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THERMAL PERFORMANCE OF BUILDING ENVELOPES FOR BUILDINGS IN ABUJA, NIGERIA

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ABSTRACT

Purpose: This research aims to determine the thermal performance of building envelope types, mainly walls, that are commonly used locally and other prescribed/recommended typologies.
Design/methodology/approach: This was carried out using computer-based simulation, with the aid of Integrated Environmental Solutions – Virtual Environment (IES-VE) software as the simulation tool, in which thermal comfort temperature ranges was used as an indicator of performance. As such durations in which thermally comfortable internal spaces can be obtainable without the reliance on non-natural means [heating, ventilation and air conditioning (HVAC) mechanisms] was determined.
Findings: The result showed that thermal comfort can be obtainable for more than 50% of the occupancy periods in Abuja for all wall types. Meanwhile the most commonly used wall types also showed improved thermal performance of up to 70% during the hot season.
Originality/value: Thus, the research was able to demonstrate in very clear terms, the comparative thermal performance of wall types used as building envelopes in Abuja-Nigeria. This approach also shows the importance of computer-based simulation in evaluating building design options. Thus, enabling architects to make informed design decisions in creating thermally comfortable buildings, with attendant low energy implications (for cooling) as well as the achievement of sustainable built environment. The research was also able to determine/demonstrate actual thermal performances of wall types prescribed in local building codes, which hitherto, have remained largely prescriptive.

Keywords: Building envelope; computer simulation; Nigeria; sustainable buildings; thermal performance.

1. INTRODUCTION

It has been established that buildings are responsible for about 40% energy consumption and responsible for up to a third of greenhouse gas emissions globally. Hence, it comes as no surprise that the push for more energy efficient and sustainable building design has been on the rise. This move is more evident amongst the developed

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countries where policies, regulations and benchmarks abound stipulating one form of compliance or the other. Examples include code for sustainable homes in the United Kingdom (UK), the leadership in energy and environmental design (LEED) building rating system in the United States of America (USA) and the German Sustainable Building Council (DGNB) system in Germany just to mention a few.

Energy Efficiency in Buildings standards is also making inroads within developing countries as exemplified by the emergence of numerous Green Building Councils in Africa, the Excellence in Design for Greater Efficiencies (EDGE) rating system in South Africa and Ghana, as well as the Buildings Energy Efficiency Guide (BEEG) in Nigeria amongst others.

Incidentally, building development in Nigeria, particularly within office typologies, and commercial and high-end housing markets are towing the line of various systems and standards for sustainable design. These emerging practices has more or less been attuned to global business practices and signification rather than compliance to any green or sustainable building targets. Despite the recent development of the building code as well as BEEG, there is limited evidence to suggest compliance within the industry.

Within this purview therefore, it is evident that there is a significant demand for improvement in building envelope performance, largely due to the role which building envelopes play in the control and demand for energy within buildings – such as through its impact on thermal comfort and ultimately cost of energy, amongst others.

Hence this research intends to evaluate the performances of recommended building envelopes specifications obtainable within local regulatory frameworks as well as other locally applicable building envelope typologies.

2. REGULATIONS FOR BUILDING ENVELOPES IN NIGERIA

In architecture, building envelope is a design variable which consists of structural materials and finishes that enclose space, separating inside from outside; balances requirements for ventilation and daylight while providing thermal and moisture protection appropriate to the climatic conditions of the site (Reffat, 2004) The building envelope is often described as a function of its permissible heat flow or heat resistance (overall heat transfer co efficient) which is described as its U-value (Papadopoulos & Giama, 2007); (Yang, Yan, & Lam, 2014). U-values have been established for a variety of materials and are available in building standards.

This information allows designers/architects to evaluate material response to climate in relation to their design requirements. For example, Cheng, Ng, and Givoni (2005) examined the effectiveness of a building's envelope in free flow building using three different levels of mass (low, medium and high) with the same heat loss coefficients for three buildings in the hot humid climate of Sala, San Diego. On the hottest summer day of the research, the high- mass building obtained an indoor temperature of 24.5˚C when outdoor maximum was 34˚C. (Shaviv, Yezioro, and Capeluto (2001)) and Ogoli (2003) reported similar results where indoor temperatures of up to 4˚C and 7˚C lower than outdoor maximum were obtained using a variety of materials for the building envelope in hot humid and equatorial climates of Israel and Kenya respectively.

Also, in Givoni's (2005) analyses, the relationship between the indoor maxima and various parameters of the outdoor climate demonstrated that the best correlation exists between the outdoor average and the indoor maximum temperatures. However, "it is also widely believed that in a hot humid climate, like Florida, it is not recommended to use thermal mass with night ventilation as a passive cooling design strategy" (Shaviv *et al*., 2001). This suggests that ventilation strategy other than natural ventilation may have to be employed, because in this case the diurnal temperature swing between day and night is not enough to dissipate heat gains. Collectively, the examples given above demonstrate that the building envelope is an important factor which influences the amount of energy a building will consume during its occupancy phase as a result of cooling, heating or lighting demand. It also demonstrates that a solution for a particular climate may not necessarily be applicable to another. Therefore, a set of particular specifications may be required for every design and location. As a result, countries have developed policy/regulations that are peculiar to their situations.

In Nigeria, the National Building Code (NBC) was the first regulatory document developed (in 2006) at national level for the regulation of the built environment development and used complimentarily with local regulations such as the Development Control Manual (DCM) for Abuja. Though the NBC contained specific guidelines that were more detailed compared to the DCM, it did not contain any clear/specific regulations towards the development of energy efficient and sustainable built environment components (Dahiru, Abdulazeez & Abubakar, 2012). Additionally, guidelines related to design issues were sometimes loosely defined. For example, the regulation on ventilation for office buildings was simply to provide natural and/or mechanical ventilation. Again, this is an open-ended regulation where the architect/developer has the discretion to design either a low energy or energy intensive building. Other regulations, again rather open-ended and perhaps vague, include that of the external wall and roof construction. For instance, the regulation for roof construction simply stipulates that roof design is done in conventional manner with minimum pitch of 30^o. Generally, the enactment of the NBC has been widely applauded, however, researchers have uncovered its shortfalls and in its review recommended that issues such as energy efficiency in buildings, sustainability and performance thresholds/indicators are incorporated (Dahiru *et al*., 2012; Mu'azu, 2011).

