/29/2025 14:25:00	12.61	12.13	0.48	0.24
222	01/29/2025 15:25:00	12.78	12.75	0.03	0.00
223	01/29/2025 16:25:00	12.70	11.87	0.83	0.69
224	01/29/2025 17:25:00	12.61	11.50	1.11	1.23
225	01/29/2025 18:25:00	12.40	11.46	0.94	0.88

226	01/29/2025 19:25:00	12.35	11.65	0.70	0.49
227	01/29/2025 20:25:00	12.22	10.84	1.38	1.92
228	01/29/2025 21:25:00	12.05	10.75	1.30	1.70
229	01/29/2025 22:25:00	11.71	11.58	0.13	0.02
230	01/29/2025 23:25:00	11.45	11.24	0.21	0.04
231	01/30/2025 00:25:00	11.11	11.56	-0.45	0.20
232	01/30/2025 01:25:00	10.89	11.12	-0.22	0.05
233	01/30/2025 02:25:00	10.64	10.71	-0.07	0.01
234	01/30/2025 03:25:00	10.55	10.34	0.21	0.05
235	01/30/2025 04:25:00	10.46	10.02	0.44	0.20
236	01/30/2025 05:25:00	10.55	9.74	0.81	0.65
237	01/30/2025 06:25:00	10.59	9.48	1.11	1.24
238	01/30/2025 07:25:00	10.34	9.43	0.91	0.82
239	01/30/2025 08:25:00	10.72	10.48	0.24	0.06
240	01/30/2025 09:25:00	11.11	12.42	-1.31	1.73
241	01/30/2025 10:25:00	11.19	13.59	-2.39	5.73
242	01/30/2025 11:25:00	11.49	12.58	-1.09	1.18
243	01/30/2025 12:25:00	11.97	12.23	-0.26	0.07
244	01/30/2025 13:25:00	12.40	12.57	-0.17	0.03
245	01/30/2025 14:25:00	12.65	13.55	-0.90	0.80
246	01/30/2025 15:25:00	12.74	13.48	-0.74	0.55
247	01/30/2025 16:25:00	12.65	13.58	-0.93	0.86
248	01/30/2025 17:25:00	12.57	14.85	-2.28	5.21
249	01/30/2025 18:25:00	12.40	11.24	1.16	1.35
250	01/30/2025 19:25:00	12.31	11.13	1.18	1.40
251	01/30/2025 20:25:00	12.10	10.98	1.12	1.24
252	01/30/2025 21:25:00	11.79	11.57	0.22	0.05
253	01/30/2025 22:25:00	11.49	11.58	-0.09	0.01
254	01/30/2025 23:25:00	11.02	12.41	-1.39	1.93
255	01/31/2025 00:25:00	10.77	11.85	-1.08	1.17
256	01/31/2025 01:25:00	10.46	11.38	-0.91	0.83
257	01/31/2025 02:25:00	10.21	10.94	-0.74	0.54
258	01/31/2025 03:25:00	9.91	10.54	-0.64	0.41
259	01/31/2025 04:25:00	9.65	10.18	-0.53	0.28
260	01/31/2025 05:25:00	9.44	9.83	-0.39	0.15
261	01/31/2025 06:25:00	9.22	9.68	-0.45	0.21
262	01/31/2025 07:25:00	8.96	9.66	-0.70	0.49
263	01/31/2025 08:25:00	9.26	10.83	-1.56	2.45
264	01/31/2025 09:25:00	9.69	11.21	-1.52	2.30
265	01/31/2025 10:25:00	10.12	11.53	-1.41	1.98
266	01/31/2025 11:25:00	10.64	11.87	-1.23	1.52
267	01/31/2025 12:25:00	11.02	12.13	-1.10	1.22

268	01/31/2025 13:25:00	11.71	12.46	-0.75	0.56
269	01/31/2025 14:25:00	12.14	12.89	-0.75	0.57
270	01/31/2025 15:25:00	12.35	12.80	-0.45	0.20
271	01/31/2025 16:25:00	12.40	11.76	0.64	0.41
272	01/31/2025 17:25:00	12.18	11.45	0.73	0.53
273	01/31/2025 18:25:00	12.01	11.26	0.75	0.56
274	01/31/2025 19:25:00	12.10	10.97	1.13	1.27
275	01/31/2025 20:25:00	11.84	11.12	0.72	0.52
276	01/31/2025 21:25:00	11.62	10.85	0.77	0.59
277	01/31/2025 22:25:00	11.37	10.56	0.81	0.65
278	01/31/2025 23:25:00	11.02	11.93	-0.91	0.82
279	02/01/2025 00:25:00	10.68	11.70	-1.02	1.04
280	02/01/2025 01:25:00	10.38	11.43	-1.05	1.11
281	02/01/2025 02:25:00	10.04	11.13	-1.09	1.19
282	02/01/2025 03:25:00	9.69	10.98	-1.29	1.67
283	02/01/2025 04:25:00	9.44	10.79	-1.35	1.83
284	02/01/2025 05:25:00	9.09	10.60	-1.51	2.27
285	02/01/2025 06:25:00	8.83	10.48	-1.64	2.69
286	02/01/2025 07:25:00	8.66	10.42	-1.76	3.08
287	02/01/2025 08:25:00	8.88	11.32	-2.45	5.99
288	02/01/2025 09:25:00	9.26	11.25	-1.99	3.96
289	02/01/2025 10:25:00	9.74	11.54	-1.80	3.26
290	02/01/2025 11:25:00	10.21	11.86	-1.65	2.73
291	02/01/2025 12:25:00	10.81	11.79	-0.98	0.96
292	02/01/2025 13:25:00	11.58	12.12	-0.54	0.29
293	02/01/2025 14:25:00	12.48	12.35	0.13	0.02
294	02/01/2025 15:25:00	12.18	12.58	-0.40	0.16
295	02/01/2025 16:25:00	12.14	12.87	-0.73	0.54
296	02/01/2025 17:25:00	12.10	12.24	-0.14	0.02
297	02/01/2025 18:25:00	11.88	11.87	0.01	0.00
298	02/01/2025 19:25:00	11.62	11.75	-0.13	0.02
299	02/01/2025 20:25:00	11.37	11.54	-0.17	0.03
300	02/01/2025 21:25:00	10.98	10.45	0.53	0.28
301	02/01/2025 22:25:00	10.51	10.32	0.19	0.04
302	02/01/2025 23:25:00	10.16	9.73	0.43	0.19
303	02/02/2025 00:25:00	9.74	9.23	0.51	0.26
304	02/02/2025 01:25:00	9.31	9.10	0.21	0.04
305	02/02/2025 02:25:00	8.92	8.75	0.18	0.03
306	02/02/2025 03:25:00	8.58	8.24	0.34	0.12
307	02/02/2025 04:25:00	8.23	8.46	-0.22	0.05
308	02/02/2025 05:25:00	7.89	8.53	-0.64	0.41
309	02/02/2025 06:25:00	7.63	8.23	-0.60	0.36

310	02/02/2025 07:25:00	7.46	8.54	-1.08	1.16
311	02/02/2025 08:25:00	7.55	8.87	-1.32	1.75
312	02/02/2025 09:25:00	7.81	9.21	-1.40	1.97
313	02/02/2025 10:25:00	8.23	9.87	-1.64	2.68
314	02/02/2025 11:25:00	8.66	10.13	-1.46	2.14
315	02/02/2025 12:25:00	9.31	10.78	-1.47	2.17
316	02/02/2025 13:25:00	10.04	11.21	-1.17	1.38
317	02/02/2025 14:25:00	10.38	11.54	-1.16	1.35
318	02/02/2025 15:25:00	10.64	11.59	-0.95	0.90
319	02/02/2025 16:25:00	10.81	11.99	-1.18	1.39
320	02/02/2025 17:25:00	10.98	12.21	-1.23	1.51
321	02/02/2025 18:25:00	10.85	11.75	-0.90	0.82
322	02/02/2025 19:25:00	10.68	11.58	-0.90	0.82
323	02/02/2025 20:25:00	10.81	11.21	-0.40	0.16
324	02/02/2025 21:25:00	10.55	11.10	-0.55	0.30
325	02/02/2025 22:25:00	10.21	10.85	-0.65	0.42
326	02/02/2025 23:25:00	9.82	10.45	-0.63	0.40
327	02/03/2025 00:25:00	9.52	10.87	-1.35	1.82
328	02/03/2025 01:25:00	9.18	11.50	-2.32	5.39
329	02/03/2025 02:25:00	8.83	11.20	-2.37	5.61
330	02/03/2025 03:25:00	8.49	10.86	-2.37	5.62
331	02/03/2025 04:25:00	8.23	10.56	-2.33	5.42
332	02/03/2025 05:25:00	7.85	10.30	-2.45	6.02
333	02/03/2025 06:25:00	7.55	10.06	-2.51	6.32
334	02/03/2025 07:25:00	7.38	10.03	-2.66	7.07
335	02/03/2025 08:25:00	7.50	10.24	-2.74	7.48
336	02/03/2025 09:25:00	7.81	10.50	-2.69	7.26
337	02/03/2025 10:25:00	8.36	10.88	-2.51	6.31
338	02/03/2025 11:25:00	8.96	11.58	-2.62	6.85
339	02/03/2025 12:25:00	9.69	11.24	-1.55	2.39
340	02/03/2025 13:25:00	10.55	11.58	-1.03	1.06

15 APPENDIX E: INTERNAL AIR TEMPERATURE DATA (BELOW GREEN ROOF)

Temperature of Room below green roof field and simulation Jan 20 – Feb 5.

