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Optimizing Residential Energy Efficiency Through Strategic Landscaping in Hot-Arid Regions

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ABSTRACT

The Kingdom of Saudi Arabia (KSA) has a hot and arid climate, with the maximum summer temperature above 50°C. This high temperature can significantly hinder energy generation and usage since air conditioning is extensively used during the summer and is the primary cause of energy consumption. These researchers have to develop innovative solutions to overcome the above issues, as these would help decrease energy usage and improve the microclimate. In this study, the researchers have determined the efficiency of having green spaces to improve outdoor thermal comfort and decrease energy consumption in residential complexes that were developed by KSA's Ministry of Housing (M.o.H). For this purpose, they have used a hybrid model that combined field data analysis and simulation modelling techniques to determine the effect of strategic landscaping on the microclimate and subsequent energy consumption. Their study showed that the integration of green spaces leads to a 3% decrease in annual energy consumption. The results noted in this study implied that the above interventions could improve thermal comfort in hot and arid conditions as they decreased the outdoor temperatures by 1.5°C and increased relative humidity in the area by 10% during the major summer months. The findings highlight how planned landscaping can help address environmental and energy challenges in areas with extreme climates. Also, the researchers concluded that the adoption of strategic landscaping helps in reducing the negative effect of the constantly increasing temperatures and high energy demands. These results could allow urban city planners and policymakers to derive insights regarding the development of an energy-efficient and resilient residential environment in the hot-arid areas, which was in line with the sustainability objectives proposed by KSA under their Vision 2030 programme.

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1. Introduction

The Vision 2030 programme that is developed by KSA includes policies that highlight their desire to become a world leader in ecological sustainability by resolving issues related to climate change after implementing innovative activities and policies. Rapid urbanisation can lead to a significant population growth rate of 2.6% [1], which gives rise to many problems affecting environmental sustainability and energy consumption. The Ministry of Housing (M.o.H.) is in charge of several residential projects and is responsible for implementing plans that can eventually decrease the environmental effect of population growth. The primary strategy included in Vision 2030 was to plant 10 billion trees or rehabilitate 74 million hectares of land. This can restore ecological activities, reduce the impact of sandstorms, and even enhance the air quality.

However, the arid and hot climatic conditions in KSA, along with their increasing dependence on contemporary architectural designs prioritising technology compared to passive solutions [2, 3], can worsen its energy requirements. There has been a significant increase in residential energy consumption, where the per capita energy usage is seen to exceed 9401 kWh each year [4]. This figure is roughly 2.5 times that consumed in China [5]. Post-oil industrialisation resulted in a shift from traditional architecture, which was noted for its harmony with the natural environment, to modern designs that frequently overlook passive energy solutions [6, 7]. This further increased KSA's energy consumption from 1.3 MW to 4.0 MWh [8], which in turn led to additional investments of SAR 20 billion each year for developing electrical infrastructure [9]. According to IPCC statistics, the temperatures could increase by 4°C by the end of the 21st century, which could increase the strain on energy resources [10]. In order to meet the Paris Climate Change Agreement, these objectives were set in order to reduce greenhouse gas emissions and build more sustainable futures for the planet. As part of the international effort in 2016, Indonesia set a target of keeping global warming below 1.5 °C. Towards the reduction of its greenhouse gas emissions by 41% by 2030, the Indonesian government has committed to achieving zero emissions by 2060 [11].

The researchers used the Köppen-Geiger climate classification system for classifying KSA's climate as (BWh), since the daytime temperatures exceeded 50°C and different topographical elements affected the regional changes [12, 13]. For example, long-term data showed an increase in the mean temperature values, wherein the mean maximal daily temperatures ranged between 30.7°C (in Tabouk) and 36.9°C (in Al Ahsa) [14]. To address these climatic issues, city management needs to incorporate novel techniques that include natural cooling techniques into their modern and urban designs [15].

Green spaces help mitigate the effects of urban heat since they lower temperatures and increase thermal comfort [16]. Vegetation improves the microclimate because it increases the leaf area index, improves ventilation, and provides shading [17] . Green spaces that are strategically constructed in residential regions can decrease surface temperatures and solar radiation, and establish a comfortable living environment [18]. According to an earlier study, optimised green space layout can significantly lower the average temperatures, while vertical greening and rooftop vegetation systems can decrease cooling loads by 20% and urban temperatures by at least 12°C [19-21]. Additionally, research has demonstrated that localised measures, such as the frequent planting of Poinciana trees, can lower desert temperatures by 0.9°C, thereby improving pedestrian comfort [22, 23]. In dry-hot regions, vegetation cover will increase by about 30-40% after vegetation coverage [24]. Considering the complexity of HVAC plant designs, thermal storage offers a technical solution that can provide a number of benefits [25]. The household sector accounted for 34% of the country's final energy consumption in 2015, which is important to note [26].

Thus, this research introduces a novel hybrid approach, integrating field data analysis and simulation modelling, to assess the potential of strategic landscaping in optimizing the energy efficiency and microclimate conditions in hot regions. By focusing on the integration of green spaces into residential urban design, it addresses critical gaps in passive cooling strategies, providing a framework for mitigating urban heat (outdoor thermal comfort) and reducing energy demands. The research contributes to sustainable urban planning by offering insights that align with KSA's Vision 2030 goals, emphasizing resilient and energy-efficient solutions adapted to extreme climatic challenges

2. Research Methodology

The primary research question included in this study was, "What effect do green spaces have on microclimate and the amount of energy required to cool the adjacent buildings?" To address this question, the researchers used a methodical, multi-phase approach [27]. The primary steps included selecting a building as a case study and monitoring the building. The researchers conducted site visits to collect accurate field data as input for computer-based simulations and modelling. This method allowed the simulations to generate analytical results and represent real-world scenarios. The second phase concentrated on understanding how green spaces could be effectively implemented in the study. This included thoroughly examining how landscape materials affected external climatic conditions in residential buildings. Several procedures are used in the study to assess how landscaping conditions affect the amount of energy required for cooling. All steps are summarised in the following manner: selecting a building as the case study, monitoring the selected building, modelling and validating the model, weather file modifications, and designing the landscaping conditions. Fig. (**1**) highlights all steps included in the study.

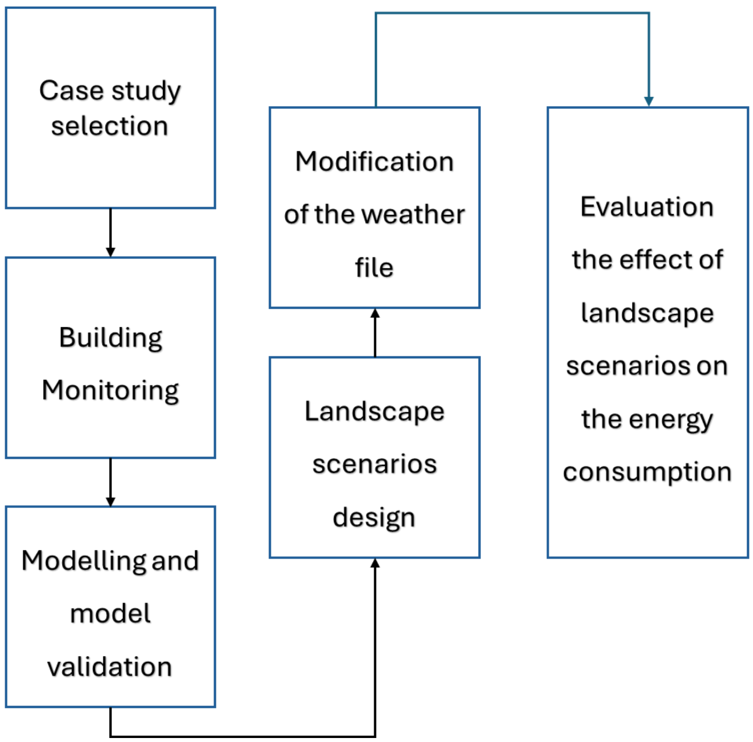


Figure 1: The framework of the present study.

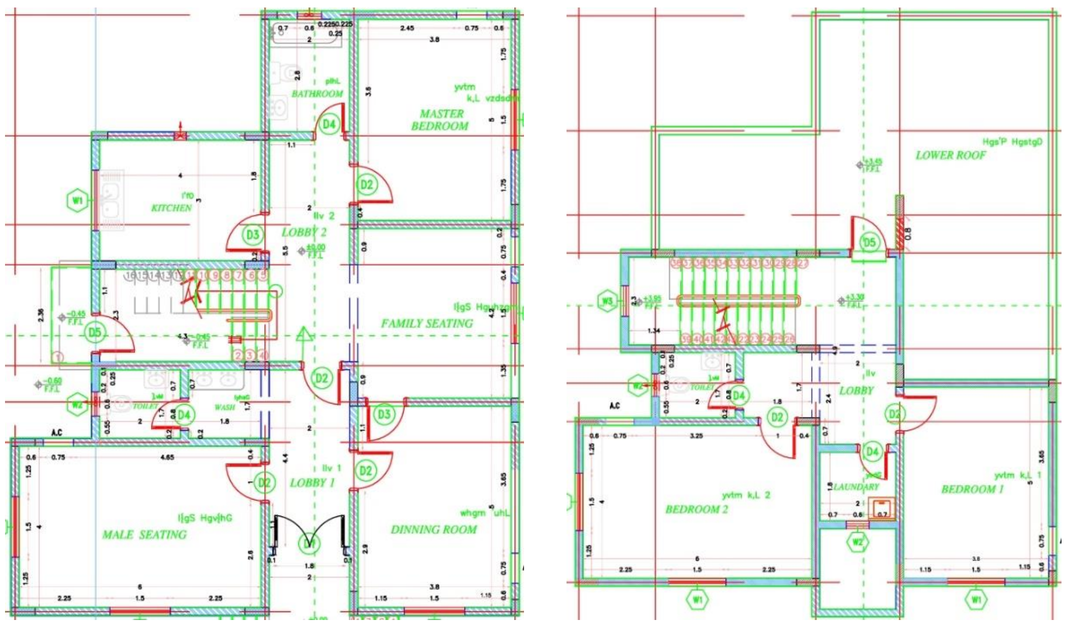
2.1. Data Collection and Field Measurements

2.1.1. Case Study Model

The case study investigates a modern and urban housing project in Hail that the M.o.H. completed in November 2018. This project, located on the urban boundary of Hail City, was developed to decrease the city centre's population density. Here, the researchers examined the architectural features and spatial context of the development; Fig. (**2**) presents the location of the development with regard to the study building drawings and the urban zone.

