Environmental and Climate Technologies
2023, vol. 27, no. 1, pp. 900–911
https://doi.org/10.2478/rtuect-2023-0066
https://content.sciendo.com

Impact of Climate Change on the Heating Demand of Buildings. A District Level Approach

Athanasia APOSTOLOPOULOU[1], Carlos JIMENEZ-BESCOS[2*], Stefano CAVAZZI[3], Doreen BOYD[4]

[1]*Nottingham Geospatial Institute, University of Nottingham, 30 Triumph Rd, Lenton, NG7 2TU, Nottingham, United Kingdom*

[2]*School of Built and Natural Environment, University of Derby, Kedleston Rd, DE22 1GB, Derby, United Kingdom*

[3]*Principal Innovation & Research Department, Ordnance Survey, Explorer House, Adanac Dr, SO16 0AS, Southampton, United Kingdom*

[4]*School of Geography, Nottingham University, Sir Clive Granger Building, NG7 2RD, Nottingham, United Kingdom*

Received 19.04.2023; accepted 15.10.2023

***Abstract* – There is no doubt that during recent years, the developing countries are in urgent demand of energy, which means the energy generation and the carbon emissions increase accumulatively. The 40 % of the global energy consumption per year comes from the building stock. Considering the predictions regarding future climate due to climate change, a good understanding on the energy use due to future climate is required. The aim of this study was to evaluate the impact of future weather in the heating demand and carbon emissions for a group of buildings at district level, focusing on two areas of London in the United Kingdom. The methodological approach involved the use of geospatial data for the case study areas, processed with Python programming language through Anaconda and Jupyter notebook, generation of an archetype dataset with energy performance data from TABULA typology and the use of Python console in QGIS to calculate the heating demand in the reference weather data, 2050 and 2100 in accordance with RCP 4.5 and RCP 8.5 scenarios. A validated model was used for the district level heating demand calculation. On the one hand, the results suggest that a mitigation of carbon emissions under the RCP4.5 scenario will generate a small decrease on the heating demand at district level, so slightly similar levels of heating generation must continue to be provided using sustainable alternatives. On the other hand, following the RCP 8.5 scenario of carbon emission carrying on business as usual will create a significant reduction of heating demand due to the rise on temperature but with the consequent overheating in summer, which will shift the energy generation problem. The results suggest that adaptation of the energy generation must start shifting to cope with higher temperatures and a different requirement of delivered energy from heating to cooling due to the effect of climate change.**

***Keywords* – Energy performance; future climate scenarios; geospatial data; OS MasterMap; TABULA typology; Urban Building Energy Modelling (UBEM).**

* Corresponding author.
E-mail address: C.Jimenez-Bescos@derby.ac.uk

Nomenclature		
GHG	Greenhouse Gas	–
LoD	Level of Detail	–
OS	Ordnance Survey	–
RCP	Representative Concentration Pathway	–
UBEM	Urban Building Energy Modelling	–
WWR	Window-to-Wall Ratio	%

1. INTRODUCTION

One of the biggest concerns facing humanity is climate change. Given that it poses the greatest threat to humans and the world's ecosystems in the coming years, global climate change has received a lot of attention [1]. The well-being of mankind and the sustainability of society's production are both impacted from climate change [2]. In 2018, the construction and building sectors were responsible for 39 % of the process-related carbon dioxide emissions [3]. The impact of climate change is observed on energy demand for heating and cooling in building stock as well [4], [5]. This results in a negative influence on the building's energy performance. Furthermore, there is no doubt that building energy performance is influenced by both building design and the overall effects of climate change [6]. Retrofitting of buildings was highlighted by Jimenez-Bescos and Oregi as an important aspect to consider reducing carbon emissions [7]. Nevertheless, by understanding the influence of climate change to building stock and estimating the heating and cooling demand, city planners and policymakers could get information, in order to create environmental goals for the reduction of the carbon emissions that actually help to tackle the complicated situation of climate change and global warming. Furthermore, Laktuka *et al.* highlighted the importance of heating and cooling in long-term policies for energy efficiency [8].

A previous research study has been implemented for the estimation of the human thermal comfort and the energy demand of a three-story building in the sub-Himalayan region of eastern India, for the climate scenarios of 2050 and 2080 [9]. The specific study has formulated some recommendations regarding building parameters, such as the thermal transmittance, the WWR and the infiltration, in that specific building type. The findings have shown that the indoor temperature will be increase, especially for the top-floor that has direct connection with the exposed roof of the building [9]. Another research from Gao *et al.*, have investigated the influence of the climate change in a newly retrofitted office building in Chengdu, and proposed an approach for energy efficiency measurements under future climate for individual buildings [10]. Apart from the above, other studies have been implemented for the mitigation of climate change and the adaptation of the building stock to it, to existing office buildings and schools [11], [12].

