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Kirk Shanks[1,a], Elmira Nezamifar[1,b]

[1]School of the Built Environment, Heriot-Watt University Dubai, P.O. Box 294345, U.A.E.
[a]K.Shanks@hw.ac.uk
[b]E.Nezamifar@hw.ac.uk

ABSTRACT

A large proportion of electricity in the UAE is consumed in meeting air conditioning cooling demands in buildings where, up to 80% of a buildings total electricity demand is for cooling. With projected climate changes in the UAE predicting an increase in annual mean temperature of 2.8^{0}C and minimal reductions in relative humidity and global solar radiation by 2050, cooling energy demands are set to increase. This paper reports on a study of how the climatic drivers of cooling energy demand change under a ‘business-as-usual’ scenario of climate change. A typical UAE office building is simulated under generated annual hourly weather datasets of 2020, 2050 and 2080. The results show an increase in cooling demand of 22.2% by 2050 and 40.0% by 2080. The comparative effect of climate changes on a number of heat gain sources and paths are examined and discussed to identify the most effective solutions for improving resilience.

KEYWORDS: climate change, adaptation, resilience, retrofit, building energy demand

1. INTRODUCTION

The climate of the UAE presents significant challenges for achieving low levels of energy demand in buildings due to the high air temperatures combined with regular high levels of solar radiation and humidity. Throughout the year outdoor air temperature is above 25°C for 75% of the typical working hours, relative humidity above 60% for more than 20% and solar radiation above 893 W/m^2 for more than 15%, meaning that mechanical cooling by air conditioning is required to maintain indoor comfort levels for the majority of the year.

The nations sustained rapid growth over the past 20 years has resulted in a large and growing building stock representative of modern high density, high rise, architectural design. As the shift in main stream design, towards more local architectural aesthetics and green building credentials, is comparatively recent much of the existing building stock do not have features that purposefully minimise the negative effects of the extreme climate.

During the most recent periods of rapid growth in UAE cities, increasing the urban density led to a rapid expansion in the number of high rise office and residential towers. This is most evident in Dubai where the majority of the high rise towers in the building stock have been constructed in the last 10 to 20 years and as such were not designed to passively address the negative energy related impacts of the climate but rather to tackle these with active mechanical solutions, i.e. air conditioning. Many of these high rise towers are typically constructed with non-load bearing external curtain walling. Such curtain walling is commonly found in various ratios of transparent glazing to opaque wall where these ratios are a key factor directly impacting energy demand for cooling. The most recent trend in these ratios has been an increase in glazing area (Aboulnaga, 2006).

Considering the recent prioritisation of sustainable development and green buildings in the UAE along with projected changes in the local climate it is appropriate to evaluate how climate change will affect cooling energy demand in existing buildings. This will help identify the generic type of retrofit solutions that will both enhance the resilience of buildings to future climate changes and reduce current cooling energy demands. This study investigates the impact climate changes will have on the generic drivers, i.e. solar gain; conduction gain and heat gain from air exchange, of cooling energy demand in a typical floor of a high rise office building in the UAE.

2. BACKGROUND

Commercial buildings in Dubai accounted for 47.33% of total electricity demand in 2012 (DEWA, 2012) where air conditioning is commonly the largest energy end use, typically accounting for 65-80% of a buildings total energy demand (Radhi, 2010). Reducing this and increases due to projected climate changes will have benefits for both building operators and national targets for CO_2 emissions and electricity supply.

Previous studies investigating the impact of climate change on building energy demands have typically used either the degree day method or dynamic thermal simulation to estimate changes in energy demands under projected changes in climate parameters. Whilst the degree day method has been shown to produce acceptable estimations of monthly heating or cooling demands when results are compared to histroical data it can only directly represent the thermal characteristics of a limited number of energy related retrofit options, e.g. insulation and airtightness. In contrast, dynamic thermal simulation can explicitly account for most fabric and energy system characteristics. The degree day method derives monthly energy demand as a function of monthly average temperature whereas dynamic thermal simulation calculates energy flows on an hourly basis as a function of the heat balance between the full range of heat gains and losses of a building under weather conditions of solar radiation, wind, temperature and humidity.This enables dynamic thermal simulation to account for both sensible and latent heat exchange, the latter of which is significant in cooling energy demands.