The researchers further collected the field data from the selected case study to evaluate its microclimate, which includes energy use and temperature control. To further assess the efficacy of green spaces, all data were integrated into computer-based modelling and simulations. They also derived insights from traditional architectural structures to help guide strategic landscaping in modern circumstances.

(**a**)



(**b**)

Figure 2: The location (**a**) and architectural plans (**b**) of the case study.

2.1.2. Building Monitoring

Buildings must be monitored to evaluate simulation model results, and the data is related to real-world situations [28]. This stage broadens the study's objectives by offering actual design strategies for residential constructions under various temporal conditions. The researchers carried out their monitoring study in 2018, when KSA witnessed severe temperatures during the summer months. This season is the ideal time to collect performance data because of the intense heat, which ensures that buildings are operating at their complete capacity. The data collection phase lasted 3 months, and the researchers recorded the weather conditions for 30 days after receiving their access approval. The M.o.H distributed the modern houses to the beneficiaries on November 1, 2018, establishing an appropriate outcome for supervision.

The data collection technique used in this study included outside weather stations that recorded critical variables. The researchers used the Davis Vantage Pro2 weather stations (Davis Vantage Pro2 6152UK) to record the external climatic data (Table **1**). These weather stations presented extensive meteorological data, which included factors like wind velocity, sun radiation, humidity, wind orientation, and temperature. This dataset helps in the accurate assessment of simulation models and assists in examining the building performance. Furthermore, the researchers placed the meteorological stations on the rooftops of buildings to ensure uninterrupted access to weather conditions. The stations were raised above the surface of the roofs using customised platforms, which could decrease the air interference and improve the accuracy of the data. They further installed solar radiation sensors in the south direction to effectively monitor the trajectory of the sun during the daytime.

Table 1: The monitoring requirements in the weather station.

Monitoring Equipment (Accuracy)	The Monitoring Process Needs	Davis Vantage Pro2 6152UK
Parameters	wind speed and direction, humidity, and temperature	Outdoor temperature, humidity, rainfall, wind, with optional solar radiation, and UV measurements
Temp.	Up to 60°C	From -40°C to +65°C
Wind speed.	Range 0 to 10 mps	Range 0 to 67 mps
Wind direction.	0° to 360°	0° to 360°
Relative Hum.	0% to 100%	0% to 100%
Storage Capacity	Up to 1440 readings	With external memory can save 2520 reading

2.2. The Computational Modelling

2.2.1. ENVI-met Modelling and Validation for Landscape Impact Assessment

The researchers selected the ENVI-met programme to simulate and evaluate the effect of landscape on the selected case study [29]. The validation technique included 4 primary components, which were:

2.2.1.1. Three-dimensional (3D) Model Development

The researchers used the ENVI-met "Spaces" feature to design a 3-D model of the selected building [30]. This feature included a grid-based modelling technique having a standard resolution of 1 m. It was noted that the site plan of the selected building was compact enough that it could fit into a 20×24-pixel grid, which can ensure the model's computational efficiency and spatial accuracy.

2.2.1.2. Surface Material Specifications

The modelling technique also considered the building materials used on the external building surface. The model integrated the following 2 primary materials [31]:

- Lightweight concrete materials are used for the building’s facade surface.
- Lightweight concrete tiles were used for designing the residential yard.

The above specifications indicated that the thermal characteristics of the building materials could precisely describe the simulations.

2.2.1.3. Weather File Integration

The ENVI-met programme applied the EPW (EnergyPlus Weather) file format for studying the input meteorological data [32]. The researchers utilised a modified weather file for validating the model to ensure data consistency and data integrity between the simulated data and the observed external conditions. This technique was seen to improve the dependability and accuracy of the simulation data.

2.2.1.4. Configuration File Settings

The configuration file defines the simulation variables and includes the tasks for every simulation run [33]. This also includes a basic information block consisting of 5 categories needed for running the model. The primary components included:

- General Simulation Settings: It mentions the start time, start date, and duration of the total simulation process.
- Weather Information: A few factors necessary for the simulation period included the maximal and minimal temperatures, wind direction, and wind speed (Table **2**).

This complete configuration guaranteed that all crucial environmental elements were effectively integrated into the ENVI-met model, which increased its ability to assess the impact of strategic landscaping on the microclimate [34].

The ENVI-met model successfully replicated the relationships between landscape components and environmental factors by following the above 4 criteria, thereby offering insightful data for maximising outdoor spaces in the selected case study [35].

Table 2: The configuration file used to simulate the case study throughout a summer.

Parameter	Definition	Value
Location	Hail, Kingdom of Saudi Arabia (KSA)	
Meteorological conditions	Mean wind speed (m/s)	3.5
	Direction of the wind	NW (315°)
	Minimum ambient temperature (°C)	28
	Maximum ambient temperature (°C)	44
	Minimum relative humidity at 2m (%)	17
	Maximum relative humidity at 2m (%)	43
Vegetation cover	Height of the tree (m)	10
	Height of grass (m)	0.25
	Depth of water (m)	0.5

The researchers validated the ENVI-met models over a simulation period of 3 days, from 15th to 17th August, at the same location. The researchers noted a significant relationship between the estimated and simulated temperatures. Fig. (**3**) indicates that the predicted air temperature values of the selected building that were derived using the ENVI-met programme were significantly higher compared to the estimated values and showed a Coefficient of Variation of the Root Mean Square Error (CV RMSE) value of 3.1% [36].

$$\mathbf{CV\ RMSE} = \frac{\frac{\sqrt{\sum_{i=1}^{Np}(mi-si)^2}}{Np}}{m}$$

After validating the results, the models were modified and combined with the initial EPW weather dataset to generate the base case models. The researchers selected 4 representative days to examine the seasonal differences for maximising simulation efficiency: February 15 (autumn), May 15 (spring), August 15 (summer), and November 15 (winter). These days helped compare the practical and theoretical simulations, which enabled a comprehensive assessment of the base case findings and determined the effect of strategic landscaping. The study could effectively balance the computational needs of the research and offer insights regarding the interaction between the microclimate and strategic landscaping when the researchers coordinated the simulated periods with the important seasonal milestones.

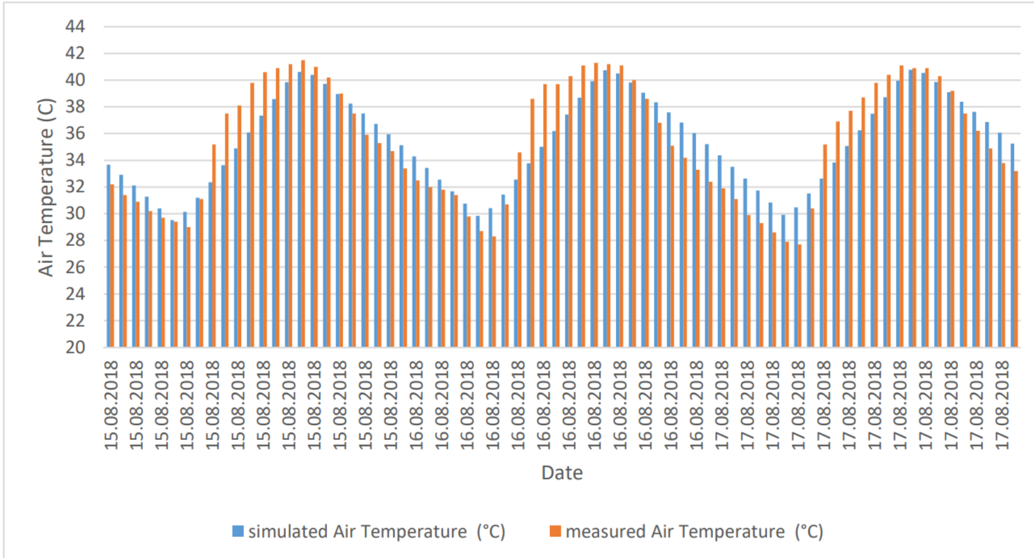


Figure 3: The validated outdoor temperatures in the case study.

2.2.2. Strategic Landscape Scenarios Investigated

Furthermore, the researchers conducted this study in 2 different stages to identify the optimal design solutions that could be used in outdoor areas. Every stage addressed a specific analytical issue [37]. Stage 1 included developing theoretical models that were dependent on the guidelines and design principles and could be used as conceptual frameworks for studying the different design scenarios arising under controlled conditions. These models predicted performance indicators like airflow patterns, shading efficiency, and thermal comfort by simulating idealised outdoor space configurations, incorporating concepts from architectural and environmental design literature, and using simulation tools. They used the theoretical models to gain insights into the relationship between the design characteristics and environmental performance. Stage 2 used practical study models since they incorporated the field data and actual-world conditions for improving the applicability of all findings. The input data used in the models was collected from various outdoor spaces, like measuring humidity, temperature, and wind patterns, along with determining user behaviour and environmental interactions. The researchers considered a few localised factors like site-specific microclimate, cultural practices, and material availability. The practical models were used to evaluate and refine the proposed design solutions by basing theoretical predictions on real-world environmental conditions, which confirmed their relevance and efficacy.

2.2.2.1. Theoretical Models

A. Grass Model Scenario

The researchers modified Step 1 in the ENVI-met model, where they substituted the lightweight concrete tiles in the yard with grass, which showed a mean density of 25 cm (Fig. **4**). Grass can be regarded as an ideal material since it allows cooling through evapotranspiration [38, 39].

B. Water Model Scenario

The microclimate around a residential building is significantly affected by the adjoining water bodies since evaporation cools the surface of the water body and acts like an effective heat sink [40]. This situation involved altering the primary case model to remove the pedestrian pathways and replace the house garden with deep water (Fig. **5**).