However, some other research studies have been done for the residential building stock. A study from has been conducted for a single-family house in Mexico from Jiménez Torres *et al.*, in order to assess the influence of climate change in the energy demand under future climate scenarios [13]. The findings have shown that the major problem for future will be the cooling demand, as the utilization of air-conditioning is predicted to increase by around 20 % and 35 % for 2050 and 2100, respectively [13]. Two other case studies in Greenland and Norway have been implemented, in order to estimate the optimal insulation thickness for the mitigation of climate change and the Greenhouse Gas (GHG) emissions, by evaluating the energy emission factor [14]. In addition to the above, other papers that deal with the housing stock and the future climate adaptation and mitigation have been published, such as the research from Rodrigues *et al.*, for a steel frame dwelling and the study from Huneidi *et al.* that estimated the energy demand of a residential villa [15], [16].

Despite all of the above, the previously mentioned research studies that have been done deal with the estimation of the energy demand at the individual building level. The aim of this paper is to investigate the annual residential heating demand under future climate scenarios at urban scale. In more detail, predictions for 2050 and 2100 of the weather data have been chosen for the energy simulations, in accordance with RCP4.5 and RCP8.5 scenarios. By this way, the indirect goal is to provide a methodology for urban energy modelling at district scale, for the rapid and holistic information of energy performance, in the form of maps, of the residential stock under the climate change, in order the policymakers to plan environmentally sustainable goals.

2. METHODOLOGY

The Annual Residential Heating Demand has been estimated with the use of an Urban Building Energy Modelling bottom-up physics-based approach. More particularly, building typologies have been used in order to divide the residential stock into archetypes based on the building age and the building form and calculate the district energy demand. In general, when referring to the term Urban Building Energy Modelling the scale of the implementation of the energy demand calculations is specified, which is urban level [17]. The methodology that has been used for the estimation of the annual residential heat demand has been validated in previous research study, and has been modified in order to match the city of London and to take into account the whole year, in contrast to Dochev's research that considers only the heating season [18].

The first step has been to acquire the appropriate datasets, both the geometric and energy-related datasets. The core datasets that are needed are the OS MasterMap Topography layer and Building Height attribute from Ordnance Survey, for the geometric data. In more detail, the OS MasterMap Topography layer contains the representation of building footprints into geospatially informed polygons, while OS Building Height attribute contains the height for each building footprint. Both of them include a special identity key for each building, which is called TOID, for assisting in dataset merging. For the creation of the building typology and the identification of each building's archetype, the Colouring London dataset from Colouring CITIES project is used, as it contains the building form and age information. Finally, the TABULA typology from Episcope, is the source for energy-related data according to building archetypes. In the following table (Table 1), all the datasets are presented along with their providers and format.

The following step has been to process the data, with Python programming language by implementing data merging, cleaning and exporting the shapefile to import to QGIS platform. In QGIS, the roof type and the Window-to-Wall ratio (WWR) have been imputed from Google Satellite View and Google Street View for each building of the case study areas, in order to create two different datasets for each case study area in Level of Detail 3 (LoD3).

TABLE 1. DATASETS

Dataset	Provider	Source	Format
OS MasterMap Topography layer	Ordnance Survey	Digimap, EDINA [19]	GPKG
OS MasterMap Building Height attribute	Ordnance Survey	Digimap, EDINA [19]	CSV
Colouring London	Colouring CITIES	https://colouringlondon.org/ [20]	CSV
OS Features API (Local Buildings layer)	Ordnance Survey	OS Data Hub [21]	API
OS Features API (District Buildings layer)	Ordnance Survey	OS Data Hub [21]	API
Statistical GIS Boundary Files for London	GREATER LONDON AUTHORITY	https://data.london.gov.uk/dataset/statistical-gisboundary-files-london [22]	SHP
OS Boundary Line	Ordnance Survey	Digimap, EDINA [19]	SHP
TABULA Typology	TABULA, EPISCOPE	https://episcope.eu/welcome/ [23]	PDF

