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Research article

Roadmap to reduce the direct effects of climate change on building performance; A case study applied to the top 8 deserts and top 8 coldest regions in the world

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ABSTRACT

Climate change significantly impacts building performance. Indoor comfort, energy demand, carbon emissions, and building maintenance costs vary according to the local climate. This research has been conducted, to investigate, simulate, analyze, compare and discuss the potential impact of climate change on thermal comfort, heating and cooling energy needs in a hospital, hotel, school and residential home located in the top 8 deserts and the top 8 coldest regions in the world. Simulations were conducted for future climate using ten (10) general circulation models (GCM) based on three emission scenarios, namely B1(low emission), A1B (middle emission), and A2 (high emission); and Representative Concentration Pathway (RCP) (RCP2.6; RCP 4.5, and RCP 8.5). The thermal performance of buildings was assessed for three periods (Current, 2050 and 2100). The results showed that in 2100, air temperature is expected to increase up to 4.9 °C in desert regions, this effect will produce an increase of 34.5% in cooling load, and 73% of the not comfortable rate in the buildings; while in the same year, in the coldest regions, the air temperature is expected to increase up to 5.5 °C, producing a decrease of heating load up to 15.5%, and an increase of comfort rate up to 25%. The thermal comfort temperature range was between 23.9 °C and 29.8 °C. In desert regions, the heating loads are very low, indeed, they represent only 6.5% of the total loads (loads used for cooling and heating), while in the coldest regions, the cooling loads represent only 7.3% of the total loads.

1. Introduction

Extreme regions are those that often experience exceptional situations on the planet, notably by their climatic characteristics - intense cold, abundant rain or on the contrary drastic drought. They are classified into two categories, the coldest zones and the hottest zones (deserts). The cold areas of the Earth are around the poles. The sun is low throughout the year and the cold is permanent [1]. The hot zones are mainly located around or near the equator between the tropics. In this area, the Sun is always high in the sky and it is hot throughout the year [2].

The alternation of climate is constantly noticed in all regions of the world. The quick global warming constitutes a huge risk to human survival on Earth [2,3]. Indeed, the accumulation of the harmful actions of humans on nature led to the destabilization of the world's climatic system; so that nowadays, the revolt of nature generates constantly major natural disasters (drought, tornado, flood, plague etc.). In many studies related to climate change, a temperature peak varies according to the simulation models. The Intergovernmental Panel on Climate Change (IPCC) recognized in one of its reports that several unexplained catastrophes can be one of the consequences of the revolt of nature [2]. Some research has shown that the global average temperature increased

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1 https://www.fsa.uliege.be/cms/c_3141277/en/fsa-directory?uid=u205356
2 https://www.uee.uliege.be/cms/c_3483040/en/uee-repertoire?uid=u220815

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to 1.1℃ between 1880 and 2012 [2]. During the 20 last years, 2016 was recognized, as one of the hottest years [4]. Some studies suggest that the average global surface temperature may increase to 3.5 °C by 2100, compared to the period 1961–1990 [1]. In the regions around the tropics, some research suggests an increase in temperature up to 4 °C in the next 100 years compared to the past century [5]. On the other hand, the concentration of carbon dioxide increased by up to 27% In 2015, compared to the CO_2 value observed in 1960 [6]. According to Energy Information Administration (EIA) [7], the building sector is made up of the residential and commercial sectors. Common uses of energy associated with the residential and commercial sectors include space heating, water heating, air conditioning, lighting, refrigeration, cooking and the use of a wide variety of other equipment [7]. The building sector is recognized as one of the main carbon emission sectors. However, this sector is strongly dominated by outdoor climate which considerably affects energy demand and indoor air quality.

Nowadays, the energy consumption of buildings forms a large part of global energy consumption [8]. The construction sector consumes up to 40% of all energy and contributes up to 30% of global annual greenhouse gas emissions [8]. Several studies conducted by several researchers such as Camilleri et al. [9], in New Zealand in 2001; Christenson et al. [10], In Switzerland in 2006; Ward et al. [11], in the UK, in 2008, found that an increase in temperature could significantly affect the thermal performance and energy demand of the buildings.

Given the massive growth of new construction in transition economies and the inefficiency of the existing building stock in the world, if nothing is done, greenhouse gas emissions from buildings will be more than double over the next 20 years [12]. Each phase of a building's life cycle (construction, in-use, renovation and demolition) affects the environment and must be studied to produce a high-performance, energy-efficient building [13].

The United States is the only country having one of the coldest regions in the world (Alaska City) and one of the hottest regions in the world (Death Valley desert in California) studied in this research. This country had consumed the 19% of the world's energy in the last decade. This record was broken by China in 2010, which has taken first place with 22.9% of the total world energy consumption. The residential and commercial sectors in the United States alone accounted for 7% of overall primary energy consumption [14]. Several studies have assessed the direct impact of climate change on energy and thermal comfort. Wang et al. [15] evaluated the effects of climate change on the energy demand in residential buildings in Australia. The results showed that for an increase in global temperature between 2 °C and 5 °C, in the next decade, energy needs will be increasing up to 530% in Australia. Arima et al. [16] studied the impacts of climate change on the different cooling loads in summer in buildings in Tokyo. They found that in August, the thermal load will increase by 26% in 2030. In 2011, Koranteng and Mahdavi [17] analyzed the thermal performance of office buildings located in Ghana and reported that by applying new passive strategies, the cooling loads can be reduced by up to 35% and the CO_2 emissions would be decreased by 27%. Abanyie et al. [18] showed that it is possible to apply passive strategy techniques to improve thermal comfort and reduce the demand for energy for heating and cooling strongly dominated by the strong change in the outdoor climate.

The level of thermal insulation of the building, the technology used during its construction, the type of glazing, the equipment, the lighting, the different operating modes and the occupant's behavior, are elements which can significantly affect the thermal comfort of the buildings [19]. The study was carried out by Roshan. al. [20] showed that the temperature will increase between 3.4 °C and 5.6 °C in 2100 in 30 regions in Iran.

Global warming indirectly destroys the human species.

Indeed, global warming has attracted great attention this decade because of its very significant impact on the environment and the behavior of the occupants. The concentration of carbon dioxide emitted by buildings can be considerably reduced by the judicious choice of building materials, ventilation systems, lighting, etc. The application of renewable energies in buildings would reduce the concentration of carbon emitted by the construction sector. Renewable energies, in contrast to fossil fuels, allow us to meet the energy needs of humans while respecting the planet and safeguarding its resources. Renewable energies are energies which, as their name suggests, are renewed on a human timescale. Solar and wind energies are indestructible energies with no limits in meteorology. The application of renewable energies would favor the planet and reduce CO_2 emissions from the building sector.

Nematchoua and al. [21] explained that one of the best ways to limit the impact of climate on buildings is to use sustainable materials in new constructions. In most cases, the building performance is higher in sustainable building than in more conventional ones [22,23]. Davide Tirelli and Daniela Besana [24] explained that the circular economy methods are strictly related to design for disassembly and for adaptability to reduce embodied carbon, whereas passive design and solar and geothermal energy production can satisfy the renewable energy demand of the building. The majority of the identified literature concerns climate change impacts on buildings in warm climates, with overheating being seen as the greatest challenge [25].

This research is based on several observations noted by its authors, drawing inspiration from the studies found in the literature. This study presents some originalities, indeed, it is observed that the current standards of thermal comfort and energy consumption such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers(ASHRAE), are established based on studies carried out most often in countries with moderate climate (not extremely hot nor cold). Regions with extreme climates deserve their standard. In addition, very few researchers direct their study to the desert and cold regions due to the very unfavorable climatic conditions. This explains why there is still a lack of data in the literature concerning this category of region. Meanwhile, the impact of occupants' behavior on energy demand and carbon emission in these regions is not known. It's very important to simulate the structures selected to suggest some adaptation strategies to the new climate.

The main objective of this research is of investigating, simulating, analyzing, comparing and discussing the potential impact of climate change on thermal comfort, heating and cooling energy needs in a hospital, hotel, school and residential home located in the top 8 deserts and the top 8 coldest regions in the world.

2. Literature review

Table 1 summarize several previous studies that analyzed the impact of climate change on thermal comfort and energy consumption in residential and commercial building.

Other recent studies in this area are those carried out by Baglivo et al. [40,41] in 2022 and 2023; Amaripadath et al. [42] in 2023.

All these results grouped in Table 1 confirm that the effects of climate change are not the same in each region of the world. Building construction materials have a major effect on all these results. The air temperature changes according to the simulation tool adapted and the IPCC scenario used. We see that a variation in air temperature directly affected the heating and cooling charge. Scenarios A1 and A1B are more moderate than RCP4.5 and RCP8.5.

3. Objective

The different parts of the research conceptual framework applied are described as follows: (i) Literature review; (ii) selection of locations; (iii) selection of the type of building and data collection; (iv) building modelling; (v) data preprocessing and calibration; (vi) Forecasting; (vii) comparisons and recommendations.

Table 1
Some research on climate change on buildings.

Author and reference	year	country	Type of building	Methods	Main results
Nematchoua et al. [26]	2019	Madagascar	Hospital	Scenarios A2, A1B and B1 and 18 models used in the IPCC	cooling will increase between 17.1% and 25.4% by 2030; 34.6% and 50.2% by 2060; and between 60.8% and 95.1% by 2090
Wang and Chen [27]	2014	United States	Residential and commercial building	Model HadCM3 of GlobalCirculation Model (GCM)	By 2080, the air temperature will increase of 3–6 ∘C.
Dodoo and Ayarkwa [28]	2019	Ghana	Residential building	IDA-ICE dynamic simulation software	Cooling energy will be increase to 6% in 2030, and 15% in 2050
Wang et al. [15]	2010	Australia	residential building	Nine GCMs models and two scenarios A1B, A1F	The total energy demand increase from 26% to 101% by 2050 and 48–350% by 2100
Peng Xu et al. [29]	2012	United States	Residential and commercial building	Model GCM, and two scenarios A1B, A1F	cooling electricity usage will increase byabout 25%.
Arima et al. [16]	2015	Japan	No information	MIROC4h model	sensible heat load increased 26%, and the latent heat load increased 10%
Rosenthal et al. [30]	1995	United States	Residential and commercial	Degreeday (DD) method	1 °C of temperature change will reduce energy cost of $5.5billion
Scott et al. [31]	1994	United States	Office building	DOE-2 Software	Building energy is significantly affected by variation of relative humidity
Jentsch et al. [32]	2008	UK	Office building	HadCM3 projection with Morphingdownscaling	Outdoor climate is expected to change in 2050
Abubakar and Lawal [33]	2020	Saudi Arabia	-	Data collected in the literature	Energy use increase significantly
Frank [34]	2005	Switzerland	Residential and office buildings	HELLIOS for building simulation	Cooling demand will increase220–1050%, and heating demand 36–58%
Andric and Ghamdi [35]	2020	Qata	Residential	CCWorldWeatherGen tool	Building energyconsumption will increase for up to 30%
Asimakopoulos et al. [36]	2012	Greece	Residential and commercial	Morphing for downscaling, TRNSYS sftware	In next 100 years, heating will be decrease to 50% and cooling will increase to 248%
Dubois et al. [37]	2022	Cold andHumid Climates	-	RCP4.5and RCP8.5; 1951–2100	annual precipitation increases of > +150 mm/yr; Temperature changes of > +4.5 ∘C limit,the GWR increase to + 30 mm/yr
Tootkaboni et al. [38]	2021	Italy	Residential	CCWorldWeatherGen	Building energy is significantly affected by variation of air temperature
Defo and Lacasse [39]	2021	Canada	-	using DELPHIN 5.9.4	The risk of mold increase in all the cities due to an increase in rain loads.
This research	2020	Top 8 hottest and coldest regions of world	Residential and commercial	10 GCM model and 03 scenario (A2, A1B, and B1)	In 2100, air temperature will be increase 4.9 °C in deserts and 5.5 °C in the coldest regions, while cooling load will increase up to 34.5%

a) With the goal to better understand the effects and implications of climate change on the energy and thermal performance of buildings in the regions with extreme climates:
   We assessed the effects of temperature and relative humidity variation on thermal comfort in four designs (Hospital, residence, hotel and school) represented in the top 8 deserts and top 8 coldest regions of the world; the projections are carried under the basis of six IPCC scenarios (B1, A1B, A2, RCP2.6, RCP 4.5, and RCP 8.5).
b) We evaluated energy consumption and dioxide carbon emissions (in natural ventilation (NV) and air-conditioned (AC)); and thermal comfort rate (in natural ventilation), in these four design buildings.
c) We Analyzed and compare the impacts of climate change on the cooling, heating and lighting energy consumption in the sixteen locations;
d) We applied renewable energy such as photovoltaic panels and wind turbines for reducing energy demand in the building sector.

4. Methodology

The different methods developed in this research are distributed in the following sub-sections.

4.1. Locations

The study considered sixteen (16) locations. These regions are essentially constituted.

a) of the top eight deserts of the world such:
   Dallol desert in Ethiopia; Rub al Khali desert in Saudi Arabia; Tirat Zvi desert in Israel; Badland desert in Australia; Kebili desert in Tunisia; Death Valley desert in California, USA; Timbuktu desert in Mali and El Azizia desert in Libya.
b) (b) of the top eight coldest regions, such as:

Antarctica; Alaska in the USA; Oymyakon City in Russia; Astana in Kazakhstan; Nuuk City in Greenland; Reykjavik in Iceland; Yellow Knife in Canada; and Helsinki City in Finland.

4.1.1. Criteria

The desert regions (or the hottest regions), such as, the coldest, regions have extreme climatic characteristics. This means that human adaptation in these regions is very difficult. So far, very little research in the literature has proposed standards more suited to these regions. Following the strong global population growth in recent decades, the need to conquer new spaces is essential. In addition, these different regions, most of them, are still virgin, with some important potential resources.

4.1.2. Description

The deserts are not always hot areas as many people think. Generally, these are regions where rainfall is scarce and irregular and where vegetation is reduced and discontinuous. They can be hot or cold and are located all over the world. The deserts are part of extreme environments. The lack of vegetation exposes the unprotected surface to the harsh climate. Semi-arid and arid zones count for about a third of the Earth's surface. This includes a large part of the Polar Regions where low precipitation occurs, often called "cold deserts". The deserts can be classified according to the amount of precipitation they receive, the temperatures that dominate throughout the year, the causes of desertification or their geographical location. Hot deserts are formed by meteorological processes, since wide variations in temperature between day and night. Although rain occurs very rarely in deserts, there may be occasional showers Depending on their formation process and the causes of desertification, there are zonal deserts, shelter deserts, continental deserts and coastal deserts. Cold deserts form at the highest latitudes, much higher than hot deserts. The aridity of cold deserts results from the dryness of the air. Hot deserts are mostly subtropical or tropical deserts as well as zonal deserts. Hot deserts are located in the subtropical latitudes, more commonly called the latitudes of horses, between 30° and 35° North and South. In the eight deserts studied, it is hot all year round, and the rainy season is very short. The maximum temperature sometimes exceeds 55 °C. The main climatic characteristics are shown in Table 2 [2].

