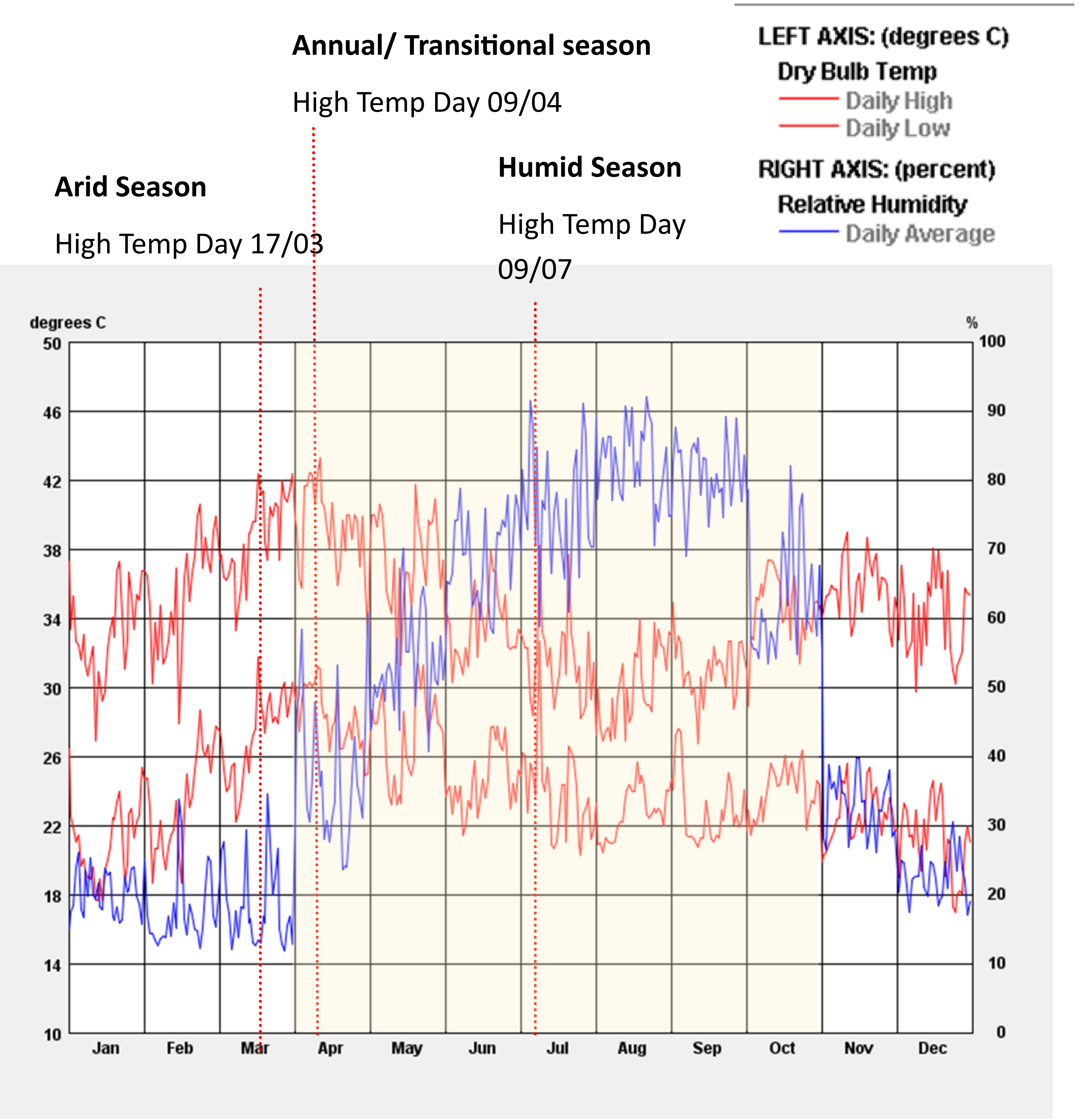
POTTERY AND MUSEUM IN ABUJA, NIGERIA

EDP Episode 2 19/20DL Erika Rees

CLIMATE AND INDOOR COMFORT PARAMETERS INVESTIGATION



Annual/ Transitional season

High Temp Day 09/04

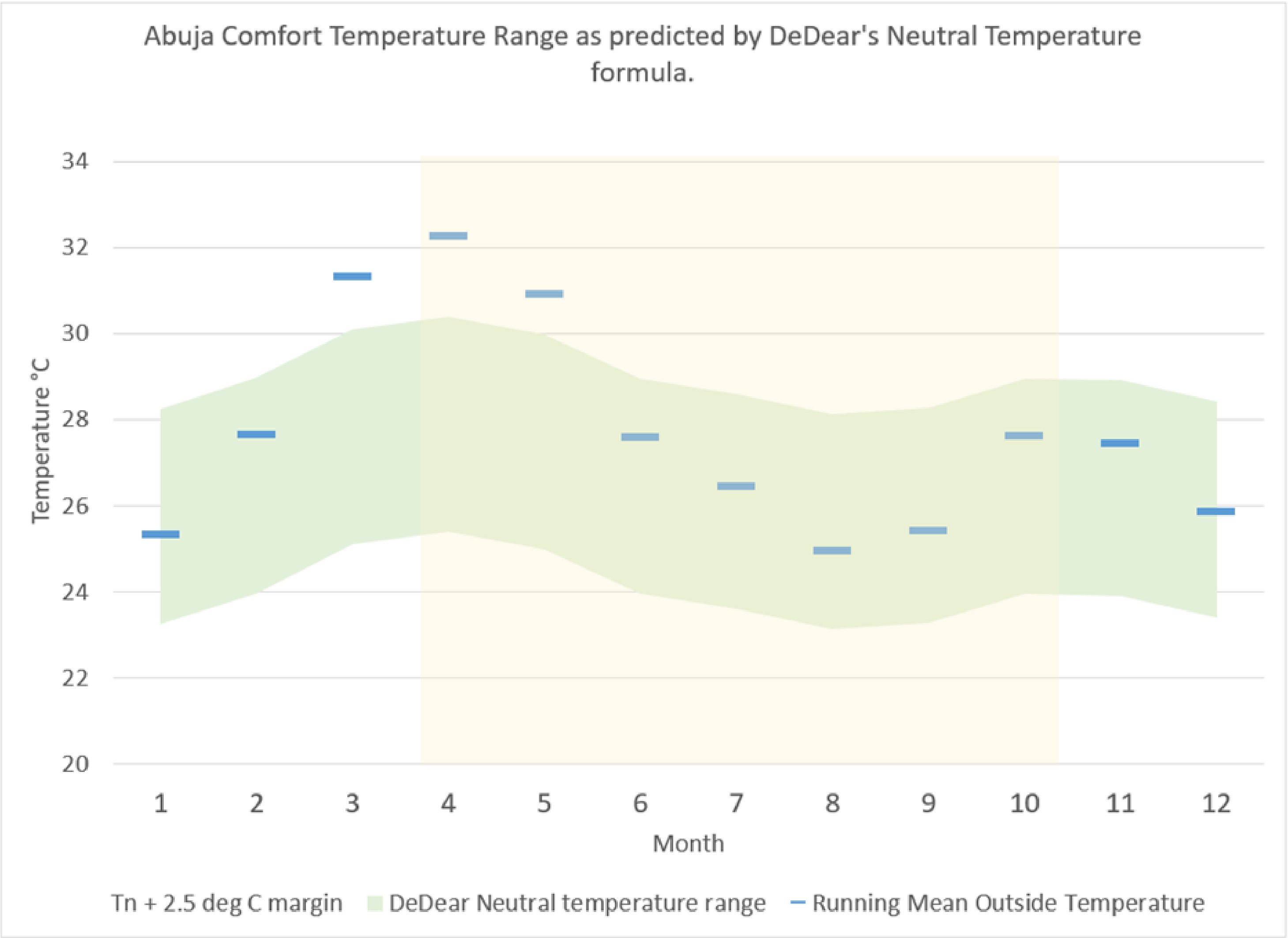
Arid Season

High Temp Day 17/03

Humid Season

High Temp Day 09/07

Fig. 1.02. Abuja Daily high and low dry bulb temperature and average relative humidity. (Climate Consultant).



HUMID SEASON

Fig. 1.03 Monthly mean outdoor Dry Bulb temperature relative to comfort range of temperatures according to the De Dear model of adaptive comfort (Category II) based on the monthly mean temperatures.

Note that the average running mean temperature falls outside of the Neutral temperature range for the months of March, April and May. As such, simple ventilation strategies to promote cooling by expelling accumulated heat gains are unlikely to be successful. At times of peak outdoor temperatures, ventilation will increase the heat gain, as can be seem in heat balance chart for the Base case building (Fig. 6.03) for months 3,4,and 5.

4.0 SELECTION OF THERMAL COMFORT MODELS

Nicols (2004) argues that field studies have shown the Fanger Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) methodology as specified in IS0 7730 to be unreliable in the hot and humid tropical climates. See Figure 4.01 of comfort temperatures in naturally ventilated buildings as predicted by PMV model and measured in field surveys.

The Fanger Operative Comfort model is calculated using the following input variables :

- Thermal Resistance of Clothing: 0.5 clo
- Metabolic : 1.4
- Air Velocity: 0.15m/s
- Relative humidity: 50%

Nicols argues that the PMV method fails to fully account for the levels of adaption used by people in tropical climates, in terms of adapting activity levels, opening windows, posture to promote cooling and clothing.

Nicols goes on to argue that methods utilising the running mean temperature have been show by field studies to be more accurate in predicting thermal comfort in the tropics. See figure 4.02 of measured comfort temperatures and comfort temperatures as predicted by the Humphreys' adaptive comfort formulae for free running buildings.

With the extreme climate as is presented in Abuja pottery , where the clothing level, Metabolic level and humidity levels are outside of Fanger PMV parameters, the original Fanger PMV and PPD methodology was deemed unsuitable for use in this analysis.

It has been decided to use a comfort model based on the running mean as it is more appropriate for the hot climate of Abuja. Reference will also be made to the calculated discomfort hours as calculated by Designbuilder in accordance with ASHRAE standard 55:2004 for adaptive comfort.

The running mean model of comfort to be used is the Operative temperature as calculated for buildings without mechanical cooling systems according to BS EN 15251.

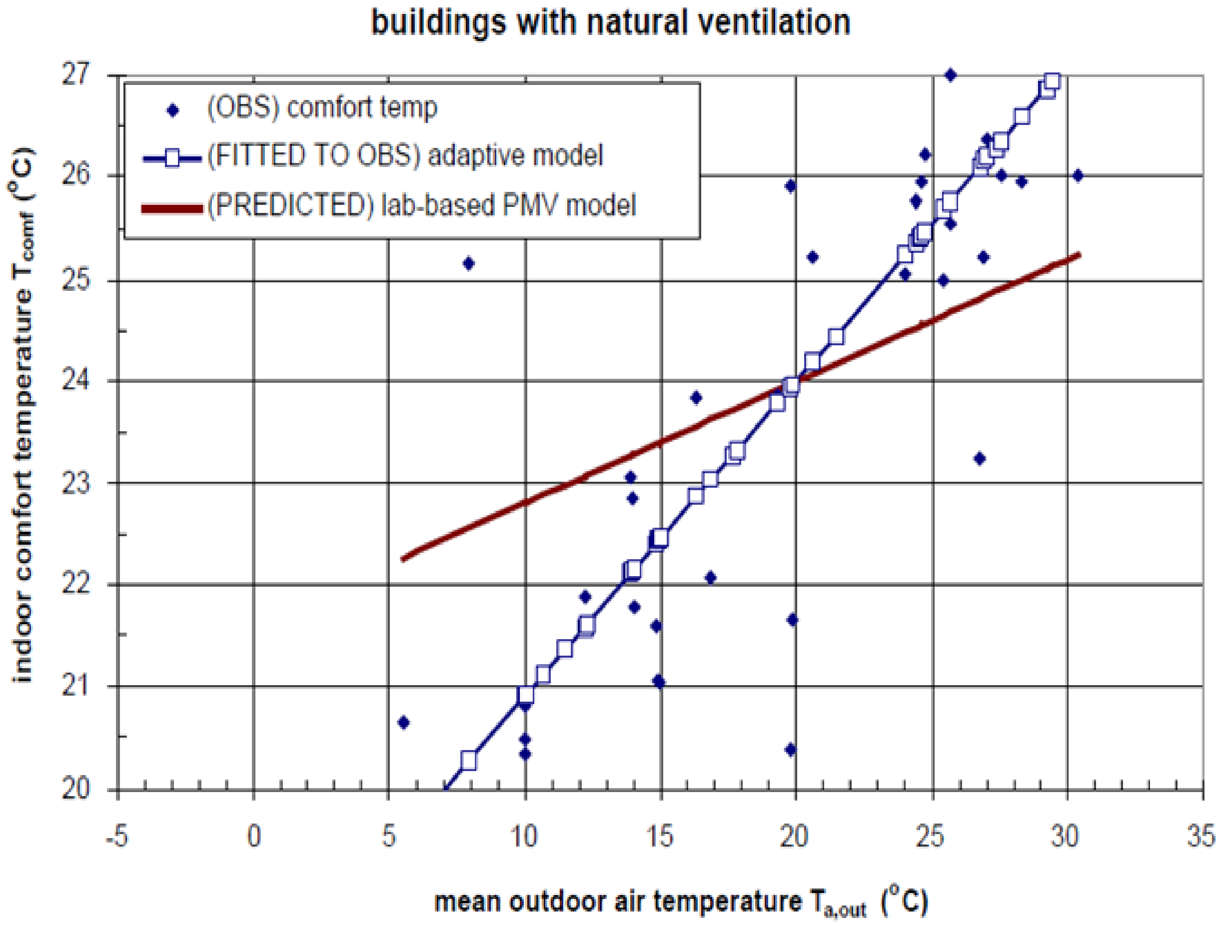


Fig 4.01. Comfort temperature in naturally ventilated buildings as predicted by the PMV model and measured in field surveys. (Nicols, 2004)