Finally, the energy model has run for both case study areas for baseline scenario and scenarios RCP 4.5 and RCP 8.5, for 2050 and 2100, in order to create the maps of the annual residential demand and the comparison maps of the different future climate scenarios. More particularly, the RCP abbreviation stands for the Representative Concentration Pathways for the greenhouse gas emissions and aerosol that are concentrated in the atmosphere and alongside to the way that land use is differentiated through years, lead to a set of future climate findings, that are used in IPCC AR5 scenarios [24]. The RCP 4.5 is a scenario that takes into account various greenhouse gas emission-reduction technologies and tactics, whereas the RCP 8.5 is a representation of reduced efforts in reducing the greenhouse gas emission with certain policies and the failure of limiting global warming in 2100 [24]. Fig. 1 illustrates the methodology described above.

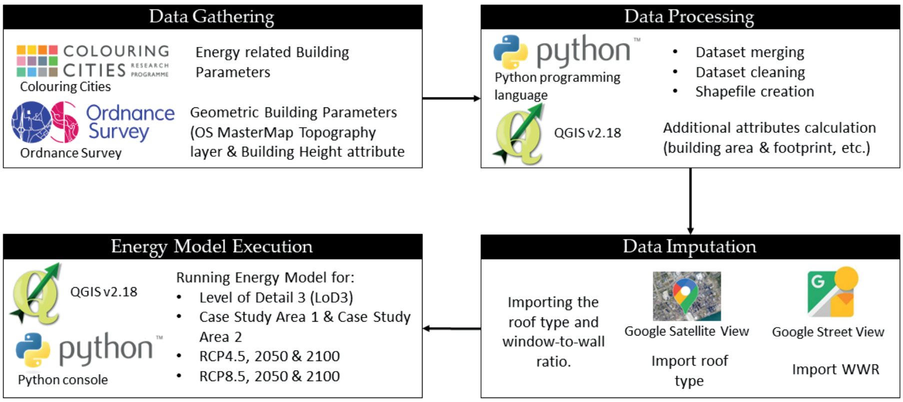

Fig. 1. Diagram of Methodology.

3. RESULTS AND DISCUSSION

3.1. Case Studies

The city that has been chosen as a case study is London. More particularly, two different residential areas have been selected. The case study Area 1 is located in the constituency of Camberwell and Peckham and consists of 177 dwellings. All dwellings in that area are old buildings that constructed in 1890s. On the other hand, the case study Area 2 is located in the constituency of Bethnal Green and Bow and consists of 48 newer-built dwellings, that constructed post 2005.

3.2. Annual Residential Heat Demand Maps

As it has been stated above, the energy model is validated from previous research study, therefore the results are presented directly. The annual residential heat demand for both case studies for the present climate, namely the baseline scenario is presented in Fig. 2 and Fig. 3.

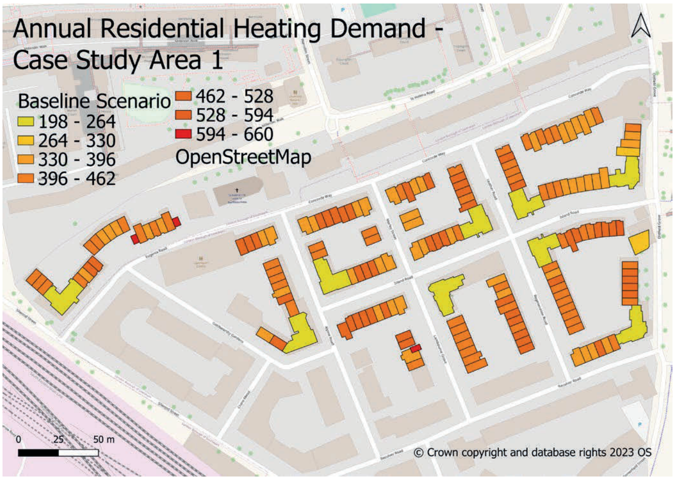

Fig. 2. Annual Residential Heat Demand for the Baseline Scenario (Present Climate), Case Study Area 1.

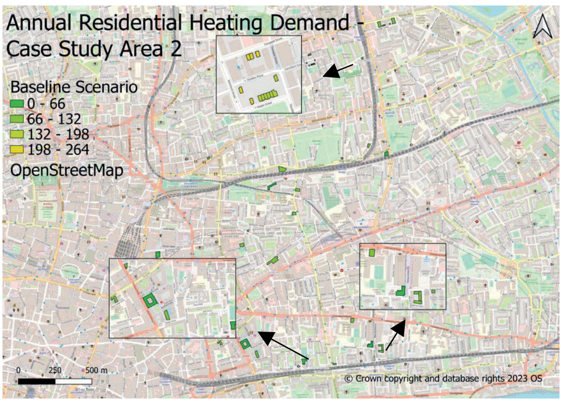

Fig. 3. Annual Residential Heat Demand for the Baseline Scenario (Present Climate), Case Study Area 2.

