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Approaches to reducing carbon dioxide emissions in the built environment: Low carbon cities

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Abstract

The interactions between water, energy, and food in terms of economic and environmental outcomes under conditions of a changing climate are something that all countries will need to understand if they intend to effectively manage the consequences. Qatar's measures to increase food security and diversification of the energy system and economy can provide valuable insights to other countries with similar climates but who have a lower capacity to respond. Through Qatari-based organisations, best practice reflecting local characteristics can be shared throughout the region and beyond.

The aim of this paper is to arrive at projections of CO_2 emissions in new cities in Qatar by 2020 using GSAS standards under a number of scenarios coupled with specific interventions that help them meet national and regional targets. The estimated CO_2 equivalent savings were calculated using GSAS energy calculator and based on the total area of the registered project and anticipated projects provided by different entities applying GSAS in Qatar. The projected annual savings of CO_2 emissions due to energy use reduction can be realised by 2020 when projects planned or under construction are completed. The projected CO_2 emission reduction is reported and compared with the international standards.

Keywords: CO_2 emissions; Urban development; Sustainable cities; Climate change; GSAS

1. Introduction

Climate change has received much attention at international forums amongst politicians and business leaders in the past decade. Scientists recognise the relationship between global warming and climate change. The carbon footprint arose out of the debate on climate change and became a tool to measure and estimate greenhouse gas (GHG) emissions related to human activities (Moss et al., 2008; Wiedmann, 2009; Wiedmann and Minx, 2007). It measures the emission of gases that contribute to heating the planet in carbon dioxide (CO_2) equivalents per unit of time or product.

Governments, policy makers and businesses are urgently required acquired to mitigate global warming and to seek ways to reduce GHG emissions in response to growing interests and concerns about climate change over the past two decades (Bo et al., 2008; Brenton et al., 2009; Courchene and Allan, 2008; Matthews et al., 2009). Awareness of global warming was raised by the Intergovernmental

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Panel on Climate Change (IPCC) and provided scientific insights on climate change to governments.

The first IPCC assessment report played an important role in the establishment of the United Nations Framework Convention on Climate Change (UNFCCC), an international environmental treaty with the goal of stabilising GHG concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system (Ercin and Hoekstra, 2012). Efforts under the UNFCCC led to the Kyoto Protocol, an international agreement to cut GHG emissions, with specific reduction targets by country was signed in December 1997 and entered into force in 2005 (Ercin and Hoekstra, 2012).

Qatar is a Non-Annex I party and therefore it is not obliged to legally introduce binding emission reduction targets. However, since environmental protection is enshrined in the constitution and climate change is a cross cutting element for sustainable development, Qatar recognises the need to be integrated into all relevant social, economic and environmental policies.

Qatar has recently hosted the Conference of the Parties (COP18) of the UNFCCC where an agreement was signed to extend the life of Kyoto protocol till 2020, with an interim arrangement to achieve progress towards the accord terminate. Although achieving a consensus approval is extremely difficult taking into account the divergent views and interests of participating countries, the conference could be considered as a successful achievement for Qatar (UNFCCC, 2012). Nevertheless, Qatar has been criticised by the media for its lack in implementing plans regarding carbon emissions reduction, (UNEP, 2013). It is well known that Qatar resides at or close to the top of the global table of CO_2 emissions per capita and that its economy heavily relies on its fossil fuels. This provides a context which aims to create an understanding of emission pathways within Qatar cities and develops approaches for their reduction. Qatar is endeavouring to address its current and future emissions, and will need to embark on programmes that reduce emissions to appropriate levels for the whole country.

The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [IPCC, 2007], indicates that the climate for the Middle East and North Africa Region (MENA) region is likely to experience temperature increases of up to 2 degrees centigrade (°C) within the next 15–20 years, and over 4 °C by the end of this century.

The overall combined predicted effects are – water scarcity, reduced water quality, reduction in air quality – affecting public health and leading to more challenging living conditions especially in cities.

Furthermore, the rise in temperature coupled with current inefficient use of natural resources such as energy and water is likely to result in an increase in the cost of energy, impacting on livelihood and savings of the population and investments in these important sectors. It is therefore imperative that appropriate measures are put in place to transit Qatar to a lower GHG emissions pathway that could reduce emissions and open up low carbon economy options for the country.

Cities are major contributors to carbon emissions and hence are at the forefront of achieving tangible reductions. Tools that quantify emissions in cities are required not only to inform policy, but also to provide the baseline knowledge to allow coherent future planning targeted towards low carbon footprint. Hence in our aspiration to reduce carbon emissions and provide future projections for the expansion of cities, creating carbon accounting methodologies which are crucial to provide the necessary policy guidance to national and local governments as well as municipalities.

By 2030, Qatar aims to be an advanced society capable of sustaining its development and providing a high standard of living for its people. The Qatar National Vision 2030 (QNV 2030) embraces four main pillars including; economic, social, human and environment developments (GSDP, 2008). QNV 2030 defines the long-term outcomes that are sought for the country and provides a framework within which national strategies and implementation plans can be developed. The initial path for this vision was set out within the Qatar National Development Strategy (QNDS) 2011–2016, launched on February the 28th, 2011. It describes a strategy for sustainable development in Qatar and promotes energy efficiency in new buildings (GSDP, 2010). This substantiates Qatar's effort to develop a national policy to manage air pollution, greenhouse gas emissions and the broader challenges of climate change. Qatar needs forward looking, evidence-based policies to be backed by information systems that ensure both; informed decisions at the outset and continuous monitoring to guarantee compliance and, over time, to measure impact and enable learning and continuous improvement.

Through their consumption demands, between 60% and 80% of all global GHG emissions can be attributed to cities (Kamal and Robert, 2009). Direct emissions from buildings are expected to grow to 26% of all GHG emissions by 2030 (IPCC, 2007). Urban density and spatial organisation are the key factors that influence energy consumption in the built environment (OECD, 2010); yet, building design, construction and operation are also clearly significant. In the short-term, substantial reductions in energy use and carbon emissions from buildings can be achieved using energy efficiency technologies that are already well established and widely used – although the levels of investment and effort required would be far beyond current applications (IPCC, 2007). A large proportion of these reductions could be achieved in economically attractive ways that result in a net benefit rather than a cost with short pay-back periods (Gouldson et al., 2011). Such approaches also offer a range of co-benefits relating to employment generation and improved health and quality of life. However, despite their carbon-saving potential, cost-effectiveness and co-benefits, various barriers combine with the tendency for buildings to have long life spans to prevent many of the basic technologies being widely adopted (IPCC, 2007).