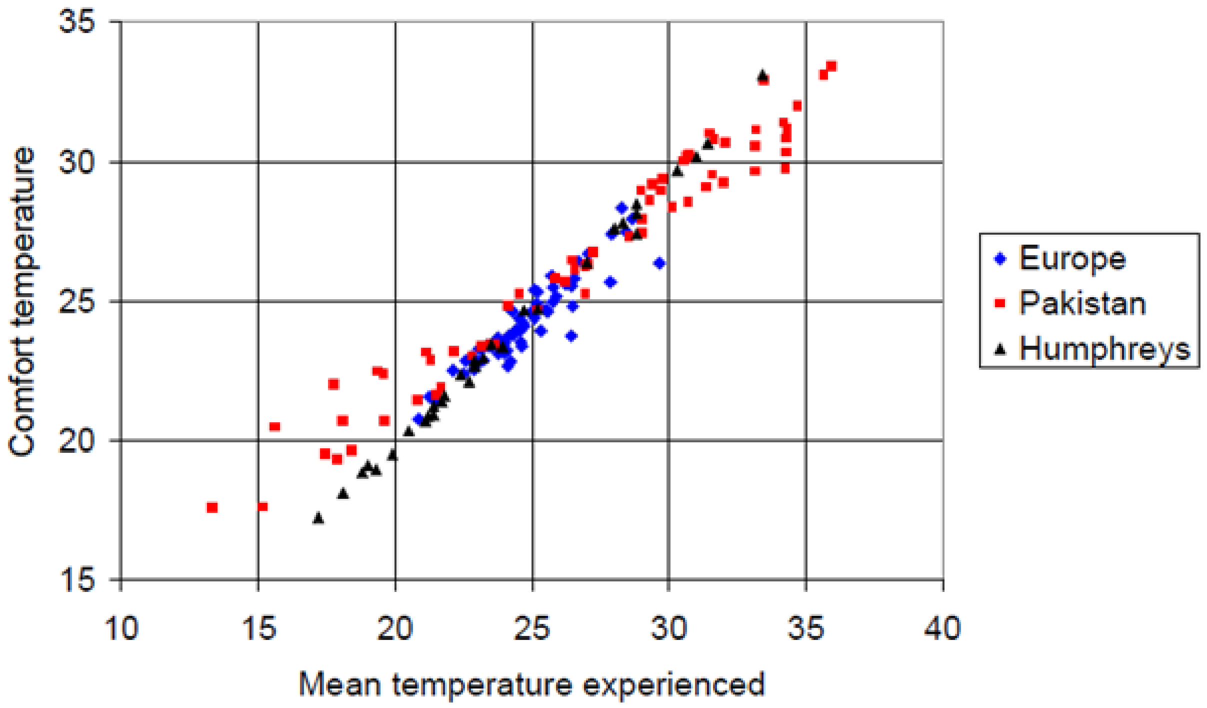


Fig. 4.02Comfort temperatures against mean temperatures as measured in Pakistan, Europe and predicted by Humphreys' adaptive formulae.

2.2 POTTERY GALLERY AND WORKSHOP:

The proposed building will accommodate a pottery gallery with a pottery workshop for staff potters and classes. There will be an internal drying space and pottery kilns. 3 rooms will be investigated.

Gallery

Anticipated metabolic level : **1.7 met** (walking about)(ASHRAE,2011)_ Clothing level: **0.36** (Summer clothing)

The building reception and exhibition space will be accommodated here. Friday evenings may also accommodate functions for exhibition openings. Consideration will need to be made of the environment for both the care of potentially historical exhibits and for human comfort. Ceramics are not light sensitive, but are potentially sensitive to fluctuating temperature and humidity.

Workshop

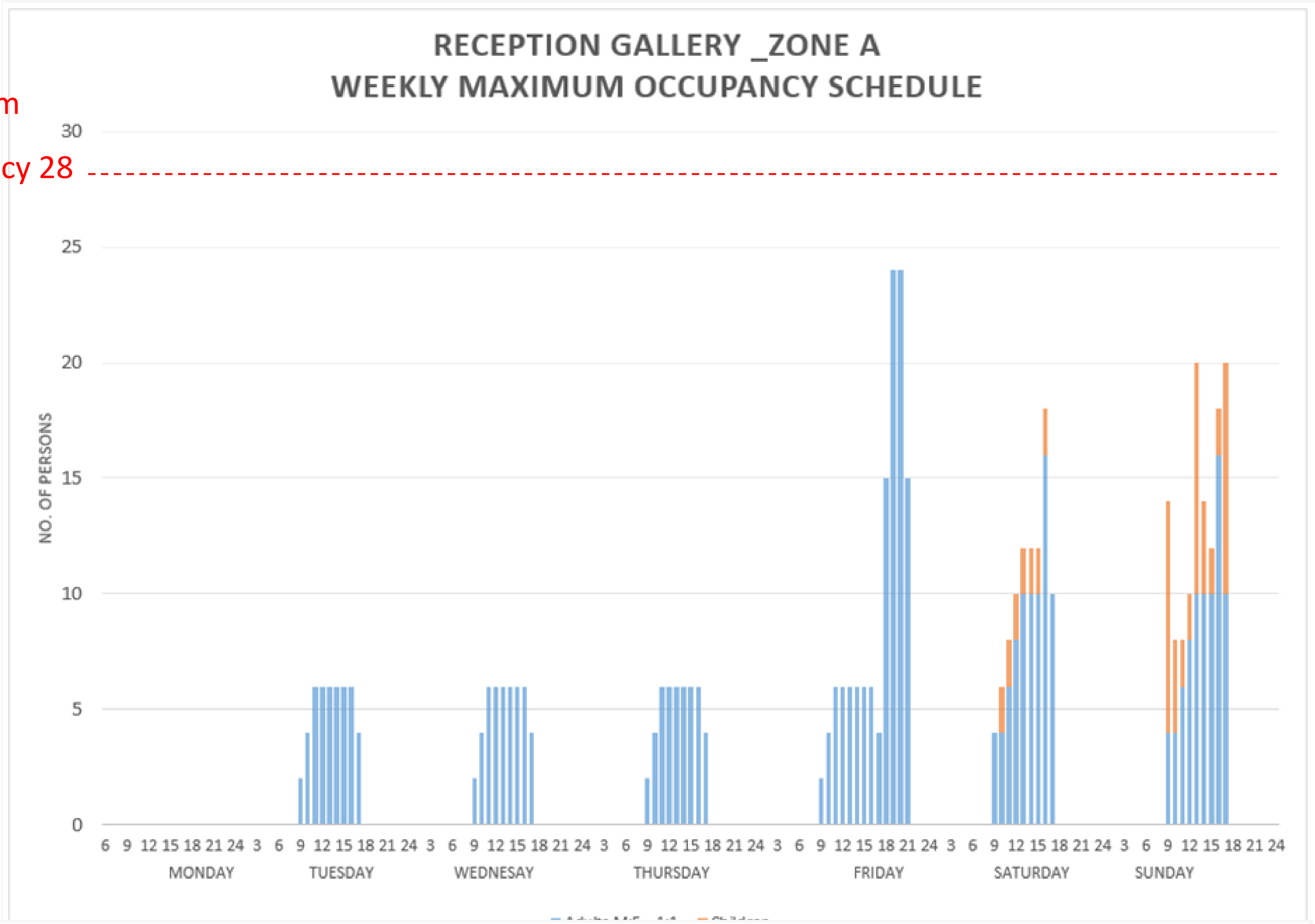
Anticipated metabolic level : **1.8—2.4 met** (Machine work) ASHRAE,2011)_ Clothing level: **0.36** (Summer clothing)

This room will be used for weekend and evening lessons for adults and children. Mid week, staff potters use the facility. Work on electrically driven pottery wheels, glazing and decorative work will be undertaken here. Clay mixing can generate dust, and some glazing compounds may have fumes. As such, ventilation for contaminant dispersal will be required in this space. Decorative work will require higher lighting levels than wheel work.

Kilns and Drying Room

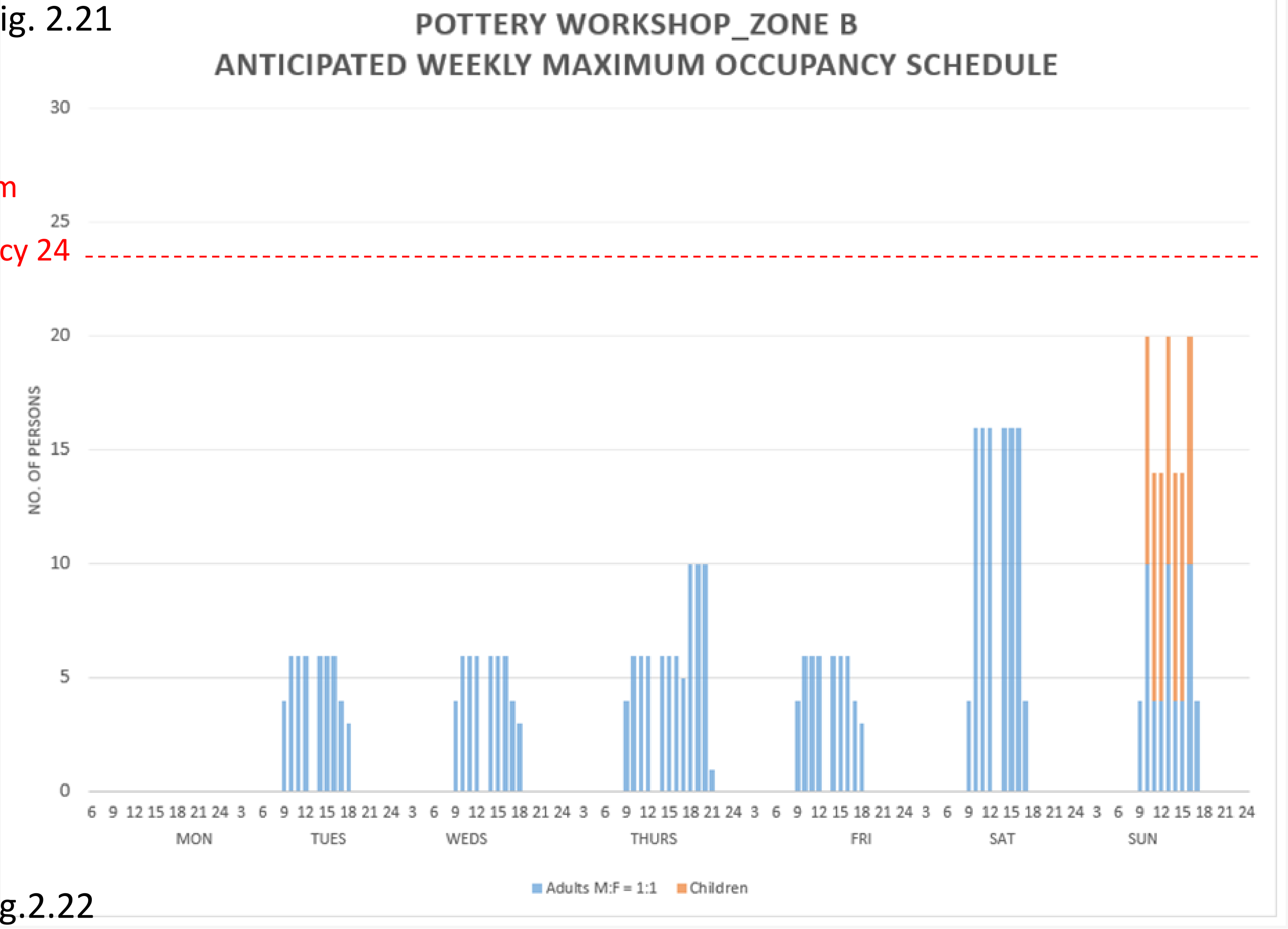
Anticipated metabolic level : **2.1 met (**Lifting / packing Table 1.4 CIBSE Guide A) _ Clothing level: **0.36**

Occupany of this room will only be intermittent, as drying shelves and kilns are being loaded and unloaded. Human comfort is not a high priority. Maintenance of an environment without draughts or uneven radiant heat is important to allow even drying of the wares to prevent cracking. Humidity will be controlled by the staff potters by the use of sheets and coverings over the wares.



