MSc Program
Environmental Technology & International Affairs

Passive Space Cooling in Abu Dhabi: Guidelines to Advance the Implementation of Estidama Pearl Villa Rating System

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 29 March 2017

Affidavit

I, **JEHAD SAEED EBRAHIM ALI ALMAZROUEI**, hereby declare

1. that I am the sole author of the present Master's Thesis, "PASSIVE SPACE COOLING IN ABU DHABI: GUIDELINES TO ADVANCE THE IMPLEMENTATION OF ESTIDAMA PEARL VILLA RATING SYSTEM", 46 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Signature

ABSTRACT

The Estidama Pearl Villa Rating System, herein PVRS, provide broad criteria for sustainable villa design and construction. However, explicit implementation of specific purposes such as energy conservation require further development of the PVRS. This Master's thesis identifies potential guidelines for advancing the passive design of villas in Abu Dhabi prescribed in the credit criteria "Cool building strategies" coded RE-2 in the PVRS.

Analysis of energy consumption for space cooling using weather normalized electrical consumption per household reveals deteriorating energy efficiency in Abu Dhabi buildings causing increasing electrical energy demand for air-conditioning. Consequently, the need for passive space cooling in building design is central to achieve sustainability.

Guidelines and implementation recommendations for passive cooling design in compliance with Estidama PVRS are listed according to three main types of passive cooling techniques; prevention of heat gains, modulation of heat gains and dissipation of heat gains to be implemented together as part of passive cooling strategy in villas i.e. not interchangeably as suggested by the performance method or the prescriptive method in RE-2. The specific guidelines and implementation recommendations are complemented with general guidelines aimed for integrated design.

The analysis in this study are mainly based on data and charts obtained from ClimateTool, a planning tool for international building, and DegreeDays, a weather online database for energy professionals, and literature conclusions on buildings efficiency in Abu Dhabi. In addition, screenshots from DVD: Best Practices for Building Design are illustrated for reference on state of the art implementation practices in the subject matter for hot and humid climate in the United States.

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LIST OF ABBREVIATIONS

ASHRAE	American Soeciety of Heating, Refrigiration, and Air Conditioning Engineers
CDD	Cooling Degree Day(s)
CDDw	Wet-bulb Cooling Degree Day(s)
DGD	Dehumidifying Degree Day(s)
IPHA	International Passive House Association
KWh	Kilo-Watt hour(s)
PVRS	Pearl Villa Rating System
UAE	United Arab Emirates

ACKNOWLEDGMENTS

Warmest thanks to the pre-luxury era people of the United Arab Emirates who have been incredibly patient in answering my curious questions about their livelihood since my childhood including my parents and grandparents. Your words about how adaptive your lifestyle was to the harsh climatic conditions is the sole inspiration of this research. My special thanks for Prof. Günther Brauner who, once I introduced the idea of the research to him, said: “I will definitely support you. I visited the Sahara and I think that people of that time were too smart in building homes to suit the climate”. The word “smart” sounded like music to me at that time; in an age where people use the term to refer to cities of big-data applications.

To the fathers of the MSc Environmental Technology and International Affairs programme, Prof. Gerhard Loibl and Prof. Hans Puxbaum, and to all faculty and staff of the Diplomatic Academy of Vienna and TU Wien who work in support of the ETIA programme; I am in debt to your endeavours. I pray that my future work shall provide the return on investment to our lovely planet “Earth”.

1 INTRODUCTION

The Pearl Rating System (PRS) introduced in 2010 by Abu Dhabi Urban Planning Council (ADUPC) as part of the Estidama Program. Estidama, meaning sustainability in Arabic, sets the foundation of sustainable building codes in Abu Dhabi with seven sustainability categories under the Pearl Villa Rating System (PVRS), which is the focus of this study. The legal requirement for villas is 1 pearl rating and additional credit points for 2-5 pearl villas are allocated to: integrative design process, conserving the natural system, ensuring quality of liveable spaces, water conservation, energy conservation & renewable energy use, building materials selection and innovation in building design & construction. (Abu Dhabi Urban Planning Council, 2010)

1.1 Rationale and hypothesis

The PVRS, offers a holistic design approach addressing several environmental protection and sustainable development aspects including passive design under its energy conservation rating category "Resourceful Energy". However, climate-sensitive building design is more specific sustainability issue that requires attention in Abu Dhabi given the high electricity consumption for space cooling. According to Abu Dhabi Distribution Company, provider for water and electricity distribution networks; Abu Dhabi demand is "over three times more electricity than the world average, with cooling and air conditioning responsible for much of this — around 70% of summer peak electricity load" (Abu Dhabi Distribution Co., 2016). Therefore, *achieving a high rating under the PVRS without a specific goal, as such in this research to reduce dependence on mechanical air-conditioning by advancing passive cooling techniques, does not unleash the full potential of the Pearl Villa Rating System in conserving energy consumed for indoor climate control.* (Hypothesis)

Traditional architecture in the Arabian Peninsula, pre-oil discovery era, was an example of buildings harmonization with local climate. Modern architecture in the region is highly dependent on mechanical equipments for climate control i.e. air-conditioning. "Part of the blame for the failure, from the climatic point of view, has been attributed to the so called 'international style', that brought science and technology to its design, adapting design ideas and features regardless of different climatic regions. This was connected with the separation of the envelope's design, which was the task of the architect, and the interior operation, which was entirely left to service engineers" (Asimakopoulos & Santamourism, 1996, p. 35). The "development of technical indoor climate control systems; as they improve the indoor climate and therewith the physical well-being of people, the incentive for climate pre-conditioning by means of climate-sensitive design has been largely lost. However, this lack of climate-sensitive design frequently leads to unwanted microclimate situations outdoors" (Esch, 2015, p. 35). Consequently, it is estimated that "40% of the world's energy consumption is attributed to the construction and use of buildings" (Österreicher, 2016).

1.2 Research objective

To understand and educate on the shortfalls of the Estidama PVRS in addressing passive cooling techniques as a climate-sensitive concept with the aim to advance the implementation of the PVRS without compromising compliance with its existing credit criteria. The target audience of the guidelines and implementation recommendation are mainly villa owners or potential owners in need of understanding the various options to consider in implementing the PVRS to reduce energy consumption for air-conditioning. It is assumed that public awareness shall play a vital role in improving the current PVRS through bottom-up evolution of the system implementation. The Pearl Villa Owners Guide states: "as the owner, you play the central role in ensuring the sustainability of your villa. Although other members of the design and construction team will have more familiarity with the technical requirements of the Pearl Villa Rating System, you establish the sustainability priorities for your villa" (Abu Dhabi Urban Planning Council, 2010). It is also assumed that for the villa owner to upgrade to 2-5 pearl villa, the economic savings in the capital investment and/or improvements in operating expenses over the life cycle of the villa are decisive factors.

The scope of the study is to review PVRS design credits and provide passive house design guidelines and implementation recommendations by means of climate-sensitive analysis of electrical energy consumption in Abu Dhabi and respective design approaches to suit the climate of Abu Dhabi. Consequently, design aspects and features shall become the determinants of subsequent construction and operational features of passive villas.

2 PASSIVE HOUSE

The International Passive House Association (IPHA) certification criteria with regards to cooling is: space cooling demand "not to exceed15kWh annually OR 10W (peak demand) per square metre of usable living space" (International Passive House Association, n.d.) and dehumidification allowance dependant on climatic conditions. "A third-party audit carried out in 2007 showed that while the average UAE building typically consumes 250 kilowatt hours (kWh) per square metre per year, the Dubai Chamber building was using less than half that amount - 120 kWh per square metre per year"

(Todorova, 2012) .The Masdar-designed smart villa that was announced in 2016 and its prototype was completed in January 2017, is the latest villa development in Abu Dhabi that has achieved 4 pearl rating. In terms of energy efficiency, “the four-bedroom eco-villa is designed to consume 97 kilowatt-hours per square meter per year without solar panels, which is 72 percent less energy than older villas in Abu Dhabi typically consume, and 46 percent less than newer properties” (Al Wasmi, 2016).

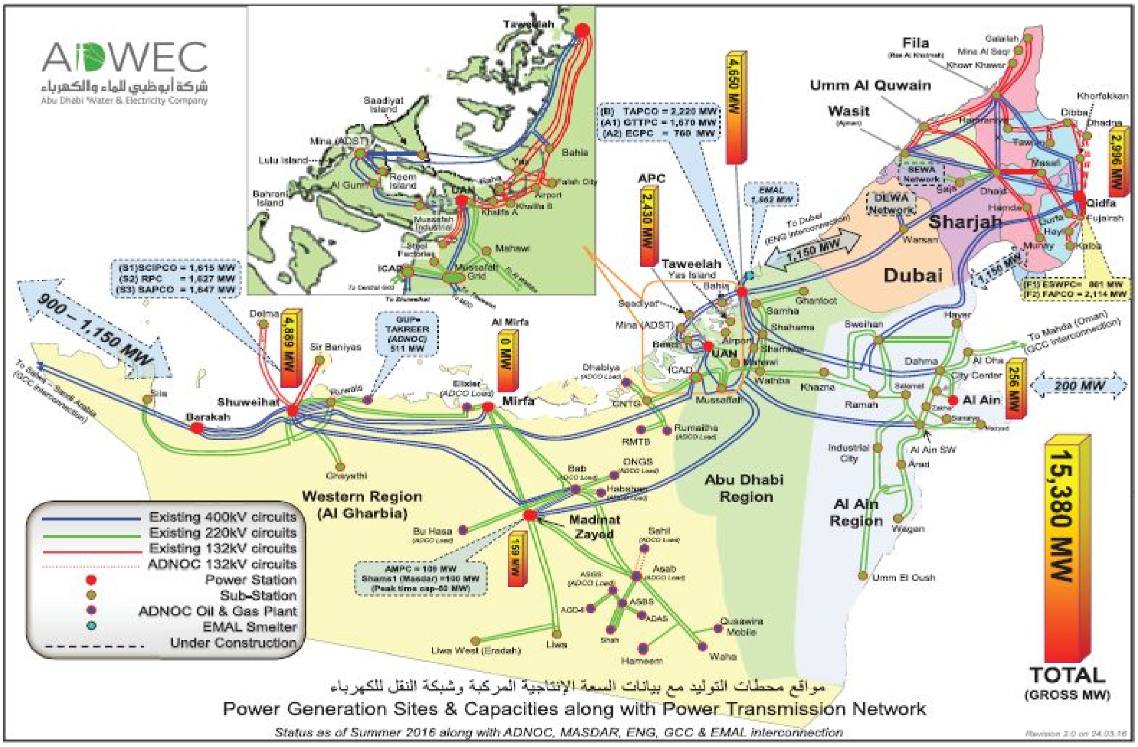
2.1 Abu Dhabi climate in context

The Köppen-Geiger climate classification allocates the code BWh to the Arabian Peninsula which translates into hot desert climate. The desert coastal climate zone of Abu Dhabi, 24.4539° N, 54.3773° E, features high temperatures year-round and its proximity to the coast of the Arabian Gulf creates significant humidity above base specific humidity of 8.5g/kg most of the year. Thus, there is no heating demand year-round while the annual cooling degree days (CDD 18.5°C) is approximately 3491.2 Kd/a and the annual dehumidifying gram days (DGD 8.5g) is around 1598.9 gd/kga. “Abu Dhabi and most of the region has a high portion of its electricity demand dedicated to cooling, mainly due to the hot and humid weather as well as the low thermal efficiency of the current building stock” (Friedrich, et al., 2014).

The elevated need for cooling and dehumidification is what drives energy demand in Abu Dhabi. Ali et al. concludes that “electrical cooling load estimate for Abu Dhabi Island corresponds to 40% of the total annual electrical load and 61% on the peak day” (Ali, et al., 2011) and according to Powerwise Abu Dhabi, “cooling and air conditioning is responsible for 70% of the peak electricity load in the summer” (Powerwise, 2017). Chris Wan, head of design management at Masdar City, states that “cooling in villas is responsible for between 40 and 70 per cent of their energy consumption” (Al Wasmi, 2016).

Therefore, despite its high rating according to the Estidama PVRS, the Masdar smart villa is not a passive villa as it could be consuming a minimum of 38.8 KWh/m^2/year for space cooling which is more than double the cooling load as per the IPHA criteria for passive houses. With this assumption, additional needs for advancing the implementation of PVRS through passive & climate-sensitive design is established. However, exact estimation of the cooling load of the prototype is not available to include its energy conservation performance in the analysis as a representative sample of future sustainable villas. Therefore, analysis of existing household electrical consumption for cooling in comparison to demand from Cooling Degree Days (CDD) is the basis of examining energy efficiency in this study.

The study of cooling electrical load is conducted on Abu Dhabi region that is part of Abu Dhabi Emirate (small box in the map) which could be considered representative of Abu Dhabi Emirate's coastal desert areas.



Source: (Abu Dhabi Water & Electricity Company, 2015)

Fig. 1 Abu Dhabi & the UAE Electrical Power Generation and Transmission Map

Ali et al. study that considers a combination of community-level and building-level seasonal load analyses using daily data for the year 2008 as representative samples to estimate the daily electrical cooling load of Abu Dhabi city concludes through the analysis of a cooling change-point model that; "as for the factors governing the day to day cooling requirements, it was found that 59% of the cooling load is due to temperature, 21% to specific humidity, 11% to the direct solar irradiance incident on a horizontal surface, and 8% to the direct solar irradiance incident on a vertical surface" (Mokri, et al., 2013).

2.2 Cooling degree days & energy consumption in Abu Dhabi

"A degree day indicates that the daily average outdoor temperature was one degree higher or lower than some comfortable baseline temperature" (United States Environmental Protection Agency, 2016). The identification of the base temperature, "the outside air temperature at which weather-related energy demand would be zero including any gains from occupants, solar radiation, lighting, equipment, etc.” (Behrendt & Christensen, 2013), is crucial for reliable calculation of cooling degree days. “Some countries use a temperature much below 20°C to adjust for solar radiation and other heat gains. For example, the ASHRAE codes use as low a temperature as (10°C) for the calculation of CDD” (Lausten, 2008). In 2008, the energy efficiency requirements in building codes based on heating and cooling degree days proposed by Laustsen in a study for the International Energy Agency IEA takes 18°C as the base point. (Lausten, 2008)

A limitation of this study arises from the presumption that “the balance point temperature depends on the building’s characteristics (thermal mass, orientation, etc.), internal (people, lights, appliances and equipment) and external (through structure, fenestration, infiltration) heat gains as well as on the set indoor temperature and, is as such, specific for each building, so the base temperature should be determined for each building separately” (Krese, et al., 2012).

Per Ali et al. study in Abu Dhabi, “the linear-to-transition region change point is estimated by plotting RMSE as a function of threshold value indicates that the linear region ends at 18.5°C” (Ali, et al., 2011). Meanwhile, a new approach introduced to the European Energy Agency in 2016 which assumes a greater HDD & CDD accuracy by accounting for maximum and minimum temperature as opposed to previous indicators using mean temperature, marks CDD base temperature at 22°C (Spinoni, et al., 2015). Hence, the cooling load resulting from CDD 22°C is compared with CDD 18.5°C in addition to CDD 24°C to consider the possibility of human adaptation in conserving energy for cooling.

For the purpose of this study, analysis of monthly cooling degree days for Abu Dhabi Airport weather station for the period 01-Jan-2000 to 31-Dec-2015 (Degree Days Weather Data for Energy Professionals, 2016) and monthly statistical data of electricity consumption from Abu Dhabi Water and electricity are obtained (Abu Dhabi Water & Electricity Company, 2015). Custom Degree Day Data is a database for energy professionals that provides reliable regression analysis of weather data when energy consumption data is fed into the database. It automatically runs day normalization of the monthly data to reduce inconsistencies resulting from different lengths of months.

For that, three linear regressions were run using the database with base temperatures 18.5°C, 22°C and 24°C. Regression Equation: y = b*CDD + c*days, where b is the CDD coefficient and c is the constant per day. If R^2 is to be considered an indication of the best base temperature for cooling in Abu Dhabi, then the result of the regression confirms the findings of Ali et al.

Table 1: Average monthly percentage of cooling load from total electrical load

	CDD 18.5°C	CDD 22°C	CDD 24°C
Cooling load/Total load	40%	31%	27%

Table 2: CDD regressions data

	CDD 18.5°C	**CDD 22°C**	**CDD 24°C**
CDD coef. (b)	7.2111202	8.1629449	9.1648003
Constant (c)	92.41	106.82	113.11
R^2	0.8833171	0.8752418	0.8611484

The baseload energy consumption (constant c), that is weather independent consumption, is then deducted from predicted monthly consumption to calculate the predicted monthly cooling load. The percentage of predicted monthly cooling load over the period of the study (2000-2015) is then averaged. The monthly average percentage of the cooling load CDD 18.5°C, matches the Ali et al. findings i.e. the cooling load is 40% of total electrical load for CDD 18.5°C [Table 1]. This offers further confidence in the study period and data normalization of the linear regression as representative of the overall picture for Abu Dhabi passive cooling needs. Henceforth, the climatic factors contributions to the cooling load established by Ali et al. are taken as given in the Energy Balance estimations.

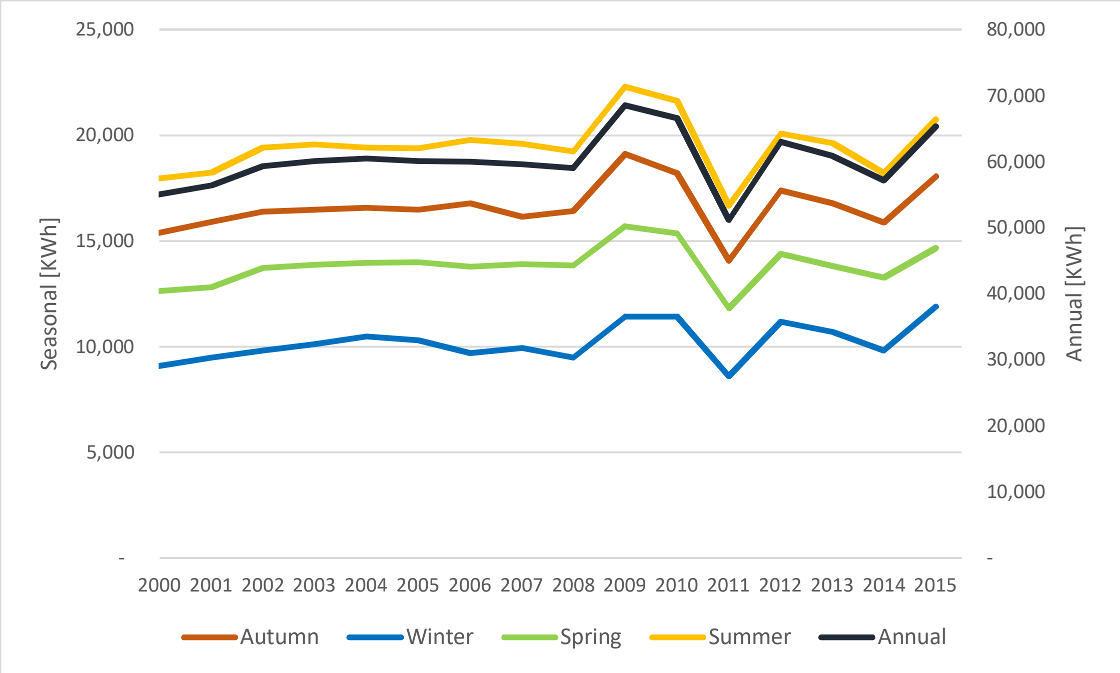


Fig. 2: Electricity consumption per household in Abu Dhabi region

Energy efficiency is analysed through charting seasonal and annual weather normalized electrical energy consumption per household [KWh/CDD] for the periods and across the three base temperatures 18.5°C, 22°C and 24°C. Fig.3 illustrates that energy efficiency over the period of the study is optimal at 18.5°C and the efficiency at base temperature 24°C is the least especially in January of each year. The less efficiency in January and winter (Fig.4) could be explained by the limitation of degree days to capture the low dehumidification needs (Fig.5) and the significant solar radiation (Fig.6 & Fig.7) in winter in since it is solely dependent on temperature measurements. Abu Dhabi receives 17% of total annual global radiation (2,027 KWh/m^{2}d) in winter (354 KWh/m^{2}d).