In the coldest cities on the planet, many of which are located in extreme northern latitudes, the air is freezing and normal minimum temperatures often drop well below the −50 °C mark. In the eight regions studied, the climate is characterized by cold temperatures all year round, with no summer heat and freezing winters. The average temperatures of the hottest month are never higher than 23 °C. In winter, the cold is permanent and is explained by the absence of solar radiation and by the loss of energy during the long polar night. On the other hand, the summer is much less cold, especially on the margins of the Arctic Ocean, which are no longer glaciated but are not immune to frosts [43]. July is the hottest month, while February is one of the coldest months. The map showing the sixteen studied regions is presented in Fig. 1. The map shows the locations of the case studies throughout the world.

It is known that there are other regions with extreme climate conditions, however, in this study, it was assessed just the case of sixteen regions in the world.

4.2. Climate data

In this research, all the climate data for simulations are downloaded from American Meteonorm software (Version 7.3.3, only based on SRES scenarios; and Version 8.1.1, provides future weather data for RCP 2.6, 4.5, and 8.5 from 10 global climate models based on CMIP5), based on the geographical coordinates of each city.

The software provided the possibility to download data in hours, days, or months according to our requirements. Hourly data of temperature, relative humidity, airspeed, solar radiation, and precipitation, for the last 30 years was collected for all the climate regions. Forecasting of air temperature and relative humidity was carried out, up to 2100 based on three scenarios established by the IPCC. Usually, measurement data can only be used in the vicinity of a weather station. Elsewhere, the data has to be interpolated between different stations. The sophisticated interpolation models inside Meteonorm allow a reliable calculation of solar radiation, temperature and additional parameters at any site in the world. The intuitive GUI in Meteonorm 7 allows you to easily manage and select your weather stations and sites.

4.3. Buildings

4.3.1. Criteria

This research was carried out for four types of buildings (residence, hospital, hotel and school), modelled with building materials most suited to extreme climates. One of the essential conditions for the buildings to be adaptive to extreme climate returns to the choice of building materials. Indeed, the building material in the regions selected in this research should have low thermal conductivity and should be thicker than those of other regions with moderated climates. These characteristics are detailed in Table 4.

The choice of these different types of buildings was not made at random, indeed, the behaviour of occupants is different in all these selected buildings. The development of a new city requires different infrastructures among which, we considered residences, schools, hospitals and hotels. Each of these buildings has very different operating criteria.

4.3.2. Description

The different buildings have different shapes with different material structures and different areas, which can accommodate several people as shown in Table 3.

- The residential building designed for this project, was a simple family house on one floor, consisting of four bedrooms, a shower room and a kitchen. The building materials mainly consisted of earth bricks and essentially glazed windows (glass thickness: 5.5 cm).
- -The school was made up of several classrooms, accommodating up to 25 students per classroom. The equipment consisted of a computer and projector per classroom.
- The hospital consisted of several office rooms and a pharmacy. Each room accommodated up to 6 beds for 6 patients.
- The hotel consisted of several rooms, a bar, a restaurant, a secretariat, a reception hall and offices. Equipment met the standards in all rooms.

The different building materials are detailed in Table 4.

Table 2
Characteristics of the sixteen selected regions.

No.	Country	Region/City	Type	Location	Temp. (C°)		RH (%)		Wind speed (m/S)		Köppen classification [63]
					Min	Max.	Min.	Max.	Min	Max	
1	Ethiopia	Dallol	Desert	14°14′N, 40°18′E	10	60	15	80	0	09	BSh
2	Israel	Tirat Zvi	Desert	32° 25′ N, 35° 31′ E	2	54	20	70	0	10	BWh
3	Tunisia	Kebili	Desert	33° 42′N, 8° 57′E	5	55	10	82	0	13	BWh
4	Mali	Timbuktu	Desert	16° 46′N, 3°0W	15	55	15	80	0	11	BWh
5	Saudi Arabia	Rub al-Khali	Desert	20°N, 50°E	15	65	20	70	0	15	BWh
6	Australia	Badland	Desert	38°14S, 145°2E	5	69	25	85	0	12	BWh
7	United States	Death Valley	Desert	36° 14′N, 116° 50′ O	10	57	25	80	0	11	BSk-Csa
8	Libya	El azizia	Desert	32° 31′ N, 13°01′E	15	56	30	85	0	10	BWh
9	Antarctica	Antarctica	Coldest region	90°S, 0°E	-80	21	60	100	0	8	EF
10	Russia	Oymyakon	Colder region	63°27N, 142°47E	-62	25	60	100	0	6	ET
11	Greenland	Nuuk	Colder region	64°10N, 51°44O	-45	23	50	100	0	5	EF-ET
12	Canada	Yellow Knife	Cooler region	62°27N,114°22O	-32	26	30	100	1	5	ET
13	Unites States	Alaska	Cooler region	64°26N, 149°4O	-35	27	30	100	0	7	ET
14	Kazakhstan	Astana	Cooler region	51°4N, 70°18E	-30	25	40	99	0	10	Dfb
15	Iceland	Reykjavík	Colder region	64° 8′ 7N,21° 53O	-39	21	50	100	0	7	ET
16	Finland	Helsinki	Cold region	60°10′N, 24°56′ E	-25	30	30	100	1	8	ET

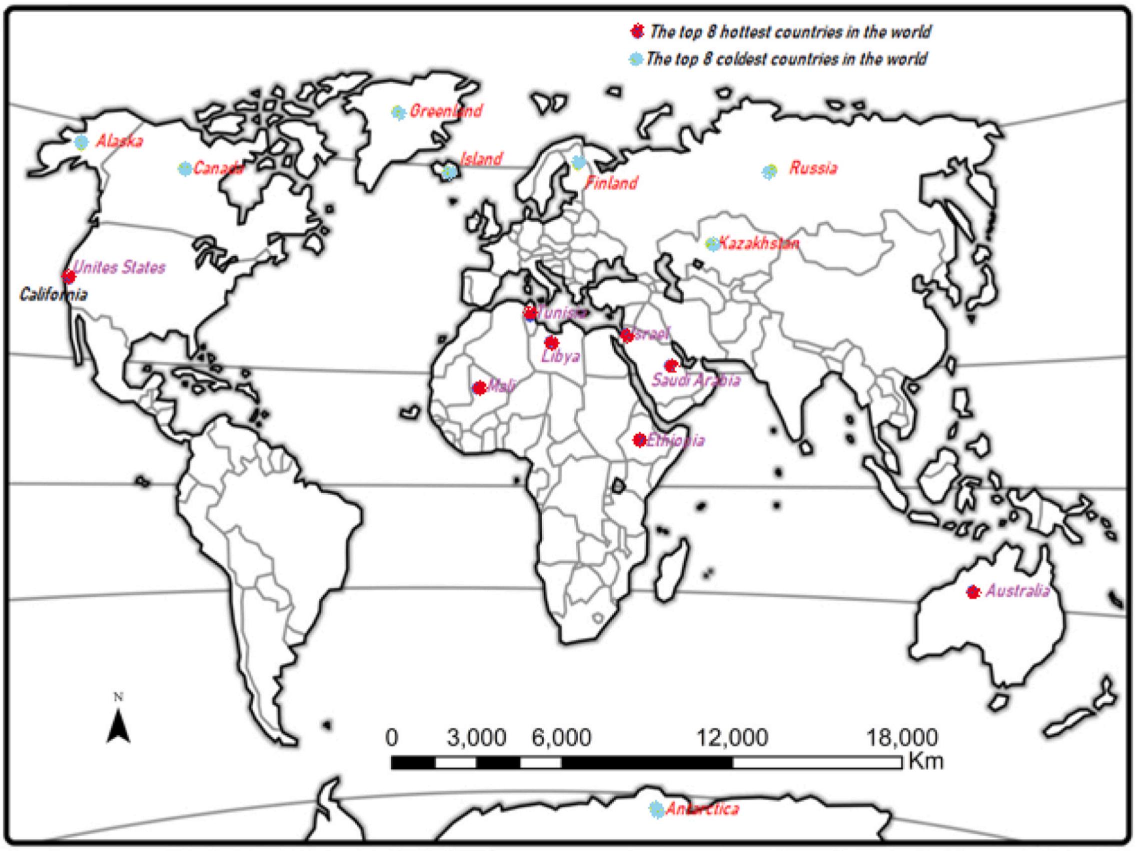


Fig. 1. World map showing the sixteen selected locations(top 8 desert and top 8 coldest regions).

Table 3
Input data for the simulations.

Parameters	Residence	Hospital	School	Hotel
Height (m)	3.5	4.0	4.0	4.0
Area (m2)	342	2766	2696	5688
Activity template	Domestic House	Hospital and care Home	Universities and colleges	Hotels
Occupancy density (people/m2)	0.023	0.150	0.203	0.094
Activity (met)	0.9	0.9	1	0.9
Clothing (Clo)	0.5—1.0	0.5–1.0	0.5–1.0	0.5–1.0
DHW: consumption rate (L/m2-day)	0.53	21.94	0.14	13.12
Fresh air(L/s-person)	10	10	5	10.40
Lighting: target luminance (lux)	100	125	300	100
Computer: power density (w/m2)	0.2	-	0.74	0.5
Other equipment: power density(w/m2)	3.58	3.58	4.00	3.15
Occupancy schedule	24/7	24/7	Mon.-Frid: 7 am-5 pm	24/7
Construction template	Project construction template	Project construction template	Project construction template	Project construction template
Air tightness (ac/h)	0.7	0.7	0.7	0.7
Glazing template	Project glazing template	Project glazing template	Project glazing template	Project glazing template
Glazing type	Preferred height 1.5 m,30% glazed Thickness: 5.5 cm	Preferred height 1.5 m,30% glazed Thickness: 5.5 cm	Preferred height 1.5 m,30% glazed Thickness: 5.5 cm	Preferred height 1.5 m,30% glazed Thickness: 5.5 cm
Local shading	1.0 m overhang	1.0 m overhang	NO	NO
Lighting template	Low standard	LED	Low standard	LED
Lighting control	yes	NO	yes	NO
Lighting schedule	Mon. –Sun. 6 pm-7 am	24/7	12/7	24/7
HVAC template	Fan coil unit(4-pipe) with district heating+ cooling	Fan coil unit(4-pipe) with district heating+ cooling	Fan coil unit(4-pipe) with district heating+ cooling	Fan coil unit(4-pipe) with district heating+ cooling
HVAC Schedule	12/7	24/7	Mon.-Frid: 7 am-5 pm	12/7
Heating: Fuel	Natural gas, COP= 1	Natural gas, COP= 1	Natural gas, COP= 1	Natural gas, COP= 1
Cooling: Fuel	Electricity from grid, COP= 1	Electricity from grid, COP= 1	Electricity from grid, COP= 1	Electricity from grid, COP= 1
Other ventilation	Natural ventilation (NV)	Natural ventilation (NV)	Natural ventilation (NV)	Natural ventilation (NV)

Table 4
Thermal characteristics of initial building constructions.

