AN ASSESSMENT OF THERMAL PERFORMANCE OF OFFICE UNITS BUILT WITH SHIPPING CONTAINERS AROUND LAGOS

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ABSTRACT

Portable cabins have steadily gained acceptability as a viable solution towards temporary housing around Nigeria. In recent times, more permanent structures are being assembled using 20feet and 40feet shipping containers as modular units. There is absence of documented habitability assessments of these units. The thermal performance assessment is just one out of many tests that can be carried out on these units to confirm how habitable they are. Temperature, air velocity and humidity assessments were taken during the dry season of the year in single module units of 20feet shipping container office units at different locations and levels of insulations, using some control factors. The micro-meteorological instruments deployed were thermometers, hot wire anemometer and a hand held hygrometer. The units with internally cladded thermal insulation were thermally more efficient as radiant heat from the steel surfaces were shut out from the interior resulting in a higher thermal mass. The vulnerability of the interior to sustained higher temperatures from solar radiation and higher humidity is dependent on volumetric air changes with the external environment via air pressure and opening configuration.

KEYWORDS: Air velocity, insulation, radiant heat, thermal control, thermal performance, thermal mass, ventilation.

INTRODUCTION

There are a lot of materials on thermal comfort and ambient passive controls in cold countries, Southeast Asia and Australia. A survey of the Science Citation and Social Science Citation Indexes [SCI and SCCI] did not reveal any articles originating from Tropical Africa. There are however many articles originating from Ghana and Nigeria when the search is opened up to the rest of the internet. Most of the articles are evaluations of thermal responses of different building typologies to the solar radiation in the area [Ngoka 1976, Ajibola 2001, Lawal and Ojo 2001, Schwerdtfeger,1984.]. The notion that an effective temperature of 23.5% is comfortable indoors [Spagnolo and De Dear, 2002] is relative once the context changes to the tropics. It must be realized that adaptive comfort is a very strong parameter in the metrics of thermal comfort. In tropical Africa where outdoor temperature can approach 40^0c during the dry season, a drop in the ambient temperature indoors is always a respite.

With over 18million shipping containers moving around the world’s oceans and the very high cost of moving them back to their countries of origin without cargo, it is very easy to find discarded containers all over the world. They are being put to use by architects who convert them to habitable units. Recently, whole communities, shopping complexes and complex housing units are being put together using disused shipping containers. Downtown Container Park in Las Vegas, Box Park and Library of things in London and Container Stack Pavilion in Dongshan, China are some of these compound units made exclusively out of the shipping containers. The ability to effectively insulate the walls of the units from the cold condition in these countries is an endeavor that is commonplace. It is normal to insulate dwelling units to prevent loss of heat energy in such places. In the tropics where the intention is to dissipate internally generated heat, the dynamics are different. Shipping containers used in habitable units are insulated to prevent the externally generated heat energy from affecting the internal space. Despite the additional costs incurred in adapting shipping containers for such units, they still remain a far less expensive option than the conventional building practices. Where temporary accommodation is required as may be the case in remote areas and construction sites, they are easily remodeled and transported to site for immediate use. Some companies have fully-adapted units of shipping containers for sale that can be moved from their yards to any location within a very short period.

BACKGROUND

A lot of studies have been carried out on thermal comfort all over the world. Different regions have adopted different guidelines that are applicable for indoor spaces where thermal comfort is desired. In Germany, the VDI-3787 [Mayer 1998] has been adopted. It uses the predicted mean vote [PMV] developed by Fanger [1970] to correlate physiological states of humans with thermal conditions in a controlled environment. It is based on thermal variables that have been reduced to seven point scale [-3 to +3].The scale of zero in the scale is labelled as neutral. ASHRAE 55 however proposes an eleven point scale [+5 to -5]. Since outdoor temperatures are believed to be out of the control of human volition in the short term, there is a lot of expectations on the designed indoor spaces to passively support thermal comfort. Recent global awareness on sustainability and energy conversation have stimulated more research in passive environmental controls. The use of window openings [Rijal et al 2007, Haldi and Robinson 2009, Stavrakakis et al 2012], place change materials [Kenisarin and Mahkamov 2016, Zhou et al 2012], various building elements [Chadan and Alleyne, 2011, Aboulnaga 1998] and plant covering on wall [Kontoleon and Eumorfopoulou 2010, Holm 1989] have been explored in the passive thermal control discourse in tropical climates. Most of these publications assume the use masonry as a standard.

In a situation where the walls of the building enclosure is high yield steel, it may be presumptuous to accept the findings of the various researches as applicable in the context. While earth and concrete have relatively high absorptivity at temperature above 20^0c which is the standard room temperature, they will not yield the stored internal heat appreciably unless the temperature of the ambient air drops at least 5 degrees below the storage temperature.

Steel on the other hand continues to absorb and emit the solar component once there is any marginal drop in surrounding temperature. The solar radiation component that is incident on the external wall of a steel compartment is radiated almost immediately to the internal space.

Heat absorption and emission in steel enclosures

Steel is a very efficient heat transmitter. It has a very high absorption capacity for solar radiation and can yield up to 90% of the absorbed heat almost immediately. A cursory look at the emissivity and absorptivity tables reveals that steel can absorb up to 80% of incident solar radiation and emit about 90% of the absorbed heat almost immediately. Concrete on the other hand can absorb just about 60% of the incident heat energy and emit about 80% of the absorbed energy. From extrapolation, the transmitivity of steel is about 0.75 while that of concrete is about 0.5. At higher temperatures, steel tends to be more efficient as a thermal transmitter. Spaces that are enclosed in steel and exposed to solar radiation are bound to get very hot. The heat is also dissipated very fast when the heat (solar) is removed provided the corrective dynamics of the space allow for good interaction with the building envelope. Where the space is fully enclosed, there is tendency for the mean radiant temperature [MRT] to be very high and sustained for longer periods. The temperature of the interior space will also remain higher for longer periods even when the external temperatures have dropped.

Emissivity coefficient ε is a constant that indicates the radiated component of heat energy from a ‘grey’ tempered material as a ratio of the ‘black’ temper of the same material in accordance with Stefan-Boltzmann Law. A table of some common construction materials is found below at a temperature of 300K since the ratio changes with temperature in most materials.

