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ABSTRACT

The population growth and the global warming would significantly affect the total building energy demand to maintain comfort conditions. Because of the global temperature rise, the heating load may decrease in some regions but considerably augment the cooling load. In addition, the energy required for cooling load is much higher than that of heating load. Thus, it is of quite importance to evaluate the future energy demand for built environment in order to put efforts in improving energy systems and efficiency, and to develop energy policies to mitigate and adapt climate change impacts. Present work consolidates the studies related to the climatic change impacts on built environment. The adopted methodology and predictions of building energy change are presented, critically analyzed and discussed in this work. Finally, the challenges related to the building energy requirement are presented.

KEYWORDS

Buildings; Climate Change; Cooling; Energy Use; Global Warming; Heating

INTRODUCTION

Climate change is a shift in global and regional climate patterns that began in the mid-twentieth century and is primarily linked to increased carbon dioxide concentrations caused by the use of fossil fuels. [1,2]. The climate change impacts include: dry bulb and wet bulb temperature rise, sea level rise, humidity, water scarcity, health problems, and extreme events such as floods, rainfall, and earthquakes etc. In dry weather, if a human being is not properly hydrated and exposed to the sun, the body is at risk of heatstroke at temperatures around 60 °C [3]. The global temperature rise for different representative concentration pathways (R.C.P.) scenarios is shown in Figure 1. The average temperature increase in the MENA (Middle East and North Africa) region is expected to be between 3 and 9 °C by 2100. Which means that by the year 2100, the RCP 8.5 scenario will have twice the prior forecasts of a 4 °C temperature increase in the Middle East [4].

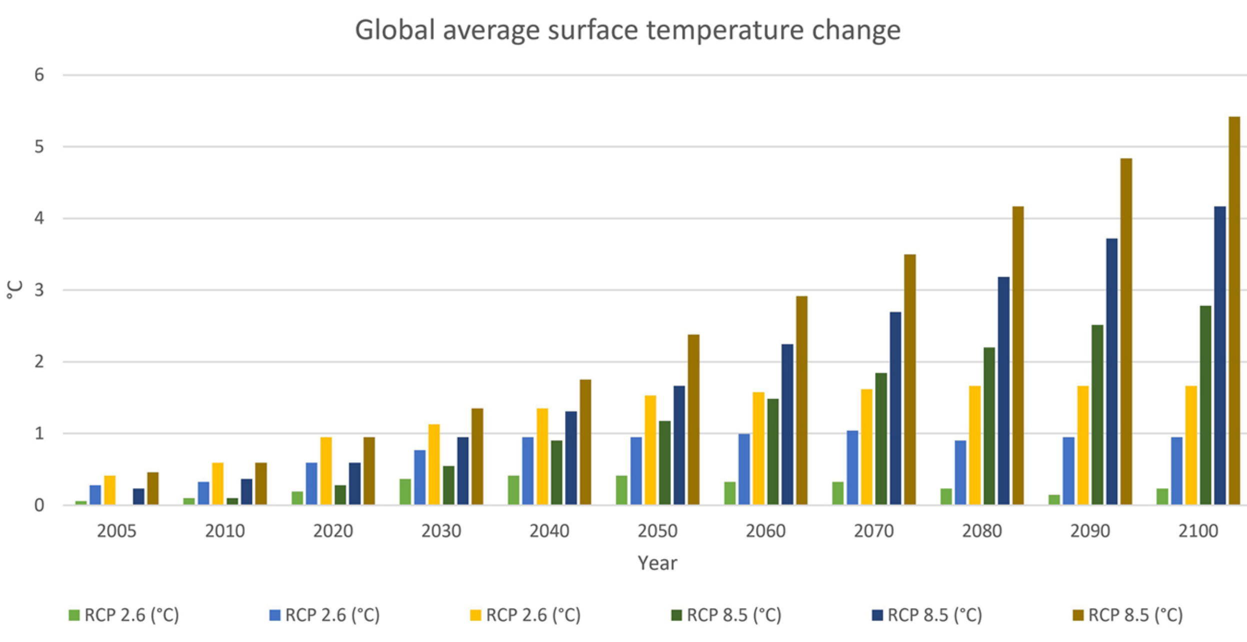

Figure 1. Global temperature rise for different representative concentration pathways (R.C.P.) scenarios [1]