	Date/Time	Field Temperature	Simulated data	Difference	Squared error
1	1/20/2025 10:50	17.6	15.82	1.78	3.17
2	1/20/2025 11:50	20.5	17.05	3.45	11.92
3	1/20/2025 12:50	21	18.35	2.65	7.03
4	1/20/2025 13:50	20.2	19.47	0.73	0.53
5	1/20/2025 14:50	20.2	20.06	0.14	0.02
6	1/20/2025 15:50	19.9	18.87	1.03	1.06
7	1/20/2025 16:50	19.8	18.54	1.26	1.59
8	1/20/2025 17:50	19.5	18.45	1.05	1.10
9	1/20/2025 18:50	19.3	18.10	1.20	1.44
10	1/20/2025 19:50	19.2	17.58	1.62	2.62
11	1/20/2025 20:50	19	17.20	1.80	3.24
12	1/20/2025 21:50	18.9	16.87	2.03	4.12
13	1/20/2025 22:50	18.5	16.75	1.75	3.06
14	1/20/2025 23:50	18.1	16.25	1.85	3.41
15	1/21/2025 0:50	17.9	16.23	1.67	2.79
16	1/21/2025 1:50	17.7	16.42	1.28	1.64
17	1/21/2025 2:50	17.5	16.24	1.26	1.59
18	1/21/2025 3:50	17.4	16.24	1.16	1.35
19	1/21/2025 4:50	17.2	16.24	0.96	0.92
20	1/21/2025 5:50	17.1	15.24	1.86	3.46
21	1/21/2025 6:50	17	14.24	2.76	7.62
22	1/21/2025 7:50	16.9	14.35	2.55	6.52
23	1/21/2025 8:50	16.6	15.12	1.48	2.18
24	1/21/2025 9:50	16.9	16.16	0.74	0.54
25	1/21/2025 10:50	17.8	17.35	0.45	0.20
26	1/21/2025 11:50	18.6	18.56	0.04	0.00
27	1/21/2025 12:50	18.9	19.64	-0.74	0.55
28	1/21/2025 13:50	19.1	20.48	-1.38	1.90
29	1/21/2025 14:50	19.1	21.05	-1.95	3.81
30	1/21/2025 15:50	19	21.27	-2.27	5.16
31	1/21/2025 16:50	19	20.81	-1.81	3.27
32	1/21/2025 17:50	18.8	19.51	-0.71	0.51
33	1/21/2025 18:50	18.7	18.60	0.10	0.01
34	1/21/2025 19:50	18.6	17.85	0.75	0.56
35	1/21/2025 20:50	18.5	17.16	1.34	1.80
36	1/21/2025 21:50	18.4	16.66	1.74	3.04
37	1/21/2025 22:50	18.3	16.32	1.98	3.93

38	1/21/2025 23:50	18.2	16.01	2.19	4.80
39	1/22/2025 0:50	18.1	15.77	2.33	5.42
40	1/22/2025 1:50	18	15.52	2.48	6.13
41	1/22/2025 2:50	17.9	16.54	1.36	1.85
42	1/22/2025 3:50	17.8	16.78	1.02	1.04
43	1/22/2025 4:50	17.7	16.75	0.95	0.90
44	1/22/2025 5:50	17.6	15.58	2.02	4.08
45	1/22/2025 6:50	17.5	15.42	2.08	4.33
46	1/22/2025 7:50	17.4	16.50	0.90	0.81
47	1/22/2025 8:50	17.7	16.85	0.85	0.72
48	1/22/2025 9:50	19.1	17.26	1.84	3.39
49	1/22/2025 10:50	19.9	17.85	2.05	4.20
50	1/22/2025 11:50	20.7	18.58	2.12	4.50
51	1/22/2025 12:50	20.8	18.98	1.82	3.31
52	1/22/2025 13:50	20.8	19.21	1.59	2.53
53	1/22/2025 14:50	21.2	20.10	1.10	1.21
54	1/22/2025 15:50	21.4	20.25	1.15	1.32
55	1/22/2025 16:50	21.5	20.28	1.22	1.48
56	1/22/2025 17:50	21.3	21.21	0.09	0.01
57	1/22/2025 18:50	20.6	19.54	1.06	1.12
58	1/22/2025 19:50	20.2	18.75	1.45	2.10
59	1/22/2025 20:50	19.7	18.25	1.46	2.12
60	1/22/2025 21:50	19.4	17.58	1.82	3.31
61	1/22/2025 22:50	19.2	17.20	2.00	4.00
62	1/22/2025 23:50	18.9	16.87	2.03	4.12
63	1/23/2025 0:50	18.7	16.10	2.60	6.76
64	1/23/2025 1:50	18.5	16.25	2.25	5.06
65	1/23/2025 2:50	18.3	16.75	1.55	2.40
66	1/23/2025 3:50	18.1	16.98	1.12	1.25
67	1/23/2025 4:50	18	17.21	0.79	0.62
68	1/23/2025 5:50	17.9	17.85	0.05	0.00
69	1/23/2025 6:50	17.7	17.98	-0.28	0.08
70	1/23/2025 7:50	17.7	17.52	0.18	0.03
71	1/23/2025 8:50	17.5	18.25	-0.75	0.56
72	1/23/2025 9:50	19.5	18.46	1.04	1.09
73	1/23/2025 10:50	20.9	18.40	2.50	6.25
74	1/23/2025 11:50	21.9	18.58	3.32	10.99
75	1/23/2025 12:50	22.2	19.82	2.38	5.67
76	1/23/2025 13:50	22.2	20.80	1.40	1.96
77	1/23/2025 14:50	22	21.53	0.47	0.22
78	1/23/2025 15:50	22.1	21.81	0.29	0.08
79	1/23/2025 16:50	22.3	21.18	1.12	1.25

80	1/23/2025 17:50	21.7	20.09	1.61	2.58
81	1/23/2025 18:50	21.2	19.10	2.10	4.43
82	1/23/2025 19:50	20.6	18.23	2.37	5.63
83	1/23/2025 20:50	20.3	17.50	2.80	7.86
84	1/23/2025 21:50	20	17.85	2.15	4.62
85	1/23/2025 22:50	19.5	17.98	1.52	2.31
86	1/23/2025 23:50	19.2	16.59	2.61	6.83
87	1/24/2025 0:50	18.9	16.85	2.05	4.20
88	1/24/2025 1:50	18.7	16.89	1.81	3.28
89	1/24/2025 2:50	18.5	16.25	2.26	5.09
90	1/24/2025 3:50	18.3	16.25	2.05	4.19
91	1/24/2025 4:50	18.1	16.58	1.53	2.33
92	1/24/2025 5:50	18	16.44	1.56	2.43
93	1/24/2025 6:50	17.8	16.85	0.95	0.89
94	1/24/2025 7:50	17.7	16.25	1.46	2.12
95	1/24/2025 8:50	17.8	16.36	1.44	2.08
96	1/24/2025 9:50	19.5	16.38	3.12	9.72
97	1/24/2025 10:50	20.8	18.25	2.55	6.50
98	1/24/2025 11:50	21.4	18.81	2.59	6.71
99	1/24/2025 12:50	21.3	19.95	1.35	1.83
100	1/24/2025 13:50	20.3	20.78	-0.48	0.23
101	1/24/2025 14:50	20.3	21.29	-0.99	0.99
102	1/24/2025 15:50	20.1	21.48	-1.38	1.89
103	1/24/2025 16:50	20	21.04	-1.04	1.08
104	1/24/2025 17:50	19.3	20.10	-0.80	0.65
105	1/24/2025 18:50	18.9	19.20	-0.30	0.09
106	1/24/2025 19:50	18.8	18.35	0.45	0.20
107	1/24/2025 20:50	18.7	17.61	1.09	1.19
108	1/24/2025 21:50	18.5	16.66	1.84	3.40
109	1/24/2025 22:50	18.4	16.14	2.26	5.13
110	1/24/2025 23:50	18.3	15.76	2.54	6.48
111	1/25/2025 0:50	18.2	15.41	2.79	7.76
112	1/25/2025 1:50	18.1	15.08	3.02	9.15
113	1/25/2025 2:50	17.9	14.85	3.05	9.27
114	1/25/2025 3:50	17.8	14.69	3.11	9.64
115	1/25/2025 4:50	17.7	14.48	3.22	10.36
116	1/25/2025 5:50	17.6	14.74	2.86	8.20
117	1/25/2025 6:50	17.5	14.69	2.81	7.88
118	1/25/2025 7:50	17.4	14.97	2.43	5.93
119	1/25/2025 8:50	17.5	15.60	1.90	3.63
120	1/25/2025 9:50	17.6	16.51	1.09	1.19
121	1/25/2025 10:50	17.5	17.61	-0.11	0.01