Effective carbon reduction in the built environment relies on a combination of planning, design, construction and use. If designed, constructed and operated using a complete system approach, new buildings offer the largest potential savings in energy use (75% or higher) (IPCC, 2007). However, this requires the consideration of measures that passively reduce energy demands in addition to an integrated approach starting from planning until use, those approaches combines technological and behavioural change. Promoting change across the life-cycle of the built environment requires an integrated approach and a diverse range of policy instruments.

There are also significant opportunities for adaptation and development of climate resilience in cities and the built environment. Urban areas are often particularly vulnerable to a range of climate change impacts. For example, most of the world's largest cities are located in coastal areas, therefore increasing their vulnerability to rising sea levels, altering agricultural zones, and increasing the severity of storms and droughts.

Heat waves are likely to be more intense in urban areas due to the heat island effect (OECD, 2010) and issues of water scarcity can have a particularly acute effect in cities. However, there is an urgent need for implementing integrated approaches to adaptation and mitigation in cities, and for the development of low carbon and climate resilient strategy plans in the built environment.

The Global Sustainability Assessment System (GSAS) is an expansion of the QSAS code designed to be the foremost green buildings standard in the Middle East and North Africa based on a comprehensive review of global best practice and its adaptation to the Qatari context. GSAS is mainly a performance-based sustainability rating system. It was developed to create a sustainable urban environment that reduces environmental impacts while satisfying local community needs, in addition to addressing all relevant aspects of sustainability, ecological impact and green building design criteria (Elsarrag and Alhorr, 2012).

GSAS covers all phases of a building's life; design, construction and operation, taking into account the specific requirements of the region. Its scope emphasises a range of sustainability issues including energy, carbon and mitigation of climate change, water and adaptation to climate change and ecosystems. There are a number of carbon footprint assessment methodologies, such as the IPCC's Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), WRI/WBCSD's GHG Protocol, Carbon Trust's Standard and UK's PAS2050 and forthcoming PAS2070 for cities. These constitute a framework to calculate the carbon footprint across sectors. But at the city level, calculation boundaries, emissions factors and other parameters still need to be investigated to identify the impact of growth and changing climate. These boundaries are specific to the spatial regions under consideration and will need to be quantified through both data analysis and modelling approaches.

The European Union has set a unilateral commitment; the target was to reduce the GHG emissions from its 28 Member States by 20% by 2020, compared to 1990 level (Radu et al., 2013).

Economically, there are two main effects for limiting CO_2 emissions; it would affect the immediate economic costs as the use of fossil fuels decreases, also long-term economic benefits would appear as environmental harm due to climate is avoided (Orszag, 2007).

Here, approaches to reducing the CO_2 emissions for the new building sector will be presented. This is crucial because as investment in the built-environment continues, the natural resources dwindle and the cost of energy increases, so requirement to deliver low-energy buildings will become more necessary. In the GSAS, CO_2-eqivelant approach is presented and used to estimate the carbon emissions from future planned cities by 2020.

2. Qatar local information

2.1. Geography

The State of Qatar is an independent state in the Southern Arabian Gulf surrounded by Saudi Arabia, Bahrain, the United Arab Emirates, and Iran. The country is situated midway along the western coast of the Arabian Gulf between latitudes 24.27–26.10 North and longitude 50.45–51.40 East. It is approximately 11,437 square kilometres on a low-lying limestone peninsula projecting northward about 160 km into the Gulf. The coastline is 550 km long and bounds the country to the west, north and east.

2.2. Climate conditions

Climate survey for Qatar has been done as the first stage of this study. Climate data including temperature, relative humidity, precipitation, sun path, solar irradiance, and prevailing wind are shown in the figures below.

Climate data show that there is sufficient solar radiation in Qatar, mainly at the south and west orientations. Rainfall is almost non-existent, averaging about 80 mm a year, only in winter.

Summers are sizzling hot by day, and warm at night, with temperatures often hitting the 40 °C mark or above. Winters are only slightly cooler by day, but can be very chilly at night. On a yearly basis, the cooling load dominates the building thermal load, while the heating load can be negligible for the energy use estimation in commercial buildings.

2.2.1. Air

Hourly outdoor dry/wet bulb temperature variations during a year in Qatar are shown in Figs. 1 and 2 respectively. While the highest and lowest outdoor temperatures during a year are 37.03 °C and 15.01 °C respectively. The original weather data are obtained from the US Department of Energy (DOE) official website.

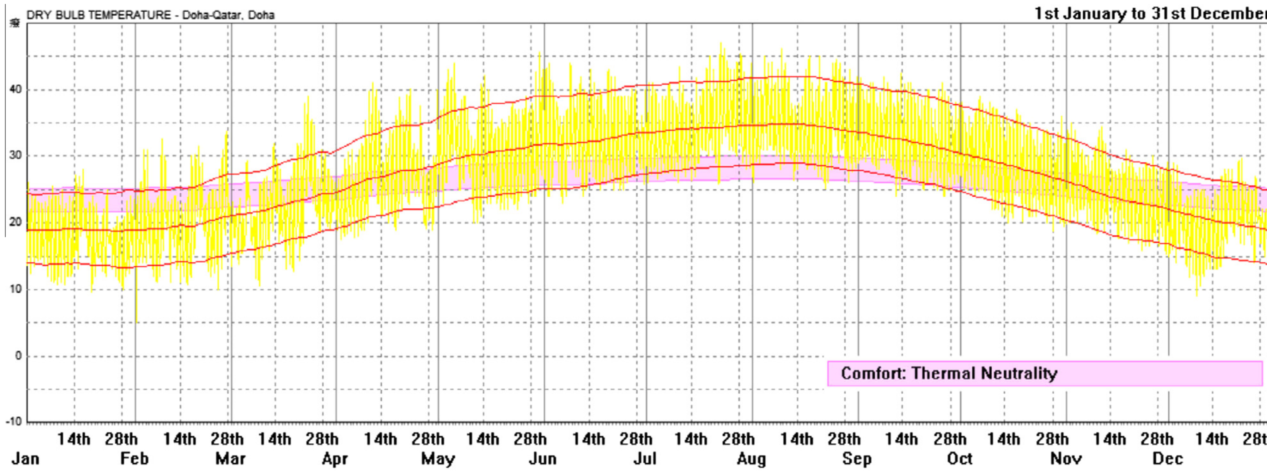

Figure 1. Outdoor dry bulb temperature variations.