N°	Building category	Building element	Layer	Component	Thickness (m)	Thermal conductivity (W/m-K)	Density (kg/m3	Specific heat capacity (J/kg K)	Source	U-value (W/m2-K)
1.	Residence	Exterior wall	Layer1	Brickwork	0.100	0.84	1700.0	800.0	CIBCE(2006)	0.194
			Layer2	Extruded polystyrene	0.079	0.034	35.0	1400.0	Uralita	
			Layer3	Cork Board	0.100	0.040	160.0	1888.0	ISO 10456	
			Layer4	Gypsum plastering	0.013	0.400	1000.0	1000.0	ISO 10456	
		Partition wall	Layer1	Gypsum Plasterboard	0.105	0.210	700.0	1000.0	BR 443 / UK NCM	0.518
			Layer2	Cork	0.050	0.040	110.0	1800.0	CIBSE	
		Roof	Layer1	Clay Tile	0.025	1.00	2000.0	800.0	ISO 10456	0.160
			Layer2	Stone Wool	0.242	0.040	30.0	840.0	Uralita	
			Layer3	Roofing felt	0.005	0.190	960.0	837.0	-	
		Internal floor	Layer1	Cast concrete (Dense)	0.100	1.40	2100.0	840.0	ISO 10456	4.73
		Ground floor	Layer1	Formaldehyde foam	0.132	0.04	10.0	1400	CIBSE Guide / Uralita	0.25
			Layer2	Cast concrete	0.100	1.13	2000.0	1000.0	CIBSE Guide	
			Layer3	Roof screed	0.07	0.41	1200.0	840	CIBSE Guide	
			Layer4	Timber flooring	0.03	0.14	650.0	1200.0	ISO 10456	
2.	Hospital	Exterior wall	Layer1	Brickwork	0.100	0.84	1700.0	800.0	CIBCE(2006)	0.35
			Layer2	Extruded polystyrene	0.079	0.034	35.0	1400.0	Uralita	
			Layer3	Concrete Block	0.100	0.510	1400	1000	ISO 10456	
			Layer4	Gypsum plastering	0.013	0.400	1000.0	1000.0	ISO 10456	
		Partition wall	Layer1	Gypsum plasterboard	0.025	0.210	700	1000	BR 443 / UK	1.92
			Layer2	Air gap	0.100	0.3	1000.0	1000.0	ISO/WD 6946	
			Layer3	Gypsum Plasterboard	0.025	0.25	900.0	1000.0	ISO 10456	
		Roof	Layer1	Clay Tile	0.0250	1.00	2000.0	800.0	ISO 10456	0.16
			Layer2	Stone wool	0.242	0.040	30.0	840.0	Uralita	
			Layer3	Roofing felt	0.005	0.19	960.0	837.0	ISO 10456	
		Internal floor	Layer1	Cast concrete (Dense)	0.100	1.40	2100.0	840.0	ISO 10456	4.73
		Ground floor	Layer1	Formaldehyde foam	0.132	0.04	10.0	1400	CIBSE Guide / Uralita	0.25
			Layer2	Cast concrete	0.100	1.13	2000.0	1000.0	CIBSE Guide	
			Layer3	Roof screed	0.07	0.41	1200.0	840	CIBSE Guide	
			Layer4	Timber flooring	0.03	0.14	650.0	1200.0	ISO 10456	
3.	School	Exterior wall	Layer1	Rubber Tiles	0.020	0.30	1600.0	2000.0	CIBSE	0.206
			Layer2	Extruded Polystyrene	0.13	0.34	35.0	1400.0	CIBSE Guide	
			Layer3	Plasterboard	0.12	0.25	2800.0	896.0	ISO 10456	
			Layer4	Cork	0.013	0.040	110	1800.0	CIBSE Guide	
		Partition wall	Layer1	Gypsum plasterboard	0.025	0.210	700	1000	BR 443 / UK NCM	1.923
			Layer2	Air gap	0.100	0.3	1000.0	1000.0	ISO/WD 6946	
			Layer3	Gypsum Plasterboard	0.025	0.25	900.0	1000.0	ISO 10456	
		Roof	Layer1	Clay Tile	0.0250	1.00	2000.0	800.0	ISO 10456	0.16
			Layer2	Stone wool	0.242	0.040	30.0	840.0	Uralita	
			Layer3	Roofing felt	0.005	0.19	960.0	837.0	ISO 10456	
		Internal floor	Layer	Cast concrete (Dense)	0.100	1.40	2100.0	840.0	ISO 10456	4.73
		Ground floor	Layer1	Formaldehyde foam	0.132	0.04	10.0	1400	CIBSE Guide A / Uralita	0.25
			Layer2	Cast concrete	0.100	1.13	2000.0	1000.0	CIBSE	
			Layer3	Roof screed	0.07	0.41	1200.0	840	CIBSE	
			Layer4	Timber flooring	0.03	0.14	650.0	1200.0	ISO 10456	
4.	Hotel	Exterior wall	Layer1	Plaster (Dense)	0.017	0.50	1300.00	1000.00	ISO 10456	0.32
			Layer2	Extruded Polystyrene	0.079	0.34	35.0	1400.0	CIBSE	
			Layer3	Brickwork	0.100	0.84	1700.0	800.0	CIBCE(2006)	
			Layer4	Plasterboard	0.100	0.250	2800.0	896.0	ISO 10456	
		Partition wall	Layer1	Gypsum Plasterboard	0.125	0.21	700.0	1000.0	BR 443 / UK NCM	0.810
			Layer2	Bio PCM,M51	0.021	0.20	235.0	1970.0	-	
			Layer3	Bio PCM, M182	0.074	0.20	235.0	1970.0	-	
		Internal floor	Layer	Cast concrete (Dense)	0.100	1.40	2100.0	840.0	ISO 10456	4.73
		Roof	Layer1	Asphalt	0.01	0.70	2100.0	1000.0	CIBSE	0.25
			Layer2	Glass Wool	0.144	0.04	12.0	840.0	CIBSE	
			Layer3	Air gap	0.200	0.034	1000.0	1000.00	CIBSE	
			Layer4	Plasterboard	0.013	0.25	2800.0	896.0	ISO 10456	
		Ground floor	Layer1	Plaster(dense)	0.017	0.50	1300.0	1000.0	ISO 10456	0.32
			Layer2	Extruded polystyrene	0.0795	0.034	35.0	1400.0	CIBSE	
			Layer3	Brick work	0.100	0.840	1700.0	800.0	Uralita	
			Layer4	Plaster board	0.103	0.25	2800	896	ISO 10456	

The materials selected for these constructions are more adapted to extreme climates.

In these different tables, we can see that all the materials chosen, have a low thermal conductivity. The goal is to select the materials the more adapted to extreme climates.

During the simulation, we fixed 20 cm and 25 cm as extruded polystyrene thickness in the desert, and cold regions, respectively; and the results are reported in Table 5 to follow.

4.4. Thermal parameters

The definition of thermal comfort varies from one standard to another. It is the state of mind of an individual expressing satisfaction through his thermal environment [44]. A broader definition is found in ASHRAE 55 [45].

Predicted Mean votes (PMV) calculation takes into account 6 parameters: air temperature, mean radiant temperature, relative humidity, air speed, clothing resistance and activity [45]. To assess the natural operating state of a building, it is recommended to conduct experimental studies under natural ventilation conditions. Despite this, several robust studies have shown that the PMV model is applicable in air-conditioned buildings, while the new adaptive model is only applicable to naturally ventilated buildings [45,46,28]. The PMV /PPD (predicted percentage dissatisfied) model was developed by P.O. Fanger based on several empirical studies and thermal equilibrium equations. The participants were evaluated on their thermal sensation based on seven points ranging from cold (−3) to warm (+3).

Standard effective temperature (SET *), is known as a model linked to the human response to the thermal environment. This model was created by Gagge and implemented in ASHRAE-1986. This model remains valid today [47].

In standard ASHRAE 55–2017, the cooling effect (CE) at a high air speed (greater than 0.2 m/s), is defined as the number that, when subtracted simultaneously from the temperature average radiation and air temperature, results in the same SET number with still air (0.1 m/s), similar to the calculation of SET value, with high air [45]. Generally, the outdoor climate impacts indoor comfort, indeed, several studies have shown that humans can easily adapt to almost all possible temperatures in any region throughout the year, the adaptive model is based on this idea [48]. In the past, a lot of experimental research has been conducted in several categories of buildings [49,36,50,37,51].

4.5. Tool of simulation

In this study, we used the most recent version of the Design Builder software (version 6.1). This software is highly renowned in this field and has served as the basis for thousands of scientific researches. Design Builder software, the same as, TRNSYS, DOE, Pleiades, Helios etc. software is very well known in the field of simulation, optimization, modelling, BIM (Building information modelling), LCC (Life Cycle Cost), LCA (Life Cycle Assessment) etc.

This software is coupled with the Energy Plus (version 9.6.0) tool to assess the consumption and energy demand of a building [52]. This software offers us most building materials with their physical thermal property. More detailed information on this software can be found in this link [53]. The modelling of the building selected is shown in Fig. 2.

Table 5
U-values in each region.

region	Exterior wall	U-Values (W/m^2-K)			
	Extruded polystyrene thickness (cm)	Residence	Hospital	School	Hotel
Desert regions	20	0.115	0.156	0.144	0.151
Cold regions	25	0.098	0.127	0.119	0.124

4.6. Validation

Temperature and relative humidity are two elements that have a profound effect on thermal comfort, energy demand and even carbon production.

Other environmental parameters which impacted thermal comfort are mean radiant temperature, and indoor air speech that were automatically evaluated by the software used in this study under the basis of several equations developed in several research works grouped in ASHRAE [54]. It is important to understand that this model can be validated based on simulated and measured data. The objective is to verify whether the difference between these two categories of data can be acceptable. Most models are validated based on the recommendations given in certain international standards. In the case of this research, we evaluated the coefficient of variation or square root error (RMSE) and mean bias error (MBE), as recommended in guide 14, ASHRAE-2017 [54]. The hourly air temperature in March 2020 was used for the validation of the model as shown in Fig. 3.

The RMSE and MBE values were calculated as shown in Eqs. 1 and 2 [54].

$$RMSE(\%) = \frac{1}{M}\sqrt{\frac{\sum_{i=1}^{N}(Mi - Si)^2}{N}} \tag{1}$$

$$MBE(\%) = \frac{\sum_{i=1}^{N}(Mi - Si)}{\sum_{i=1}^{N}Mi} \tag{2}$$

Where Si and Mi main simulated and measured data over a given interval I, respectively the total number of data implemented.

The different results found are very important for the validation of this model. The results are given in Fig. 3, while a comparison of values is shown in Table 6.

In Guideline 14 presented by ASHRAE [54], it is recommended that a simulation model can be considered calibrated if the following guideline is followed:

- Hourly MBE between ±10% and hourly RMSE smaller than 30%.

As seen in the table6, the results indicate the Hourly MBE +8.9%, and RMSE 8% which are below the requested in ASHRAE Standard, therefore, the new simulation model used in this research can be validated and produce accepted results.

4.7. Scenarios

In this research, we used six scenarios: B1 (Low), A1B (med.), A2 (High), RCP 2.6, 4.5, and 8.5; established by the IPCC for making the various climate projections. Roughly speaking, RCP8.5 is comparable to SRES A2, RCP6.0 to B2, and RCP4.5 to B1. But, SRES does not have any equivalent scenario to RCP2.6. Energy demand and carbon emissions are assessed under scenario A2, representing one of the most extreme cases of the SRES scenarios.

The projection on the global average surface warming was carried out, up to 2100 by IPCC as detailed [55].

- The B1 scenario was based on global environmental sustainability, and suggested a temperature change increase between 1.1 and 2.9 °C;
- the A1B scenario was focused on rapid economic growth, and suggested a temperature change increase between 1.4 and 3.8 °C;
- the A2 scenario was developed based on regionally oriented economic development and suggested a temperature change increase between 2.0 and 5.4 °C.

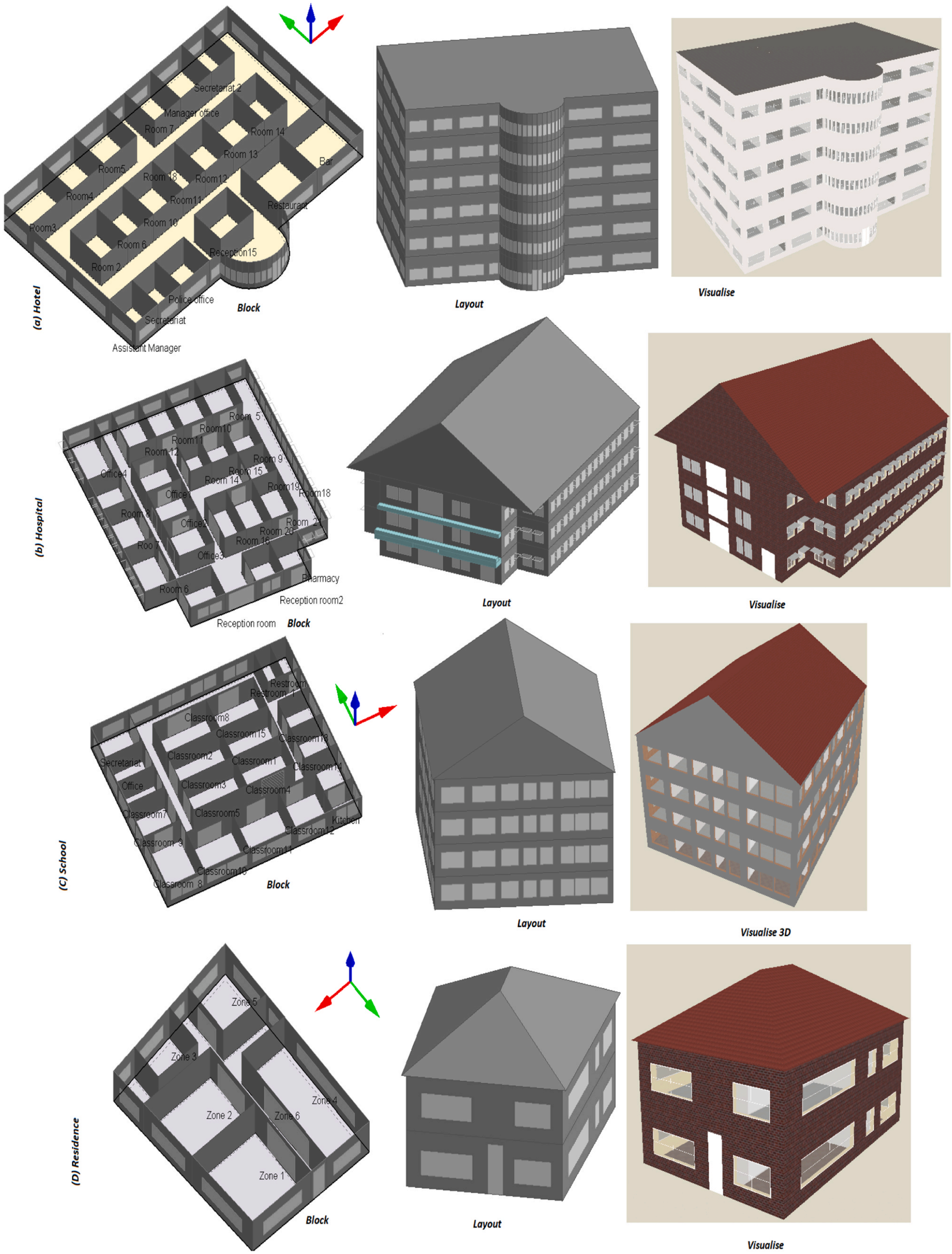


Fig. 2. Simulated building model developed using Design Builder (EnergyPlus).

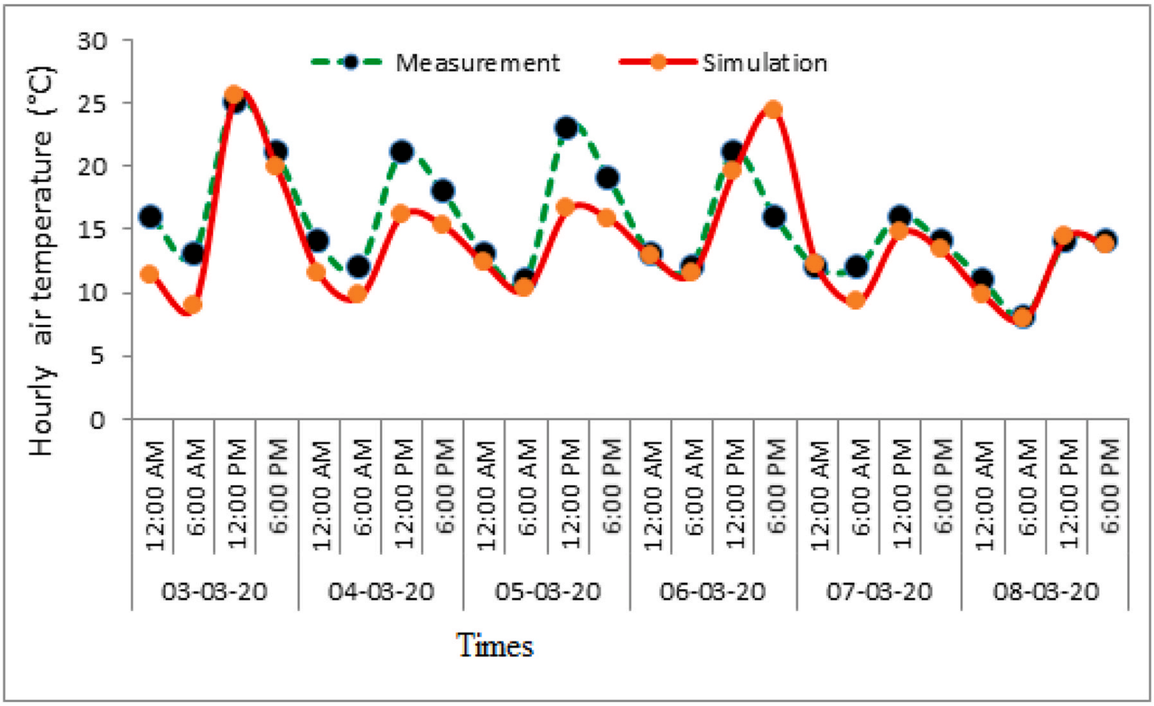


Fig. 3. Comparison between measured and simulated air temperatures during the monitored period: Mars 03–08, 2020.

