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John Littlewood
Robert J. Howlett
Lakhmi C. Jain *Editors*

Sustainability in Energy and Buildings 2022

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Sustainability in Energy and Buildings 2022

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Preface

The 14th International Conference on Sustainability and Energy in Buildings 2021 (SEB22) is a significant international conference organised by a partnership made up of KES International and The Sustainable and Resilient Built Environment research group, Cardiff Metropolitan University.

SEB-22 invited contributions on a range of topics related to sustainable and resilient buildings and renewable energy and explored innovative themes regarding building adaptation responding to climate change mitigation and other local, national and global challenges.

The aim of the conference was to bring together University researchers, Government and Scientific experts and Industry professionals to discuss the minimisation of energy use and associated carbon emissions in buildings, neighbourhoods, cities in the urban context but also rurally; from a theoretical, practical, implementation, modelling and simulation perspective. The conference formed an exciting chance to present, interact, and learn about the latest research and practical developments on the subject with real world impact. SEB22 will be held in a hybrid form with physical and virtual attendance, in response to agile work patterns following the global COVID-19 pandemic.

The conference featured two General Tracks chaired by experts in the fields:

- Sustainable and Resilient Buildings
- Sustainable Energy Technologies.

In addition, there were eight Invited Sessions proposed and organised by prominent researchers.

It is important that a conference provides high quality talks from leading-edge presenters. SEB-22 featured the keynote speaker Prof. Pete Walker, Centre for Innovative Construction Materials, Department of Architecture and Civil Engineering at the University of Bath UK.

The conference attracted submissions from around the world. Submissions for the Full-Paper Track were subjected to a two-stage blind peer-review process. With the objective of producing a high-quality conference, only the best of these were selected for presentation at the conference and publication in the Springer as book chapters. Submissions for the Short Paper Track were subjected to a ‘lighter-touch’ review and published in an online medium, but not in the Springer book.

Thanks are due to the very many people who have given their time and goodwill freely to make SEB-22 a success. We would like to thank the members of the International Programme Committee who were essential in providing their reviews of the conference papers, ensuring appropriate quality. We thank the high-profile keynote speakers for providing interesting talks to inform delegates and provoke discussion. Important contributors to the conference were made by the authors, presenters, and delegates without whom the conference could not have taken place, so we offer them our thanks. Finally, we would like to thank the administrative staff of KES International.

It is hoped that you find the conference an interesting, informative, and useful experience; and remain connected through the KES International Virtual Conference Experience.

Cardiff, Wales, UK — John Littlewood
Shoreham-by-Sea, UK — Robert J. Howlett
Selby, UK — Lakhmi C. Jain

SEB-22 Conference Chairs

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About the Editors

John Littlewood is a Professor of Sustainable and Resilient Buildings, and holds a Ph.D. in Building Performance Assessment. He is the head of the Sustainable and Resilient Built Environment research group in Cardiff School of Art and Design at Cardiff Metropolitan University (UK). He has been General Chair for the Sustainability in Energy and Buildings international conference in 2014, 2017 and from 2019 to date. He coordinates three professional doctorates in Art and Design Practice, Engineering, and Sustainable Built Environment. He is a Chartered Building Engineer and his innovation, and research expertise is industry focused, identifying and improving fire and thermal performance in existing and new dwellings to enable occupant quality of life. In addition, to helping organisations use innovative materials in offsite manufacturing and in construction to deliver a sustainable and resilient built environment. He has authored, co-authored and co-edited over 160 peer-reviewed articles and book volumes for Springer.

Robert J. Howlett is the Academic Chair of KES International a non-profit organisation which facilitates knowledge transfer and the dissemination of research results in areas including Intelligent Systems, Sustainability, and Knowledge Transfer. He is Visiting Professor at 'Aurel Vlaicu' University of Arad, Romania, and has also been Visiting Professor at Bournemouth University, UK. His technical expertise is in the use of artificial intelligence and machine learning for the solution of industrial problems. His current interests centre on the application of intelligent systems to sustainability, particularly renewable energy, smart/micro grids and applications in housing and glasshouse horticulture. He previously developed a national profile in knowledge and technology transfer, and the commercialisation of research. He works with a number of universities and international research groups on the supervision teams of Ph.D. students, and the provision of technical support for projects.

Professor Lakhmi C. Jain Ph.D., Dr. H.C., M.E., B.E.(Hons), Fellow (Engineers Australia), is with the Liverpool Hope University and the University of Arad. He was formerly with the University of Technology Sydney, the University of Canberra and Bournemouth University.