Studies from many different climates increasing cooling energy demands in mechanically conditioned buildings or increased risk of overheating in free running buildings by 2050. Under the hot arid climate of the UAE a study of impacts due to projected climate change by Radhi (Radhi, 2009) reports predicted increase in air conditioning demand (cooling + fans) in typical residential villas of approximately 10% to 35% by 2050, depending on the future CO_2 emissions scenario considered. Under relatively similar climate conditons Delfani et al. (Delfani et al. 2010) analysed historical weather data to show how cooling energy demand increases with increases in wet bulb and dry bulb ambient temperature illustrating the importance of accounting for change in relative humidity.

Studies of impacts on future energy demands have high uncertainty arising from uncertainties in methods of projecting future climate conditions, specifying properties of building fabrics and energy systems and accounting for changes in operational behaviour, particularly in terms of future internal heat gains from equipment (Li et al. 2012). Future hourly weather data for use in simulations of future building energy demands are generated from pojections of future climates which are provided by the various global circulation models (GCM) developed by a number of climate research institutions around the world. Outputs from these various GCM's represent a number of scenarios of growth and change of the socio-technical energy system, global carbon cycles and other factors considered to influence the global energy balance. This means there are a wide range of projected future weather conditions for the locations modelled. Not only does this wide range of future scenarios create uncertainty of which scenario will unfold but is compounded by the process of translating the effects of these into hourly weather data that can be used in dynamic thermal simulations of buildings. Such uncertainties have been the focus of a number of studies utilising probabilistic methods to increase certainty (Jenkins et al. 2011; Wan et al. 2011; Kershaw et al. 2011). However, whilst being highly uncertain, translated future annual hourly weather datasets remain one of the only ways of investigating what adaptations are likely to be needed in the future to address rising cooling demands.

Although accounting explicitly for uncertainties in projected future weather conditions is beyond the scope of this study, the findings can readily inform the design of studies investigating the implications of climate change uncertainties on the resilience, future energy demands and suitability of retrofit options for buildings in the UAE region.

A number of studies in hot arid climates (Radhi et al. 2009; Radhi et al. 2013; Delfani et al. 2010) identify additional insulation and increased thermal mass as retrofit options that substantially reduce rising cooling energy demand. Tian and de Wilde (Tian and de Wilde, 2011) highlight implications for chiller sizing, noting that chiller size should be specified separately for current weather conditions and future weather conditions. This indicates that in some cases cooling plant sized under current weather conditions may not meet cooling demands in future weather years.

In contrast to similar studies reported in the literature this study primarily seeks to evaluate the impact of climate changes on the factors directly affecting the dynamic heat balance, and thus cooling demand, of buildings in the region. We examine how the various environment related heat gains change into the future to enable identification of generic types of energy efficiency options.

3. METHODOLOGY

3.1 Approach

Dynamic thermal simulation of a typical air conditioned office floor in a recently built high rise office tower was used to estimate the impact of projected climate changes and some retrofit energy effiicnecy technologies on annual cooling energy demand and its associated drivers. The typical office floor modelled is from a recent high rise office development with a moderate window to wall ratio (38%), representing average characteristics of high rise office towers in Dubai.

The basecase model was constructed in IES-VE version 2013.0.02 and simulated under a standard annual hourly EnergyPlus Weather (EPW) dataset for Abu Dhabi airport. The selection of a weather dataset for Abu Dhabi airport is due to this location having both an established hourly weather dataset used for building energy simulations (IWEC, 2001) and projections of future hourly climate changes from runs of a suitable General Circulation Model (GCM). Abu Dhabi airport is approximately 100km from Dubai and lies close to the sea thereby having a similar climate. Simulation results from the basecase were compared to those of future annual weather datasets for 2020, 2050 and 2080. For each of these future years the energy balance of the building was analysed to identify both the key drivers of change in cooling demand and types of technologies that would offset increases in these demands.

3.2 Basecase model

The basecase model, consisting of a square floor plan with a central service core of lifts and washrooms, was prepared using the dimensions and typical specifications from the 31st to 39th floors of Al Kazim Towers, Dubai. The cooling system was modelled as a constant volume air conditioning system with open-top unlimited cooling capacity to ensure the setpoint temperature was achieved in each period simulated.