C. Tree Model Scenario

Trees efficiently alleviate heat stress in urban areas by providing shade and converting solar energy into latent heat flow through transpiration. Tree transpiration is the primary source of latent heat flux in cases where the ground is primarily covered by impermeable materials 41]. This situation involved modifying the fundamental case model to include 10 m high trees with dense foliage, particularly palm trees, in the yard (Fig. **6**).

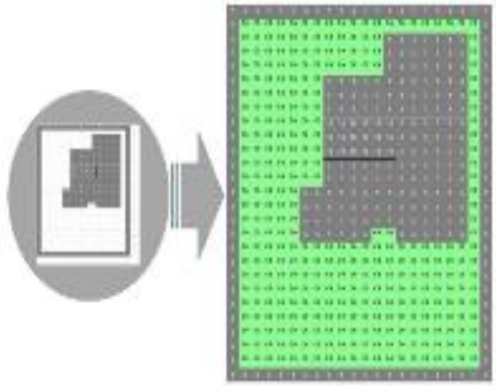


Figure 4: Replacing lightweight concrete tiles in the yard of the ENVI-met model with grass.

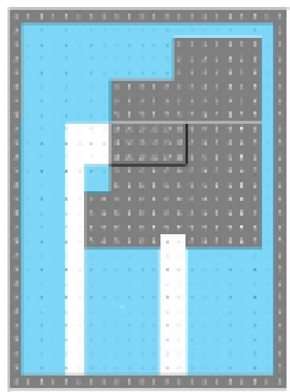


Figure 5: Replacing the lightweight concrete tiles in the yard of the ENVI-met model with deep water.

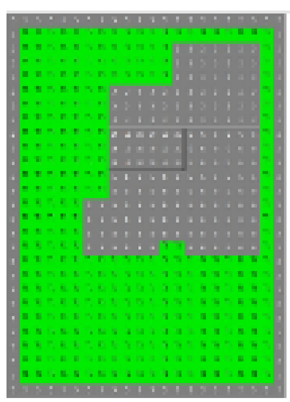


Figure 6: Replacing the lightweight concrete tiles in the yard of the ENVI-met model with tall trees.

2.2.2.2. Practical Model

This scenario was influenced by classical landscape designs including big trees, local plants, grass, and water features around the building. The conceptual design included several elements such as pedestrian paths, a garage, and structural modifications to the building (Fig. **7**). The study also cited site trials undertaken by Shashua-Bar [42], which highlighted the advantages of combining grass, trees, and shade mesh under similar climatic conditions. Furthermore, this technique ensured that the theoretical design ideas could be successfully integrated into the actual applications.

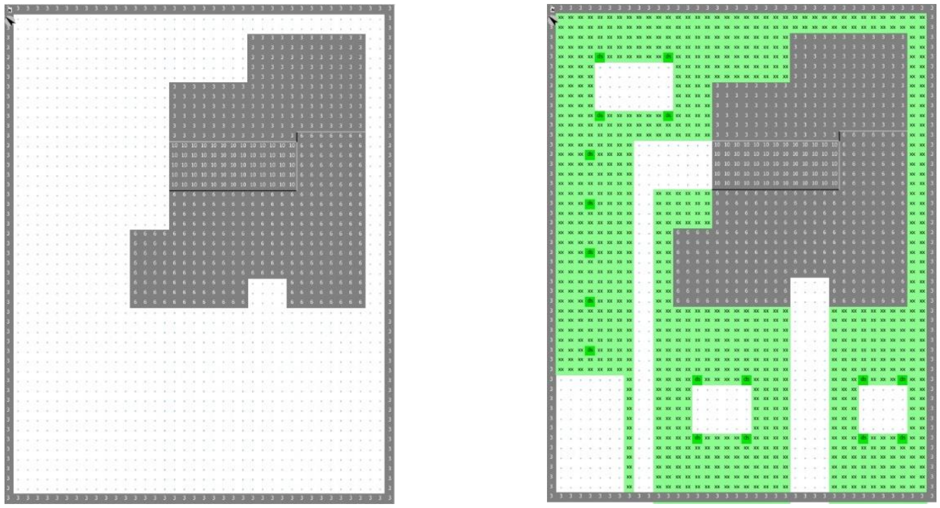


Figure 7: The design of the landscape of the case study house.

2.2.3. Modifying the Weather Files for Energy Consumption Analysis

Here, the researchers modified the primary weather files to determine the influence of strategic landscaping, particularly green spaces, on the microclimate and energy consumption. The incorporation of the landscape design into the primary case model was assessed to determine its effect on the annual heating and cooling requirements.

The weather file was updated using Meteonorm® data to account for microclimatic variations caused by the proposed strategic landscaping initiatives. The DesignBuilder® base case model was updated to incorporate these changes to measure the decrease in energy usage. The freshly updated weather file helped in thoroughly assessing the effect of introducing green spaces like water features, grass, and trees on the heating and cooling loads, thereby highlighting the possible energy-efficiency benefits of strategic landscaping.

2.2.4. Building Simulation Tools

2.2.4.1. ENVI-met Models

Researchers can create models and run energy simulations for individual buildings by using building simulation, which simplifies the modelling of system dynamics using specialised software [43]. They used the ENVI-met simulation tool in this study to accurately represent the external microclimate. The practical application of ENVI-met in urban environmental planning allows it to stand out among the few simulation tools used to examine the effect of landscape on microclimate [44].

ENVI-met is described as a computational tool that simulates the urban microclimate, which makes it an invaluable resource for environmental and landscape design for new urban developments [45]. According to Bande, the input data for ENVI-met simulations included extensive data regarding external landscapes, pavement properties, building materials, and meteorological variables, such as wind speed, relative humidity, temperature, and wind direction [46]. The interactive features of the tool allowed the examination of the selected buildings' microclimate and green space performance.

2.2.4.2. DesignBuilder Models

It is necessary to include numerous crucial factors while modelling these buildings, such as building orientation, construction specifications, architectural drawings, material characteristics, and HVAC system configurations [47].

The researchers implemented 3 primary stages before modelling the base case study. Formal architectural and building designs were initially collected to accurately model the buildings using the simulation programme. The researchers conducted regular site visits to validate the preliminary architectural designs and assess the existing state of the selected building. The walkthroughs revealed anomalies, like broken windows, that could jeopardise the legitimacy of old conventional structures. To verify and improve the simulation models, the researchers collected the field values and integrated them into the DesignBuilder.

DesignBuilder offered an extensive platform for assessing microclimate and energy usage [48]. The study highlighted subtle aspects of building performance using its sophisticated modelling capabilities, ensuring that simulations were calibrated to depict real-world settings.

2.2.5. Energy Consumption of the Case Study House

It is crucial to examine occupancy behaviour models to understand the energy needs for heating and cooling in a conventional Saudi residential building. Alshahrani and Boait undertook a questionnaire study to explore energy consumption patterns in residential structures across Saudi Arabia [49]. The researchers surveyed to decrease the bias and hence distributed the questionnaire to all participants, irrespective of their gender or place of origin. The completed questionnaire was collected from 383 respondents from different cities who offered data regarding energy consumption, occupancy behaviours, and building design.

The survey data revealed the presence of 5 primary zones in a conventional Saudi house, which included a living room, dining room, guest area, family room, and bedrooms. The data was integrated into DesignBuilder to examine the cooling and heating needs of the above 5 zones. This technique helped assess the energy consumption trends and offered valuable insights into the thermal efficiency of typical residential buildings in the KSA.

2.2.6. Computational Investigation of Passive Traditional Strategies

The researchers used the DesignBuilder software to determine the efficiency of using 4 conventional passive design strategies [50]. In this stage, they concentrated on determining the effect of incorporating all strategies into the modern M.o.H designs in the KSA.

This was accomplished by combining a computational model of a conventional residence with the architectural features of modern home designs. This hybrid model enabled a direct comparison of the altered design and the base case. The study offered valuable insights into the potential use of conventional passive techniques.

3. Results and Discussion

3.1. Impact of Green Spaces and Strategic Landscaping on the Microclimate and Energy Consumption of Hail City

The researchers carried out computational analysis using DesignBuilder to evaluate how vernacular passive design techniques were incorporated into modern M.o.H. buildings in KSA. The study assessed the effects of 3 conventional passive strategies previously mentioned in Section 2.5—on building performance with the help of a realistic model. A computational model was designed based on the architectural elements of a conventional house and was subsequently modified to include the features of modern house designs, resulting in a hybrid model that allowed for a thorough comparison with the base model. The study examined how the microclimate was modified in two phases: theoretical study models, which simulated situations based on design principles, and practical study models, which considered the field data and real-life circumstances. The base case was compared to practical and theoretical study models to allow a thorough assessment of the effects of the techniques on the microclimate, particularly with regards to Hail City's green space design.

3.1.1. Theoretical Scenarios for the Four Seasons

3.1.1.1. Winter

The researchers collected the hourly profiles for the relative humidity and temperature variations for February 15, from 01:00 to 00:00 (Fig. **8**). After analysis, it was concluded that Scenario 1 (grass) showed the maximal temperature at 16:00, while the base scenario displayed the lowest temperature at approximately 06:00. Furthermore, Scenario 1 displayed higher temperatures and lower relative humidity at 12:00, which could be due to increasing solar radiation absorption. On the other hand, the condition that included trees showed shading as it decreased the exposure to direct sunlight.

The temperature fields were distributed between 9 and 13.5°C, where the southeast corner displayed the lowest temperature since it was significantly affected by the cold northerly winds (Fig. **9**). All the results indicated that the scenario with grass could offer the best solution during the winter months since grass helped in optimising the humidity levels and regulating the temperatures.

