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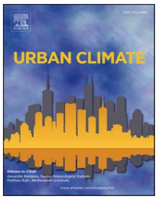

# Urban microclimate impacts on residential building energy demand in Auckland, New Zealand: A climate change perspective

Zahra Jalali [a,*], Asaad Y. Shamseldin [a], Amir Ghaffarianhoseini [b]

[a] *Department of Civil and Environmental Engineering, Faculty of Engineering, University of Auckland, Auckland, New Zealand*
[b] *Department of Built Environment Engineering, School of Future Environments, Auckland University of Technology, Auckland, New Zealand*

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## ABSTRACT

Urban development affects the urban microclimate (UMC) and, consequently, buildings' energy consumption patterns. Considering the urban heat island (UHI) effect in the energy simulation of buildings, especially regarding the uncertainty of future weather data, can support more accurate results and sustainable building designs. This study aimed to analyse the impact of urban microclimate on the energy consumption of an existing residential building in Auckland, New Zealand. The weather data was morphed using the Urban Weather Generator (UWG) and the data from an airport weather station. An existing building was simulated using the EnergyPlus simulation engine to examine the heating and cooling needs of a residential building under varying urban weather conditions and district characteristics. The inputs and assumptions were set based on the New Zealand energy code and available building documents and details. The results showed that the UHI effect has a noticeable impact on cooling demand in summer and heating demand in winter, with a difference of approximately 4.35% and 2.6%, respectively. The findings emphasise the role of urban morphology and characteristics in influencing local weather conditions, thereby highlighting the significance of urban design and arrangement in energy efficiency.

## 1. Introduction

Urban development affects the urban morphology (Ghaffour et al., 2020) and, consequently, the urban microclimate (Mosteiro-Romero et al., 2020). Urban microclimate has a significant impact on building energy consumption patterns, (Liu et al., 2019; Li et al., 2020; Javanroodi and Nik, 2019; Li et al., 2019) space cooling demand (Mosteiro-Romero et al., 2020), heating demand (Mosteiro-Romero et al., 2020; Hong et al., 2021; Meng et al., 2020), and peak cooling electricity demand of buildings (Hong et al., 2021). The urban microclimate is affected by climate change (Tsoka et al., 2021), building footprints, (Taleb and Abumoeilak, 2021; Kamal et al., 2021) vegetation (Eslamirad et al., 2020) and can change the heating and cooling energy requirements (Dahlan et al., 2022) and increase the overheating risk (Tsoka et al., 2021; Erell and Zhou, 2022) in residential buildings (Kamal et al., 2021). Urban microclimate and ongoing climate change are determinants of a building's energy behaviour and the indoor environment (Al-Hafith et al., 2023) by increasing air temperature (Tsoka et al., 2021) and humidity (Shi et al., 2019). However, building energy models are often considered self-standing models and urban morphology and local weather conditions are neglected in the simulations made by these models (Vuckovic et al., 2020; Boccalatte et al., 2020).

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* Corresponding author.
*E-mail address:* zjal182@aucklanduni.ac.nz (Z. Jalali).

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Microclimatic conditions are overlooked in building energy performance simulation by using rural weather data rather than urban microclimate weather data (Mosteiro-Romero et al., 2020; Yang et al., 2023). The main challenge in evaluating UHI impacts on building energy consumption is the lack of data with high spatial resolution and coverage (Li et al., 2019). The number of weather stations is limited due to the restrictions of the weather stations, so using prediction models to forecast local climate conditions is necessary (Kamal et al., 2021). The weather data for building performance simulation is measured in airports with vast and open concrete surfaces, which is different to the actual urban areas (Brozovsky et al., 2022), especially in residential areas with more green areas. Also, the majority of studies in urban microclimate don't consider real cases for simulation and use regular building shapes in isolated scale environments (Liu et al., 2019).

Neglecting the effect of local urban surface and location-specific climate data on the energy simulation of the buildings is criticised (Brozovsky et al., 2022). Taking a comprehensive approach to analysing future energy use in buildings that account for climate change (Jalali et al., 2023) and the urban heat island (UHI) phenomenon is crucial (Tsoka et al., 2021). Considering UHI in weather data and energy simulations provides more credible results in energy simulations (Tsoka et al., 2021; Liu et al., 2017). Future studies should investigate the UHI effect in the context of future climate change and urbanisation, particularly in areas where urban growth is projected to be significant (Li et al., 2019; Hirano and Fujita, 2012).

Microclimate effects need to be considered for more accurate building energy performance simulation (Yang et al., 2023; Stavrakakis et al., 2021). The accuracy of quantification of the energy consumption of the buildings can support engineering applications (Javanroodi and Nik, 2019) and more sustainable designs and improve the assessment of the energy efficiency program and policy (Li et al., 2020; Tsoka et al., 2021) to meet ambitious goals and trends of policies regarding climate change resilience (Stavrakakis et al., 2021).

The research conducted by Chambers and Griffiths (Chambers and Griffiths, 2008) in New Zealand revealed a notable increase in hot days and warm nights across both rural and urban regions. While there was a decrease in cool days and cold nights, the rise of warm extremes was more pronounced in urbanised zones compared to rural areas. Concurrently, Boretti and Watson (Boretti and Watson, 2011) voiced concerns regarding a National Institute of Water and Atmospheric Research (NIWA) paper, contending that the recorded average warming of 0.9 °C across seven meteorological sites in New Zealand is mainly attributable to Urban Heat Island (UHI) effects rather than anthropogenic global warming. Their argument indicates the influential role of heat islands in driving temperature variations.

Nouri (Nouri, 2015) conducted a study focusing on Auckland City in New Zealand, analysing the historical and conceptual projects aimed at improving thermal comfort in urban spaces. The analysis highlighted that with future increases in urban density and climate impacts, the number of days exceeding 25 °C is expected to rise from 20+ to 60+. The effects of UHI need further consideration, and the study emphasised the importance of incorporating solutions into local policies and design guidelines in Auckland. Given projected population growth, urban density, and CO2 emissions, addressing microclimate concerns and adapting to climate change effects will be crucial for the city in the coming decades.

The studies reviewed shed light on various aspects of urban microclimate and its implications in New Zealand. The analysis by Chambers and Griffiths (Chambers and Griffiths, 2008) revealed a trend of increasing hot days and warm nights in both rural and urban areas, with urbanised regions experiencing more significant increases. On the other hand, Boretti and Watson (Boretti and Watson, 2011) criticised the NIWA's observations, suggesting that the observed warming can be attributed to urban heat island effects rather than anthropogenic global warming. Lastly, Nouri's study (Nouri, 2015) emphasised the necessity to tackle microclimate issues and adapt to the effects of climate change in Auckland, as it is expected that the number of days surpassing 25 °C will rise due to urban density and the influence of climate changes. The review of urban microclimate studies in New Zealand conducted by the present authors as a part of this study uncovered a huge knowledge gap in consideration of future urban microclimate status in the built environment and climate change research (Jalali et al., 2022). This motivated the authors to conduct a case study in New Zealand and investigate the impact of urban microclimate exacerbated by climate change effects on the energy consumption of buildings (Jalali et al., 2022).