Professor Jain serves the KES International for providing a professional community the opportunities for publications, knowledge exchange, cooperation and teaming. Involving around 5000 researchers drawn from universities and companies world-wide, KES facilitates international cooperation and generate synergy in teaching and research. KES regularly provides networking opportunities for professional community through one of the largest conferences of its kind in the area of KES.

Impact of Climate on Building Energy Performance, Urban Built Form and Urban Geometry

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Abstract. The study investigates the impact of climate on the residential building energy performance and its relationship with urban built form and geometry of the built environment. It aims to identify the most energetically sustainable urban built form and optimal urban geometry in different climates that results in higher energy performance of buildings. Geometrical models of four urban built forms are developed, and a simulation method is used to conduct sensitivity analyses over the four case studies (cities of London, Singapore, Helsinki and Phoenix) that are selected based on specific climatic criteria. The Energy Equity (EE) indicator is used for demonstration of the results, which simultaneously considers the amount of building energy demand as well as energy generation by building-mounted PVs. The results show that increasing the cut-off angle (i.e., reducing buildings distance) reduces building energy demand in cooling-dominated buildings (i.e., in Singapore and Phoenix) between 6% and 56% while increases building energy demand in heating-dominated buildings (i.e., in London and Helsinki) between 2% and 16.5%. Hence, the impact of distance between buildings on building energy demand is more significant in hot climates. In general, building energy demand in London is the lowest among the case studies, while it is the highest in Singapore (up to 219% higher than London). London also shows the highest value of EE (demonstrating the best energy performance) and Helsinki shows the lowest (up to 51% lower than London). It is recommended to use the tunnel-court built form to have a more energy-efficient buildings, specifically in hot climates.

Keywords: Building energy performance · Urban built form · Climate

1 Introduction: The Importance of Design with Climate

It has been well-established by different studies that building energy performance correlates with urban built form and density [1–3], while urban density is directly related to the geometry of the built environment [4]. The correlation itself is influenced by climate

The original version of this chapter was revised: The second author's name has been changed to "Amira Elnokaly". The correction to this chapter is available at https://doi.org/10.1007/978-981-19-8769-4_41

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and dependent on the geographical location of a city. For instance, both the magnitude and type of building energy demand and the potential of renewable energy generation, specifically solar energy, depend on climate and location. They consequently influence the relationship of energy with urban form and geometry [5]. This makes it vital to design buildings according to climatic conditions during the early stages of the design process [6]. Climatic variables must be known to predict the thermal behavior of the building envelope [7].

In contemporary building designs and with the use of mechanical equipment (e.g., air conditioning system) to provide satisfying thermal conditions, less attention has been paid to climatic conditions. Built forms have become very similar in every corner of the world regardless of climate, reflecting the loss of traditional skills with respect to a climate-sensitive design. More recently, with more focus on sustainability, we have begun to consider climate conditions for achieving sustainable building/urban designs. For instance, Dursun and Yavas [8] emphasized that to have a sustainable urban development, a climate-sensitive urban design guideline is urgently needed and the urban built environment should be consistent with climatic conditions. Muhaisen [9] suggested general rules and guidelines for the design of courtyards in four different climatic regions. Kocagil and Oral [10] showed that building form and settlement texture are influential parameters for heating/cooling loads of buildings in a hot-dry climate zone to provide optimum conditions. Khalili and Amindeldar [11] identified that traditional courtyards have emerged in the hot-arid regions of Iran to reduce the detrimental aspects of the climate providing better microclimatic conditions for occupants. Strømann-Andersen and Sattrup [12] argued that in northern European cities with high latitudes and low solar inclinations, urban density is of particular concern since urban geometry affects solar access more than in other urban centers around the world.

Therefore, climate not only influences building energy demand but also determines suitable built forms and density of urban areas. Although previous studies have investigated the impact of climate on building energy demand, few have considered the impact of climate on the energy performance of buildings with different built forms and urban geometric variables. The aim of this study is identification of the most energetically sustainable urban built form and optimal urban geometry in different climates that results in higher energy performance of buildings. Building energy performance includes energy demand along with solar energy generation from roof-mounted PV panels that is necessary to be considered to achieve sustainable cities of future. Four case studies from different climate zones are selected and for each case, the correlation of building energy performance with urban geometric variables and the selected built forms is investigated. Simulation method is adopted for energy simulation of the built form models, and consequently, a comparative analysis suggests the most energy-efficient urban built forms in the different climates.