Surface Material	**Emissivity coefficient - *ε*-**
Anodized Aluminium	0.77
Asbestos Board	0.96
Brick, red rough	0.93
Brick, fireclay	0.75
Clay	0.91
Concrete	0.85
Granite	0.45
White Marble	0.95
Plastered Masonry	0.93
Mortar	0.87
Plaster	0.98
Plaster Board	0.91
Porcelain, Glazed	0.92
Soil	0.90 – 0.95
Oxidized Steel	0.79
Stainless Steel, Weathered	0.85

Galvanized Steel, Old	0.88
Tile	0.97
Pine Wood	0.95
Wrought Iron	0.94

Table1. Emissivity coefficients of common materials

Source: Engineering Toolbox Tables

Substance	**Absorb Factor - Fraction of Incident Radiation Absorbed**
Aluminum, anodized	0.15
Brick, glazed	0.35
Brick, common light red	0.55
Marble, white	0.44
Granite, reddish	0.55
Porcelain	0.50
Steel, vitreous enameled green	0.76
Steel, vitreous enameled dark red	0.81
Steel, vitreous enameled blue	0.80
Iron, galvanized new	0.64
Iron, galvanized white washed	0.22
Concrete	0.60
Asbestos cement, roof tiles red	0.69
Tile, clay red	0.64

Fig. 2 Solar absorptivity coefficients of some common materials

Source: Engineering Toolbox Tables

METHODOLOGY

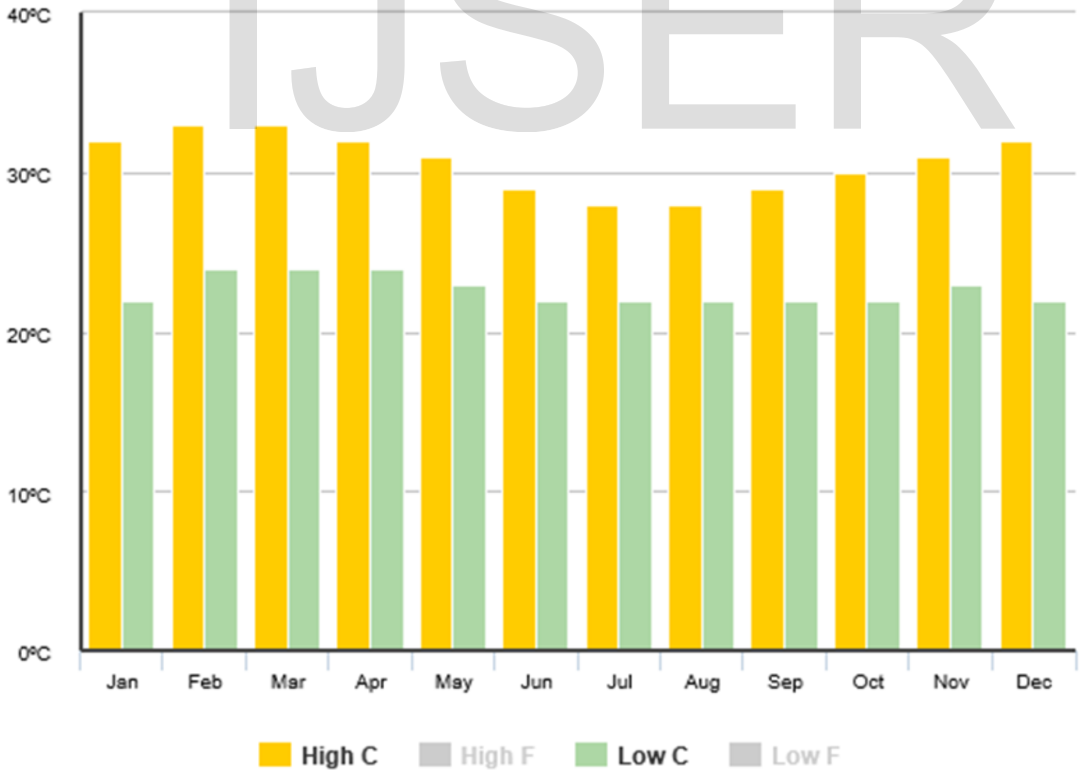
The research location is centered on the Lekki Peninsula in Lagos. Lagos is a tropical city in Nigeria with a temperature range of 21 ^{0}C-38^{0}C. The higher temperatures are recorded during the day around 3pm while the lower temperatures are recorded around 3am in the early hours of the morning. The daily range can sometimes be up to 6^{0}. The location of the research site is coastal and temperatures of 13^{0}C have been recorded on cooler nights and during the harmattan period. Cold winds borne by the ocean currents are responsible for such phenomenon which is usually not sustained.

Fig 1. Lagos State of Nigeria

Fig 2. Research location; Lekki Peninsula

The air velocity in the city is averaged at 7km/hr. - 12 km/hr at a height of 10m. At a height of 1.5m where most of the activities in the city are taking place, an attempt can be made to extrapolate the air velocity by using the equation $\frac{\overline{V_Z}}{\overline{V_1}} = [\frac{Z}{Z_1}]^{\propto}$ where $\overline{V_1}$ is the mean air velocity at height of anemometer which is 10m, $\overline{Vz}$ is the height at which readings are required, Z_1 is the anemometer height and Z is the height at which mean velocity and other micrometeorological readings are being taken, α is the mean velocity exponent, estimated at 0.25 as proposed for suburban areas by Aynsley et al [1977].

Relative humidity in Lagos ranges from 80% to 95%. Indoor thermal comfort is directly influenced by three environmental parameters. Temperature, humidity and air velocity. These three variables have levels of intricate relationships among them that are difficult to correlate without resolving to reduction within the domain of linear relationships between two out of the three at a given time.



	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

High °C	32	33	33	32	31	29	28	28	29	30	31	32
Low °C	22	24	24	24	23	22	22	22	22	22	23	22

Table 3. Minimum and Maximum average monthly temperature readings for Lagos State
Source; Nigerian Meteorological Agency

To assess the performances of the portable cabin units made with shipping containers that are commonly used in Nigeria, a control unit was set up that consisted of just the basic unit without insulation. An initial field survey carried out established that the units built with shipping containers are mostly finished with polished wood or plasterboard paneling with underlays of insulating materials. The two major materials used for insulation are rock wool and polyurethane foam. Corrugated mild steel sheets are also used to construct portables cabin but are mainly used as roadside shops and are not standardized. Where uninsulated units are being used in shipping containers, they were deployed as storage units and bulk sales point for selling bagged materials like cement. Such units are not intended to meet human habitability standards since they only house goods. The units being investigated in this research are those that are built for residential and office use by construction industry professionals. Two other fabricated units of office design were subjected to the same micrometeorological investigations on two locations in the same area. One is a built up area with a lot of infrastructure to give enough alteration in the micro environment. Another location was selected on the beach front with very clear landscape that has the typical waterfront micro climate next to a large water body. The Atlantic Ocean is close to the second location.

For each location and unit, readings were taken three times a day for a period of five days per location. Indoor and outdoor temperatures were compared taking note of the humidity levels and the wind velocity. Statistical evaluation were used to assess the performance of each unit and inferences drawn. Wind speed was taken at a height of 10m above ground in each location and extrapolated. This is to adjust for the variable readings that were observed at the ground level. The values were irregular and changed continuously, making it difficult to record any figure as reading for the chosen time of taking the readings. At higher altitudes, the wind direction was more stable and there were less fluctuations in the readings observed in the sensitive equipment.