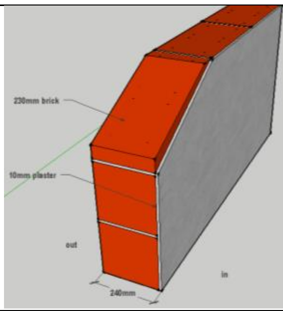
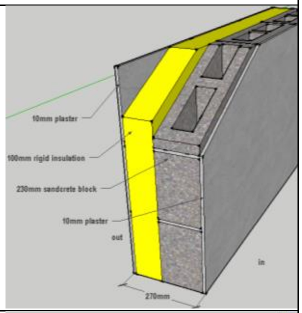
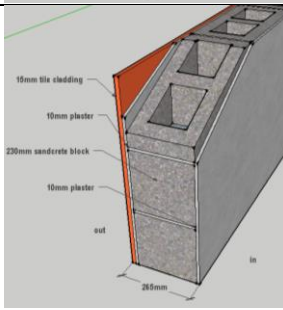
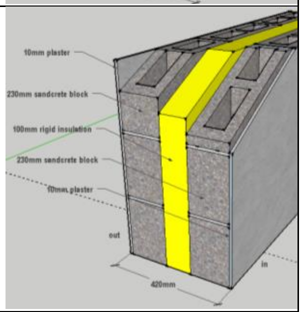
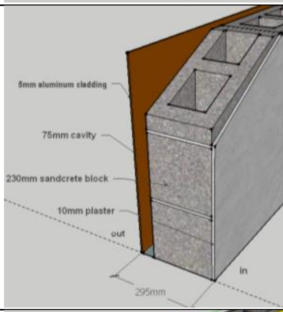
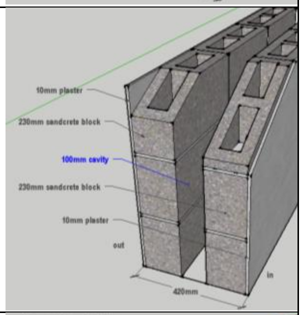
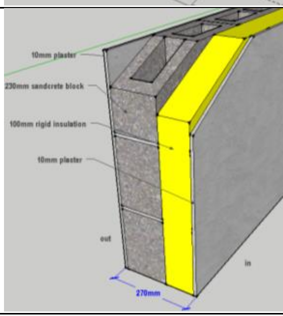
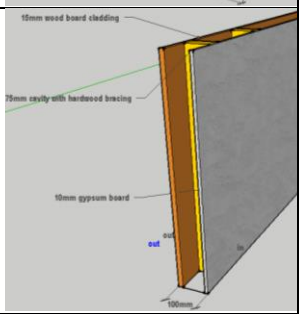
More recently, there has been increasing demand for a robust road map for energy efficiency in buildings which critically takes into account local and global considerations towards obtaining sustainable built environments (Ochedi *et al.*, 2016; Amasumou *et al*., 2017). Consequently, the Buildings Energy Efficiency Guidelines was developed by the Federal Ministry of Power, Works and Housing in conjunction with the Energy Commission of Nigeria (ECN) and in collaboration with German Corporation for International Cooperation (GIZ) as part of the National Energy Support Programme (NESP). This document provided finer details compared to what is obtainable in the NBC. Notwithstanding, the recommendations emphasised the need to incorporate an integrated design process in the development of building designs taking numerous lessons from bioclimatic design disposition as well as vernacular architecture of the sub regions. As such, the recommendations were more performance based and less of technical specifications in nature in which computer-based simulations have become widespread due to its reliability, cost effectiveness and have also been applied in developing world contexts (Musa *et al.*, 2018; Jimoh & Onazi 2019).

3. EVALUATING PERFORMANCES OF BUILDING ENVELOPES

3.1. Building envelope typologies

Eight building envelope types were selected for evaluation. Nine-inch cement based (*Sandcrete*) blocks is the most popular type of block used for buildings in Nigeria and it is one major recommendation contained in the NBC for building envelopes. Bricks are seldom used. Notwithstanding, the typology is also included for evaluation. Furthermore, the sandcrete blocks are often clad with tiling or aluminium particularly in recent developments. Other wall types often recommended but with limited local application include insulated walls, cavity walls and wooden walls. Table 1 shows the wall types whose performance were evaluated.

Table 1: Wall types used as building envelopes in Abuja, Nigeria

	General description	**Sectional diagram**		**General description**	**Sectional diagram**
Wall 01	Brick wall, with plastered internal face		Wall 05	block wall with insulation to the external and plastered on both faces	
Wall 02	Block wall with plastered internal face, and tile clad external face		Wall 06	Double wall with insulation in between and plastered on both faces	
Wall 03	block wall with plastered internal face, and aluminium clad external face		Wall 07	Double wall with cavity in between and plastered on both faces	
Wall 04	block wall with insulation to the internal and plastered bon both faces		Wall 08	Lightweight wall made of wood board to the external and gypsum board to the internal.	

3.2. Thermal performance evaluation

Studies have shown that cooling load demands account for up to 50% of energy consumed in buildings. This suggest that a reduction in the demand for cooling has a significant potential in reducing building energy consumption. Therefore, the longer the duration in buildings where comfortable temperature ranges are obtainable, the lower the potential energy demands. The objective of the simulation in this section is therefore to identify the wall type with the best thermal performance.

With the adoption of the attainment of satisfactory thermal requirement as a performance indicator, a design degree day method was adopted as for thermal comfort evaluation. In this method, base-case temperature is identified and the total duration with cooling or heating requirement (to achieve comfort) is calculated (Day, Knight, Dunn, & Gaddas, 2003). Due to climatic disposition of Abuja, only cooling degree days CDD are examined because of the prevalent high temperature which negates the demand for heating throughout the day time or working hours.

Also, the Humphery's adaptive thermal comfort model was chosen because it suits buildings designed based on natural ventilation strategy (Yang *et al*., 2014). Though there exists a few variations in the adaptive thermal comfort model, Humphrey's formula was adopted in this research because result from fieldwork aimed at developing thermal comfort indices for various locations in Nigeria corroborate the adaptive model (Adunola, 2014) (Ogbonna & Harris, 2008). It is also considered that when mean external temperature range between 10^{o}C and 30^{o}C, then adaptive thermal comfort is applicable in the design of naturally ventilated building (Humphreys, Rijal, & Nicol, 2013).

Nicol, Humphreys, and Roaf (2012) showed that the adaptive thermal comfort temperature can range from +/-2^{o}C to as high as +/-7^{o}C depending on the adaptive options available to the occupants. However, in this research the more conservative median temperature range of +/-3^{o}C is applied to enable gradual acclimatisation for the occupants already accustomed to air-conditioned spaces.

According to this model, adaptive thermal temperature range for Abuja is between 24.0^{o}C and 28.5^{o}C while mean annual comfort temperature is 26.1^{o}C. Therefore, impact of design iterations (output) will be aimed at achieving maximum duration of temperature ranges between 22^{o}C and 29^{o}C.