Table 6
Comparison of errors found in this study and this of ASHRAE standard.

Validation criteria	ASHRAE, Guideline 14 [54]	This work
MBE (%)	±10%	+8.9%
RMSE (%)	less than 30%	8.0%

- the RCP 2.6 scenario is a "very stringent" pathway. It implies that CO_2 emissions decrease from 2020 onwards and become almost zero in 2100, suggesting a temperature change increase between 1.5 and 2.5 °C.
- the RCP 4.5 scenario is shown by the IPCC as an intermediate scenario. The peak of emissions will be achieving probably in 2040, then will decrease. It requires that the CO_2 concentration start decreasing in 2045 to reach roughly half of the levels of 2050 by 2100, suggesting a temperature change increase between 2.5 and 3.5 °C.
- In the RCP 8.5 scenario, emissions are expected to continue to increase in the 21st century. This scenario is known to be the most unlikely but may come true, suggesting a temperature change increase between 3.5 and 5.5 °C.

Some examples of research using these scenarios are given in the references [56,26,57].

4.8. Application of renewable energy

The strong growth in carbon emissions from the building sector has been noted in recent years. Several studies have shown that the building sector contributes to more than 35% of carbon emissions in the atmosphere [8]. Conscious of this fact, we have chosen in this study to use materials with low emission of carbon concentration, and we have introduced several sources of renewable energy to the simulated buildings such as photovoltaic panels and wind turbines whose main characteristics are described in the following sub-sections.

4.8.1. Description of photovoltaic panel

In this study, we have introduced photovoltaic panels with a surface area of 100 m^2 on the roof of each of the buildings studied. The different cells were made of polycrystalline, with base load, and direct current with inverter. Its optimal inclination was 30–35° from the horizontal. We introduce the same surface of photovoltaic panels (PV) on the roof of each of the buildings studied to evaluate under the same conditions for all the buildings the quantity of energy generated by the PV.

4.8.2. Description of wind turbine

The installed wind turbine was of medium size. Available schedule: 24/7; rotor type: horizontal; rotor speed: 41 Rev/min; rotor diameter: 19 m; overall height: 31 m; number of blades: 3; maximum tip speed ratio 8; maximum power coefficient 0.4.

4.9. Simulations

The duration of the simulations depends on the power of the simulator. The different output parameters depend greatly on the characteristics of the buildings and it were assumed two possible cases:

- In the first stage, we conducted simulations of the four types of buildings in natural ventilation. This phase aims to assess the different real parameters of buildings to propose more suitable standards (adaptive model).
- In the second stage, we installed the air conditioning (Fan coil unit (4-pipe) with district heating+ cooling); we introduced the photovoltaic panels and the wind power. The purpose of this stage was to assess the impacts of renewable energy on the environment.

5. Results

The different results found in this research are distributed in several sub-sections detailed below.

5.1. Air temperature and relative humidity change

As shown in Fig. 4 and 5, the air temperature change is different in the two categories of the region. The future variation of air temperature

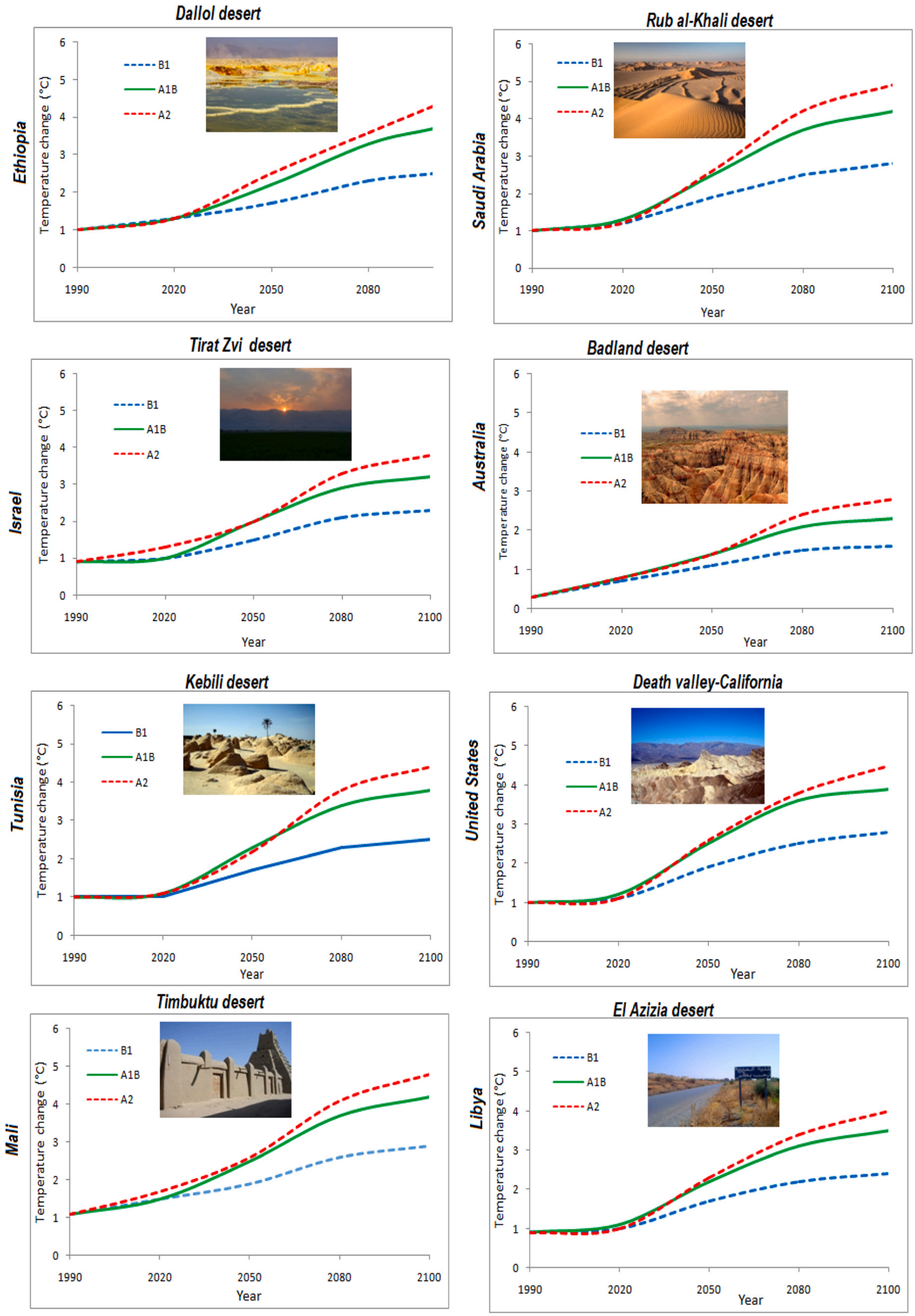


Fig. 4. Projections of temperature change in degree Celsius in the top 8 deserts of world for the B1(low), A1B(med), and A2(high) scenarios.

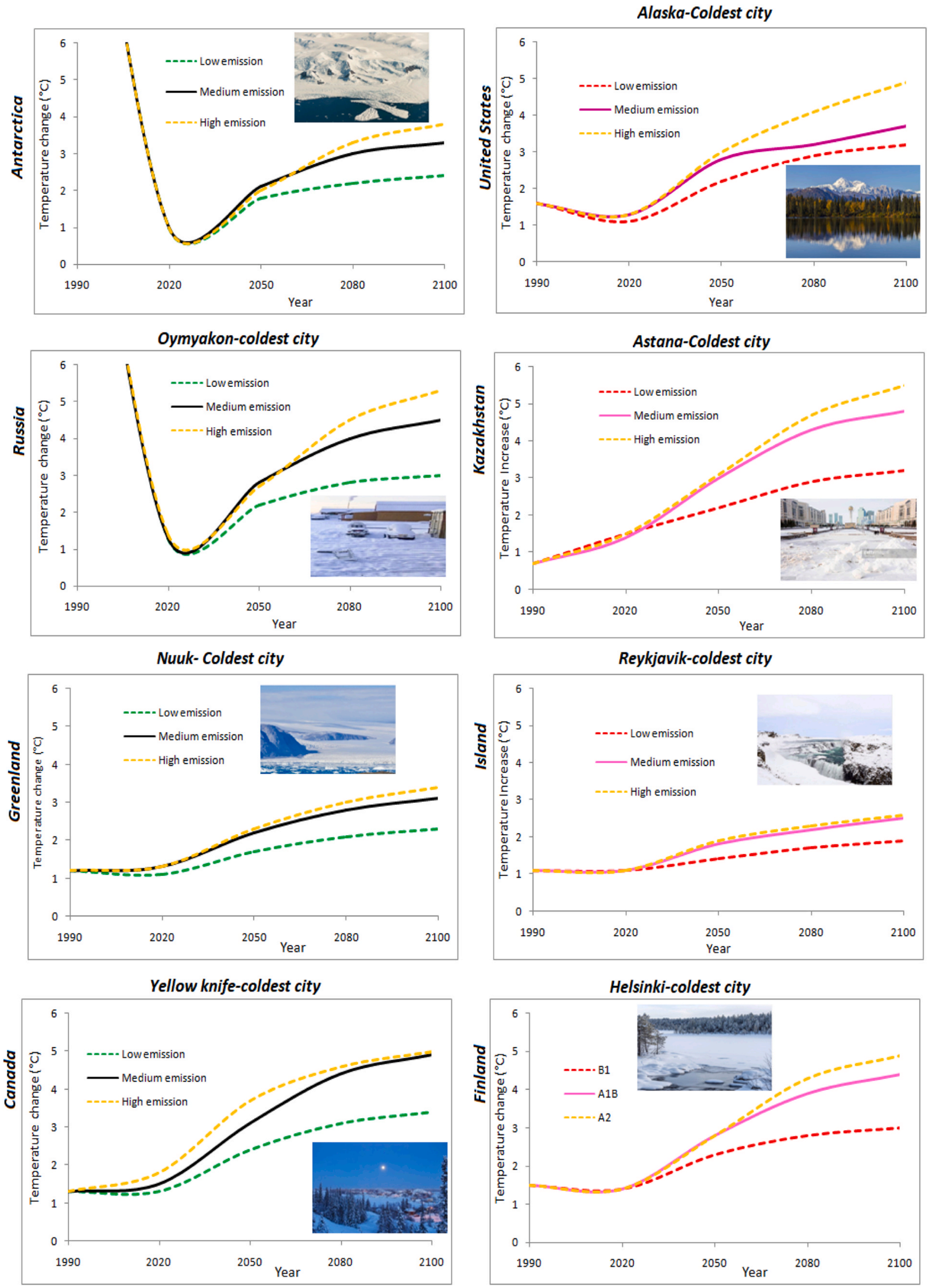


Fig. 5. Projections of temperature change in degree Celsius in the top 8 coldest regions of world for the B1(low), A1B(med), and A2(high) scenarios.

is compared to the hourly data of air temperature between 1961 and 1990. This means this interval is considered the reference range in this study. The different air temperature change grouped into two categories is given in Fig. 6.

If nothing is done to prevent the evolution of the climate, in the desert regions, the temperature will increase most quickly in the desert of Rub al-Khali in Saudi Arabia (up to 4.9 °C in 2100); on the contrary, in the same category of region, the temperature will increase the least in the Badland desert in Australia (2.8 °C in 2100).

In addition, in the coldest regions, the temperature increases the most in the city of Astana in Kazakhstan (up to 5.5 °C in 2100). The results detailed in Fig. 6 show the air temperature will increase faster in the coldest than hottest regions.

Fig. 7 shows the projection of relative humidity change in the top 8 coldest and hottest regions in the world. Through this figure, we can easily deduce that the variation of the relative humidity is unstable and very difficult to predict. Indeed, in the desert region between 1990 and 2100, relative humidity change alternated from −2 to 2%; while in very cold regions it is likely that relative humidity change is between −10% and 2%.

5.2. Thermal comfort assessment

In all the research, thermal comfort has been studied in natural ventilation, and the detailed results are given in sub-sections 3.2.1 and 3.2.2.

5.2.1. Thermal acceptability

Fig. 8 shows a Psychrometric chart according to the ASHRAE Standard 55–2017 in the top 8 deserts of the world. These diagrams are derived from the hourly meteorological data of each region. It is seen that the adaptive comfort temperature ranges for each desert region are not the same. Some desert regions have harsher climates than others.

Overall, it was noticed in the buildings that, PMV values varied from −1 (slightly cool) to +1 (slightly warm), which corresponds to PPD values of less than 20%. It was interesting to see that when the Standard Effective Temperature (SET) were between 23.3 °C and 29.1 °C; the Cooling effect was between 1.0 °C and 1.5 °C. These different results may justify the state of thermal comfort is not very bad in the different categories of buildings studied. In general, in all these regions, the outside climate is extreme. These results may be due to the rigorous choice of construction materials which have a significant impact on the thermal comfort of the occupant.

Fig. 9 shows adaptive chart according to the standard: EN-16798 and also ASHRAE Standard 55–2017. Fig. 9 (1−4) represents the coldest regions, it is given the operative temperature range as a function of outdoor running mean temperature. These different regions are recognized to be “too cool”. The operative temperature is categorized into three classes: class1, acceptability limits between 21.3 °C and 27.6 °C; class 2, acceptability limits between 20.3 and 28.6 °C; and class 3, acceptability limits from 19.3 °C to 29.6 °C.

In addition, in Fig. 9(a-d) representing the hottest regions, the operative temperature range is given as a function of the prevailing mean outdoor temperature.