2 Methodology

The study initially develops geometric models of the four selected built forms using three influential geometric parameters. Secondly, case studies from different climate zones are selected. Finally, simulation trials are performed to obtain building energy demand and solar energy generation from roof-mounted PVs. The results from different case studies are compared to identify the impact of climate on building energy performance, urban built form and urban geometry.

2.1 Developing Geometrical Models of Different Built Forms

Geometrical models of four urban built form, namely, pavilion, terrace, court and tunnel-court form are developed (see Fig. 1) using three geometrical parameters, namely, the cut-off angle (θ), the plan depth (x) and the number of floors (n) [4]. These three variables explain the whole geometry of a built environment and have a significant effect on building energy performance [13]. As shown in Fig. 1 (right), the cut-off angle represents the distance between buildings (L) in the site plan.

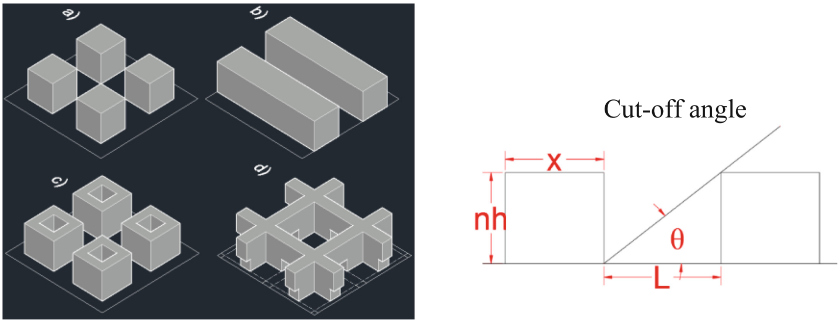

Fig. 1. Generic urban built forms **a** pavilion, **b** terrace, **c** court, and **d** tunnel-court (left), section showing cut-off angle (right).

2.2 Case Study Selection and Energy Simulation

Case studies from different climatic conditions are selected using the Köppen climate classification system (also known as the Köppen–Geiger) [14]. It divides the earth into five main zones, Group A: tropical (mega thermal) climates, Group B: dry (arid and semiarid) climates, Group C: temperate (mesothermal) climates, Group D: continental/cold (microthermal) climates, Group E: polar and alpine (montane) climates. Four large metropolitan cities are selected as the case studies based on their diverse climatic conditions to represent each of the main climate zones. Their great populations show their significant contribution to overall urban energy consumption. Hence, providing guidelines for the optimization of energy with respect to their built form and geometry is beneficial for future developments of these cities that can conserve significant amounts of energy and prevent high levels of carbon emissions.

Group A: Singapore (tropical hot and humid climate): The metropolitan City of Singapore, located at the latitude of 1.3521° N and longitude of 103.8198° W, is an equatorial city with a hot, humid and rainy climate. Energy consumption of buildings contributes about a third of Singapore's total electricity production [15]. Although using passive design strategies are encouraged in 80% of the residential built area, the energy performance of a building is measured according to active mechanical systems [16].

Group B: Phoenix (hot and arid climate): The metropolitan City of Phoenix as the capital of the state of Arizona in the USA, located at the latitude of 33.4484° N and longitude of 112.0740° W. Phoenix has a long, hot summer and short, mild winter. It is one of the sunniest cities in the world (in a desert location) with approximately 300 days of sunshine per year. It makes this city a suitable candidate for this study since the potential of PV energy harvesting is being considered.

Group C: London (temperate climate): The metropolitan City of London as the capital of England, located at the latitude of 51.5074° N and longitude of 0.1279° W. It has a temperate climate with warm summer and without dry season.

Group D: Helsinki (continental cold climate): The metropolitan City of Helsinki as the capital city of Finland, located at the latitude of 60.1699° N and longitude of 24.9384° W. It has a continental cold climate with warm summer and without a dry season. Its intense winters impose a significant heating load on buildings.

This study does not find any necessity to analyse a city from group E because there are no large metropolitan urban areas in these parts of the World; and the outcome would be identical to the continental cold climate with similar (but sharper) trends.