As it can be seen from the maps, the Area 1 with the old buildings is characterized by a higher annual residential energy demand, compared to Area 2. Undoubtedly, there are the expected results as the energy related data of the old buildings, such as the construction materials of the walls, that have an increased thermal transmittance, lead to lower energy performance rate of the dwellings.

Following the baseline scenario are the future climate scenarios. The maps for case study Area 1 are presented in Fig. 4. In Fig. 4(a) and (b), the annual residential heat demand, in 2050 and 2100, is presented in accordance with the RCP4.5 weather data scenario. In Fig. 4(c) and (d), the heating demand for the same decades is presented, under the worst-case future climate scenario, namely the RCP8.5. For Case Study Area 2, the same maps are shown in Appendix.

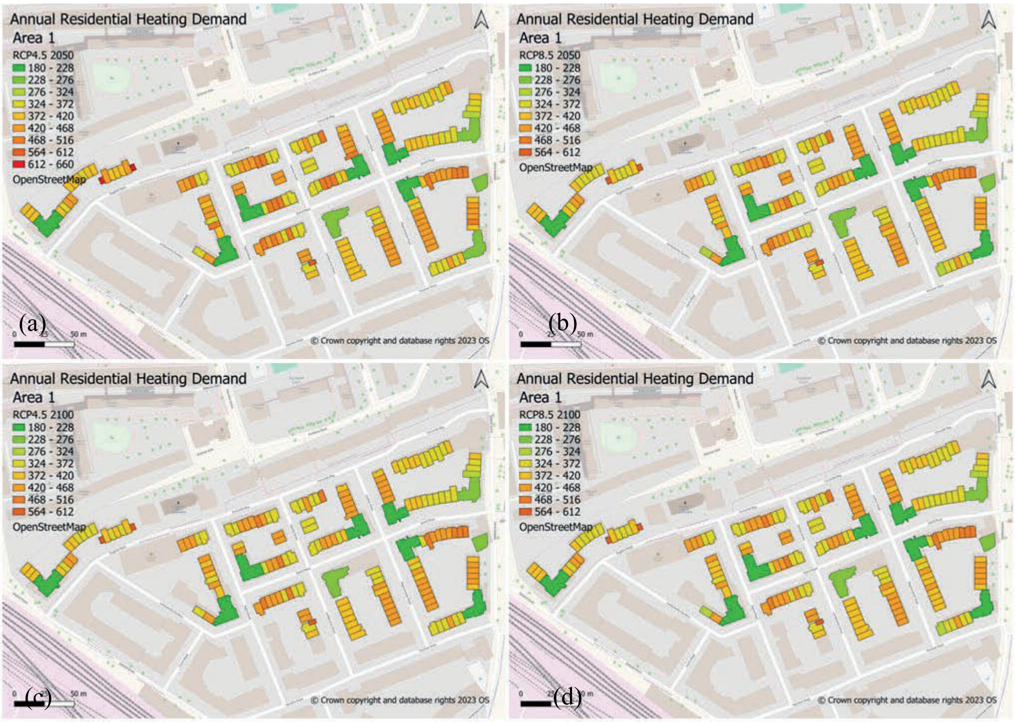

Fig. 4. Annual Residential Heat Demand for Future Climate Scenarios, Case Study Area 1. (a) Future Climate Scenario: RCP4.5, 2050. (b) Future Climate Scenario: RCP8.5, 2050. (c) Future Climate Scenario: RCP4.5, 2100. (d) Future Climate Scenario: RCP8.5, 2100.

As it is obvious, the difference in the annual energy demand is not that clear with this mapping. Hence, it has been decided to calculate the percentage difference of the energy demand from the baseline scenario compared to the future climate scenarios. The findings are presented in the sub-section below.