Maximum Occupancy 28

Fig. 2.21



Maximum Occupancy 24

Fig.2.22

oom/ Kiln

Table 2.22 ABUJA POTTERY MUSEUM AND WORKSHOP ENVIRONMENTAL BRIEF

	Lighting				**Indoor Air Quality**			**Wind Speed**	**Indoor Ambient Noise (unoccupied)**	**Temperature (other than for comfort)**	**Notes**
	Min. average maintained illuminance at work plane.	UGR Unified Glare Rating Limit	Uo Illuminance Uniformity	R_a Colour Rendition Index	Ventilation (Fresh air requirements)	Building Contaminants Dispersal	Relative Humidity (if humidifcation or dehumidfication systems are installed.)				
unit	Lux				Ls^{-1}/p	Ls^{-1}/m2			$L_{aeq.30mins}$dB		
A. Gallery space	100 min. at floor level.	28 min.	0.4 min.	80 min.	10 – 15 Default 12 During occupied hours (Max occupancy 28.) =336 Ls^{-1}	Estimate at 1.4. Based on Cat 2 non low polluting building. =264 Ls^{-1}	For Artifacts: Must not be lower than 40% or higher than 70% for safe storage of objects, but must remain stable. For People: Between 25% to 60% otherwise. In occupied spaces. Therefore 40 -60% taken as range. Max fluctuation in 24hr period +- 3%.	Slight draughts will be acceptable. <1.0 m/s	40	16- 20°C Recommended for museum storage. Minimise fluctuations, and very gradual changes less likely to cause damage.	No recommended lighting limits for museums in SLL Code for Lighting if exhibits are not sensitive to light . Ceramics are not light sensitive. Minimum standards for circulation spaces has been used instead as a minimum. Localised display lighting can be used on exhibits. For long term display of ceramic items, maintenance of stable temp and humidity is important. Ceramics are not light sensitive.
Ref.	1,a	1, a	1, a	2							
Reception.	300	22	0.6	80							Localised task lighting for reception.
Ref.	1	1	1	1	4		3,7,9		6	3	3
B. Pottery Workshop	300	25	0.6	80	10 – 15 Default 12 During occupied hours (Max. Occup. 24) = 288 Ls^{-1}	Estimate at 2. Based on Cat 1 non low polluting building. =194 Ls^{-1}	Between 25% to 60%. Limit max absolute humidity to 12g/kg	Activity can tolerated draughts . <1.5 m/s	40	Comfort Range_ see adaptive comfortt	For both general prep work and glazing. If handpainting light level requirements are higher. Clay mixing produces dust to be extracted and extra ventilation required during glazing.
Ref.	1	1	1	1	4	8	5.		6		
C. Kiln and Drying Space	50	28	0.4	20 Safety colours need to be recognisable.	10 – 15 Default 12 During occupied hours	Estimate at 1.4. Based on Cat 2 non low polluting building. =87 Ls^{-1}	Varies. See notes.	Not draughty or even drying will cause craking. < 0.8m/s.	n.a. (mostly uncooupied)	Can be outside comfort range as only occupied for short time.	Ideally; gradual reduction in humidity from very high levels and increase in temperature to prevent cracking during drying. If machines not used, clay will be wrapped to manually control humidity locally during drying. Higher ventilation levels for dispersal of heat is anticipated to be required, but will be covered in thermal analysis.
Ref.	1	1	1	1	4	8		10.			

6.0 BASE CASE I BUILDING AND TYPICAL ABUJA OFFICE BUILDING SPECIFICATIONS

A 2 storey building typical of the form of low rise buildings in Abuja is proposed and investigated as the base case.

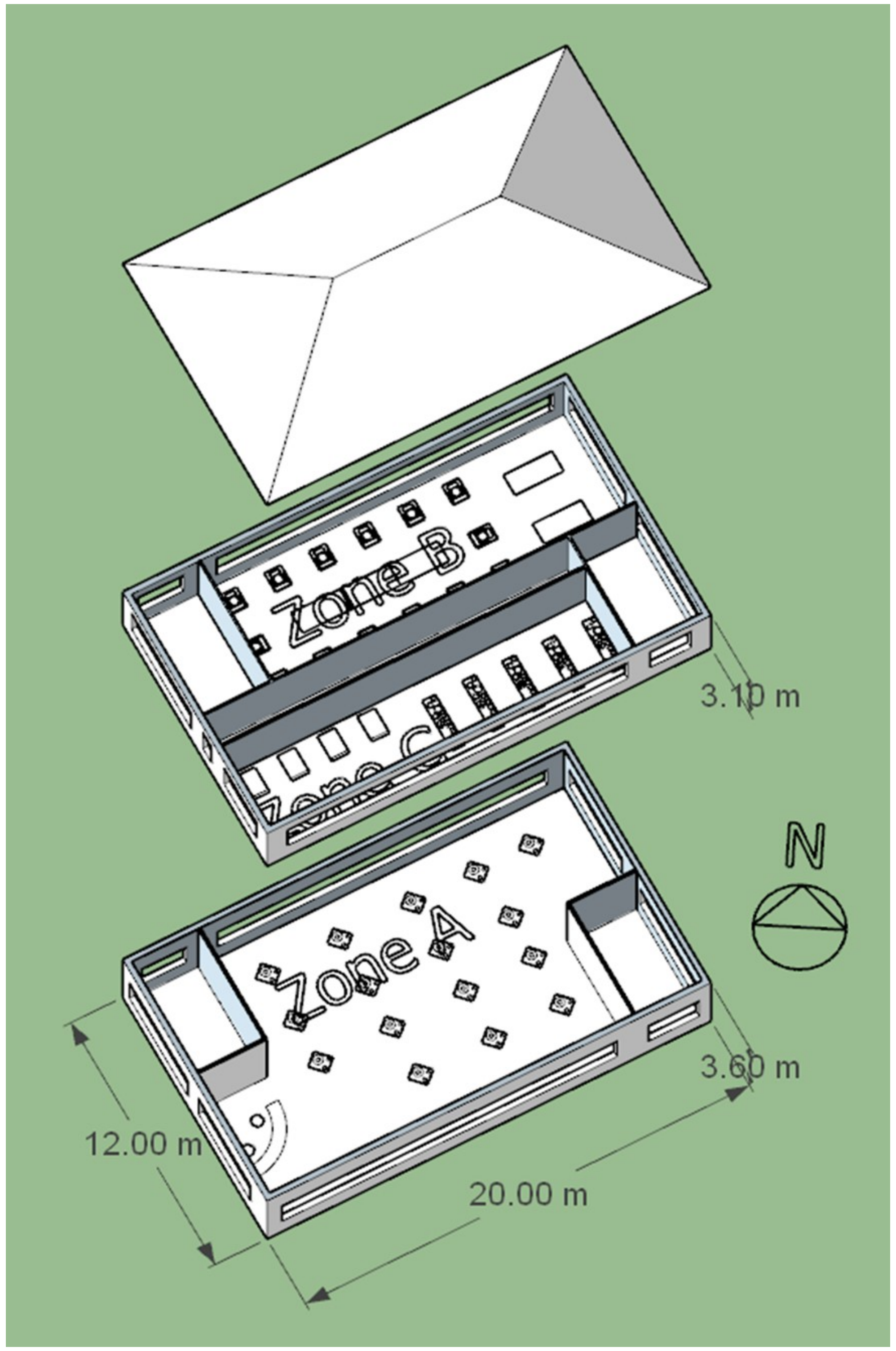


Fig 6.01 Base Case I axonometric.

The base case building was aligned with the street frontage as the other buildings on the street. It was located centrally in the frontage, despite the afternoon shade to the West. This was because the shade would only extend to any building by late afternoon, so the shading benefit would be minimal. However, there would be substantial losses to available daylight factors and crucially wind flow to the west of the building.

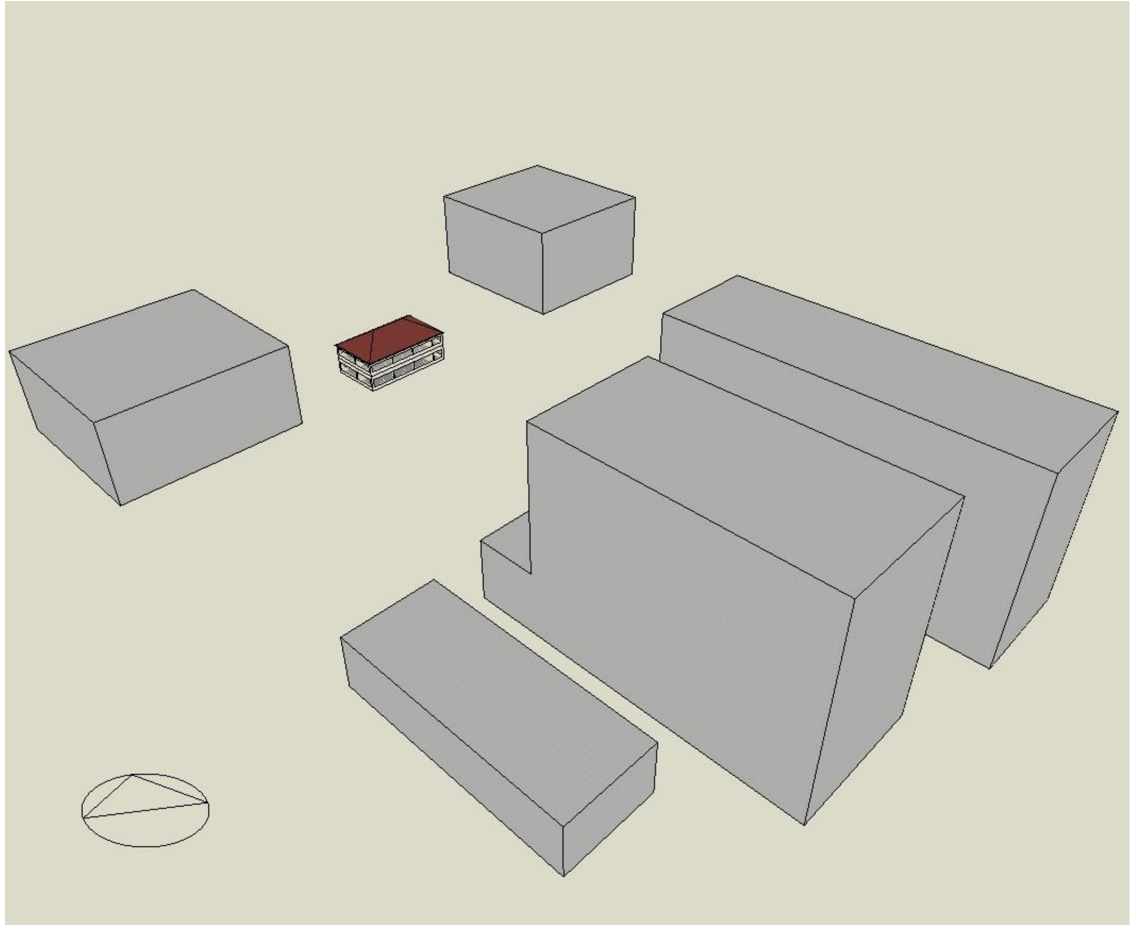


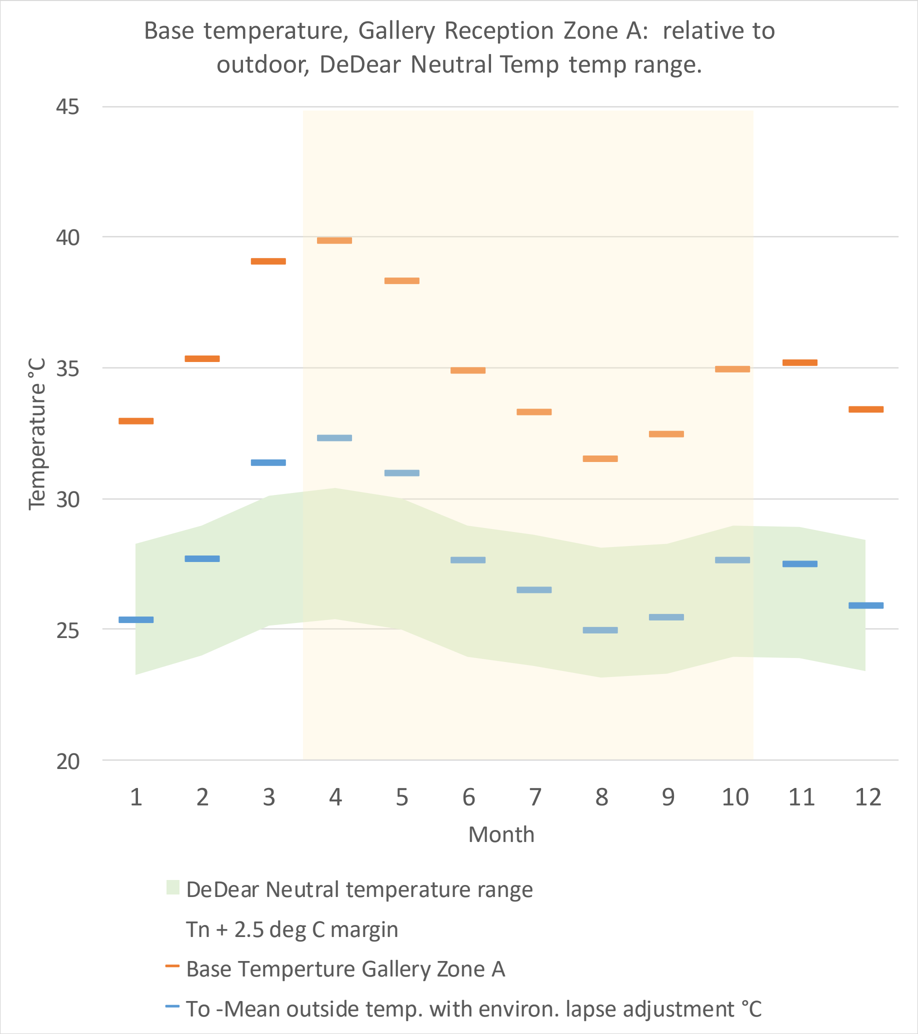
Fig 6.02 Base Case I site axonometric.