The research was carried out and readings taken in and around three adapted units of disused 20ft shipping containers. A control unit which was devoid of insulation and finishes and two other units with different insulating materials were subjected to micro meteorological examination. Ambient condition around the sites of the experiment were also recorded. Readings were taken between 9.00a.m and 3.00pm. When the outdoor temperatures were relatively higher. All units were covered with insulated roofing systems with 600mm eaves on all the sides of the units to prevent direct solar radiated component from influencing the readings

The control unit

The unit is devoid of the standard insulations that are used in the other two units. The window is yet to be installed but the door opening is boarded for taking of readings as would have been in a room with closed doors and open windows.

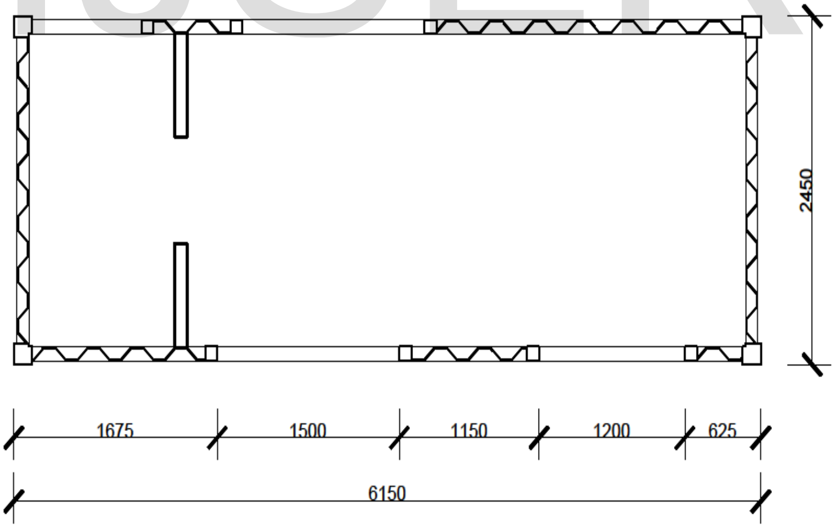


Fig 3. Floor Plan of the control unit showing the walls, internal partitioning and openings

The test units

The units for the research are identified as unit A and unit B. unit A is finished internally with 38mm thick rock wool cladding laid over with 12.5mm thick laminated plywood. Unit B is cladded internally with 44mm thick polyurethane foam finished with 12.5mm thick medium density fiber wood finish. The window openings are 900mm high while the door openings are 2050mm high.

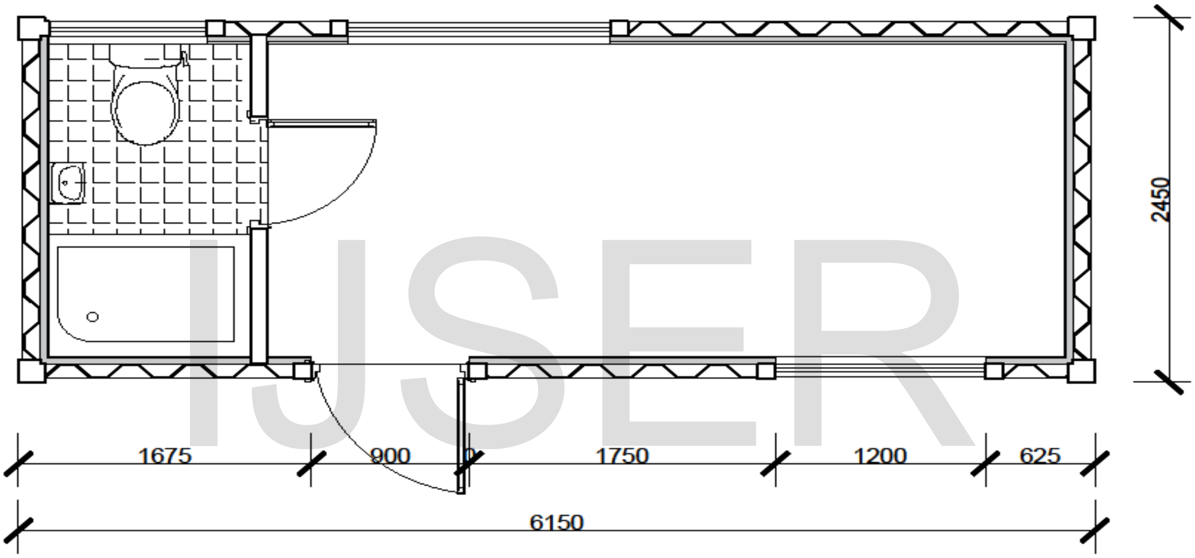


Fig 4. Floor plan test of unit A

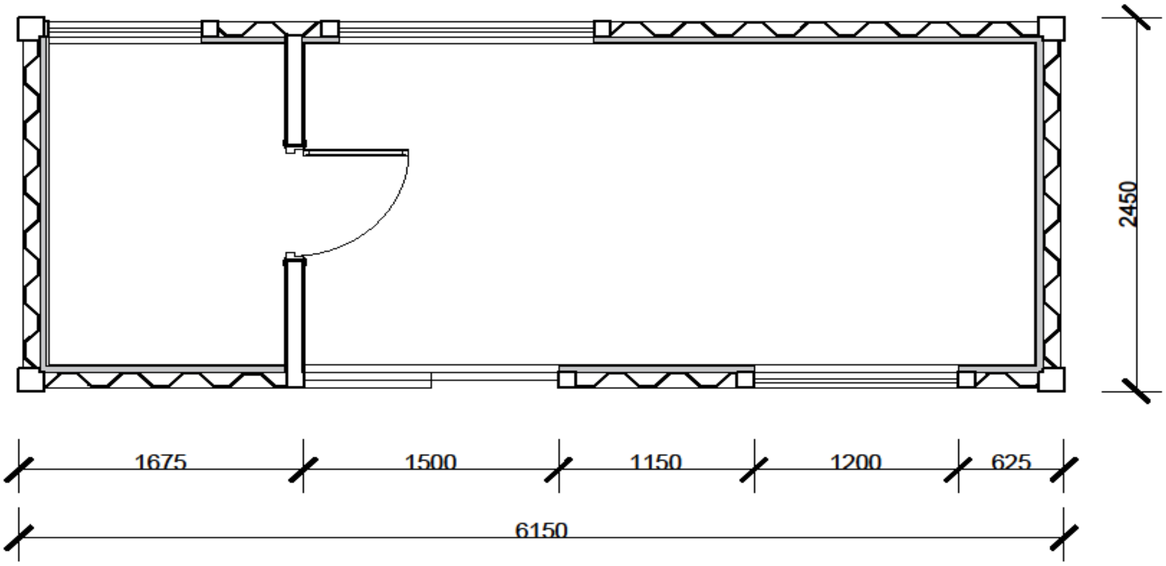


Fig 5. Floor plan of test unit B

READINGS

At the prompt of the time for reading, data is recorded from the equipment for about 10minutes. Only the minimum and maximum values taken at each time of recording are being used for this assessment. This will also accommodate the fluctuating readings from the sensitive equipment. An average could have been used but such an approach may not take cognizance of cases of asymmetric readings.