3.3. Present Climate to Future Climate Scenarios - Percentage Difference in Annual Residential Heat Demand Maps

The percentage difference of the annual residential heating demand from the present climate to the future weather data has been calculated, in order to create a clearer picture of the climate change situation. Figure 5 shows an obvious difference between the RCP4.5 and RCP8.5 scenarios, for Case Study Area 1. It can be seen that, by taking into consideration the worst-case scenario, the percentage difference of the energy demand, for both 2050 and 2100 years, could reach even 13 % increase. On the other hand, for the scenario RCP4.5, the highest percentage change of heating demand could reach up to 8 % for 2050, and up to 9 % for 2100.

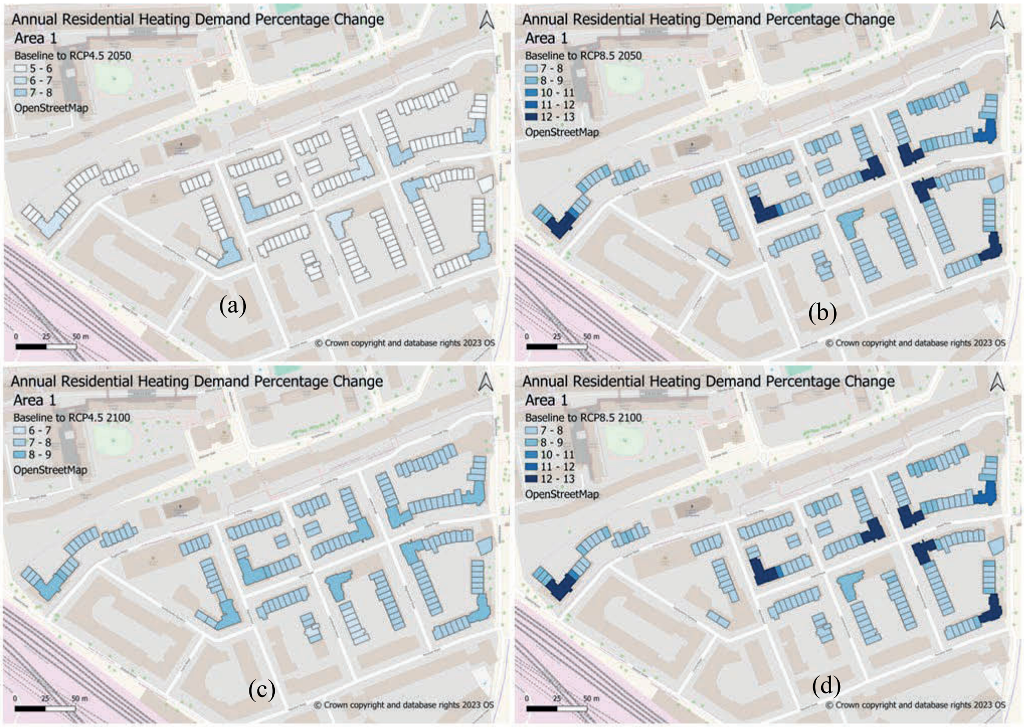

Fig. 5. Percentage Difference in Annual Residential Heat Demand from Present Climate to Future Climate Scenarios, Case Study Area 1. (a) Future Climate Scenario: RCP4.5, 2050. (b) Future Climate Scenario: RCP8.5, 2050. (c) Future Climate Scenario: RCP4.5, 2100. (d) Future Climate Scenario: RCP8.5, 2100.

Apart from these, the results show that there is no such difference between the year 2050 and 2100 for the worst-case scenario. Therefore, it could be stated that for the worst-case future climate scenario, the annual heating demand will be decreasing at a higher rate, compared to RCP4.5, leading to an increased cooling demand in the summer seasons.

As for the Annual Residential Energy Demand maps, for Case Study Area 2, the percentage difference from present climate to future climate scenarios is presented in Annex.

However, in order to be able to make faster comparisons between the Case Study Areas, the years and the scenarios, a bar chart of the results has been created.

3.4. Present Climate to Future Climate Scenarios - Percentage Difference in Annual Residential Heat Demand Graph

The following bar chart (Fig. 6) shows the annual residential heating demand change from the present climate to future climate scenarios for both case study areas, namely the Area 1 with old dwellings and the Area 2 with the new-built dwellings.

From the bar chart, the difference in the change of the heating demand between the Case Study Area 1 and Case Study Area 2 is obvious. This points out that due to the fact that older buildings already have a high annual heating demand, the climate change will impact their energy performance, but there will be no such extreme influence as for new-built buildings.