The indoor environment of various buildings studied in these regions is known to be "comfortable". The operative temperature range characterized by 80% acceptability limits is between 22.9 °C and 30.8 °C; while the operative temperature range characterized by 90% acceptability limits is between 23.9 °C and 29.8 °C. These results show that when the operative temperature decreases to 1 °C in the 80% of acceptability range; the half of 20% of occupants who found initially their environment not acceptable change their sensation and vote “environment acceptable”.

5.2.2. Thermal sensation

Fig. 10 shows the different values of the Predicted Mean Votes (PMV) function of hourly indoor air temperature (Ta); and Thermal Sensation Votes (TSV) function of hourly operative temperature (Top) in the selected locations. The following equations were established as adaptive models in the studied regions.

(a) In the Residence:

$$PMV = 0.396T_a - 10.77, R^2 = 0.972 \quad (1)$$

$$TSV = 0.142T_{op} - 3.497, R^2 = 0.947 \quad (2)$$

(a) in the Hotel:

$$PMV = 0.243T_a - 6.265, R^2 = 0.804 \quad (3)$$

$$TSV = 0.123T_{op} - 2.908, R^2 = 0.851 \quad (4)$$

(b) in the Hospital:

$$PMV = 0.192T_a - 4.195, R^2 = 0.863 \quad (5)$$

$$TSV = 0.156T_{op} - 3.206, R^2 = 0.749 \quad (6)$$

(c) in the School:

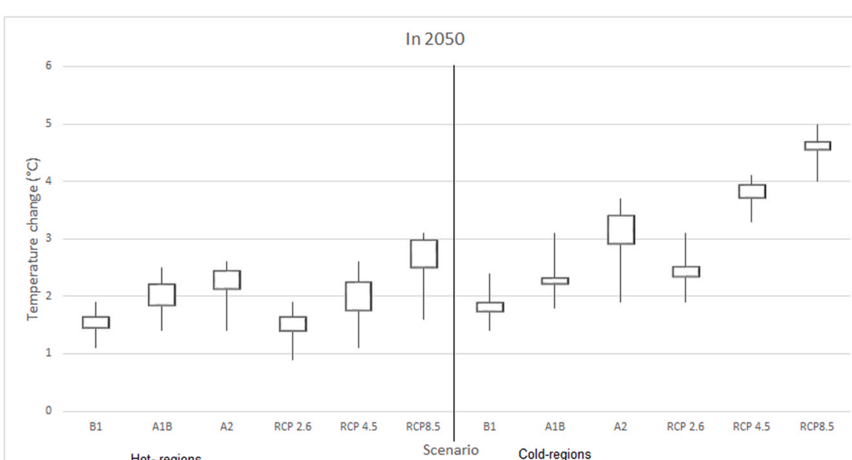


Fig. 6. Air temperature increases in (2050) compare to (1961—1990).

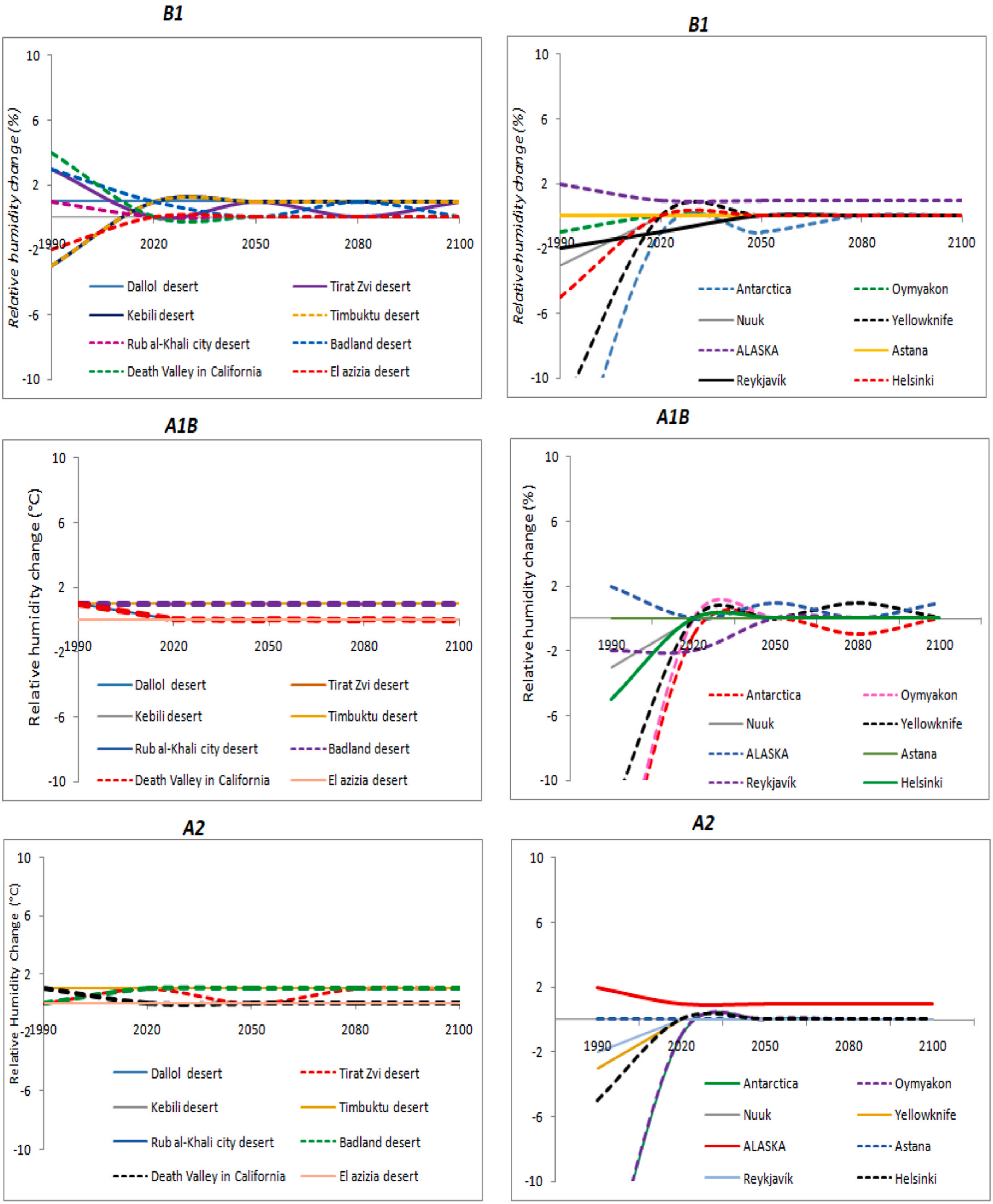


Fig. 7. Projections of relative humidity change in percentage in the top 8 coldest regions and top 8 deserts of world for the B1(low), A1B(med), and A2(high) scenarios.

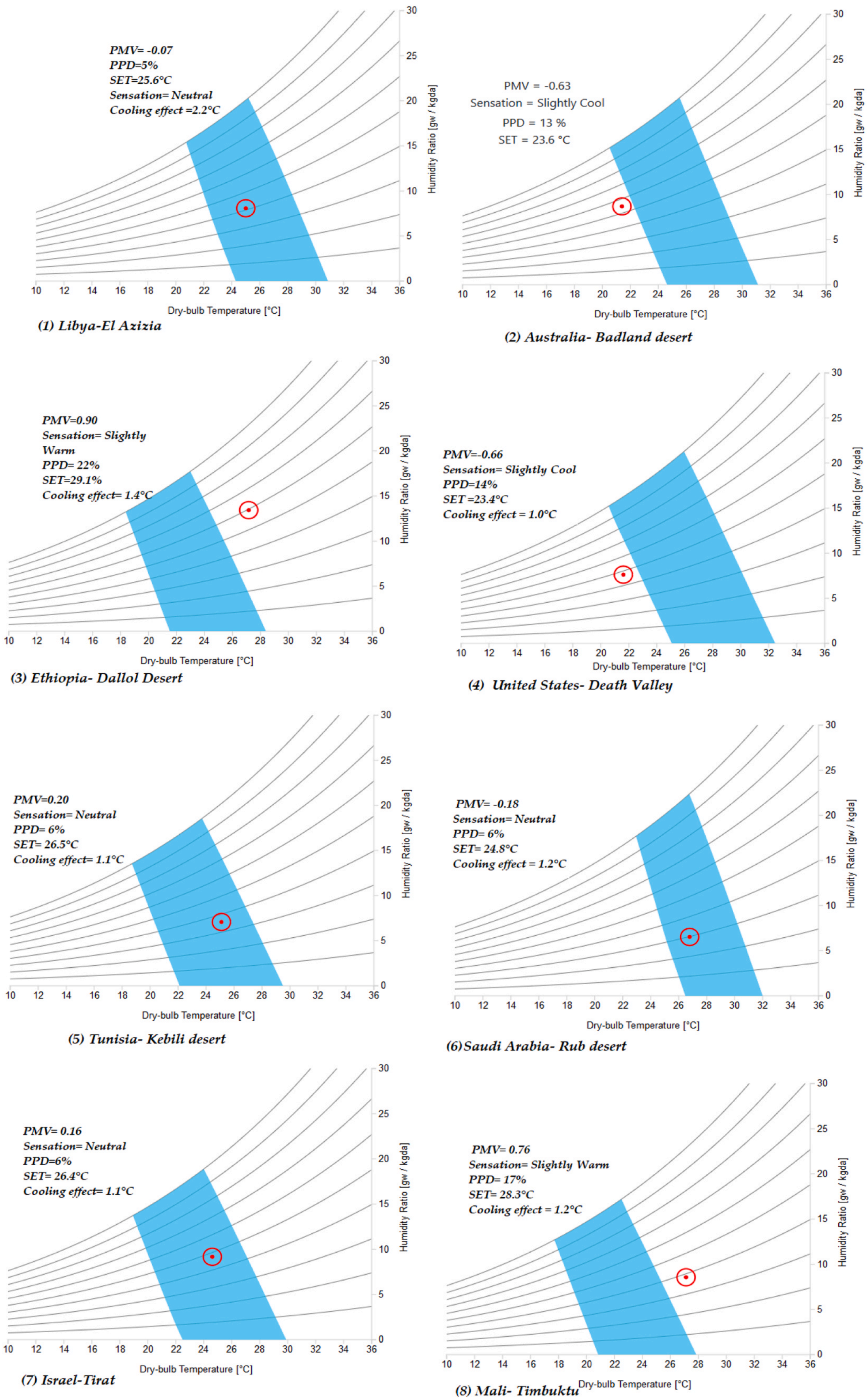


Fig. 8. Psychrometric chart according to the ASHRAE Standard 55–2017 in the top 8 deserts of world(blue spectrum is the comfort zone and the red circle is point of thermo-neutrality).

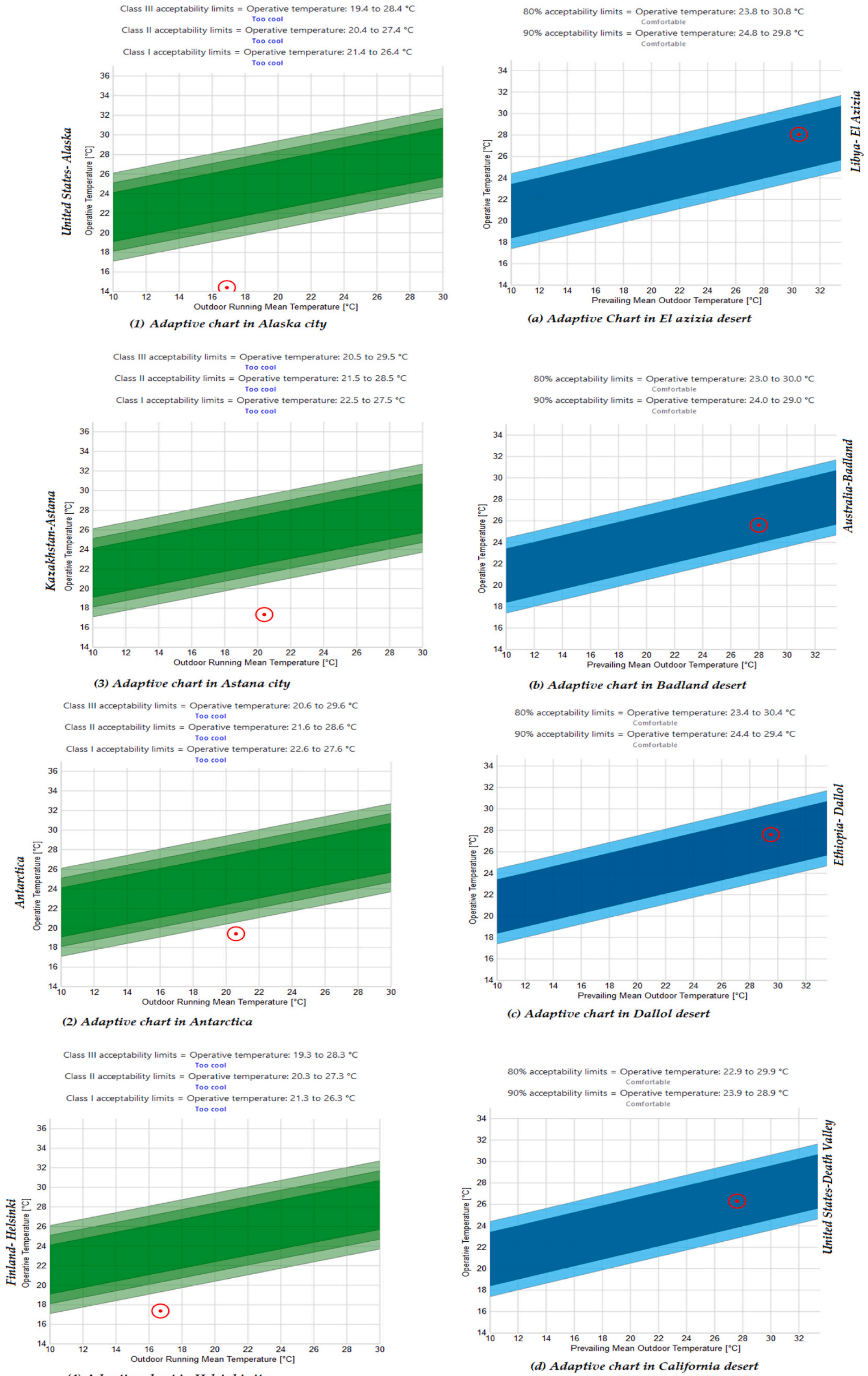


Fig. 9. Adaptive chart according to the standard: EN-16798(in left,1–4) and ASHRAE Standard 55–2017(in right a-d).