Although high rise office buildings in Dubai commonly include substantial floor areas for other functions such as, commercial space; multi-storey car parking; plant rooms and swimming pools; etc., these were not included in the model. This was done to minimise the range of possible factors influencing cooling demand under changing climate conditions thereby making causal relationships more apparent. In this way the results and discussion can be considered as being generalisable for open plan spaces in any UAE building.

The typical floor modelled was specified with an adiabatic floor and ceiling. The finished floor level datum was set at 80.0m above ground and no external shading or overshadowing was included. In reality some high rise towers are located close to other similarly tall buildings such that some overshadowing and reflection is likely albeit the extent and duration of these would be directly dependent on orientation and relative position of other buildings and is thereby site specific. As the aim of the study was primarily to investigate climate change impacts in a generic context such that the results would be indicative for a wide range of office buildings, overshadowing and reflection of external buildings and obstructions were excluded.

3.3 Future weather datasets for simulation

The study centres around simulations for a single set of future weather conditions for 2020, 2050 and 2080 under the A.2 SRES climate change scenario. The two main sources of projected annual hourly weather data for future years are those generated by General Circulation Models (GCM) and those by Regional Climate Models (RCM). Whilst RCM data is considered to be the most accurate these were only available for a limited number of specific locations around the world, e.g. major cities in the UK, but not for any location in the UAE. However, a tool, called CCWorldWeatherGen, developed by the University of Southampton and University of Malaya (Jentsch et al. 2013), was used to generate suitable future hourly weather data for the simulations. Generating such future weather datasets involves morphing typical current annual weather data of a location that has appropriate and established typical weather year data, such as Abu Dhabi, with projections of climate changes for the location from a GCM such as the Hadley Centre’s HadCM3. The futures scenario represented by the HadCM3 projections is the A2 scenario known as the ‘business as usual’ scenario of sustained moderate to high CO_2 emissions, for more detail on this scenario see (IPCC).

Whilst such EPW – GCM morphed weather data has significant uncertainties and limitations it is considered to be an appropriate “practical approach to deriving weather files suitable for climate change impact assessment in the built environment.” (Jentsch et al. 2013). However, it is important to note that morphed projections of future weather can be considered to include marginal overestimates of some weather parameters (Jentsch et al. 2008). Although further work on RCM datasets for the UAE and GCC region in general is needed to determine the extent of such uncertainties the datasets generated for this study remain the only available UAE future weather years for use in building dynamic thermal simulation tools.

The generated hourly weather datasets generally show increasing external air temperature (T_{ext}); decreasing relative humidity (RH_{ext}) and marginally decreasing global solar radiation (I_g). The extent and implications of these climate changes can be understood further by considering the rise in annual mean temperature, from 27.14°C currently to 31.86°C in 2080, and the resultant changes in the proportion of annual working hours where external conditions exceed typical threshold levels for cooling demand in the UAE, see Table 1 below. The much greater increase in temperature conditions compared to small reductions in relative humidity and solar radiation indicate that changes in cooling energy demands will be predominantly driven by outdoor temperature.

Table 1 Climate characteristics, Abu Dhabi Airport

Year	Proportion of working hours T_{ext} > 24.0°C	Annual mean temperature °C	Proportion of working hours RH_{ext} >60 %	Proportion of working hours I_g > 893.0 W/m^2
Current	75%	27.14	20%	15.8%
2020	79%	28.56	18%	15.7%
2050	86%	29.94	17%	15.1%
2080	92%	31.86	16%	14.6%

Note: I_g = 893.0 W/m^2 is the amount of solar radiation under average clear sky conditions

4. RESULTS DISCUSSION

The main interest when consideriing the impacts of climate change on energy demand in buildings is how much this changes under projected future weather conditions. However, assessing the relative influence of current building design characteristics on these changes can help identify appropriate strategies for adaptation and improvement of resilience. To identify which design features are the main sources of future changes in cooling demands we analysed the results from simulations in terms of heat gain sources and paths for the modelled basecase building.

4.1 Future cooling demands

Results from the simulations show that cooling energy demand, including that for dehumidifcation, increases steadily under projected climate changes in the UAE, see Table 2 below. The rate of this increase generally remains uniform with a doubling of the scale of increase across each 30 year period from 2020 to 2050 and 2050 to 2080. This reflects the case that the basecase building design provides no thermal capacity to absorb increases in heat gains.