This study aims at a comparative analysis of the effect of the urban microclimate of a residential neighbourhood on the energy simulation of a residential building in Auckland, New Zealand.

## 2. Method

This study involves creating an energy model for a residential building using specific design details and data to analyse the heating and cooling requirements throughout a year using urban microclimate weather data. The simulation studies are reported to be more suitable for analysing the effects of urban morphology on air-conditioning energy use rather than experimental and statistical analysis (Li et al., 2020).

Fig. 1 Shows the methodological workflow in which the historical, present, and future downscaled weather data are streamed to environmental simulation programs. The urban microclimate weather data is created using UWG tool to assess the impacts of the context of the model and the environment surrounding the building on the energy performance of the building. Simulation inputs and climatic data are set as fixed variables according to the New Zealand Energy Code (I. A. E. Ministry of Business, 2021) and the available details and documents of the building.

This research was carried out through computer simulations using the EnergyPlus simulation engine, with the model developed using the Grasshopper software using Honeybee plugin to visualise the model and the results of the simulation. EnergyPlus was chosen for its validation in compliance with ASHRAE Standard 140 and its successful comparison with other building simulation engines (Judkoff and Neymark, 2006; Al-janabi et al., 2019; Al-Saadi and Al-Jabri, 2020).

The following will explain the selected study area and the district and urban weather generator for the specific context of the simulation, followed by the description of the reference building and inputs and assumptions of the simulation.

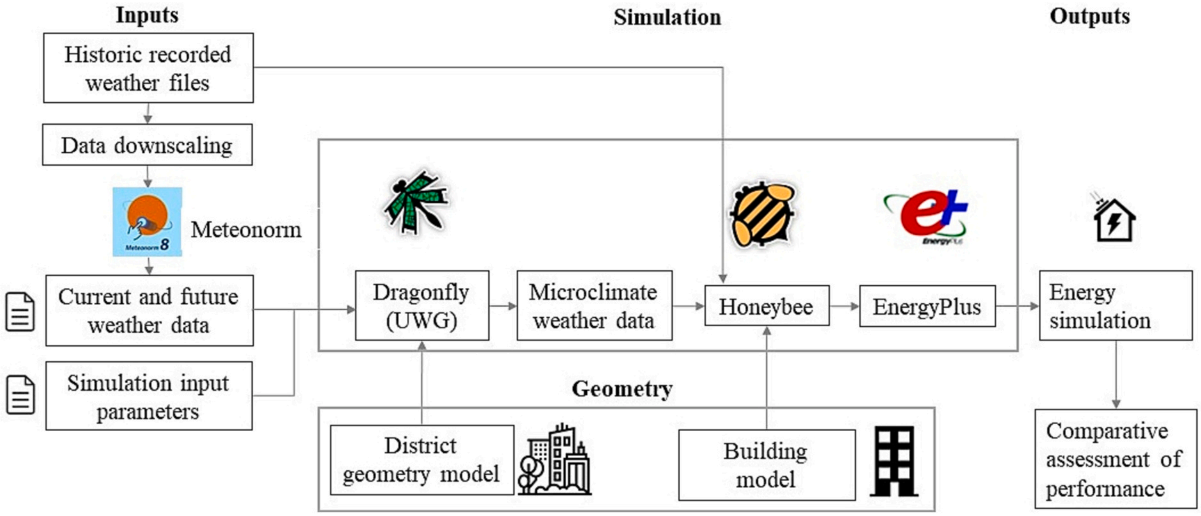

**Fig. 1.** Workflow of the method.

### 2.1. Description of the study area

The case study is located in Auckland (36.8S, 174.7E), the largest city in New Zealand (Silva, 2019). Auckland is a metropolitan region and the most populous city in New Zealand, characterised by a fast pace of development (Imran and Pearce, 2015). The fast-paced urban development in Auckland and the anticipated rise in summer overheating make it increasingly urgent to consider urban microclimate studies in this region (Jalali et al., 2022). As a subtropical region, Auckland typically experiences warm and humid summers, along with mild winters (Chappell, 2013). The mean temperature across the year has a mild fluctuation annually from 14° to 16° (Chappell, 2013). The location of the district used in the present study is located south of Auckland City, with low-rise buildings