The simulation method is adopted for the energy analysis of the case studies. An urban energy simulation software, CitySim, is used to perform an energy analysis on the geometrical models of the chosen built forms. CitySim considers parameters such as the shadowing effect of adjacent buildings, radiative inter-reflection between external surfaces, and the Urban Heat Island (UHI) effect [17], which are important features for investigating the impact of the geometry of the built environment on building energy performance. UHI effect is considered by calculating the surface temperature of all the surfaces existing in the site plans on an hourly basis. The climate files of each of the case studies are derived from the Meteonorm database, which contains 10 years of average data for each location plus their horizon files [18]. Theoretical site plans of buildings are developed for each built form to be fed into CitySim for energy analysis, which includes heating/cooling, lighting and appliances energy demands. Each site plan is composed of a 5 * 5 grid of similar buildings while only the energy performance of the central block is taken into account to not only limit the edge effect, but also, provide a more realistic microclimatic condition of a built environment composed of a specific form of buildings. Simulation trials are repeated by changing the geometrical variables to identify the impact of each variable on the building energy performance. Subsequently, the whole process is repeated separately for each case study using its relevant climate data. To ensure a like-for-like comparison between built areas with different geometries, the parameters such as building materials, insulation, infiltration rate (0.5 ACH), glazing ratio (40%), occupant density (35 m^2/person) and room setpoint temperature (20 °C for heating and 24 °C for cooling) are kept constant. All buildings are assumed to be highly insulated with wall and roof U-values of 0.18 and 0.13 W/m^2K, respectively. In practice, the physical characteristics of a building envelope might be influenced by climatic conditions. For instance, the value of glazing ratio in Helsinki and Singapore should be different since solar gains have an opposite impact on their building energy demand. However, in this study, to be consistent in all case studies and to focus the study on the impact of climate, these parameters are kept constant for all climatic zones.

In addition to climate and horizon files, the other input data for the simulation that is variable for different case studies is the heating/cooling period considered for energy simulations. This factor is the direct offspring of the climate that is varied for different climates. In Singapore, the average temperature during the day and the night is almost constant throughout the year. Therefore, buildings require only cooling related energy all year round, which is defined as the annual electrical energy consumption of the air-conditioning system [15]. Cooling energy is considered to be supplied by a heat pump in the simulations for this study. Therefore, it increases the total electricity consumption of buildings. Looking at historical climate data for Phoenix [19] and following information provided by authors of previous studies on this city [20, 21], the typical building cooling period is considered to be from April to October and the heating period from November to March. Phoenix and Singapore both have a hot climate, however, they possess considerably different climatic conditions that create different building energy requirements. Singapore requires 12 months of cooling while Phoenix requires seven months of cooling and five months of heating. Due to the desert location of Phoenix, there is normally a substantial change in temperature between daytime and nighttime, therefore, the thermal behavior of the hot-dry climate is very distinctive due to wide daily and seasonal fluctuations [10]. In London, the heating season begins in October and lasts until the end of May according to SAP [22]. Due to the temperate climate of the UK and its mild summers, normally no cooling load is considered for residential buildings [23–25]. Helsinki has a cold climate with a long heating season. To be consistent with London case study, only the heating period is considered for simulation trials of Helsinki, which is similarly the period between October and May. For the purpose of this study, gas is used for preparation of heat for homes.

For each case study, 216 simulation trials are conducted for different building plans. These site plans are obtained by combining the changes in the geometric variables that means altering the number of floors (from 1 to 30), cut-off angle (25°, 45° and 65°), and plan depths (from 6 to 60m with 6m intervals). The selection of 6m interval is based on the passive to non-passive area ratio determined in the LT method [26]. The resulting values of building energy demand are given in kWh/m^2/year for each plan. Meanwhile, it is assumed that 90% of all building roofs are covered by PVs to obtain the solar energy potential of buildings in different climates. A dimensionless energy indicator termed Energy Equity [13] is used, which is defined as the ratio of the yearly energy generation by building-mounted PVs over building energy demand. It is an indication of building energy self-sufficiency. Please note that if seasonal self-sufficiency is accounted (instead of yearly one), the outcomes might be different.

3 Results and Discussion

In this section, initially the impact of cut-off angle on building energy demand is investigated, and subsequently, the comparative analysis of building energy performance in different climates is illustrated.

3.1 Impact of Cut-Off Angle in Different Climates

To investigate the impact of cut-off angle on building energy demand in each case study, building plans composed of similar buildings but different cut-off angles are simulated. The results for different climates are collected, and exemplar cases are shown in Fig. 2, which represents the general trends of all cases.