122	1/25/2025 11:50	17.6	18.83	-1.23	1.51
123	1/25/2025 12:50	17.7	19.99	-2.29	5.24
124	1/25/2025 13:50	17.8	20.90	-3.10	9.62
125	1/25/2025 14:50	17.9	21.58	-3.68	13.52
126	1/25/2025 15:50	17.9	21.88	-3.98	15.84
127	1/25/2025 16:50	17.8	21.40	-3.60	12.95
128	1/25/2025 17:50	17.6	20.51	-2.91	8.47
129	1/25/2025 18:50	17.5	19.63	-2.13	4.55
130	1/25/2025 19:50	17.4	18.83	-1.43	2.05
131	1/25/2025 20:50	17.3	18.07	-0.77	0.59
132	1/25/2025 21:50	17.2	17.00	0.20	0.04
133	1/25/2025 22:50	17.2	16.39	0.81	0.65
134	1/25/2025 23:50	17.1	15.95	1.15	1.33
135	1/26/2025 0:50	17	15.56	1.44	2.08
136	1/26/2025 1:50	16.9	15.23	1.67	2.81
137	1/26/2025 2:50	16.9	14.92	1.98	3.91
138	1/26/2025 3:50	16.8	14.65	2.15	4.62
139	1/26/2025 4:50	16.8	14.40	2.40	5.77
140	1/26/2025 5:50	16.8	14.68	2.12	4.49
141	1/26/2025 6:50	16.7	14.64	2.06	4.24
142	1/26/2025 7:50	16.7	14.93	1.77	3.13
143	1/26/2025 8:50	16.8	15.62	1.18	1.38
144	1/26/2025 9:50	16.9	16.65	0.25	0.06
145	1/26/2025 10:50	16.9	17.82	-0.92	0.85
146	1/26/2025 11:50	17	18.85	-1.85	3.44
147	1/26/2025 12:50	17.1	19.66	-2.56	6.54
148	1/26/2025 13:50	17.2	20.07	-2.87	8.24
149	1/26/2025 14:50	17.3	20.07	-2.77	7.67
150	1/26/2025 15:50	17.3	19.89	-2.59	6.69
151	1/26/2025 16:50	17.2	19.62	-2.42	5.84
152	1/26/2025 17:50	17	19.06	-2.06	4.24
153	1/26/2025 18:50	17	18.43	-1.43	2.05
154	1/26/2025 19:50	16.9	17.78	-0.88	0.78
155	1/26/2025 20:50	16.8	17.27	-0.47	0.22
156	1/26/2025 21:50	16.7	16.38	0.32	0.10
157	1/26/2025 22:50	16.7	15.95	0.75	0.56
158	1/26/2025 23:50	16.6	15.63	0.97	0.95
159	1/27/2025 0:50	16.5	15.33	1.17	1.38
160	1/27/2025 1:50	16.4	15.05	1.35	1.83
161	1/27/2025 2:50	16.4	14.79	1.61	2.60
162	1/27/2025 3:50	16.3	14.55	1.75	3.06
163	1/27/2025 4:50	16.2	14.39	1.81	3.26

164	1/27/2025 5:50	16.2	14.69	1.51	2.28
165	1/27/2025 6:50	16.1	14.67	1.43	2.04
166	1/27/2025 7:50	16.1	14.94	1.16	1.34
167	1/27/2025 8:50	16.1	15.55	0.55	0.30
168	1/27/2025 9:50	17.8	16.38	1.42	2.02
169	1/27/2025 10:50	18.9	17.27	1.63	2.67
170	1/27/2025 11:50	20.6	18.18	2.42	5.88
171	1/27/2025 12:50	21	19.28	1.72	2.97
172	1/27/2025 13:50	21.6	19.87	1.73	2.99
173	1/27/2025 14:50	21.8	20.14	1.66	2.76
174	1/27/2025 15:50	21.7	19.87	1.83	3.35
175	1/27/2025 16:50	21.8	19.75	2.05	4.20
176	1/27/2025 17:50	21.3	21.25	0.05	0.00
177	1/27/2025 18:50	21	19.25	1.75	3.05
178	1/27/2025 19:50	20.2	18.85	1.35	1.82
179	1/27/2025 20:50	19.3	18.32	0.98	0.96
180	1/27/2025 21:50	18.8	18.20	0.60	0.36
181	1/27/2025 22:50	18.5	17.86	0.64	0.41
182	1/27/2025 23:50	18.2	17.20	1.00	1.00
183	1/28/2025 0:50	18	17.30	0.70	0.49
184	1/28/2025 1:50	17.8	16.57	1.23	1.51
185	1/28/2025 2:50	17.7	16.58	1.12	1.25
186	1/28/2025 3:50	17.6	16.42	1.18	1.39
187	1/28/2025 4:50	17.4	16.24	1.16	1.35
188	1/28/2025 5:50	17.3	16.50	0.80	0.64
189	1/28/2025 6:50	17.2	16.20	1.00	1.00
190	1/28/2025 7:50	17.1	15.78	1.32	1.73
191	1/28/2025 8:50	17.1	15.30	1.80	3.25
192	1/28/2025 9:50	18.4	16.36	2.04	4.17
193	1/28/2025 10:50	19.5	17.56	1.94	3.76
194	1/28/2025 11:50	20.7	18.84	1.86	3.44
195	1/28/2025 12:50	21.5	20.06	1.44	2.07
196	1/28/2025 13:50	22.4	21.03	1.37	1.88
197	1/28/2025 14:50	22.7	21.72	0.98	0.96
198	1/28/2025 15:50	22.8	22.00	0.80	0.63
199	1/28/2025 16:50	22.5	21.57	0.93	0.87
200	1/28/2025 17:50	21.9	20.34	1.56	2.42
201	1/28/2025 18:50	21.2	19.32	1.88	3.52
202	1/28/2025 19:50	20.7	18.41	2.29	5.23
203	1/28/2025 20:50	19.9	17.63	2.27	5.17
204	1/28/2025 21:50	19.3	17.04	2.26	5.10
205	1/28/2025 22:50	19	16.57	2.43	5.88