Table 2: Summary of properties of selected wall types

Wall type	Thickness (mm)	U-value (W/m^{2}K)	R-value (m^{2}K/W)	Mass (kg/m^2)
Wall 01	240	2.4189	0.2363	307.80
Wall 02	265	2.0814	0.2982	607.75
Wall 03	320	1.5992	0.4482	554.10
Wall 04	270	0.0807	12.2154	393.00
Wall 05	270	0.0807	12.2154	393.00
Wall 06	420	0.0787	12.5364	1106.00
Wall 07	420	1.1192	0.7164	1097.00
Wall 08	100	1.6071	0.4452	29.20

4. Performance Evaluation using Computer-based Simulation

Computer based simulation have become increasingly popular in the last few decades for the purposes of performance evaluation. Among the numerous software available, Integrated Environmental Solutions Virtual Environment (IES-VE) is the simulation software chosen for this research while and the validation exercise for the software has been provided elsewhere (Mu'azu, 2015). One of the considerations for its selection is the capability of the software to conduct energy load deductions due to numerous factors including heat gains, design alterations etc.

Furthermore, the simulation tool contained a module known as Macroflo which deals with bulk air flow movement. The module adopts zonal airflow calculations to estimate bulk air flow movement in and within the building, driven by wind and buoyancy induced pressure. As such air movements and associated temperature responses can be deduced. This was sufficient from an architectural perspective, to analyse infiltration and natural ventilation gains in buildings.

Otherwise, a detailed numerical simulation of fluid flow and heat transfer process used in computational fluid dynamics would have been required. This level of understanding in building physics and engineering is beyond the scope of this research.

4.1. Simulation constants

Abuja was selected as the site location and its attendant simulation weather files input was made constant throughout the simulation using a one sample model building. Occupancy profile, which is the duration investigated was also made constant. This reflected mainly official working hours of 0800-1700hrs daily from Monday to Friday throughout the year culminating to a total of 2340hrs. This represents daytime hours which also encapsulate durations when high temperatures are mostly obtainable.

5. Results and Discussion of Findings

5.1. Results

Fig 1 shows the thermal performance of all the walls types with the thermal comfort durations expressed in percentages of occupied hours. The chart also shows performances during hot months which spans from January – June months and throughout the year. A detail of monthly performance analyses of each wall type is provided in Appendix A.

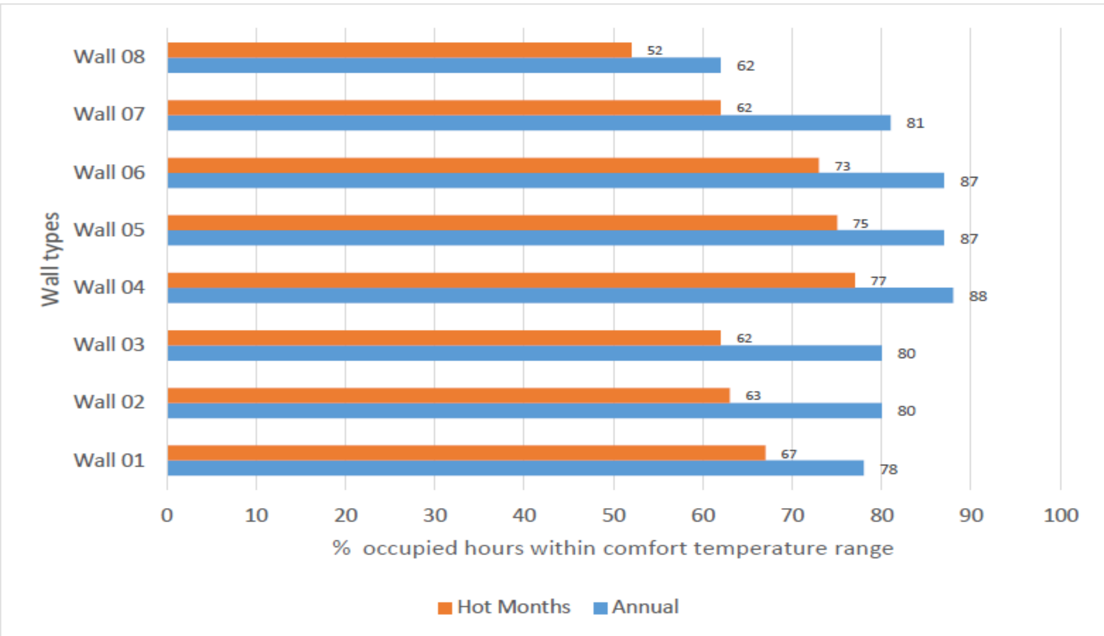


Figure 1: Thermal performances of wall types from simulation

5.2. Discussion of findings

The wall types, wall 01, wall 02 and wall 03 prescribed in local building codes and commonly obtainable within the local built environment are all capable of providing thermally comfortable internal spaces for a minimum of 50% of the occupancy periods. Though the literature review suggested poor/non-robust energy efficient content in the local building regulations, in which case structural integrity enjoyed more concern as against any environmental/thermal performance requirements (Dahiru *et al.*, 2012; Geiseller *et al.* 2018).

However, the results showed that the existing regulation for walls is indeed energy efficient. Whether this is by mere coincidence or well calculated is another matter entirely. It also showed that the trending material used for cladding has limited/insignificant implication on the building's thermal performance. In fact, wall 02 and 03 showed a lower performance during hot season compared to the widely used wall 01.

Meanwhile, for the much-advocated insulated wall types, all the types evaluated (wall 04, 05 and 06) showed the high thermal performances, providing thermally comfortable internal spaces for longer than 70% of the occupancy periods both in the hot season and all year-round scenarios. Furthermore, providing insulation towards the external leaf showed improved performance compared to all other iterations (even though marginally). Notwithstanding, the difference of 1% performance has the potential of translating to a more significant implication particularly when considering a life cycle analyses.

In addition, even though it is obvious that the cost implication of constructing the insulated walls will be higher than the common uninsulated wall (wall 01), this cost component may be viewed as a hindrance against the adaptation of this type of wall construction for higher performance building envelopes. However, detailed energy analyses over the building's life cycle with focus on the attendant cost of energy consumed versus cost of construction can reveal the trade-offs or return on investment for choosing the insulated wall type. Moreover, it has been argued that green/energy efficient buildings can come with a price particularly at the initial stage (Dalibi *et al*. 2017).

Conversely, the result showed that the cavity wall (wall 07) had a poorer performance compared to that of insulated walls though generally higher than the widely used common wall (wall 01). In fact, through the hot months, wall 01 showed better performance compared to wall 07. With this outcome, and coupled with the cost of constructing the cavity wall, it can be said that wall 07 is not recommended as a good thermal performance building envelope.