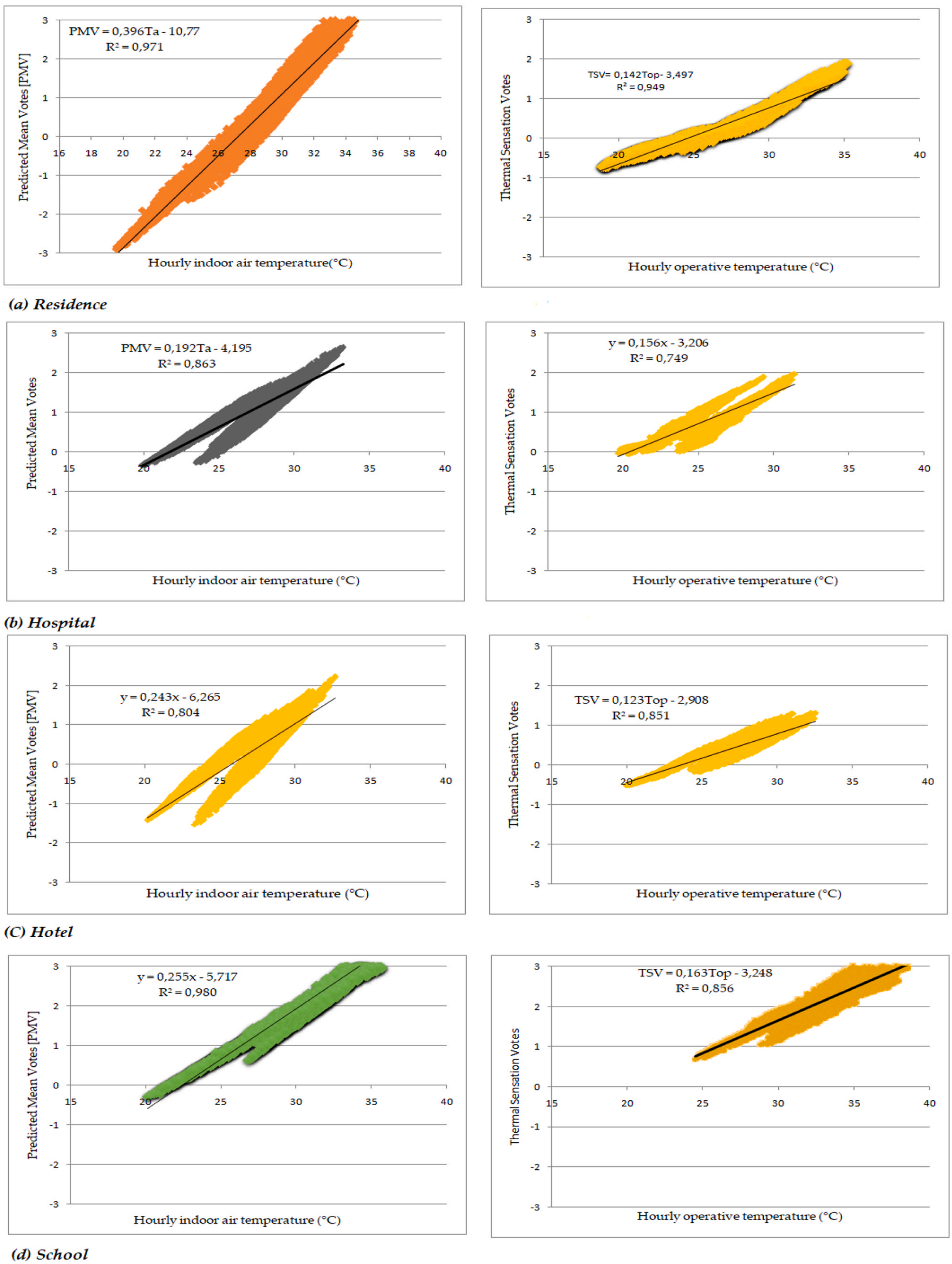


Fig. 10. Predicted Mean Votes(PMV) function of hourly indoor air temperature(Ta); and Thermal Sensation Votes(TSV) function of hourly operative temperature (Top) in the selected locations ((a) residence; (b) hospital; (c) hotel; and (d) school), in natural ventilation.(NV).

$$\mathrm{PMV} = 0.255\mathrm{T_a} - 5.717, \mathrm{R}^2 = 0.980 \quad (7)$$

$$\mathrm{TSV} = 0.163\mathrm{T_{op}} - 3.248, \mathrm{R}^2 = 0.856 \quad (8)$$

It is very interesting to notice that in all four types of buildings, we got a linear curve with a strong correlation coefficient (R^2 *nearby* 1). This means that these different formulas can be generalized in other regions with extreme climates. Indeed, as shown in Fig. 10, in the residence: when the indoor air temperature was from 19.5 °C to 34.5 °C; PMV ranged between −2.9 and 3.0; while TSV were between −0.7 and 1.8. At this time, the neutrality temperature (the neutral temperature is evaluated for PMV = 0) was 27.19 °C, while, the thermo-neutrality temperature (the temperature of thermo-neutrality is evaluated for TSV = 0) was 24.62 °C.

On the other hand, in the hotel and hospital, we got some important linear correlation coefficients ($R^2 = 0.804$; $R^2 = 0.851; 0.863$; $R^2 = 0.749$). Indeed, when the operative temperature was between 19.9 °C and 32.7 °C; PMV ranged between −1.2 and 2.3; while TSV were from −0.5 to 1.9. At this time, the neutrality temperature ranged between 21.9 °C and 25.8 °C, and the thermo-neutrality temperature ranged from 20.6 °C to 23.7 °C. In the case of school, we also got a significant linear correlation coefficient ($R^2 = 0.980; R^2 = 0.856$), at the set neutral temperature of 22.4 °C, when indoor temperature air ranged between 20.2 °C and 34.7 °C; while PMV varied from −0.3 to 3.

These results show among the four building type studied, a school is the least comfortable.

5.3. Inventory of energy demand and carbon emission in naturally ventilated buildings

In natural ventilation, the energy used for heating and cooling buildings is excluded. The energy concentration evaluated in this case comes from the lighting of the building and the operation of some equipment (Radio, television, computer, cooking, printing etc.). As shown in Fig. 11, the annual energy demand was estimated to be between 14.2kWh/m^2 and 529.4 kWh/m^2 in the desert regions; and, from 13.6kwh/m^2 to 529.0 kwh/m^2 in the coldest regions. In addition, the carbon dioxide emission during building operations in both regions is between 7.5 kgCO_2/m^2 and 321.6 kgCO_2/m^2. The carbon dioxide emission concentration is 249% higher in the hospital than in the three other buildings (residence, school and hotel).

5.4. Inventory of energy in air-conditional buildings

5.4.1. Annual cooling potential and load

The annual passive cooling potential mentions the period during which a building consumes energy for cooling.

Fig. 12 shows the comparison between the annual passive cooling potential (estimated cooling potential) and annual cooling load (simulated cooling load) for the sixteen selected locations. In the four types of buildings (residential, hospital, school and hotel), Cooling energy is very low in the coldest regions, while in the case of the hottest regions, the Dallol desert in Ethiopia has the highest annual passive cooling potential (from 28.9% to 91.1%) as well as the highest annual cooling energy consumption (between 207.4 kWh/m^2 and 397.8 kWh/m^2) compared with the seven other deserts. Badland desert in Australia has the lowest passive cooling potentials (between 1.1% and 59.8%) as well as the lowest cooling loads (from 7.3 kWh/m^2 to 70.8 kWh/m^2).

5.4.2. Annual passive solar heating potential and annual heating load

The passive solar heating potential means the period during which the buildings require energy for their heating. In Fig. 12, we can see the comparison between the annual passive heating potential (estimated heating potential) and annual heating load (Simulated heating load) in the different types of buildings for the sixteen selected locations.

It is interesting to notice that in the hottest regions (deserts), the passive solar heating potential is very low and does not exceed 15%, for passive heating load between 0 and 57.5kWh/m^2. In contrast, in the coldest regions, Antarctica has the highest annual passive heating potential (from 43.6% to 92.9%) as well as the highest annual heating energy consumption (between 192.6 kWh/m^2 and 692.4 kWh/m^2) compared with the other top 7 cold regions. Reykjavik in Iceland has the lowest passive heating potential (22.7–85.9%) as well as the lowest heating load (80.7–221.3 kWh/ m^2). Fig. 13 gives the linear regression of the annual passive potential and an annual load of cooling and heating in the four buildings. We got several strong correlations: firstly, between the annual cooling potential and annual cooling load; secondly between the annual passive heating potential and annual heating load and results are shown in Table 7.

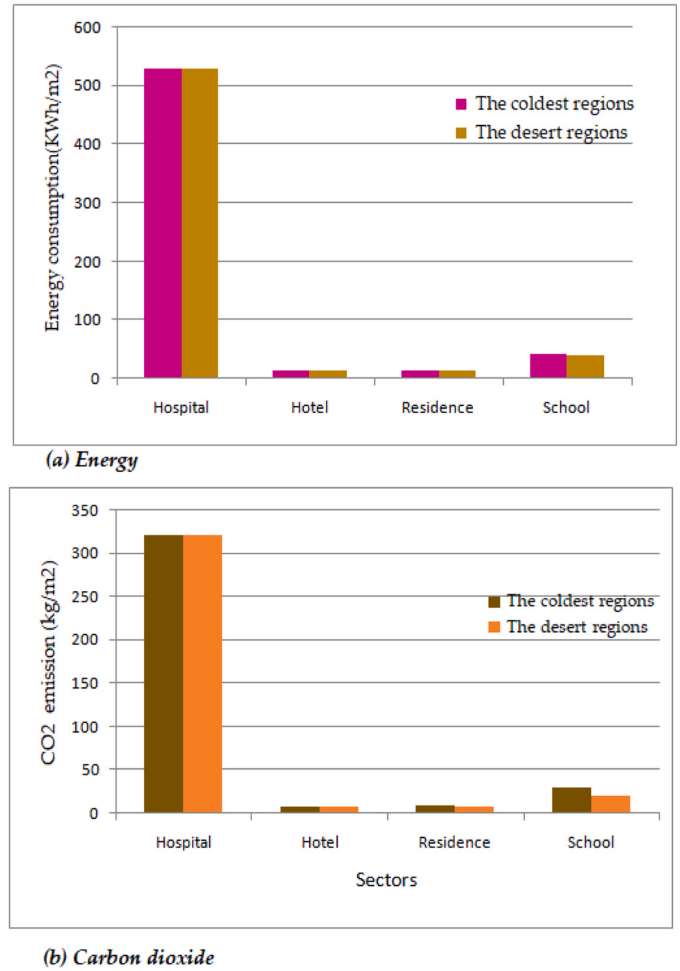
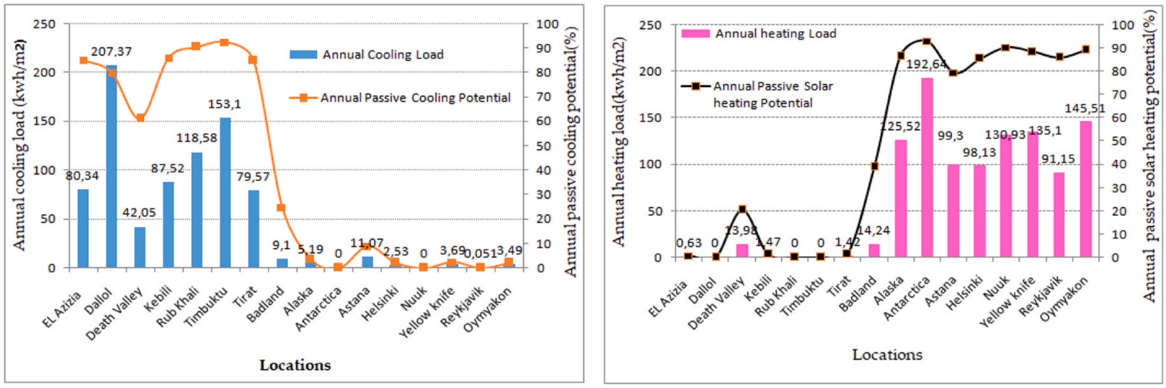


Fig. 11. Comparison of energy consumption(a) and CO_2 emission(b)in the two categories of regions(desert and coldest regions) in hospital, hotel, residence and school in natural ventilation.

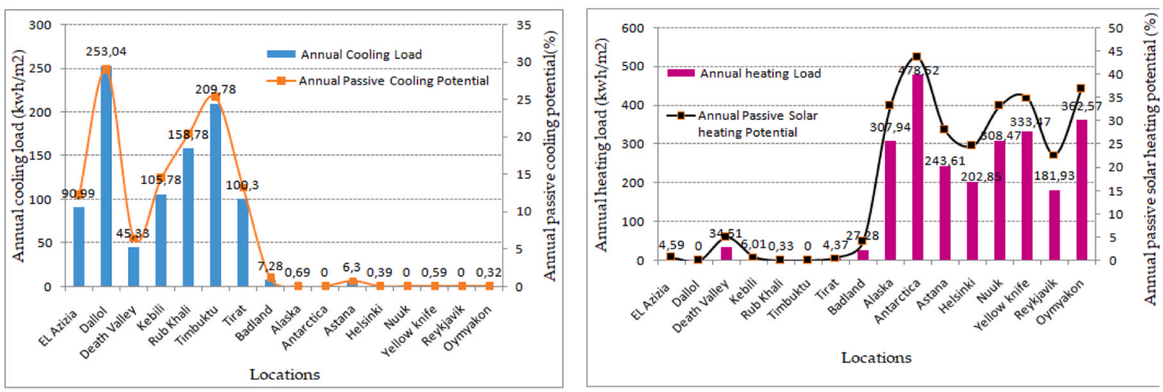
5.4.3. Energy demand and energy generated

In desert and cold regions, Net energy demand (E) is given in Table 8. Through this table we can see that, energy consumption is the lowest in residential buildings and the highest in hospitals. Several reasons can explain this, indeed, we can observe through the results that cooling and heating energy are the lowest in the residence building. In Table 3, we can see that scheduled lighting is 12/7 in residential buildings, and 24/7 in hospitals.