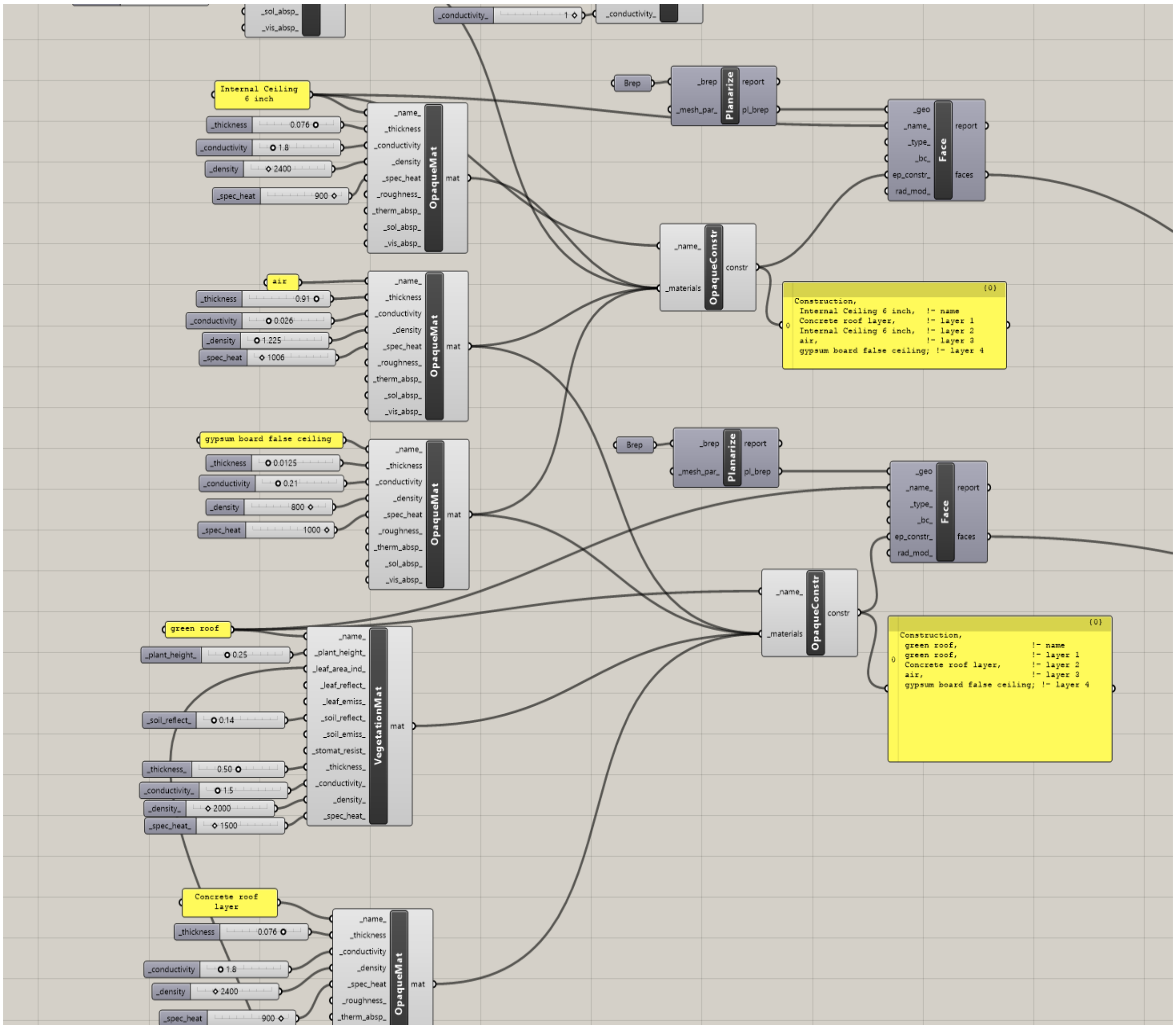
206	1/28/2025 23:50	18.7	16.20	2.50	6.25
207	1/29/2025 0:50	18.5	15.89	2.61	6.83
208	1/29/2025 1:50	18.3	15.60	2.70	7.30
209	1/29/2025 2:50	18.1	15.32	2.78	7.74
210	1/29/2025 3:50	18	15.04	2.96	8.75
211	1/29/2025 4:50	17.8	15.28	2.52	6.35
212	1/29/2025 5:50	17.7	15.35	2.35	5.52
213	1/29/2025 6:50	17.6	15.29	2.31	5.34
214	1/29/2025 7:50	17.3	16.85	0.45	0.20
215	1/29/2025 8:50	17.8	16.87	0.93	0.86
216	1/29/2025 9:50	19.7	17.58	2.12	4.49
217	1/29/2025 10:50	21.5	18.75	2.75	7.56
218	1/29/2025 11:50	21.1	19.75	1.35	1.82
219	1/29/2025 12:50	21	19.55	1.45	2.11
220	1/29/2025 13:50	21.8	20.27	1.53	2.34
221	1/29/2025 14:50	21.9	20.64	1.26	1.58
222	1/29/2025 15:50	22	20.31	1.69	2.86
223	1/29/2025 16:50	22.2	19.14	3.06	9.38
224	1/29/2025 17:50	21.3	20.12	1.18	1.39
225	1/29/2025 18:50	20.6	18.85	1.75	3.06
226	1/29/2025 19:50	19.8	18.50	1.30	1.69
227	1/29/2025 20:50	19.3	18.12	1.18	1.39
228	1/29/2025 21:50	19	17.89	1.11	1.23
229	1/29/2025 22:50	18.7	17.52	1.18	1.39
230	1/29/2025 23:50	18.5	17.10	1.40	1.96
231	1/30/2025 0:50	18.3	16.52	1.78	3.17
232	1/30/2025 1:50	18.2	16.20	2.00	4.00
233	1/30/2025 2:50	18	16.40	1.60	2.56
234	1/30/2025 3:50	17.9	16.42	1.48	2.19
235	1/30/2025 4:50	17.8	16.50	1.30	1.69
236	1/30/2025 5:50	17.7	16.75	0.95	0.90
237	1/30/2025 6:50	17.6	16.24	1.36	1.85
238	1/30/2025 7:50	17.3	15.75	1.55	2.40
239	1/30/2025 8:50	17.5	15.29	2.21	4.88
240	1/30/2025 9:50	19.3	16.44	2.86	8.20
241	1/30/2025 10:50	19.9	17.72	2.18	4.75
242	1/30/2025 11:50	20.2	18.95	1.25	1.56
243	1/30/2025 12:50	20.2	20.03	0.17	0.03
244	1/30/2025 13:50	20.5	20.87	-0.37	0.13
245	1/30/2025 14:50	20.8	21.50	-0.70	0.50
246	1/30/2025 15:50	20.4	21.91	-1.51	2.28
247	1/30/2025 16:50	20.2	21.57	-1.37	1.88

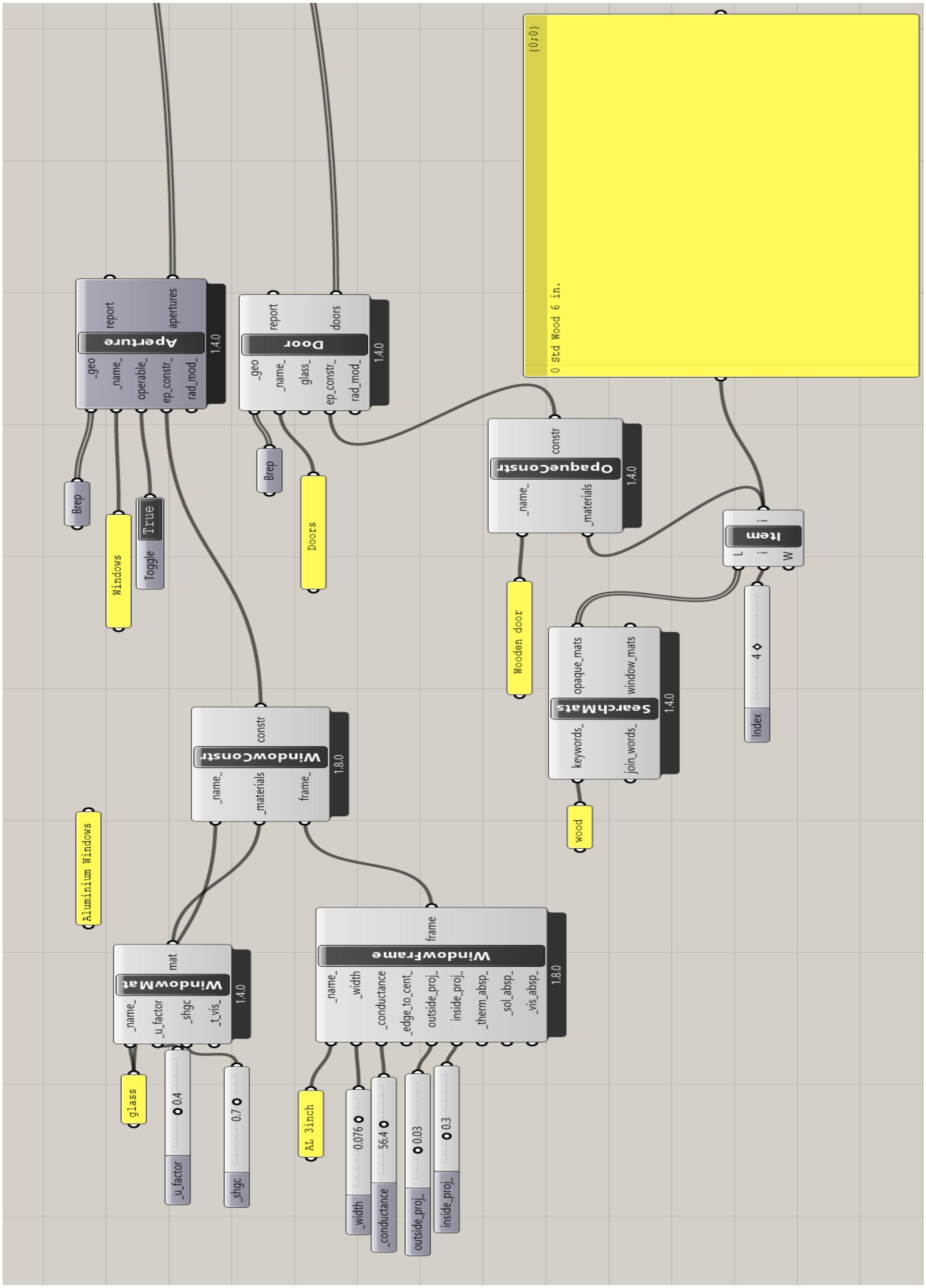
248	1/30/2025 17:50	19.6	20.62	-1.02	1.05
249	1/30/2025 18:50	19.4	19.73	-0.33	0.11
250	1/30/2025 19:50	19.2	18.90	0.30	0.09
251	1/30/2025 20:50	19	18.11	0.89	0.80
252	1/30/2025 21:50	18.8	16.93	1.87	3.49
253	1/30/2025 22:50	18.6	16.30	2.30	5.28
254	1/30/2025 23:50	18.5	15.85	2.65	7.04
255	1/31/2025 0:50	18.3	15.46	2.84	8.06
256	1/31/2025 1:50	18.2	15.11	3.09	9.53
257	1/31/2025 2:50	18.1	16.58	1.52	2.31
258	1/31/2025 3:50	17.9	16.78	1.12	1.25
259	1/31/2025 4:50	17.8	16.85	0.95	0.90
260	1/31/2025 5:50	17.7	16.75	0.95	0.90
261	1/31/2025 6:50	17.5	16.87	0.63	0.40
262	1/31/2025 7:50	17.3	16.98	0.32	0.10
263	1/31/2025 8:50	17.4	16.58	0.82	0.67
264	1/31/2025 9:50	18.5	16.63	1.87	3.49
265	1/31/2025 10:50	19.3	17.90	1.40	1.97
266	1/31/2025 11:50	19.6	19.10	0.50	0.25
267	1/31/2025 12:50	19.9	20.20	-0.30	0.09
268	1/31/2025 13:50	20.1	21.07	-0.97	0.94
269	1/31/2025 14:50	20	21.66	-1.66	2.74
270	1/31/2025 15:50	19.8	21.83	-2.03	4.13
271	1/31/2025 16:50	19.5	21.26	-1.76	3.10
272	1/31/2025 17:50	19.3	20.26	-0.96	0.92
273	1/31/2025 18:50	19	19.25	-0.25	0.06
274	1/31/2025 19:50	18.9	18.34	0.56	0.31
275	1/31/2025 20:50	18.6	17.53	1.07	1.14
276	1/31/2025 21:50	18.5	16.45	2.05	4.19
277	1/31/2025 22:50	18.4	15.95	2.45	6.02
278	1/31/2025 23:50	18.2	15.64	2.56	6.57
279	2/1/2025 0:50	18.1	16.87	1.23	1.51
280	2/1/2025 1:50	18	16.52	1.48	2.19
281	2/1/2025 2:50	17.8	16.24	1.56	2.43
282	2/1/2025 3:50	17.7	16.27	1.43	2.04
283	2/1/2025 4:50	17.6	15.74	1.86	3.46
284	2/1/2025 5:50	17.5	15.87	1.63	2.66
285	2/1/2025 6:50	17.4	15.90	1.50	2.26
286	2/1/2025 7:50	17.3	15.22	2.08	4.32
287	2/1/2025 8:50	17.4	15.89	1.51	2.29
288	2/1/2025 9:50	17.5	17.02	0.48	0.23
289	2/1/2025 10:50	17.5	18.38	-0.88	0.78