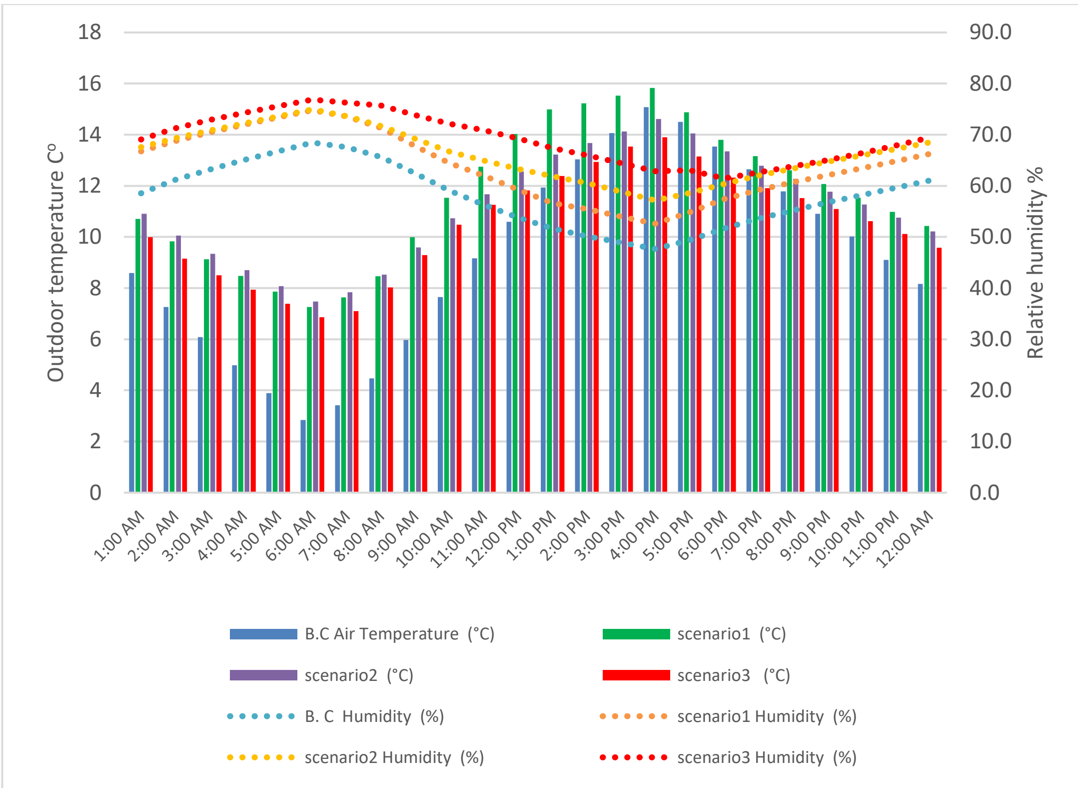


Figure 8: The temperature and relative humidity of Hail City in the winter, specifically at 12:00 on 15 February.

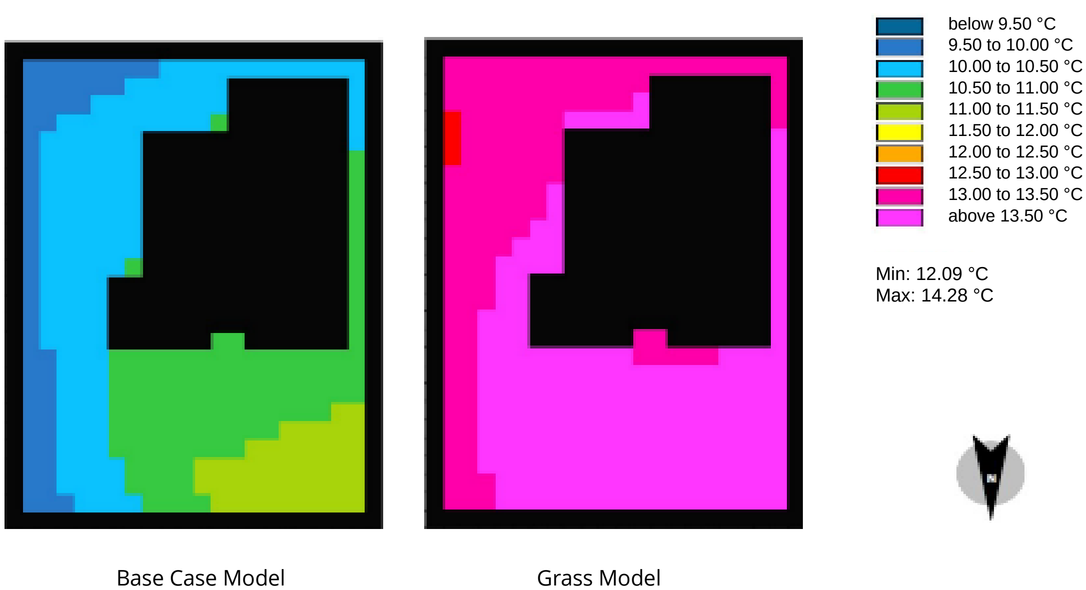
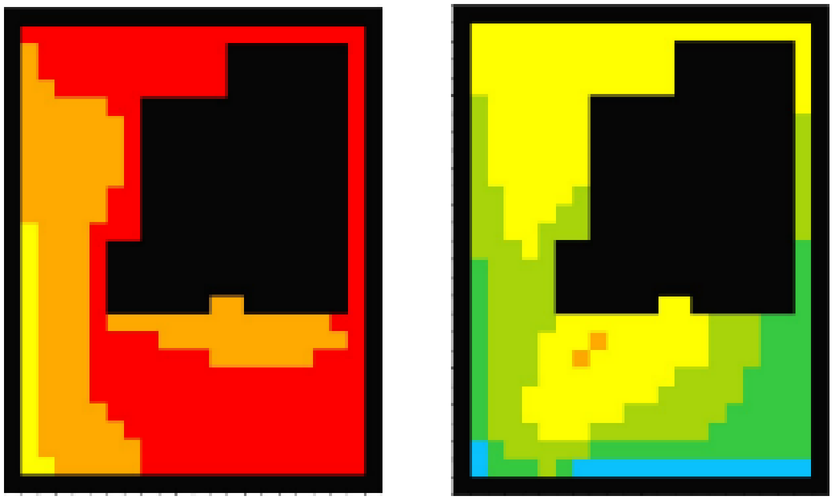


Figure 9 (contd.......)



Water Model Tree Model

Figure 9: The spatial temperature distribution in the case study at 12:00 on 15 February.

3.1.1.2. Spring

The researchers collected the hourly profiles for the relative humidity and temperature variations for May 15, from 01:00 to 00:00 (Fig. **10**). After analysis, they concluded that Scenario 1 showed a maximal temperature and minimal relative humidity at 16:00, while Scenario 3 (long trees) showed the lowest temperature and maximal relative humidity values at 06:00. Furthermore, the temperature maps at 12:00 (Fig. **11**) indicated that Scenario 3 displayed low temperatures because of high evaporation rates and low solar radiation exposure, which highlighted the cooling effect of long trees.

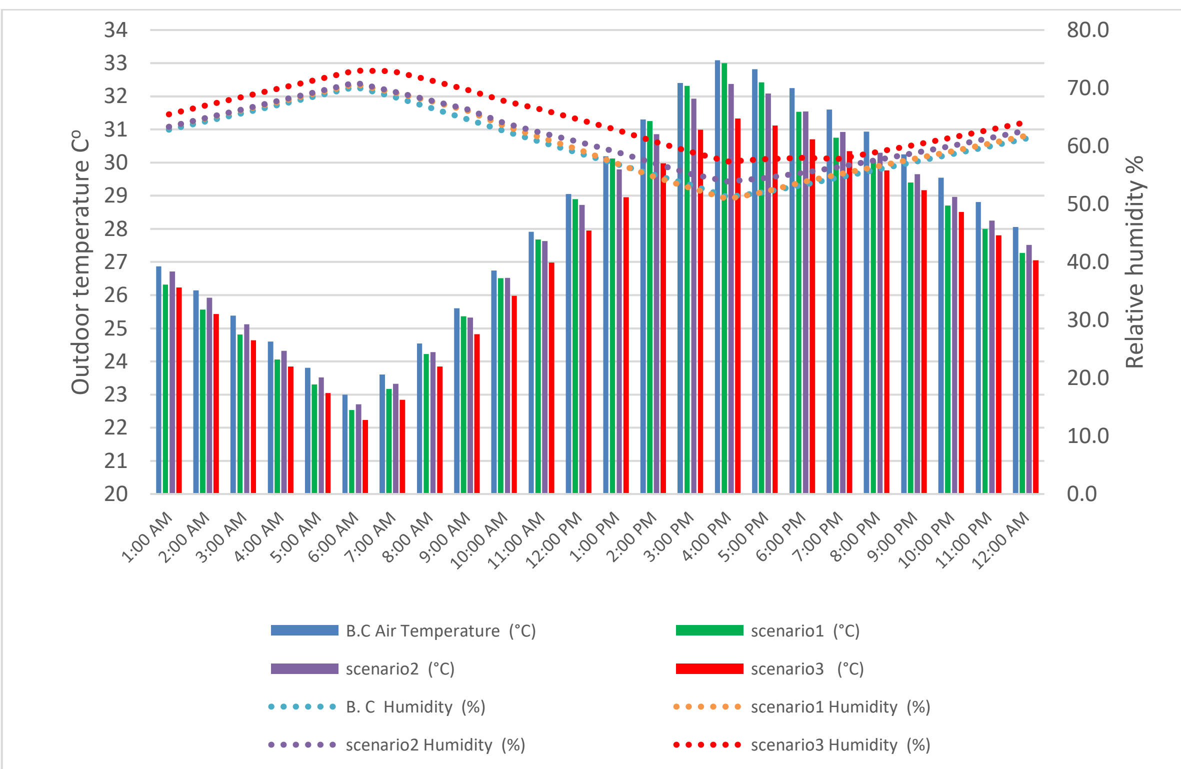


Figure 10: The temperature and relative humidity of Hail City in the spring, specifically at 12:00 on 15 May.