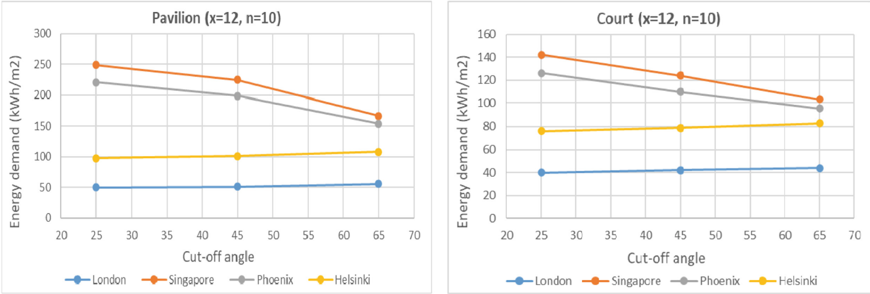

Fig. 2. Impact of cut-off angle on building energy demand in different climates (exemplar cases).

It can be seen from Fig. 2 that, in both London and Helsinki, greater cut-off angle results in higher building energy demand. It means that, for all the built forms, energy demand of buildings is the highest for built environment with a cut-off angle of 65°, while having cut-off angle of 25° leads to the lowest building energy demand. For instance, for pavilion buildings with plan depths of 12 m and 10 number of floors in London, energy demand is equal to 50, 51 and 56 (kWh/m^2) for the $\theta = 25°$, $\theta = 45°$ and $\theta = 65°$ cases, respectively. In Helsinki, varying the cut-off angle from 25° to 65° can increase building energy demand between approximately 2% and 12%, depending on the plan depth. The main reason for this outcome is the shadowing effect of the neighbor buildings. Higher cut-off angles mean building are closer to each other, which blocks a larger portion of sunlight. This not only reduces the solar gain of buildings through glazing, but also decreases the amount of energy stored in building thermal mass. As a result, buildings need more energy to satisfy their heating energy demand [27]. It means that a higher urban density is not advantageous for continental/cold/temperate climates. Considering urban energy planning targets for these cities, this may encourage urban planners to plan new urban built areas to have lower cut-off angles by increasing the distances between buildings.

The results show an opposite trend for the cities of Singapore and Phoenix. In Singapore, changing the cut-off angle from 25° to 65° can diminish building energy demand from approximately 8–56% depending on the plan depth. Therefore, higher density reduces building energy demand in hot climates that buildings are cooling-dominated. The reason is that by increasing the cut-off angle the buildings become closer and therefore the shadowing effect of adjacent buildings protects them from intense solar radiation (which reduces solar heat gain) that consequently decreases the cooling energy requirement of a building [28–30]. However, the trend of this reduction in Phoenix is not as pronounced as for Singapore due to the fact that the buildings in Phoenix demand heating load in wintertime, while cooling is required for buildings in Singapore all year round. This heating load is the element that mitigate the sharpness of this trend. Changing cut-off angle from 25° to 65° in Phoenix can reduce building energy demand between approximately 6% and 47% (depending on the plan depth).

In general, the change in the building energy demand by altering cut-off angle is significantly smaller in heating-dominated buildings than the change it imposes to the cooling-dominated buildings. The analysis of this section emphasizes that the impact of urban density on building energy demand definitely depends on the climate and geographical location.

3.2 Comparison of Different Climates

Here, the results obtained from all case studies are aggregated to make a comparison between the energy performance of the studied built forms in the different climates. The resulting values of building energy demands from the four case studies are compared, and eight exemplar cases are shown in Fig. 3. These cases are selected in the way to represent the whole range of values for the geometric variables including high and low-rise buildings, small and great depth buildings, and high/low cut-off angles. They are the similar cases from the different case studies (shown by different colors), that have been chosen among more than 200 datasets obtained from the simulation trials, where the general trend of all of them are similar. In each case, built form, cut-off angle (θ), plan depth (x) and number of floors (n) are kept constant, which means the density is constant too as a result of the similarity of all parameters considered. Therefore, the only variable in each case is climate.