290	2/1/2025 11:50	17.6	19.60	-2.00	4.01
291	2/1/2025 12:50	17.8	20.55	-2.75	7.58
292	2/1/2025 13:50	17.8	20.15	-2.35	5.52
293	2/1/2025 14:50	17.9	20.58	-2.68	7.18
294	2/1/2025 15:50	18	21.50	-3.50	12.25
295	2/1/2025 16:50	17.9	21.20	-3.30	10.89
296	2/1/2025 17:50	17.8	20.14	-2.34	5.49
297	2/1/2025 18:50	17.7	19.29	-1.59	2.52
298	2/1/2025 19:50	17.5	18.56	-1.06	1.13
299	2/1/2025 20:50	17.4	17.82	-0.42	0.17
300	2/1/2025 21:50	17.3	16.66	0.64	0.41
301	2/1/2025 22:50	17.2	16.16	1.04	1.07
302	2/1/2025 23:50	17.2	15.88	1.32	1.75
303	2/2/2025 0:50	17.1	15.63	1.47	2.16
304	2/2/2025 1:50	16.9	15.41	1.49	2.22
305	2/2/2025 2:50	16.8	15.16	1.64	2.70
306	2/2/2025 3:50	16.7	14.86	1.84	3.40
307	2/2/2025 4:50	16.6	14.58	2.02	4.09
308	2/2/2025 5:50	16.5	14.80	1.70	2.91
309	2/2/2025 6:50	16.4	14.69	1.71	2.94
310	2/2/2025 7:50	16.4	14.93	1.47	2.15
311	2/2/2025 8:50	16.4	15.64	0.76	0.58
312	2/2/2025 9:50	16.5	16.71	-0.21	0.04
313	2/2/2025 10:50	16.6	17.96	-1.36	1.84
314	2/2/2025 11:50	16.7	19.21	-2.51	6.29
315	2/2/2025 12:50	16.8	19.50	-2.70	7.29
316	2/2/2025 13:50	16.9	20.25	-3.35	11.22
317	2/2/2025 14:50	17.1	18.85	-1.75	3.06
318	2/2/2025 15:50	17.1	17.50	-0.40	0.16
319	2/2/2025 16:50	17.1	17.12	-0.02	0.00
320	2/2/2025 17:50	17	16.87	0.13	0.02
321	2/2/2025 18:50	16.9	16.45	0.45	0.20
322	2/2/2025 19:50	16.8	16.23	0.57	0.32
323	2/2/2025 20:50	16.7	15.87	0.83	0.69
324	2/2/2025 21:50	16.6	15.90	0.70	0.49
325	2/2/2025 22:50	16.6	16.00	0.60	0.36
326	2/2/2025 23:50	16.4	15.67	0.73	0.53
327	2/3/2025 0:50	16.3	15.36	0.94	0.89
328	2/3/2025 1:50	16.2	15.33	0.87	0.76
329	2/3/2025 2:50	16.2	16.20	0.00	0.00
330	2/3/2025 3:50	16.1	16.50	-0.40	0.16
331	2/3/2025 4:50	16	16.78	-0.78	0.61

332	2/3/2025 5:50	15.9	16.97	-1.07	1.14
333	2/3/2025 6:50	15.8	17.21	-1.41	1.99
334	2/3/2025 7:50	15.3	16.98	-1.68	2.82
335	2/3/2025 8:50	16.4	16.25	0.15	0.02
336	2/3/2025 9:50	18.3	16.60	1.70	2.89
337	2/3/2025 10:50	19.5	17.87	1.63	2.67
338	2/3/2025 11:50	20.1	19.20	0.90	0.80
339	2/3/2025 12:50	20.5	20.16	0.34	0.12