Lastly, wall 08, which is the wooden wall type showed the lowest thermal performance even though thermally comfortable internal space can be achieved for 50% of occupancy period. As this wall type is mostly associated with temporary structures and low-income dwellings, it can be said that an upgrade from this wall type to at least the common wall type (wall 01) can lead to an improved standard of living among the low-income households based on thermal performances.

6. CONCLUSION

The foregoing IES-VE simulation and results focusing on the envelope as a building element suggests that environmental simulation tools can strengthen the performance-based nature of existing building design guidelines in Nigeria towards energy efficiency and sustainable built environment.

The study also suggests that more is required to buttress current building regulations obtainable in Nigeria to adequately facilitate the evolution of energy efficient and sustainable buildings. The result demonstrates that an understanding of the fundamental ideas behind energy efficiency and sustainable design can always be deployed towards optimising the performance of key elements such as the building envelope.

For a country such as Nigeria, these findings are of high importance as it enables curtailing energy demand in buildings mainly for cooling through informed design decisions. As such, it has the potentials to play a key role in reducing energy demand, utility cost and adverse emissions (from use of generators, amongst others,. to bridge energy supply) gaps cannot be over emphasized.

Hence, information in this research also holds potential to inform the development of local and national regulatory frameworks appropriate to Nigeria and possibly further informing such developments in similar contexts.

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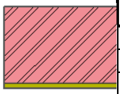
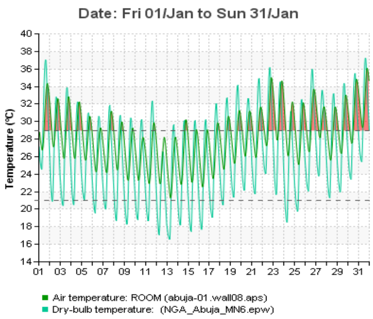
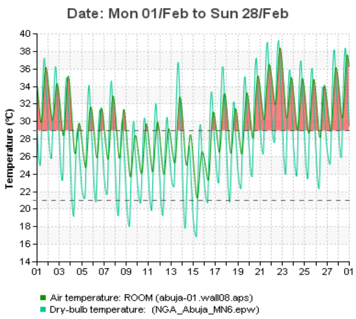
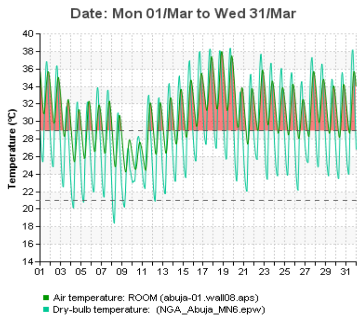
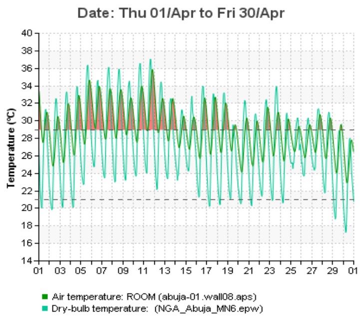
APPENDIX A: MONTHLY THERMAL PERFORMANCE OF WALL TYPES

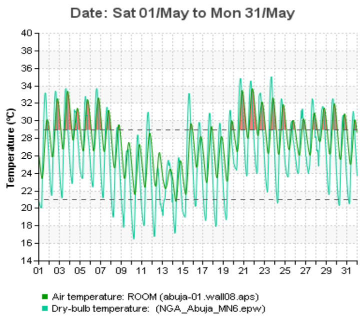
Descriptio	Wall ID: WALL – 01		Thermo physical properties			
	Material compositi (outside to inside	Thickn	U-value (W/m^2K)		2.4189	
	Common Brick		R-value (m^2K/W)		0.2363	
	Plaster		Mass (kg/m^2)		307.8	
			Thermal perfo (%)	Too cold <	Comfortable Between 21°C and 29°C	Too hot
			Annual		7	
			Hot months (Jan-Jun)		6	