Day	Time	Humidity (%)	Air speed at 10m (km/hr.)	Derived air speed at 1.5m (km/hr.)	Outdoor temp. (^{0}C)	Indoor temp. (^{0}C)	
1	9.00	84	6	3.7	27.3	27.3	MIN
			6	3.7	27.4	27.3	MAX
	12.00	70	6	3.7	31.7	31.8	MIN
			7	4.4	31.7	31.9	MAX
	15.00	63	6	3.7	32.2	32.8	MIN
			8	5.0	32.5	33.2	MAX
2	9.00	79	6	3.7	29.1	28.8	MIN
			8	5.0	29.1	29.0	MAX
	12.00	67	9	5.6	32.2	32.3	MIN
			9	5.6	32.3	32.3	MAX
	15.00	63	12	7.5	33.6	33.9	MIN
			13	8.1	33.7	34.0	MAX
3	9.00	79	10	6.2	29.9	29.8	MIN
			11	6.9	30.1	29.9	MAX
	12.00	67	6	3.7	32.4	32.5	MIN
			7	4.4	32.6	32.7	MAX
	15.00	71	19	11.8	32.2	32.4	MIN
			19	11.8	32.2	32.5	MAX
4	9.00	79	13	8.1	30.8	30.5	MIN
			14	8.7	30.8	30.6	MAX
	12.00	67	17	10.6	32.9	33.1	MIN
			17	10.6	33.1	33.1	MAX
	15.00	63	15	9.3	32.8	33.1	MIN
			10	6.2	33.1	33.2	MAX
5	9.00	94	25	15.6	23.5	23.3	MIN
			26	16.2	23.5	23.4	MAX
	12.00	89	12	7.5	25.8	26.0	MIN
			13	8.1	26.0	26.1	MAX
	15.00	84	15	9.3	28.2	28.3	MIN
			16	10.0	28.2	28.4	MAX

Table 4. Control unit readings at the ocean side

Day	Time	Humidity (%)	Air speed at 10m (km/hr.)	Derived air speed at 1.5m (km/hr.)	Outdoor temp. (^{0}C)	Indoor temp. (^{0}C)	
1	9.00	94	4	2.5	25.2	25.3	MIN
			5	3.1	25.3	25.3	MAX
	12.00	81	10	6.2	28.8	29.1	MIN
			10	6.2	29.0	29.2	MAX
	15.00	63	4	2.5	32.1	32.4	MIN
			4	2.5	32.1	32.6	MAX
2	9.00	80	No wind	No wind	26.6	26.9	MIN
			No wind	No wind	26.6	27.0	MAX
	12.00	67	51	31.7	32.3	32.8	MIN
			6	3.7	32.5	32.9	MAX
	15.00	68	6	3.7	32.4	33.0	MIN
			7	4.4	32.5	33.0	MAX
3	9.00	89	4	2.5	28.1	28.2	MIN
			4	2.5	28.3	28.4	MAX
	12.00	79	25	15.6	29.9	30.2	MIN
			26	16.2	30.1	30.2	MAX
	15.00	67	6	3.7	32.2	32.4	MIN
			6	3.7	32.2	32.5	MAX
4	9.00	84	15	9.3	29.2	29.4	MIN
			16	10.0	29.4	29.6	MAX
	12.00	67	19	11.8	32.0	32.3	MIN
			19	11.8	32.0	32.3	MAX
	15.00	63	9	5.6	33.0	33.6	MIN
			10	6.2	33.1	33.9	MAX
5	9.00	89	43	26.8	27.4	27.6	MIN
			44	27.4	27.4	27.7	MAX
	12.00	70	7	4.4	28.8	29.1	MIN
			7	4.4	29.1	29.1	MAX
	15.00	75	19	11.8	30.7	30.8	MIN
			19	11.8	30.8	31.0	MAX

Table 5. Control unit readings in the built up area

Day	Time	Humidity (%)	Air speed at 10m (km/hr.)	Derived air speed at 1.5m (km/hr.)	Outdoor temp. (^{0}C)	Indoor temp. (^{0}C)	
1	9.00	94	4	2.5	25.2	25.1	MIN
			5	3.1	25.3	25.2	MAX
	12.00	81	10	6.2	28.8	28.6	MIN
			10	6.2	29.0	28.8	MAX
	15.00	63	4	2.5	32.1	31.9	MIN
			4	2.5	32.1	32.0	MAX
2	9.00	80	No wind	No wind	26.6	26.3	MIN
			No wind	No wind	26.6	26.4	MAX
	12.00	67	51	31.7	32.3	32.4	MIN
			46	28.6	32.5	32.5	MAX
	15.00	68	6	3.7	32.4	32.4	MIN
			7	4.4	32.5	32.4	MAX
3	9.00	89	4	2.5	28.1	28.1	MIN
			4	2.5	28.3	28.1	MAX
	12.00	79	25	15.6	29.9	29.9	MIN
			26	16.2	30.1	29.9	MAX
	15.00	67	6	3.7	32.2	32.2	MIN
			6	3.7	32.2	32.2	MAX
4	9.00	84	15	9.3	29.2	29.2	MIN
			16	10.0	29.4	29.3	MAX
	12.00	67	19	11.8	32.0	31.7	MIN
			19	11.8	32.0	31.8	MAX
	15.00	63	9	5.6	33.0	32.5	MIN
			10	6.2	33.1	32.7	MAX
5	9.00	89	43	26.8	27.4	27.2	MIN
			44	27.4	27.4	27.3	MAX
	12.00	70	7	4.4	28.8	28.9	MIN
			7	4.4	29.1	28.9	MAX
	15.00	75	19	11.8	30.7	30.6	MIN
			19	11.8	30.8	30.6	MAX

Table 6. Unit A readings in the built up area

Day	Time	Humidity (%)	Air speed at 10m (km/hr.)	Derived air speed at 1.5m (km/hr.)	Outdoor temp. (^{0}C)	Indoor temp. (^{0}C)	
1	9.00	94	4	2.5	25.2	25.1	MIN
			5	3.1	25.3	25.1	MAX
	12.00	81	10	6.2	28.8	28.5	MIN
			10	6.2	29.0	28.6	MAX
	15.00	63	4	2.5	32.1	31.8	MIN
			4	2.5	32.1	31.8	MAX
2	9.00	80	No wind	No wind	26.6	26.2	MIN
			No wind	No wind	26.6	26.3	MAX
	12.00	67	51	31.7	32.3	32.0	MIN
			46	28.6	32.5	32.2	MAX
	15.00	68	6	3.7	32.4	32.4	MIN
			7	4.4	32.5	32.4	MAX
3	9.00	89	4	2.5	28.1	28.0	MIN
			4	2.5	28.3	28.1	MAX
	12.00	79	25	15.6	29.9	29.8	MIN
			26	16.2	30.1	29.9	MAX
	15.00	67	6	3.7	32.2	32.2	MIN
			6	3.7	32.2	32.2	MAX
4	9.00	84	15	9.3	29.2	29.2	MIN
			16	10.0	29.4	29.2	MAX
	12.00	67	19	11.8	32.0	31.8	MIN
			19	11.8	32.0	31.9	MAX
	15.00	63	9	5.6	33.0	32.5	MIN
			10	6.2	33.1	32.5	MAX
5	9.00	89	43	26.8	27.4	27.4	MIN
			44	27.4	27.4	27.4	MAX
	12.00	70	7	4.4	28.8	28.7	MIN
			7	4.4	29.1	28.8	MAX
	15.00	75	19	11.8	30.7	30.5	MIN
			19	11.8	30.8	30.6	MAX