It is often assumed that the humans are able to adapt to any potential warming induced by forecasted climate change using newly created technologies. Throughout the world, the wet-bulb temperature rarely reaches 31 °C. As long as the wet-bulb temperature remains below 35 °C, the human body can adapt to excessive dry-bulb temperatures (usually known as temperature) by sweating and other evaporative cooling processes [3]. Humans will experience hyperthermia if the temperature rises beyond 35 °C for an extended length of time, as metabolic heat dissipation becomes impossible. The IPCC (Intergovernmental Panel on Climate Change) business-as-usual scenario in greenhouse gas emissions (RCP 8.5) will result in values exceeding 35 °C for wet bulb temperature in the main coastline cities. The GCC (Gulf Cooperation Council) countries have their major ciities along the coastline and are located in low-elevation regions, causing higher temperatures and humidity.

The precipitation will rise over large areas of the Middle East. Winter (December to February) is expected to be the prevailing season for rainfall across the Gulf, and the predicted rise in rainfall would primarily occur during this period. Extreme rainfall can easily overstrain the urban built infrastructure [3]. Rise in temperature because of climate change will cause sea level rise that can make coastline areas of the Middle East susceptible to climatic change effects [5].

The climate change not only affect the building energy demands but also the fresh water supply. The global change in ambient conditions may increase the energy consumption to desalinate water or to treat water in order to make it drinkable [6–8]. Gulf countries characterized by extreme weather and reliance on fossil fuels would be especially susceptible to such impacts. Given that cooling services consume around 80% of the energy produced in these countries, increased cooling demand would have an effect on both building environmental impact and grid stability [9]. Because of the substantial difference between the ambient (temperatures in the Middle East commonly reach over 40 °C) and indoor comfort temperature (indoor temperature is set to 18–20 °C) in hot climates, the required energy for cooling is accountable for the majority of energy end-use (The cooling systems in Middle Eastern countries are estimated to consume up to 80% of the total energy produced.) [10].

With the Gulf countries' abundant fossil fuel resources, such an increase in electricity demand could be met by adding extra production capacity. However, additional fossil-fuel-based electricity generation would increase these countries' already substantial carbon footprint, which would accordingly result in lower air, land, and water quality [11–13]. Because of the global change in ambient conditions, the total energy load for built environment will be considerably augmented. Hence it is necessary to evaluate the future energy demand in order to improve energy systems and efficiency, and to develop energy policies to mitigate and adapt climate change impacts. This review consolidates the studies related to the climatic change impacts on built environment. The adopted methodology and predictions of building energy change are presented, critically analyzed and discussed in this study.

LITERATURE REVIEW

According to the study by Andric et al. [14], the most substantial shift in the heating to cooling demand ratio will occur in the built environment in locations with hot climatic conditions. Furthermore, whereas some studies looked at heating and cooling demand, others looked at total building energy use (which also contains electricity usage for lighting and miscellaneous appliances). However, many works [15–19] provided results in both forms. Table 1 shows the predicted change in heating and cooling energy requirements for different regions.

Andric et al. [20] analyzed the impact of climate change on building heat demand under three weather scenarios and these scenarios involving district upgrades. From 2050, the heat demand density of buildings is expected to fall by 22.3 % to 52.4 %, depending on the scenario. According to several projections, energy consumption for cooling and desalination plants will skyrocket in the twenty-first century as a result of Doha's significant temperature rise and large population growth.