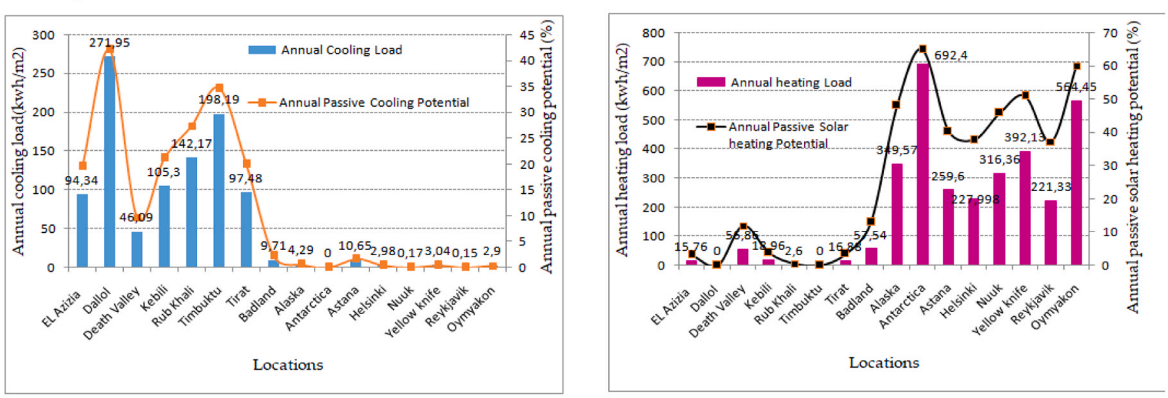
In the specific case of this study, it is seen that in summer, more precisely in June, July and August, the net energy consumption is between 5% and 10% higher in desert than in cold regions, while in winter (October, December, and January etc.), energy demand is between 20%



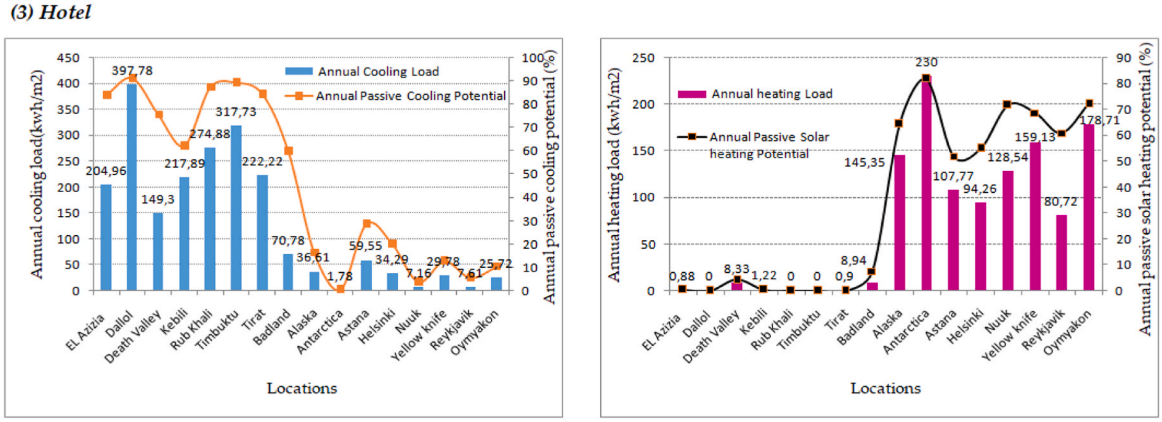
(1) Residence



(2) Hospital



(3) Hotel



(4) School

Fig. 12. Comparison between the annual passive cooling and heating potential (%) versus annual cooling and heating load (kWh/m2).

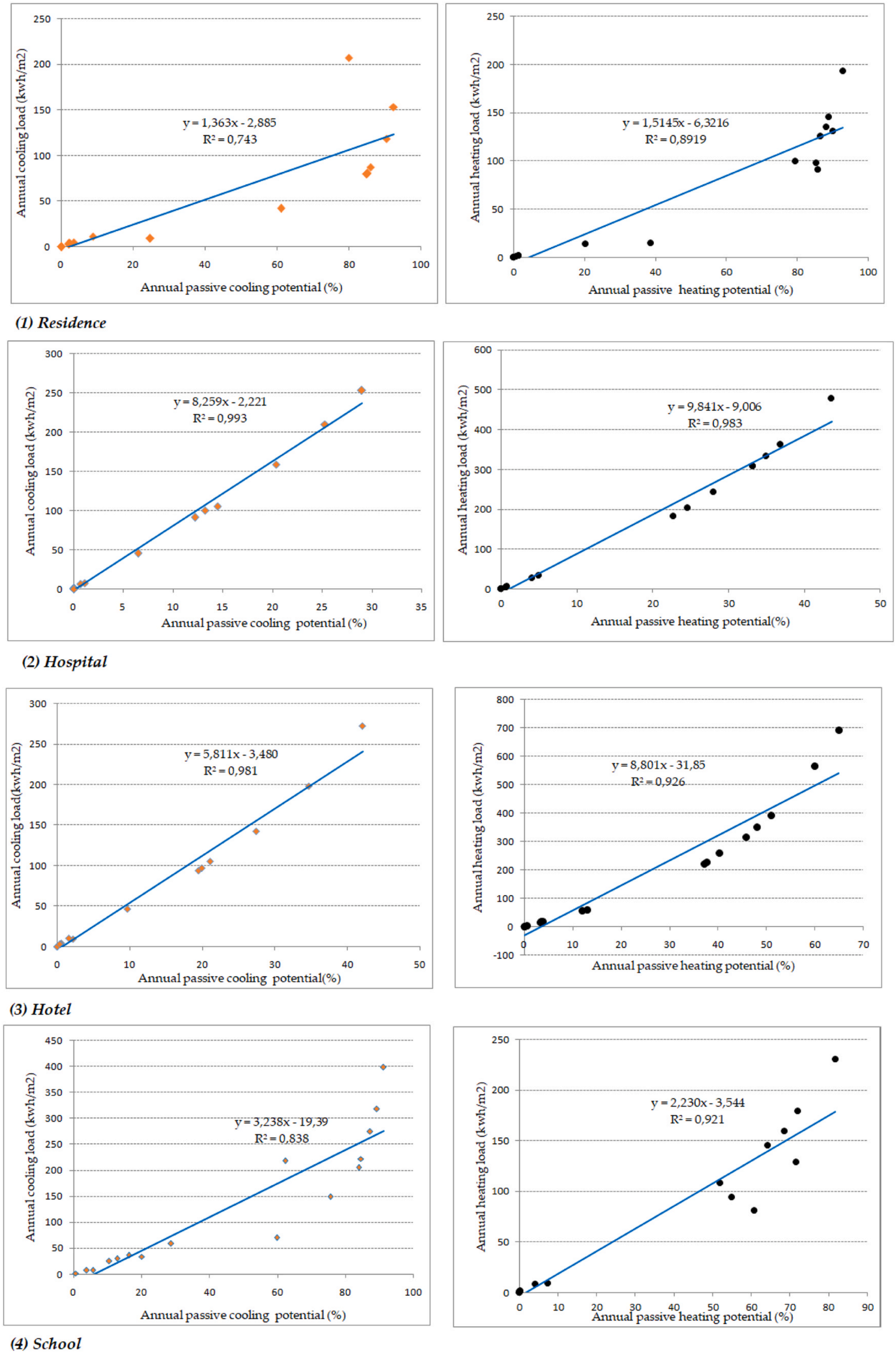


Fig. 13. Linear regression of the annual passive potential (%) and annual load (kWh/m2).

Table 7
Detailed validation of the linear regression between the annual bioclimatic potential in each region and annual energy loads in the four buildings.

	Passive cooling potential/ cooling load		Passive heating potential/ heating load	
	R (Pearson coefficient)	R^2 (Regression coefficient	R (Pearson coefficient)	R^2 (Regression coefficient)
Residential	0.862	0.743	0.943	0.891
Hospital	0.996	0.993	0.991	0.983
Hotel	0.990	0.981	0.962	0.926
School	0.915	0.838	0.959	0.921

and 40% higher in cold than desert regions.

Some details regarding net electricity and gas are shown in Table 9. In this study, the main cooling source is electricity, and the main heating source is gas. This reason explains why the gas quantity is very high in the coldest zones, while low in the hottest regions. In contrast, Electricity demand is very high in the hottest region, while low in the coldest regions.

Through this table, we can see that the quantity of renewable energy produced is highest in the cold zone. This seems contradictory because we know that, solar panels have the highest efficiency in hot areas. In the case of this study, it is normal, because the amount of total green energy generated comes from both the solar panels and the wind turbine. Note that the efficiency of the wind turbine is higher in cold than hot areas. In addition, the wind turbine that we installed in this study has a very high yield, in view of its characteristics given in section 3.8.2.

5.5. Operational carbon

Fig. 14 shows the projection of dioxide carbon concentration per sector in each region. It is important to notice that during the building operation, Dallol desert has the highest carbon dioxide emission in residential, hotel, school, as well as hospitals (between 68.3 and 432.8kgCO_2/m^2 in 2000; between 71.3 and 433.9 kgCO_2/m^2 in 2050; from 104.1 to 442.5 kgCO_2/m^2 in 2100), compared with the other top 7 deserts of the world. In contrast, the Badland desert in Australia showed the lowest carbon dioxide emission (between 33.8 and 278.6 kgCO_2/m^2 in 2000; from 42.6 to 282.2 kgCO_2/m^2 in 2050; between 47.6 and 300.1 kgCO_2/m^2 in 2100). On the other hand, in cold regions, Alaska in the USA and Yellow Knife in Canada showed the highest carbon dioxide emission (from 28.6 to 364.1 kgCO_2/m^2 in 2000; between 28.9 and 368.1 kgCO_2/m^2 in 2050; from 29.6 to 372.1 kgCO_2/m^2 in 2100). These results show that CO_2 emission is higher in deserts than in cold regions. To summarize, it is interesting to notice that during all the seasons, the carbon emission rate is higher in hospitals than in the three other types of buildings (residences, hotels and schools).

6. Discussions

6.1. Analysis and comparison of climate change on the thermal comfort

The results show the variation of the air temperature and the relative humidity outside have a direct impact on the thermal comfort and the energy demand for heating and cooling in a building. These conclusions do not seem new they confirm the results found by several researchers [26,56].

Through these results, we can deduce that if nothing is done to reduce the impact of the evolution of the external climate, in the worst case (according to scenario A2 of the IPCC), we can expect an increase in temperature up to 4.9 °C in desert areas, and up to 5.5 °C in the coldest regions in 2100. These results show that the outside temperature increases very quickly in cold areas than in desert areas. The cause of the strong temperature increase in the poles or very cold regions is not always clearly explained. It has been the subject of several scientific debates. According to the chief scientist of the American Oceanic and Atmospheric Agency (NOAA) in 2015, the Arctic has warmed twice as fast as the rest of the world [43]. According to a report by IPCC 2014 [2], the temperature increase could reach 4.5 °C in the next decade in the majority of world countries. By comparing these results with those found in this study, we can deduce that air temperature increases more quickly

Table 8
Net energy consumption for each building type is distributed in sixteen regions according to three periods (current, 2050 and 2100).

E (kwh/m2)		Residence			Hospital			School			Hotel		
Cities		current	2050	2100	current	2050	2100	current	2050	2100	current	2050	2100
Desert regions	Azi.	15.8	22.2	55.0	593.2	584.1	604.3	220.7	238.5	281.2	383.0	387.0	410.5
	Bad.	133.2	242.4	249.2	457.8	460.5	503.7	59.3	76.1	80.9	315.1	267.6	266.1
	Dal.	112.7	118.4	171.7	743.71	745.9	762.4	408.2	413.6	460.8	539.7	543.0	593.2
	Dea.	12.9	53.1	73.9	562.0	576.0	579.7	173.0	182.7	218.1	379.1	361.18	379.19
	Keb.	-24.6	-12.3	22.8	590.7	600.0	619.2	222.3	246.6	289.5	383.5	399.5	427.3
	Rub.	-	-	-	618.0	640.6	652.0	46.1	84.1	291.3	404.2	372.5	377.3
	Tir.	7.1	58.9	77.8	594.4	630.8	651.4	234.2	243.9	270.9	383.6	402.9	-
	Tom.	51.8	143.7	196.7	695.5	713.3	736.5	324.9	377.6	418.8	461.2	-	547.6
Cold regions	Ala.	52.9	52.9	49.3	807.3	793.9	766.2	203.4	202.2	195.7	639.8	631.2	593.8
	Ant.	-226.5	-192.6	-192.4	848.5	864.3	863.6	171.2	192.2	190.9	850.1	1002.5	987.4
	Ast.	-81.1	-73.6	-69.5	700.1	694.8	680.0	151.8	165.3	175.6	506.3	497.7	482.1
	Hel.	-26.3	-120.8	-124.9	678.7	608.1	576.8	133.3	105.5	104.8	493.4	428.9	-
	Nuu.	-207.2	-251.6	-260.0	705.2	673.9	642.9	87.5	69.2	57.7	705.2	673.9	642.9
	Oym.	119.4	-	-	872.9	-	-	232.9	-	-	864.1	393.7	-
	Rey.	-185.2	-266.8	-14.5	602.1	561.3	539.9	57.1	33.9	25.8	431.4	393.7	377.3
	Yel.	46.0	41.4	37.3	821.3	805.3	781.7	201.9	205.4	203.6	669.5	649.5	610.3

Table 9
Distribution of electricity and gas in both regions in three periods (current, 2050 and 2100).