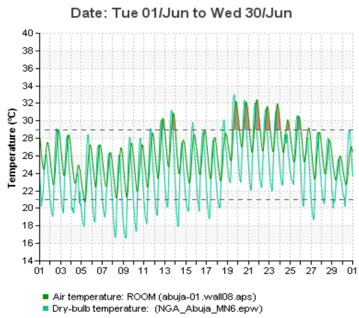


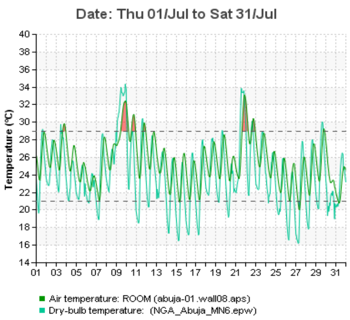


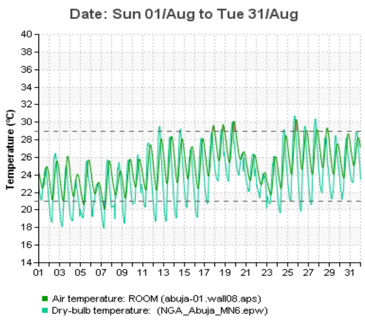


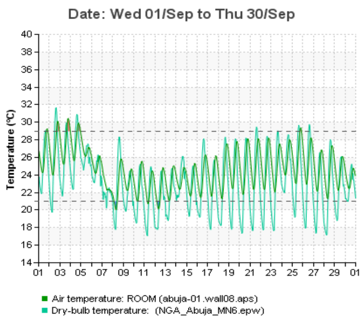


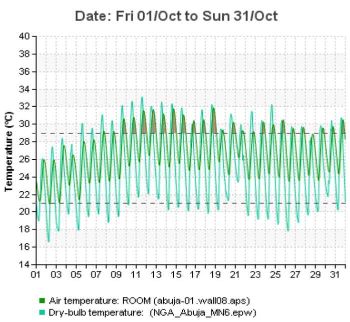


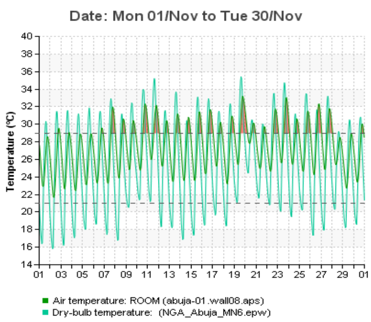


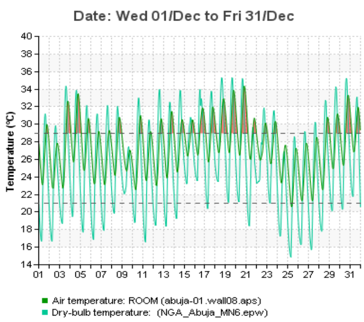


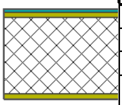


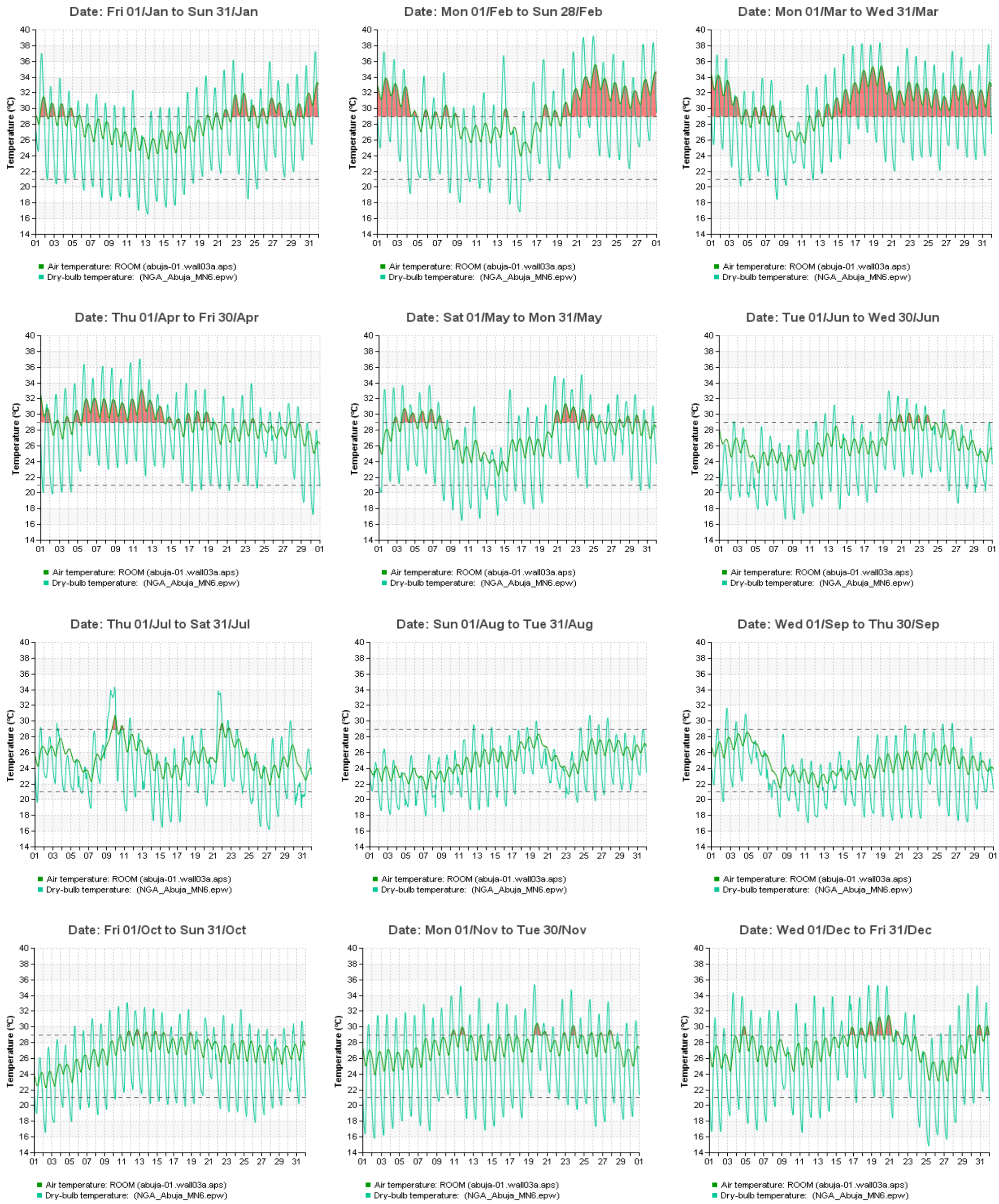


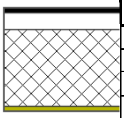