Radhi [16] investigated the effects of climatic change on building energy requirements in Al-Ain. The years 2009 and 2050 were used as the baseline and observation periods, respectively. Heat requirement was expected to drop from 9.5 % to 39.2 %, while cooling demand and total building energy consumption were expected to rise from 7.3 % to 24.1 % and 4.1 % to 12.5%, correspondingly. Roshan et al. [21] conducted the similar research for Iran. In this situation, the reference period and observation period were 2005 and 2050, respectively. A drop in heat demand and an increase in cooling demand were recorded in this study (14 % and 30 %, respectively). Andric et al. [22] established weather forecasts for 2020, 2050, and 2080, as well as four building refurbishment scenarios. According to the findings, residential construction energy consumption in Qatar might rise by up to 9 %, 17 %, and 30 % in 2020, 2050, and 2080, correspondingly, if no mitigating measures are taken.

Even with a decline in heating demand of 263 % and an increase in cooling demand of about 17 %, overall building energy demand in Tokyo grew by approximately 13 % in 2050. Heating demand accounted for only 5 % of total building energy usage in the benchmark weather conditions in Tokyo, while space cooling accounted for over 95% of total building energy consumption [18]. Shen [17] concluded similar results for hot desert climate region, Phoenix, US. They discovered that after a 49 % and 24 % fall/rise in heating/cooling demand, respectively, building energy consumption increased by up to 7 %. In Hobart, US, on the other hand (mild temperate oceanic climate), total building energy demand fell by up to 26 %, despite a +173 % increase in cooling demand and a -28 % fall in heating demand. It can be concluded that for the same case study site, the results produced by different writers can differ.

Though, it should be noted, that fall/rise rates are based on the building's reference heating/cooling ratio [1]. To put it another way, a lower percentage decrease in heating demand than an increase in cooling demand does not always imply a lower total building energy demand, and vice versa. Overall, future heating demand is expected to decline (7–52 %), whereas cooling demand is expected to grow dramatically (up to 1050 %). The decrease/increase rates differed significantly based on the climate and case study building(s) in question, with buildings and building energy systems in extreme climates being more vulnerable [23]. Climate models and forecasted weather data are the main sources of ambiguity in the expected increase/decrease rates. It is necessary to continue developing dynamic large-scale building energy simulation tools, as well as large-scale building renovation strategies and approaches that take into account new factors (economic and societal). Furthermore, constant efforts are required to enhance climate models and reduce uncertainty.

During heat waves, the surge in cooling demand would raise electrical demand peaks on a grid already under stress. Aside from the increased danger of system failures and power outages, more natural gas self-consumption (and consequently reduced exports) and increased construction environmental impact would be further drawbacks. Changes in building energy consumption patterns will have an impact on the built environment's overall sustainability [24,25]. Environmental performance of buildings is measured by assessing the environmental impacts of all key building lifecycle phases (construction, operation, destruction, and recycling/landfilling), either through a Life Cycle Assessment or a Life Cycle Inventory [26,27]. According to the majority of research, the operating phase contributes the most to the overall environmental impact over the course of a lifespan, ranging from 50 percent to 95 percent [28,29].

Table 1. Building energy requirement prediction with respect to climate change for different locations

Location	Predicted year	Change in heating load	Change in cooling load	Ref
Al-Ain, U.A.E.	2050	-9.5 – -39.2 %	+7.3 – +24.1 %	[16]
Iran	2050	-14 %	+30 %	[21]
Sydney, Australia	2050	-66 – -81 %	+93 – +146 %	[15]
Melbourne, Australia	2050	-30 – -42 %	+69 – +111 %	[15]
Turin, Italy	2050	-16 %	+30 %	[30]
Stockholm, Sweden	2081 – 2100	-25 – -30 %	+2 – +14 %	[31]
Vienna, Austria	2050	-11 – -30 %	+28 – +92 %	[32]
Miami, US	2050	-79 %	+30 %	[33]
Orlando, US	2050	-57 %	+35 %	[33]
Key West, US	2050	-68 %	+27 %	[33]
Curitiba, Brazil	2050	-79 %	+210 %	[19]
Florianopolis	2050	-82 %	+120 %	[19]
Sapporo, Japan	2040 – 2050	-27 %	+23 %	[18]
Tokyo, Japan	2040 – 2050	-263 %	+17 %	[18]
Hobart, US	2040 – 2069	-28 %.	+173 %	[17]
Phoenix (Arizona), US	2040 – 2069	-49 %	+24 %	[17]