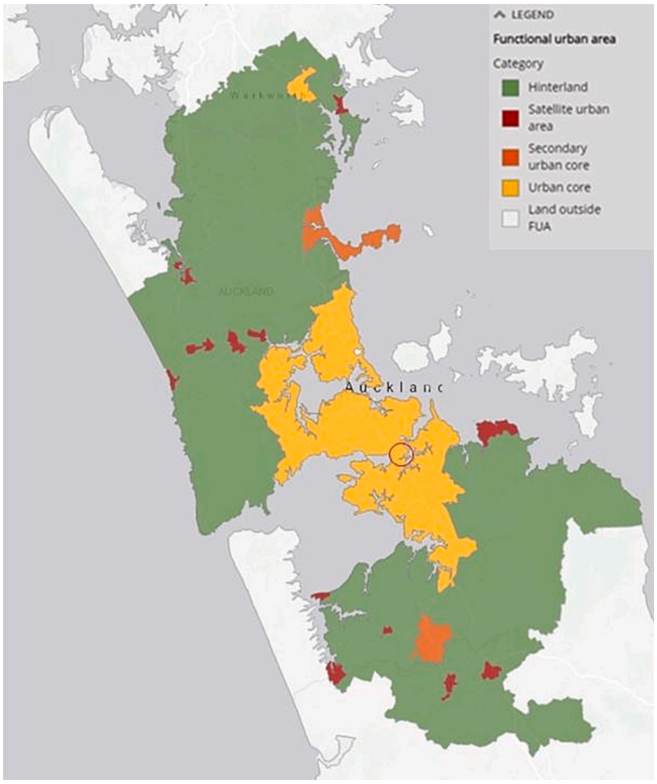

**Fig. 2.** The urban area classification of the study area. Source: (Stats, 2020).

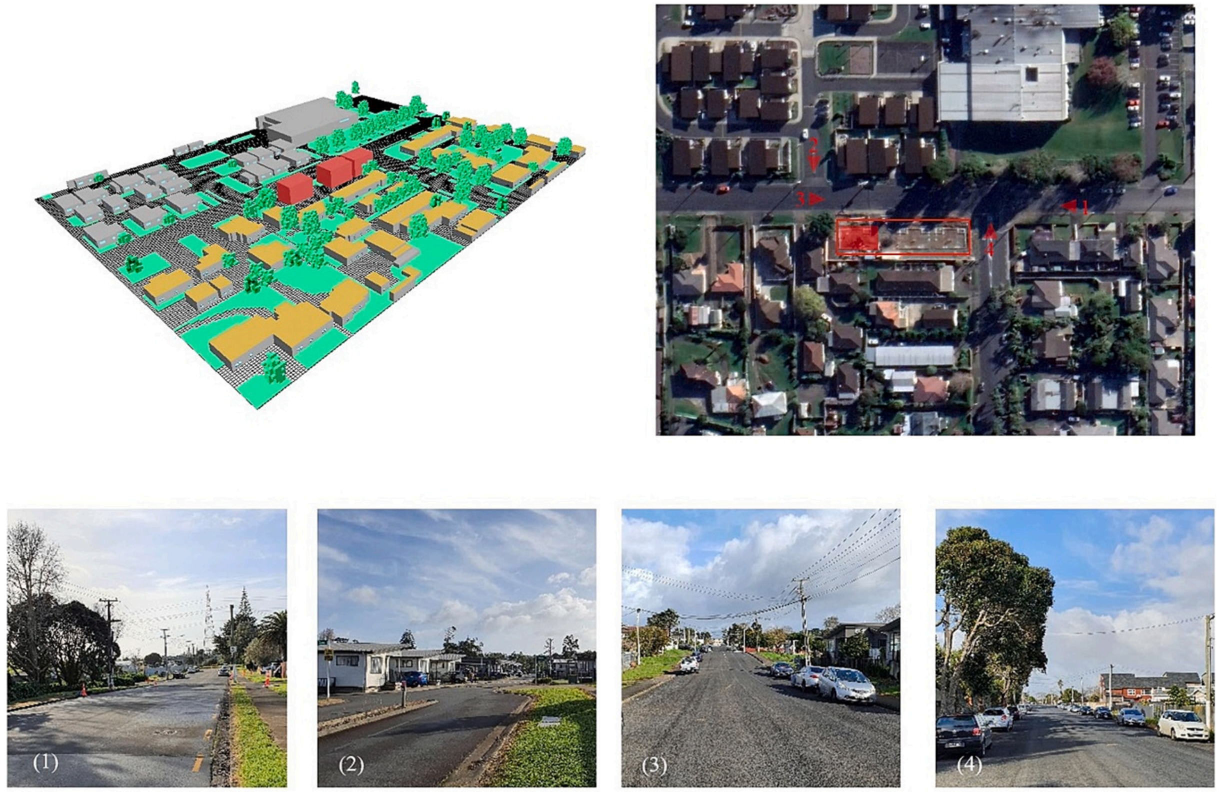

**Fig. 3.** The district map and 3D model.

**Fig. 4.** The location of Auckland Airport weather station.

and scattered trees. In terms of New Zealand regulations, the area is classified as a major urban area (Fig. 2). Auckland's population is spread out across an extensive land area, exhibiting a notably lower population density in contrast to the population distribution seen in cities in European or Asian countries. Presently, Aucklanders have a cultural preference for low-rise residential structures and depend on extensive private mobility, influencing the layout of urban residential areas (Memon et al., 2007)."

The dimension of the district is 180 × 230 m, and the considered district has approximately covers 40000m$^2$ floor area. The height of buildings in this area varies greatly, ranging up to 10 m in height (see Fig. 3).

For this project, the weather data from the Auckland airport station was used as the rural input data. Specifically, the rural weather data used in the simulation were obtained from Auckland Airport, which is the closest airport weather station to the district of interest. The district is around 12 km far from the Auckland Airport weather station (Fig. 4). The study examines the effect of different albedo and geometry of the urban context on air temperature and energy consumption.

### 2.2. The urban weather generator

The research employs the Urban Weather Generator (UWG) as a tool for predicting urban microclimates, which operates on the basis of the Town Energy Balance. UWG has been successfully validated in various climates, including Abu Dhabi, Basel, Toulouse, Singapore, Barcelona, and Rome (Akkose et al., 2021).

UWG modifies existing weather datasets collected from locations outside urban areas in order to estimate and account for large-scale climate phenomena (Akkose et al., 2021). UWG estimates the variations in environmental conditions within urban canyons by comparing them to measurements taken at a weather station located in an open area outside of a city (Naboni et al., 2019). This tool effectively simulates the energy exchanges between a mesoscale atmospheric model and the various urban surfaces present in the area of study (Vuckovic et al., 2020). The UWG tool uses rural weather files and modifies hourly relative humidity and air temperature for the simulation of microclimate conditions in urban spaces. UWG uses epw files used by EnergyPlus software for simulation.

The UWG algorithm requires a user-specified Extensible Markup Language (XML) file. The XML file describes the factors affecting microclimate, including reference site coordination, urban morphological details, building properties affecting urban microclimate and geometry and characteristics of the urban canyon, including surface material and vegetation coverage. The UWG algorithm accounts for convective/advective and radiative heat transfers between the components of the model (Akkose et al., 2021).

The Dragonfly plugin (Fig. 1), which is fully integrated into the Grasshopper parametric modelling tool, was used to put UWG into operation. The UWG produces annual weather files that are needed for building energy simulations (Akkose et al., 2021). By utilising energy conservation principles and taking into account the impacts of the urban canopy and boundary layers on microclimate conditions (Bueno et al., 2014), the Urban Weather Generator (UWG) calculates the impacts of the urban heat island (UHI). (See Fig. 1.)

The actual setting of the district consists of dark asphalt roads and weatherboard claddings of buildings and green areas (grass cover and trees). The model takes into consideration the shading impact of trees by incorporating a vegetation coverage ratio that represents the proportion of the urban surface area (excluding buildings) covered by vegetation, which contributes to shading the road surface. The proposed assumptions for the albedo values of the buildings and urban surfaces are presented in Table 1. The emissivity value of surfaces is 0.9.

The nonbuilding sensible heat at street level, including sources such as cars and pedestrians, is assumed to be high. The traffic parameter is 4 W/m$^2$. Additionally, the UWG calculations take into account the glazing ratio of the buildings. The glazing-to-wall ratio has been set to 0.2.

### 2.3. Future weather files

Two sets of weather data were used to represent both past and future climates. The past climate data comprises historical weather data, while the future climate data is synthesised from multiple scenarios of predicted future climates. To simulate the energy performance of the existing condition, a standard EPW file with the past climate data is utilised. Three periods have been examined, historical data (2000–2019) and two future periods of 2050 and 2090. Projections for 2050 and 2090 are commonly used as reference points for assessing the impacts of climate change because they represent mid-century and end-of-century scenarios, respectively (Wong et al., 2010; van Hooff et al., 2016).

This research employs a total of five climate scenarios spanning the period from 2000 to 2019 to 2090. The 90-year period is divided into two segments, representing the climate conditions at the beginning, middle, and end of the century. The Intergovernmental Panel on Climate Change (IPCC) used two pathways, namely RCP 4.5 (intermediate stabilisation pathway) and RCP 8.5 (high pathway), among many other different pathways, for its report assessments (Meinshausen et al., 2011). This study uses RCP 4.5 and RCP 8.5 climate change scenarios.