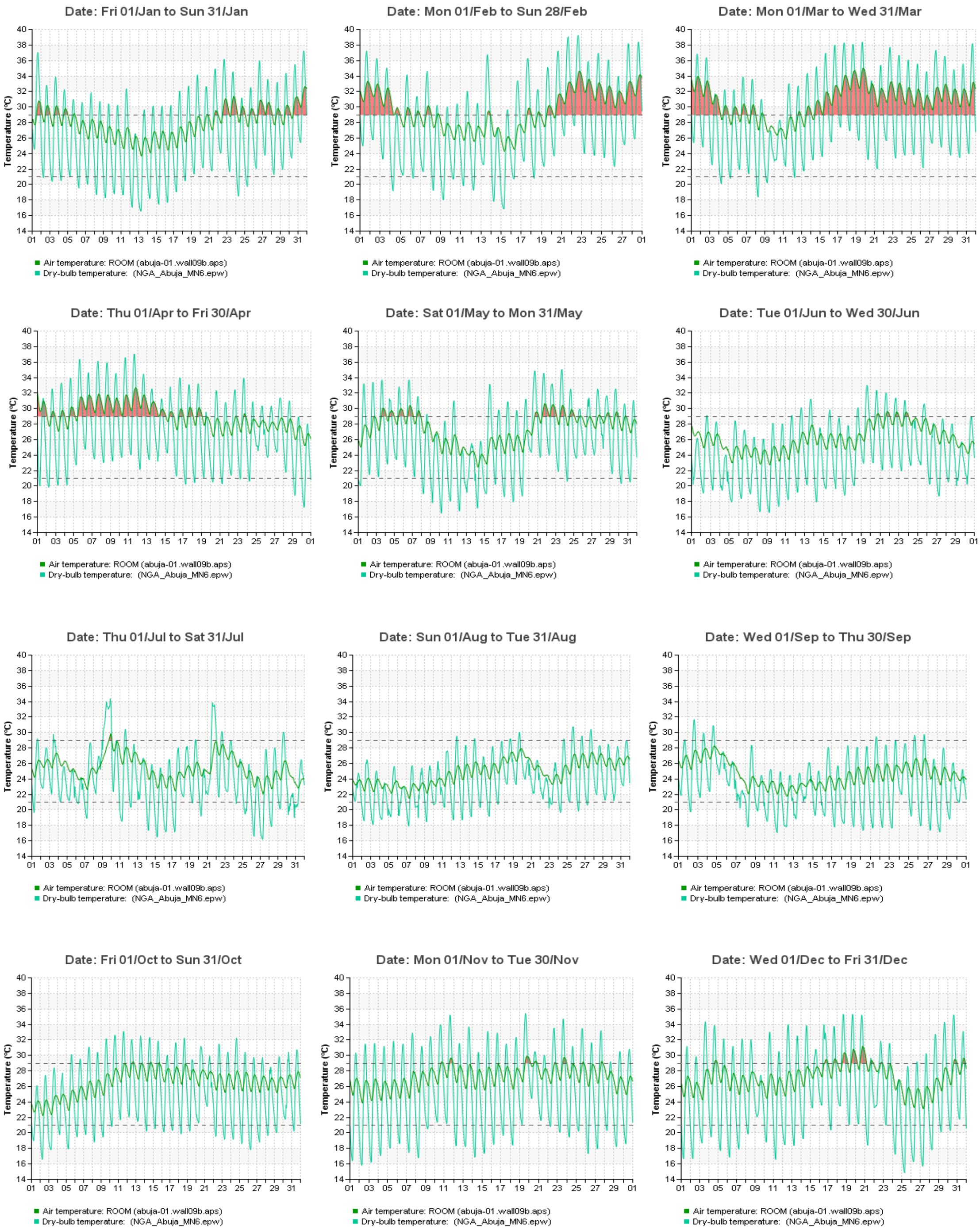




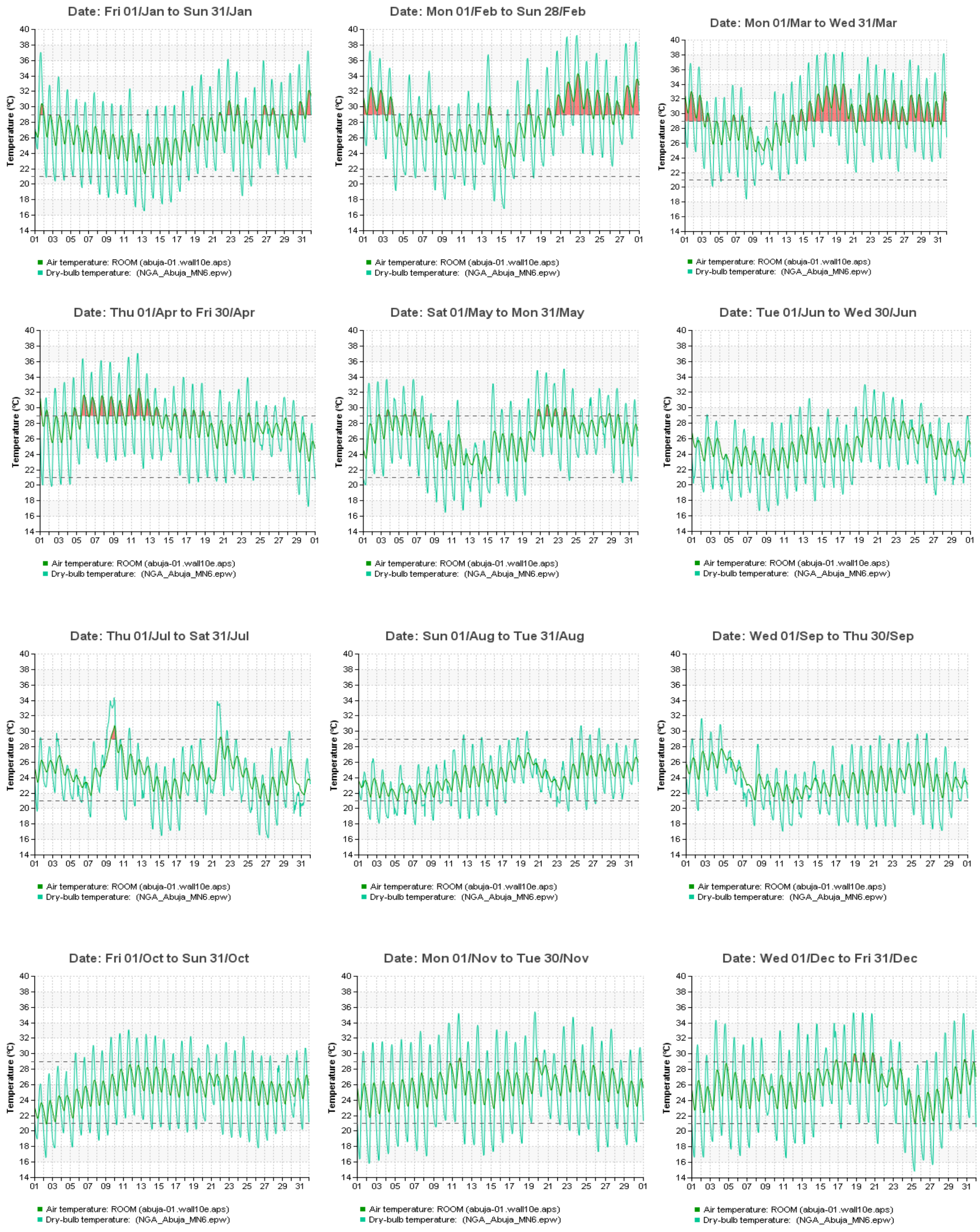
Descriptio	Wall ID: WALL – 02		Thermo physical properties			
	Material compositi (outside to inside	Thickn	U-value (W/m^2K)		2.0814	
	Granite		R-value (m^2K/W)		0.2982	
	Plaster		Mass (kg/m^2)		607.75	
	Hollow Concrete block		Thermal perfo (%)	Too cold <	Comfortable Between 21°C and 29°C	Too hot
	Plaster					
			Annual		8	
			Hot months (Jan-Jun)		6	