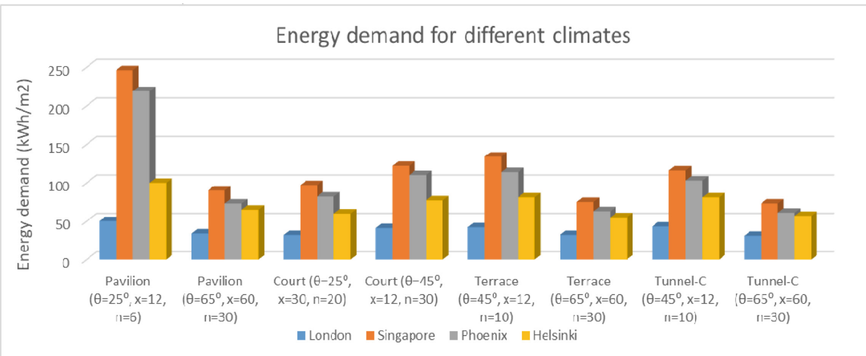

Fig. 3. Comparison of the energy demand of the built forms with similar geometric parameters in different climates (representative selection of 8 cases out of 216 datasets).

It can be observed that the lowest energy demand belongs to London, having a significant difference compared to the others. The next lowest energy demand is associated with Helsinki and is followed by Phoenix. Finally, the highest energy demand belongs to Singapore. The low energy demand of London is due to its temperate climate which necessitates less heating energy to reach the thermal comfort temperature of occupants. Due to the cold climate of Helsinki, the outside temperature has a larger divergence from the inside setpoint room temperature. Phoenix and Singapore mainly require cooling demand that itself requires more energy compared with heating demands. Moreover, according to their climatic conditions, they demand energy 12 months of a year, while it is only eight months for London and Helsinki. Therefore, these two case studies show higher energy demand. Notably, the weather in Phoenix is harsher and hotter in the summer period which requires higher cooling demand to the buildings but requires less total energy than Singapore which requires cooling all year round (Phoenix buildings require heating for five months of a year).

To investigate the scale of these differences, the case of terrace form with θ = 45°, x = 12 m and n = 10 is analysed here. The resulting energy demand of buildings in London, Helsinki, Phoenix and Singapore are 42, 81, 114 and 134 kWh/m^2/year, respectively. This shows that yearly building energy demand in Helsinki, Phoenix and Singapore are 93%, 171% and 190% higher than in London. This highlights the significant impact of climate on building energy demand.

Among the cases shown in Fig. 3, the first case that is composed of pavilion form with θ = 25°, x = 12 m and n = 6 shows a relatively abnormal high energy demand for the Phoenix and Singapore case studies. In this specific instance, the energy demands for these two case studies are unexpectedly much higher than in London and Helsinki, and their percentage differences are not following the above-mentioned trend. In fact, the energy demand for Phoenix and Singapore are 338% and 392% higher than London, respectively, while they have only a 12% difference between each other. This substantial difference is due to a combination of three features, (i) it is a pavilion, (ii) it has a small plan depth, and (iii) it has a low cut-off angle. The pavilion built form consists of smaller internal space compared with other built forms [4], therefore, its envelope energy efficiency is more vulnerable to outside weather conditions. In addition, it has a small plan depth that makes it even more sensitive to the changes happening outside the building, and finally (and more importantly), the low cut-off angle increases the cooling load of the building in hot climates (i.e., Phoenix and Singapore). As previously demonstrated in Fig. 2, in hot climates, the increasing cut-off angle would decrease cooling demand of buildings. Therefore, in plans with a low cut-off angle, the difference between energy demand in hot climates and the cities such as London and Helsinki (that require heating load) are very significant. By increasing the cut-off angle, the difference is significantly reduced (e.g., θ = 65°).

A similar analysis is now performed by considering PV energy generation in addition to building energy demand for the different climates. Similar cases to Fig. 3 are compared using their EE values, as shown in Fig. 4.

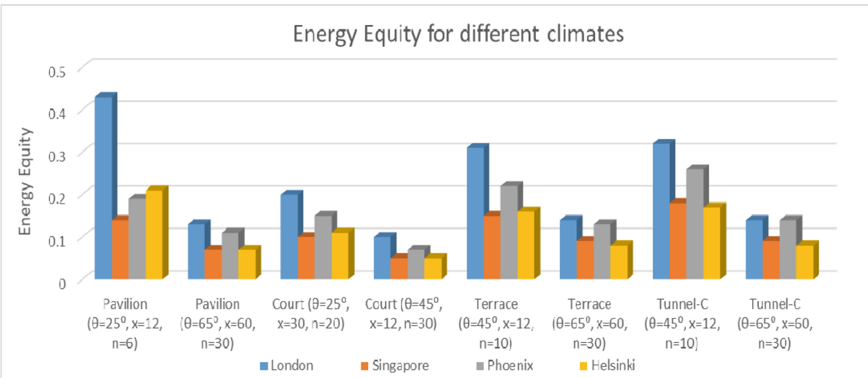

Fig. 4. Comparison of the Energy Equity (EE) of the built forms with similar geometric parameters in different climates.