Table 3: seasonal electrical cooling consumption and solar radiation levels

Season	Autumn	Winter	Spring	Summer
% annual consumption	28%	17%	23%	32%
% annual Solar radiation (Gh)	23%	17%	29%	31%
% annual Diffuse solar radiation (Dh)	21%	18%	28%	32%

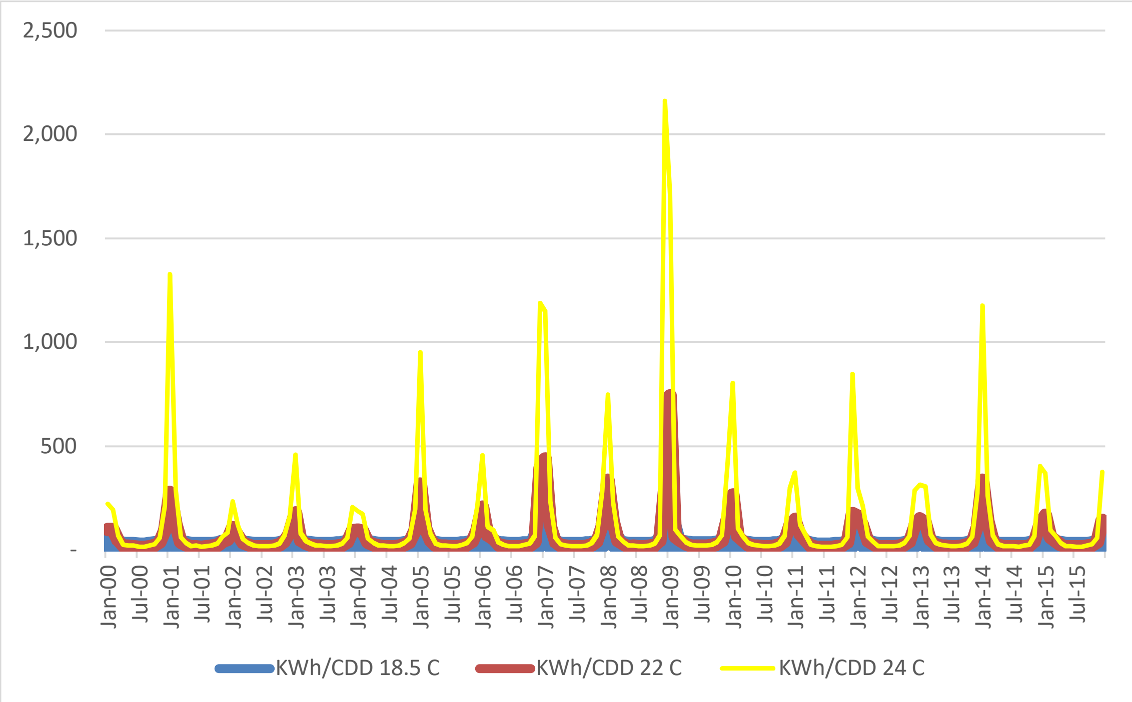


Fig. 3: Weather Normalized Energy Consumption 2000-2015 [KWh/CDD]

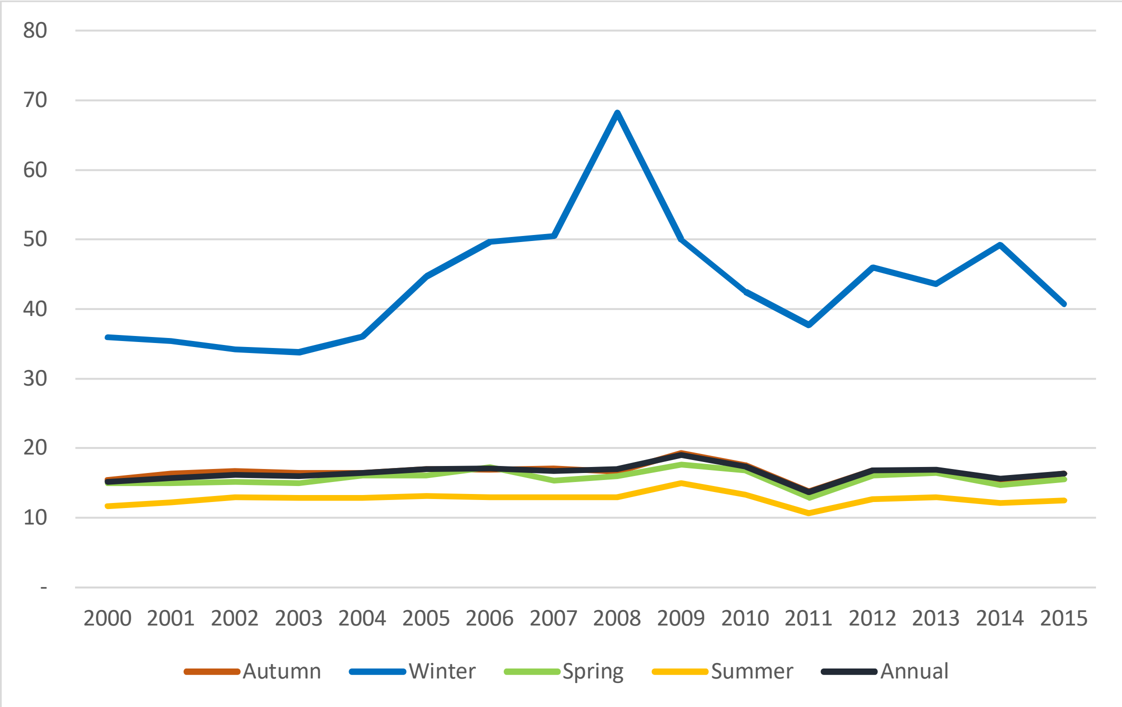


Fig. 4: KWh / CDD 18.5°C

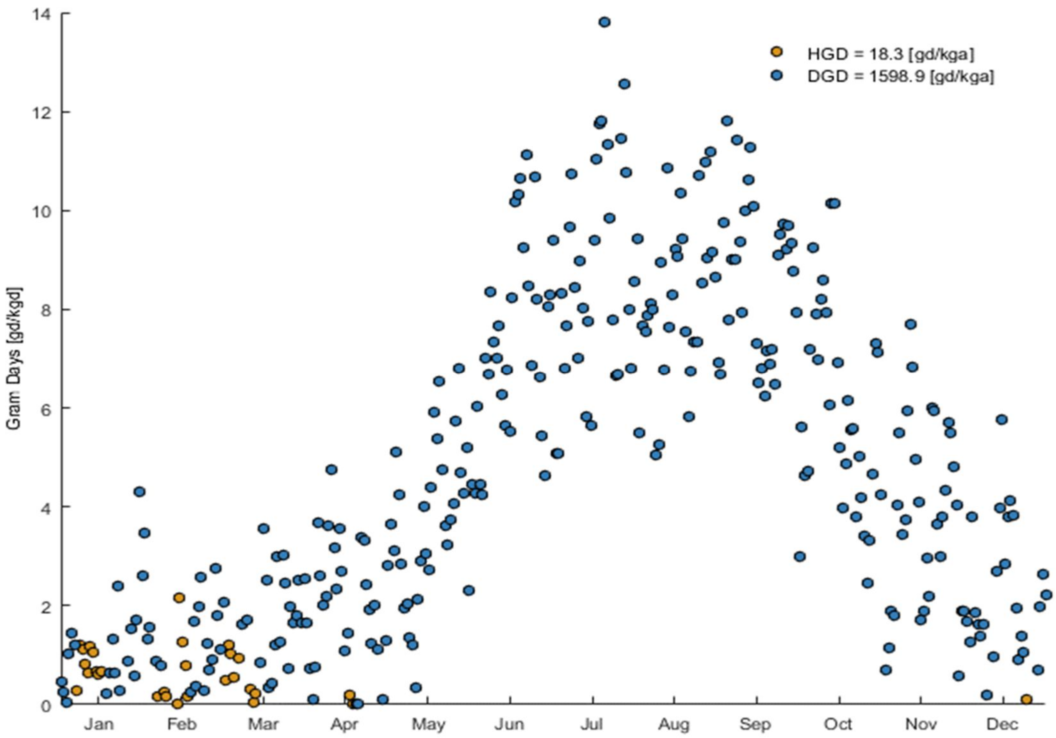
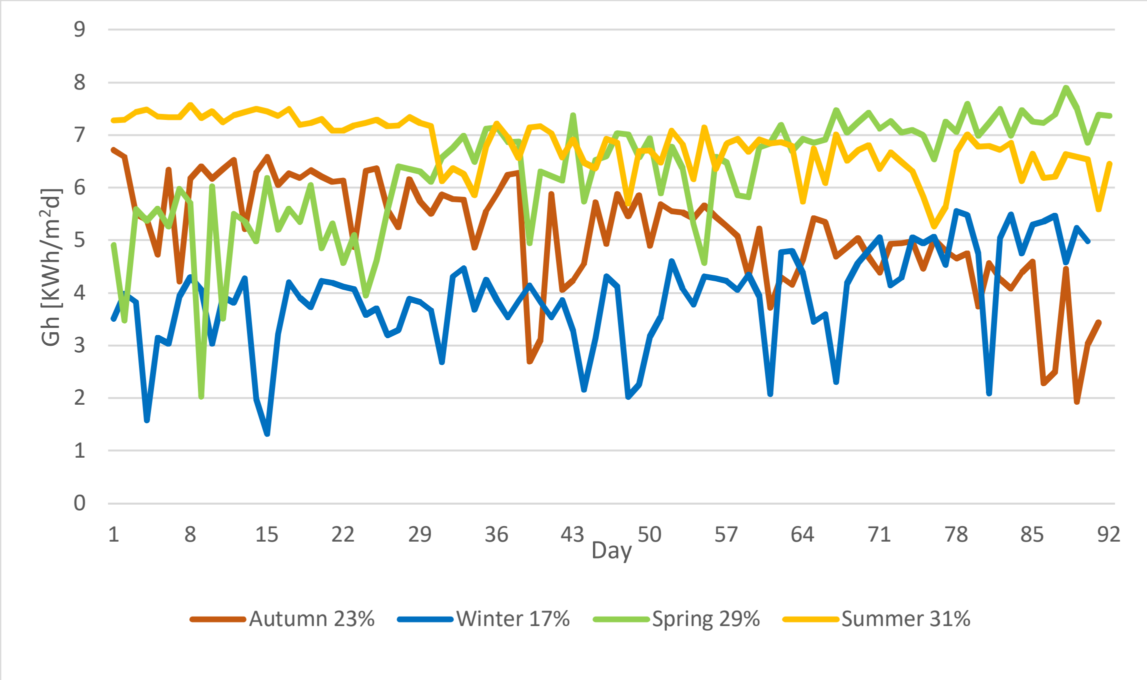
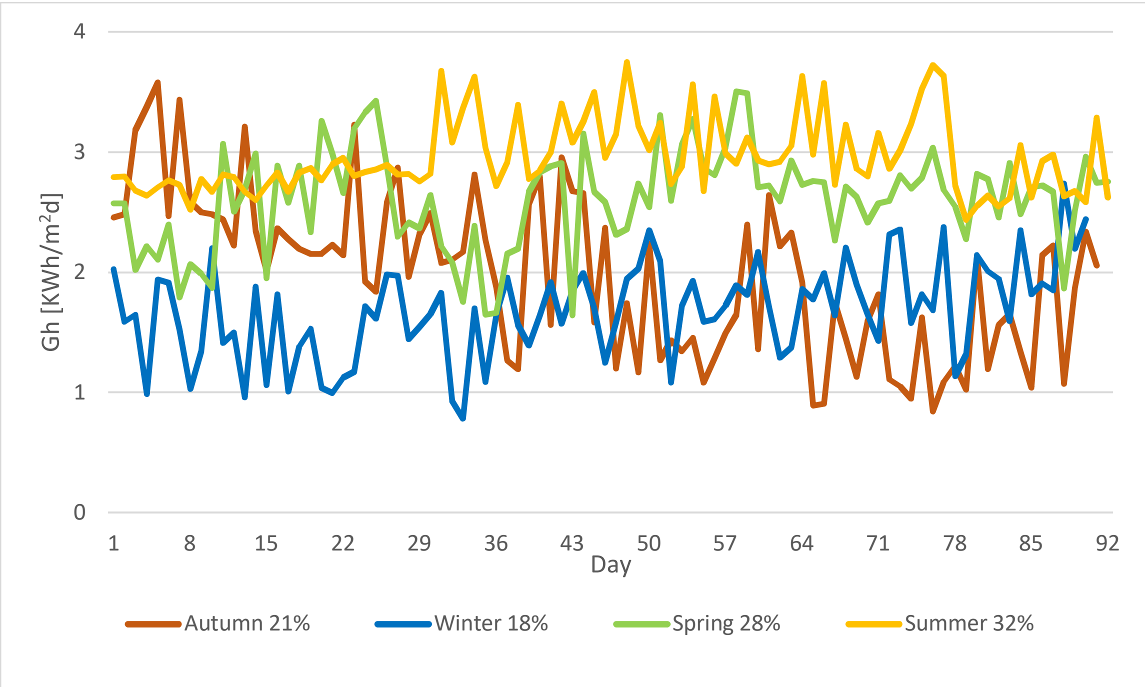


Fig. 5: Humidifying & dehumidifying degree days by ClimateTool



Source: ClimateTool brushed graph using MATLAB

Fig. 6: Average daily global solar radiation by season (Gh)



Source: ClimateTool brushed graph using MATLAB

Fig. 7: Average daily diffuse radiation by season (Dh)

2.2.1 Estimation of cooling efficiency in Abu Dhabi

Using the regression equation, the predicted baseload (weather independent consumption) is deducted from actual monthly electrical usage to calculate the monthly cooling load. The highest electrical cooling demands were registered in August, July and

September respectively. To estimate cooling energy efficiency, the year 2000 as the first year in the period was chosen as the base year to compare the following years to, using weather normalized consumption [KWh/CDD].

a) Assuming that the predicted electrical load, not the actual electrical consumption, is more reliable to estimate the passive house load; the difference between the actual [KWha/CDD] & the predicted [KWhp/CDD] weather normalised consumption is considered the efficiency attributed to the buildings and/or systems in the base year as follows:

$$\frac{\text{KWhp/CDD - KWha/CDD}}{\text{KWhp/CDD}}$$

b) Change in cooling degree days (∆ CDD) and change in KWha/CDD (∆ KWh/CDD) are compared to estimate change in efficiency (∆ Efficiency). It is assumed that the optimal situations for passive design is when the percentage (∆ KWh/CDD) is equal to percentage change in (∆ CDD) but they have opposite signs.

c) The result is then adjusted for the efficiency attributed to non-weather factors calculated in step a, to get efficiency change net of buildings and /or systems performance. Positive change is increasing efficiency and negative is a decrease.

Figures 8 & 9 illustrates that the efficiency in Autumn has decreased for all years except for 2014 where the calculation could be skewed due to changes in population resulting from regulatory alteration in Abu Dhabi requiring public sector employees to reside locally or lose housing allowance, and its impact on calculating consumption per household. Although aimed at reducing traffic between Abu Dhabi & Dubai caused by Abu Dhabi employees residing in Dubai & Northern Emirates, post taking effect, trends like converting one family residence to multi-family residences were registered although not as common as in the period 2009-2011 caused by the financial crisis effects on Dubai & Abu Dhabi job markets. In addition, winter efficiency was negative from 2005 to 2009.

Figures 10.1 – 10.15 illustrate the monthly divergences from 2001-2015 between ∆ CDD, ∆ KWh/CDD and ∆ Efficiency resulting from the divergence from the base year.

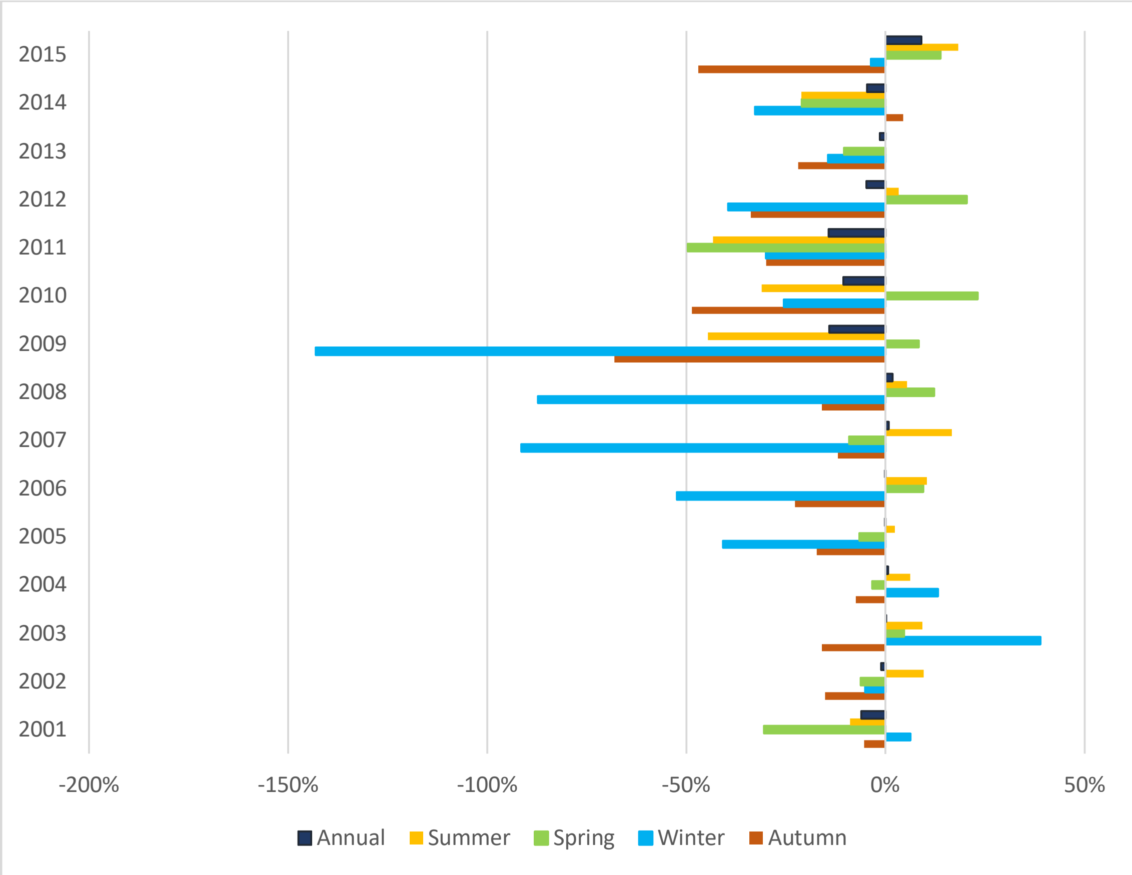


Fig. 8: Δ Efficiency from base year 2000

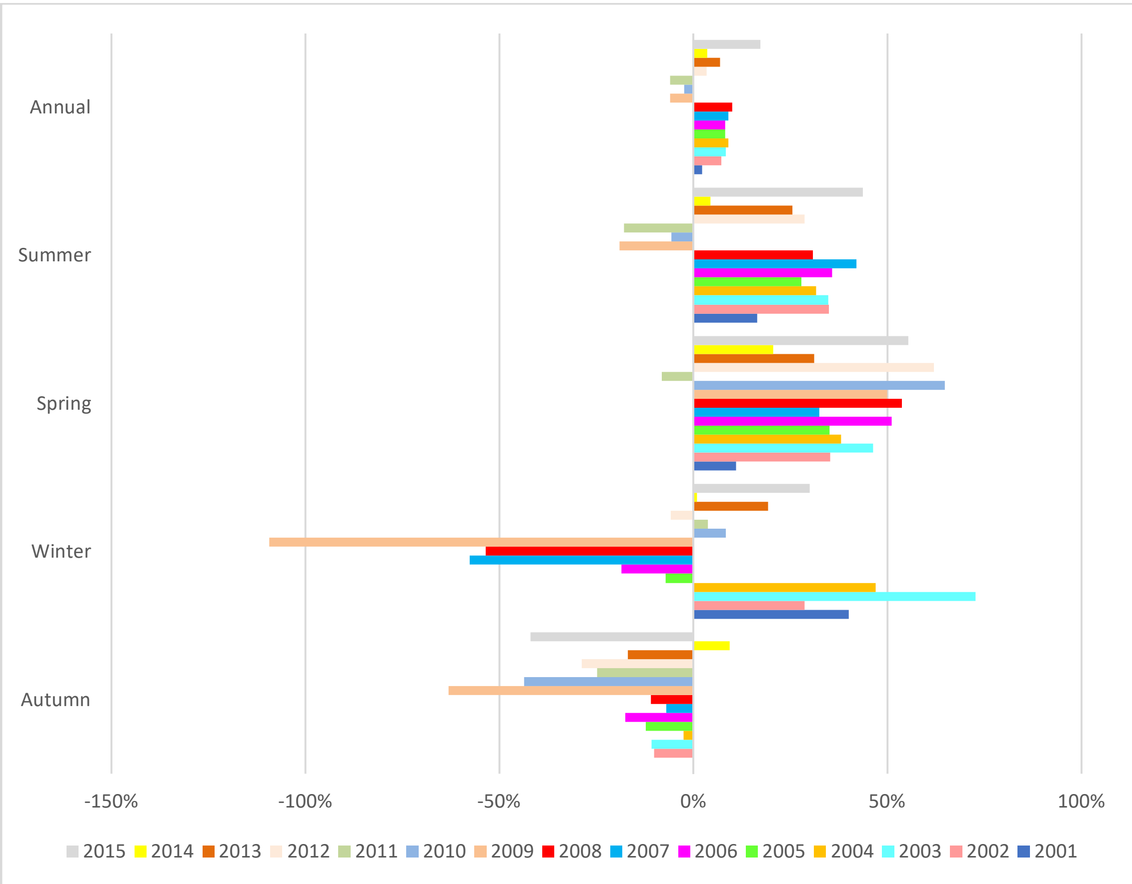


Fig. 9: Efficiency net of base year efficiency

Figures 10.1 – 10.15

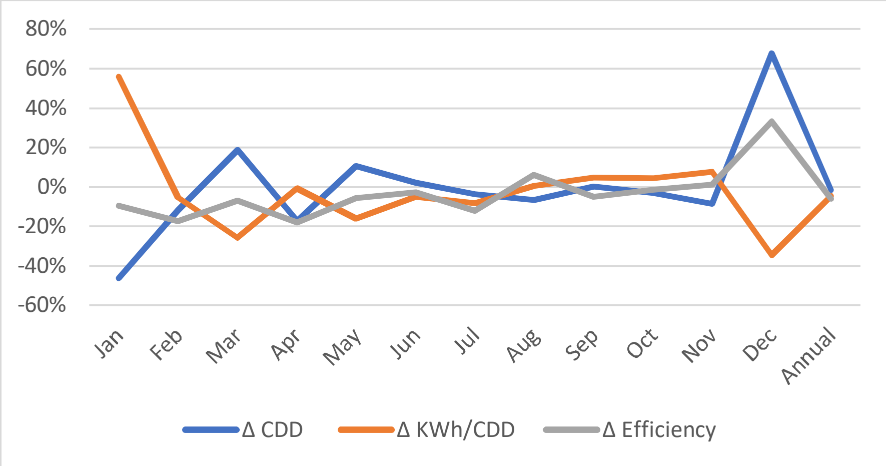


Fig. 10.1: Efficiency – 2001

Efficiency decreased in the first half of the year 2001 compared to base. Divergence is high during winter.