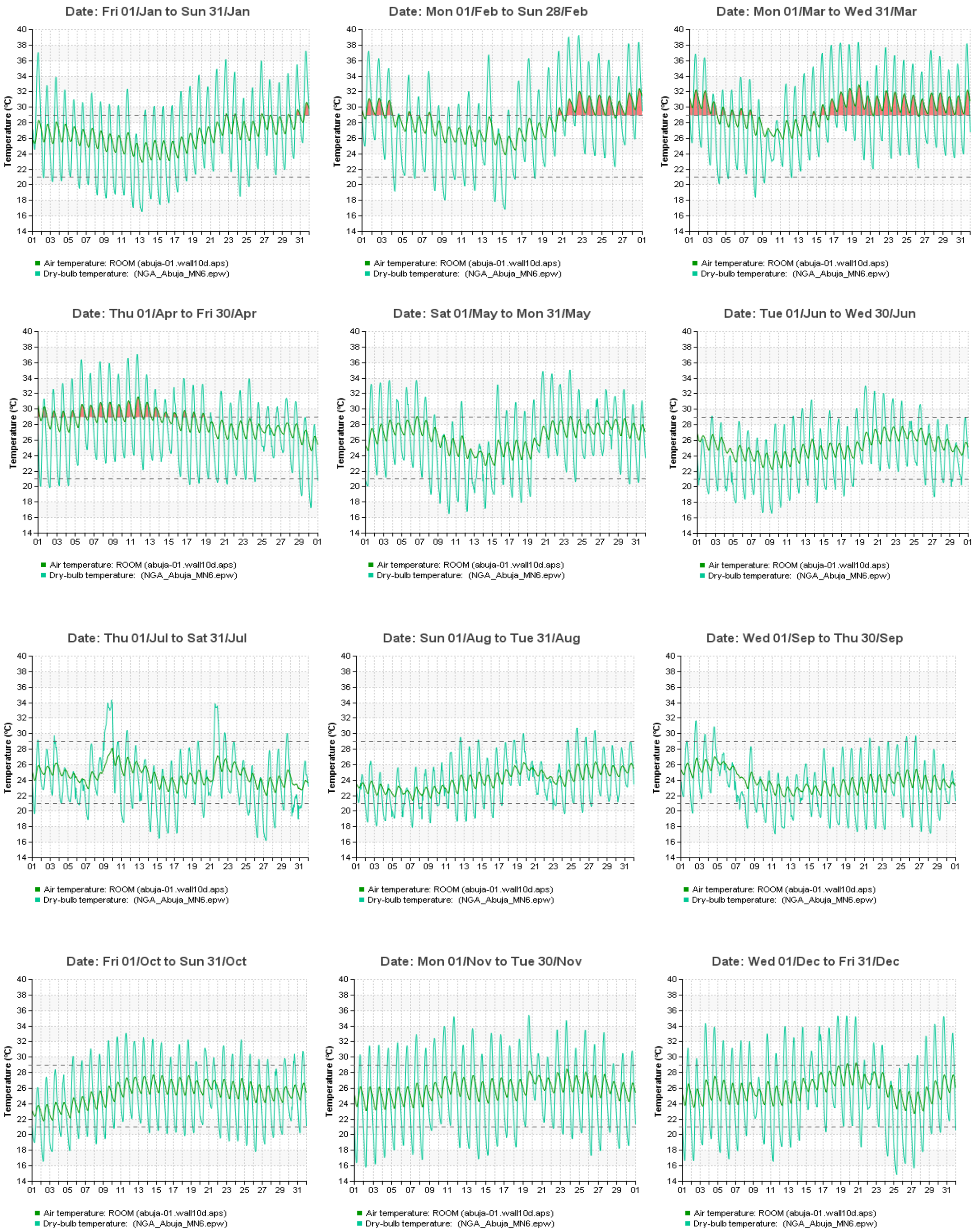
Descriptio	Wall ID: WALL – 03		Thermo physical properties			
	Material compositi (outside to inside	Thickn	U-value (W/m^{2}K)		1.5992	
	Aluminium sheet cladding		R-value (m^{2}K/W)		0.4482	
	Cavity		Mass (kg/m^2)		554.1	
	Hollow Concrete block		Thermal perfo (%)	Too cold <	Comfortable Between 21ºC and 29ºC	Too hot
	Plaster					
			Annual		8(	
			Hot months (Jan-Jun)		6:	

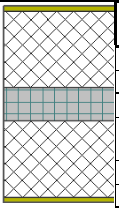


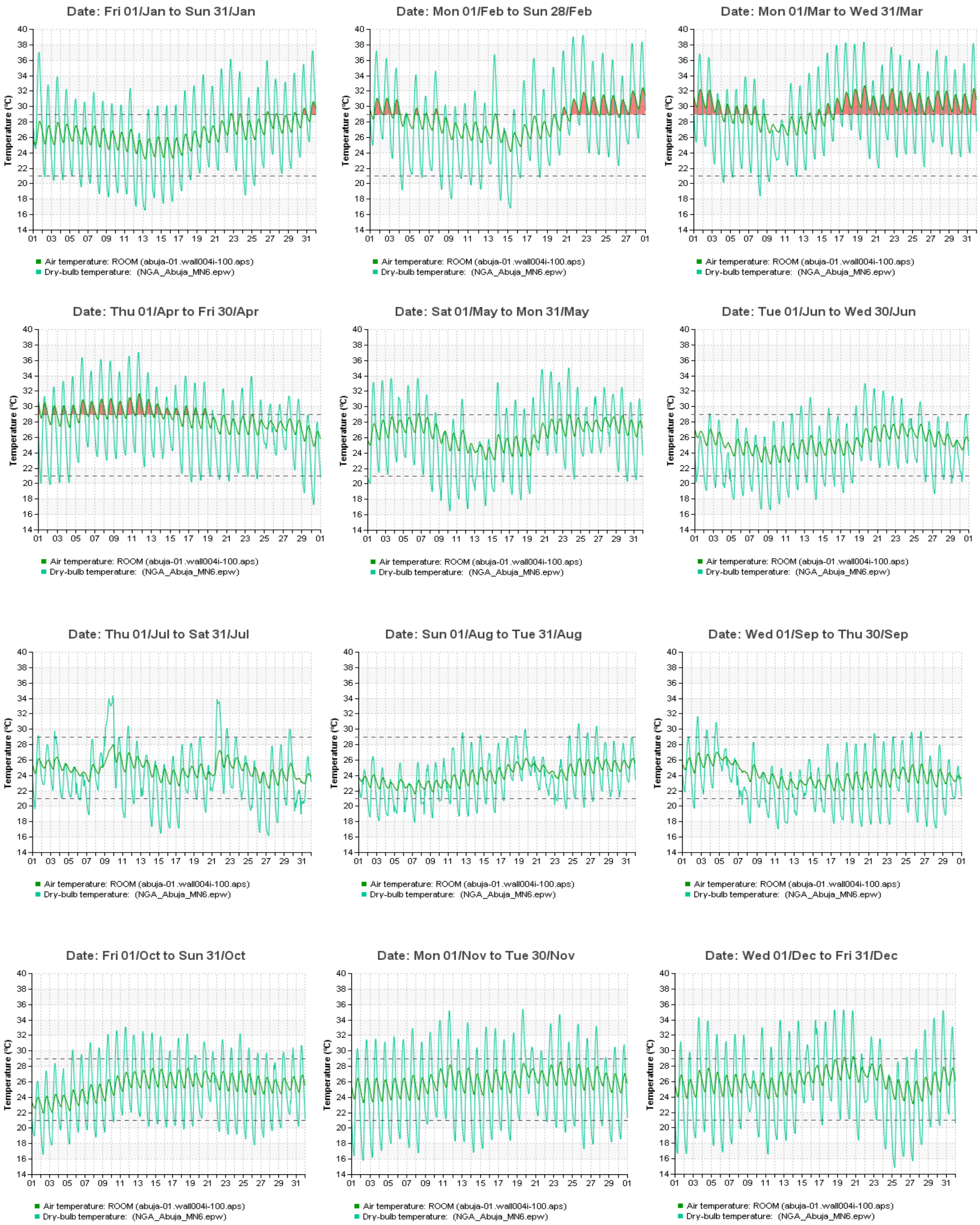
Descriptio	Wall ID: WALL – 04		Thermo physical properties			
	Material compositi (outside to inside	Thickn	U-value (W/m^{2}K)		0.0807	
	Plaster		R-value (m^{2}K/W)		12.2154	
	Hollow Concrete block		Mass (kg/m^2)		393.0	
	Insulation		Thermal perfo (%)	Too cold <	Comfortable Between 21ºC and 29ºC	Too hot
	Plaster					
			Annual		8	
			Hot months (Jan-Jun)		7	