Table 7. Unit B readings in the built up area

Day	Time	Humidity (%)	Air speed at 10m (km/hr.)	Derived air speed at 1.5(km/hr.)	Outdoor temp. (^{0}C)	Indoor temp. (^{0}C)	
1	9.00	84	6	3.7	27.3	27.1	MIN
			6	3.7	27.4	27.2	MAX
	12.00	70	6	3.7	31.7	31.4	MIN
			7	4.4	31.7	31.5	MAX
	15.00	63	6	3.7	32.2	32.1	MIN
			8	5.0	32.5	32.1	MAX
2	9.00	79	6	3.7	29.1	28.8	MIN
			8	5.0	29.1	28.9	MAX
	12.00	67	9	5.6	32.2	31.8	MIN
			9	5.6	32.3	31.9	MAX
	15.00	63	12	7.5	33.6	33.6	MIN
			13	8.1	33.7	33.7	MAX
3	9.00	79	10	6.2	29.9	29.7	MIN
			11	6.9	30.1	29.8	MAX
	12.00	67	6	3.7	32.4	32.3	MIN
			7	4.4	32.6	32.4	MAX
	15.00	71	19	11.8	32.2	32.2	MIN
			19	11.8	32.2	32.2	MAX
4	9.00	79	13	8.1	30.8	30.4	MIN
			14	8.7	30.8	30.5	MAX
	12.00	67	17	10.6	32.9	32.8	MIN
			17	10.6	33.1	32.8	MAX
	15.00	63	15	9.3	32.8	33.1	MIN
			10	6.2	33.1	33.1	MAX
5	9.00	94	25	15.6	23.5	23.2	MIN
			26	16.2	23.5	23.3	MAX
	12.00	89	12	7.5	25.8	25.7	MIN
			13	8.1	26.0	25.8	MAX
	15.00	84	15	9.3	28.2	28.3	MIN
			16	10.0	28.2	28.3	MAX

Table 8. Unit A readings in the ocean front environment

Day	Time	Humidity (%)	Air speed at 10m (km/hr.)	Derived air speed at 1.5(km/hr.)	Outdoor temp. (^{0}C)	Indoor temp. (^{0}C)	
1	9.00	84	6	3.7	27.3	27.1	MIN
			6	3.7	27.4	27.1	MAX
	12.00	70	6	3.7	31.7	31.4	MIN
			7	4.4	31.7	31.4	MAX
	15.00	63	6	3.7	32.2	32.1	MIN
			8	5.0	32.5	32.2	MAX
2	9.00	79	6	3.7	29.1	28.6	MIN
			8	5.0	29.1	28.6	MAX
	12.00	67	9	5.6	32.2	31.8	MIN
			9	5.6	32.3	31.8	MAX
	15.00	63	12	7.5	33.6	33.6	MIN
			13	8.1	33.7	33.6	MAX
3	9.00	79	10	6.2	29.9	29.6	MIN
			11	6.9	30.1	29.7	MAX
	12.00	67	6	3.7	32.4	32.2	MIN
			7	4.4	32.6	32.2	MAX
	15.00	71	19	11.8	32.2	32.2	MIN
			19	11.8	32.2	32.2	MAX
4	9.00	79	13	8.1	30.8	30.3	MIN
			14	8.7	30.8	30.4	MAX
	12.00	67	17	10.6	32.9	32.6	MIN
			17	10.6	33.1	32.6	MAX
	15.00	63	15	9.3	32.8	32.8	MIN
			10	6.2	33.1	32.9	MAX
5	9.00	94	25	15.6	23.5	22.8	MIN
			26	16.2	23.5	22.9	MAX
	12.00	89	12	7.5	25.8	25.6	MIN
			13	8.1	26.0	25.7	MAX
	15.00	84	15	9.3	28.2	28.1	MIN
			16	10.0	28.2	28.2	MAX

Table 9. Unit B readings in the ocean front environment

DISCUSSION

Adequate field experiments are required to generate long term data in the determination of indoor thermal environments [Fountain et al, 1996]. Indoor thermal performance is also dependent on the surrounding meteorological composition [Singh et al 2010]. The thermal mass of steel is at the lower end of the spectrum in building materials. The thermal performance of any interior environment with respect to the ambient conditions is directly related to the thermal mass of the shell [Gregory et al 2008]. Relevant data for different steel models for assuming thermal performance is lacking especially in the tropics since it is not a common material for building envelope construction. One of the secondary functions of a built shell is to modify external micro climatic conditions for human comfort. Buildings can also help in the resolution of the current energy problems by enhancing comfort levels and saving costs in mechanical climate controls. The U.S. Department of Energy estimates that 50% to 70% of energy consumed in an average American home is taken up by space heating and cooling. This percentage tends to rise in the colder regions of the world. In hotter climates, energy is expended more on cooling and ventilation. Al-Homoud [2005] recommends thermal insulation for roofs and walls of buildings in all climates. By using insulation to manipulate the interior heat parameters, it is assumed that the outdoor air quality is acceptable to a large extent. Chemical concentrations in the air, air speed and humidity also affect human comfort and may need to be monitored and sometimes modified too. In small spaces like the 20 feet shipping containers which are under investigations, it is assumed that the variations in air parameters around the room are minimal [Chen 2009]. The air is supposedly well mixed. This may not be acceptable in large spaces like cinemas and theaters where parameters may change appreciably within the space. Less emphasis is laid on the air velocity in the experiment. Melikov et al [2007] observed that low velocity measurements with a hot-wire or hot-sphere anemometer are prone to errors. The equipment need frequent calibrations and have their limitations. It is generally argued that air velocity affects ventilation and ultimately internal temperature of a space [Mahdavi and Proglhof, 200]. The levels of humidity may also have a great impact on human comfort. When air is cool and dry, it is generally perceived as fresh [Fang et al 2004]. This is irrespective of the cleanliness of the air. The humidity of air and the velocity lend themselves to minimal passive environmental controls.

Temperature and heat transfer on the other hand, can be manipulated to a very large extent passively.