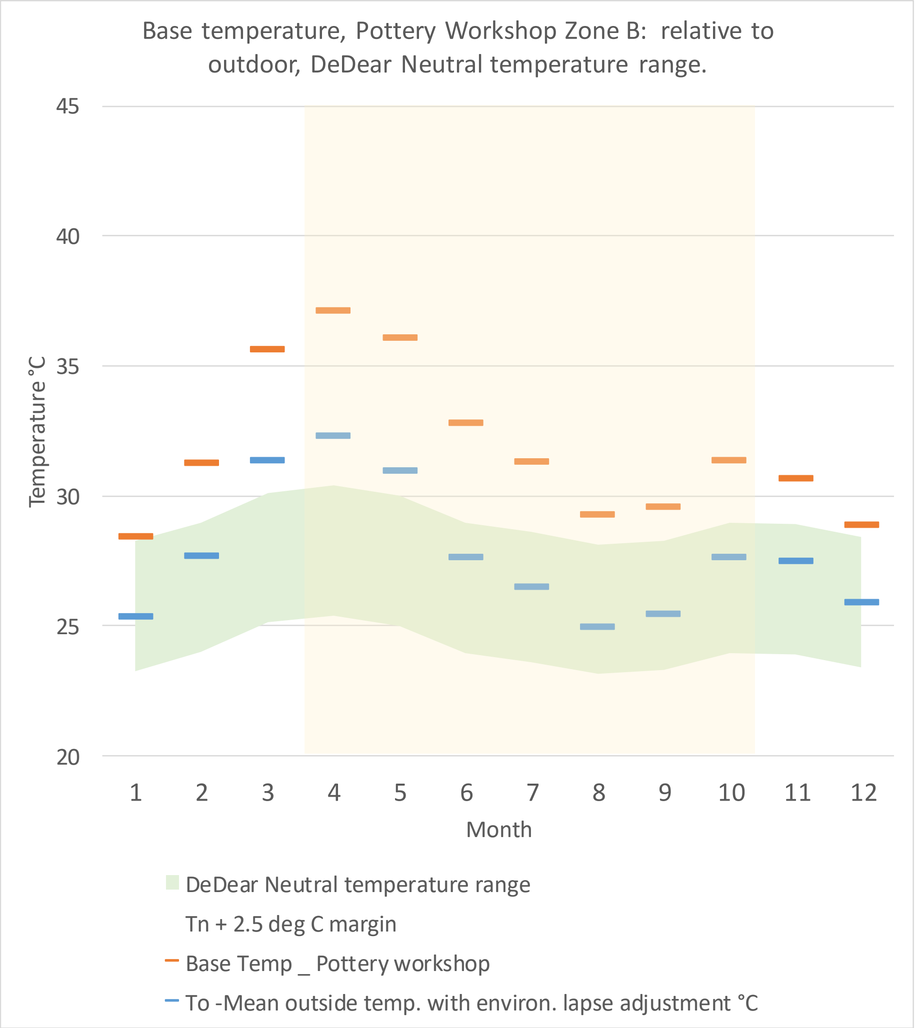
Table 6.01 Base Case Building and Typical Abuja building detailed specification

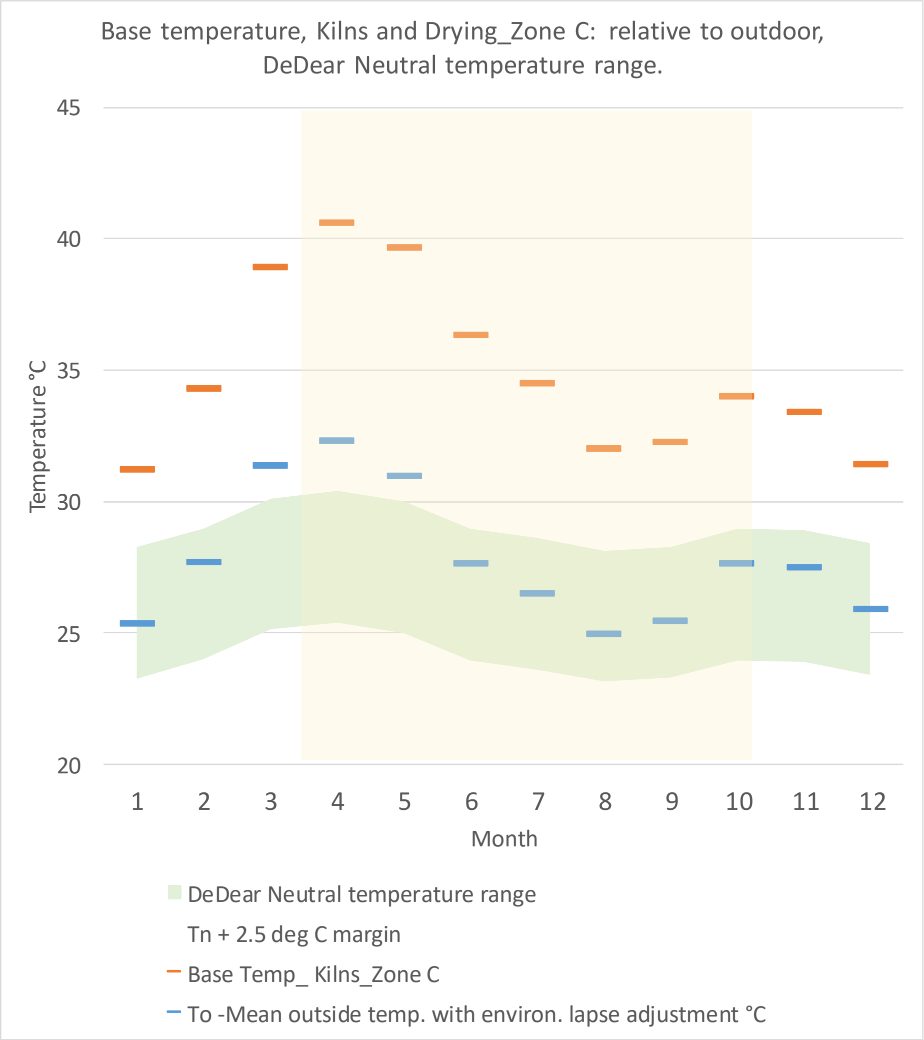
	Typical Low Rise Office Building in Abuja (Mu'azu)	Base Case Building Specifications	Ref.
Orientation	Dependent on access road, mostly NW or NNW	Aligned with road frontage to SE.	4
Compactness Ratio ($CR = P^2/4A$)	$4 < CR < 8$	4.27	4
Form Factor ($FF = SA / V$)	$0.1 < FF < 0.2$	0.48	4
Wall/ Glazing ratio	Average 50%	50%	4
Glazing specification	All buildings have single glazing; clear, coloured or reflective	Single glazed 6mm grey in wood frames U-value: 6.12; g-value: 0.57; Solar transmission: 0.46	4, 5
Window shading	Most buildings do have no external shading.	External shading not allowed for as complicated to perform steady state heat balance to account for them.	4
External walls	Basic 225 hollow core blocks clad in either plaster, facing brick or tiles.	225 hollow core bricks with 13mm plaster and 20mm External render Whole Construction U-value (including surface resistances): 1.2	4, 5
Roof	No data.	Clay tiles on membrane with plasterboard ceiling (unoccupied) Whole Construction U-value (including surface resistances): 2.8	5
Floor slab	No data.	Ceramic tiles on screed on 150mm dense concrete slab on grade Whole Construction U-value (including surface resistances): 2.79	5
Floor to ceiling height	Average 3.1m Local regulatory minimum 2.4m.	Ground floor 3.6m; First floor 3.1m	4
Infiltration Level	No data.	1.5 ac/h . Estimated from table 4.24 CIBSE guide A for 2 storey building with air permeability of $20m^3/hr$@50Pa. (Leaky).	5
Assumed ventilation level	No data.	Based on U.K. Part F Building Regulations 2010 requirements: $10L^{-1}/p$ at maximum building capacity of 52 persons.= $1872m^3/hr$ = 0.94 ach for steady state model	6
Lighting Gains	No data.	**Gallery:** 10W/m2 during opening hours **Workshop :** 0W (assumed daylighting) until 18:00 then 12W/m2. **Kilns &Drying area Room:** 0 W	5
Equipment Gains	No data.	**Gallery:** Fridge _ Heat gain 16W; x 24 hrs; 2 x computers_ heat gain 97W; 2 x monitors_heat gain 90W, 1 x printer heat gain 13.7 W **Workshop:** 12 x pottery wheels_ Heat gain 7W (560 W model)(estimated from equation $\phi g = Pa/\eta t$, CIBSE Guide A 6.6.1)**Kilns & Drying Room:** 4 x kilns _Heat gain 440W each (Convention oven CIBSE Guide A table 6.18)	5

Refs 1. Mu'azu 2

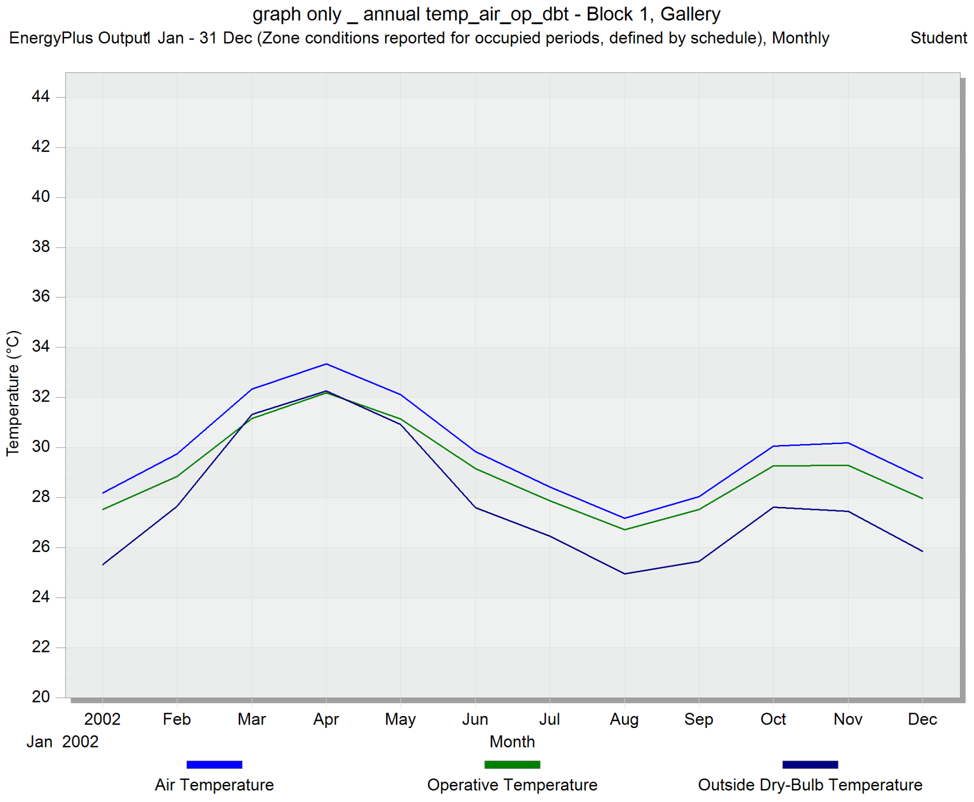
Base Case Steady State Heat Analysis with Building Base Temperature and De Dear Neutral Temperature, based on the running mean.