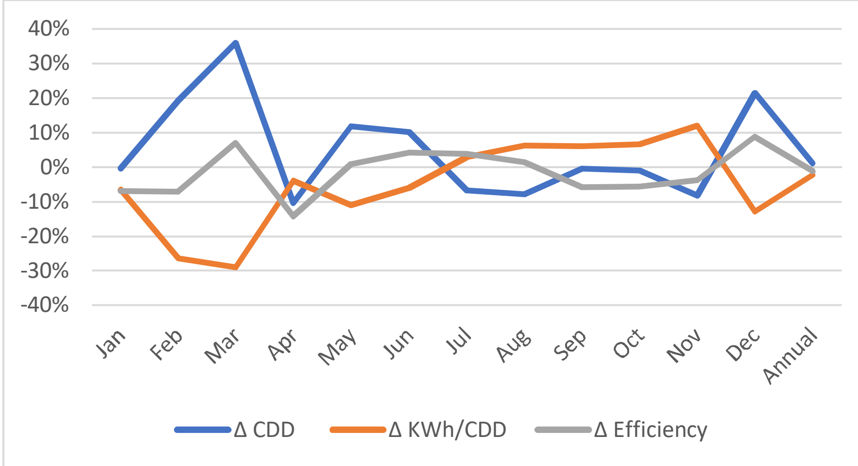


Fig. 10.2: Efficiency – 2002

Efficiency is fluctuating throughout the year and decreasing slightly overall.

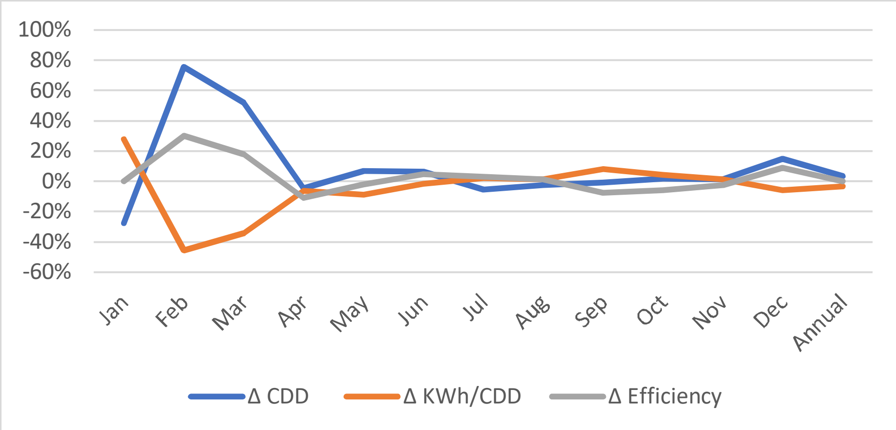


Fig. 10.3: Efficiency – 2003

Increase in efficiency in the first quarter and stabilizing during the rest of the year.

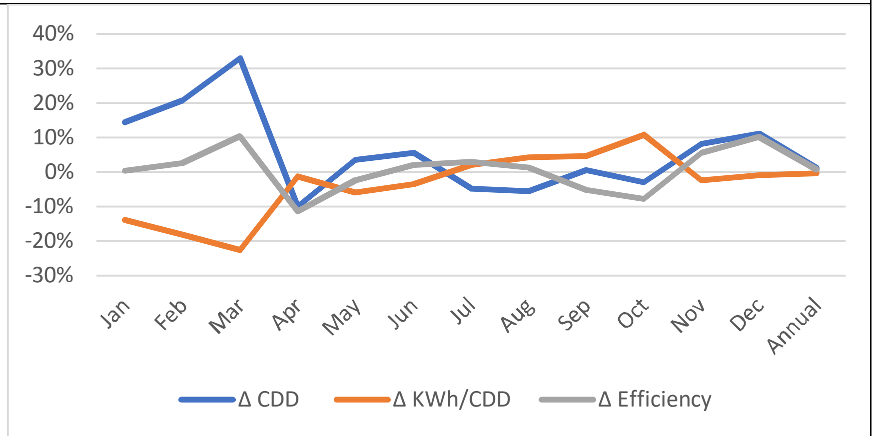


Fig. 10.4: Efficiency – 2004

The annual efficiency is equal to base year.

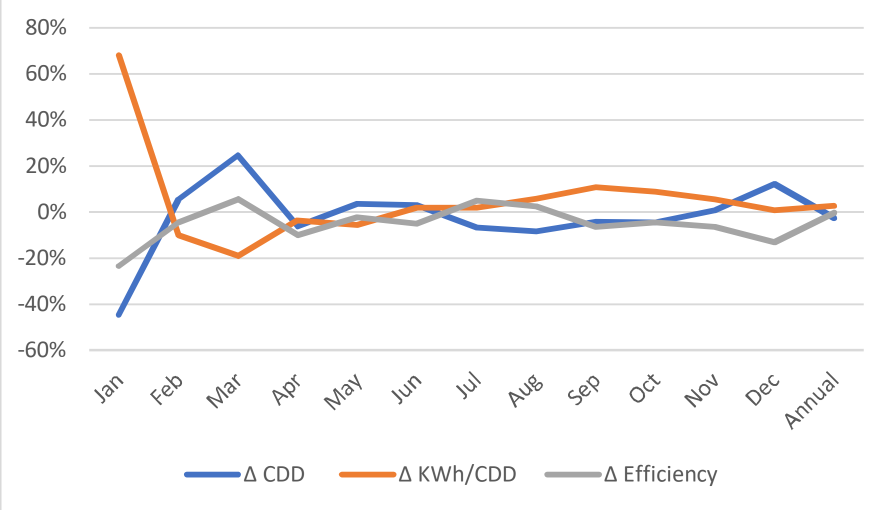


Fig. 10.5: Efficiency – 2005

Decreasing efficiency throughout the year.

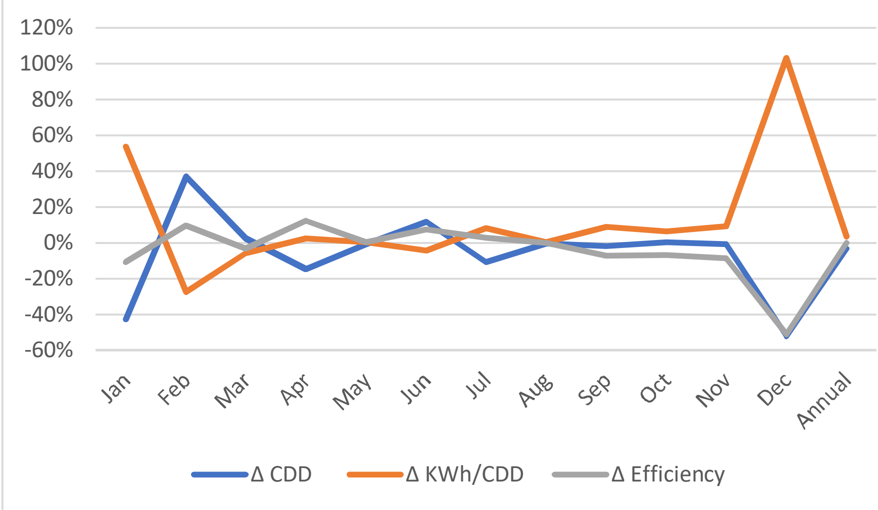


Fig. 10.6: Efficiency – 2006

Stable efficiency throughout the year except in January & December.

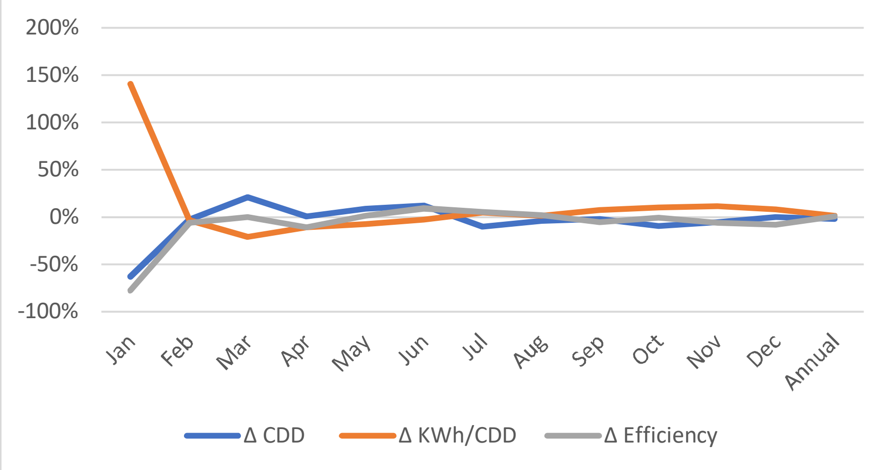


Fig. 10.7: Efficiency – 2007

Stable efficiency throughout the year except in January.

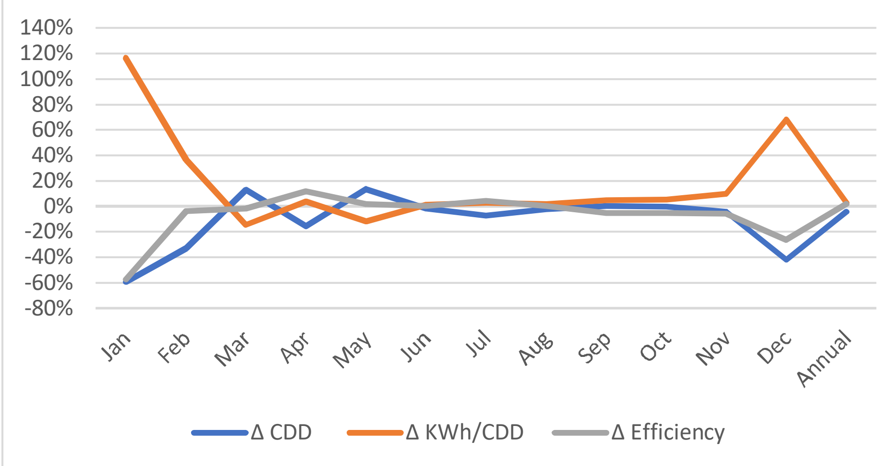


Fig. 10.8: Efficiency – 2008

Stable Efficiency except in winter when it decreased compared to base year.

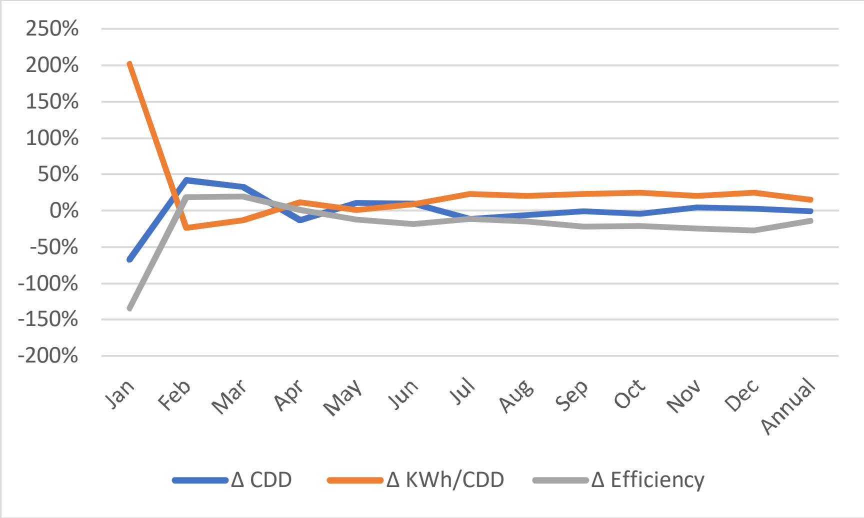


Fig. 10.9: Efficiency – 2009

Efficiency decreased during most of the year.

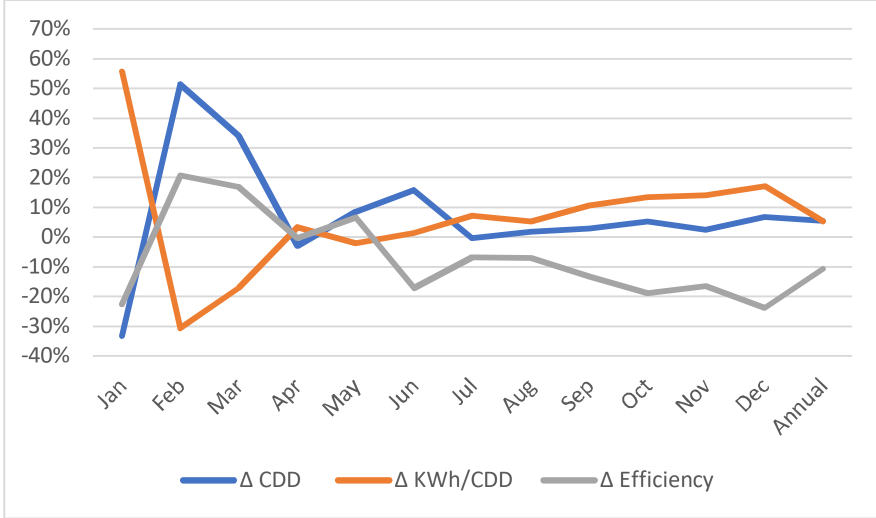


Fig. 10.10: Efficiency – 2010

Fluctuating efficiency overall and plummeting in general.

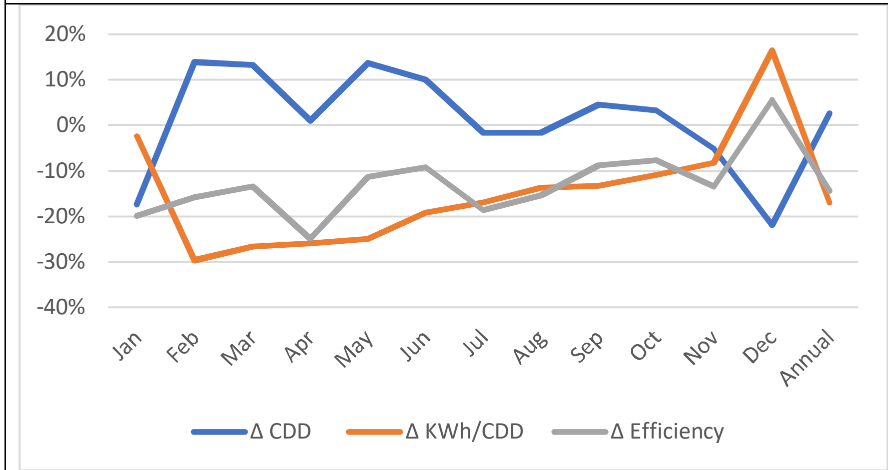


Fig. 10.11: Efficiency – 2011

Less efficient than base year.

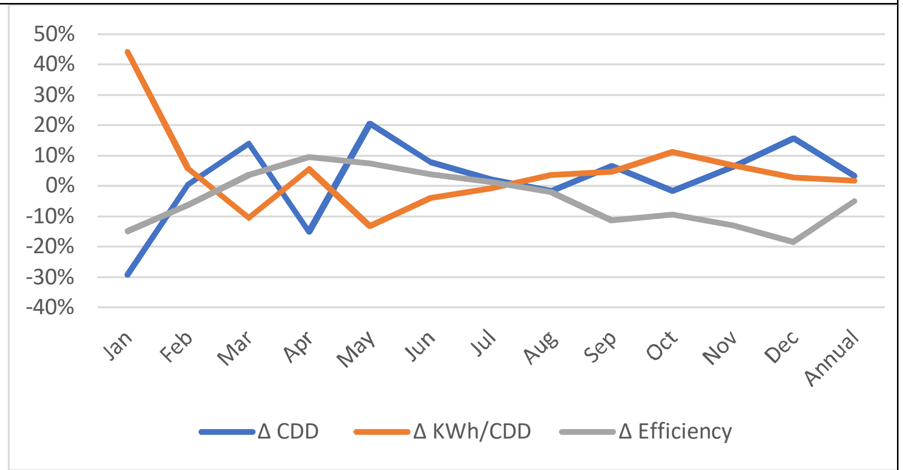


Fig. 10.12: Efficiency – 2012

More efficient from March to July only.

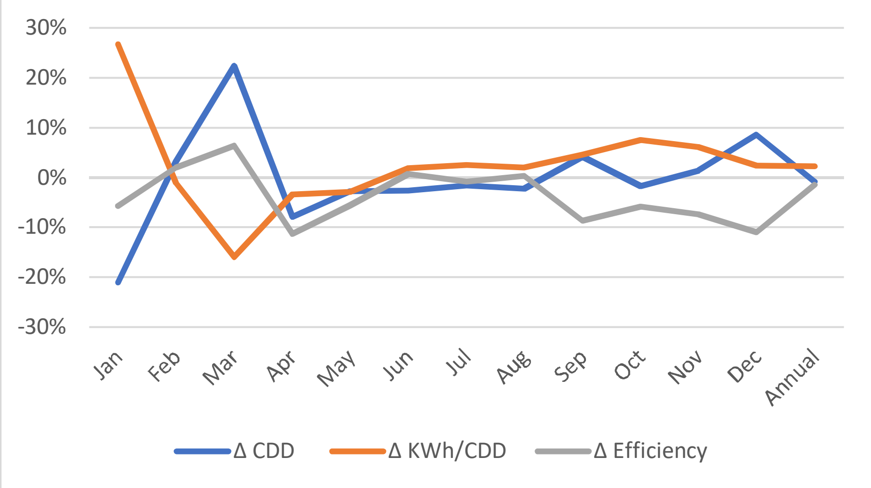


Fig. 10.13: Efficiency – 2013

Efficiency decreased overall and through the year but stable in summer.

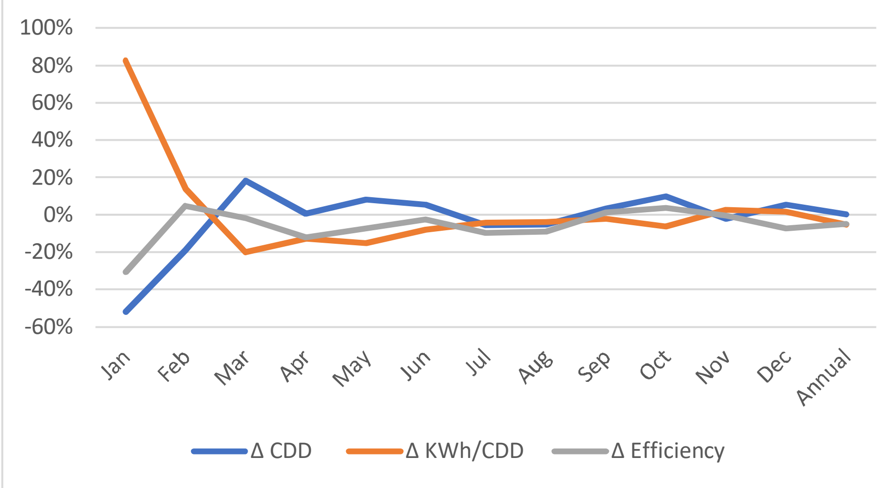


Fig. 10.14: Efficiency – 2014

Stable efficiency throughout the year except in January & February.