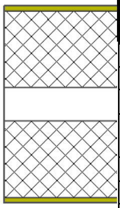


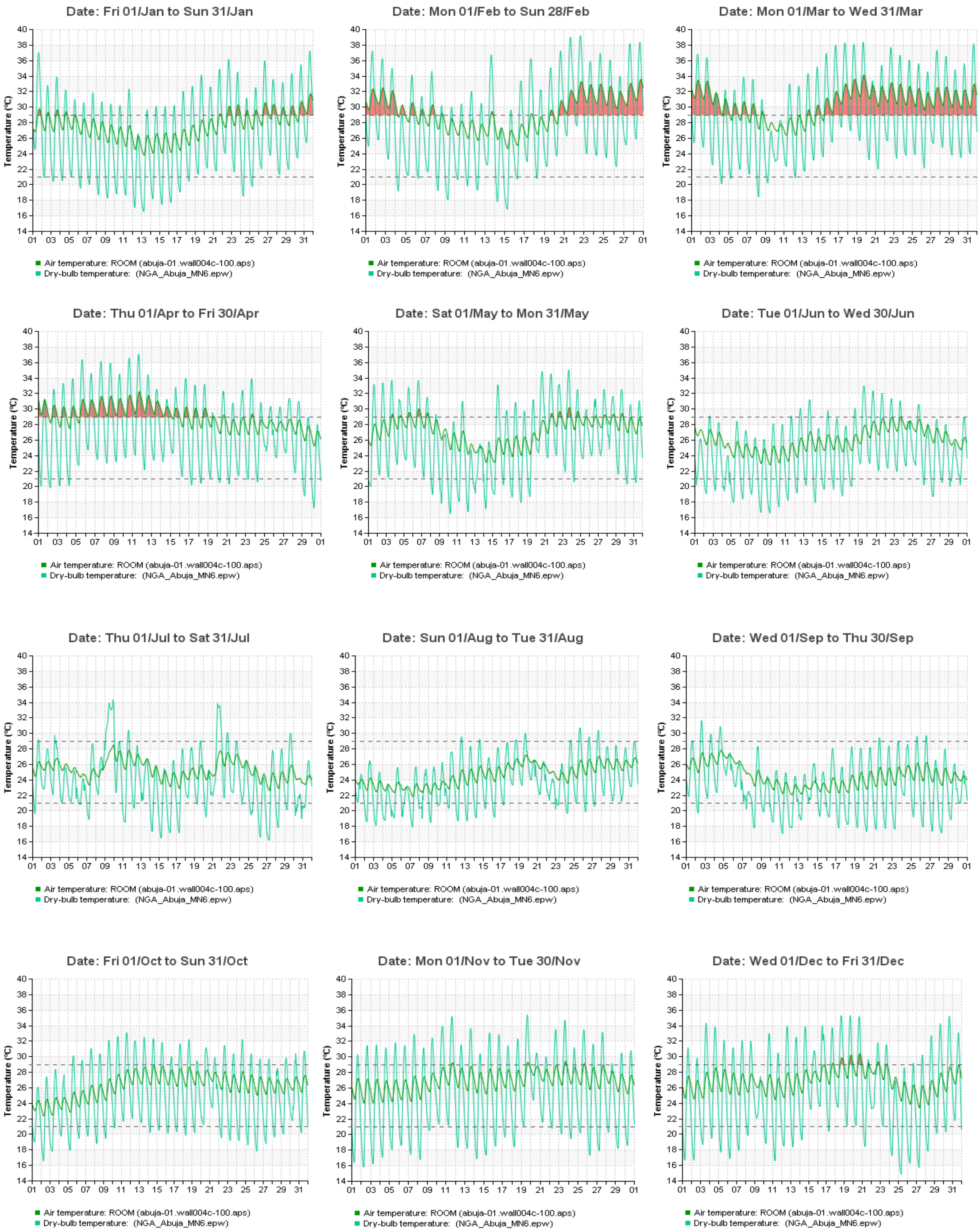
Descriptio	Wall ID: WALL – 05		Thermo physical properties			
	Material compositi (outside to inside	**Thickn**	U-value (W/m^2K)		0.0807	
	Plaster		R-value (m^2K/W)		12.2154	
	Insulation		Mass (kg/m^2)		393.0	
	Hollow Concrete block		Thermal perfo (%)	Too cold <	Comfortable Between 21°C and 29°C	Too hot
	Plaster					
			Annual		8	
			Hot months (Jan-Jun)		7	

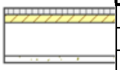


Descriptio	Wall ID: WALL – 06		Thermo physical properties			
	Material compositi (outside to inside	Thickn	U-value (W/m^{2}K)	0.0787		
	Plaster		R-value (m^{2}K/W)	12.5364		
	Hollow concrete block		Mass (kg/m^2)	1106.0		
	Insulation		Thermal perfo (%)	Too cold	Comfortable Between 21ºC and 29ºC	Too hot
	Hollow concrete block					
	Plaster		Annual		8	
			Hot months (Jan-Jun)		7	



Descriptio	Wall ID: WALL – 07		Thermo physical properties			
	**Material compositi (outside to inside)**	**Thickn**	U-value (W/m^{2}K)	1.1192		
	Plaster		R-value (m^{2}K/W)	0.7164		
	Hollow concrete block		Mass (kg/m^2)	1097.00		
	Cavity Hollow concrete block		Thermal perfo (%)	Too cold <	Comfortable Between 21ºC and 29ºC	Too hot
	Plaster		Annual		81	
			Hot months (Jan-Jun)		62	



	**Material composit (outside to insid**	**Thickn**	U-value (W/m^{2}K)		1.6071	
	Weather board		R-value (m^{2}K/W)		0.4452	
	Cavity		Mass (kg/m^2)		29.2	
	Gypsum plasterboard		Thermal perfo (%)	Too cold	Comfortable Between 21^{o}C and 29^{o}C	Too hot
			Annual		6	
			Hot months (Jan-Jun)		5