Table 2 Basecase annual cooling and dehumidification demand intensity

Year	Annual cooling + dehumidification demand ($kWh/m^2.yr$)	Change compared to Current weather year (%)
Current	149.6	-
2020	165.8	+10.8
2050	182.8	+22.2
2080	209.3	+40.0

One of the primary heat gains from the current climate are solar gains which are generally a factor of 10 times greater than those due to conduction and inflitration, see Table 3 below. However solar gains are not the main driver of increasing cooling demand across future years. In future years projected solar gains effectively remain constant, see Table 3 below, whereas heat gains due to rising air temperature, as evidenced by changes in external conduction gain; infiltration gain and demand for cooling of incoming fresh air for ventilation, i.e. air system input, all increase. This highlights that introducing technologies that reduce solar gain will have a constant impact on the change in cooling demands across future years but thereby the proportion of overall demand this represents will reduce. The reduction in cooling demand provided by technologies that address conduction across the external envelope, i.e. insulation and airtightness technologies, will increase as the climate changes, see Table 3. Similarly technologies that reduce the cooling load for conditioning incoming fresh air, such as cross-over heat recovery units, can be expected to continue providing significant offsetting of increases due to rising outdoor air temperatures, see Table 3. The potential savings in cooling demand provided by such heat recovery options can be expected to reduce if the technologies only provide sensible heat recovery, as indicated by the falling ratio of sansible:latent total air system input in Table 3 below.

Table 3 Basecase heat gains

Year	External conduction gain (MWh/yr)	Infiltration gain (MWh/yr)	Total air system input / Ratio sensible:latent (MWh/yr)	Solar gain (MWh/yr)	Internal gains (MWh/yr)	Cooling + dehumidification demand (MWh/yr)
Current	3.0	3.6	31.6 / 2:1	30.6	80.0	172.9
2020	4.0	6.1	40.5 / 2:1	30.7	80.0	191.7
2050	4.9	8.5	50.6 / 1.3:1	30.6	80.0	211.3
2080	6.3	11.8	67.0 / 1:1	30.5	80.0	242.0

Note: Internal gains include those due to people, lighting and equipment. Air system input includes both sensible and latent demands of conditioning incoming fresh air to 20°C.

Reducing solar gain can be achieved in three ways, i.e. introducing shading; reducing the solar gain properties of glazing and reducing the area of glazing. This latter approach of reducing glazing area has the added benefit of reducing conductive heat gain due to high external temperatures. However, as shown in Figure 1 below glazing is less resilient to future increases in external temperature than external walls. The rising rate of increase in conductive heat gain through glazing compared to that of external walls is simply due to the higher thermal conductivity of glazing compared to that of external walls, i.e. U-values of 1.89 W/m^2K and 0.35 W/m^2K respectively. Whilst it can be seen that reducing the amount of glazing area will help reduce the scale of conductive gain this would have a significant impact on the daylight and view characteristics of internal spaces.