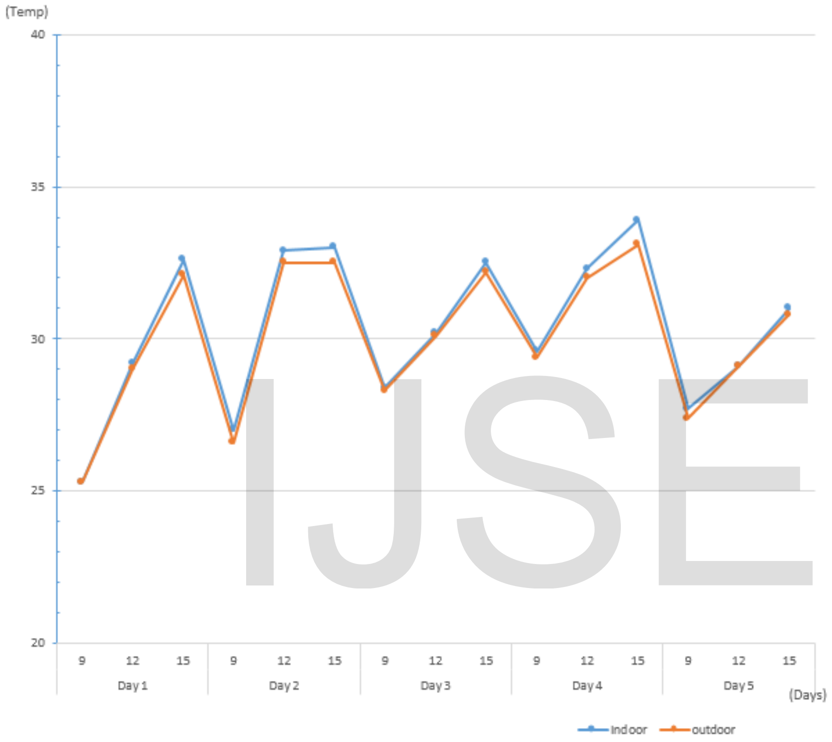


Fig 3. Control Unit (Built Up)

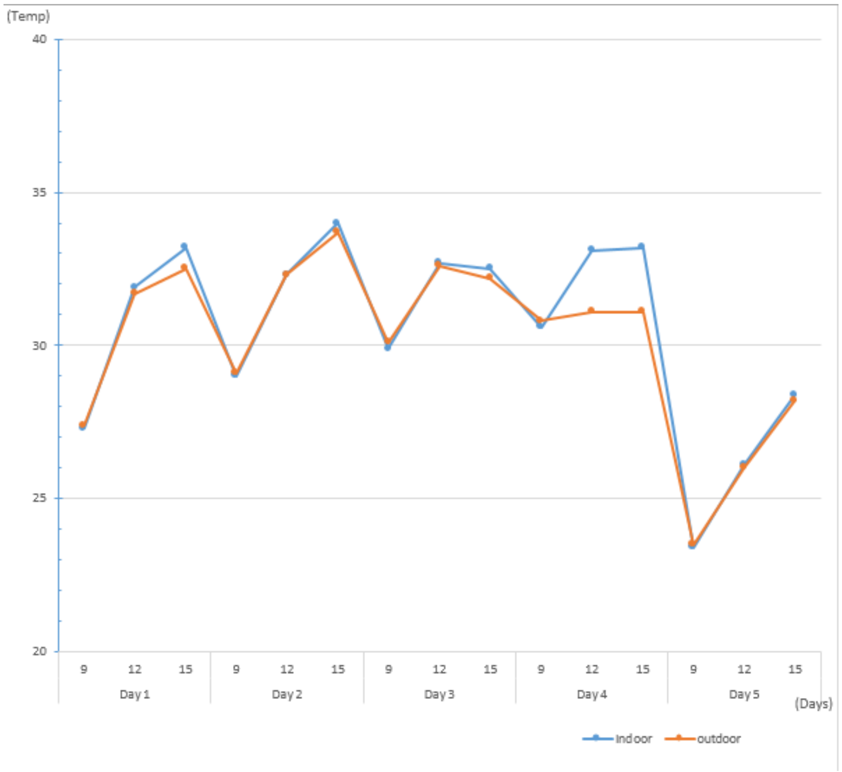


Fig 4. Control Unit (Ocean Side)

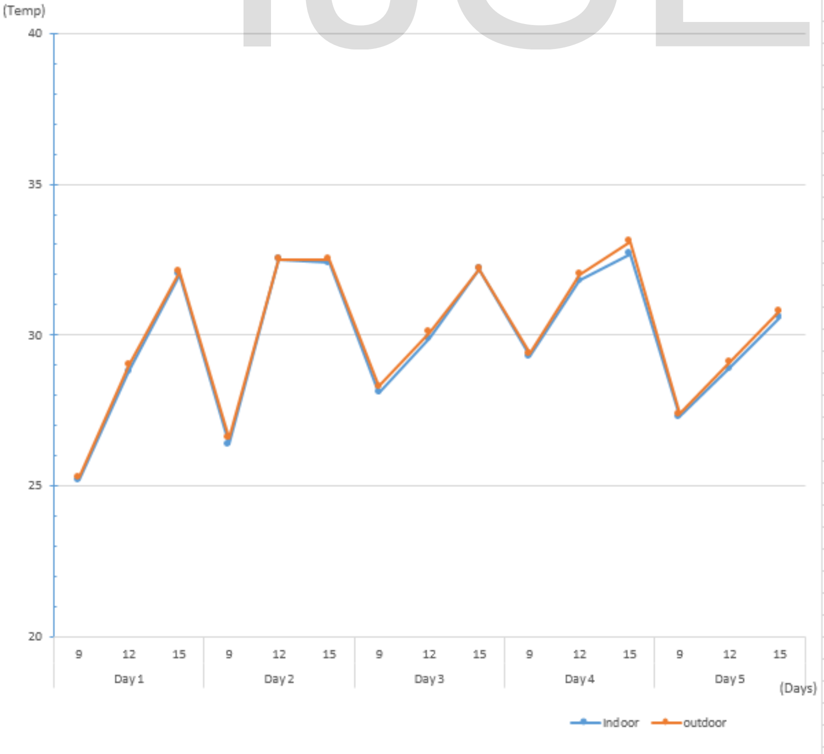


Fig 5. Unit A (Built Up)