Having similar geometry, density and built form in each case, Fig. 4 shows only the impact of climate on the EE indicator. It can be seen that the EE of London is higher than the others in all cases except with $\theta = 65°$, where the domination of the London case study, with respect to Phoenix, is not very significant (the reason will be discussed in the last paragraph of this section). Phoenix is ranked second in this comparison, achieving higher values than Singapore and Helsinki except in the first case. As explained when considering the results of Fig. 3, in that exceptional case, the cooling load in Phoenix and Singapore is very high which creates a substantial reduction in their EE. In this case, Helsinki, despite its low solar potential, acquires a higher value of EE than those. By way of a holistic comparison of the lowest-ranked case studies, Helsinki and Singapore, it is seen that Helsinki has greater EE than Singapore in site plans with low cut-off angles, while it is opposite in cases with large cut-off angles. This is connected to their energy demand (the denominator of the EE equation). It is shown in Fig. 2 that increasing the cut-off angle increases the energy demand of Helsinki (and decrease Singapore's) that reduced its EE value (and magnifies Singapore's). Therefore, although the amount of solar radiation in Singapore is substantially greater than in Helsinki, their EE values are relatively similar. According to the results of the simulation trials of PV energy generation, London PV generation is 1% more than Helsinki, Singapore is 54% more than London and Phoenix is 26% more than Singapore. Therefore, although there is a 55% difference between the PV generation potential of Helsinki and Singapore, their EE values remain similar.

As discussed above, for the cases with $\theta = 65°$, the EE of London is very close to that of Phoenix (and in the last case they are almost equal). The reason again is that in plans with high cut-off angle, building energy demand in London is increased while in Phoenix it is decreased (Fig. 2), which causes an opposite impact on the EE. Moreover, the reason that in the last case their EE is equal is that this is a tunnel-court form with $\theta = 65°$. For the tunnel-court form the roof surface area available for PV installation is greater than in other built forms, and in Phoenix, the intensity of solar radiation is greater than the other studied cities, especially London. These two features combined considerably increase the EE of Phoenix which results in equality of its value with London's.

4 Conclusion

In this study, four cities are analysed to investigate the impact of climates on their building energy performance and its relationship with urban geometric variables and built forms. The results show that by increasing the cut-off angle, the energy demand of buildings in London and Helsinki rise while it reduces building energy demand in Singapore and Phoenix. The reason is that energy demand in London and Helsinki is heating-dominated while in Singapore and Phoenix is cooling-dominated. The findings show that closely packed buildings provide shade for their neighbours, resulting in cooler environments that increases the heating load while decreases cooling load. The impact of cut-off angle on the building energy demand of cooling-dominated buildings is significantly higher than on heating-dominated buildings.

The direct comparison of the studied built forms in the chosen case studies shows that yearly building energy demand is a minimum in London while it is maximum in

Singapore. Helsinki and Phoenix are in the middle, though Phoenix shows higher energy demand than Helsinki. Building EE is the highest for London (i.e., buildings in London can achieve energy self-sufficiency easier than in the other case studies) that is followed by Phoenix because of their higher potential for solar energy generation with respect to their building energy demand. The value of this indicator is low for Singapore and Helsinki with approximately similar values. When the cut-off angle of the building plan is low, Helsinki acquires higher EE while Singapore shows higher values in case of having a greater cut-off angle.

In general, pavilion form acquires highest energy demand in all case studies. Tunnel-court form shows the lowest energy demand in Singapore and Phoenix, while the terrace and court forms show the lowest energy demand in Helsinki and London. Meanwhile, the tunnel-court form achieves the highest value of EE in all case studies, where the lowest value belongs to the pavilion. The magnitude of difference between EE of tunnel-court and pavilion forms is significantly higher for cooling-dominated buildings. The tunnel-court form performs between 7% and 32% higher than pavilion form in London and Helsinki, while it performs between 27% and 67% higher than pavilion form in Singapore and Phoenix. It demonstrates the higher importance of choice of built form in hotter climates. Hence, although the tunnel-court form is the best choice in all climates, it is specifically recommended to be used in hot climates. This built form together with a low cut-off angle is the best choice for cold climates while it should be planned with a large cut-off angle in hot climates to achieve the energetically sustainable solutions in the built environments around the world.