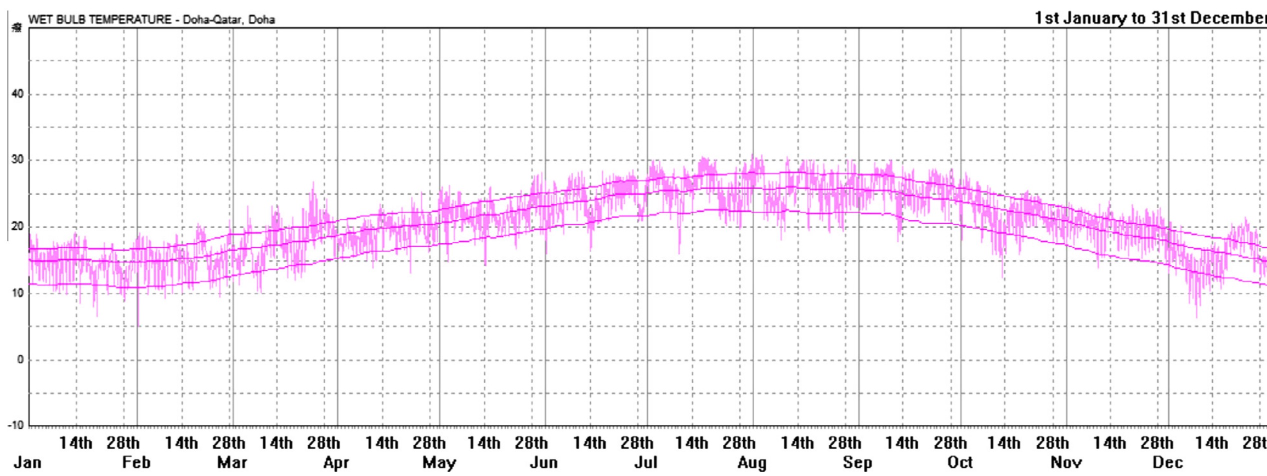

Figure 2. Outdoor wet bulb temperature variations.

The hourly outdoor air relative humidity (RH) variation is shown in Fig. 3 below. The data show that the daily average RH is always greater than 40%, and the daily maximum RH often goes above 80%. Dehumidification for air-conditioning is required year-round.

The hourly cloud coverage condition is shown in Fig. 4 below. Combined with the solar radiation data, there is great potential for using solar energy for buildings in Qatar.

After plotting hourly air properties to a psychometric chart (as shown in Figs. 5 and 6 below), it is indicated that

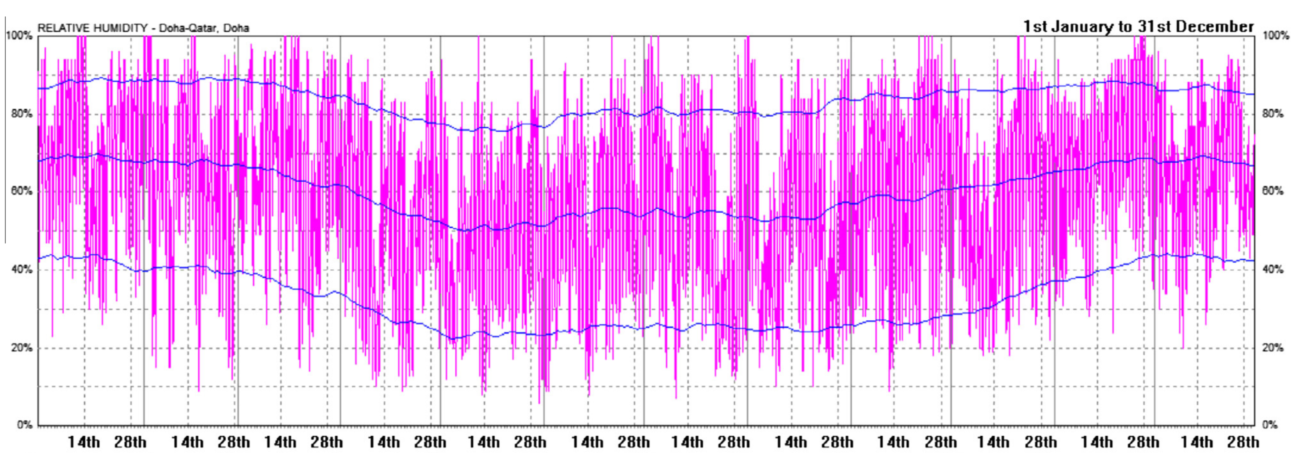

Figure 3. Relative humidity.

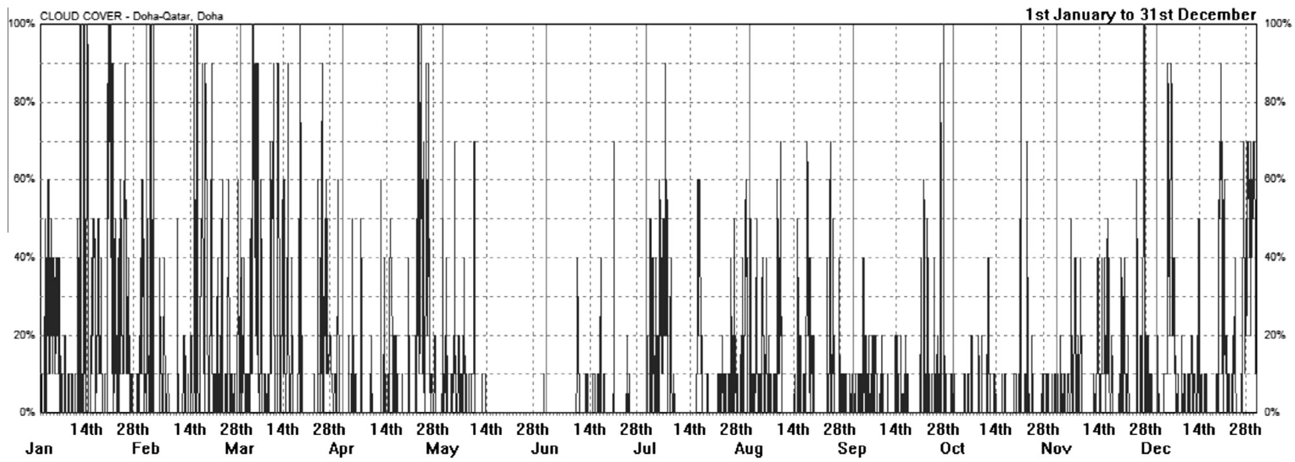

Figure 4. Cloud coverage.