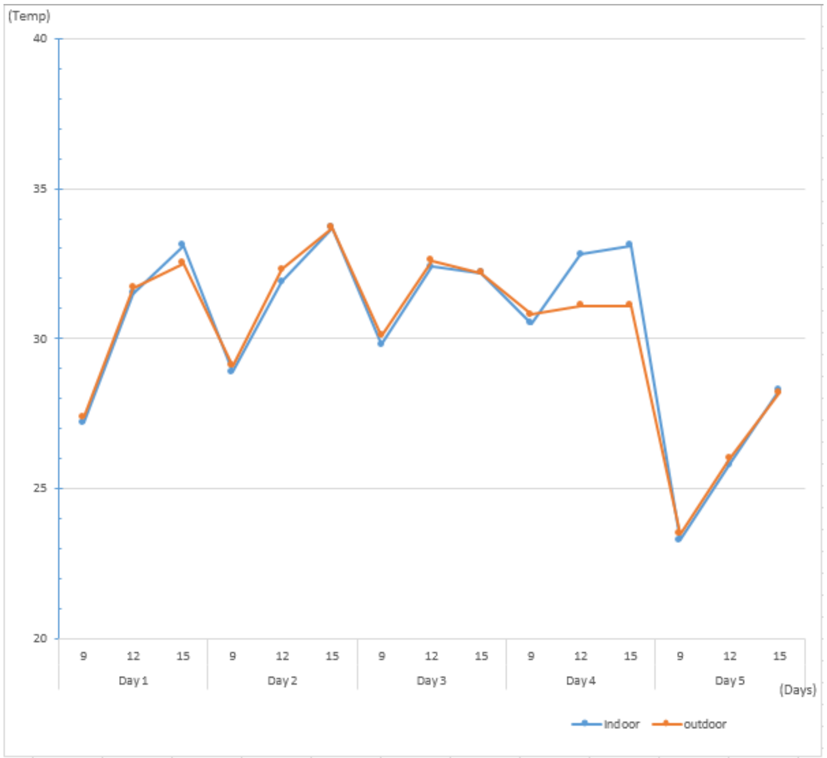


Fig 6. Unit A (Ocean Side)

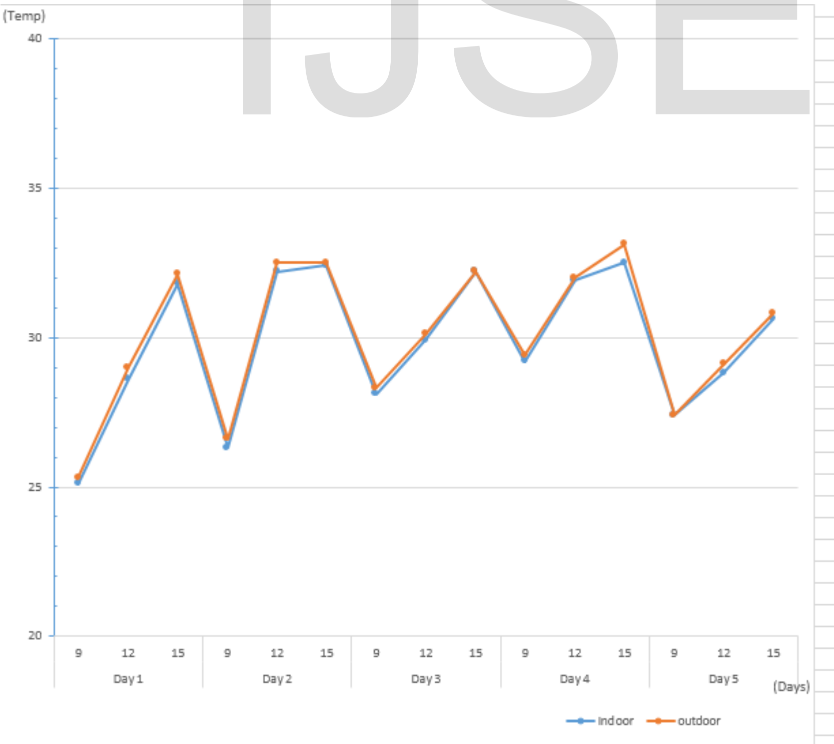


Fig 7. Unit B (Built Up)

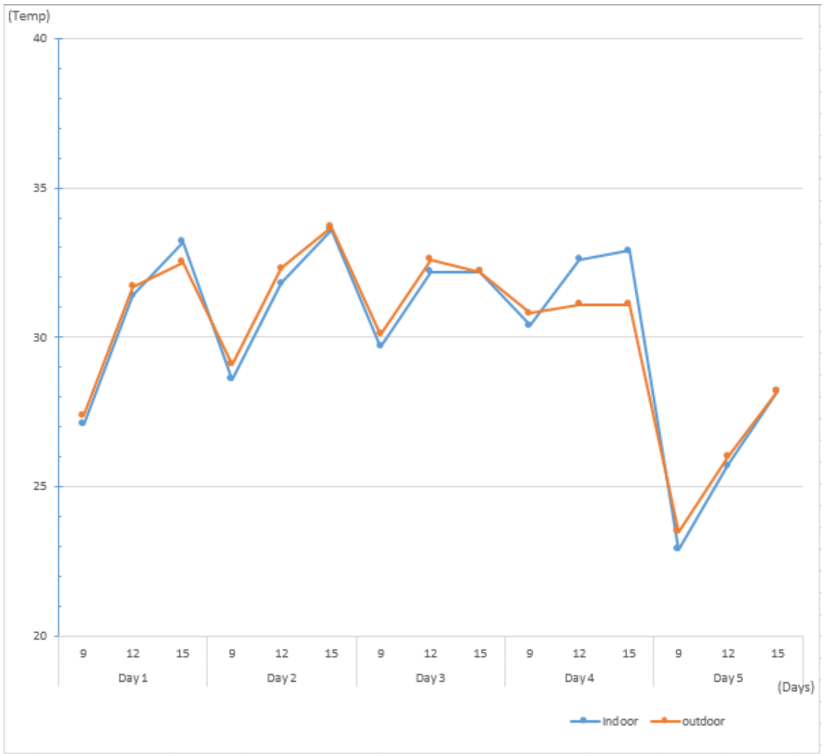


Fig 8. Unit B (Ocean Side)

A statistical analysis of the results does not show any significant difference in the indoor and outdoor temperature readings when correlations were carried out at 0.05 level of significance. The significant difference is observed when the datum is moved from 0 ^{0}C to 22 ^{0}C. This is tenable since readings below this temperature were not observed throughout the investigation. The general trend shows the control unit having slightly higher or equal indoor temperatures with respect to outdoor temperatures in the mornings and more deviations as the days progressed till 15.00hrs. A deduction can be made that the cooler overnight conditions that were transmitted indoors are quickly regressed by the solar heating that takes place at sunrise. Shavir et al (2001) submitted that thermal mass and night ventilation may determine the direction of the temperature swings within the building on a daily basis. The continuous higher readings observed during the day may indicate that day time ventilation in the unit is not efficient enough to dissipate the heat generated by the radiant sources of the unit which are the walls. On the other hand, the insulated units A and B actually indicate lower temperatures in the interior of the units at the same period. The insulation reduces the radiant heat being contributed to the interior of the units. It can be deduced that such a phenomenon and the inefficient ventilation processes in the units as predicted by Shaviv et al (2001) slow down the heating process of the interior. The slight differences in the two readings actually reveal the levels of insulation efficiency of the two insulation composites for the different units. In larger structures that are naturally ventilated, temperature differences occur all over the building no matter how small [Yao et al 2009]. The settings of the research allowed for cross ventilation at all times. This will allow the tendency for equilibrium where the temperature outdoor and the one indoor will want to converge due to heat transfer between the two environments. A different setting that does not allow such a direct exchange of heat will definitely yield more significant differences in the indoor and outdoor temperature readings. It is not farfetched to assume differences of over 1^0 C in the outdoor and indoor temperatures in such instances. If a 1.5^0C difference in the PMV scale can take thermal comfort to the next level on the Fanger Scale [Fanger 1970] then the differences in the readings are significant. In terms of thermal comfort which is the ideal in thermal performance evaluation in buildings, many variables are involved. The taking of air velocity measurements and the relative humidity may help to further analyze the results obtained in the temperature readings and determine if the units are comfortable within limits set by the thermal comfort discourse. The target environment must offer a respite from the general environment by virtue of its composition if thermal comfort must be achieved. Self-regulation in enclosed spaces more often than not will determine if occupants are comfortable [Wohlwill 1975]. Issues related to physiological, psychological and behavioral adaptations [Brager De Dear 1998, De Dear et al 1998] which are all in the domain of self-regulation differ from person to person in the sensation of adaptive thermal comfort which the current discourse has used to shift the paradigm from environmental parameters to individual.