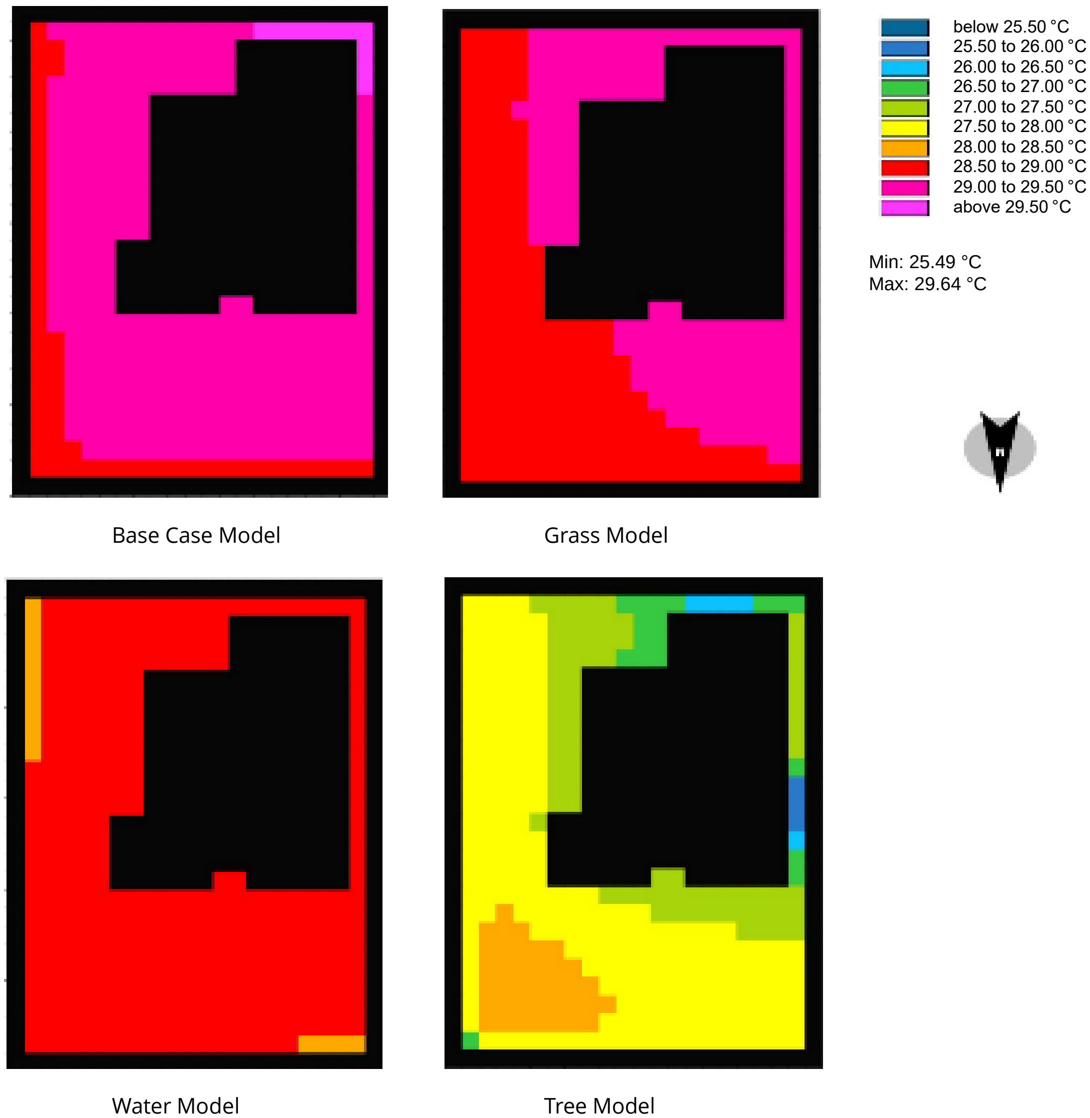


Figure 11: The spatial temperature distribution in the case study house at 12:00 on 15 May.

3.1.1.3. Summer

The researchers collected the hourly profiles for the temperature and relative humidity variations for August 15 (Fig. **12**), from 01:00 to 00:00. After analysis, they noted that the profiles for Scenario 1 (grass) displayed the maximal temperature and minimum relative humidity at 16:00. On the other hand, Scenario 3 (long trees) showed the highest relative humidity and lowest temperature at 06:00. The results showed that the grassy regions showed a maximal temperature at 12:00 because of high solar radiation absorption and low evaporation rates. Furthermore, Scenario 3 with long trees offered shade and cooling effects, which decreased the temperatures to 39°C in comparison to 42°C shown by Scenario 1 with grass. The maximal and minimal temperatures for Scenario 3 were seen to range from 32.5 to 36°C, whereas the temperatures for other scenarios were seen to fluctuate between 35.5 and 36.5°C (Fig. **13**).

3.1.1.4. Autumn

The researchers collected the hourly profiles for the temperature and relative humidity variations for November 15 (Fig. **14**). The results indicated that the base case showed a maximal temperature of 19.2°C at 16:00 while Scenario 3 showed a minimal temperature of 17.5°C at 06:00. Furthermore, Scenario 3 displayed a high relative humidity and low temperatures because of low exposure to solar radiation. It was seen that the temperature values shown by Scenario 3 ranged between 13 and 16.5°C, in comparison to 16°C to 17.5°C shown by other scenarios (Fig. **15**). The above results highlighted the cooling effect of long trees.

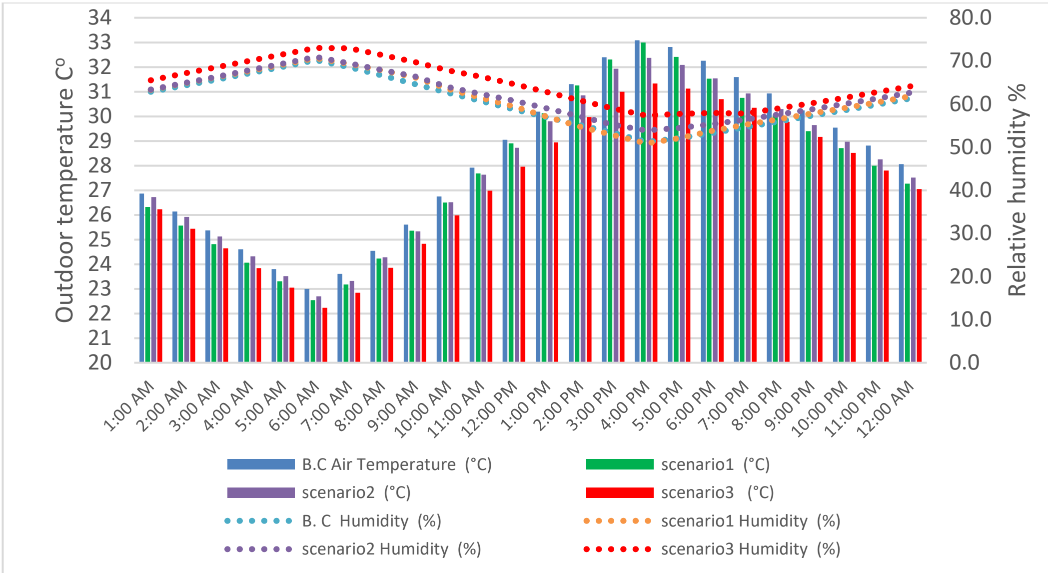


Figure 12: The temperature and relative humidity of Hail City in the summer, at 12:00 on August 15.

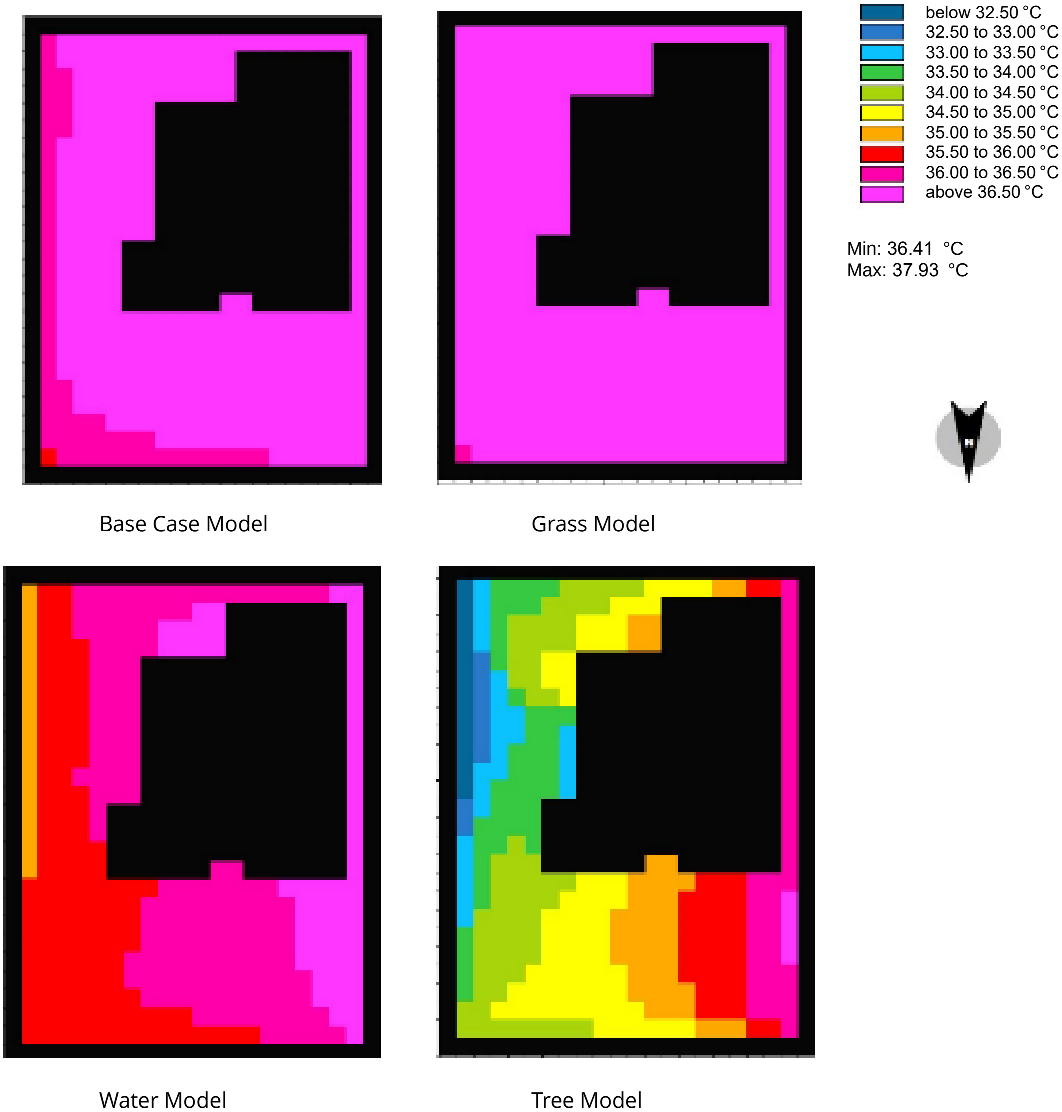


Figure 13: The spatial temperature distribution in the case study house at 12:00 on 15 August.