RCP 4.5 represents a climate scenario that involves the moderated and stabilised emissions of greenhouse gases, aiming to limit global warming by achieving a CO$^2$ concentration of roughly 538 ppm by 2100. In contrast, RCP 8.5 presents a “business as usual” scenario characterised by a significant increase in emissions, leading to a CO$^2$ concentration of about 936 ppm by 2100, resulting in severe climate impacts without substantial mitigation efforts. These scenarios help model the potential impacts of different emission pathways on global climate, making them valuable tools for climate change research (Meinshausen et al., 2011).

Meteonorm software was used for generating future weather files. Meteonorm is a commonly used tool for generating climate data. It features a large climatic database and allows for spatial interpolation in areas without any historical climate records (Remund and Kunz, 2020). Meteonorm software utilises the statistical downscaling method to estimate climate variables at the local level. It integrates multiple data sources, including satellite data, reanalysis data, and ground measurements, to build a comprehensive climate

**Table 1**
The assumptions of albedo values of urban surfaces.

| District surface | Albedo [−] | Thickness [cm] | Volumetric heat capacity [J-m3K] | Conductivity [W/m-K] | Roughness [cm] |
|---|---|---|---|---|---|
| Asphalt roads | 0.12 | 12 | 2.214 | 1.16 | 0.1 |
| Concrete sidewalks | 0.3 | 12 | 2.083 | 1.63 | 0.1 |
| Loamy soil | 0 | – | 1.40400 | 0 | 0.15 |
| Roofs | 0.28 | – | – | – | 0.02 |
| Walls | 0.45 | – | – | 0.87000 | 0.02 |
| Vegetation | 0.2 | 25 | – | – | – |

database. Through statistical downscaling, Meteonorm establishes empirical relationships between large-scale meteorological variables and local-scale parameters. It employs regression-based techniques and statistical models to downscale climate data to specific locations, considering factors like latitude, altitude, and geographical characteristics. The software relies on Global Climate Models (GCMs) specified in the IPCC assessment report to provide data and information (Tootkaboni et al., 2021).

### 2.4. *Case study building*

The case study selected for analysis is situated in the southern part of Auckland, and it comprises three residential buildings for multiple families that house six units. The neighbourhood is situated in a low-density urban region, and most of the surrounding structures are one or two-story residential buildings. The building consists of three floors and features a total ground footprint area of 630 square meters and a height of 12.4 m. Window to wall ratio is 13.5%. Table 2 displays different physical characteristics of the buildings, and Fig. 5 exhibits the plan and 3D representations of the buildings.

The thermal resistance of building elements, such as walls, roofs, and windows, was set based on the permissible thermal transmittance allowed by the New Zealand standards suitable for the Auckland climate zone, which is classified as zone 1 in New Zealand (I. A. E. Ministry of Business, 2021). The key features of the buildings are presented in Table 2.

The initial model was created by Grasshopper using the available drawings of the building, closely adhering to the floor plan and material specifications of the residential block being studied. To account for the shading impact of nearby high-rise residential buildings, two additional structures were modelled, as depicted in Fig. 3. Additionally, the units on the upper and lower floors were also modelled to prevent any interference with heat transfer from the ceiling and floor of the unit being studied.

### 2.5. *Simulation procedure*

The objective of this step is to perform a comparative analysis of the case study's performance was conducted through simulation-based methods. An energy model of an existing building was developed to represent the conditions of the building regarding the available geometrical and construction data of the building. After the development of the energy model, the simulation was run for the current and projected weather conditions. The building's average annual cooling and heating demand were calculated and recorded for each iteration using the EnergyPlus engine. The cooling and heating densities per conditioned floor area (kWh/$m^2$) were reported as the output of the simulation.

To assess different configurations within the district, a comparison was made between the UHI-free condition, which utilises rural EPW (Environmental Productivity World), and the UHI-influenced scenario, employing UWG-morphed (Urban Weather Generator) settings. The indoor temperature setpoints ranged from 18 °C to 25 °C. A constant ventilation rate was assumed throughout the duration and was accounted for in the calculation of thermal loads. The occupancy schedule, thermal setpoints, and infiltration rate were set according to the New Zealand Energy Building Code. The models' occupancy schedule is modelled after residential buildings, with the living room being occupied between 6 am and 10 pm and the bedroom being occupied between 10 pm and 6 am. The infiltration rate has been considered to be 0.0003 ($m^3$/s per $m^2$ façade), which is an average infiltration rate. The air changes per hour (ACH) is set to 0.5.

**Table 2**
Building components and R-values.

| Building component | R-value ($m^{2\circ}C/W$) |
|---|---|
| Floor (Ground slab) | 1.52 |
| Mid floor | 1.9 |
| Framed wall constructions with cavities (weatherboard and timber studs) | 2.04 |
| Glazing in on-solid walls (Double glazing) | 0.26 |
| Roofs or ceilings (Corrugate iron with building paper) | 2.93 |

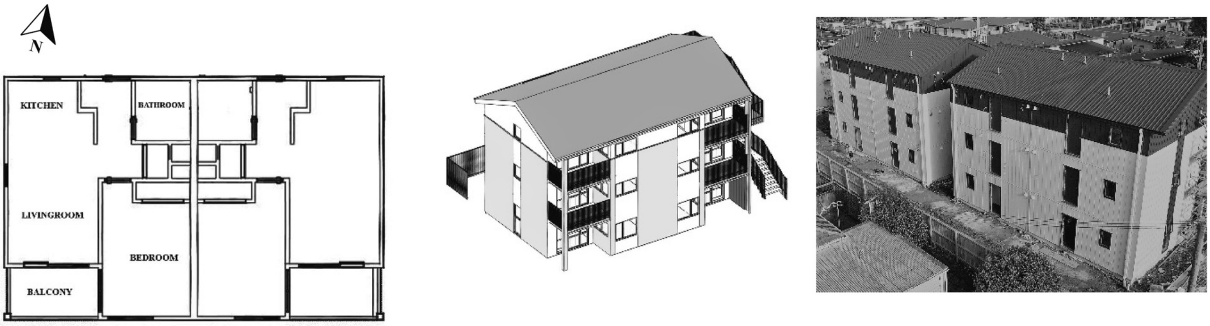

**Fig. 5.** 3D model and plan of the case study.

## 3. Results and discussions

In this section, the presentation of the simulation results is structured as follows. In the first sub-section, the main climatic characteristic of the dry bulb temperature is presented. In the following subsection, the results of the effect of urban microclimate conditions on the heating and cooling energy are shown for the case study.

### 3.1. Validation of energy performance simulation

The validation of the simulation outcomes involved a comparative analysis. The findings of the study were compared against those of other independent studies (Jaques et al., 2021). The existing research findings related to the cooling and heating of residential buildings in New Zealand were extracted and organized for a comparative assessment with the results of simulation.

Table 3 shows the space heating and cooling energy use for the case studies in Auckland based on a report from the Building Research Association of New Zealand (BRANZ) on sustainability and housing in New Zealand (Jaques et al., 2021).