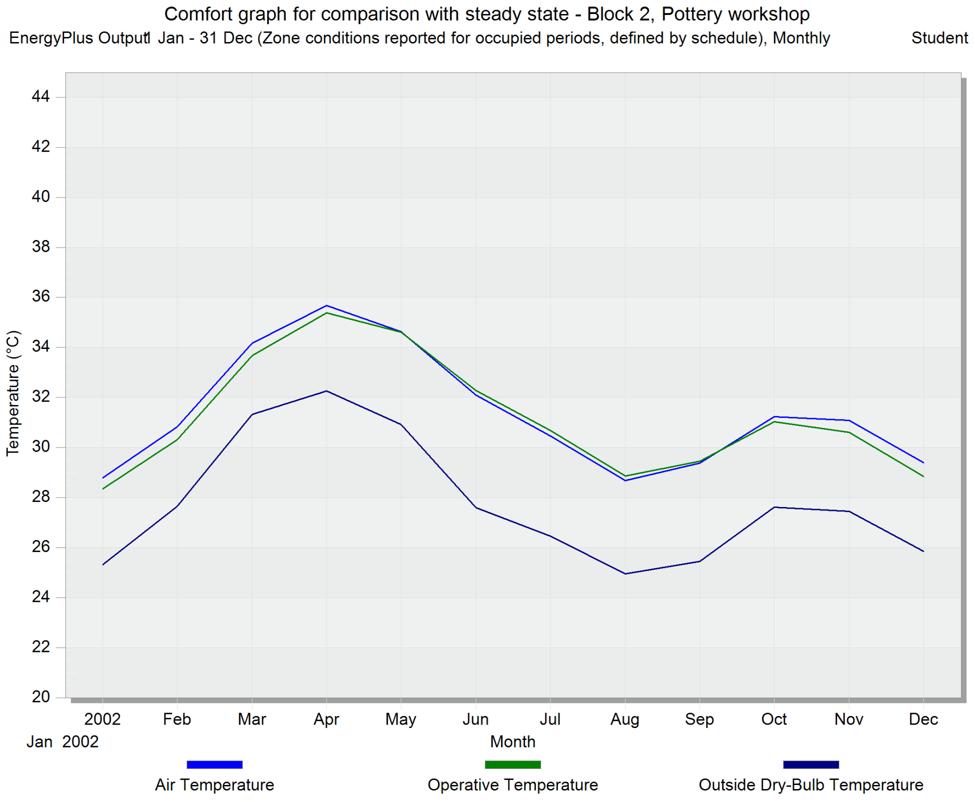

Base temperature, Gallery Reception Zone A: relative to outdoor, DeDear Neutral Temp temp range.

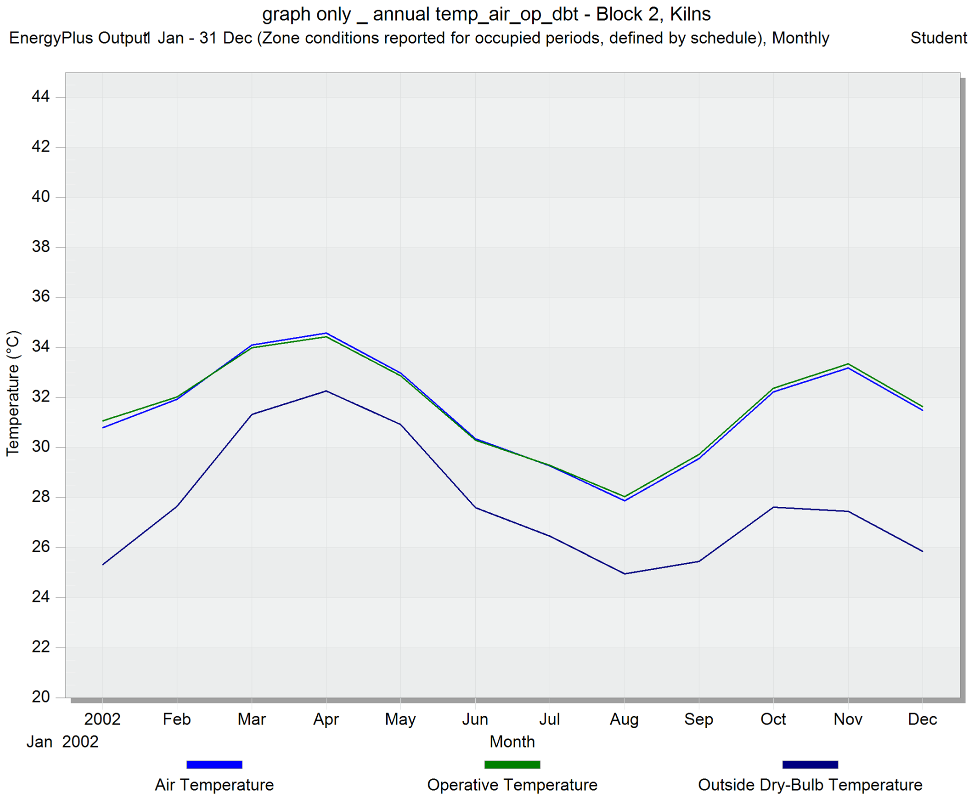

Base temperature, Pottery Workshop Zone B: relative to outdoor, DeDear Neutral temperature range.

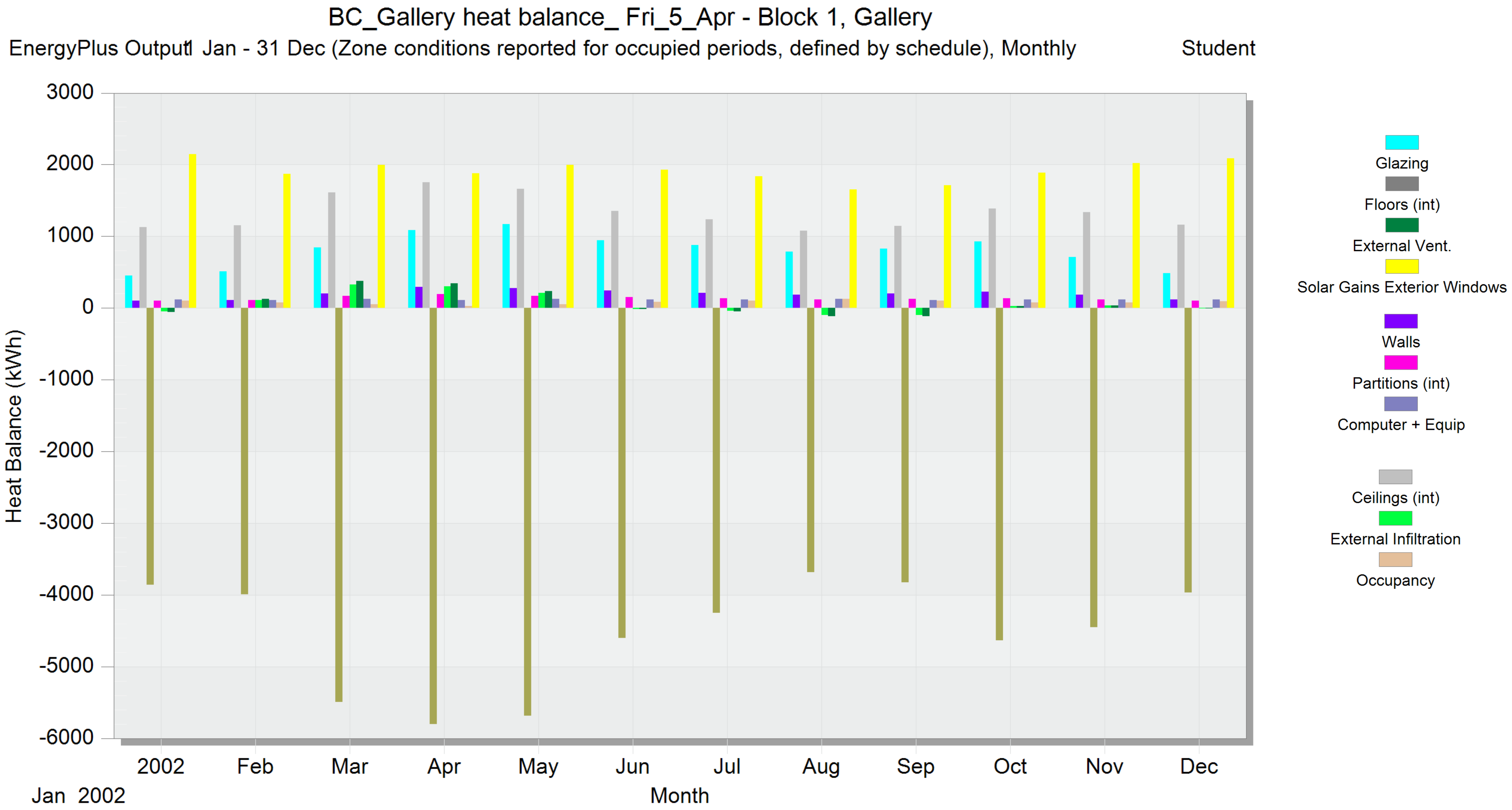

Base temperature, Kilns and Drying_Zone C: relative to outdoor, DeDear Neutral temperature range.

Design Builder Simulation - Base Case I _Matching criteria and scheduled ventilation.


graph only _ annual temp_air_op_dbt - Block 1, Gallery


Comfort graph for comparison with steady state - Block 2, Pottery workshop


graph only _ annual temp_air_op_dbt - Block 2, Kilns



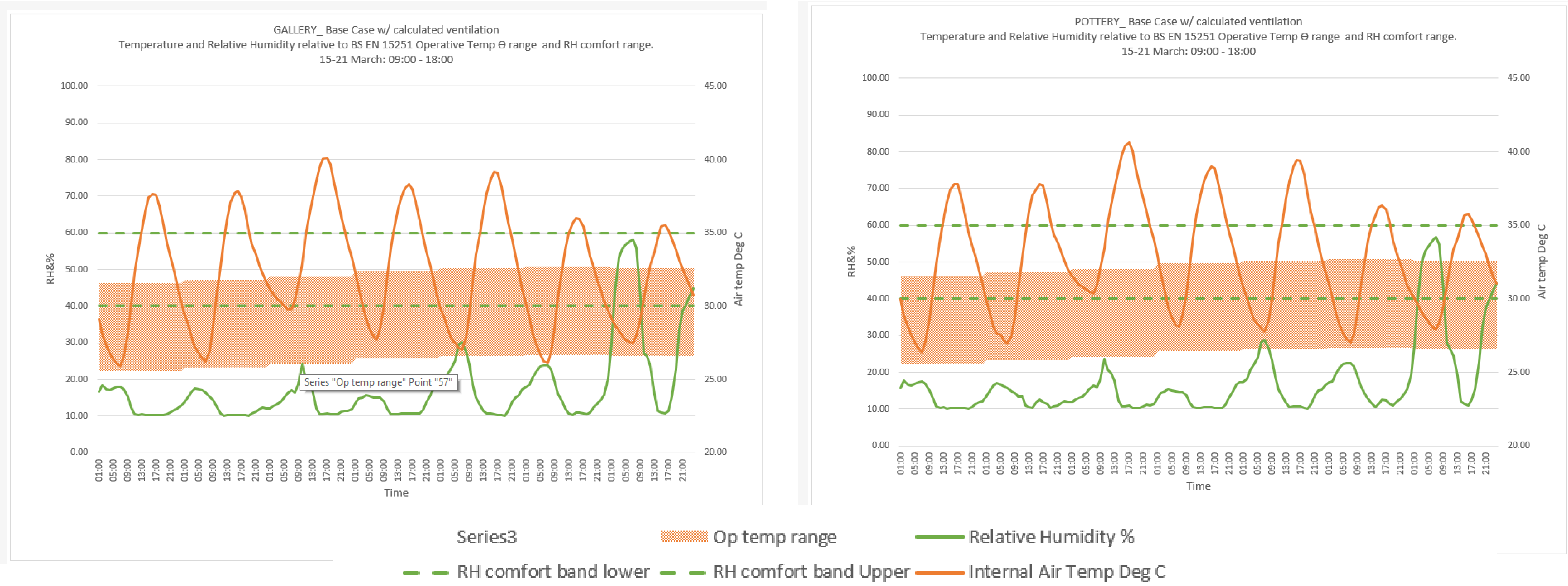
There is a significant difference between the steady state anaylsis base tempeartures and those modelled in designbuilder. This I have attributed to the heat loss to the floor slab., which has been modelled differently in the two models. The steady state models assumes the ground floor slab as adiabatic.

The simulation model ground temperature was manually modified to be 2°C lower than the monthly mean air temperature as recommended by Designbuilder helpfiles.

Conclusions:

- The uninsulated ground floor slab is contributing a lot to the (desirable) heat loss. The upper floors (kiln and workshop) are radiating heat to the ground floor through the ceiling but the thermal capacity of the ground is moderating this.
- The occupancy and equipment gains are relatively insignificant when analysed on a monthly basis compared to the main fabric heat flows.
- The ventilation and infiltration do not always contribute to the cooling, when the outside temperature is high. In March, April and May the ventilation and infiltration combined contribute quite significantly to the heat gain in the Gallery. This indicates that considerable care need be taken with the ventilation control and scheduling. That the outdoor temperature exceeds comfort temperatures by the De Dear comfort model can be seen in figure 1.03.