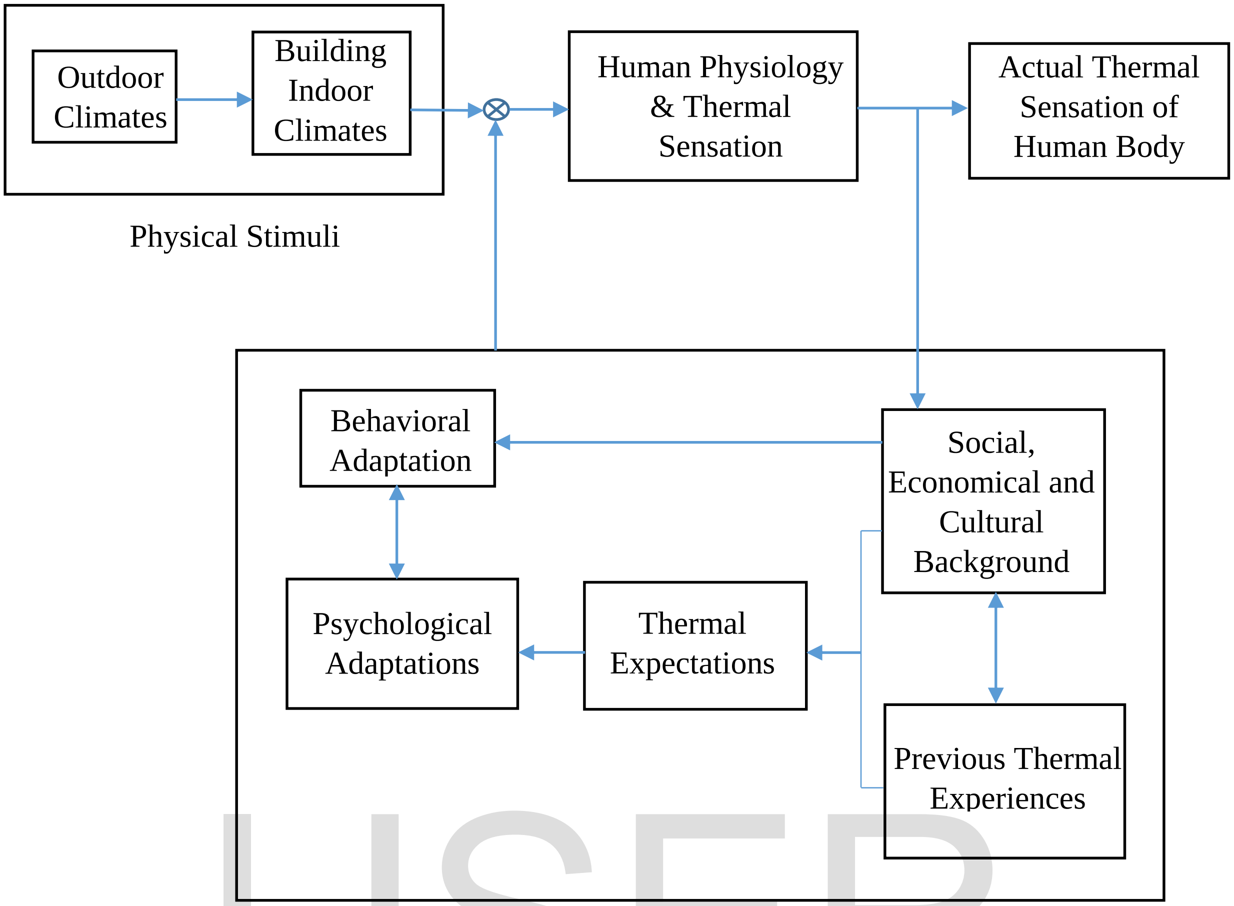


Fig 9. Thermal Comfort Adaptive model

Source: Yao et al [2009]

There is a need to consider the spatial and enviro-spatial implications of the units used for the research and their interpretations in the thermal performance discourse. The total spacing for cross-ventilation is about 3.1m^2 while the total wall area for the shell is 51.6m^2. Such a large surface area covered by the steel shell will transmit more heat. The openings constitute less than 10% of the walls which is about 3% effective cross ventilation aperture in the Bernoulli equation. Stavrakakies et al [2012] concluded that multiple openings and wind ward location of the openings will achieve maximum ventilation. Heiselberg and Sandberg [2006] proved that opening area, window type, temperature difference, pressure difference, control strategy and local geometry all affect the volume flow rate of air through a naturally ventilated room. The limiting assumptions which were part of the classical approach in ventilation calculation became less relevant in large openings. The definition of "large openings" was not made clear in the previous publications but having an opening of 5% of the total wall surface cannot be considered as large. In essence, ventilation efficiency is increased by increasing the size of openings in rooms.

By examining the statistical analysis and graphs, it is obvious that there is a lag as the temperature rises in the outdoor readings before such readings are attained indoors, an indication of an effective thermal mass in the experimental units. The control unit shows a different trend. The temperatures indoor rise above the outdoor temperature after the first readings at 9.00hrs, the same period when the experimental units start showing a thermal mass efficiency.

CONCLUSION

The readings and the analysis show that the effect of cross ventilation cannot be under emphasized in the deployment of shipping containers as domestic housing or office accommodation where mechanical ventilation is not available. The use of the units without adequate insulation in the hot tropical environment generates higher temperatures in the interior during the day. Such a condition is undesirable as it offers no respite from the hot and humid environment that is typical of the area for most of the year. Units that have adequate insulation perform better. The aspect of volumetric air changes may become more relevant if the units have people in them. This will take care of heat generated by human metabolism and the moisture from respiration by individuals in the space. The research has shown that with adequate insulation, the thermal performance of housing units built with shipping containers is satisfactory. Higher levels of thermal comfort can be achieved by monitoring the ventilation. Where active thermal controls are to be deployed for the units, provision of higher levels of insulation will definitely save energy costs.

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