The comparison of similar case studies with the results of this study for the baseline weather data showed the outputs of simulation and BRANZ report are aligned.

### 3.2. Weather data results

The selected neighbourhood represents an urban typology characterised by homogeneous building types with single uses. The results showed that there are some variations between the results derived from the airport epw file and the UWG tool. As Fig. 6 shows, the average monthly temperature is around 0.20–0.36 °C different, and the variation of the temperature will change to 0.17–0.33 °C by 2090 (RCP 8.5).

Fig. 7 illustrates the comparison between solar irradiation and relative humidity for both baseline and future weather data. The graph reveals that solar irradiation is slightly lower in the summer months but higher in the winter months. Conversely, relative humidity exhibits an opposite trend, with higher values in warmer months and lower values in colder months. Notably, there is no significant difference in relative humidity between the RCP 4.5 and RCP 8.5 scenarios.

Fig. 8 compares the temperature variation in the first week of February as the hottest month of the year in Auckland and the first week of July as the coldest week of the year (Macara, 2018). In future years (until 2090), the temperature difference will increase up to 1 °C, considering the urban microclimate effect. The temperature difference under RPC 8.5 shows the average hourly temperature could increase up to 0.95 °C in 2090 while using the baseline (2000–2019) weather data during the same period; this value is up to 0.97 °C for the baseline weather data.

Fig. 9 presents the results of the analysis comparing rural and UMC weather data for heating degree days (HDD) and cooling degree days (CDD). In the baseline weather data, the average HDD decreased from 1207.6 to 1122.5 due to the UHI effect. Under the RCP 8.5 scenario, the HDD value increases up to 524.0 by 2090, and the UHI effect subsequently decreases this value to 470.7. Similarly, for CDD in the baseline weather data, the average increased from 18.4 to 19.2 under the influence of UHI. Under the RCP 8.5 scenario by 2090, the CDD value increased up to 169.7, but the UHI effect decreased the value slightly to 183.9. These findings provide valuable insights into the disparities in HDD and CDD between the two datasets across different time periods and climate scenarios.

### 3.3. Impact of urban microclimate on building energy performance

The data provided in Fig. 10 contains information on cooling and heating values for Auckland under different scenarios, namely the baseline (2000–2019) and two Representative Concentration Pathways (RCPs), RCP 4.5 and RCP 8.5, at two future time points, 2050 and 2090. The cooling and heating values represent the difference between the average annual energy demand for cooling and heating in each scenario compared to the baseline, measured in kilowatts per hour per year. Under the baseline scenario, the average cooling demand for Auckland was 9.63 kWh/m$^2$/yr’ and the average heating demand was 13.12 kWh/m$^2$/yr. Under the RCP 4.5 scenario, the average cooling demand is projected to increase to 16.05 kWh/m$^2$/yr by 2050 and 20.23 kWh/m$^2$/yr by 2090, while the heating demand is projected to decrease to 8.90 kWh/m$^2$/yr and 8.03 kWh/m$^2$/yr respectively, by 2090. Considering the effect of UHI 0.36 kWh/m$^2$/yr increase in the cooling and 0.76 kWh/m$^2$/yr decrease in heating demand was observed.

The comparison of the cooling and heating demand (Fig. 10) for a given area using two different urban surface models of Urban Weather Generator (UWG) and the rural data showed the difference in cooling demand between UWG and rural data is relatively small,

**Table 3**
Building components, R-values and simulation results.

| Building component | R-value (m$^{2\circ}$C/W) | | |
|---|---|---|---|
| | Simulation settings | Single-storey building | Medium density development building |
| Floor (Ground slab) | 1.52 | 1.3 | 1.3 |
| wall | 2.04 | 1.9 | 1.9 |
| Glazing | 0.26 | 0.26 | 0.26 |
| Roofs or ceilings | 2.93 | 2.9 | 2.9 |
| Heating and cooling demand (kWh/m$^2$/yr) | 22.75 | 21.9 | 27.5 |