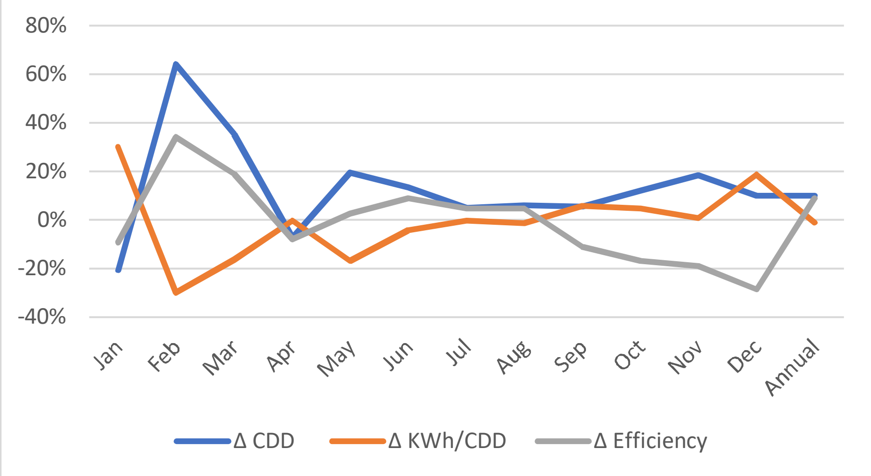


Fig. 10.15: Efficiency – 2015

Efficiency improved overall and fluctuating during the year compared to base.

2.3 Passive house energy balance

The law of conservation of energy can be expressed, for passive buildings, in the Passive House Energy Balance Equation where total heat gains equals total heat losses. (One Sky Homes, n.d.)

Equation: $(Q_S + Q_I) = (Q_T + Q_V) = Q_C$

Q_S: Solar Heat Gains [KWh/a]

Q_I: Internal Heat Gains [KWh/a]

Q_T: Transmission Heat Losses [KWh/a]

Q_V: Ventilation Heat Losses [KWh/a]

Q_C: Annual Cooling/Heating Demand [KWh/a]

For the purpose of analysing the passive cooling load, it is assumed that:

a) the total predicted CDD 18.5°C load = total cooling demand Q_C

b) the air conditioning (electrical cooling load) is adjusted for efficiencies in calculating (total predicted load * % of actual cooling load). This is assumed to be equivalent to the heat rejection needs or the Ventilation Heat Losses (Q_V) required for indoor thermal comfort in existing villas to implement passive cooling since the other heat loss variable (Q_T) is dependent on the existing envelop.

c) the difference between a & b is the Q_T, the heat transmission losses, that are attributed to the building envelop is assumed for existing villas.

d) Q_S shall be relevant in the prevention of heat gains as a passive cooling techniques and its reduction shall passively reduce the total cooling load Q_C, hence reduces Q_V & Q_T for existing and to be designed new villas.

e) Q_I is not investigated in this study because it is approximately 1% of the cooling load, hence negligible.

For new villas, the load allocation of Q_V and Q_T are left open to all possibilities since no envelop limitations exist like in b & c. However, these load allocations shall not compromise the PVRS minimum requirement and, if applicable, shall advance the additional design for credits.

The energy balance graphs Figures 11.1 – 11.16 demonstrate how the air conditioning demand (a/c load) is following the cooling load (Q_C) curve and sometimes exceeding it. Increasing external temperature or solar gain indicates how unsustainable is the current cooling system in Abu Dhabi.

Figures 11.1 – 11.16

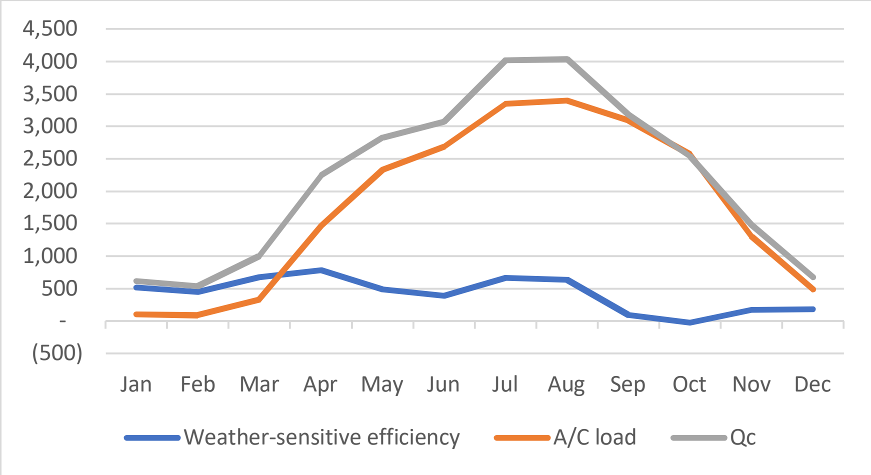


Fig. 11.1: Energy Balance – 2000

A/C load following demand curve but efficiency is good.

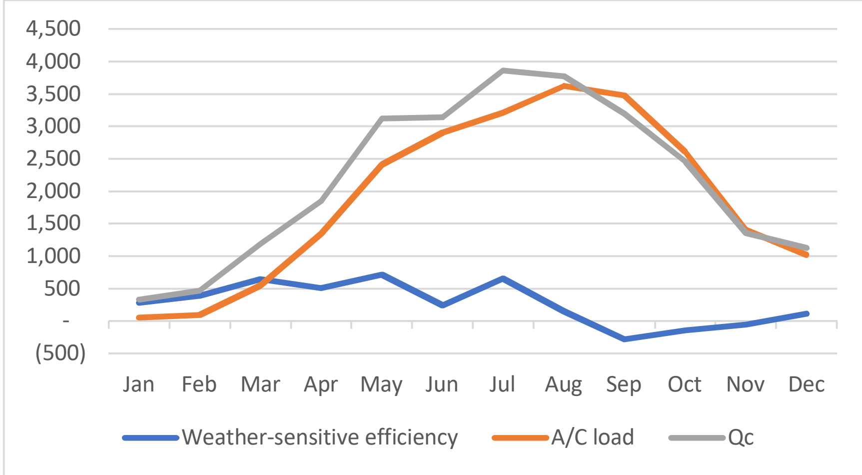


Fig. 11.2: Energy Balance – 2001

Efficiency decrease in Autumn.

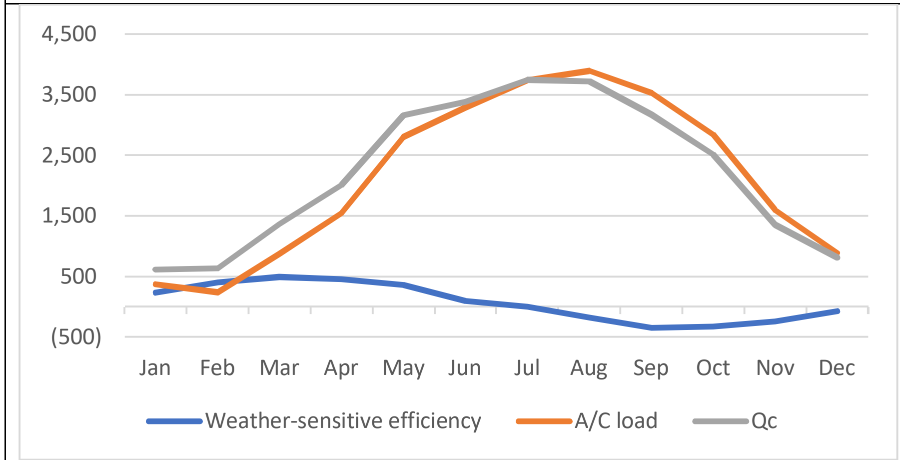


Fig. 11.3: Energy Balance – 2002

A/C load is more than predicted demand based on CDD in the 2nd half of year.

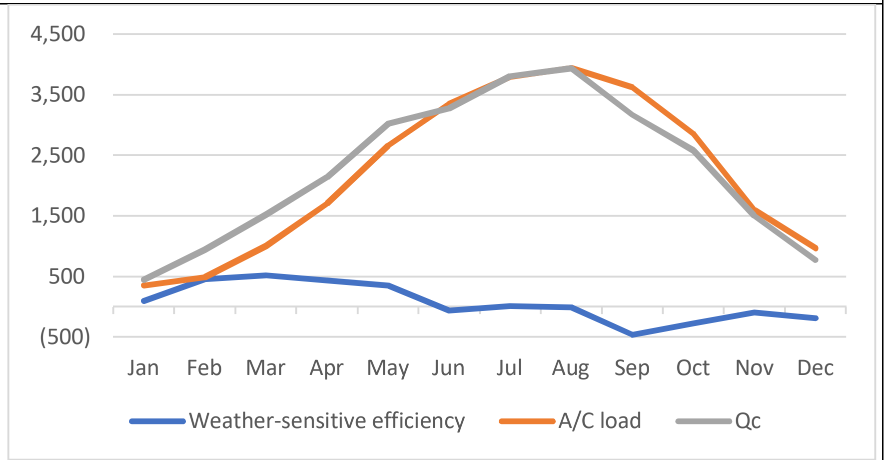


Fig. 11.4: Energy Balance – 2003

A/C load is more than predicted demand based on CDD in the 4th quarter of year

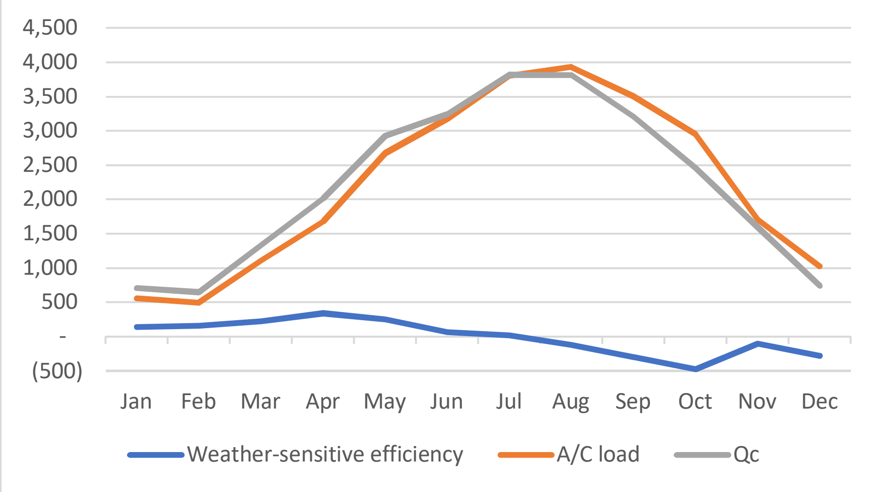


Fig. 11.5: Energy Balance – 2004

A/C load is overpasses predicted demand based on CDD in the 2nd half of year.

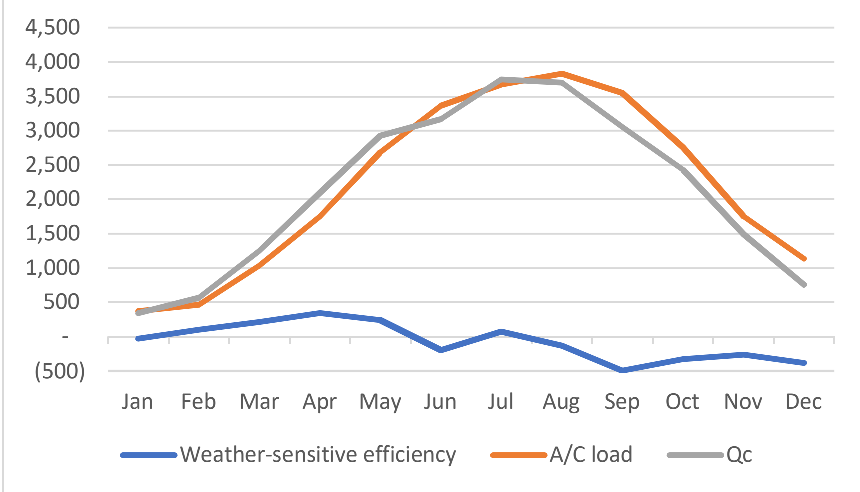


Fig. 11.6: Energy Balance – 2005

A/C load is more than predicted demand based on CDD in the 2nd half of year.

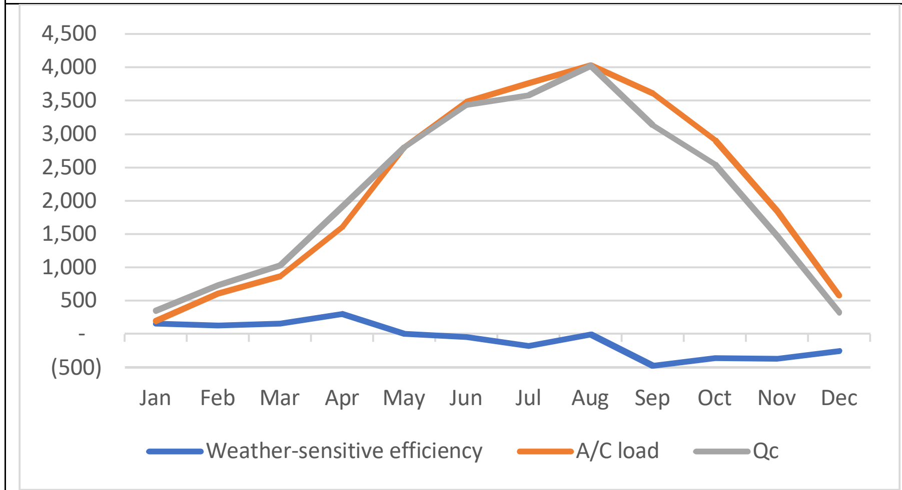


Fig. 11.7: Energy Balance – 2006

A/C load is more than predicted demand based on CDD in the 2nd half of year.

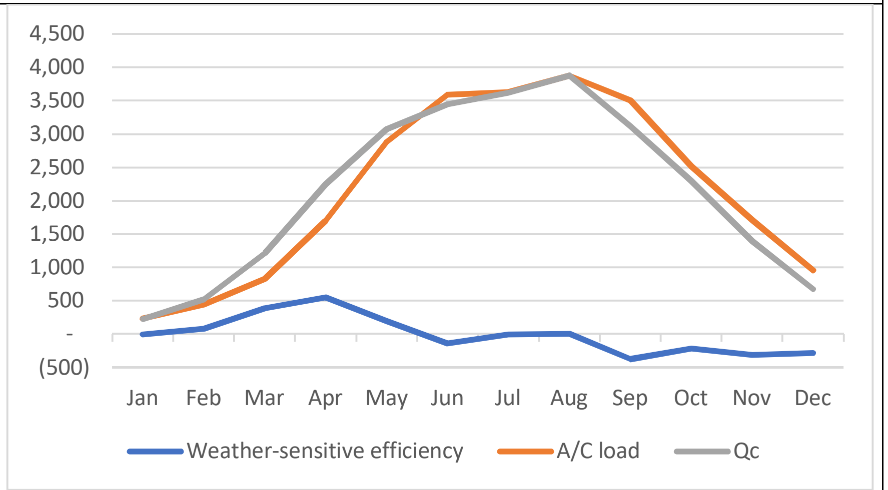


Fig. 11.8: Energy Balance – 2007

A/C load is more than predicted demand based on CDD in last four months

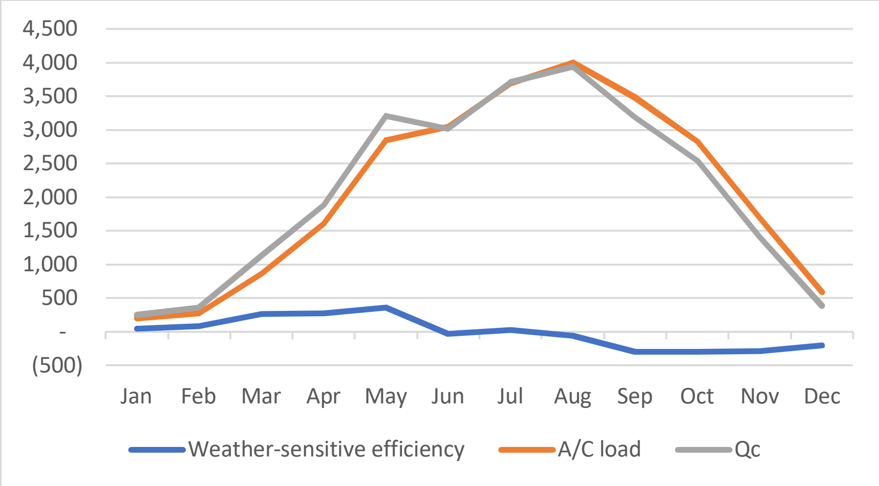


Fig. 11.9: Energy Balance – 2008

A/C load is more than predicted demand based on CDD in the 2nd half of year.

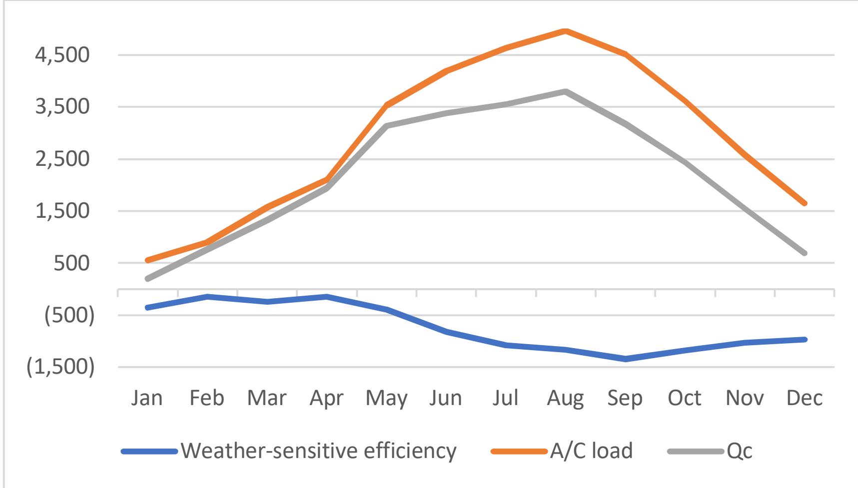


Fig. 11.10: Energy Balance – 2009

High inefficiency; a/c load exceeds demand for cooling yearound.

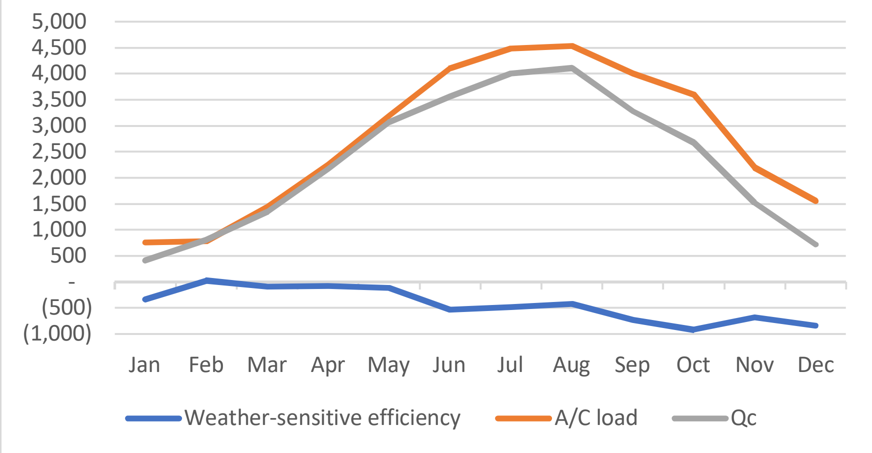


Fig. 11.11: Energy Balance – 2010

Consumption is more than CDD demand.

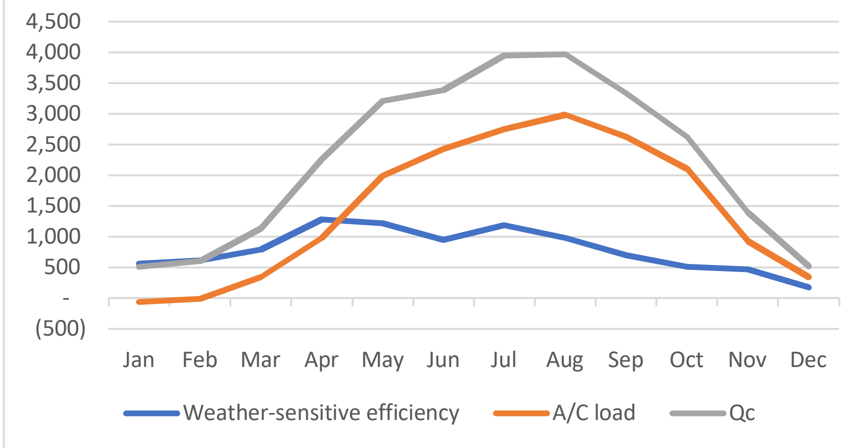


Fig. 11.12: Energy Balance – 2011

A/C load is less than demand (but data could be skewed due to population uncertainties)

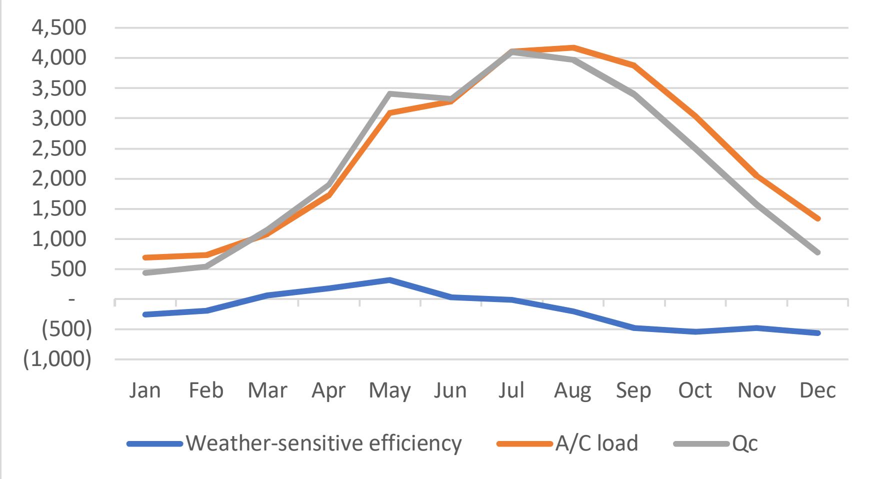


Fig. 11.13: Energy Balance – 2012

Efficiency decreased in the second half of year.