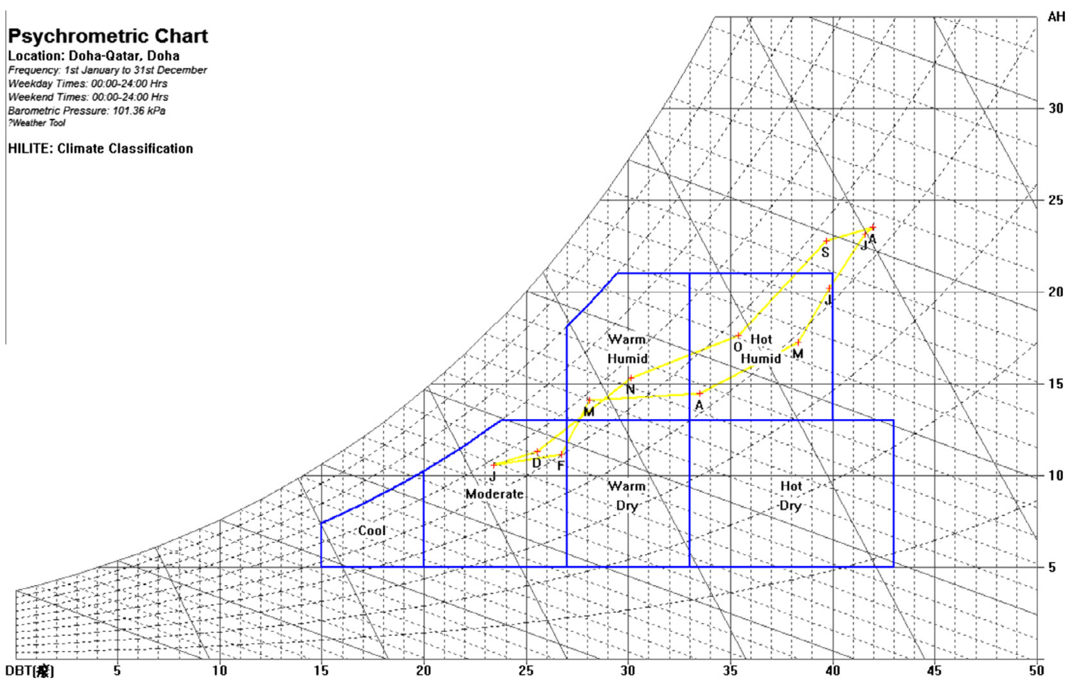

Figure 5. Psychometric chart: average monthly max data points and climate classification.

on average, in only three months (D, J, and F) the weather in Qatar is moderate, while in most of the other months are warm humid, hot humid or even very hot humid.

The psychometric chart also shows that cooling load is the dominating thermal load, and heating load is almost negligible.

2.2.2. Rainfall

The data show that rainfall is negligible in Qatar. Precipitation during the summer is zero, while the month with highest precipitation (February) has only about 17 mm rainfall, including drizzle, rain, hail, sleet, or snow (as shown in Fig. 7). The annual precipitation is less than 100 mm.

2.2.3. Wind

The prevailing wind direction indicated by the yearly cumulated values is northwest. However, wind with a speed higher than 30 km/hr does not last for more than 38 h per year in any direction (as shown in Fig. 8).

2.2.4. Solar

Figs. 9–12 show solar radiation by different orientations. Annual cumulated solar radiation amounts from different orientations are different. The data show that the west and south walls of a building receive the most solar radiation (less than the roof).

2.3. Energy

A large part of the energy demand in the State of Qatar originates from the built environment. The demand for water and power has been rising rapidly and significantly. However, utility infrastructure projects are planned to meet the increasing demands of power and desalinated water.

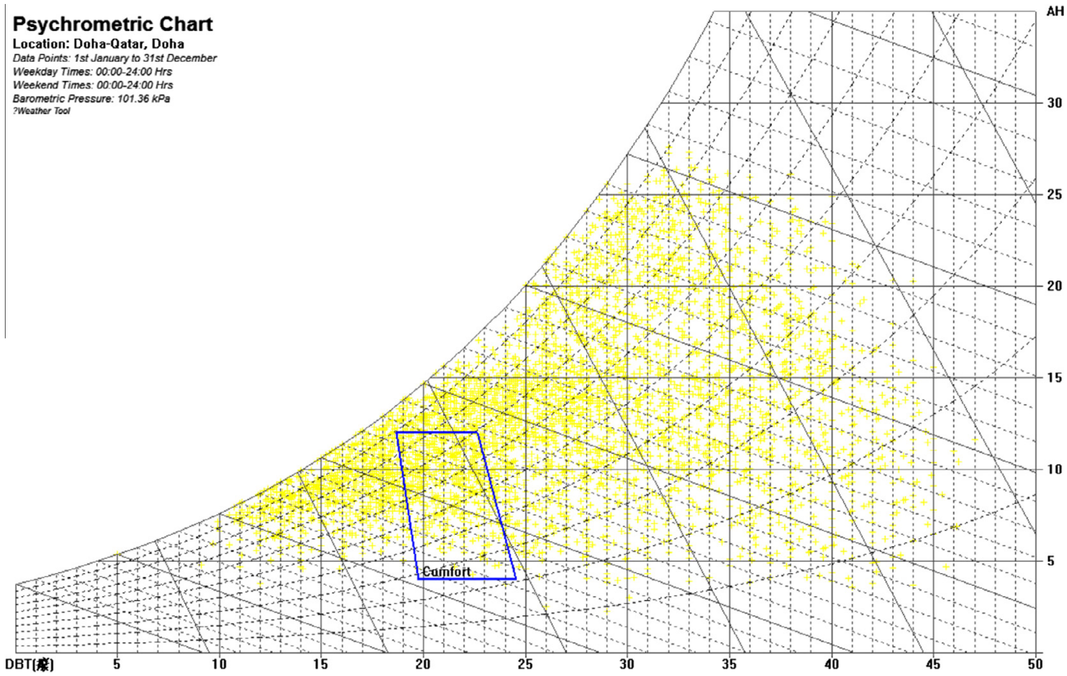

Figure 6. Psychometric chart: hourly data points and thermal comfort zone (medium activity).

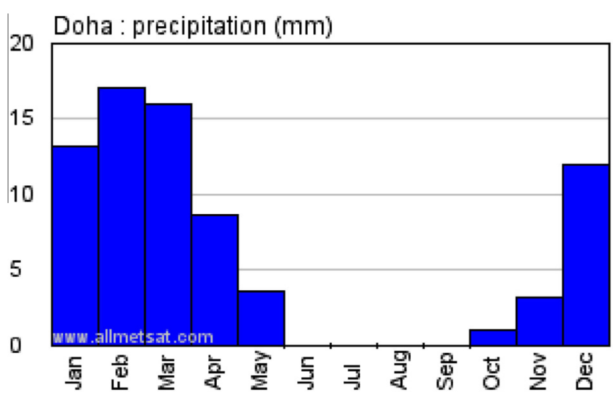

Figure 7. Precipitation.

Qatar's energy demand is expected to rise by approximately 15% over the next five years, and existing developments and new investments are expected to double the capacity of electricity and water generation. Large investments in infrastructure projects are changing the energy topology and pricing strategies which will respectively affect utility companies and consumers.

For residential consumers, a new regulation was proposed in 2003 by the Qatar General Electricity and Water, and new energy regulations for commercial buildings came into effect at the end of 2010. Development of a building energy standard will be one of the instruments towards new regulation.