16 APPENDIX F: RHINO/GRASSHOPPER SCRIPTS

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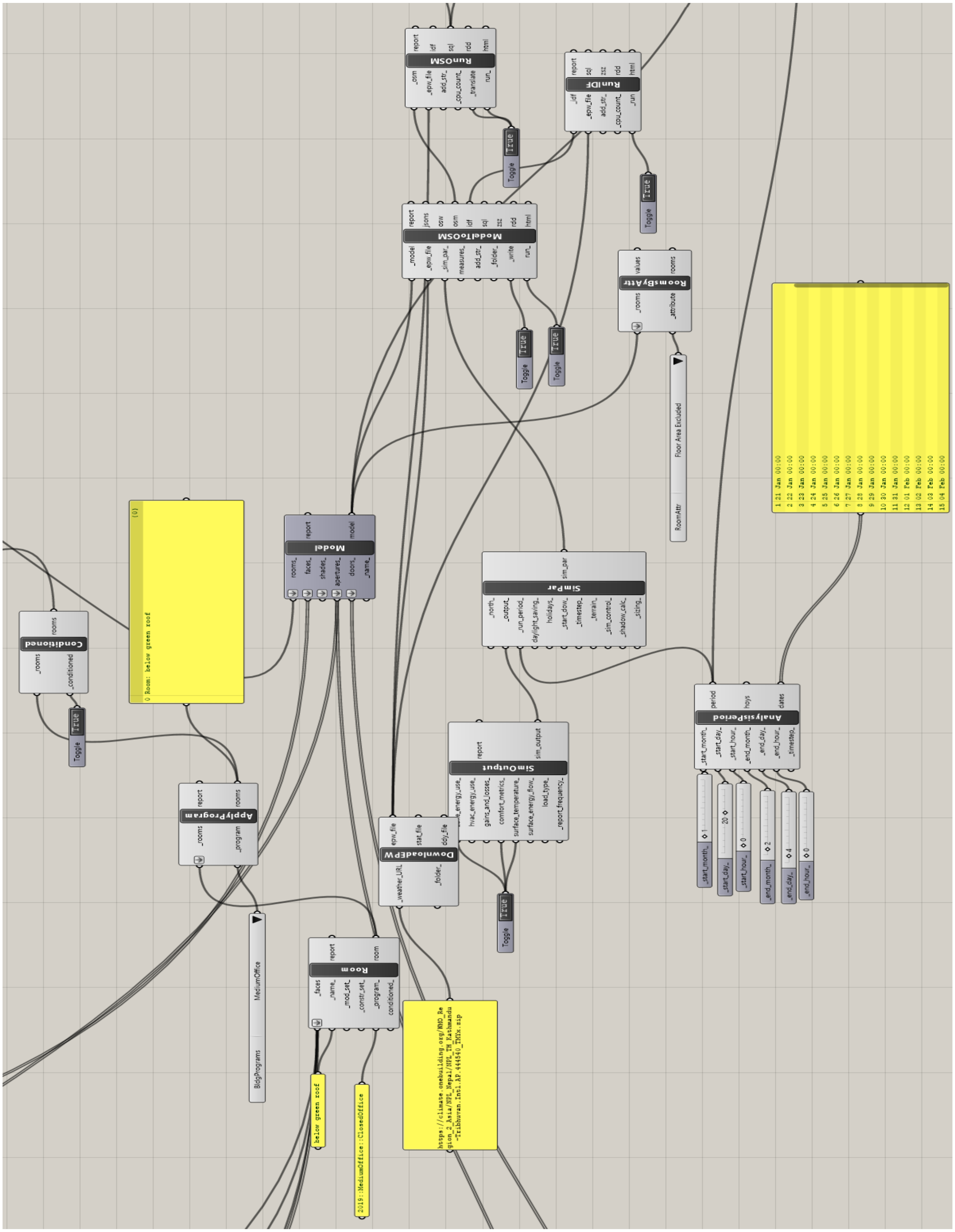
Door
OpaqueConstr
Item
SearchMats
WindowConstr
WindowMat
WindowFrame
Brep
Windows
Toggle
True
Doors
Wooden door
wood
Aluminium Windows
glass
AL 3inch
{0;0}
0 Std Wood 6 in.
_u_factor
_shgc
_width
_conductance
outside_proj_
inside_proj_
Index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RunIDF
ModelToOSM
RoomsByAttr
Model
SimPar
Conditioned
ApplyProgram
SimOutput
DownloadEPW
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AnalysisPeriod
below green roof
2019::MediumOffice::ClosedOffice
MediumOffice
BldgPrograms
Floor Area Excluded
RoomAttr
Toggle