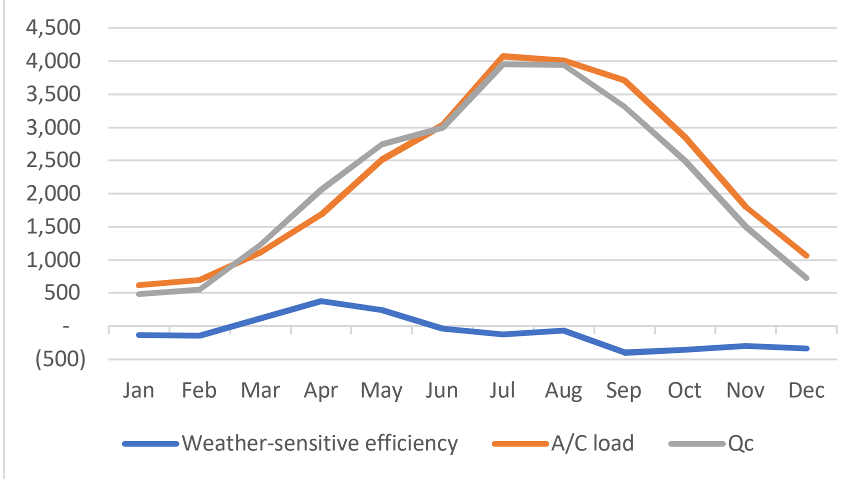


Fig. 11.14: Energy Balance – 2013

Efficiency decreased in the second half of year.

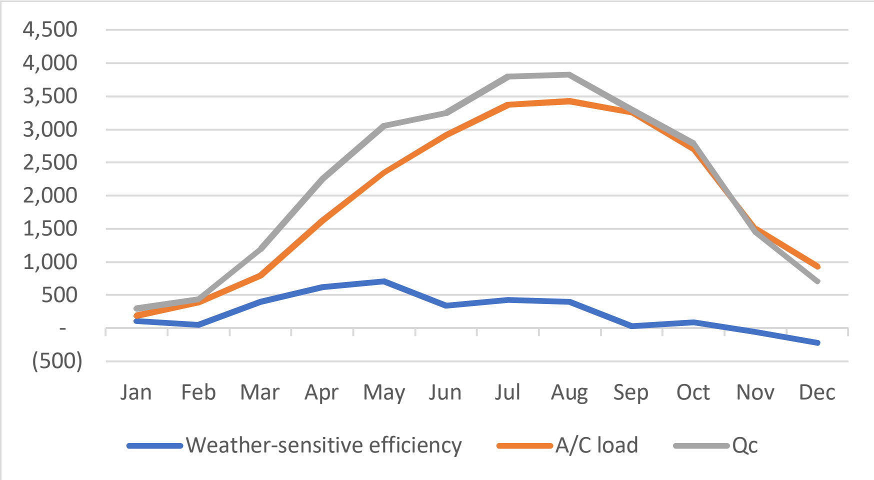


Fig. 11.15: Energy Balance – 2014

Efficient consumption but data could be skewed due to population changes.

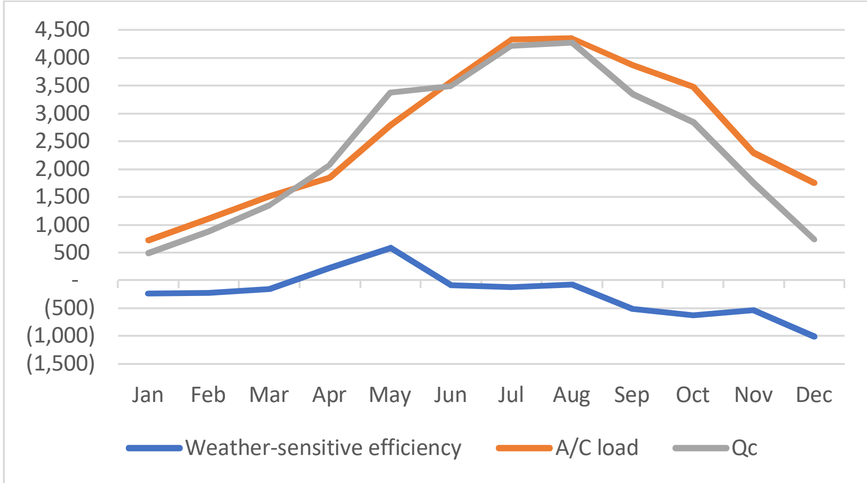


Fig. 11.16: Energy Balance – 2015

Consumption for cooling exceeds CDD cooling demand in 2nd half of year.

In addition, the rate of increasing a/c load compared to the base year outpaces the rate of increasing cooling requirement established by the CDD method Fig.12. In other words, the current space cooling solutions in Abu Dhabi are highly dependent on climate control equipments rather than building design for energy efficiency, hence the need for passive cooling to be impartial of sustainable building design.

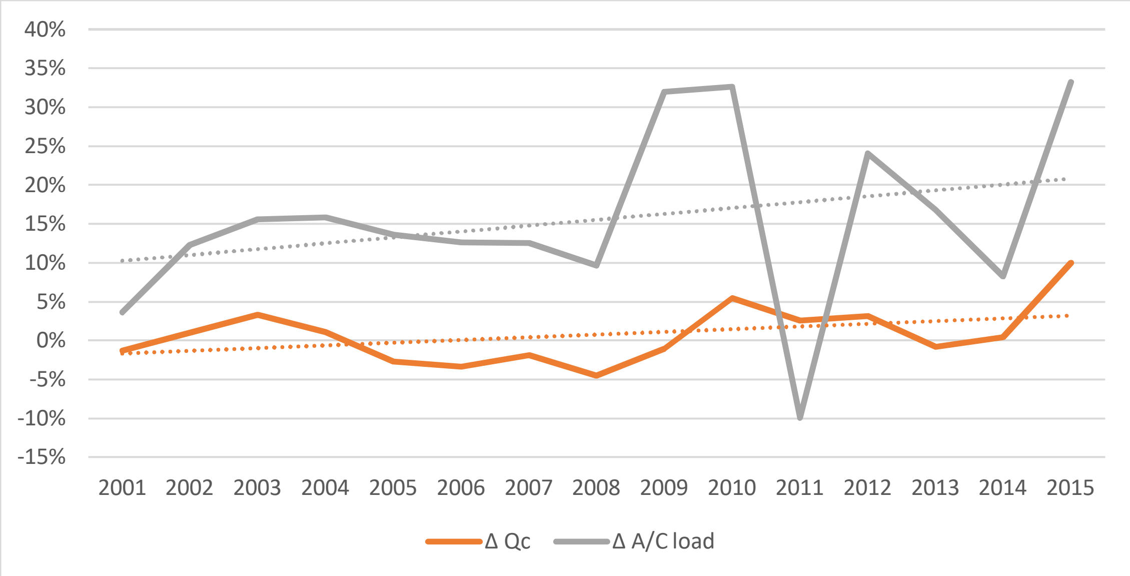


Fig. 12: A/C electrical load vs. cooling requirement (Δ Qc)

2.3.1 Abu Dhabi buildings in context

To apply the climate factors contributions to cooling demand in Abu Dhabi as established by Ali et al., the latent cooling requirement is calculated using wet-bub-CDD 18.5°C. “The cooling degree method has a major flaw, i.e. it considers only a linear dependence between cooling energy consumption and sensible cooling load, thereby ignoring latent loads, which become more significant at higher outdoor temperatures” (Krese, et al., 2012). “The latent cooling load is significant in the case of hot and humid climate conditions when controlled indoor humidity is maintained” (Krese, et al., 2011). “The easiest way to include latent loads in cooling degree days is to calculate them with wet-bulb temperature θw instead of dry-bulb temperature” “as such, contains information about air temperature as well as moisture content” (Krese, et al., 2012). “Whereas the CDD method presumes that moist air, regardless of state, cools down at constant absolute humidity, the wet-bulb CDD (CDDw) method leaves open both possibilities of cooling moist air; i.e. cooling with and without dehumidification (consideration)” (Krese, et al., 2012).

As previously established by weather normalization of electricity consumption that the base temperature of 18.5°C provides the best consistencies and efficiency year-round with the exception of consistencies in winter, performance shall be tested thereafter using the wet-bulb temperature corresponding to 18.5°C that is equal to 17.64°C at calculated average dew point for the period of 17.17°C and Pressure of 1013.25 hPa (Rotronic, n.d.).

Allocating the Ali et al. findings on climatic factors contributions over the study period are illustrated in Fig.13 for existing buildings and Fig.14 for new buildings. The predicted cooling load is larger than the a/c load and the difference could be attributed to the existing buildings and/or systems design. Thereafter, Fig.15 exhibits the efficiencies distribution in the buildings energy balance which could be indicative that the A/C systems efficiencies exceeds the efficiencies of the buildings because its contributions to the heat loss through cooling and dehumidification exceed the solar gain on the other side of the energy balance. The monthly predicted cooling load for the year 2015 is illustrated in Fig.16 to consider weather sensitive passive cooling on monthly or seasonal basis.

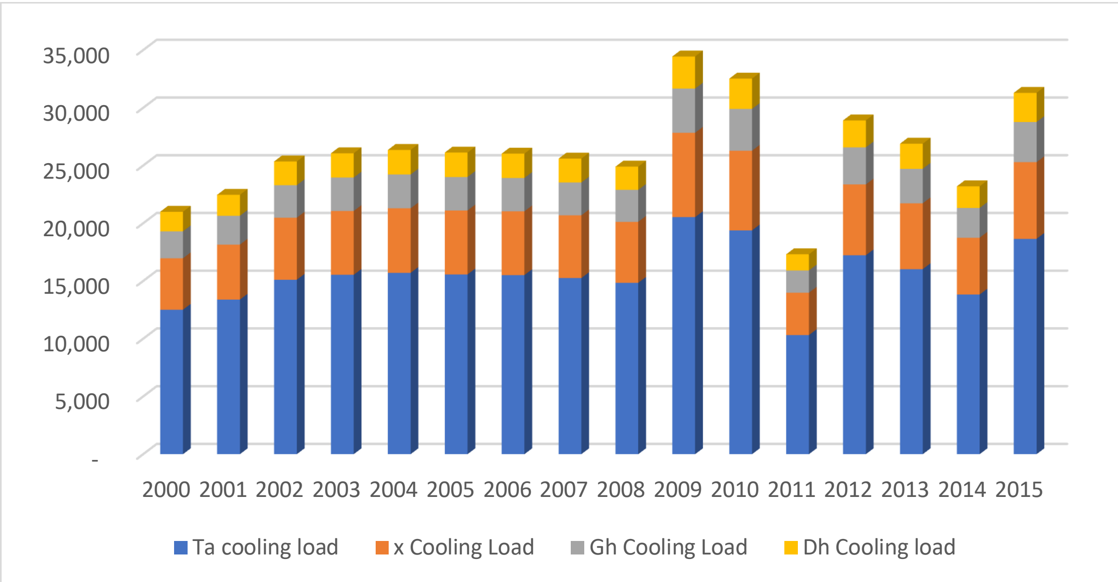


Fig. 13: Climatic factors contributions to the a/c load - existing buildings

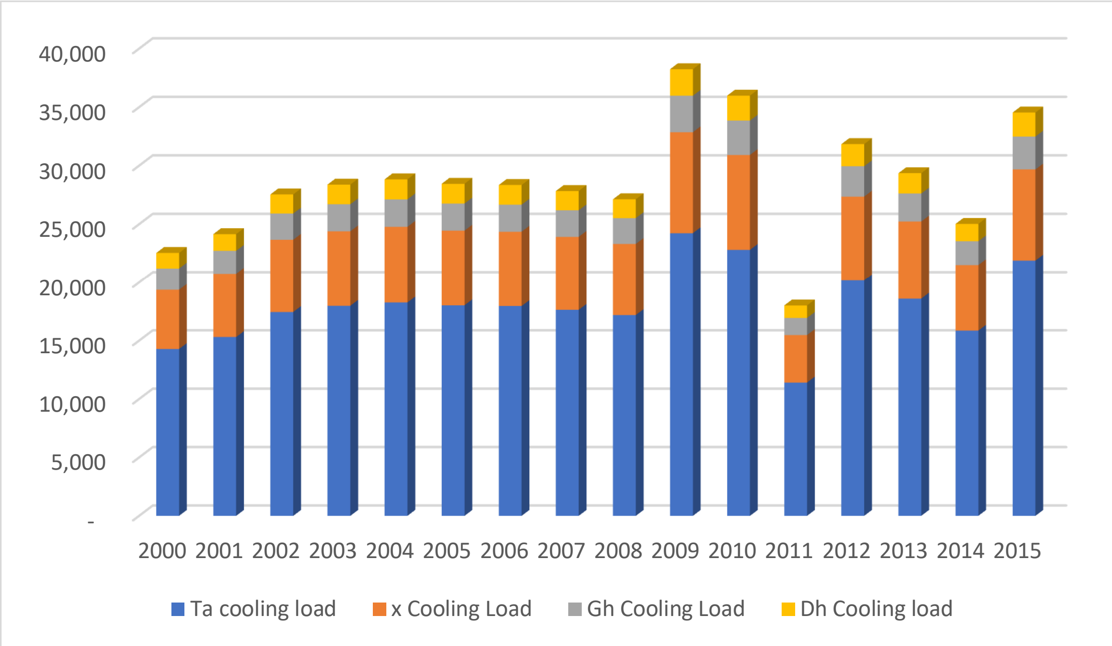


Fig. 14: Predicted Passive Cooling Load - new buildings

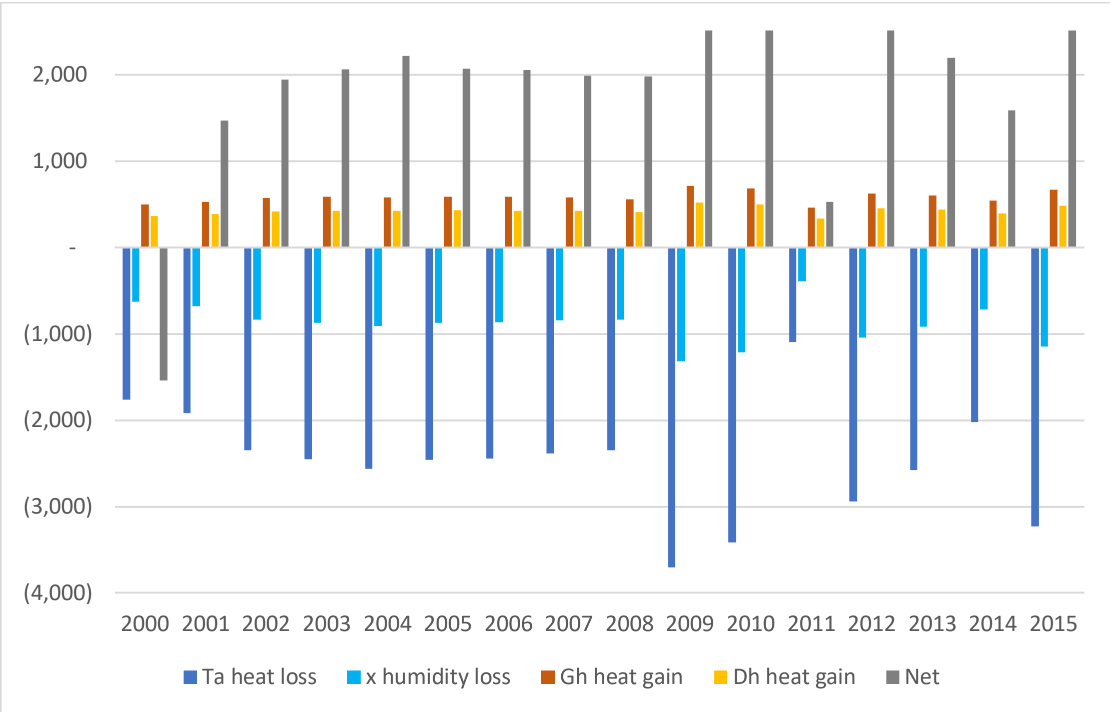


Fig. 15: Existing Buildings & Systems efficiency

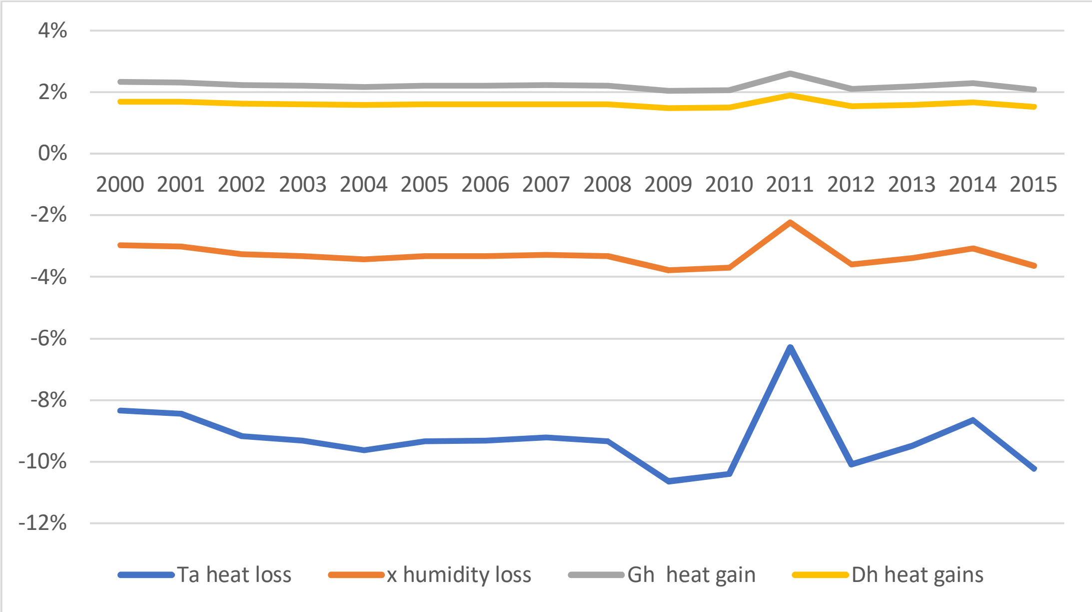


Fig. 16: Efficiencies in the Energy Balance in Abu Dhabi

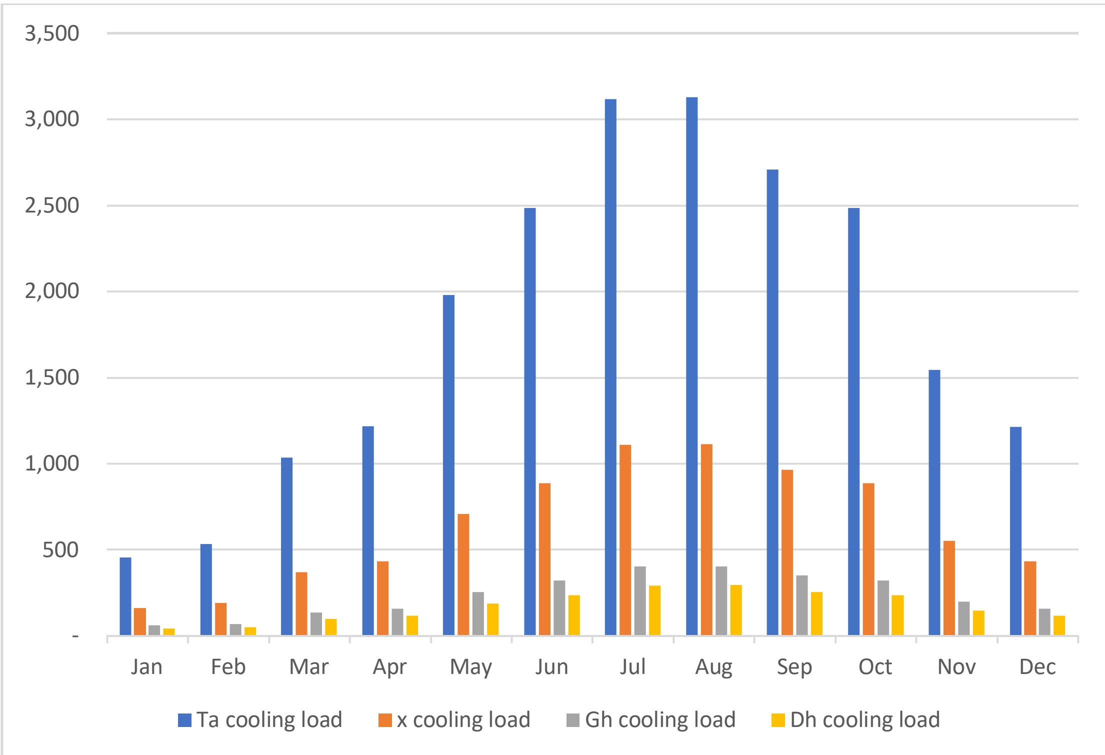


Fig. 17: Predicted monthly passive cooling load – 2015

Ta: attributed to air temperature

X: attributed to humidity

Gh: attributed to global solar radiation

Dh: attributed to diffuse solar radiation

3 ESTIDAMA PVRS SHORTFALLS ON PASSIVE COOLING

The following question is dealt with to conduct a qualitative assessment of PVRS:

Is design credit criterion relevant to the owner's goal; (in this case) to reduce dependence on mechanical equipments i.e. air conditioning; hence reduce energy costs for cooling the villa & design a passive house.