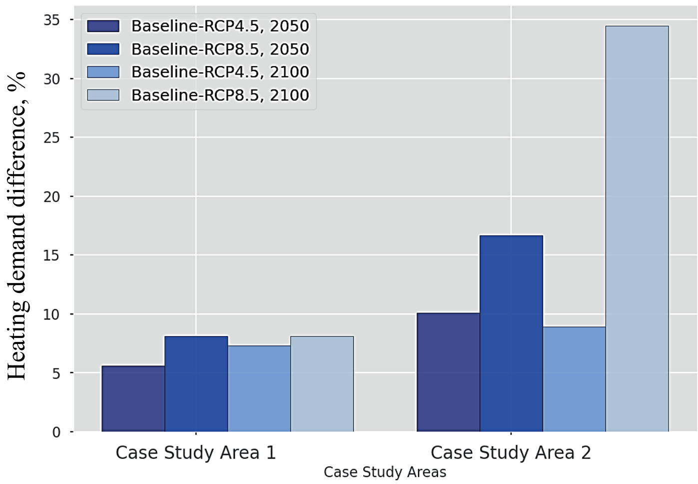

Fig. 6. Annual Residential Heating Demand Percentage Change from Present Climate to Future Climate Scenarios.

In particular, the most noticeable difference between Area 1 and Area 2, is for the worst-case scenario in 2100. For Case Study Area 1, the percentage difference is around 9 %, in contrast to Case Study Area 2 that nearly touches 35 % heating demand difference. Nonetheless, even for RCP4.5 scenario, in 2050, it can be seen that the percentage difference is almost double for the newer buildings compared to the 1890s dwellings. At this point, it should be pointed out that the specific energy model does not take into account any renovations that have been conducted to dwellings.

Apart from the comparison between the case study areas, the above graph helps for the comparison between the future climate scenarios. From the graph, it is evident that there is slight difference between the scenarios for Case Study Area 1, and higher difference between the scenarios for Case Study Area 2. Undoubtedly, this is happening due to the construction year difference that has been stated above. Moreover, for Area 1 and RCP4.5, the percentage difference in heating demand is 3 % higher from the year 2050 to 2100, and slightly higher (less than 1 %) for RCP8.5. On the other hand, for Area 2, a reverse behavior is observed. For RCP4.5, the percentage difference of the heating demand is lower by 1 % for the year 2100 than the year 2050, in contrast to RCP8.5 that follows the same pattern as Case Study Area 1.

4. Conclusion

The purpose of this research study has been the examination of the influence of the climate change to the energy performance of the residential stock, by estimating the annual residential heating demand in present and future climate scenarios and comparing the findings of two different case study areas, with old and new-built buildings. The findings have shown a distinction between the percentage difference of the heating demand for Area 1 and Area 2.

For old residential stock, it has been seen that there is lower influence on the heating demand from future weather scenarios, as even in present climate the heating demand is extremely high, whereas the heating demand in newer dwellings has been highly affected from the predicted climate, giving extremely increased percentage change for RCP8.5 scenario, specifically. In other words, there has been a higher percentage change in energy demand for newer than older dwellings, and for RCP8.5 than RCP4.5.

Therefore, on the one side, the study found that a reduction in carbon emissions under the RCP4.5 scenario will result in a tiny drop in district-level heating demand, necessitating the provision of slightly higher levels of heating through the use of sustainable alternatives. On the other side, adhering to the RCP8.5 scenario of carbon emission and carrying on as usual will result in a considerable decrease in heating demand because of the rise in temperature but with the concomitant overheating in summer, which will shift the problem of energy generation. The findings imply that, as a result of climate change and the rising temperature, the energy generation must begin to adapt in order to handle the increase of the global temperature and the possible overheating of dwellings. This means that a shift in the energy delivered from heating to cooling might be essential, leading to the need for further research on future cooling demand investigation.

As regards to recommendations for future research studies, larger areas should be tested, in order to have bigger sample size, the influence of the building age to the results should be examined, in order to understand the distinction between the Case Study Area 1 and Case Study Area 2, and finally, the importation of the refurbishment of the residential stock could add more reliability to the results.

ACKNOWLEDGEMENT

To EPSRC Centre for Doctoral Training (CDT) in Geospatial Systems and to Ordnance Survey for funding this research and supporting it with geospatial data.