3. Methods for expressing energy performance

The systematic evaluation and expression of energy performance provides a means for defining energy ratings, compliance, and certificates in building regulations. This can either encourage or mandate building designers, engineers, owners, and users to improve the energy performance of buildings or meet a prescribed rating.

For the purpose of energy code development, GSAS building rating system has adopted the International Organization of Standardization (ISO)-European Committee for Standardization (CEN) and Energy Performance Coefficient (EPC) approach. Unfortunately, some changed have been made in some normative parameters to suit the local environment.

There are five levels of assessment in the GSAS: building's thermal behaviour, technical systems, primary energy source CO_2 emissions and NOx and SOx emissions. The standardised normative calculation methods are used, which complies with the global trend towards performance-based code (Elsarrag and Alhorr, 2012).

For a given building, the following energy performance indicators shall be specified as follows for the energy performance rating:

3.1. Energy performance indicators

The major purpose of building energy calculation is to establish the performance rating with different perspectives considering: (1) energy need for cooling, (2) energy delivery through technical systems to satisfy the need, and (3) primary resource utilisation of, and emissions produced by the building. The calculation starts from the energy need for heating and cooling and finishes at primary resource consumption and emissions production to meet energy requirements. This enables users to evaluate the building

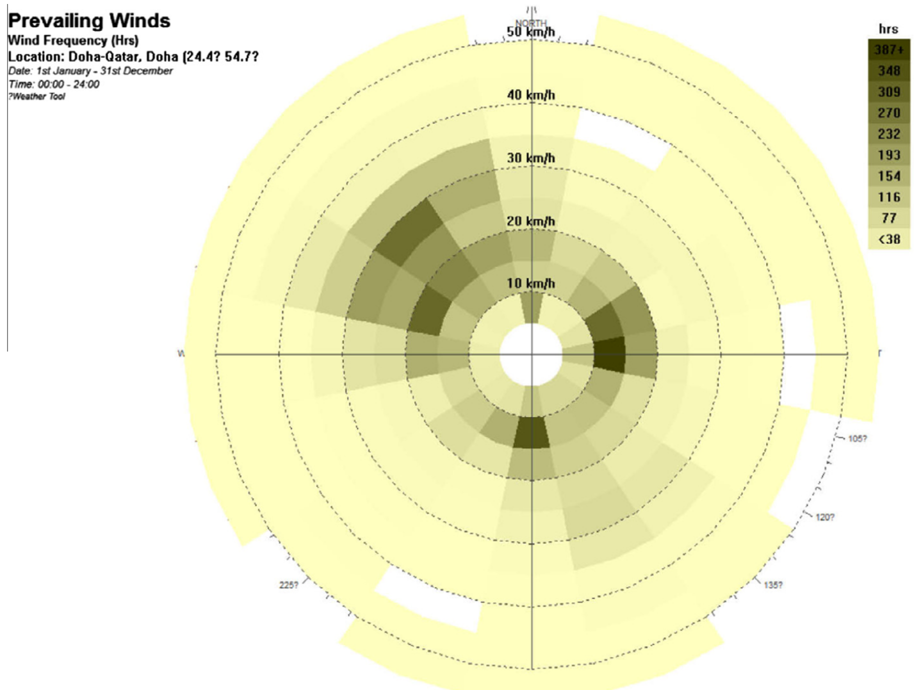

Figure 8. Wind frequency (h).

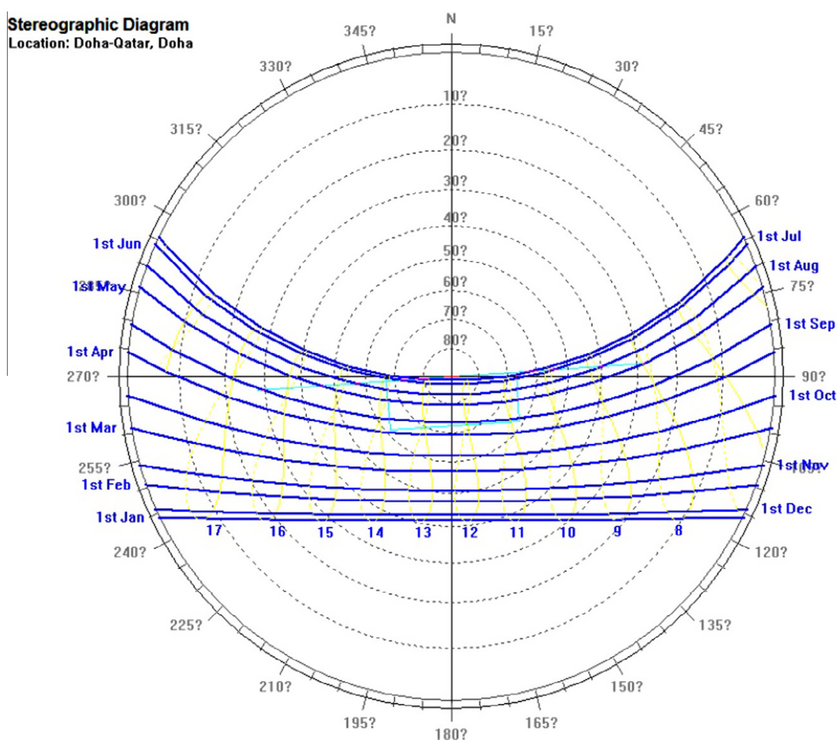

Figure 9. Sun path: stereographic diagram.

energy performance at independent levels. The performance indicators at these levels are defined as energy need for heating and cooling (Qnd), delivered energy (Edel), and primary energy (Epri) associated with the CO_2, NOx, and SOx emissions.

3.1.1. Thermal energy need (Qnd)

The ultimate purpose of the building thermal need calculation, is to evaluate the architectural building design together with systems – non HVAC – that significantly influence the energy need of the building (typically those

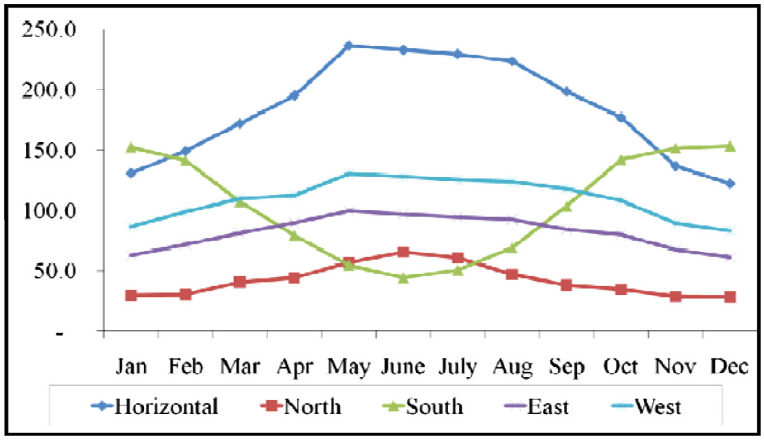

Figure 10. Global solar radiation per month in all orientations (kWh/m^2).