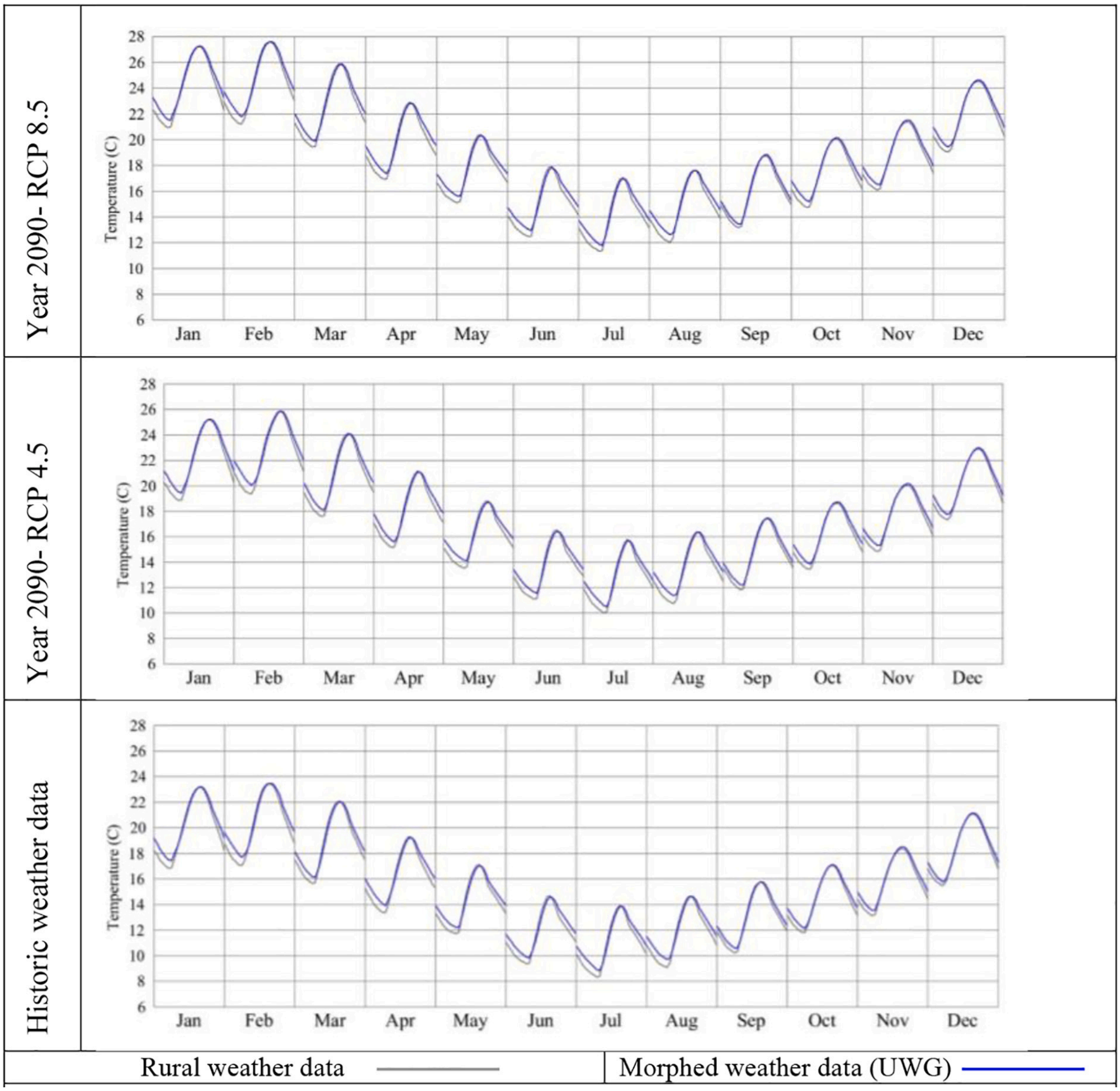

**Fig. 6.** The comparison of the outdoor temperature (Dry-bulb temperature) under the influence of urban microclimate.

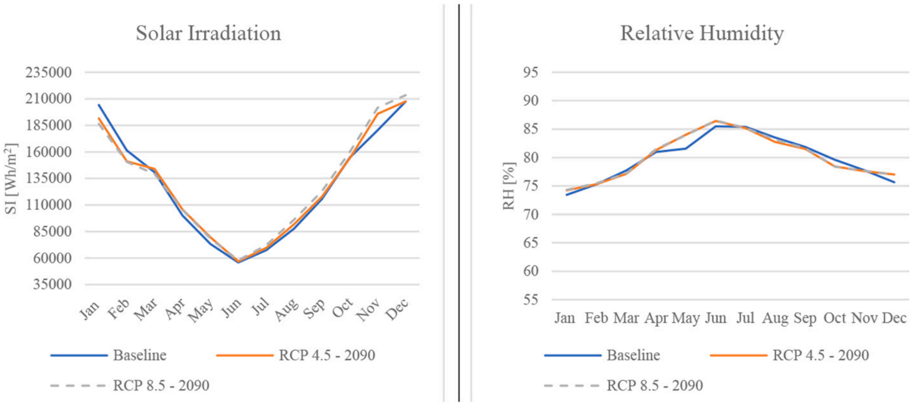

**Fig. 7.** The comparison of baseline and future Solar Irradiation and Relative Humidity data.

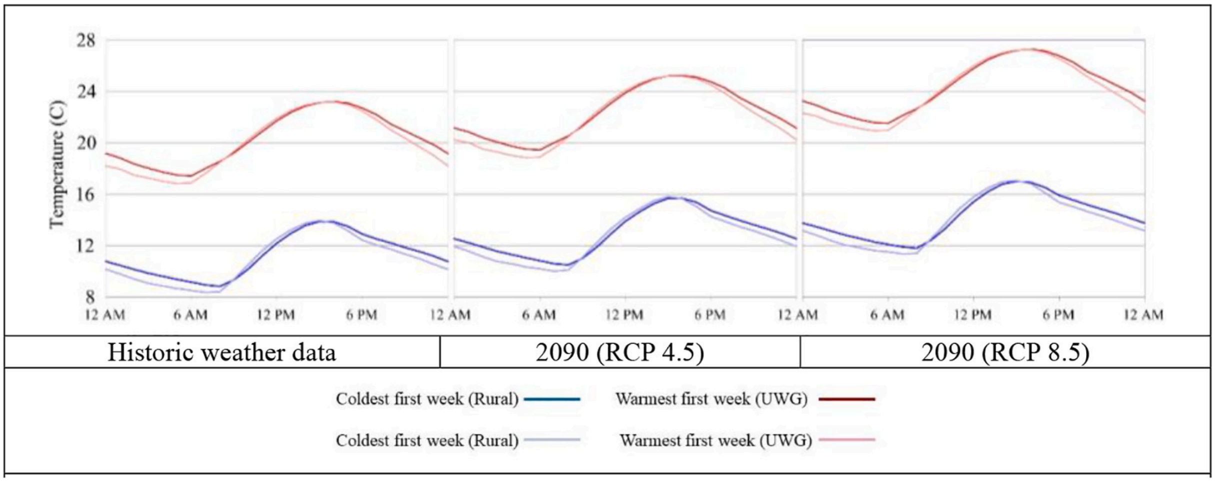

**Fig. 8.** The outdoor dry-bulb temperature variation during the coldest and warmest weeks of the year.

with the largest difference being 0.98 kWh/m$^2$/yr in 2090 under RCP 8.5. The difference in heating demand between UWG and rural data is smaller than that of cooling demand, with the largest difference being 0.53 kWh/m$^2$/yr. Overall, the data suggest that the choice of the urban surface model may have a greater impact on heating demand projections than on cooling demand projections. However, the differences observed between the two models are generally small, indicating that the choice of urban surface model is unlikely to significantly affect overall energy demand projections in residential districts.

Fig. 11 shows the cooling energy during summer and heating energy in winter for two different weather data sets: Rural epw (weather data obtained from rural areas) and UMC-epw (weather data obtained from urban areas using Urban Weather Generator). The data is presented for three different periods of 2000–2019, 2050, and 2090 under different climate change scenarios based on RCP 4.5 and RCP 8.5. Under both scenarios of RCP 4.5 and RCP 8.5, the cooling demand increased in both rural epw and UMC-epw from 2000 to 2019 to 2050 and 2090. The increase is more intense for UMC-epw results compared to rural epw data.

A literature review conducted by Li et al. (Li et al., 2019) exploring case studies around the world, including Greece, the UK, Hong Kong, Japan, Bahrain, the US, China, Australia, Italy, Spain and Singapore, showed UHI effects could result in a median increase of 19% in building cooling energy consumption. However, there is significant variability observed globally, with the range spanning from 10% to as high as 120% (Li et al., 2019). On a global scale, UHI can lead to a median increase of 19% in building cooling energy usage, with a wide range spanning from 10% to as high as 120%. Conversely, these studies also indicate a consistent decrease in building heating energy consumption due to UHI, with a median decrease of 18.7% and a range of 3% to 44.6% (Li et al., 2019).

The UHI effect makes a difference of 4.35% in cooling g demand in summer and 2.6% in heating demand regarding the baseline weather data. This value falls into the minimum variation caused by the UHI effect compared to the results deprived by the literature review. The district studied in this research is characterised by low-rise residential buildings and a substantial presence of trees and grass for vegetation cover. The low density and height of the buildings in the area contribute to the lower anticipated variation in the observed values.