<u>Relevance to Passive Cooling</u>

a. Prevention of heat gains
b. Modulation of heat gains
c. Rejection of heat from interior to heat sink

3.1 Analysis

Analysis of total credit points reveals that up to 13 credit points only, could be considered relevant to implement a strategy of passive space cooling. Moreover, the 4 credit points for IDP-1 is highly recommended for verification of the economic competitive advantage of passive cooling strategy through performing Life Cycle Cost Analysis (LCCA). In addition, up to 15 credit points could be selectively applied based on needs and economic value. This further confirms that achieving 2 Pearl villa rating that requires 30 credit points on top of achieving required credits is not necessary for a passive villa design terms of space cooling only and, depending on passive cooling needs & choices.

Table 4: PVRS relevancy matrix to passive cooling techniques

PVRS category	Passive Cooling relevant criteria	Credits
Natural Systems	NS-1	2
Livable Villa	LV-R1 LV-R2 LV-R3 LV-9	- - - 1
Resourceful Energy	RE-2 Prescriptive Method RE-2 Performance Method	1 to 4 5 to 6

The advantages of each criterion to passive cooling strategy development are as follows:

NS-R1: provides microclimate assessment as part of natural system assessment in the design stage that can be decisive in landscaping for passive cooling.

LV-R1: requires urban assessment of the site which can produce decisive information on cooling loads for different sites.

LV-R3: building code requirement for minimum ventilation that shall be adhered to if passive ventilation is considered.

RE-2: is an improved version of RE-R1on minimum energy performance, hence RE-R1 is not illustrated. However, to improve the energy performance of the villa, it is essential to address the issue with implementing either the prescriptive or the performance method for passive cooling.

IDP-1: LCCA is expected to provide economic value comparison between operational cost reduction of passive cooling techniques and capital investment for passive strategy design & implementation.

3.2 Conclusions

Thermal comfort as per ASHRAE-55, is “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (Autodesk, 2015). Climate related factors influencing human thermal comfort include air temperature, radiant temperature from surfaces surrounding occupants, air velocity and relative humidity. A passive house, according to IPHA, saves up to 90% of energy compared with conventional houses in Central Europe. On one hand, the requirement of Abu Dhabi PVRS “Performance Method” for passive design under RE-2 is up to 50% reduction in “the annual external heat gains” compared with the baseline. The label “reduction of external heat gains” addresses only one aspect of passive cooling techniques of a passive house which, although contributes the lion share to the cooling load, has its limitations if standalone implementation is assumed. The “Prescriptive Method” under RE-2 for passive design, on the other hand, puts requirements for building envelop (U-value, SHGC & infiltration rates & roof solar reflectance) that mainly deals with another passive cooling technique of a passive house which is “modulation of heat gains” in addition to one technique for prevention of heat gains i.e. shading devices specifications.

The thermal comfort zone in Fig.18 shows that the need for cooling & dehumidification is present year-round and is significant from April to November.

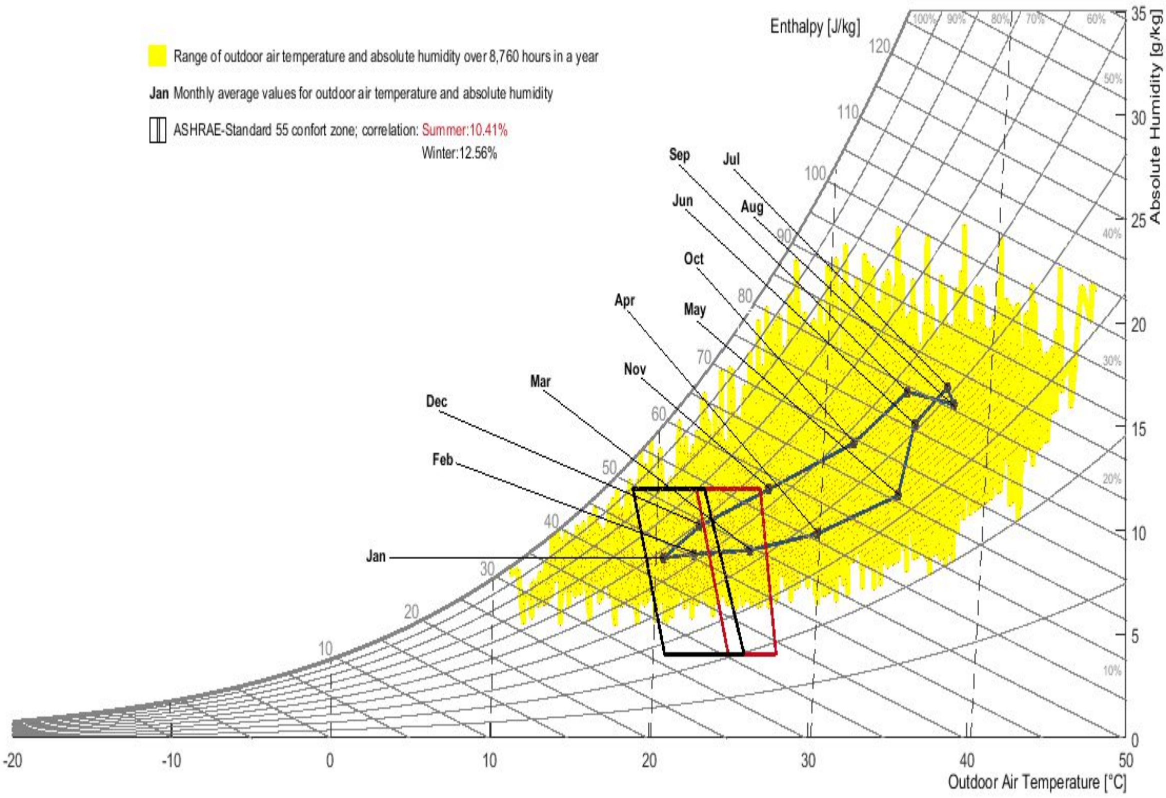


Fig. 18: Abu Dhabi Psychrometric chart made with ClimateTool

Review of literature on passive houses, passive cooling techniques and climate-sensitive buildings, revealed there are three main categories of passive cooling techniques in buildings; 1) prevention or reduction of heat gains to the envelop through modulation of the microclimate around the house and solar control, 2) modulation of heat gains in the building envelope and 3) rejection of internal heat gains to heat sink(s).

Different techniques from these categories are implemented together as part of a passive cooling strategy in passive houses and not interchangeably as PVRS requires "Prescriptive Method" or "Performance Method". Therefore, the PVRS can be considered as a bundle of sustainable building standards that undervalues the importance to climate-sensitive building design and what the more specific passive house concept provides. Furthermore, "the lack of climate-sensitive design frequently leads to unwanted microclimate situations outdoors. Furthermore, indoor microclimate control systems deteriorate the outdoor climate as they exhaust their waste heat, greenhouse gases and other pollutants into the open air" (Esch, 2015).

This difference influences the economic significance to the villa owner in making decisions on sustainability of his/her house when comparing the operational costs over the lifetime of the building to the capital investment in the project design and construction with or without passive techniques. In addition, it influences the performance of the Estidama system as part of the Abu Dhabi government initiatives for sustainability.

4 GUIDELINES AND RECOMMENDATIONS

4.1 General guidelines

1. Passive cooling strategy cannot be effective if implemented the way it is described by RE-2 of PVRS. Therefore, designing a passive house entails that the passive cooling strategy is to be a matrix of passive cooling techniques for prevention of heat gains, modulation of heat gains and dissipation of heat gains that are suited for the Abu Dhabi climate and the villa microclimate.
2. Adopt multi-purpose design approach in implementing the PVRS requirements and criteria to achieve passive cooling.
3. Utilize the information produced for assessments required by PVRS, such as the assessment of the microclimate and the urban assessment of the site, to advance understanding and decision making of passive cooling.
4. Consider thermal adaptation to higher base temperatures like 22°C or 24°C as a long-term goal conservation of energy.
5. Investigate seasonal and/or monthly sensitive measures in the passive cooling strategy.

4.2 Specific guidelines

4.2.1 Prevention of heat gains

Prevention of external heat gains is vital to the passive cooling strategy as it influences the other side of the energy balance equation significantly i.e. heat losses, hence allocation of resources to protect the building from heat gains is instrumental. Therefore, climate suitable design for prevention of heat gains is anticipated to reduce the 40% cooling load. “Efficient heat-gain control techniques bring mean indoor temperatures down close to the level of the mean outdoors; or avoid re-heating when indoor temperatures are already under externals” (Alcala, 2011).

1. The landscape design is the foremost multi-purpose design strategy to be considered in implementing RE-2 of PVRS for modulation of the microclimate around the villa.
2. Solar control to prevent heat gains can be tackled by the prescriptive method of RE-2 with additional recommendations under 4.3.2.
3. Account for shading provided by vegetation in the assessment of need for shading equipments as it could be economically effective.

4.2.2 Modulation of heat gains

The cooling load calculation starts at this point where the external heat is convicted through the building envelop.

1. Consider the influence of envelop thickness in addition to the u-value requirement under RE-2.
2. The size of fenestration as required by PVRS is considered sufficient for passive design and suitable orientation of the fenestration key in optimizing its performance.
3. Solar reflectance of the roof as required by RE-2 of the PVRS is highly recommended because the roof receives the highest heat levels year-round as per figures 19.2-19.5.
4. Phase Change Materials (PCM) specifications can aid passive cooling significantly although not a criterion by PVRS.

Figures 19.1 – 19.5

Obtained from ClimateTool (Liedl, 2016)

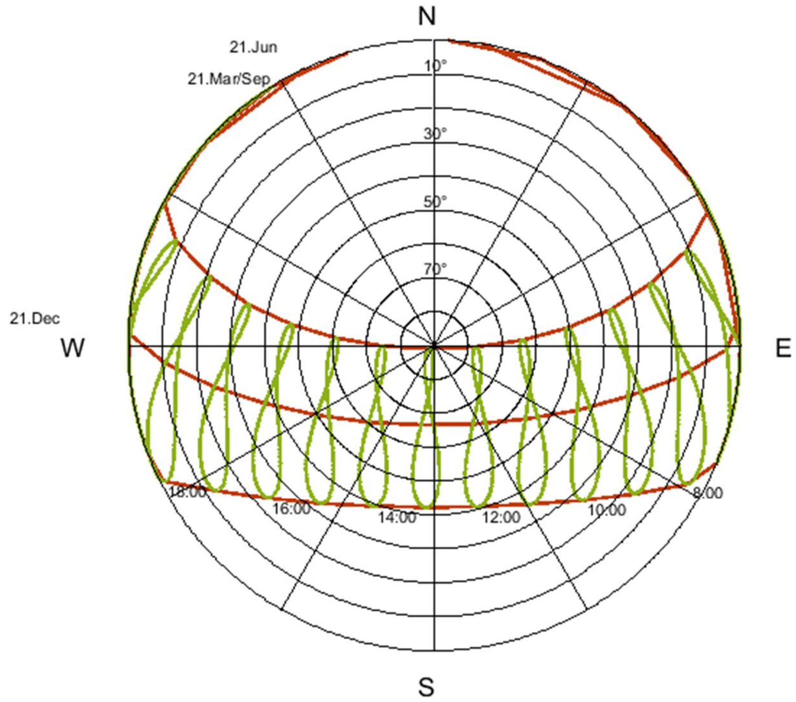


Fig. 19.1: Sun path in Abu Dhabi

Figures 19.2 – 19.5: Solar radiation on buildings [Kwh/m^2 per day] & orientation

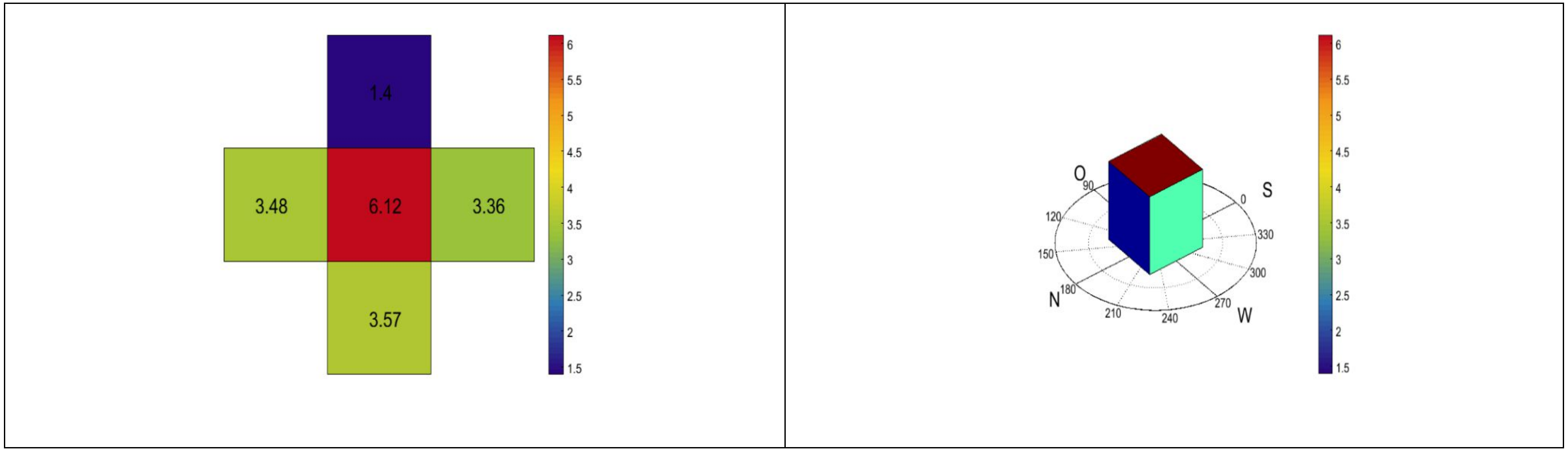


Fig. 19.2: 21 September solar radiation & orientation, data assumed to be representative of Autumn

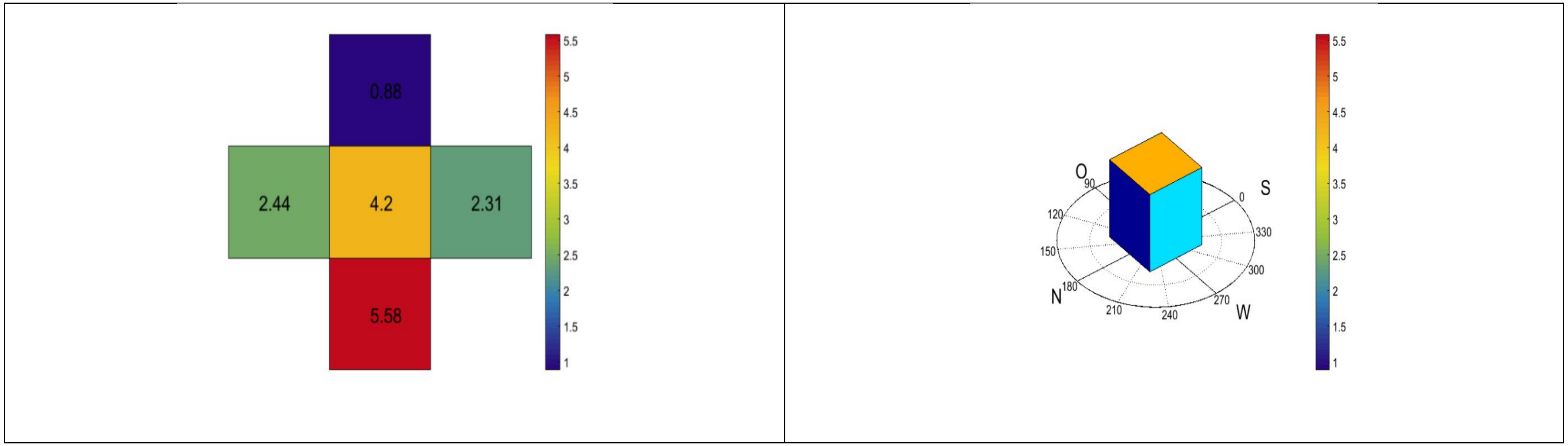


Fig. 19.3: 21 December solar radiation & orientation, data assumed to be representative of Winter

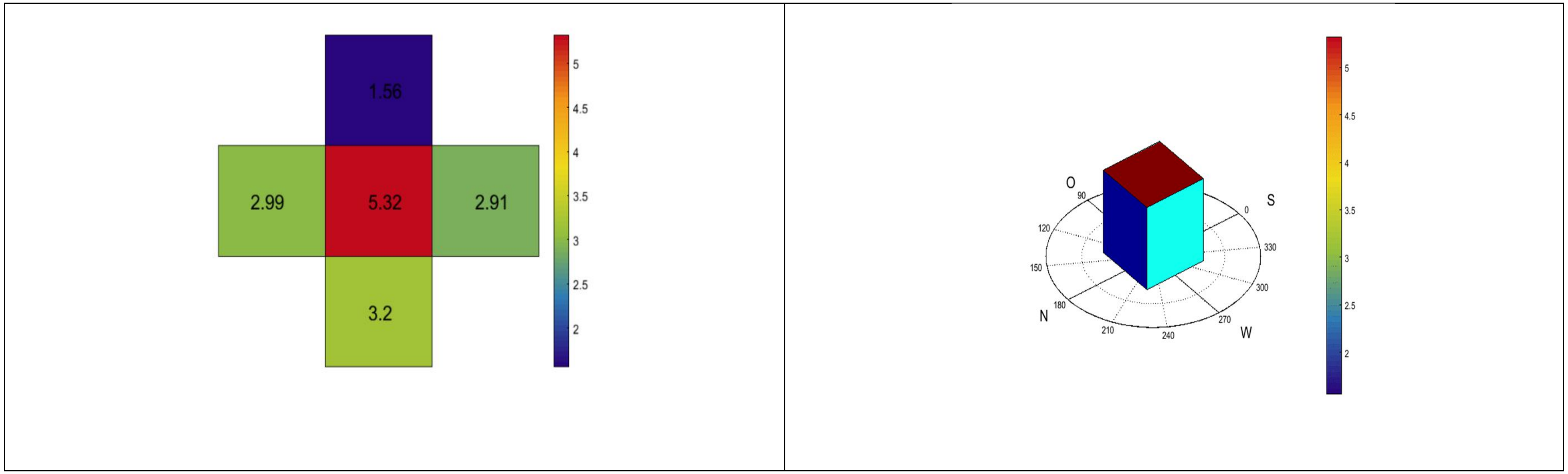


Fig. 19.4: 21 March solar radiation & orientation, data assumed to be representative of Spring

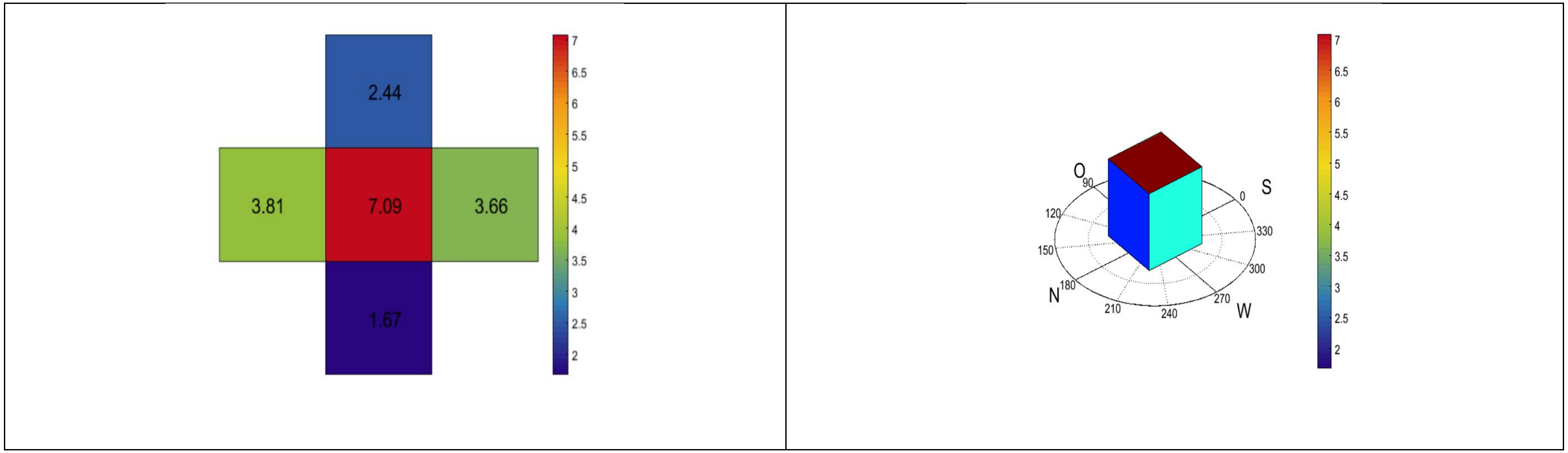


Fig. 19.5: 21 June solar radiation & orientation, data assumed to be representative of Summer

4.2.3 Dissipation of heat gains

1. Note that stored coolness from night ventilation, when applicable for unoccupied rooms during the night can also modulate heat by transferring coolness in early morning hours, hence multi-purpose design for modulation and dissipation of heat gains.
2. Note when implementing LV-8 of PVRS that tackling heat gains from artificial lighting by increasing natural daylight, for example, could be counterproductive to passive cooling techniques in Abu Dhabi because it increases the likelihood of solar radiation penetration to the interior. In mixed and cold climates, "these problems are more severe in passive solar buildings and buildings with large openings. The direct solar gains through the windows of the building, the heat conducted through the building's non-opaque elements and the internal heat gains are useful for passive heating purposes in winter, but they are undesirable during the summer months" (Asimakopoulos & Santamourism, 1996).
3. Internal heat dissipation can be achieved through the rejection of indoor heat to heat sinks like water bodies and the upper atmosphere by natural processes of heat transfer.
4. Note that during high outdoor temperature, some of ventilation and cooling techniques have limitations that must be accounted for in order to produce alternative passive cooling strategy for such limitations.