BASE CASE II MISMATCH ANAYLSIS ARID SEASON , HOTTEST WEEK 15—21 MARCH


GALLERY_ Base Case w/ calculated ventilation
Temperature and Relative Humidity relative to BS EN 15251 Operative Temp Θ range and RH comfort range.
15-21 March: 09:00 - 18:00

POTTERY_ Base Case w/ calculated ventilation
Temperature and Relative Humidity relative to BS EN 15251 Operative Temp Θ range and RH comfort range.
15-21 March: 09:00 - 18:00

Max RH% (all 58.21 Ashrae _ Standard 55 Discomfort hrs 51.00 hrs
Min Rh % 10.12 Max. temp (all hours) 40.12 °C
d RH% 48.09 Min temp. (all hours) 25.91 °C

Standard Deviation 10.25 dT 14.22 °C
Standard Deviation air temp 3.79 °C

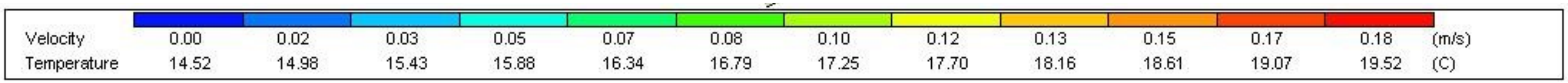
Max temp exceed during occupancy hours 8.09 °C
Hours comfort range exceeded 81/168 hrs
Total degree hours Θ range exceeded 284.49 °C.hr

Max RH% (all hours) 56.71 Ashrae _ Standard 55 Discomfort hrs 55.00 hrs
Min Rh % 10.04 Max. temp (all hours) 40.62 °C
d RH% 46.67 Min temp. (all hours) 26.37 °C
Standard Deviation
RH 9.75 dT 14.25 °C

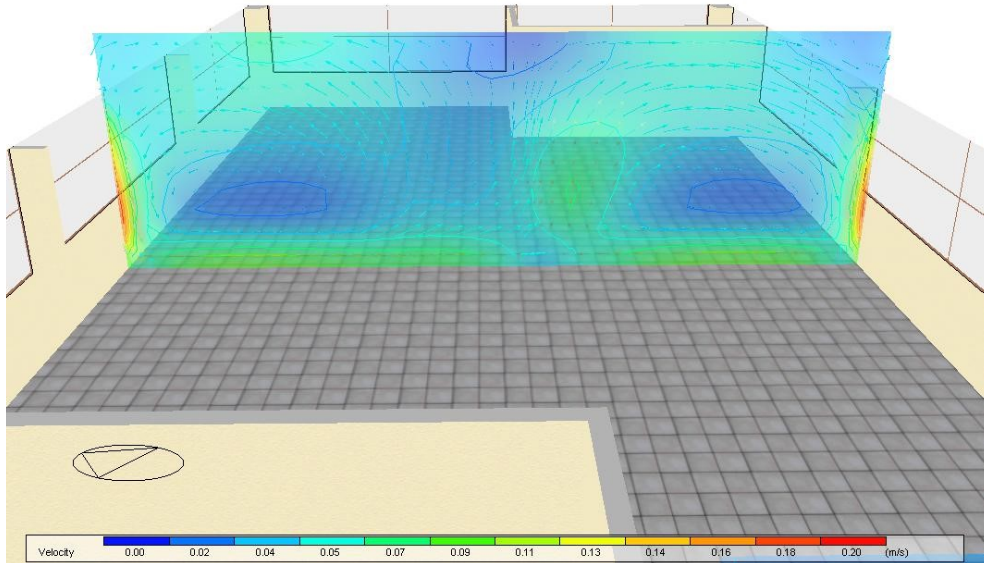
Standard Deviation air temp 3.67 °C

Max temp exceed during occupancy hours 8.59 °C
Hours comfort range exceeded 89/168 hrs
Total degree hours Θ range exceeded 313.54 °C.hr

BASE CASE_CFD ANAYLSIS DURING SUMMER DESIGN WEEK



Velocity	0.00	0.02	0.03	0.05	0.07	0.08	0.10	0.12	0.13	0.15	0.17	0.18	(m/s)
Temperature	14.52	14.98	15.43	15.88	16.34	16.79	17.25	17.70	18.16	18.61	19.07	19.52	(C)

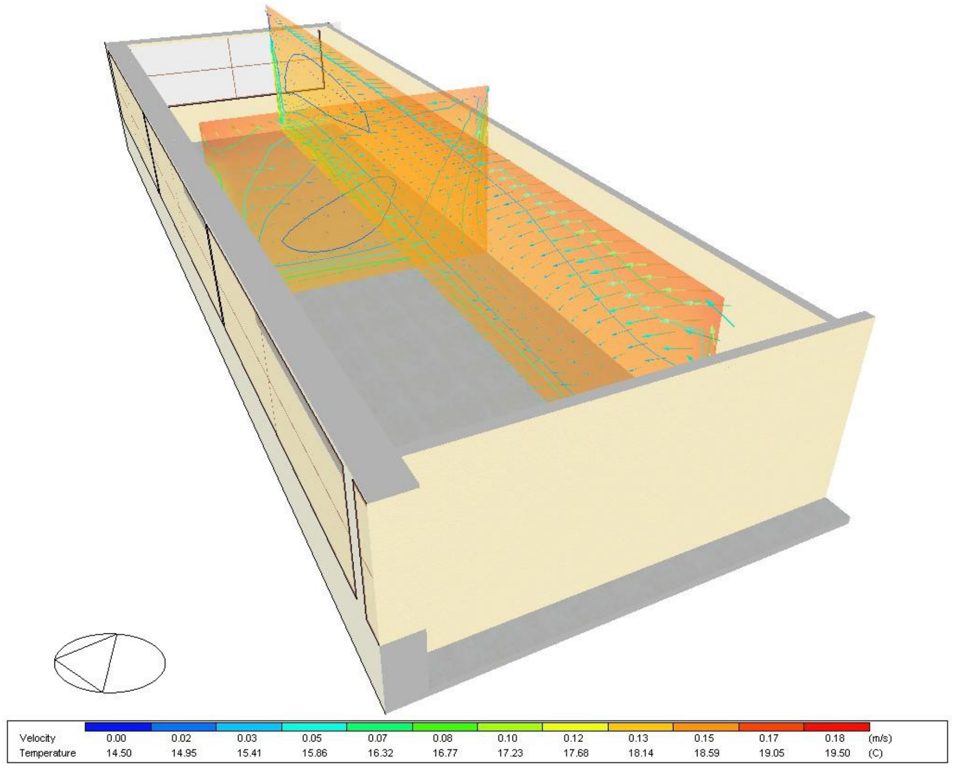


BC_SUMMER WEEK_GALLERY

Wind speed in range of approx. 0.02—0.05m/s.

Therefore increase in operative temperature ≈ 0°C.

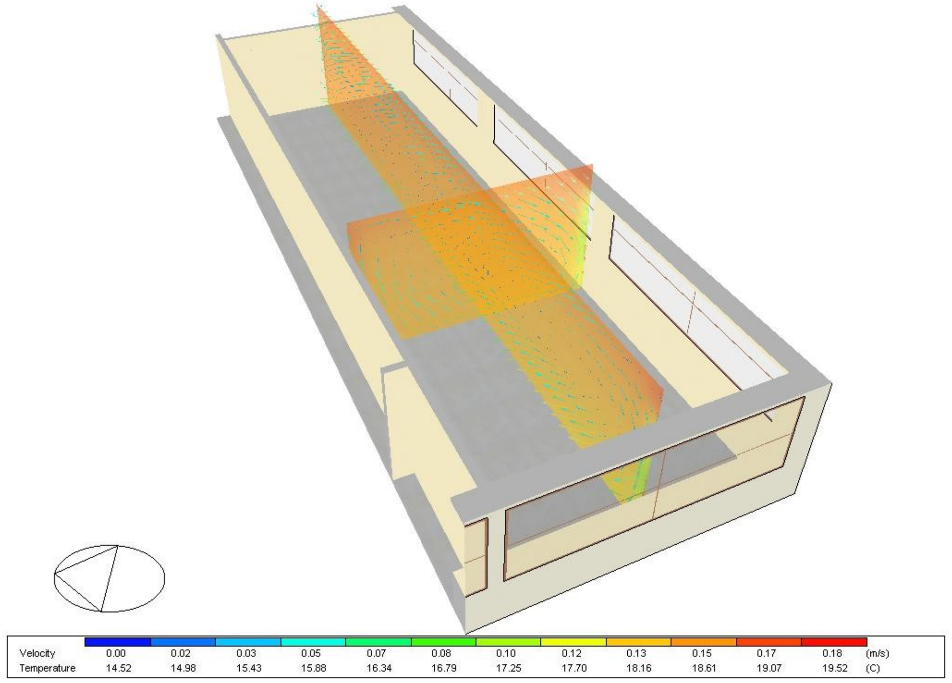
(BS EN 15251, see Fig below.)



BC_SIMMER WEEK_WORKSHOP

Wind speed in range of approx. 0.13—0.15 m/s.

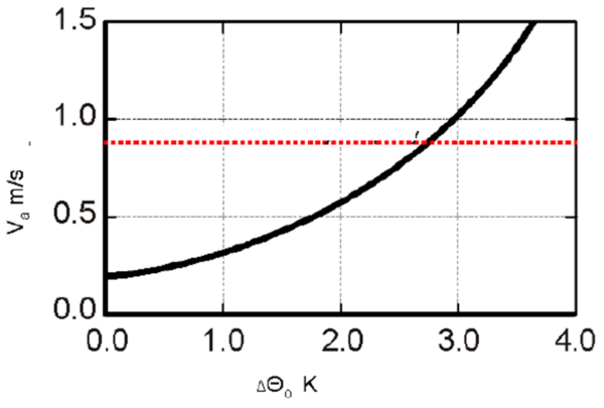
Therefore increase in operative temperature ≈ 0°C.



BASE CASE_SUMMER WEEK_KILNS

Wind speed in range of approx. 0.13—0.15 m/s.

Therefore increase in operative temperature ≈ 0°C.



Key

$\Delta\Theta_o$ = Increase in operative temperature, K

V_a = Air speed, m/s

Figure A2 - Air speed required to offset increased temperature (EN ISO 7730). The air speed increases by the amount necessary to maintain the same total heat transfer from the skin. Acceptance of the increased air speed will require occupant control of device creating the local air speed.

Fig. x. BS EN 15251.

9.0 PASSIVE STRATEGIES INVESTIGATION

Nigerian Vernacular Architecture Review

Nigeria is a country with 2 predominant climates, the hot and arid north, and the hot and humid monsoonal south. Abuja, however lies in the transitional zone and is affected by both climates as distinct seasons.

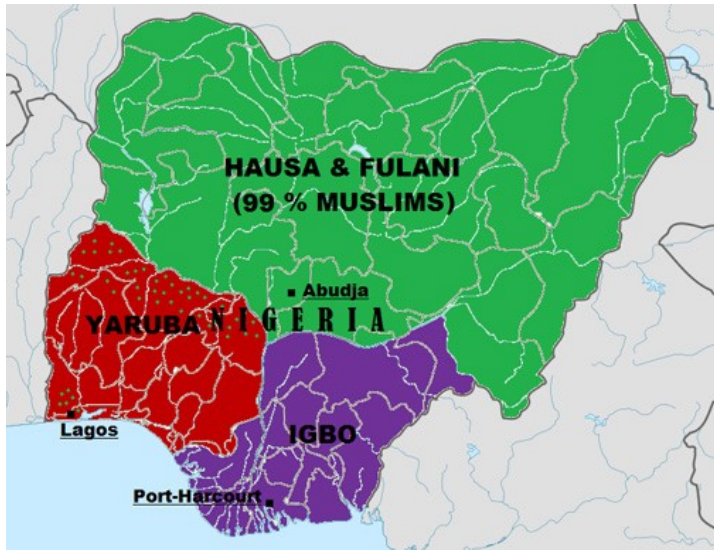


Fig 9.01. Tribal Map of Nigeria. (https://www.gatestoneinstitute.org/4206/nigeria-middle-belt).

Hausa Tribe Architecture

- Compact Building Form.
- Windows small and few in number to keep out solar gain and dust during the Harmattan season.
- Building materials consist of mud, grass, cornstalks and timber.
- Roofs are flat and made of mud.