REFERENCES

[1] Hoegh-Guldberg O., *et al.* The human imperative of stabilizing global climate change at 1.5 °C. *Science* 2019:365(6459). https://doi.org/10.1126/science.aaw6974

[2] Santamouris M., *et al.* Heat mitigation technologies can improve sustainability in cities. An holistic experimental and numerical impact assessment of urban overheating and related heat mitigation strategies on energy consumption, indoor comfort, vulnerability and heat-related mortality and morbidity in cities. *Energy and Buildings* 2020:217:110002. https://doi.org/10.1016/j.enbuild.2020.110002

[3] Santamouris M., Vasilakopoulou K. Present and future energy consumption of buildings: Challenges and opportunities towards decarbonisation. [Online], [Accessed: 04:04:2023]. Available: https://reader.elsevier.com/reader/sd/pii/S2772671121000024?token=4F6457740C0129AFB8E37F5A5E86E172D2DDFBE0E31089BB7EF61425F9DEC7307B909B3A14FA86565797E18E6343B195&originRegion=eu-west-1&originCreation=20230404110610

[4] Wang R., Lu S. A novel method of building climate subdivision oriented by reducing building energy demand. *Energy and Buildings* 2020:216:109999. https://doi.org/10.1016/j.enbuild.2020.109999

[5] Ibrahim A., Jimenez-Bescos C. Assessing the Performance Gap of Climate Change on Buildings Design Analytical Stages Using Future Weather Projections. *Environmental and Climate Technologies* 2020:24(3):119–134. https://doi.org/10.2478/rtuect-2020-0091

[6] Wang R., Lu S., Zhai X., Feng W. The energy performance and passive survivability of high thermal insulation buildings in future climate scenarios. *Building Simulation* 2022:15(7):1209–1225. https://doi.org/10.1007/s12273-021-0818-3

[7] Jimenez-Bescos C., Oregi X. Implementing User Behaviour on Dynamic Building Simulations for Energy Consumption. *Environmental and Climate Technologies* 2019:23(3):308–318. https://doi.org/10.2478/rtuect-2019-0097

[8] Laktuka K., Pakere I., Lauka D., Blumberga D., Volkova A. Long-Term Policy Recommendations for Improving the Efficiency of Heating and Cooling. *Environmental and Climate Technologies* 2021:25(1):382–391. https://doi.org/10.2478/rtuect-2021-0029
[9] Thapa S., *et al.* Simulation of thermal comfort and energy demand in buildings of sub-Himalayan eastern India. Impact of climate change at mid (2050) and distant (2080) future. *Journal of Building Engineering* 2023:68:106068. https://doi.org/10.1016/j.jobe.2023.106068
[10] Gao B., Zhu X., Ren J., Ran J., Kim M. K., Liu J. Multi-objective optimization of energy-saving measures and operation parameters for a newly retrofitted building in future climate conditions: A case study of an office building in Chengdu. *Energy Reports* 2023:9:2269–2285. https://doi.org/10.1016/j.egyr.2023.01.049
[11] Amaripadath D., Rahif R., Zuo W., Velickovic M., Voglaire C., Attia S. Climate change sensitive sizing and design for nearly zero-energy office building systems in Brussels. *Energy and Buildings* 2023:286:112971. https://doi.org/10.1016/j.enbuild.2023.112971
[12] Baba F. M., Ge H., Wang L., Zmeureanu R. Assessing and mitigating overheating risk in existing Canadian school buildings under extreme current and future climates. *Energy and Buildings* 2023:279:112710. https://doi.org/10.1016/j.enbuild.2022.112710
[13] Jiménez Torres M., Bienvenido-Huertas D., May Tzuc O., Bassam A., Ricalde Castellanos L. J., Flota-Bañuelos M. Assessment of climate change's impact on energy demand in Mexican buildings: Projection in single-family houses based on Representative Concentration Pathways. *Energy for Sustainable Development* 2023:72:185–201. https://doi.org/10.1016/j.esd.2022.12.012
[14] Gaarder J. E., Friis N. K., Larsen I. S., Time B., Møller E. B., Kvande T. Optimization of thermal insulation thickness pertaining to embodied and operational GHG emissions in cold climates – Future and present cases. *Building and Environment* 2023:234:110187. https://doi.org/10.1016/j.buildenv.2023.110187
[15] Rodrigues L. T., Gillott M., Tetlow D. Summer overheating potential in a low-energy steel frame house in future climate scenarios. *Sustainable Cities and Society* 2023:7:1–15. https://doi.org/10.1016/j.scs.2012.03.004
[16] Al Huneidi D. I., Tahir F., Al-Ghamdi S. G. Energy modeling and photovoltaics integration as a mitigation measure for climate change impacts on energy demand. *Energy Reports* 2022:8:166–171. https://doi.org/10.1016/j.egyr.2022.01.105
[17] Ali U., Shamsi M. H., Hoare C., Mangina E., O'Donnell J. Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis. *Energy and Buildings* 2021:246:111073. https://doi.org/10.1016/j.enbuild.2021.111073
[18] Dochev I. Computing Residential Heat Demand in Urban Space using QGIS. A Case Study for Shumen, Bulgaria. 2016. [Online]. [Accessed: 14.04.2021]. Available: http://programm.corp.at/cdrom2016/files/CORP2016_proceedings.pdf
[19] Digimap. [Online]. [Accessed: 28.09.2023]. Available: https://digimap.edina.ac.uk/
[20] Colouring London. [Accessed: 26.06.2021]. [Online]. Available: https://colouring.london
[21] Survey O. OS Data Hub. Free Maps & API Data for Developers. [Online]. [Accessed 28.09.2023]. Available: https://osdatahub.os.uk/
[22] London Datastore – Greater London Authority. [Online]. [Accessed: 28.09.2023]. Available: https://data.london.gov.uk/
[23] Episcope. Tabula. [Online]. [Accessed: 28.09.2023]. Available: https://episcope.eu/welcome/
[24] San José R., Pérez J. L., González R. M., Pecci J., Garzón A., Palacios M. Impacts of the 4.5 and 8.5 RCP global climate scenarios on urban meteorology and air quality: Application to Madrid, Antwerp, Milan, Helsinki and London. *Journal of Computational and Applied Mathematics* 2016:293:192–207. https://doi.org/10.1016/j.cam.2015.04.024