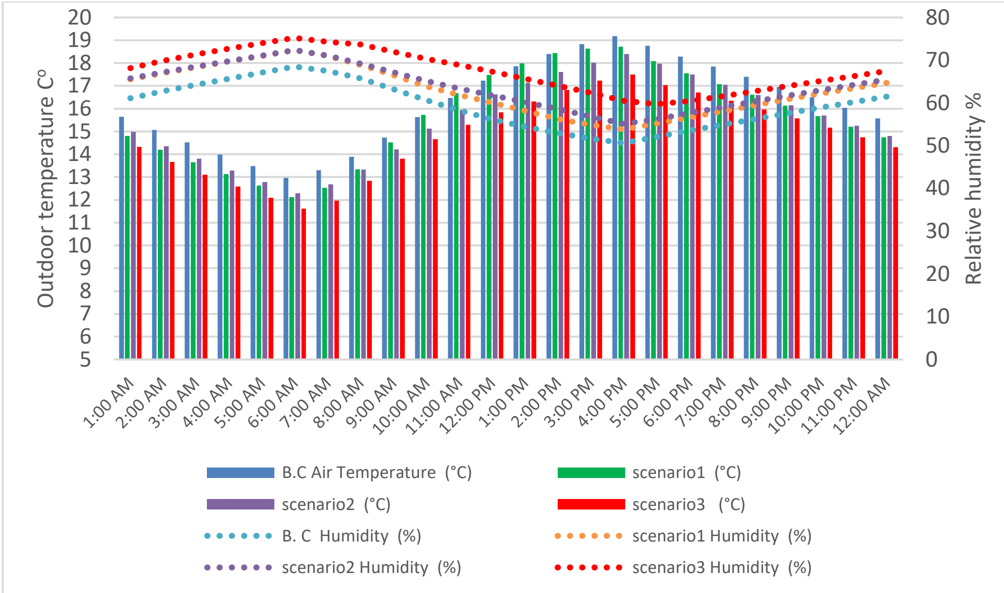


Figure 14: The temperature and relative humidity of Hail City in the autumn, specifically at 12:00 on 15 November.

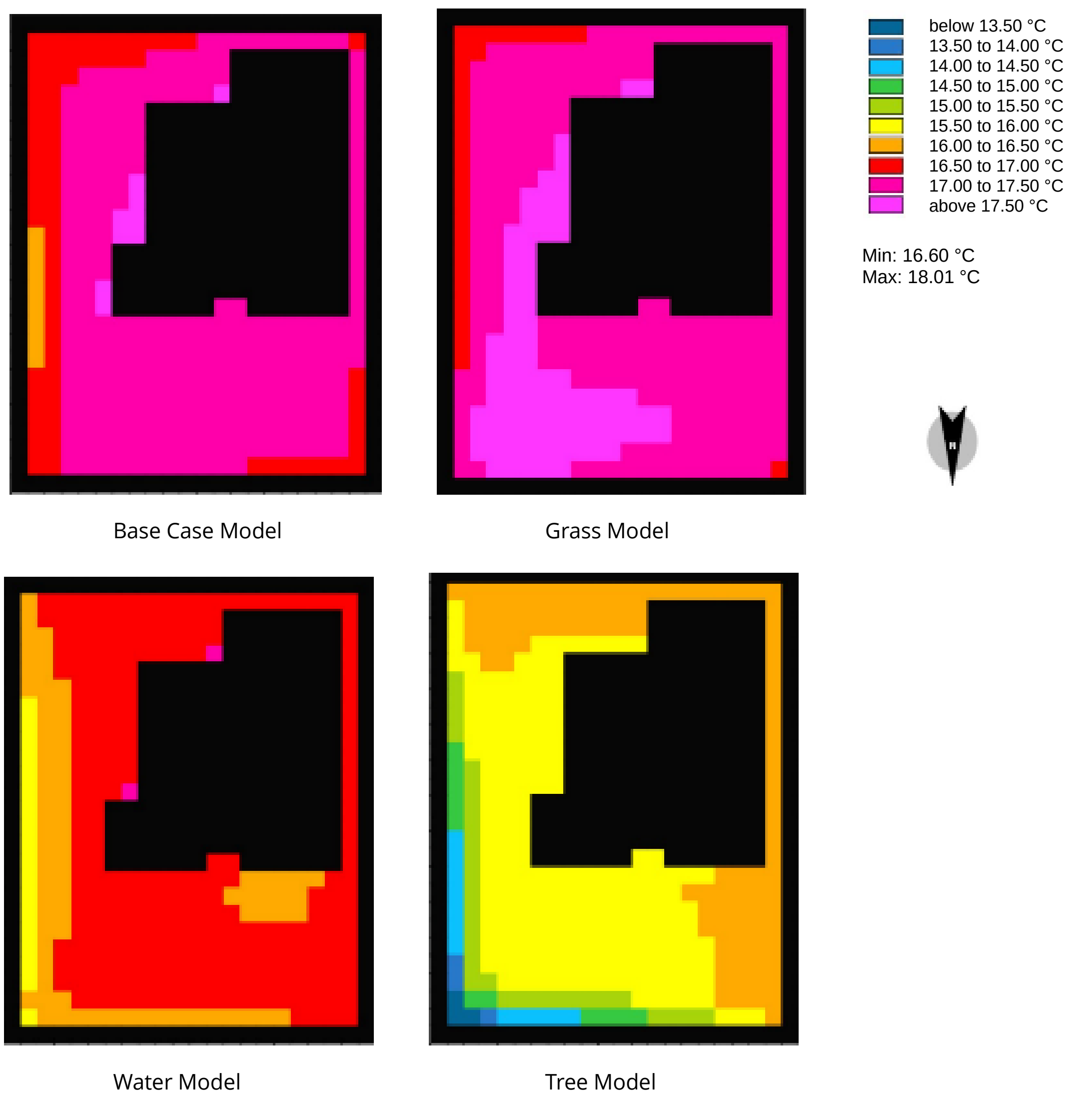


Figure 15: The spatial temperature distribution in the case study house at 12:00 on 15 November.

Scenario 1 displayed the best performance during the winter months as they showed consistent heating effects in the regions that were already exposed to high solar radiation. The water features and trees included in the surroundings helped stabilise the temperature, thereby displaying the complementary role played by different landscape factors in improving the thermal comfort of the residents (Fig. **16**).

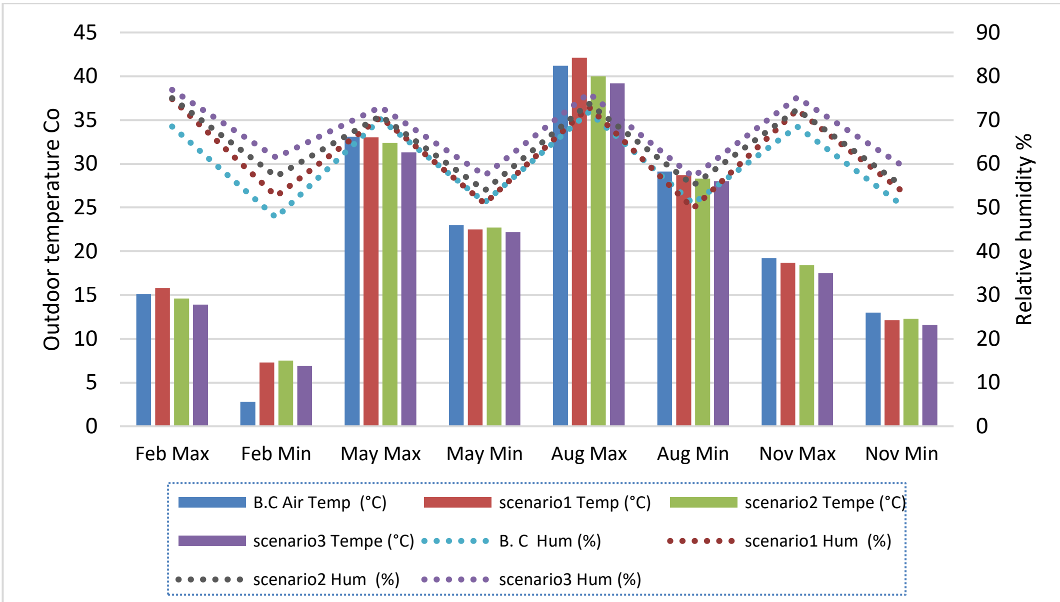


Figure 16: A summary of the influence of the three strategic landscaping scenarios on the microclimate in Hail City.

3.1.2. Practical Scenarios for Seasonal Microclimates

3.1.2.1. Winter

The spatial distribution of relative humidity and temperature for a modern residence with a landscape design is shown in Fig. (**17**). The water features and long trees could help stabilise the external temperature, wherein the northern regions of the building site showed temperatures above 12.5°C because of the wind-breaking impact of the long trees (Fig. **18**).