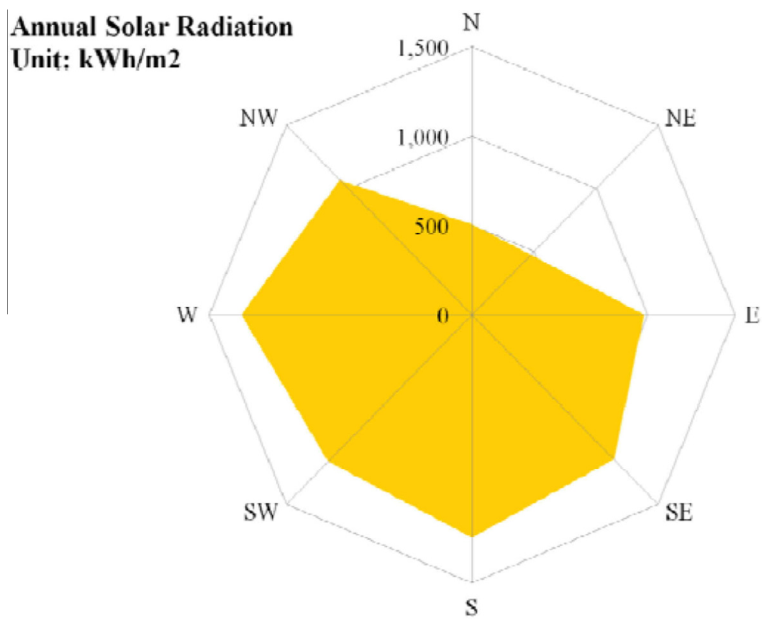

Figure 11. Solar radiation received by a vertical surface facing different orientations.

systems that produce internal gains, such as the lighting system and appliances). The building elements (shape, glass-wall ratio, building materials, and orientation) and internal heat gain (occupant activities and dissipated heat from appliances and systems) are major parameters to the performance. The performance evaluation in this level is to rate the building and system designs with respect to their performance, to reduce the energy need at the building consumer level.

3.1.2. Delivered energy (Edel)

The purpose of the delivered energy calculation is to evaluate the energy efficiency of all energy consuming systems including HVAC systems. The delivered energy is supplied energy to the technical building systems to satisfy the uses taken into account heating, (de)humidification, ventilation fan, pump, domestic hot water, lighting, and equipment.

This is primarily dependent on the type of usage, but heavily influenced by the installation of more energy efficient energy systems and the installation of renewable energy generation systems on-site.

3.1.3. Primary energy (Epri) and CO_2 emission

The purpose of the primary energy and emissions calculation is to evaluate the environmental impacts of energy utilisation by buildings in the ecosystem level. Application of zero emission power generation technology (renewable, nuclear energy, or fossil fuel driven plants with emission capture and storage) reduces the primary resource depletion and/or emissions.

4. Carbon context

The Gulf Cooperation Council (GCC) Countries have high energy consumption rates and Qatar has the highest energy consumption rate per capita in the world. As illustrated in Figs. 13a and 13b, the per capita emission

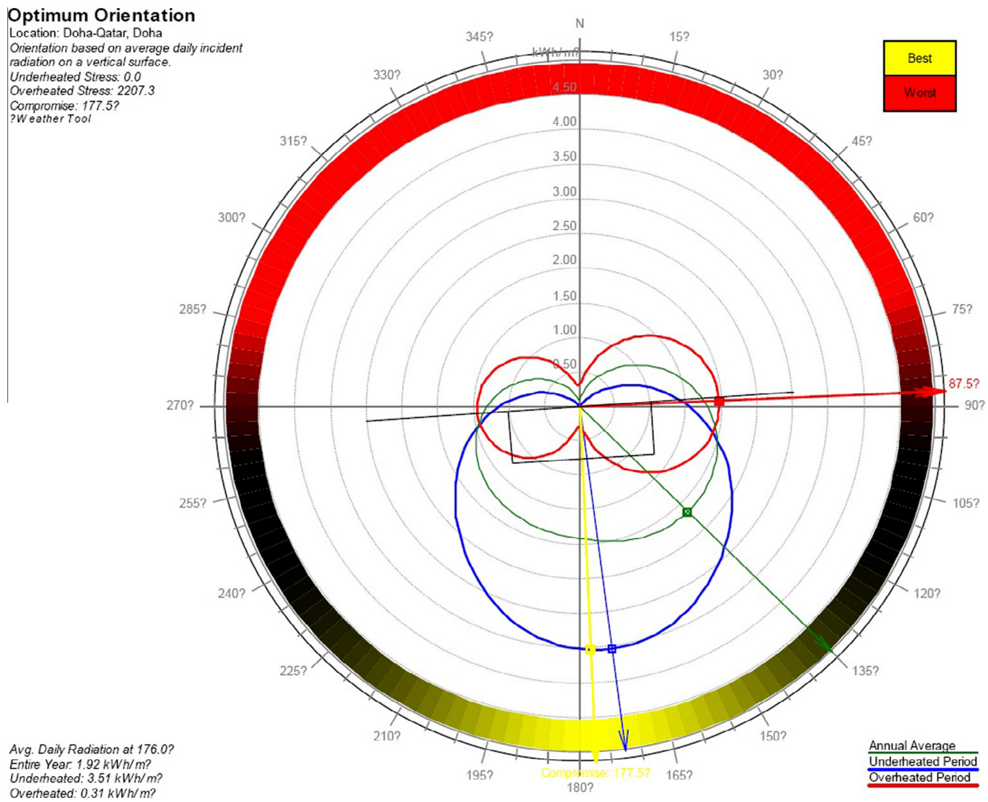

Figure 12. Optimum solar vertical exposure orientation in Qatar.

of carbon is closely correlated with the per capita consumption of energy.

In 2007, Qatar produced its first comprehensive national greenhouse gas emissions inventory based on a countrywide exercise in public consultation and data collection. This was updated in 2011, published within Initial National Communication (INC) with some data given in Fig. 14.