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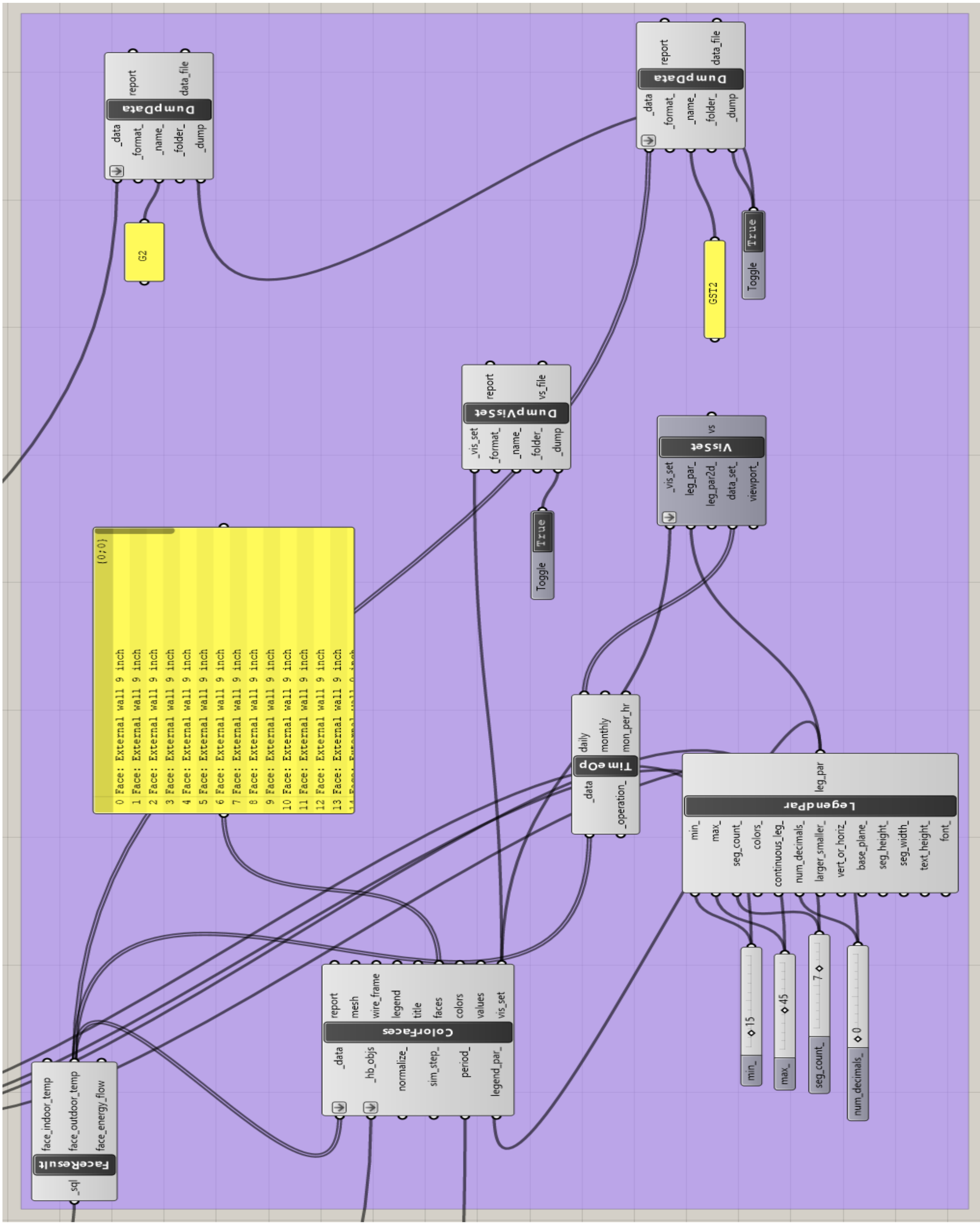
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G2
DumpData
Toggle
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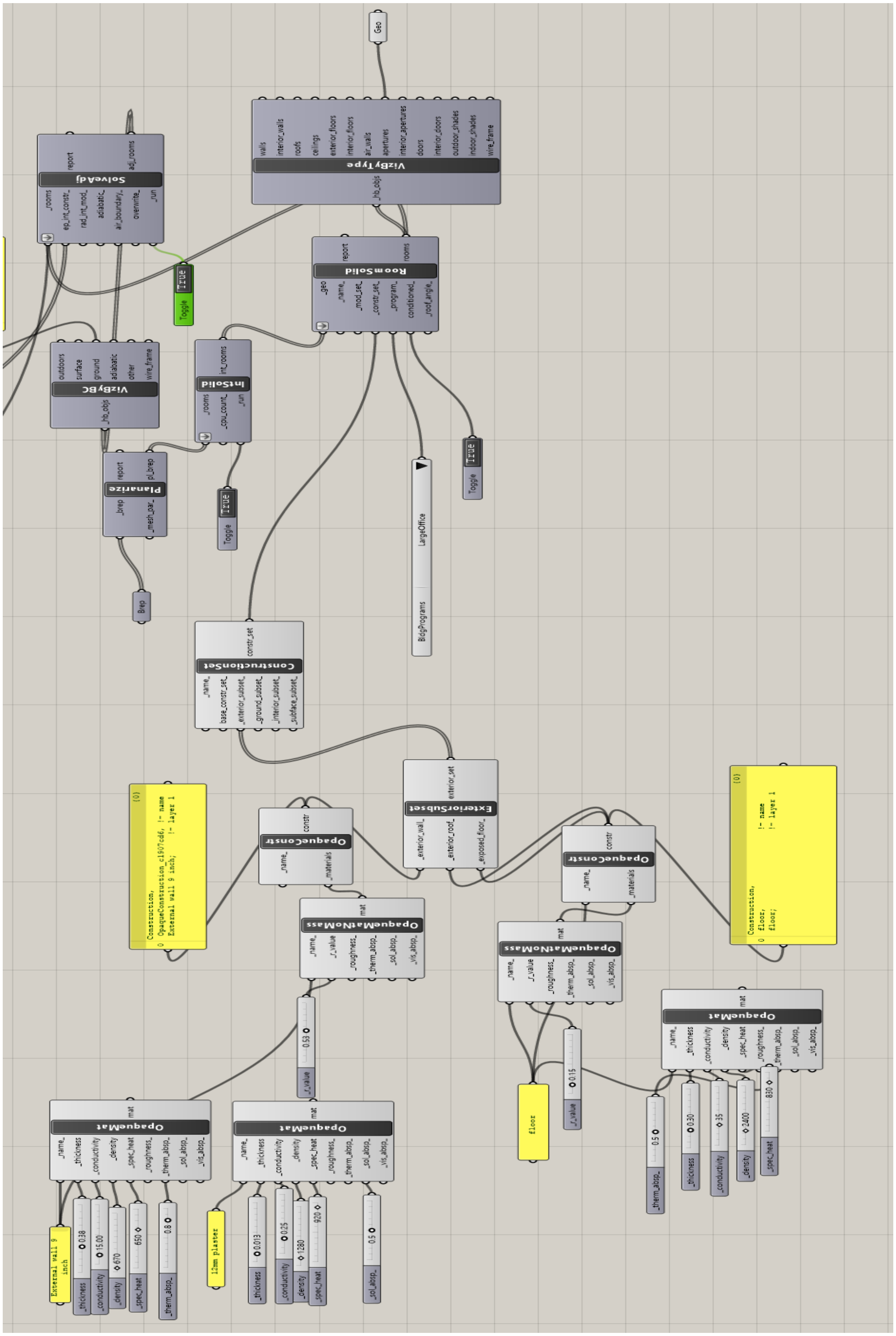
GST2
DumpVisSet
VisSet
Toggle
True
TimeOp
LegendPar
ColorFaces
FaceResult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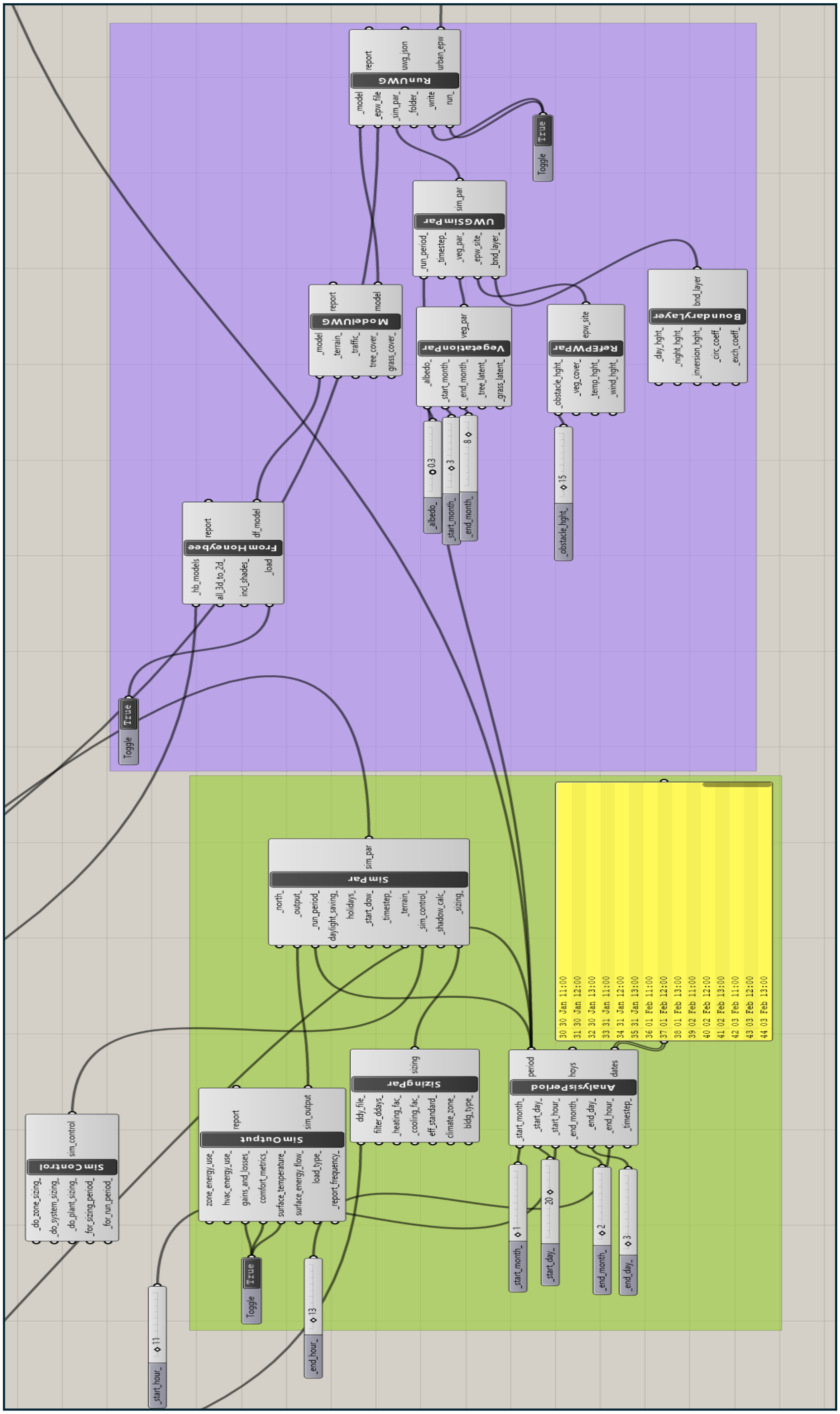
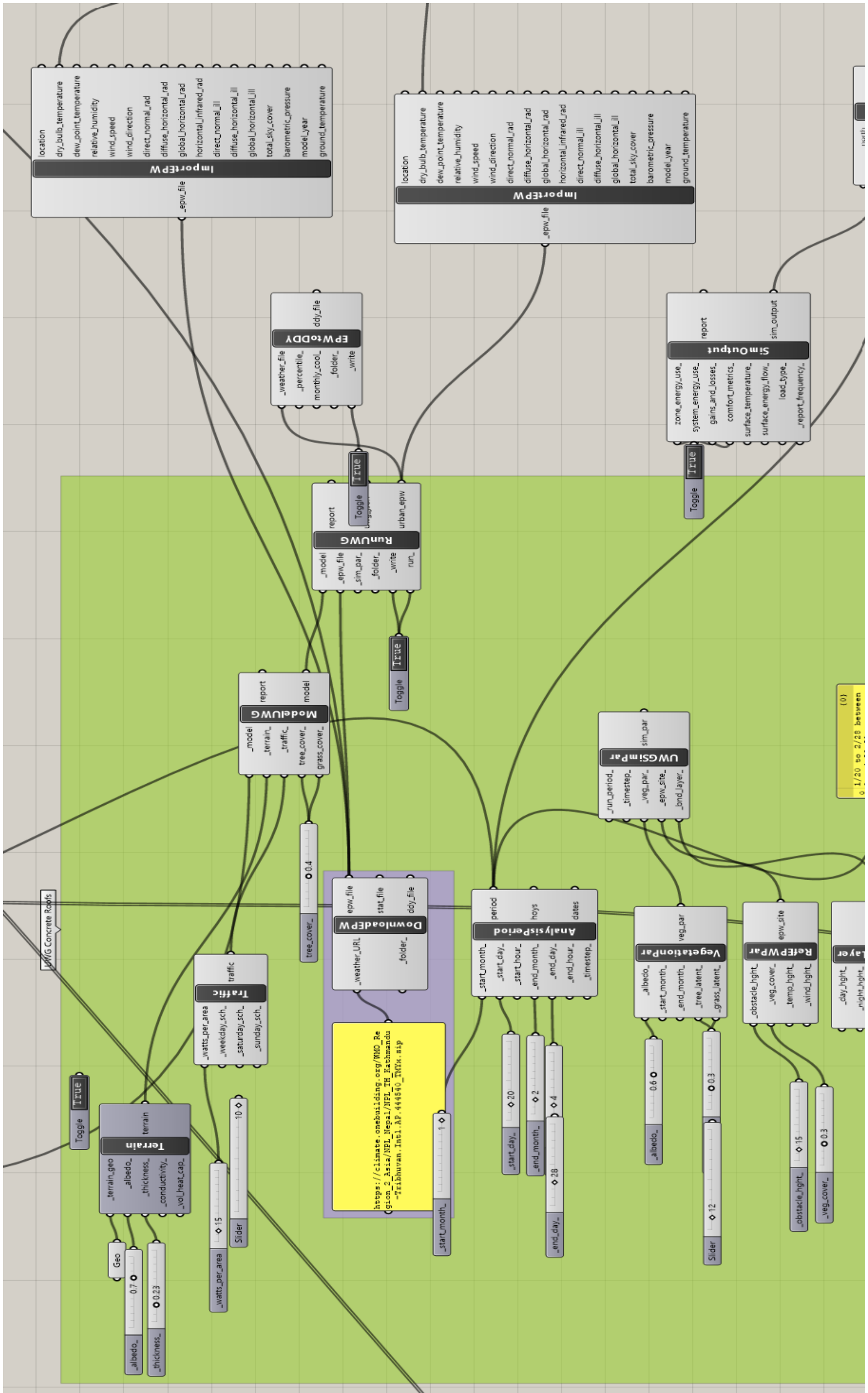
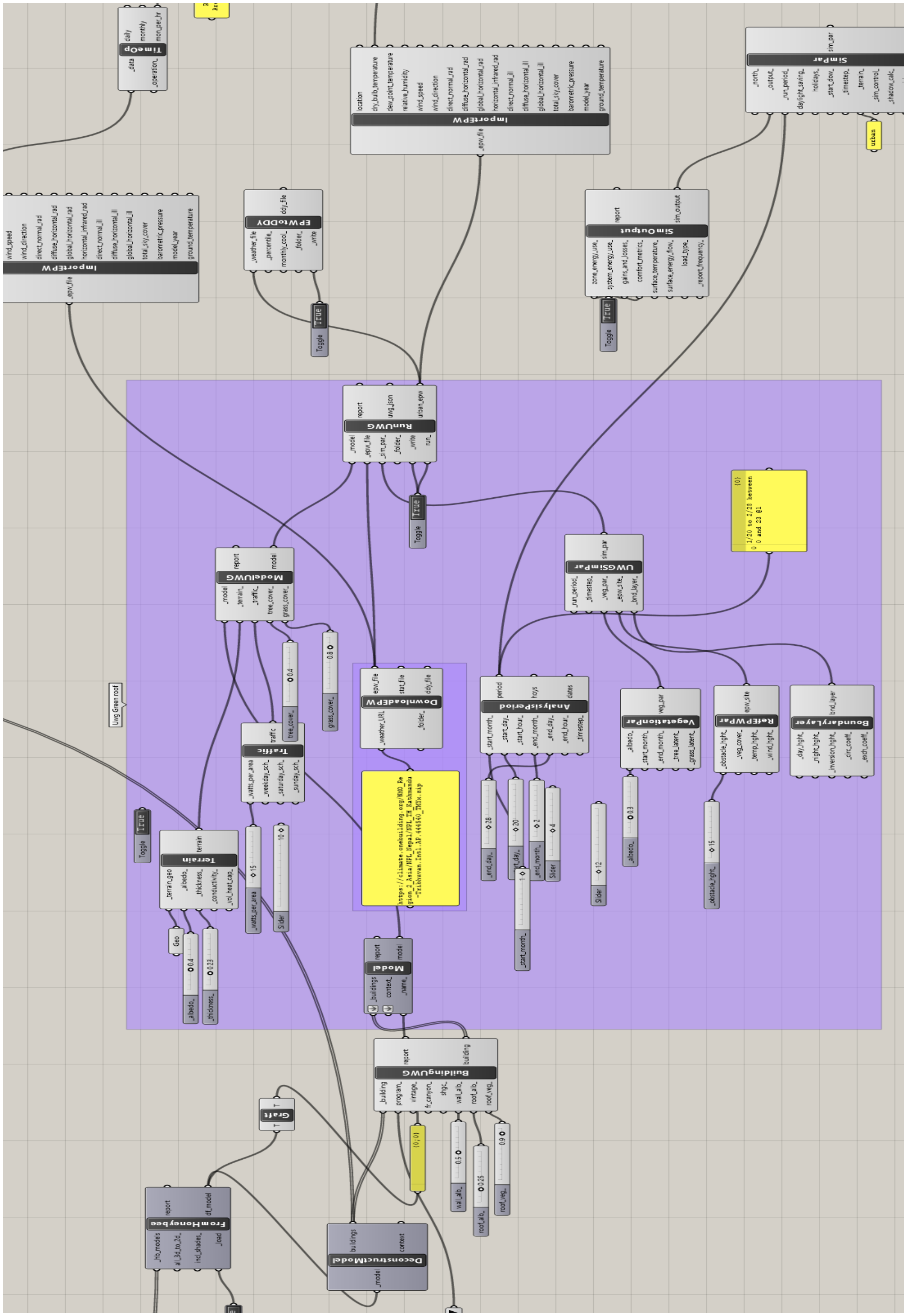
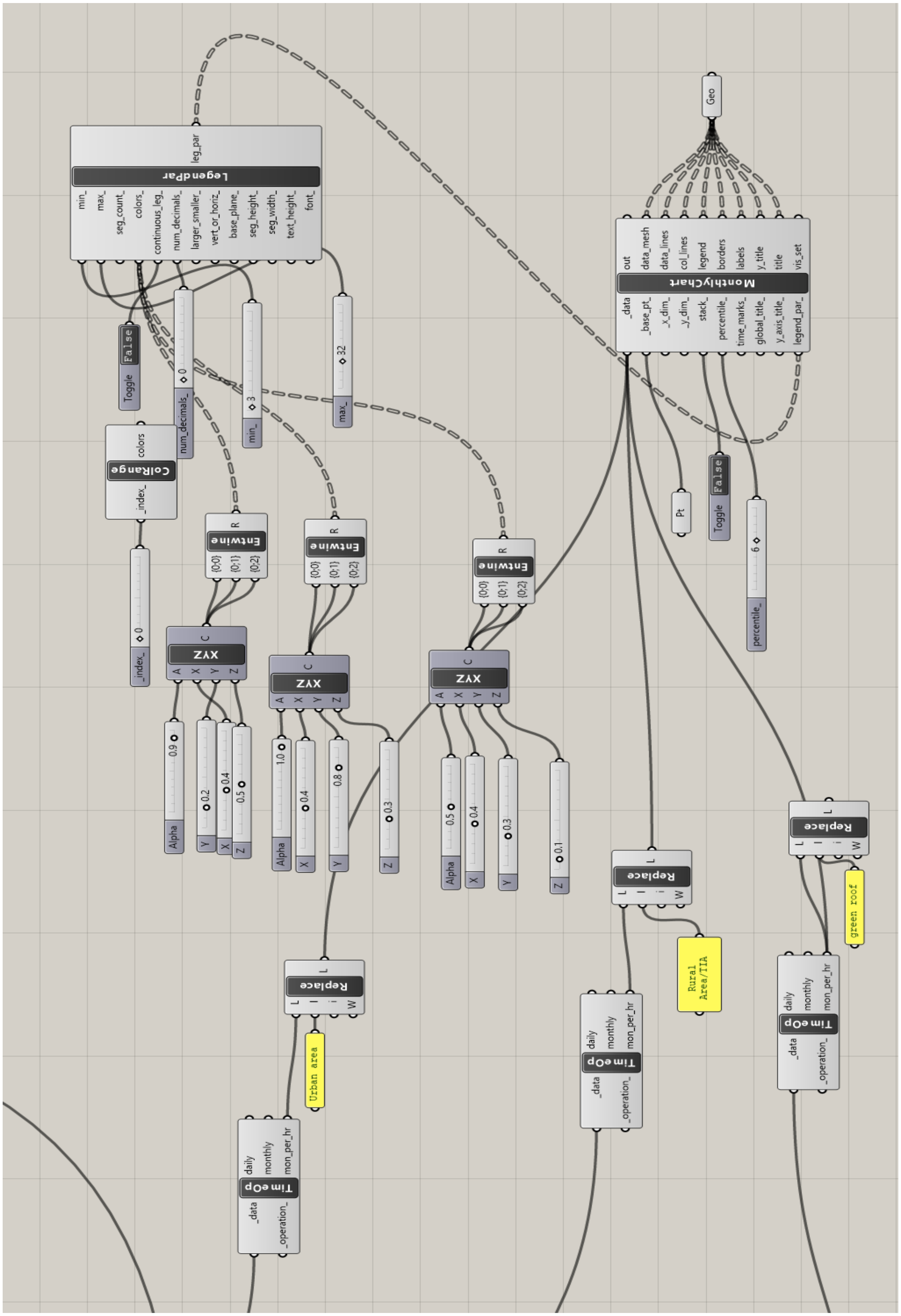
SolveAdj
RoomSolid
Toggle
True
VizByBC
IntSolid
Planarize
Brep
LargeOffice
BldgPrograms
ConstructionSet
ExteriorSubset
OpaqueConst
OpaqueMatNoMass
OpaqueMat
floor
External wall 9 inch
12mm plaster