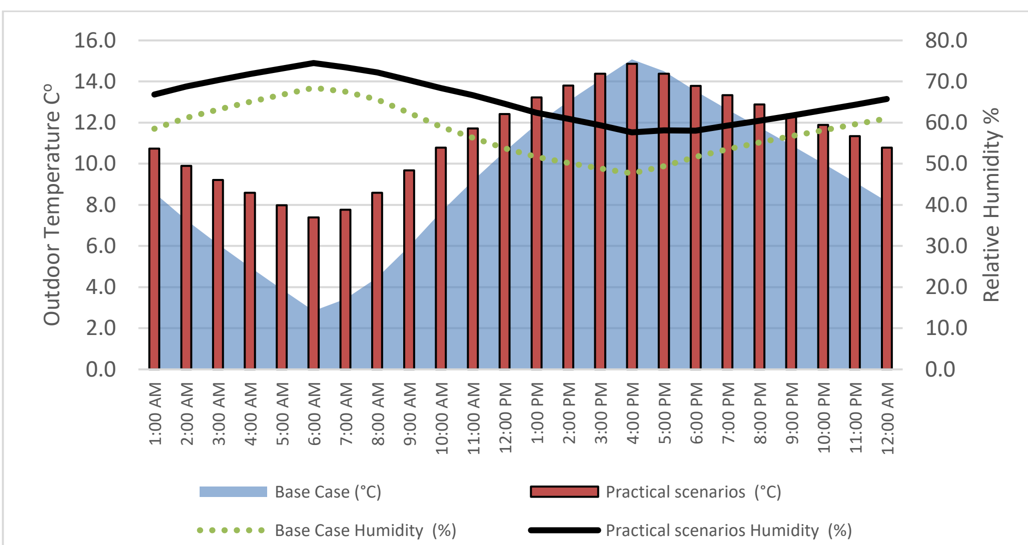


Figure 17: The temperature and relative humidity in the developed case of the case study house in the winter, specifically at 12:00 on 15 February.

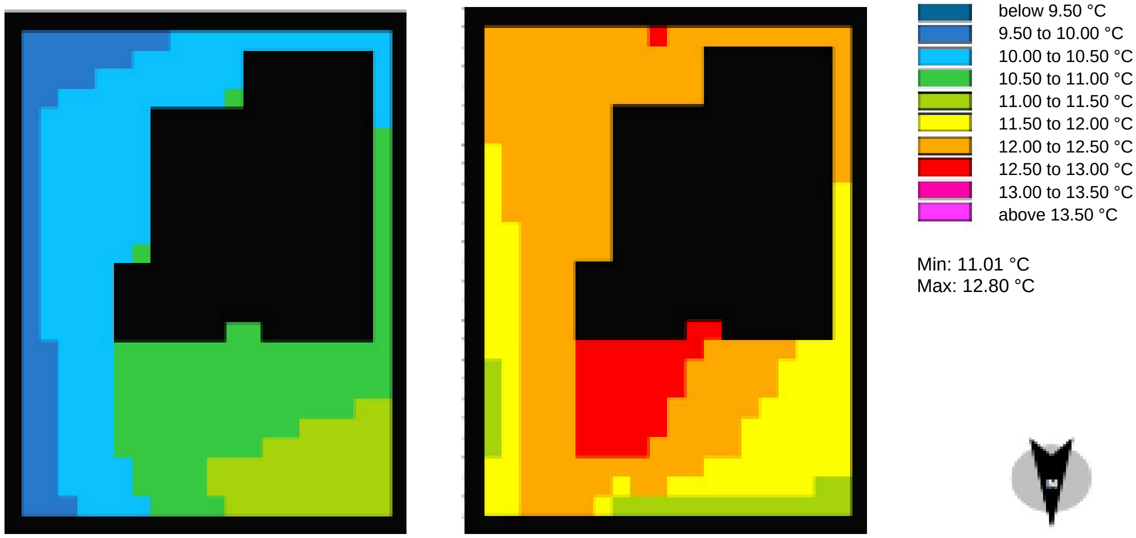


Figure 18: The spatial temperature distribution of the developed case at 12:00 on 15 February.

3.1.2.2. Spring

The researchers noted that during the spring season (Fig. **19**), all shaded regions in the west and south showed cooling effects, with a 0.6°C decrease in the temperature values and a 3% increase in the relative humidity (Fig. **20**). These results have highlighted the important role played by evaporation and shaded regions in improving the thermal comfort of the residents.

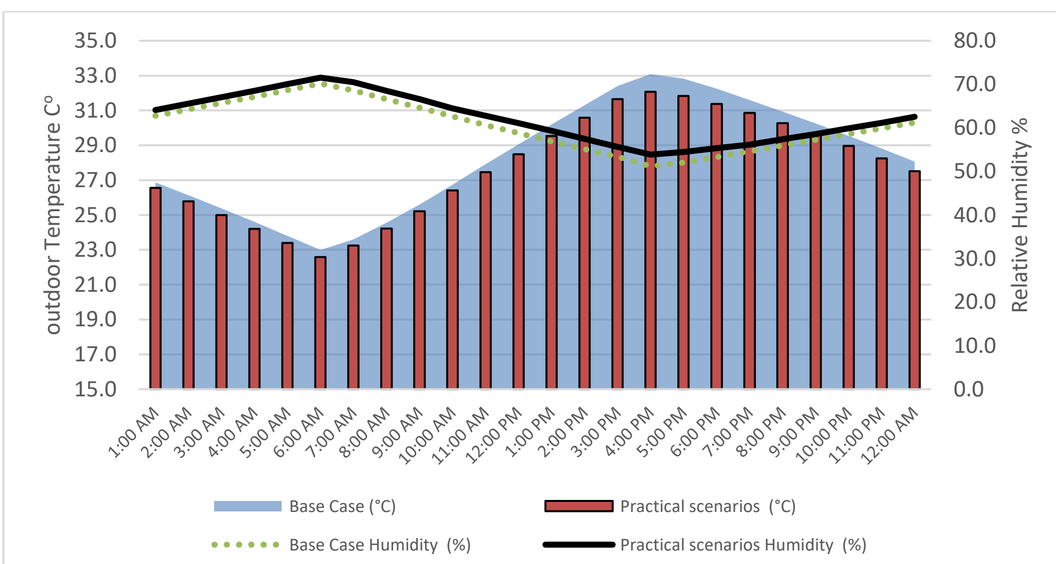
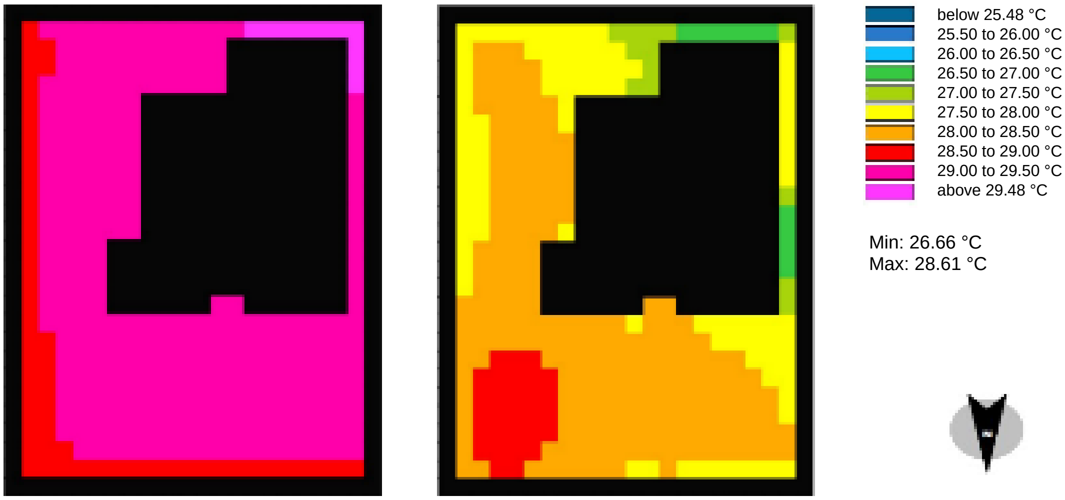


Figure 19: The temperature and relative humidity in the developed case of the case study house in the spring, specifically at 12:00 on 15 May.

3.1.2.3. Summer

The cooling effect of the water features and long trees during the summer months is highlighted in Fig. (**21**). The results indicated that the above factors decreased the external temperature by 1.6°C and showed a 20% increase in the relative humidity (Fig. **22**), which highlighted their role in reducing heat stress.



Base Case Model Scenario 4 Model

Figure 20: The spatial temperature distribution of the developed case at 12:00 on 15 May.

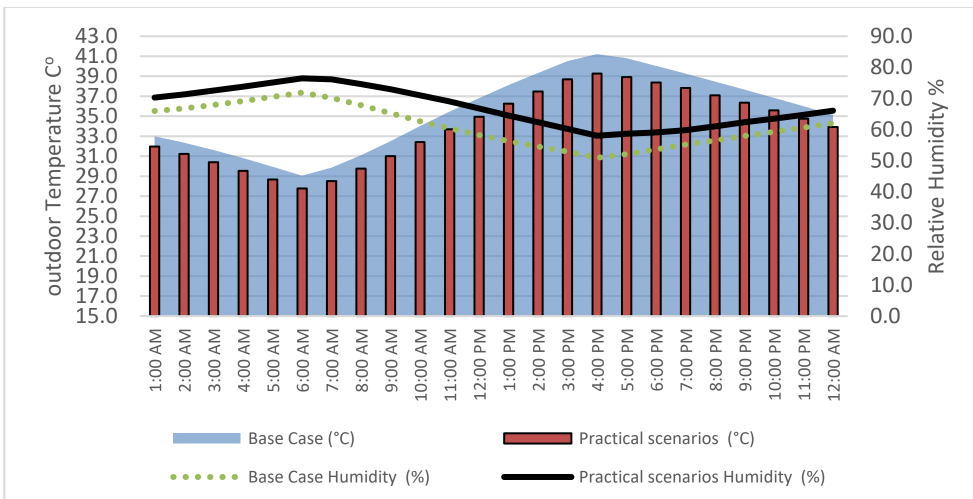
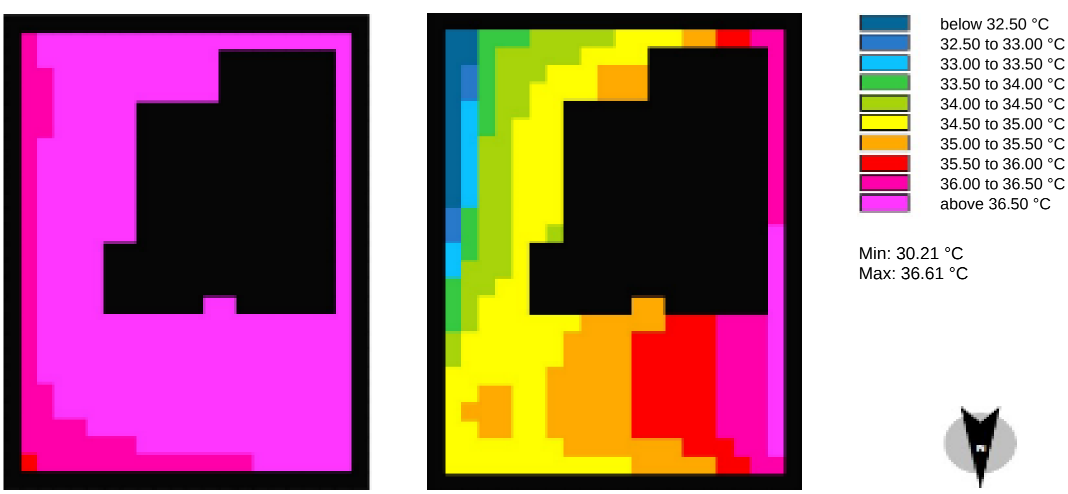


Figure 21: The temperature and relative humidity in the developed case of the case study house in the summer, specifically at 12:00 on 15 August.