Fig. 9.02 Traditional Hausa façade. (http://www.ateliermasomi.com/blog/187)

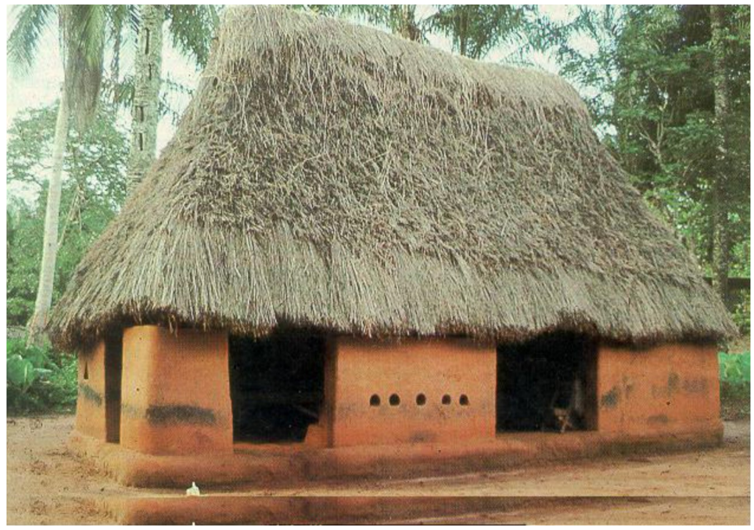


Fig. 9.03 Traditional Igbo hut.

Igbo Tribe Architecture

- Building materials; mud grass, bamboo and raffia.
- Thatched and pitched roofs allow for better water shedding in the monsoonal climate.

The Hausa and Igbo tribe's architecture typify the strategies for the hot and dry, and hot and humid climate types respectively. Abuja however, has a season of each so the investigation will try to determine the most effective strategies for the hybrid climate.

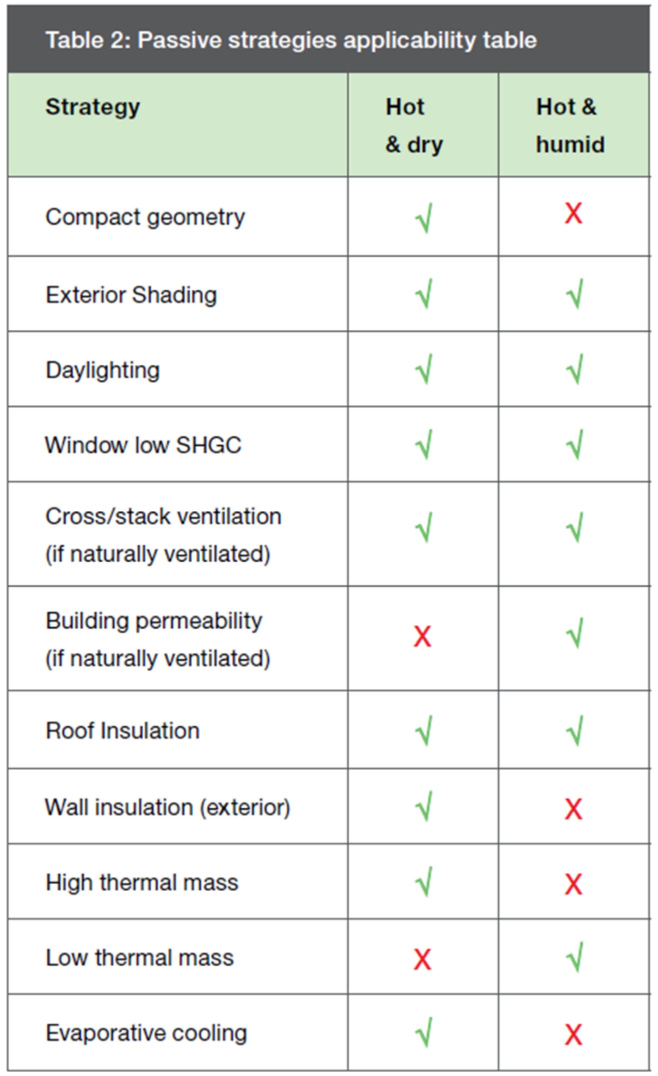


Table 2: Passive strategies applicability table

Strategy	Hot & dry	Hot & humid
Compact geometry	√	X
Exterior Shading	√	√
Daylighting	√	√
Window low SHGC	√	√
Cross/stack ventilation (if naturally ventilated)	√	√
Building permeability (if naturally ventilated)	X	√
Roof Insulation	√	√
Wall insulation (exterior)	√	X
High thermal mass	√	X
Low thermal mass	X	√
Evaporative cooling	√	X

Table 9.01. Passive Strategies applicable to Nigerian Climate zones. (Federal Ministry of Power, Works and Housing)

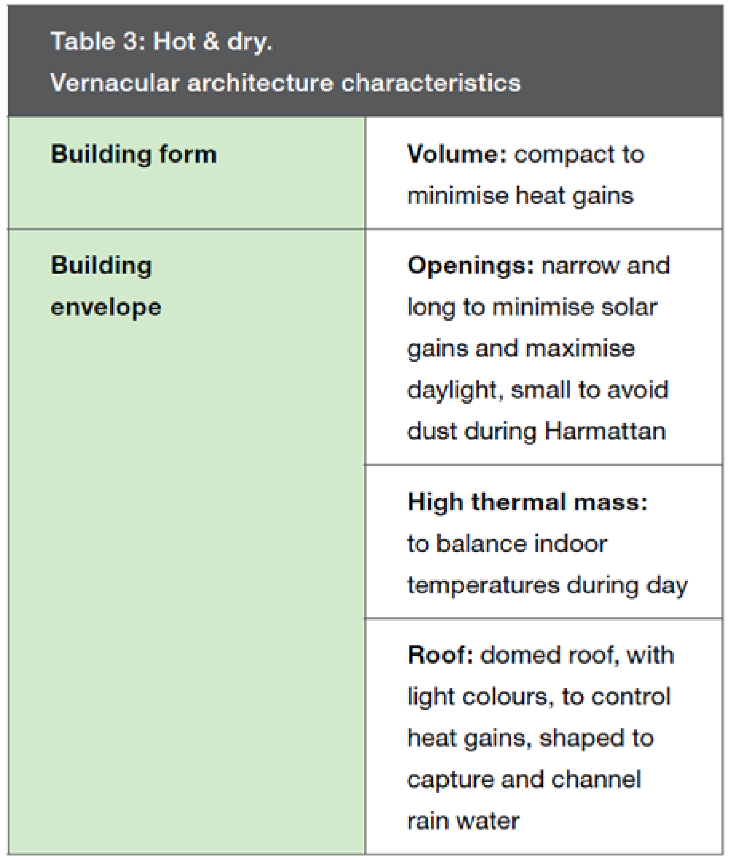


Table 3: Hot & dry.
Vernacular architecture characteristics

Building form	**Volume:** compact to minimise heat gains
Building envelope	**Openings:** narrow and long to minimise solar gains and maximise daylight, small to avoid dust during Harmattan
	High thermal mass: to balance indoor temperatures during day
	Roof: domed roof, with light colours, to control heat gains, shaped to capture and channel rain water

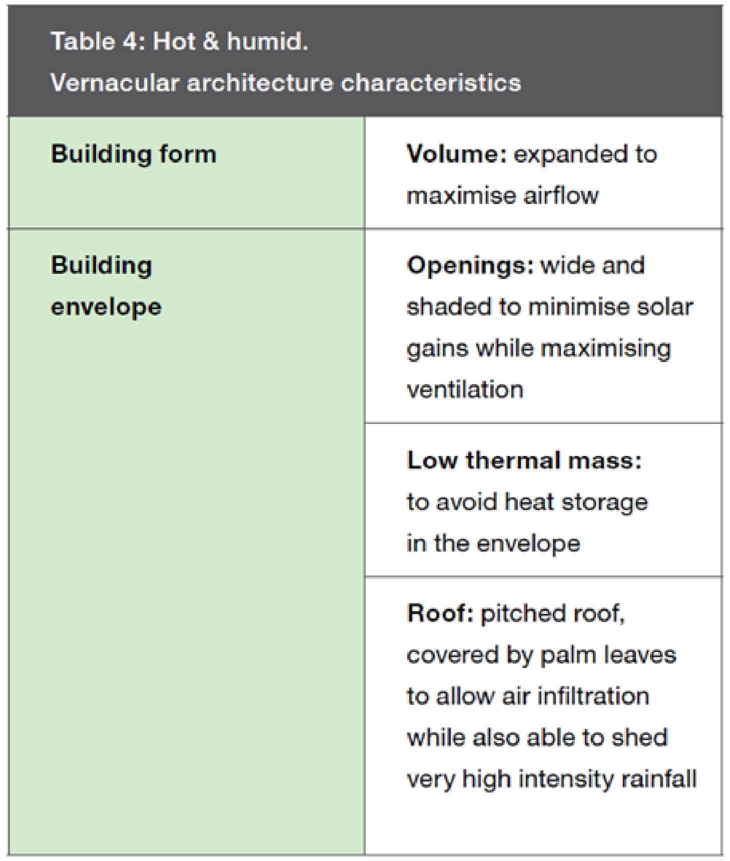


Table 4: Hot & humid.
Vernacular architecture characteristics

Building form	**Volume:** expanded to maximise airflow
Building envelope	**Openings:** wide and shaded to minimise solar gains while maximising ventilation
	Low thermal mass: to avoid heat storage in the envelope
	Roof: pitched roof, covered by palm leaves to allow air infiltration while also able to shed very high intensity rainfall

Table 9.02. Vernacular Architecture Characteristics. (Federal Ministry of Power, Works and Housing)

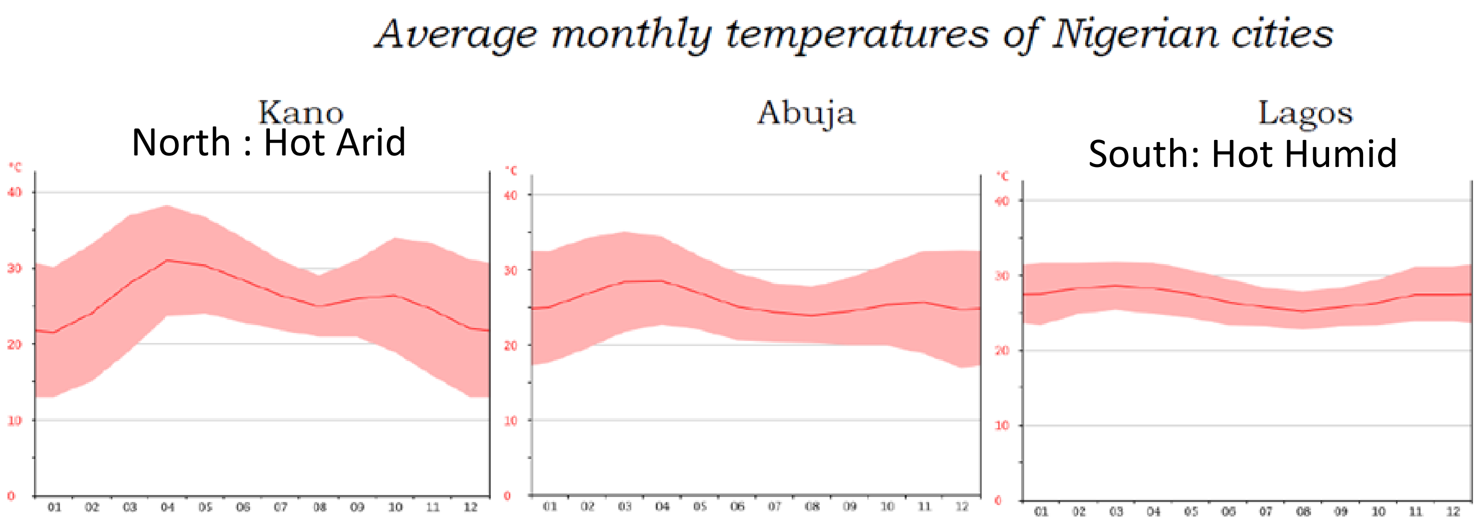


Figure 9.04 (Mu'azu,2015)

Source: NIMET (2010)