Qatar has adopted a tiered or multi-level approach to promoting low carbon and climate resilient development in its built environment. This integrated approach starts with a strategic vision for development at the national level that sets the broad social, human, economic and environmental priorities. Key elements of this vision are then pursued through a national development framework and an associated national spatial strategy that provide the context for strategic planning. The key climate and broader sustainability related elements of this framework are then operationalised through the application of GSAS. Based on a comprehensive review of global best practice and its adaptation to the Qatari context, GSAS which is a building and urban-level certification system that seeks to promote low carbon, climate resilient buildings that are also sustainable in broader terms. It covers all phases of a building's life; design, construction and operation, it also takes into account the specific requirements of the region, and it's scope emphasises a range of sustainability issues. GSAS is based on 8 categories of assessment that are weighted in terms of their importance to the overall score that is assigned to proposed new developments. Each building type, whether it is civic, commercial or residential (plus a variety of sub-categories within civic, including for example schools, mosques, sports facilities) has a reference level for energy demand in kWh/m^2/year.

It offers various means for meeting these requirements in the design and operating stages considering building envelope, building services and human factors. Each building type, whether it is civic (including all its sub-categories, such as schools, mosques and sport facilities), commercial or residential has a benchmark level for CO_2 emissions in kg CO_2/m^2/year. This reference level is compared to the design level.

The Energy Performance Coefficient (EPC) is an objective energy performance rating for the designed building. The EPC value of 1 means that the energy performance of the designed building is equal to the energy performance of the referenced building. For the methodology to derive a sensible reference value, the ASHRAE 90.1 2007 budget-cost simulation was performed to benchmark the average energy usage per unit area in Qatar.

GSAS CO_2 benchmarks are required to be at least 30% below the existing average levels of CO_2 in the building type design using current standards. Consecutive Energy Performance Coefficient, $EPCCO_2$, rating scales of −1, 0, 1, 2 and 3 are specified for the GSAS energy scoring system. For instance, the building will earn a negative score if its cooling need is greater than the benchmark, (as shown in Fig. 15).

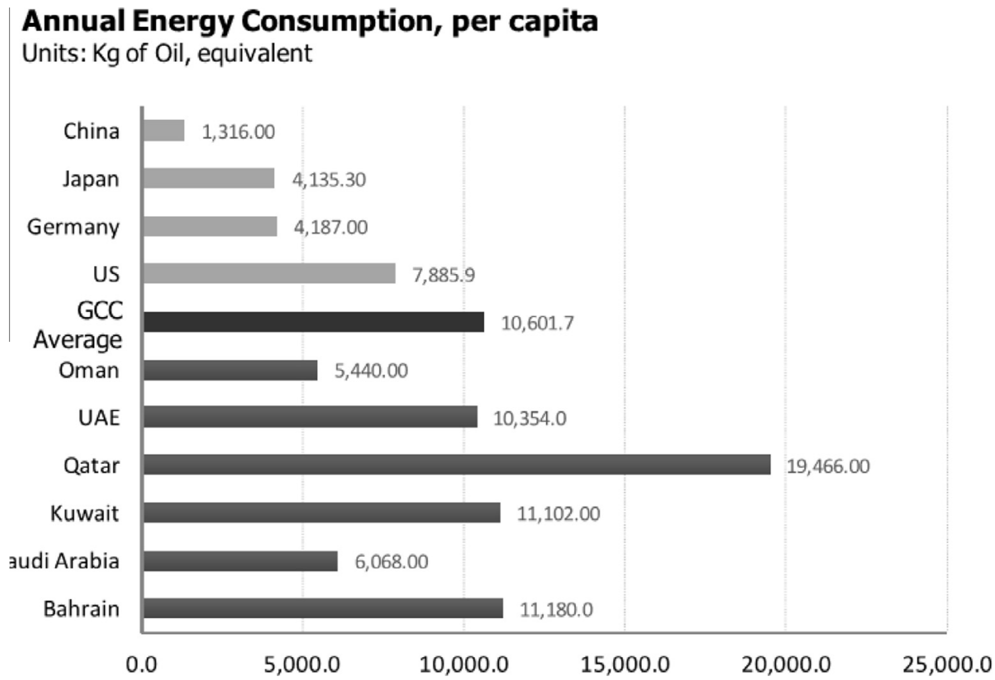

Figure 13a. Comparative annual energy consumption per capita, showing Qatar's position.

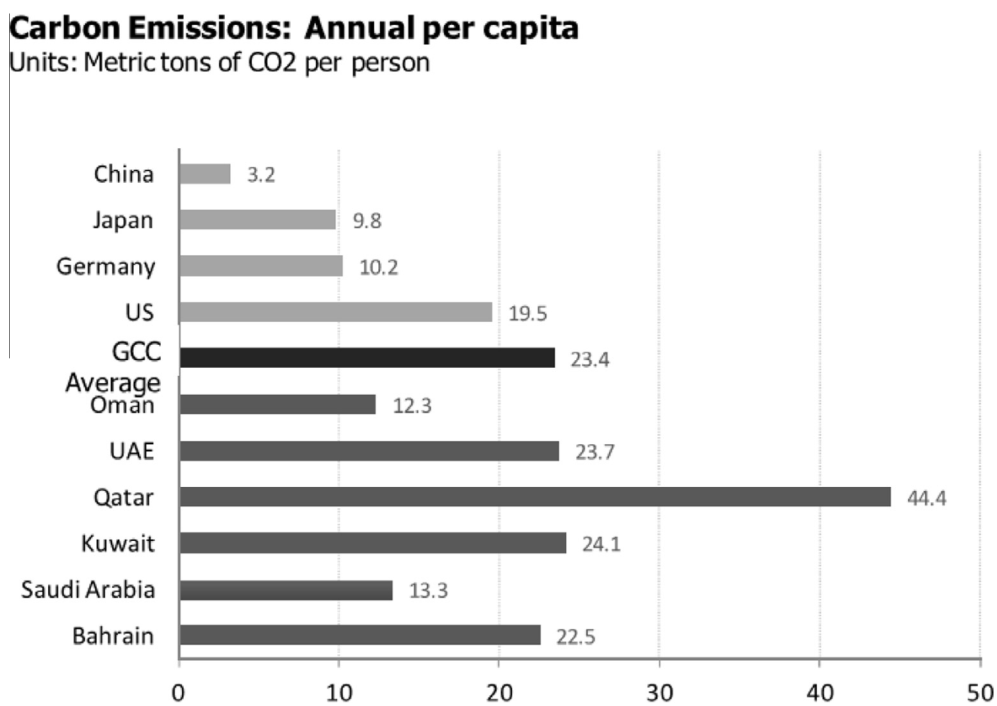

Figure 13b. Comparative annual CO_2 emissions per capita, showing Qatar's position.

Policy makers need to consider the application of these technologies in their master plan to reduce the environmental impact through the choice of regional power generation processes. At the building rating level these regional policy decisions will impact the building energy performance as expressed at the third level: Epri and CO_2, NOx, and SOx emissions.