RunUWG
UWGSimPar
ModelUWG
VegetationPar
RefEPWPar
BoundaryLayer
FromHoneybee
SimPar
SizingPar
AnalysisPeriod
SimOutput
SimControl


ImportEPW
ImportEPW
EPWtoDDY
SimOutput
RunUWG
ModelUWG
UWGSimPar
DownloadEPW
AnalysisPeriod
VegetationPar
RefEPWPar
Traffic
Terrain
UWG Concrete Roofs
https://climate.onebuilding.org/WMO_Region_2_Asia/NPL_Nepal/NPL_TH_Kathmandu-Tribhuvan.Intl.AP.444540_TMYx.zip


ImportEPW
TimeOp
SimPar
EPWtoDDY
SimOutput
RunUWG
ModelUWG
UWGSimPar
DownloadEPW
AnalysisPeriod
VegetationPar
RefEPWPar
BoundaryLayer
Traffic
Terrain
Model
BuildingUWG
Graft
FromHoneybee
DeconstructModel


LegendPar
MonthlyChart
ColRange
Entwine
XYZ
Replace
TimeOp
Toggle
False
Geo
Pt
Urban area
Rural Area/TIA
green roof

17 APPENDIX G: PLAGIARISM TEST

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18 APPENDIX H: CERTIFICATE OF IOEGC


IOE Graduate Conference

Certificate of Participation

THIS CERTIFICATE IS AWARDED TO

Adarsha Maharjan

in recognition of an invaluable contribution as

POSTER PRESENTER

at the 16th IOE Graduate Conference

Organized by Tribhuvan University, IOE, Thapathali Campus in association with IOE, Office of the Dean held from April 18-20, 2025 at Thapathali Campus, Kathmandu, Nepal.

Dr. Raj Kumar Chaulagain
Convener
16th IOE Graduate Conference

Dr. Khem Gyanwali
Campus Chief
Thapathali Campus

Prof. Dr. Sushil Bahadur Bajracharya
Dean
Institute of Engineering

19 APPENDIX I: POSTER