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Adaptation of climate-responsive building design strategies and resilience to climate change in the hot/arid region of Khartoum, Sudan

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Abstract

Climate change has become one of the most discussed topics in recent decades. Indices show climate alterations have occurred in Khartoum, Sudan, resulting in uncomfortable and challenging-to-manage indoor conditions. In this study, Khartoum's climate data from 1981 to 2015 was analyzed and compared to identify trends in temperature, precipitation, and sand-dust storm intensification. Metronome Company created Khartoum's hourly weather file from averages of basic climate parameters available for 1996 to 2015 and Meteonorm 7.2.1 calculated an hourly climate file for Khartoum in 2070. These figures were then related to design characteristics and lifecycles of local buildings. To counter 2070 climate conditions, resilient design strategies were evaluated to optimize thermal comfort for building users and minimize energy usage today and in the future. A comparison of design strategies from the year 2015 to those for 2070 discovered that strategies must shift to more active-cooling by the year 2070 when natural ventilation and active heating will no longer be beneficial design strategies during all seasons. While two-stage evaporative cooling is the most strategic for all of Khartoum's seasons, more resilient passive-design strategies should be adapted for use with Khartoum's underutilized renewable resources to reduce future active-cooling demand and optimize thermal comfort.

Introduction

In the recent decades, numerous scientists have expressed great concern about climate change and global warming, considering them to be serious threats to mankind and the natural environment

(Omondi et al., 2014). The year 2015 AD was the hottest year since 1850 AD though the previous three decades the global weather conditions had been considered the hottest since 1850 AD. In 2015 alone, the global temperature increased 0.75 °C,[1] which was greater than the cumulative increase from 1961 to 1990 AD [URL1, 2019]. These global temperature increases are caused by the accumulation of carbon dioxide emissions in the atmosphere which result, in the majority, from the burning of fossil fuels, therefore, there is urgent need to reduce this increased emissions through reducing reliance on fuel fossil consumption and relay more on renewable energy to achieve sustainable development. According to the 2013 report from Intergovernmental Panel on Climate Change (IPCC), if the current emissions trends continue without finding sustainable solutions, the average rate of global temperature increase over the years 2081 to 2100 AD will reach 4.8 °C which is greater than the cumulative of 1986 to 2005 [URL2, 2013].

Global warming is also projected to negatively influence global precipitation, evaporation, and evapotranspiration rates [Schlosser & Houser, 2007; Hu et al., 2017]. Alongside recent reports documenting climate change occurrences at global, regional and local levels, these dangers to human and environmental wellbeing demand that the international community respond with urgency and take appropriate measures to reduce greenhouse gas emissions. This would however, require researchers to find appropriate, climate-responsive design solutions to anticipate and respond to future climate change. Success cannot be achieved by merely altering individual behaviors and consumption patterns; to sufficiently reduce energy emissions there is a need for global adoption of new low-carbon technologies which help to decarbonize the byproducts of energy use [Remund, Lang, & Kunz, 2013; Spence & Pidgeon, 2009]. Comprehending climate-related behaviors and patterns at global, regional, and local levels is essential for designers in the field of environmental science; with this knowledge they can develop such things as early warning systems and counters to future climate challenges.

The design of climate-responsive buildings may meet these challenges and has the potential to collectively change user behaviors during climate extremes. Hansen, Sato, and Ruedy, (2012) and Kamal (2013) describe this adaptability of buildings as a phenomenon of climate change [Snow & Deo Prasad, 2011; Hansen et al., 2012; Kamal, 2013]. It is imperative for researchers in the fields of the built environment to proffer sustainable solutions for this dilemma at urban, regional, and global levels [Charter, 2007]. Failing to incorporate sustainable design strategies will lead to poorly naturally ventilated buildings in the future which experience longer overheating duration in summer season. Hence, this will demand the use of air-conditioning system to achieve acceptable thermal comfort level [Watkins, Palmer, Kolokotroni, & Littlefair, 2002; Roberts, 2008].

The aims of this study are to reveal conditions affecting thermal comfort in Khartoum, Sudan, and suggest relevant building-design strategies to increase resilient to both current and projected climatic conditions. To achieve this, the objectives include discovery of climate change trends through evaluation of Khartoum's climate data from 1981 to 2015; understanding how climate trends affect buildings; and identifying ways to enhance future thermal comfort of building users in Khartoum.