Fig. 12 demonstrates the summer indoor temperature of the living room using various weather datasets. The temperature range in

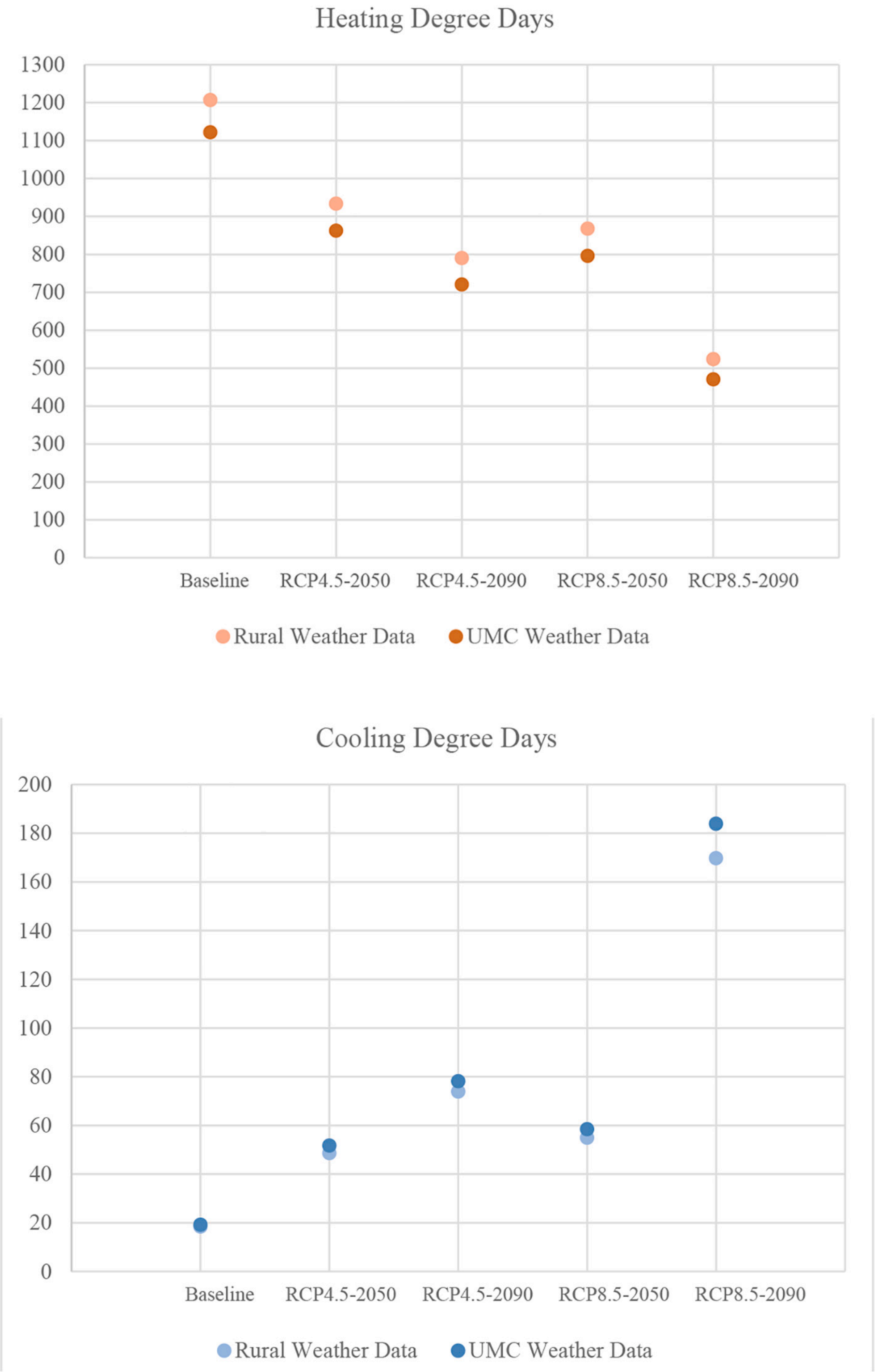

**Fig. 9.** The effect of urban microclimate data on CDD and HDD.

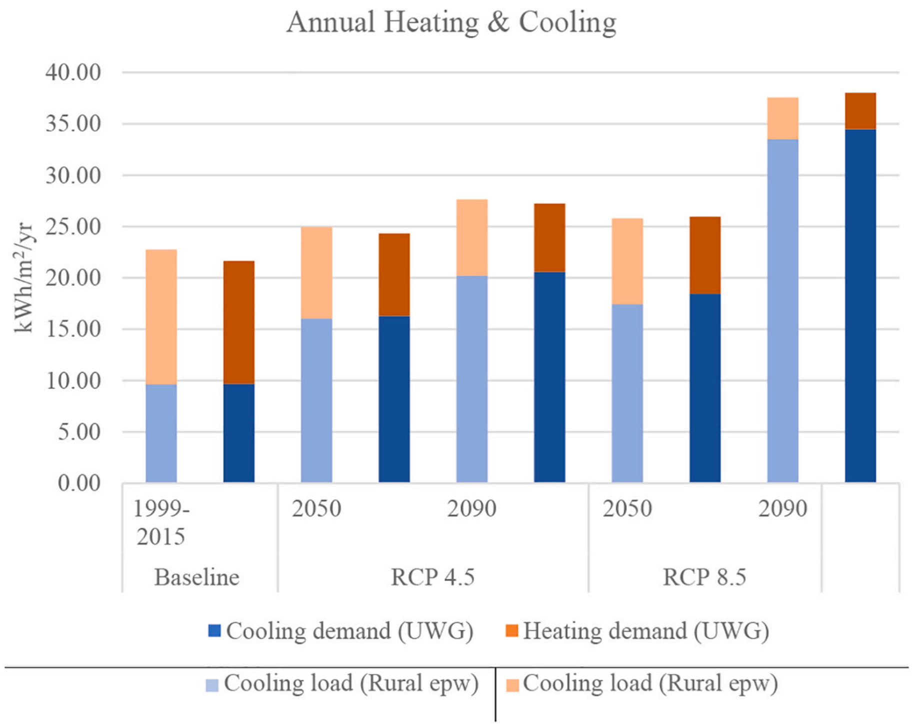

**Fig. 10.** The average annual heating and cooling results.

indoor rooms is 19 °C to 29.5 °C for the UWG-morphed datasets for the year 2090 (RCP 8.5). In comparison, this value ranges from 18 °C to 28.8 °C for the historical weather dataset. The impact of modified weather data utilising UWG and urban microclimate on the indoor temperature of the room is demonstrated to be minimal. Nevertheless, the figure reveals that the impact of climate change on indoor temperature is considerable and will have a more pronounced effect on indoor temperature, especially concerning urban microclimate, in the future years.

## 4. Conclusion

The study presented a simulation-based analysis of the impact of urban context on the energy performance of residential buildings. The results of the simulation were compared based on two different urban morphology. The impacts of a typical residential district morphology in Auckland were compared to the weather data recorded in an airport with open concrete surfaces. The morphed weather data based on building context increased the cooling load and decreased the heating load of residential buildings. Overall, the results showed the effect of urban microclimate reduced the heating energy consumption and increased the cooling energy demand of the spaces in residential buildings.