4.3 Implementation recommendations

4.3.1 General implementation recommendations

1. Consider a concept-based designer for designing passive villa and forming the functional image of the passive cooling techniques.
2. Villa owners with technical or design background can utilize different design software for passive house design such as PHPP, Revit and Sketch up.
3. Assessment of the microclimate as part of PVRS NS-R1, Natural Systems Assessment & Protection, shall be translated into passive design guidelines specific to villa needs, PVRS requirements, constraints & limitations and the influences of climatic factors such as the solar radiation, daylight, wind, air quality, sound, materialization and landscaping on the passive house.
4. Solar orientation and shading patterns of the demonstrated at the regional, sub-regional and context of the villa site as part of the Urban Systems Assessment for PVRS LV-R1 shall be incorporated in the passive villa design.

5. Incorporate economic savings from thermal adaptation to comfort temperatures higher than 18.5°C in the energy conservation calculations for the Life Cycle Costing under IDP-1.
6. Climate adaptive architectural design concepts shall provide the basis for seasonal and monthly consideration to exploit natural ventilation, natural lighting and use & activation of thermal mass for passive space cooling.

4.3.2 Prevention of heat gains

1. Landscaping for the modulation of the microclimate around the villa can prevent heat gains through vegetation and water bodies. “Vegetation provides shade to its surroundings, therewith reducing solar heat gains of the shaded surfaces. Combined with water, it also lowers temperatures through evapotranspiration, improving microclimates in warm periods” (Esch, 2015).
   a) Thermal insulation through vegetated surface systems like living wall on façade or green roofs, earth-sheltered building design, elevational design, penetration design and atrium-style design. The latter is a typical basement design in traditional buildings in some countries in the Middle East. Screenshots from supplemented DVD on Best Practices in Sustainable Building Design (Özer, et al., 2013) are provided in figures 20.1 – 20.15 for reference.
   b) Solar heat moderation can be achieved by canopy shading, vegetated surface systems
2. Shading structures as per LV-R2, shading devices as per RE-2 and the landscape plan for shading shall be complementary of each other spontaneously with and seasonally retractable devices. Orientation recommendations is provided in figures 19.2-19.5 as obtained from ClimateTool. It is assumed that orientation graphs for 21 September, 21 December, 21 March and 21 June are representative of design considerations for Autumn, Winter, Spring and Summer respectively.

Figures 20.1 – 20.15

Screenshots obtained from DVD supplemented to Best Practices for Sustainable Building Design (Özer, et al., 2013)

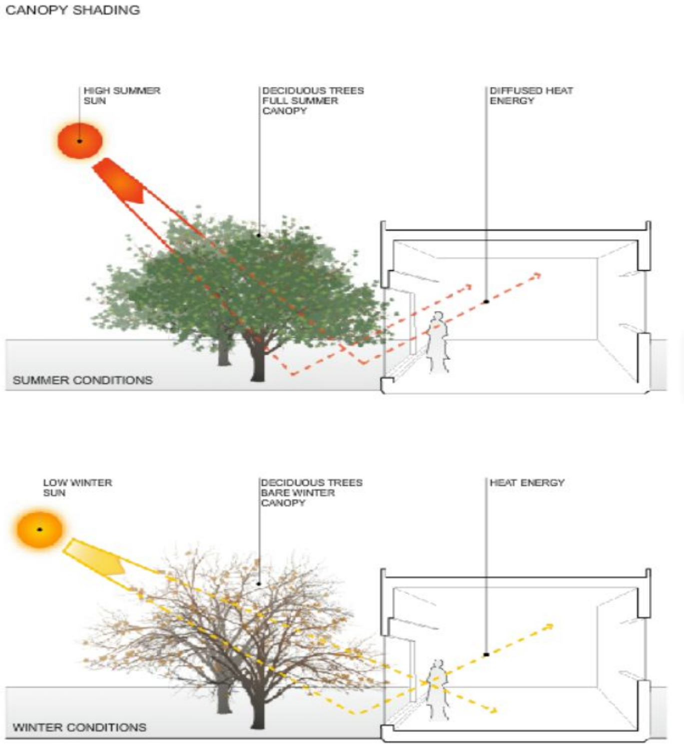


Fig. 20.1: Canopy shading

Proper location of trees and its shade on the roof is effective with southwest and west facing walls and windows.

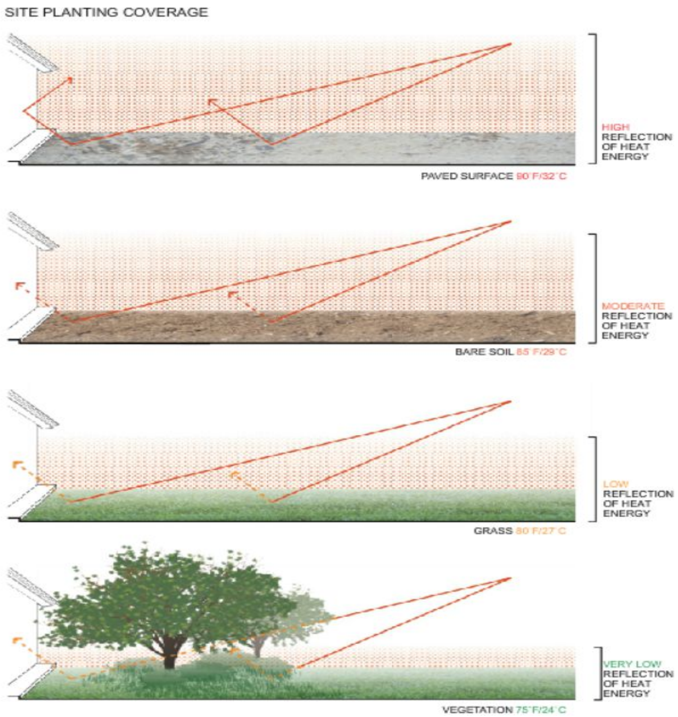


Fig. 20.2: Site planning coverage

Planting provides cooling effect through evapotranspiration.

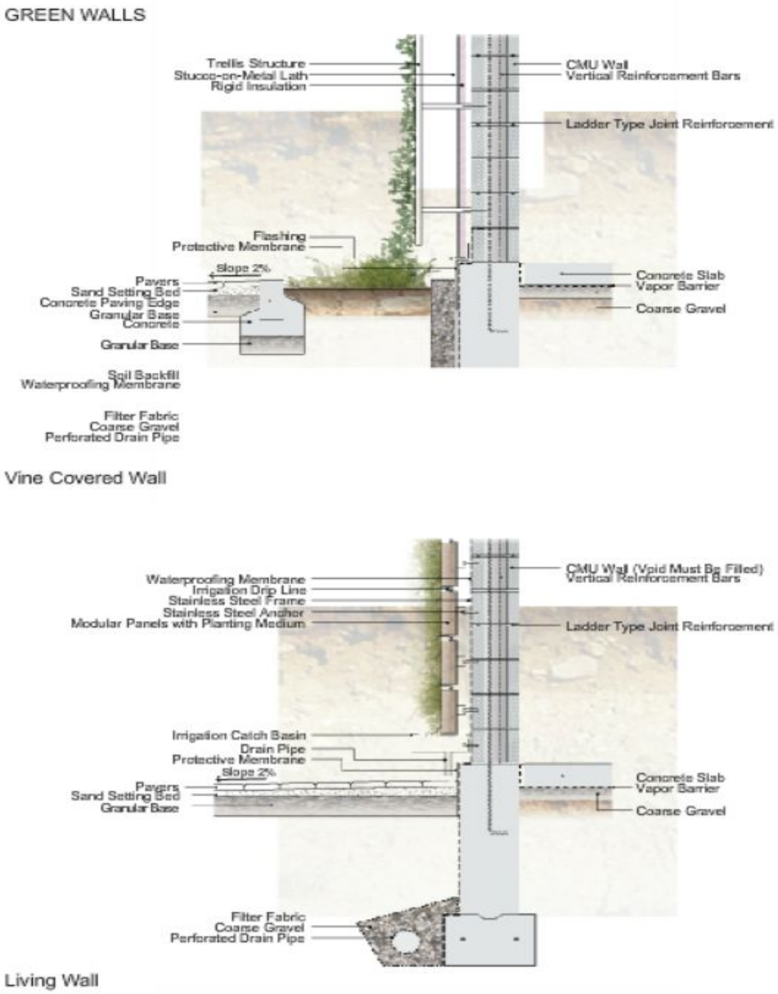


Fig. 20.3: Green walls

On south and east facing walls blocks the sun in summer

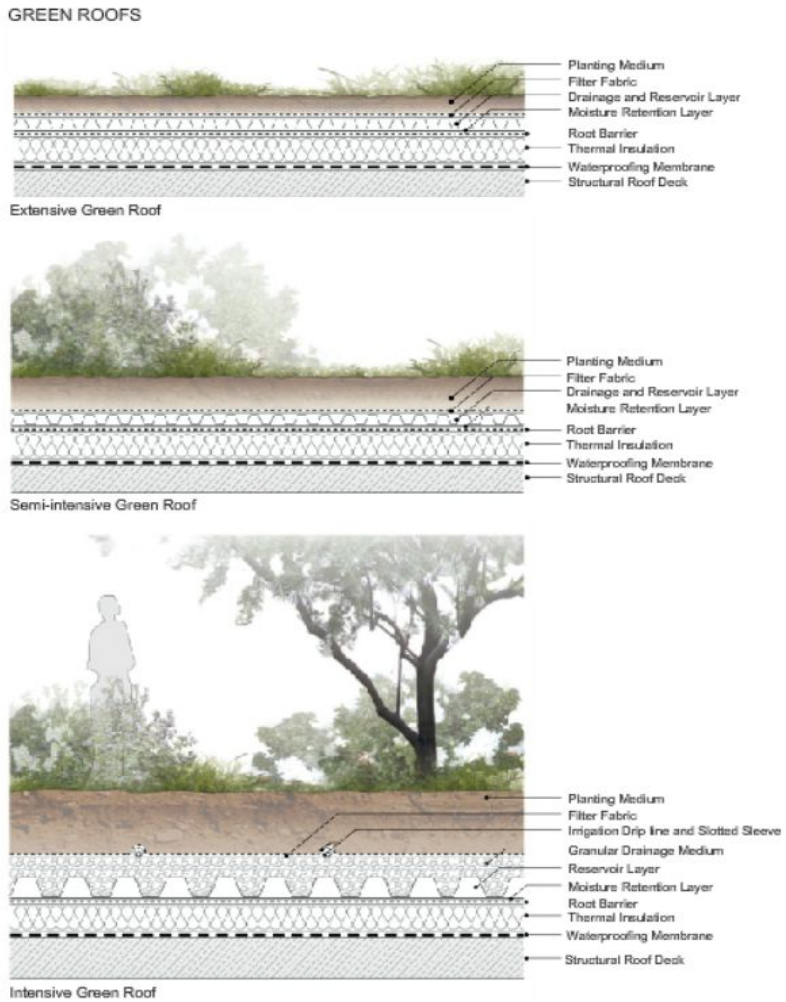


Fig. 20.4: Green roofs

Moderates solar heat and evapotranspiration of plants reduce heat load on building.

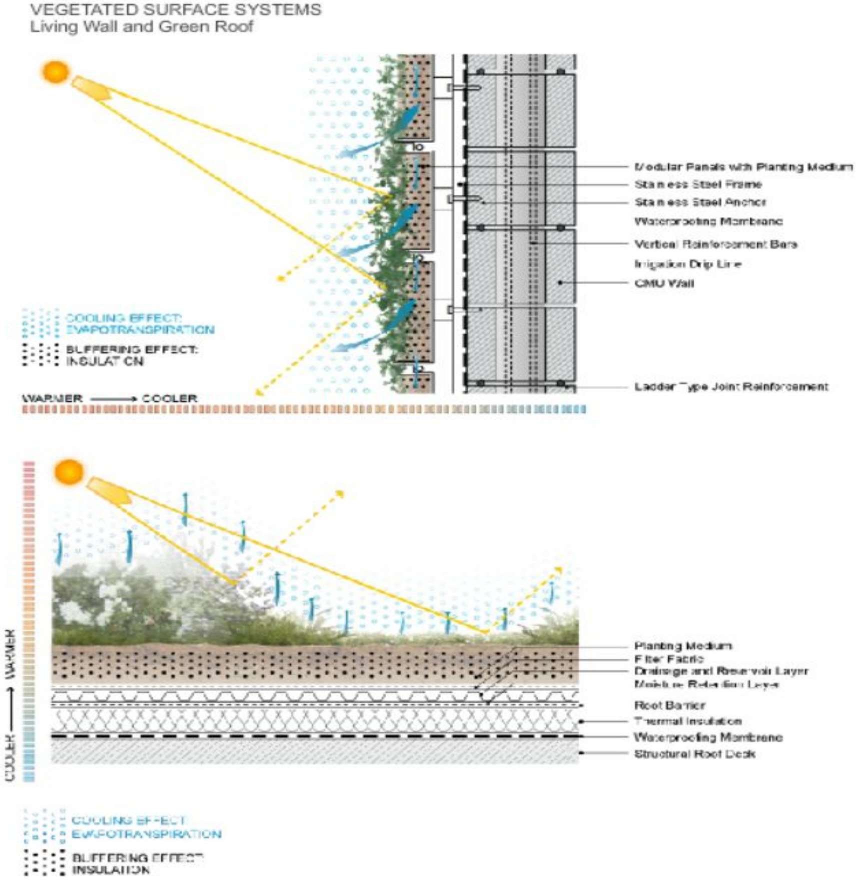


Fig. 20.5: Vegetated surface systems (a)

Provides insulation and have high capacity for heat absorption

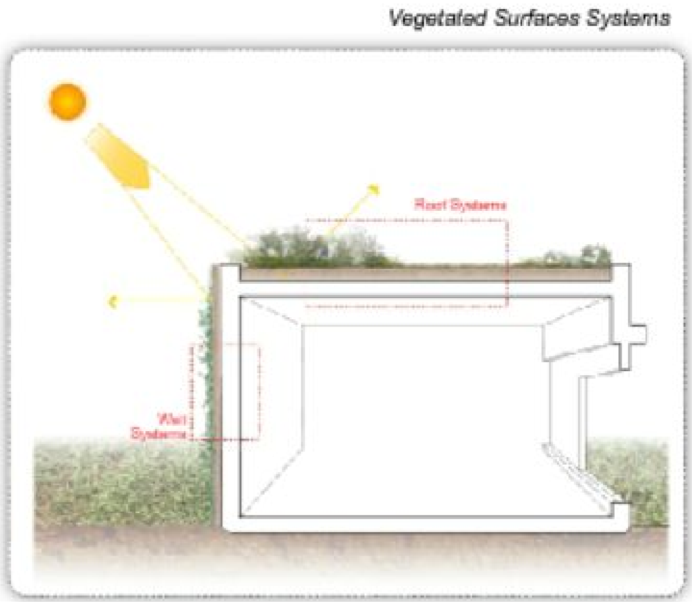
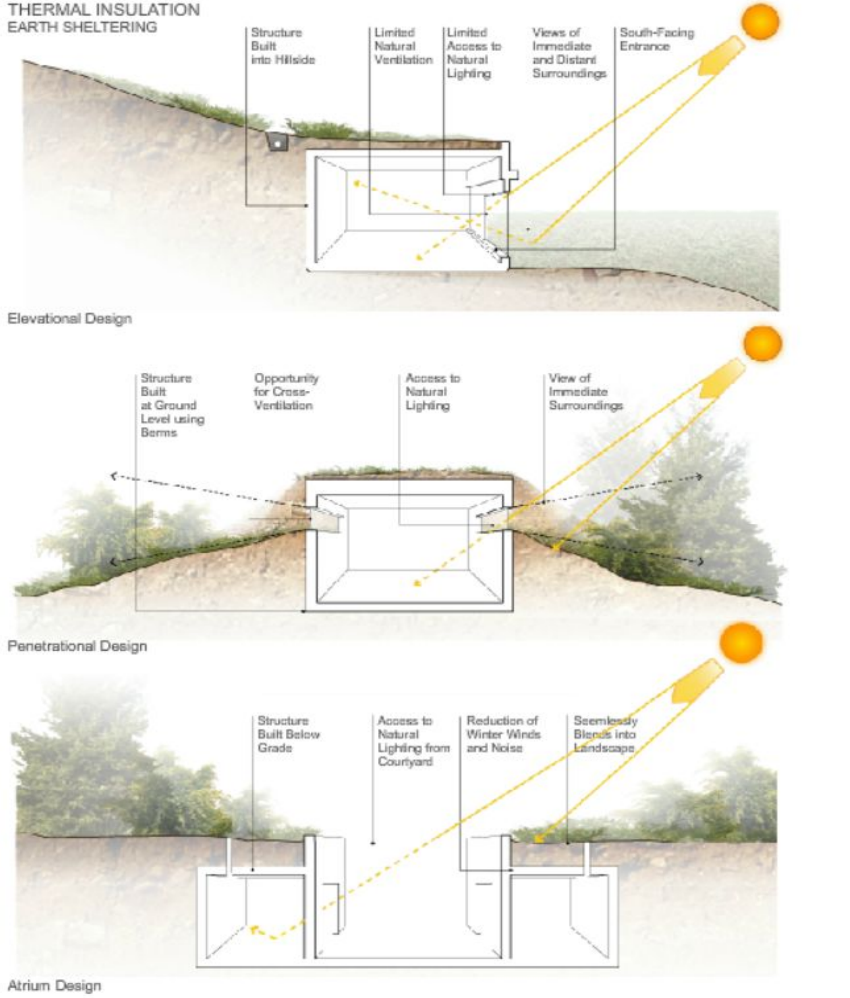


Fig. 20.6: Vegetated surface systems (b)



The earth covered side of the house is protected and insulated while south façade provides solar heating.

Cross ventilation through the two sides of the house provide cooling effect.

Not recommended for Abu Dhabi's hot and humid climate as courtyard might become overheated.