Section snippets

Study area: Khartoum, Sudan

The city of Khartoum, Sudan, was founded in 1820 CE and later became the capital of this northeastern African country. The city's name derives from its shape which resembles an elephant trunk (Al Khartoum in Arabic). Its development is focused around 15°33′06″ N latitude, 32°31′56″ E longitude and it averages 380 m above sea level. The city's location in the center of the country coupled with its strategic position at the confluence of the Blue and White Nile Rivers made it one of the most …

Research methodology

The methodology of this research is based on case-study problem solving in which Khartoum's climate data from 1981 to 2015 was analyzed via a linear trends method. Trend is a substantial change that occurs to the time-series value of a parameter or variable and is recognized through statistical parametric or non-parametric means. Time series verse data is a method suitable for climate change issues. It enables researchers to perceive trends in a specified time frame [Shi & Xiangde, 2008]. …

Climate data analysis of Khartoum, Sudan

For climate parameters from 1981 to 2015, trend analysis was evaluated in order to observe variations which occur in trend equations and R-square values of climate parameters on a seasonal basis. Monthly averages of the relative humidity, temperature, wind speed, and rainfall were considered and the results are shown in (Table 1). …

Comfort model

The adaptive comfort model used in this study assumes that buildings are naturally ventilated and occupants can close and open windows according to their thermal desires. Hence, building users' thermal response will depend in part on the outdoor climate and may have a wider comfort range than those in buildings with centralized heating ventilation and air-conditioning (HVAC) systems. For the ASHRAE Standard 55 model, there must not be any mechanical cooling system nor does this method apply if …

Passive cooling strategies adaptable in Khartoum, Sudan

Adapting passive cooling measures in building design and construction denotes utilizing any design techniques or feature that help in providing optimum living condition for building dwellers without

the need for using power [Taleb, 2014]. Passive strategies using in building has become more popular after 1970s energy crisis. In order for the passive cooling strategies to operate effectively climate should critically be analyzed. The board strategies that are to be discussed in this research are …

Future scenario of building climate-responsive design strategies for Khartoum in the year 2070

Climate change is one of the greatest challenges facing humanity currently. It is widely accepted that the effects of greenhouse gas emissions on global climate indicate that energy consumption in buildings should be reduced and building should be able to resist climate change effects for a long time. However, this requires contemporary and future buildings to cooperatively function under extreme changing weather conditions [Guan, 2009]. Future projections of climate are inevitable and …

Results and discussion

Trends analysis of Khartoum climate data from 1981 to 2015 was conducted on a seasonal basis, the parameters studied were monthly relative humidity, average monthly temperature, average monthly wind speed, and average monthly rainfall. The analysis produced the following results:

- Relative humidity decreases in the dry and hot seasons, and increases in the wet season. …
- Temperature increases in all the three seasons of the year. …
- Wind speed increases in dry seasons and decreases in hot and wet seasons. …

…

Conclusion

This study examined Khartoum's 1981–2015 climate data through an extensive statistics analysis of trends on a seasonal basis. The findings proved that there has been change in Khartoum's climate.

Relative humidity has decreased in dry and hot seasons, and increased in wet seasons. Temperature increased throughout the seasons of the year. Wind speed increased in dry seasons and decreased in hot and wet season. Rainfall increased in dry and hot seasons and decreased in wet seasons.

Analysis of the …

Author contributions

Mobark Mohamed Osman and Harun Sevinc conceived and designed the paper outline. Mobark Mohamed Osman conducted the analysis and wrote the paper. Harun Sevinc supervised; provided sources, materials, and comments; and edited the paper. …

Conflicts ofinterest

The authors declare no conflict of interest. …

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> …Resilient design strategies need to be applied to prevent overheating and poor ventilation, while sustainable approach demands avoiding use of air-conditioning system to achieve acceptable thermal comfort [9]. Previous research carried out for other regions revealed a set of conditions affecting thermal comfort and suggested relevant building-design strategies to increase resilience level of the built environment [9]. This approach is

based on the adaptive comfort model with assumption that „Buildings are naturally ventilated, and occupants can close and open windows according to their thermal desires.…

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