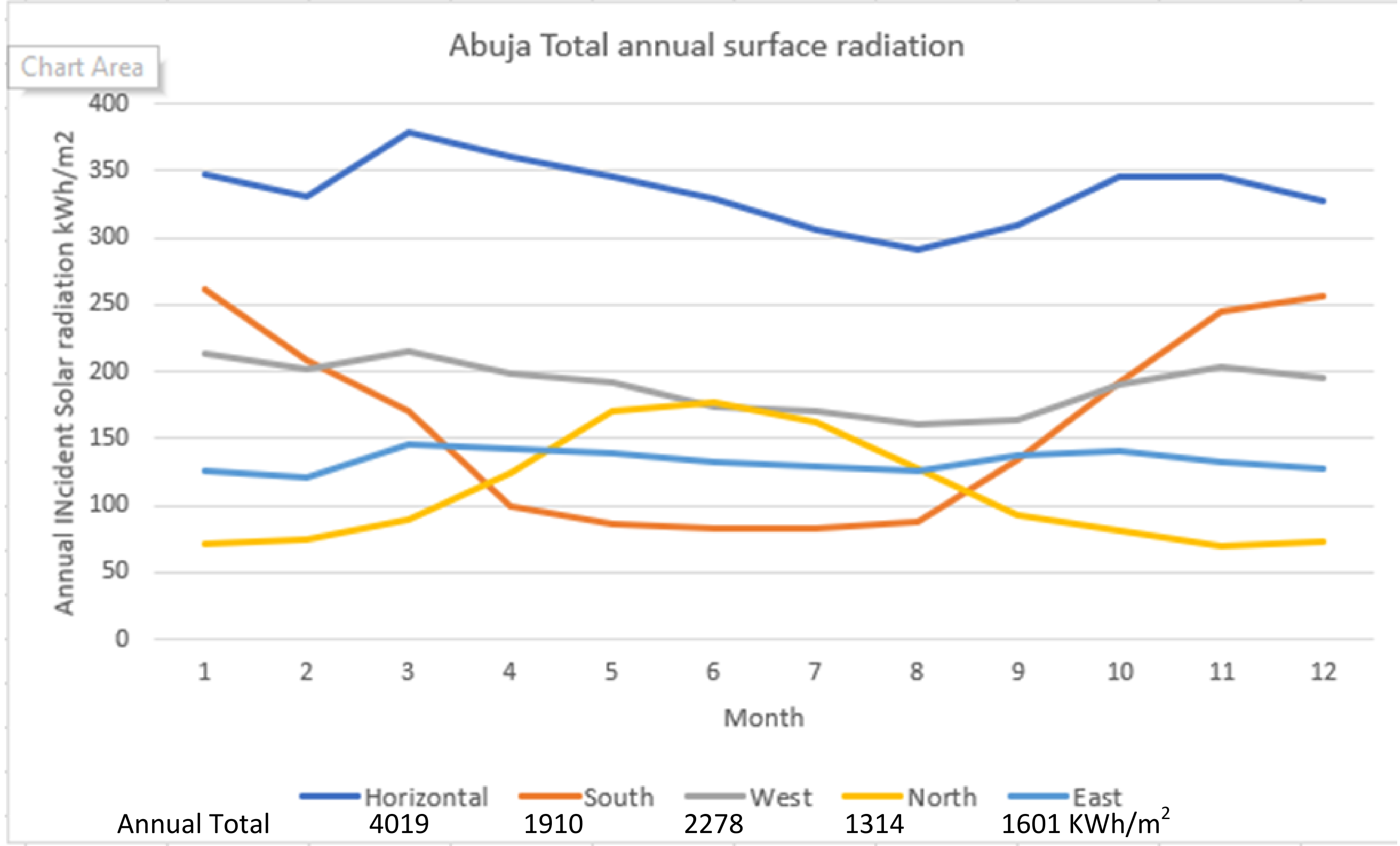


Fig 9.05 Abuja total annual incident solar radiation based on monthly means.

Looking at the annual incident solar radiation graph (fig 9.05) , it is clear that the roof (horizontal surface) receives the most solar radiation. Secondly is the west façade which actually receives more radiation than the South.

Reducing the solar radiation can be achieved by various means, a selection of which are listed:

1. Compact form with small roof area.
2. Shading the roof, although this would reduce night time radiative heat loss .
3. Venting the heat gain from the roof at hight level. A heavy mass roof may retain the heat

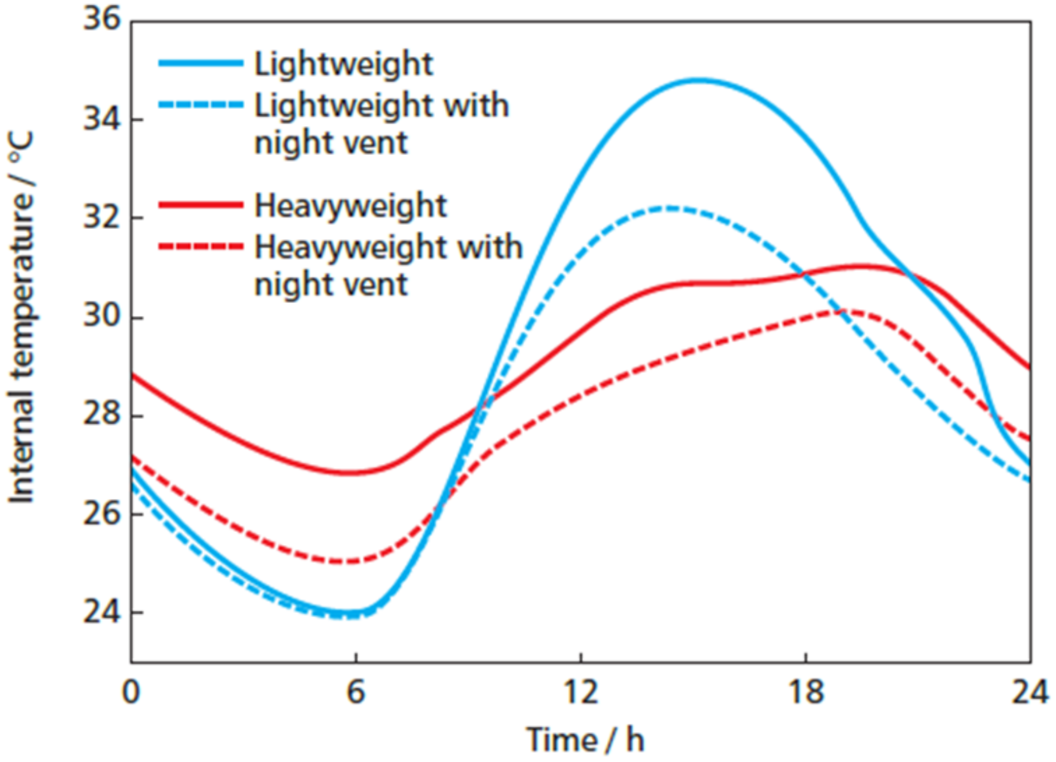
The difference is vernacular roof construction highlights the dichotomy of the Abujan climate. The roof surface will receive the most solar irradiation as illustrated in fig.9.05

In the hot arid climate, a compact form reduces the roof area. The roof is of high mass material, thus modulating the heat gains to re-radiate the heat out later in the cooler evening. In this climate the skies are generally clear allowing good night radiative heat loss. Furthermore the diurnal temperature variation is greater due to the clear skies, and assisting the cooling of the mass. Some heat may be radiated back inside, and for some evenings that may be beneficial.

In the hot humid climates, the roofs are lightweight and air permeable, allowing plenty of ventilation at high level. These roofs will not retain heat and accumulated heat can be vented away. There is less potential for night cooling of a thermal mass due to overcast skies and low diurnal temperature variation.

Fig. 9.06 (CIBSE AM 10.)

Effect of thermal mass and ventilation on peak indoor temperature.



10.0 INVESTIGATIVE STRATEGIES

Three strategic approaches will be adopted to reduce the internal air temperatures in the investigation.

1. Solar Protection

- Orientation
- Form factor
- WWR ratios
- glazing type
- shading

Heat Modulation

- Thermal mass
- PCM

Heat Dissipation

- Convective cooling (Air) ventilation
- Evaporative cooling_ (Water)
- Radiative cooling_ (night time)

INVESTIGATIONS

I. Reduce WWR to 20% to South, West and East facades only.

Reduce solar gain, without impacting daylight provision to north facing Workshop.

II. Heavy mass Abobe walls 500 thick externally and 300 internally.

Stablise the internal temperature and humidity with the thermal mass and vapour absorptivity or adobe.

Density 1800kg/m3, U-value 0.683 W/(m.K), Vapour resistance 7, Thermal capacity 900J/(kg.K) (Parra)

III. Shelter ground floor into site slope by 1.8m at the South retaining windows to South at high level. See figure 10.01

IV. Removal of ceiling at 1st floor, and introduction of central atria linking gallery to roof void. Introduction of a glazed rooflight to provide high level ventilation.

V. Amend ventilation schedule to full capacity at night during unoccupied hours and 30% during daytime occupancy hours. (Reversing base case ventilation operation schedule.)

Promote ventilative cooling during cooler night hours and reduce ventilative heat gains in the day.

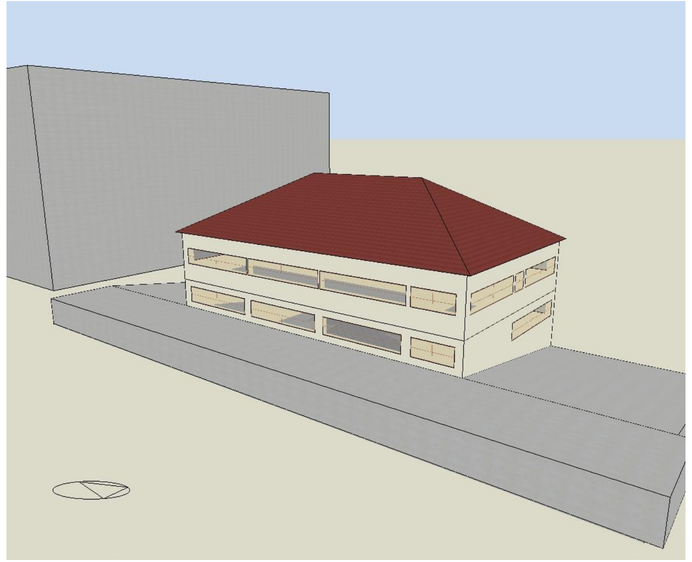


Fig. 10.01 Investigation III _

POTTERY AND MUSEUM IN ABUJA.

INVESTIGATIONS AND CONCLUSIONS

Thermal Comfort Comparison	March 15- 21 GALLERY		WORKSHOP		SUB TOTAL Arid Season	April 5- 11 GALLERY		WORKSHOP		SUB TOTAL Mid Season
	Total degree hours ϴ range exceeded	Ashrae _ Standard 55 Discomfort hrs	Total degree hours ϴ range exceeded	Ashrae _ Standard 55 Discomfort hrs	Degree hours % change on BC	Total degree hours ϴ range exceeded	Ashrae _ Standard 55 Discomfort hrs	Total degree hours ϴ range exceeded	Ashrae _ Standard 55 Discomfort hrs	Degree hours % change on BC
	°C.hr	hrs	°C.hr	hrs		°C.hr	hrs	°C.hr	hrs	
BASE CASE II_ Calculated ventilation	284.49	51.00	313.54	55.00	0.00%	261.70	51.00	291.80	55.00	0.00%
Investigation I _ 20%WWR to S, E,W walls.	239.97	51.00	288.93	55.00	88.44%	226.36	51.00	273.65	55.00	90.34%
Investigation II _ Abobe Walls	304.36	51.00	321.89	55.00	104.72%	284.35	51.00	302.30	55.00	105.99%
Investigation III_ Earth Sheltering	217.02	51.00	277.97	55.00	82.77%	203.84	51.00	261.45	55.00	84.06%
Investigation IV _ roof vent+ internal atria	297.47	51.00	353.05	55.00	108.78%	309.07	51.00	323.83	55.00	114.35%
Investigation V_ night cooling schedule	284.52	51.00	131.59	55.00	69.58%	296.43	51.00	291.84	55.00	106.28%
FINAL PROPOSAL: I,III,IV	160.26	50.00	279.42	55.00	73.52%	195.53	51.00	267.43	55.00	83.64%

Thermal Comfort Comparison	July 8-14 GALLERY		WORKSHOP		SUB TOTAL Humid Season	TOTAL		
	Total degree hours ϴ range exceeded	Ashrae _ Standard 55 Discomfort hrs	Total degree hours ϴ range exceeded	Ashrae _ Standard 55 Discomfort hrs	Degree hours % change on BC	Total degree hours ϴ range exceeded	Ashrae _ Standard 55 Discomfort hrs	Degree hours % change on BC
	°C.hr	hrs	°C.hr	hrs		°C.hr	hrs	
BASE CASE II_ Calculated ventilation	84.37	49.25	93.74	54.75	0.00%	1329.64	316.00	0.00%
Investigation I _ 20%WWR to S, E,W walls.	70.62	49.25	86.26	55.00	88.08%	1185.79	316.25	89.18%
Investigation II _ Abobe Walls	87.37	50.25	93.83	54.75	101.73%	1394.10	317.00	104.85%
Investigation III_ Earth Sheltering	59.49	49.25	82.89	55.00	79.94%	1102.66	316.25	82.93%
Investigation IV _ roof vent+ internal atria	87.54	49.25	105.21	54.75	108.22%	1476.17	316.00	111.02%
Investigation V_ night cooling schedule	84.37	49.25	93.76	54.75	100.01%	1182.51	316.00	88.93%
FINAL PROPOSAL: I,III,IV	50.35	50.25	83.84	55.00	75.34%	1036.83	316.25	77.98%

The high thermal mass proposal did not perform as well as hoped in reducing temperatures even in the arid season. This could be down to the Base Case ventilation schedule which did not promote night time cooling to exhaust the heat gain. Night time cooling strategies are only effective, but particularly so, during the arid season as evidenced by the results of investigation V. This is when there is greater diurnal temperature variation. Reducing the solar gains through the windows is effective, but does have the drawback of reducing daylight. Investigation IV had the drawback of increasing solar gain through the roof due to the use of a glazed roof window for ventilation. None of the strategies were successful at raising the air velocities to any notable degree. A less compact form may have promoted ventilation, although at the expense of solar gain.