Base Case Model Scenario 4 Model

Figure 22: The spatial temperature distribution of the developed case at 12:00 on 15 August.

3.1.2.4. Autumn

Shaded regions in the north western region of the site reported air temperatures below 22°C during the autumn months (Fig. **23**). The presence of 3m-long walls that blocked direct sunlight led to an 11.5% increase in the relative humidity (Fig. **24**). These results highlight the long-term advantages of strategic landscaping.

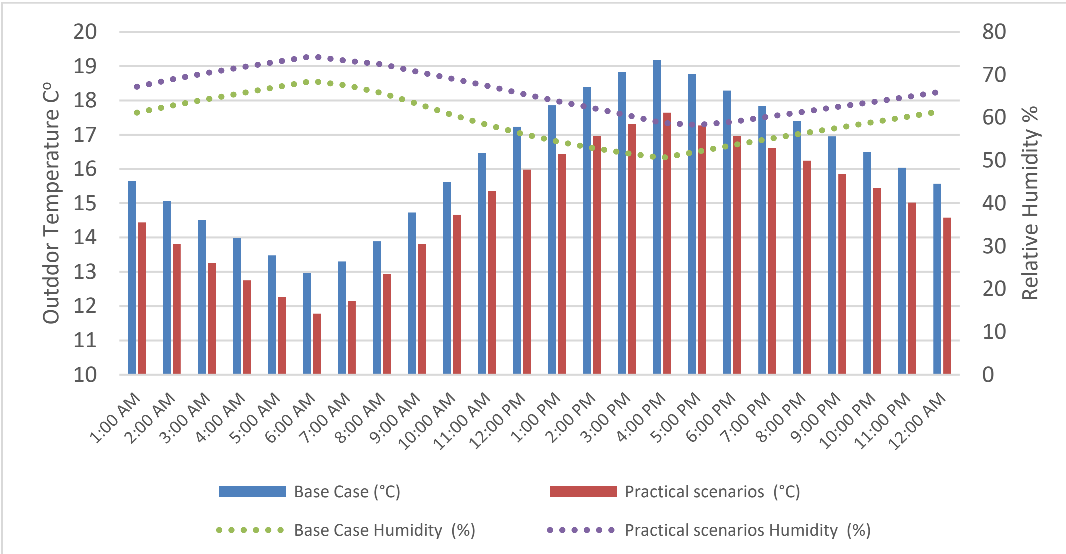


Figure 23: The temperature and relative humidity in the developed case of the case study house in the autumn, specifically at 12:00 on 15 November.

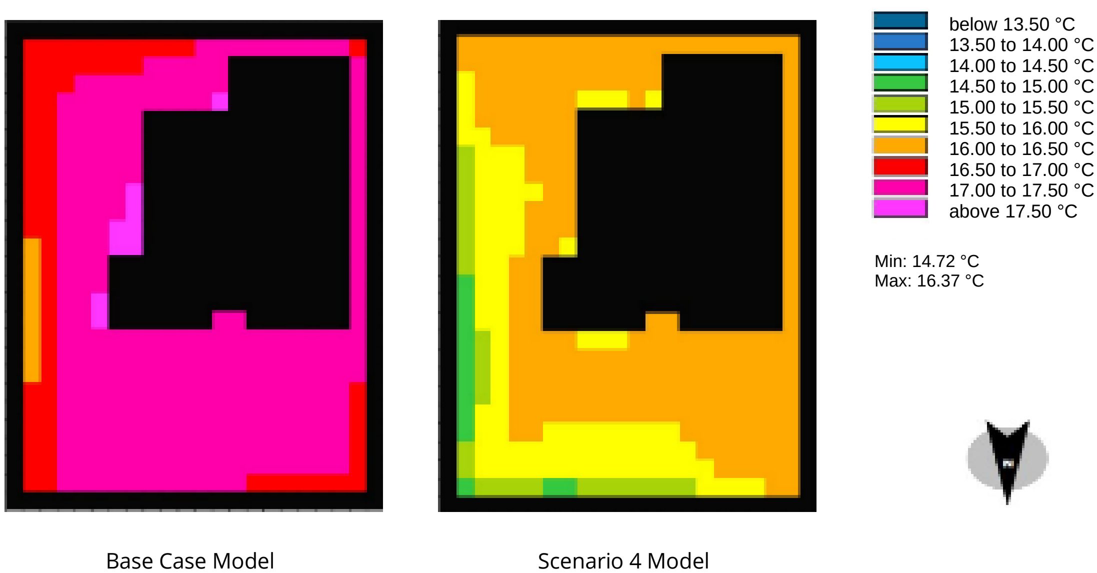


Figure 24: The spatial temperature distribution of the developed case at 12:00 on 15 November.

3.1.3. Energy Consumption Analysis

The impact of strategic landscaping on the energy usage was evaluated by altering original meteorological files to take into consideration the microclimatic effects of newly constructed green spaces. As shown in Table **3**, the seasonal analysis indicated that the average temperature decreased and relative humidity increased for many periods. By adjusting the weather file to account for hourly data fluctuations, the impact of the terrain could be thoroughly evaluated.

Table 3: The percentage of improvement in the hourly weather records.

Season	Temperature Modification (%)	Relative Humidity Modification (%)
Winter	+ 24.9	+ 14.2
Spring	- 1.9	+ 3
Summer	- 4.2	+ 9.8
Fall	- 7.5	+ 11.4

A comparison of the monthly heating and cooling loads for the base case and retrofitted models is shown in Fig. (**25**). Strategic landscaping resulted in a 6.9% decrease in annual cooling demand and an 18.5% reduction in the heating load. The annual reduction in energy use for heating and cooling was around 8.2%. These findings highlight the value of strategic landscaping in decreasing energy consumption and improving thermal comfort in modern residential buildings.

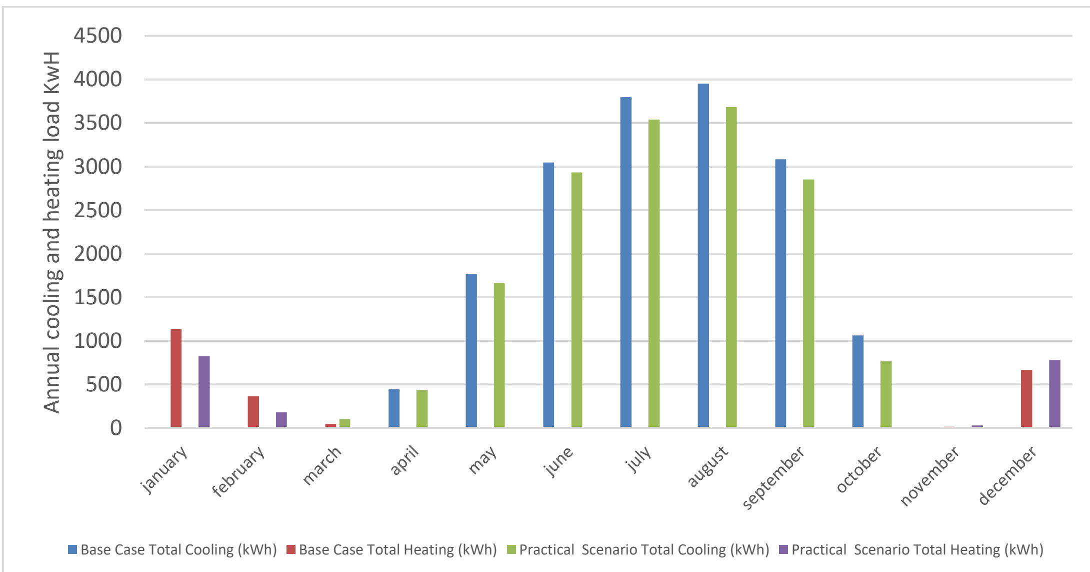


Figure 25: The influence of strategic landscaping on the energy consumption of the case study house in Hail City.

4. Conclusion

This study shows how incorporating green spaces into the residential complexes can increase energy efficiency and microclimates in hot-arid locations. Using cutting-edge modelling technologies like ENVI-met and DesignBuilder, the study successfully assessed the advantages of adding grass, trees, and water features to modern residential buildings in Hail City, Saudi Arabia. The primary findings indicate that these steps can lower the external temperatures by 1.5°C and increase relative humidity by 10% during the hottest summer months while decreasing the annual cooling energy consumption by up to 6.9%. The comparison between the real-world and theoretical situations indicated that strategic landscaping was essential for reducing the effects of urban heat islands, optimising outdoor thermal comfort, and supporting the KSA's Vision 2030 sustainability goals.

In this study, the researchers have presented the practical role played by green spaces in residential urban planning strategies; however, they have also highlighted the need to incorporate conventional passive designs into modern construction. Additional research needs to be conducted to determine the scalability of the above strategies across different climatic zones in addition to their long-term effect on energy systems and urban resilience.

Conflict of Interest

The author declare that there are no conflicts of interest regarding the publication of this paper.

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