DISCUSSION

Though the predicted pace of change in building energy demand is uncertain, the trend is clear: heating demand will decline in the future, while cooling need will rise. These changes will have an impact on the design of both buildings and energy systems. All modeling approaches, however, are hampered by simplifying assumptions and accompanying uncertainties [34]. The authors of the evaluated research assumed that during the summer months, the gap between the interior comfort set point temperature and the external temperature would increase as a result of the rising outdoor temperatures, increasing the energy demand for cooling. During the wintertime, on the other hand, the difference between the indoor comfort set point temperature and the outdoor temperature will diminish, lowering the energy demand for heating.

All studies on the topic should clearly specify sources of reference for meteorological data, building attributes, and methodologies utilized for climate and building energy modeling to comprehend such variances in results (as was the case in the four studies discussed within this paragraph). To properly appreciate the impact size, the implications should also be shown for heating and cooling demand as well as overall building energy consumption, as the data reveal. Furthermore, based on the findings, it is necessary to do simulations for various building types in order to analyze the influence on the built environment, as the impact scale may differ. Finally, given the uncertainties associated with climate change modeling, such studies should not be expected to deliver precise conclusions or prescribe actions, but rather to provide future trends and guidance.

Significant research efforts have been done over the last three decades to reduce building energy consumption and provide long-term heating and cooling solutions for the ever-growing metropolitan environment. Building adaption measures and the creation of sustainable urban energy systems were the focus of these studies. Potential changes in future building energy demand, on the other hand, were initially neglected. In heating-dominated climates, the expected increase in air temperature (according to all available climatic scenarios) will reduce the difference between outdoor air temperature and building internal comfort temperature, lowering building energy consumption [35].

As a result, proper mitigation through envelope repair becomes even more critical. One could argue that the extra materials and resources used during the renovation phase increase the building's environmental impact; however, case studies have shown that emission reductions achieved during the operation phase provide both environmental and economic benefits, as well as a lower overall environmental impact [36]. Furthermore, if the right materials are chosen during the building envelope construction phase, climate change's negative consequences could be mitigated [37].

The increase in environmental consequences could be minimized by remodeling and enhancing the energy efficiency of existing buildings, or by replacing fossil-fueled energy production units with renewable energy systems such as solar power plants, wind farms, and tidal power plants [38,39]. However, in order to implement such solutions on a large scale, new environmental rules that take into account societal and economic factors unique to the Gulf region should be devised [40].

Andric et al. [22] proposed the incorporation of energy-efficient windows and 50 mm expanded polystyrene as insulation that proved to be far more effective than the green walls/roofs addition under the different climate change scenarios. Other positive benefits of green infrastructure (such as air quality, heat island effect, and residents' health) should be considered in the final verdict. Additional aspects of urban greenery, such as the effects on urban air quality, should be examined.

As a result, rehabilitation of older buildings could reduce heat demand even more: better insulation levels reduce building heat losses to the environment, cutting heating energy demand in cooler climes [41,42]. The influence on cooling energy demand, on the other hand, is less noticeable. Greater insulation levels in warmer climates may reduce heat gains from the environment during the day (when the external temperature is usually higher than the interior comfort temperature), but they may also prevent heat release from the building to the atmosphere at night (when the outdoor temperature is generally lower than the indoor temperature) [23].

CONCLUSION

The building industry is a large emitter of CO_2, and great efforts are being undertaken to create a more sustainable urban environment. Future changes in building energy demand, on the other hand, are usually disregarded. It is false to design the future urban environment and energy systems based on existing weather conditions. Current heat demand will decrease while cooling demand will increase due to changing weather variables (direct effects of climate change) and the implementation of building renovation regulations (indirect effects of climate change). When constructing building adaptation and renovation measures, as well as urban energy systems, such possible changes in building energy consumption and heating/cooling ratios must be carefully considered. The major goal of this research was to give an up-to-date assessment of modeling methodologies for forecasting building energy demand, assessing consequences, and considering potential implications for building and urban energy system design (sizing of the base load and peak load units, operational parameters, etc.).

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