The findings of this study have important implications for understanding and evaluating the urban microclimate in residential neighbourhoods. The study provided valuable insights that can assist in further assessments and investigations of the topic. One significant observation from the results is that urban morphology and characteristics play a role in influencing the local weather conditions. This implies that factors such as the layout, design, and physical features of urban areas have an impact on the weather patterns experienced at a smaller scale within the neighbourhood.

The study also examines the impact of climate change on the urban microclimate and subsequently energy performance of the buildings. While the energy consumption of the case study follows a similar pattern for both weather data from airport stations and UWG morphed dataset, the differences between the thermal load will decrease in the long-term future by 2090.

Overall, these findings contribute to a more realistic understanding of energy simulation in urban contexts. They provide valuable information that can guide the development of sustainable and energy-efficient urban environments. By considering the influences of urban morphology, characteristics, and building energy performance, policymakers, architects, and urban planners can make informed decisions to create environmentally friendly and liveable cities.

This study utilised inputs based on the New Zealand Energy building code and actual data from a specific building to conduct the analysis. It's important to note that the findings presented in this study are limited to the specific application and building type that was studied, which was a single residential block. Therefore, these results should be interpreted with caution and considered within the scope of the research.

The recommendation for future research is to investigate other factors that affect urban microclimate, such as the type and albedo of materials and their coverage rate. Additionally, future studies should compare results from more compact urban areas, such as CBD

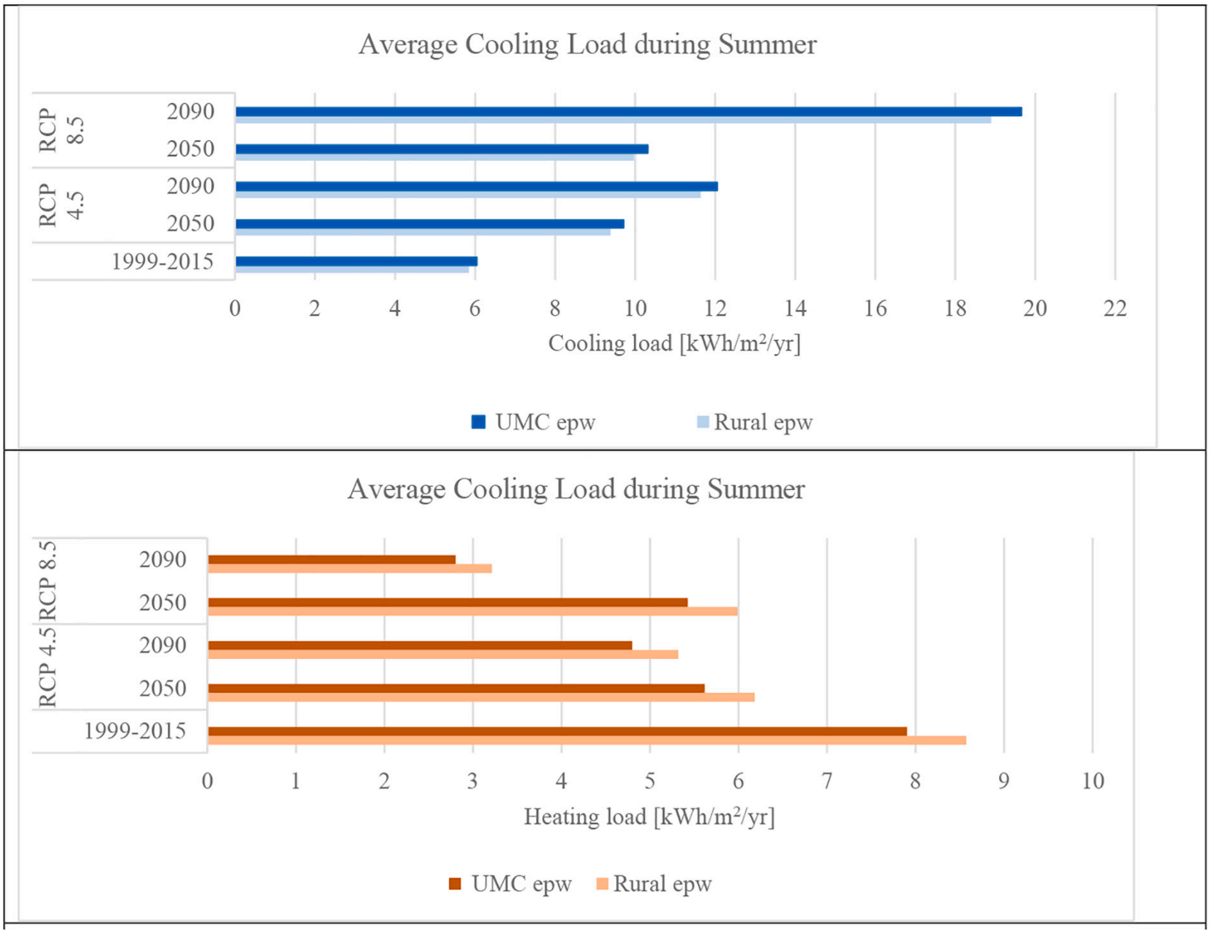

**Fig. 11.** The comparison of monthly cooling and heating demand using rural weather data and urban microclimate weather data.

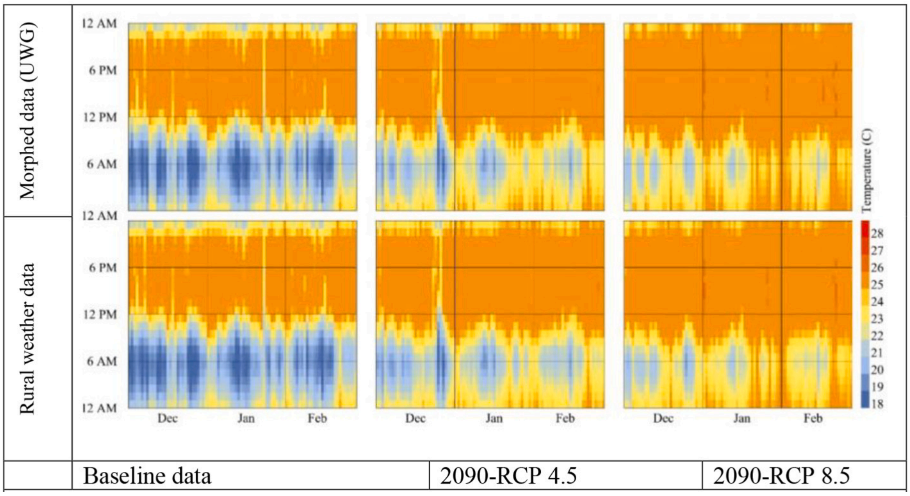

**Fig. 12.** The indoor dry-bulb temperature in a living room based on different weather datasets.

(central business district), to those from low compact urban areas to gain a better understanding of the impact of urban design on the microclimate of high-density urban areas.

## CRediT authorship contribution statement

**Zahra Jalali:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Asaad Y. Shamseldin:** Writing – review & editing, Supervision. **Amir Ghaffarianhoseini:** Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The authors are unable or have chosen not to specify which data has been used.

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