5. Enforcing standards in new cities

New cities in Qatar have deployed the GSAS green buildings standard to every building. This is clearly one of the largest implementation programmes for a green buildings standard worldwide. The forecast impact of the application of GSAS on carbon emissions from these

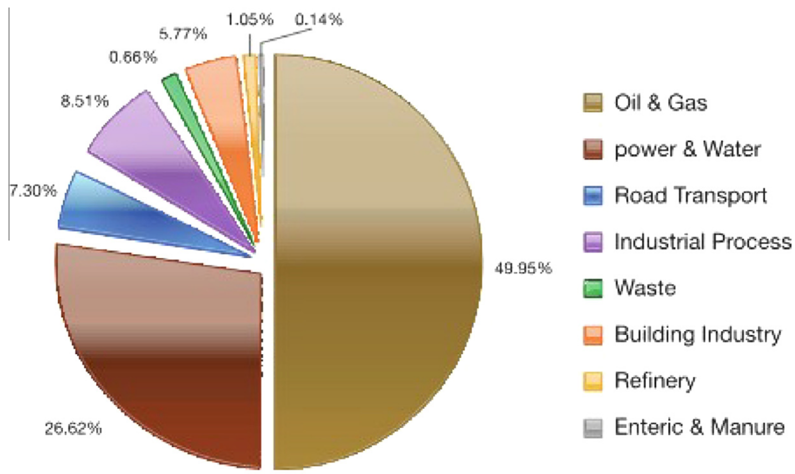

Figure 14. GHG emissions inventory by sectors in Qatar.

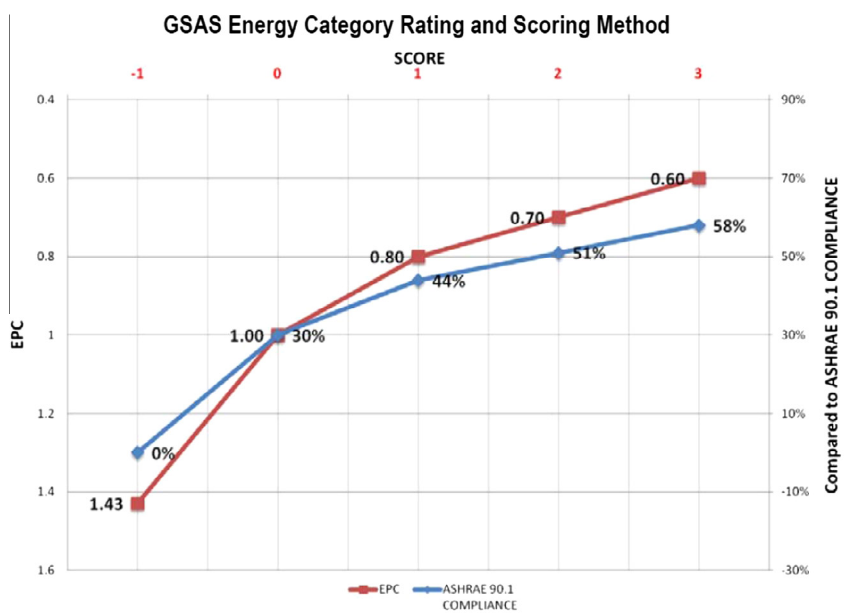

Figure 15. Comparison between GSAS Eref based scoring versus ASHRAE compliance levels.

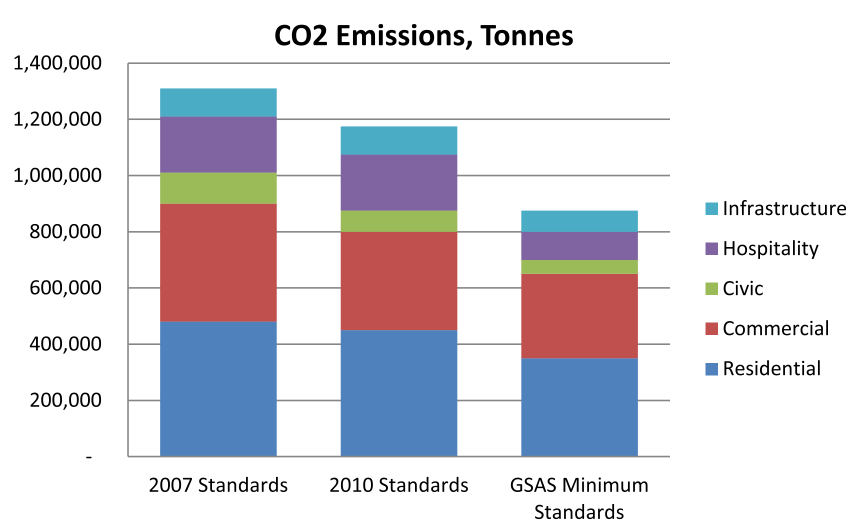

Figure 16. Forecast impact of GSAS standard on CO_2 emissions from new cities in Qatar by 2020.

cities is shown in Fig. 16, based on the following assumptions:

(a) Buildings meet the minimum energy requirements i.e. EPC = 1 (30% less than ASHRAE 90.1).
(b) 50% completion of the buildings stock by 2020.

Such reductions are subject to proper management and operations of the buildings in the post occupancy state.

These most modern of construction projects, will benefit from world leading urban planning and integrated thinking on transport, utilities, commercial and recreational services. District cooling will be used to maintain a cool environment in buildings and towers by the use of chilled water, with a central control facility responsible for operating, managing and maintaining the cooling system. This approach achieves much greater efficiencies than decentralised air cooling.

Implementing GSAS-Design energy and carbon benchmarks can deliver considerable savings in CO_2 emitted, through active measures which are introduced during the occupancy of the buildings. Buildings that do not achieve the minimum benchmarks will achieve a minus score and certification will be denied. There is an increasing level of legislation addressing energy and CO_2 issues in Qatar.

6. Conclusions

Qatar has developed, adopted, implemented and assured ambitious standards on climate change for the built environment. It has achieved this through an integrated multi-level approach that connects long-term aspirations for sustainable development at the national level with demanding standards for sustainable buildings at the project level. As well as applying it to individual buildings, it has applied this approach to significantly improve the carbon-related performance of new cities, neighbourhoods, parks and across its very substantial programme of public works. Critically, it has also applied this approach to substantially improve the sustainability of the sporting facilities under development for the 2022 FIFA World Cup™ Qatar and across the activities of the Qatar Olympic Committee.

Implementing GSAS-Design energy efficiency measures will lower CO_2 emissions from buildings sector by more than 30% compared to current standards. A future priority is to facilitate learning and continual improvement throughout this process, for example by developing robust baselines and approaches for evaluating outcomes. These can be applied at various scales so that a better understanding of the factors shaping the actual carbon intensity and climate resilience of the built environment in Qatar can be propagated.

Acknowledgements

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