ANNEX

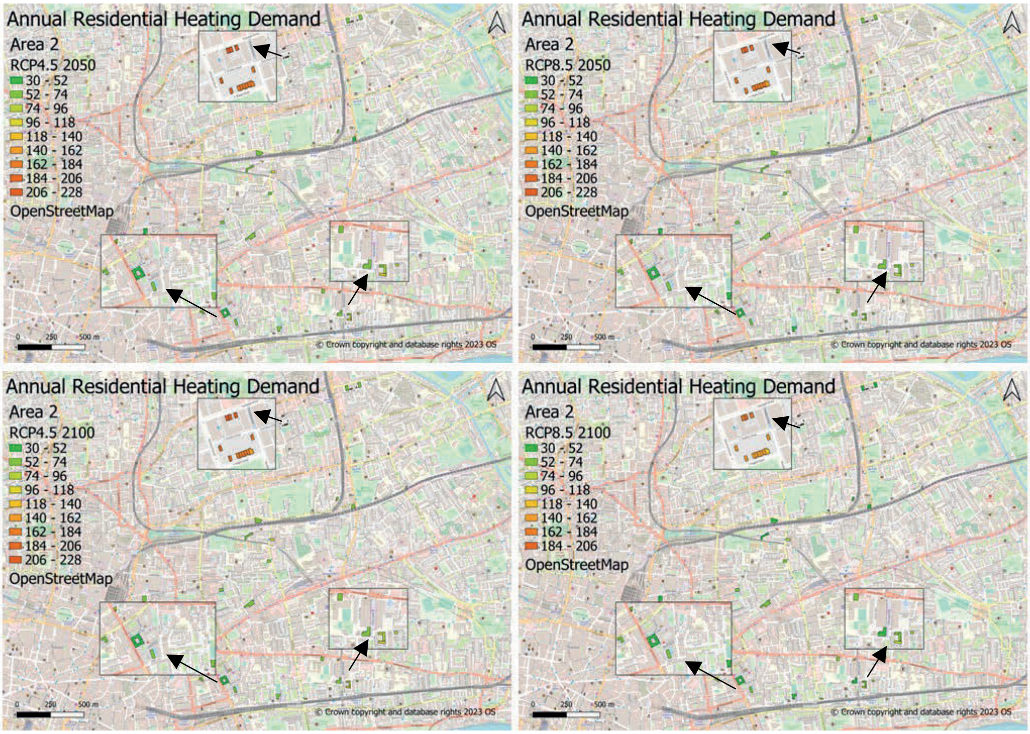

Fig. 7. Annual Residential Heat Demand for Future Climate Scenarios, Case Study Area 2.

Fig. 8. Percentage Difference in Annual Residential Heat Demand from Present Climate to Future Climate Scenarios, Case Study Area 2.