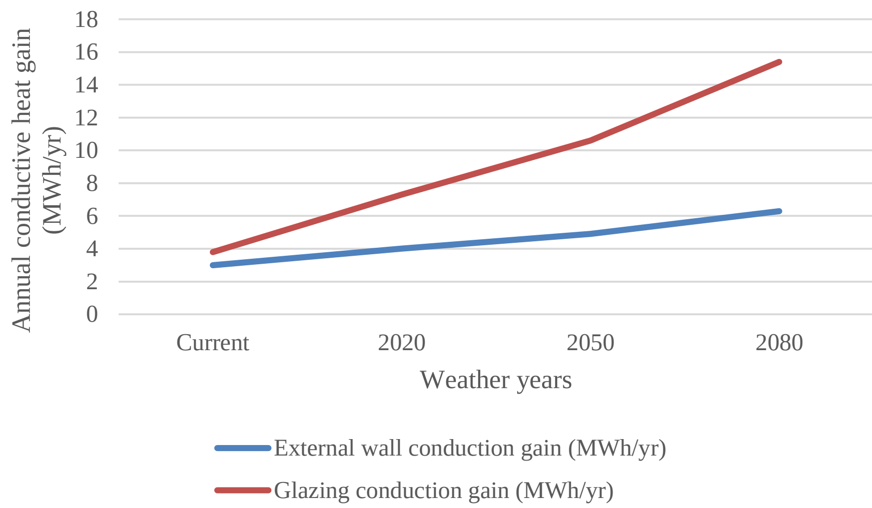

Figure 1 Conduction gains

Further increases in heat gain are due to infiltration where increasing ambient air temperature increases the amount of heat gain due to ingress of hot air through cracks and small openings in the envelope. Although the increase in this is greater than that of combined conduction heat gains through glazing and external walls, see Table 4 above, the assumed existing high airtightness of the building, i.e. 0.25 ach at normal pressures, mean that there are very limited practical ways in which to reduce this further. The significant increase in infiltration gains over future years illustrates the value of addressing airtightness during design and construction.

As noted earlier, rising cooling demands are also driven by the need to condition incoming fresh air delivered to spaces through the air conditioning system, see “Air system input” in Table 4 above. With the basecase adopting a minimal fresh air provision of 8.0 l/s.person, during occupied periods, the main way to address this is by introducing heat recovery from cooler exhaust air to pre-cool incoming fresh air.

4.2 Generic retrofit options

The basecase results show that although solar gains are one of the main climatic drivers of cooling demand, heat gains due to air temperature have the greatest relative increase in future years. Initial opportunities for addressing this latter factor using technologically mature products are increasing the insulation properties of the glazing and opaque external walls. Although addressing solar gains would not lead to improved resilience to future climate changes, as discussed in section 4.1, it is a primary heat gain source that can be reduced significantly by adding external shading.

4.2.1 Improved glazing

Although the basecase glazing is of a moderately good performance, i.e. U-value = 1.8 W/m^2K and g-value = 28%, it is possible to increase its insulating properties. Retrofitting with improved double glazing having a higher performance low-e coating and Krypton gas fill, resulting in an improved U-value

= 0.76 W/m^{2}K and g-value = 27%, the conductive heat gain through the buildings glazing reduces across future years, see Table 4. However the resultant impact on annual cooling demand is not fully equivalent and is marginal, ranging from 1.5% to 3.1%, see Table 4. This illustrates not only the comparatively small amount of conduction heat gain and high amount of solar gain, even with glazing of high solar performance, but also the heat retention effect of increasing the insulating properties of the glazing. Whilst the improved insulating properties reduce the amount of conduction between the internal space and higher external air temperature this improvement also reduces conduction of heat in the other direction, i.e. from internal spaces to lower outdoor temperatures, during the cooler times of the year. In these latter periods the internal heat gains, which are of a larger scale than solar gains, i.e. approximately 80.0 MWh/yr and 30.0 MWh/yr respectively, drive a demand for cooling when the outdoor temperature is slightly lower than that when cooling is needed in the basecase scenario. Effectively improving the glazing in this way reduces cooling demand in high external temperature conditions but increases it in lower external temperatures albeit the associated reduction is marginally greater than the increase. This indicates the importance of optimising the U-value of retrofitted glazing to maximise improvement of resilience.

Table 4 Glazing annual conduction gains

Year	Basecase glazing annual conduction gain (MWh/yr)	Retrofit glazing annual conduction gain (MWh/yr)	Retrofit glazing reduction in annual cooling demand compared to Basecase (%)
Current	3.8	2.8	1.5
2020	7.3	4.5	1.5
2050	10.6	6.2	2.5
2080	15.4	8.7	3.1

4.2.2 Improved external walls

The basecase buildings external walls do not have any insulation resulting in a relatively poor U-value = 0.35 W/m^{2}K. Retrofitting an additional 125mm of EPS insulation behind the outer panel layer improves the walls performance to U = 0.18 W/m^{2}K, which can be considered as a moderate to high performance specification. The impact of this retrofit is similar in terms of both the elemental reduction in conduction gain and cooling demand to that of improved glazing. The annual conduction gain through external wall elements is reduced by approximately 50% across future years, see Table 5 below, whereas the effect on annual cooling demand is low ranging from 0.5% to 1.0%. The main reason for this and implication for retrofit specification is the same as that for improved glazing discussed in section 4.2.1.