Fig. 20.7: Earth sheltering

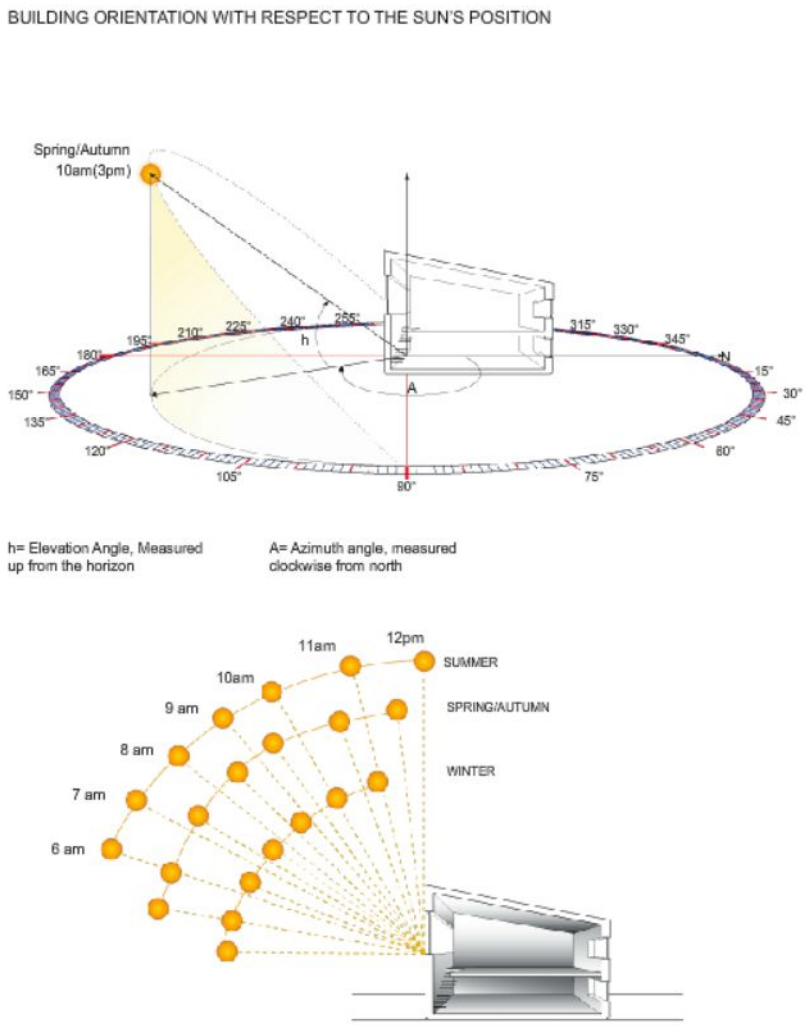


Fig. 20.8: Building orientation with respect to the sun's position

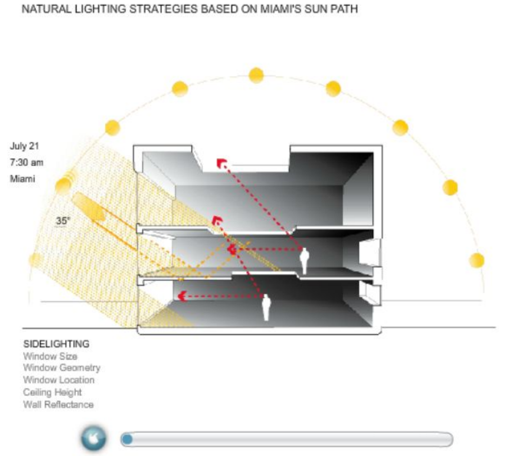


Fig. 20.9: Natural lighting strategies (a)

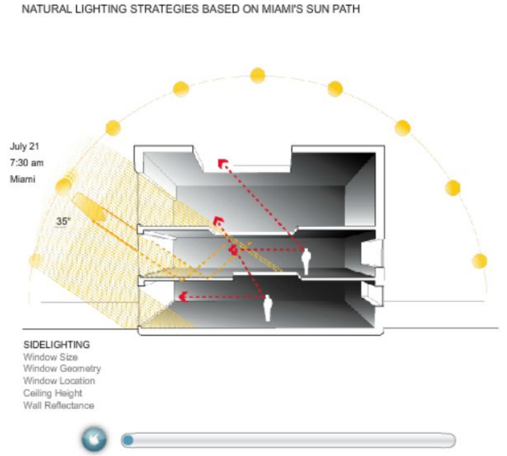


Fig. 20.10: Natural lighting strategies (b)

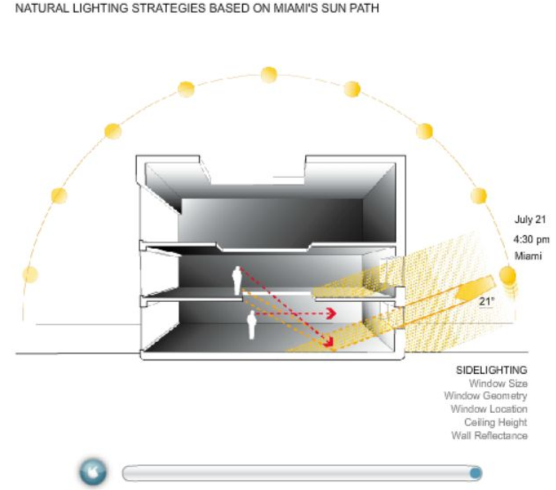


Fig. 20.11: Natural lighting strategies (c)

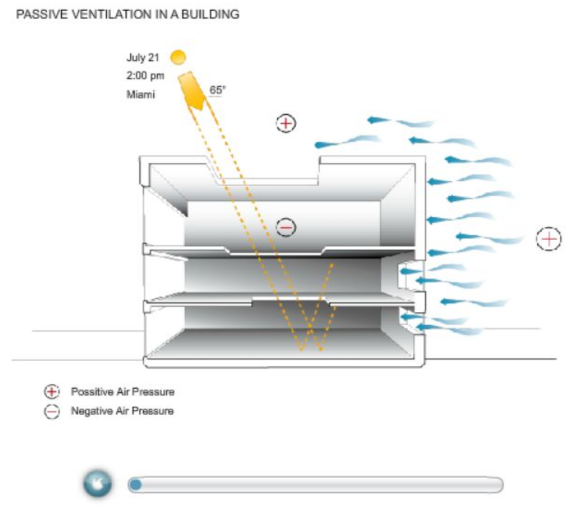


Fig. 20.12: Passive ventilation (a)

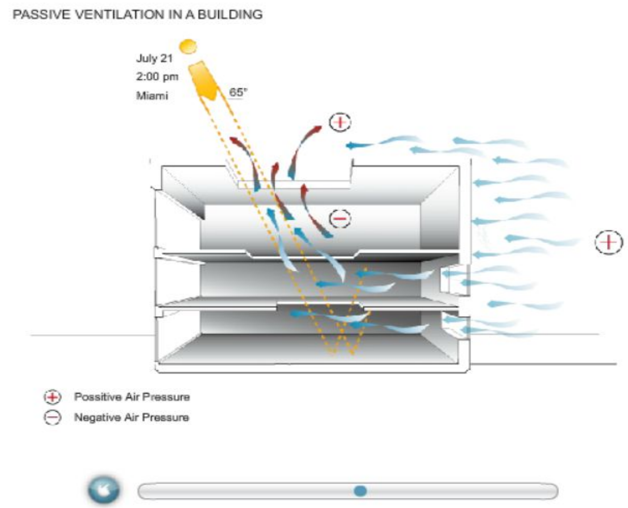


Fig. 20.13: Passive ventilation (b)

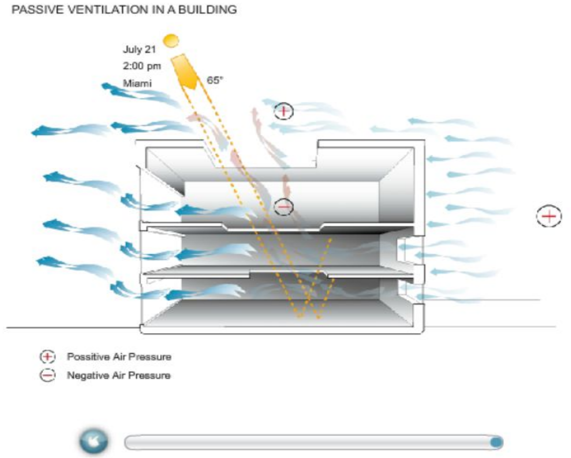


Fig. 20.14: Passive ventilation (c)

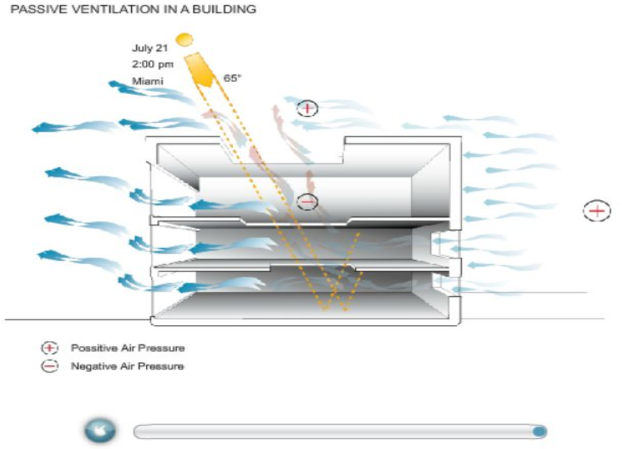


Fig. 20.15: Passive ventilation (d)

4.3.3 Modulation of heat gains

In traditional architecture of hot and dry climates "the buildings were massive constructions with few and small openings and light colours on the external surface. In hot and humid climates, where ventilation is desirable, we find light weight structures with large openings and large overhangs." (Asimakopoulos & Santamourism, 1996)

1. Increasing the thermal mass by increasing the envelope thickness adds to the removal of heat gains from the cooling load through heat storage and time delay of heat flow to the interior. This contributes to the reduction of peak cooling and the regulation of indoor temperature swings. However, its shall planned carefully for humidity considerations and economic factors as additions to thermal mass could be costly.
2. Consider maintaining zone temperatures at the lower end of the comfort zone in order to optimize performance of the glazing, envelop and roofing solar reflectance specifications.
3. Study various strategies of adding Phase Change Materials (PCMs) to wallboards, roofs and ceilings. "PCMs are utilized in building construction because of their capacity for storing latent and sensible heat." (Özer, et al., 2013)

4.3.4 Dissipation of heat gains

"The use of natural heat sinks for excess heat dissipation from interior spaces, including: natural ventilations, evaporative cooling, ground cooling and radiative cooling" is essential in case the desired comfort level cannot be achieved by prevention and modulation of heat gains.

1. Consider one or a combination of the Abu Dhabi climate suitable options and their implantation potential as described by ClimateTool in figures 21.1-21.4.
2. Study the option of wind towers as in traditional Arab houses "Barjeels" that can be implemented as part of bonus PVRS credits under "Innovating Practices" coded IP-1. Note, however, that noise levels in the era of Barjeels had less urban noise pollution, hence this recommendation shall in compliance with the "Indoor Noise" credits coded LV-9 of PVRS or other minimum criteria in building codes of Abu Dhabi.

Figures 20.1 – 20.4

Obtained from ClimateTool (Liedl, 2016)

Fig. 20.1: Evaporative cooling potential

Good potential for evaporative cooling from December to March could contribute to seasonal climate adapted design of the villa

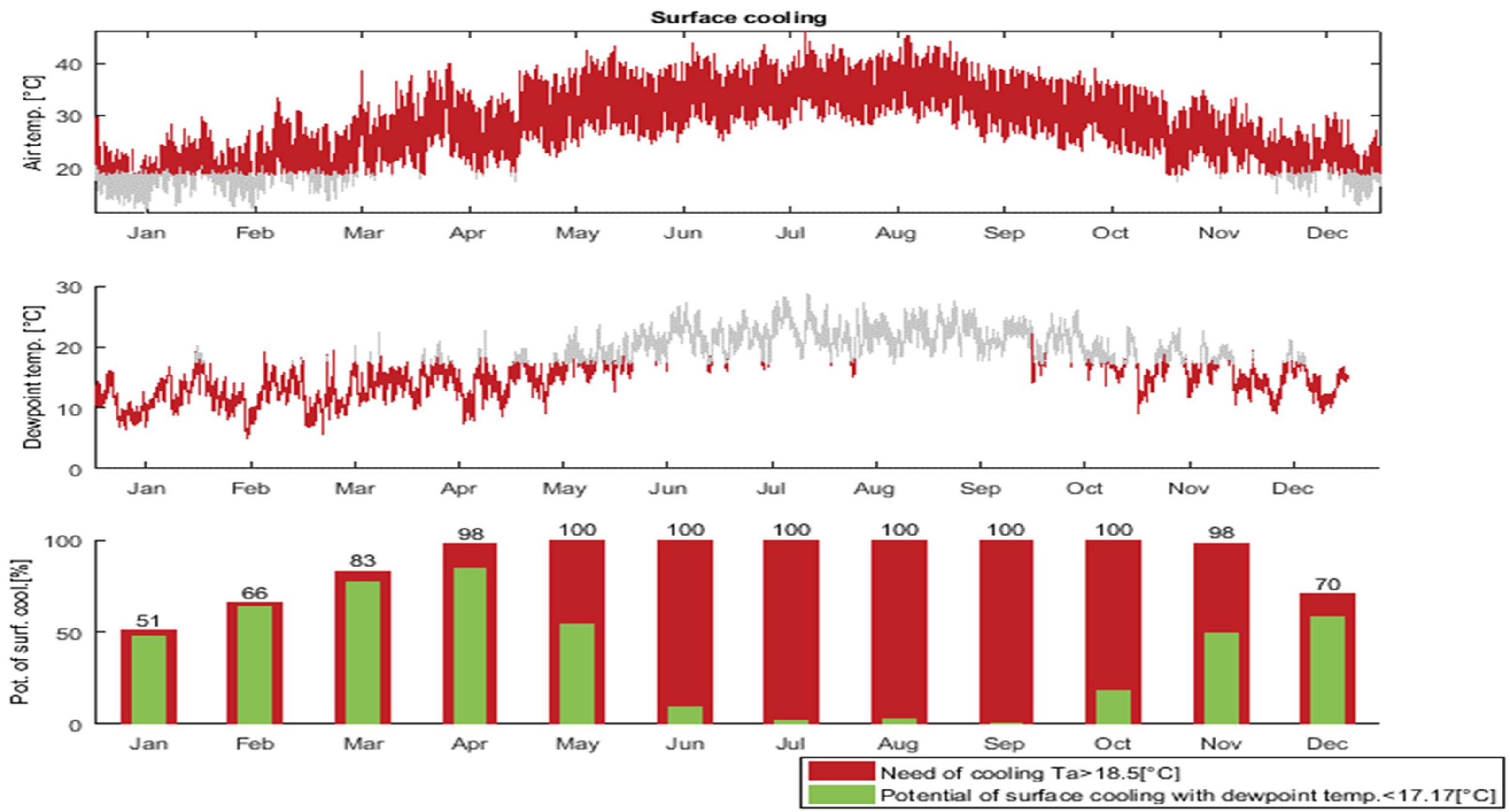


Fig. 20.2: Surface cooling potential

Surface cooling is promising in Abu Dhabi except in summer.

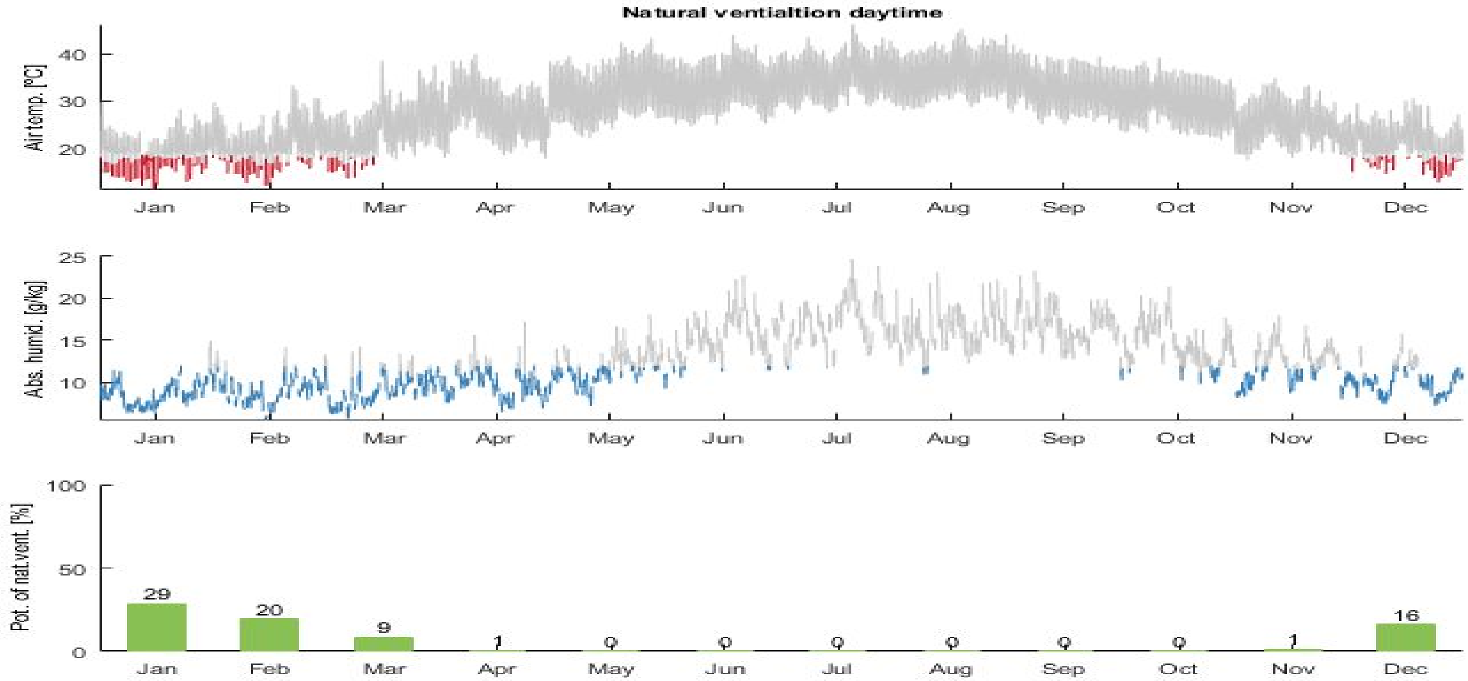


Fig. 20.3: Natural ventilation potential

Only possible in Winter and most probably during the night.

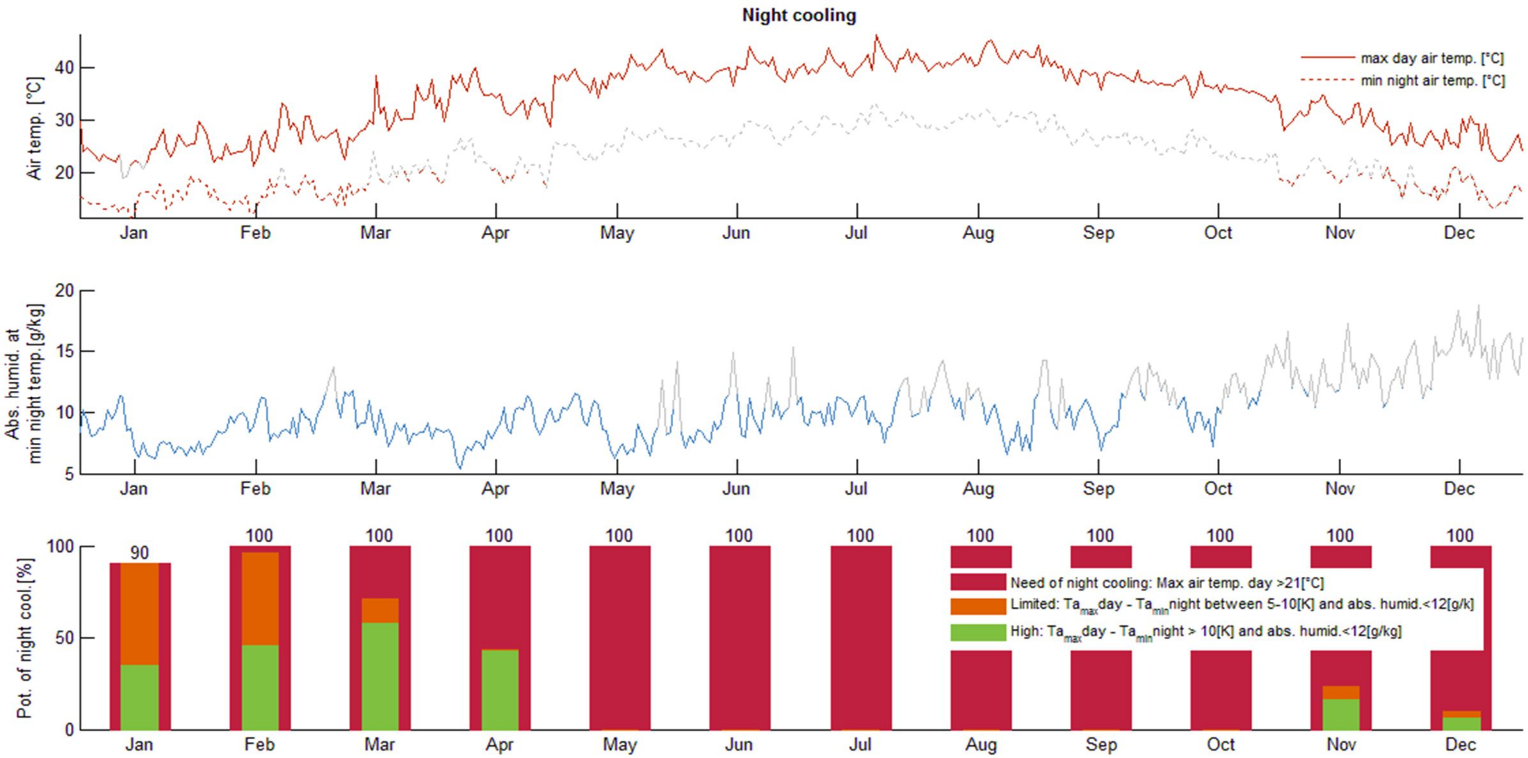


Fig. 20.4: Night cooling potential

Good potential for night cooling from January to April. Implementation of climate adapted design, hence, very important for seasonal adaptive measures.

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