It should be noted that energy performance is not the only variable to be considered while designing a building, and there are other priorities such as social and economic aspects that should be considered at the same time. Hence, this study suggests design recommendations to identify the highest energy-performance built forms and urban geometry for different climates, and the main variables and design criteria affecting it.

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A Decision Support Tool for the Co-design of Energy and Seismic Retrofitting Solutions Within the e-SAFE Project

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Abstract. The innovation project e-SAFE, funded by the EU under the H2020 Programme, is developing a new deep renovation system for non-historical reinforced concrete (RC) framed buildings, which combines energy efficiency and improved seismic resistance. The present paper describes the main functionalities of a Decision Support System (e-DSS) that is being developed by e-SAFE experts, aimed at guiding the technicians and the building owners through a conscious preliminary co-design activity, and leading to the choice of the most suitable renovation solution amongst those envisaged by the e-SAFE portfolio. The e-DSS allows assessing—with a reasonable degree of approximation—the energy performance of the building before and after the proposed renovation action, the environmental benefits in terms of decarbonization (i.e. reduction in CO_2 emission for space heating, space cooling and DHW preparation), the expected costs and time for the building renovation and the expected time of Return of the Investment (ROI), based also on the savings in the annual operating costs. The paper explains the criteria used by the tool to identify those solutions that are not suitable for the selected building, and discusses the degree of approximation behind the calculation of energy, cost and environmental performance.

Keywords: Energy renovation · Seismic renovation · Decision support · Energy saving · Decarbonization

1 Introduction

The topic of combined energy and seismic upgrading of buildings has become increasingly important because of the growing attention to the economic, social and environmental sustainability in the real estate sector. However, frequently retrofit actions are not

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chosen based on a detailed evaluation and comparison of the several possible alternatives, but rather on the designer's experience and widespread best practices. In addition, the building process can be particularly complex from both a technical (e.g. because of the low number of companies specialized in combined seismic and energy retrofitting) and an administrative point of view (e.g. because of bottlenecks in the approval process for renovation actions in apartment buildings).

For these reasons, there has been a growing interest in the development of Decision Support Systems (DSS) to guide the decision process of various retrofit interventions. As an example, some authors [1–3] analyzed and grouped the most common decision-making methods and found that multi-criteria approaches are widely used in DSSs within the construction sector. In addition, some companies and universities have already started developing decision support tools themselves. Amongst them, Kamari et al. [4, 5] applied a hybrid approach based on a genetic algorithm able to define several scenarios and to evaluate their performances in terms of energy consumption, thermal comfort, and investment costs. Another interesting reference can be found in the RENO-EVALUE tool [6], which is meant as a basis for dialogue among building professionals and building users while also supporting the formulation of specific objectives for renovation projects. This system can also be used for comparing alternative project proposals and to follow-up on a project and assess its actual performance. Furthermore, Campos and Neves-Silva developed a DSS tool called EnPROVE ("Energy consumption prediction with building usage measurements for software-based decision support") that supports investors in the selection of the most suitable renovation scenarios by considering budget, technical, and usage constraints [7, 8]. Although being a powerful tool for ranking energy-efficient long-term projects, it needs a technical consultant to define legislation and incentive schemes that can be applied in the specific location where the renovation should take place.

What emerges from the review of existing DSS tools is that several renovation scenarios are first generated through genetic algorithms or user-defined schemes, and then they are assessed and finally ordered according to the stakeholders' priorities.

Differently from such approaches, this paper introduces a new Decision Support System called e-DSS, developed within the H2020 project e-SAFE. Indeed, this tool is specifically designed to support professionals, building managers and residents in choosing amongst the different technologies made available by the e-SAFE project. The main outcome of the tool is the comparison between energy, environmental and economic performance of the building in its current state and after the renovation: these results are helpful to the designer during the preliminary design process, since it allows him/her to show the residents all the potential benefits of the selected solution. Furthermore, the e-DSS guides the designer in the selection of the most appropriate renovation solution amongst those envisaged in e-SAFE, based on a series of checks regarding the shape of the building, the nearby context and the presence of balconies and large glazed surfaces.

The paper describes the main features of the e-DSS in its first release, its current limitations and the criteria behind the selection process for the most suitable renovation solutions. Further developments and functionalities are being implemented and will be available in 2023 in the second release of the tool.