Table 5 External wall annual conduction gains

Year	Basecase external wall annual conduction gain (MWh/yr)	Retrofit external wall annual conduction gain (MWh/yr)	Retrofit external wall reduction in annual cooling demand compared to Basecase (%)
Current	3.0	1.6	0.5
2020	4.0	2.1	0.8
2050	4.9	2.6	0.9
2080	6.3	3.3	1.0

4.2.3 Fixed external shading

Retrofitting external shading with 1.5m fixed shades above all large areas of glazing around the building results in much reduced solar gain, i.e. from approximately 30 MWh/yr in the basecase to approximately 18 MWh/yr. Not all of this reduction in annual solar gain offsets the cooling demand as some of it occurs during days when the air conditioning is not running, i.e. Fridays and Saturdays. This results in an effective reduction in annual solar gain of approximately 16 MWh/yr. This reduction in solar gain remains effectively constant across future years resulting in cooling demand reductions that decrease proportionally into the future, i.e. from 5.5% under current conditions down to 3.9% in 2080. This is because under current projections of climate change, the main driver of increasing cooling demands is rising external air temperature.

5. CONCLUSION

Using simulations of a typical office floor in a high rise tower, with average thermo-physical attributes, under projected changes in the UAE climate we have examined the influence of climatic heat gain sources on future cooling demands and identified the types of options that would improve resilience. The results show that whilst addressing solar gain is an important opportunity to reduce current cooling demand the proportional benefit of this diminishes as the climate changes. Rather we find that what is most important in terms of improving resilience is addressing heat gains due to rising external temperatures. Although pursuit of this can be done by improving the insulating performance of glazing and external walls the most significant benefits can be achieved by technologies that reduce the cooling load needed to condition incoming fresh air for occupants.

REFERENCES

Aboulnaga, M.M. “Towards green buildings: Glass as a building element – the use and misuse in the gulf region” Renewable Energy 31 (2006) 631-653

DEWA. “Electricity Consumption (GWh), DEWA Electricity Statistics 2012.” http://www.dewa.gov.ae/aboutus/electStats2012.aspx

Radhi, H. “On the optimal selection of wall cladding system to reduce direct and indirectCO2 emissions.” Energy, 35 (2010) 1412–1424 page 1413…

Radhi, H. “Evaluating the potential impact of global warming on the UAE residential buildings – a contribution to reduce CO2 emission.” Building and Environment, 44 (2009) 2451-2462

Delfani, S., Karami, K., Pasdarshahri, H. “The effects of climate change on energy consumption of cooling systems in Tehran.” Energy and Buildings, 42 (2010) 1952-1957

Li, D. H. W., Yang, L., Lam, J. C. “Impact of climate change on energy use in the built environment in different climate zones – A review.” Energy 42 (2012) 103-112

Jenkins, D.P., Patidar, S., Banfill, P.F.G., Gibson, G.J. “Probabilistic climate projections with dynamic building simulation: Predicting overheating in dwellings.” Energy and Buildings 43 (2011) 1723-173

Wan, K.K.W., Li, D.H.W., Liu, D., Lam, J.C. “Future trends of building heating and cooling loads and energy consumption in different climates.” Building and Environment 46 (2011) 223-234

Kershaw, T., Eames, M., Coley, D. “Assessing the risk of climate change for buildings: A comparison between multi-year and probabilistic reference year simulations.” Building and Environment 46 (2011) 1303-1308

Radhi, H., Sharples, S., Fikiry, F. “Will multi-façade systems reduce cooling energy in fully glazed buildings?” A scoping study of UAE buildings. Energy and Buildings 56 (2013) 179-188

Tian, W., de Wilde, P. “Uncertainty and sensitivity analysis of building performance using probabilistics climate projections: A UK case study.” Automation in Construction 20 (2011) 1096-1109

IWEC, American Society of Heating, Refrigeration and Air-Conditioning Engineers (2001)

Jentsch, M.F., James, P.A.B., Bourikas, L., Bahaj, AB. S. “Transforming existing weather data for worldwide locations to enable energy and building performance simulation under future climates.” Renewable Energy 55 (2013) 514-524

IPCC, Working Group I: The scientific basis. http://ipcc.ch/ipccreports/tar/wg1/029.htm#f1

Jentsch, M.F., Bahaj, AB. S., James, P.A.B. “Climate change future proofing of buildings – Generation and assessment of building simulation weather files.” Energy and Buildings 40 (2008) 2148-2168