Electricity and gas		Desert regions			Cold regions		
		Net electricity demand (kWh/m^2)	Green electricity generated (kWh/m^2)	Net gas demand (kWh/m^2)	Net electricity demand (kWh/m^2)	Green electricity generated (kWh/m^2)	Net gas demand (kWh/m^2)
Residential building	Current	54.8–165.5	91.8–169.6	0.0–14.2	13.3–25.2	44.1–351.8	91.1–145.3
	2050	28.6–232.9	120.3–286.8	0.0–9.2	14.7–37.6	204.5–409.6	86.3–202.2
	2100	38.4–291.0	119.5–286.1	0.0–5.8	14.7–50.9	90.3–407.2	82.3–200.4

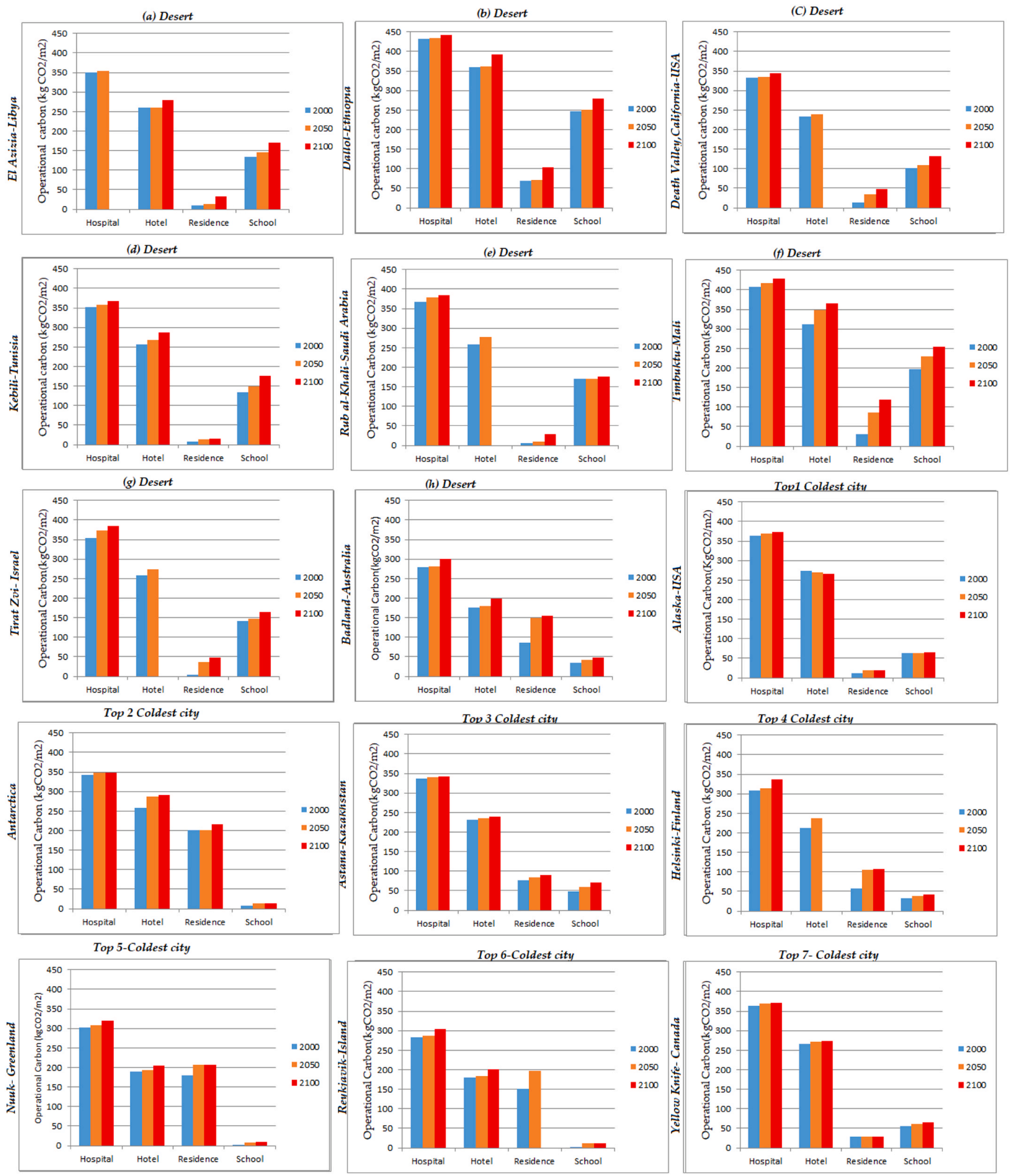


Fig. 14. Projection of dioxide carbon concentration per sector in each region in 2000, 2050 and 2100 for the A2 scenario (in air conditioned).

in regions with extreme climates. These different changes in temperature have an impact direct on thermal comfort.

The outdoor air temperature was recognized to be between −80 °C and 27 °C in the top 8 coldest regions and from 2 °C to 69 °C in desert regions. At this time, in the buildings selected, the indoor air ranged between 20.2 °C and 34.7 °C; the neutrality temperature ranged between 21.9 °C and 27.2 °C, and the thermo-neutrality temperature range from 20.6 °C to 24.6 °C. It is interesting to notice that the thermal comfort temperature range was between 23.9 °C and 29.8 °C. Because at this time, more than 90% of occupants found their environment comfortable. The range is over this reported by ASHRAE 55, Which the thermal comfort temperature range was between 23 °C and 26 °C [45]. The ASHRAE 55 standard was established based on several studies carried out in several types of climates. It is important to update this standard based on more recent studies taking into account the evolution of the current climate. The real state of thermal comfort of the building can be quantified in natural ventilation. Indeed, the new global database is a representation of all the effects related to the adaptive comfort observed in most regions of the world [43].

6.2. Analysis and comparison of climate change on the energy demand

As shown in Table 10, we see that the values of the bioclimatic potential based on a psychometric diagram in all the different regions studied do not always correspond to those of energy values and comfort based on simulation. This conclusion confirms the results found by Ali-Toudert et al. [58].

The desert regions have the highest cooling load and the lowest heating load, while the cold regions have the highest heating load and the lowest cooling load. This is completely normal because it is very cold in the polar zone and very hot in the desert zone. The results showed in the case of desert regions, the Dallol desert has the highest cooling load, while the Badland desert has the lowest annual cooling potential. In contrast, in cold regions, the annual heating load calculation indicates that Antarctica has the highest heating load while the Reykjavik region has the lowest passive heating potential. The geographic position of these different regions has a significant effect on these different loads. Through Table 11. We can see that heating and cooling potential were the highest in the hospital and the lowest in residential buildings. This can be a consequence of the type of building materials chosen in each type of building and also of the period of occupation of each type of building. The heating loads in the desert regions, only represent 6.5% of the cooling loads, while the cooling loads in the coldest regions, only represent 7.3% of the heating loads. These findings justify the results found successively in 2012, by Kharchi et al. [59]; in 2016 by Ghedamsi et al. [60], and later in 2017 by Belkacem et al. [61]. Carbon dioxide emissions are highest in hospitals, this is due to the building materials, the HVAC system used, and the health of the occupants.

In desert regions, cooling load is expected to increase up to 10.3%, for an increase of the temperature up to 2.6 °C in 2050; and, up to 34.5%, for an increase of temperature till 4.9 °C in 2100. These results are nearby this of Peng Xu and al. [29] who showed that in the next 100 years in certain types of buildings, cooling energy will increase up to 25%. In contrast, in the top 8 cold regions, the heating load will decrease up to 15.5%, for an increase of air temperature up to 5.5 °C, in the next 100 years. These findings confirm the results found by several researchers who showed that climate change could contribute to reducing heating energy and increasing cooling energy [34,62,63].

In the hottest regions, the primary energy demand was the highest in the Dallol desert between 112.7 and 743.7 kWh/m^2. The Badland desert showed the lowest primary energy demand from 59.3 to 457.8 kWh/m^2 compare to 7 other deserts. This reason may be due to the extent of their area, and also to the geographic position of these regions. McLeod et a. [64], Found in 2012 that in buildings with low energy consumption, the heating demand is less than 15 kWh / m^2.yr, while the Primary Energy demand is less than 120 kWh/m^2.yr. By comparing these results to those found in this research, we can deduce that buildings located in an extreme climate zone require more energy in their operation.

Table 11
Annually quantity of carbon produces by each of the building selected in the two regions.

CO_2 (kg/m^2.yr.)	Desert		Top 8 cold region	
	NV	AC	NV	AC
hospital	321.6	178.6—432.8	321.6	282.3—342.2
Hotel	7.5	175.3—359.8	7.5	180.1—258.1
Residence	8.2	68.5—86.7	8.9	150.4—200.6
School	20.2	33.8—247.7	30.8	-

6.3. Analysis and comparison of climate change on the CO_2 emission concentration

Table 11 gives the comparison between carbon dioxide emission concentration in the four types of buildings in natural ventilation (NV) and air conditioning (AC).

We can see from this table the dioxide carbon emission is the highest in the building with air conditioning. This is normal because the building emits carbon during heating and cooling. Under the basis of scenario A2, we can see that carbon dioxide emission is expected to increase up to 15% in 2050. In addition, it is interesting to notice that the concentration of carbon is higher in hospitals than in other buildings studied. Embodied carbon was estimated to be 213.2 kgCO2/m2 in the school; 175.6 kgCO_2/m^2 in the Hospital and 164.8 kgCO_2/m^2 in the residence. Embodied carbon concentration depends enormously on the type of building materials. It is recommended to choose materials of low emissions more adapted to the current climate during the building construction [65].

7. Implications and limitations of the study

7.1. Limitations of the study

The authors of this research propose a new standard of comfort and energy consumption more suited to regions with an extreme climate. However, it is known that any scientific study has some limits. In the specific case of this research, we note that:

(a) Only four types of buildings were analysed in this research;
(b) It is difficult to find a meteorological station in an area with an extreme climate. In the literature, most of the studies conducted to predict the evolution of the climate in these regions have the facility of downloading the data from the Meteonorm software. The different empirical data produced by the meteonorm tool are reliable;
(c) The activity of the occupant in the buildings has been fixed;
(d) Previously, only three IPCC scenarios were used in this research. For reducing the impacts of major limitations, we have also evaluated the variation of air temperature by using three new

Table 10
Summary of the cooling and heating in the two extreme climates.

Climate Zone Representative location		Hot zone The top 8 deserts in the world				Cold Zone The top 8 cold regions in the world			
Building		Residence	School	Hospital	Hotel	Residence	School	Hospital	Hotel
Estimation	Annual passive cooling potential (%)	24.7—92.3	59.7—91.1	1.1—28.9	2.2—42.1	0.0—8.8	0.6—28.7	0.0—0.7	0.0–1.6
	Annual passive solar heating potential (%)	0.0—38.8	0.0—7.5	0.0—4.9	0.0—13.1	79.4—90.1	51.9—81.8	24.6—34.9	37.1—64.9
Simulation	Annual cooling load (kWh/m2)	9.1—207.4	70.7–397.8	7.3–253.1	9.7—271.9	0.0–0.7	0.0—59.6	0.0—10.6	0.0—4.2
	Annual heating load (kWh/m2)	0.0—13.9	0.0—1.2	0.0—15.7	0.0—34.5	91.1—192.6	80.7—230.0	181.9—478.6	221.3—692.4

IPCC scenarios such as RCP 2.6; RCP 4.5; and RCP 8.5. In addition, the studies conducted in regions with the same type of climate were applied to compare and validate the prediction model and most of the results. Other types of buildings located in these regions are investigated in view of creating a new data base more adapted to deserts and the coldest regions of the world. Despite these different limits recognized by the authors of this research, it is important to notice that the limitations are minimized in the manuscript. This manuscript represents a contribution despite all these limitations. It is important to emphasize that this study contains important results which can provide guidance to new and future researchers in this field.

7.2. Global Implications for the practice

This study reveals several implications. The impact of climate change on thermal comfort and energy demand in regions with extreme climates is now known. The range of thermal comfort proposed in this research can serve as a basis for future design specialists. Nowadays, regions with extreme climates are more and more coveted, because they are full of important potential not yet exploited because of the unfavourable climatic conditions in these regions. In Meteonorm tool, the database of ground stations is extended with data from five geostationary satellites to fill gaps in areas where no weather stations are available [66]. The satellite data is available on a global grid. The data was correlated with long-term ground measurements to obtain homogenous long-term averages. Usually, measurement data can only be used in the vicinity of a weather station. Elsewhere, the data has to be interpolated between different stations. The sophisticated interpolation models inside Meteonorm allow a reliable calculation of solar radiation, temperature and additional parameters at any site in the world. The intuitive GUI in Meteonorm 7 allows you to easily manage and select your weather stations and sites [66]. The comfort indexes such as PMV, PPD, SET, TSV etc. are automatically generated by Design Builder software, as among the output data, when you check "Fanger indices" and "Adaptive ASHRAE Standard 55", on the interface of output data, of design Builder tool. The information proposed in this study concerning the different cooling and heating loads can help engineers to design building prototypes suitable for extreme climates.

8. Conclusion

In summary, in this research, it was found that the impact of global warming in regions with an extreme climate is not the same as in other regions of the world. Indeed, the air temperature change is faster in extreme climate regions. In addition, the results show that climate change will have a considerable impact on indoor climatic conditions and the energy performance of residential and commercial buildings located in the coldest and desert areas of the world. Applying more effective mitigation and adaptation strategies, as shown in this study, with the choice of construction materials, could easily improve the energy and thermal performance of buildings in extreme areas under present and future climatic conditions. Some specific contributions based on the results of this research are:

(1) In the hottest regions of the world, under the basis of results found in this study, the air temperature is expected to increase up to 2.6 °C in 2050, and 4.9 °C in 2100; while, in the coldest regions of the world, this one will be increasing till 3.7 °C in 2050, and up to 5.5 °C in 2100. These results confirm that air temperature increases faster in the coldest than hottest regions.
(2) Cooling effect was expected to be between 1.0 °C and 1.5 °C when the Standard Effective Temperature was set between 23.3 °C and 29.1 °C
(3) The operative temperature range characterized by 80% acceptability limits is between 22.9 °C and 30.8 °C; while the operative temperature range characterized by 90% acceptability limits is between 23.9 °C and 29.8 °C.
(4) In the top 8 desert regions, the thermal comfort temperature range was between 23.9 °C and 29.8 °C.
(5) For the indoor air ranged between 20.2 °C and 34.7 °C; the neutrality temperature was ranged between 21.9 °C and 27.2 °C, and thermo-neutrality temperature range from 20.6 °C to 24.6 °C.
(6) The carbon dioxide emission concentration is 249% higher in the hospital than in the three other buildings (residence, school and hotel).
(7) In the desert regions, annual passive cooling potential can increase up to 91.1%, as well as the annual cooling energy consumption which can reach 397.8 kWh/m2 in the buildings. In contrast, in the coldest regions, the annual passive heating potential can increase up to 92.9%, as well as, the annual heating energy consumption which already reaches 692.4 kWh/m^2.
(8) In winter, energy demand is between 20% and 40% higher in cold than in desert regions.
(9) The carbon dioxide emission concentration coming from residential buildings is expected to increase by more than 15% in 2050.
(10) The indoor discomfort rate is expected to increase up to 73%, depending on the climatic regions with an increase in outside air temperature up to 4.9 °C in 2100.

As global warming continues, it is expected that energy demand for cooling and heating will considerably rise in both new and existing buildings in the Extreme climate regions. This study introduced another climate change approach for cooling and heating systems in commercial and resident buildings in extreme climates, for different weather scenarios. This approach considered the long-term effects of climate change on building performance.

The different results found in this research can allow us to better understand the effects and implications of climate change on the energy and thermal performance of buildings in regions with extreme climates. Although some of the building typologies analysed seem not to exist in the specific regions selected, they have been adapted by rising insulation thickness up to 25 cm, according to the regions to limit heat transfer. Wider studies, covering all of the hottest and coldest areas, may be recommended as a supplement to this research.

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

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