Independent verification of a climate-based worldwide building energy index

By

Prof. Bimal Kumar
Dr Rohinton Emmanuel
School of Built and Natural Environment
Glasgow Caledonian University

Submitted to:

Dr Branka Dimitrijevic
Director
CIC Start Online
Glasgow Caledonian University
70 Cowcaddens Road
Glasgow G4 0BA

19 October 2010

Independent verification of a climate-based worldwide building energy index

Context

The SME partner IES, has prototyped a set of energy indices that can be used to assess, classify and compare any worldwide climate (weather data or extrapolated climate change data) for the purposes of understanding climate and for the use in sustainable building design.

The indices are intended as rapid and interactive holistic design tools applicable to any building type, with any design strategy, in any location worldwide and for the simple quantification of the impact of climate change on building energy progressively over a sustainable building's lifecycle.

The basis of the indices is the fact that climate underlies building energy use and it is therefore possible to compare designs relative to climate, visualize where design emphasis needs to be placed and directly and interactively track the effect of design strategies.

The index is applicable to both the design and operational phases of buildings and is directly usable by building professionals without the need for specialist energy knowledge i.e. Architects, quantity surveyors, students, etc.

Aim and Objectives

The SME was in need of an independent peer review and detailed verification to prove the prototyped index performs successfully. With this need in mind the academic partner carried out a review of the Climate Energy Index (CEI) and the Building Energy Index (BEI) developed by the SME partner with the aim of verifying their scientific soundness and ease of applicability. The following tasks were performed:

A peer review or the physics and implementation of the Index
An extensive series of tests to confirm the validity of the Index
A series or robustness tests

The academic partner of this project comprised of a team from the School of Built & Natural Environment, comprising of Prof. Bimal Kumar and Dr. Rohinton Emmanuel. We undertook an independent academic review of this interesting idea for the mutual benefit of improving the index as well as to learn valuable insight into current thinking on assisting in sustainable building design.

The SME partner has worked previously with this academic partner and wished to maintain the relationship that is proving beneficial to both parties.

Review

Principles of the Indices – CEI and BEI

Efforts to quantify normative energy consumption in buildings (especially housing) began with the energy crisis in the 1970s. Given the wide disparity in energy consumption patterns even within the developed world and the importance of the built environment in reducing national energy consumption, there was a need to benchmark building energy performance with a view to standardize and codify the best practices. A review of such early attempts is given by Yannas (1994).

One of the early 'energy indices' was developed by Yannas (1990). According to this index (called the Energy Index – EI), a notional detached dwelling complying with the 1990 UK Building regulations would consume approx. 100-115 kWh per annum per m^2 of floor area. A building fulfilling all the known 'good design' principles (i.e. south facing windows, double glazing, insulated walls and roofs, tight construction – 0.5 ACH and mechanical ventilation with heat recovery) will have an EI of less than 30 kWh/year/m^2 (Yannas, 1996). This compares well with the most stringent current standards (for example the Passivhus standards [Feist, 2008] or the Code for Sustainable Homes [DCLG, 2006]).

Attempts to quantify the 'climate burden' imposed by external climate on buildings have an even longer history. Early attempts from the time of Silpasastra in India (Achcharya, 1979) and Vitruvius (Morgan, 1960) in Rome focused on design exemplars based on climate types. An approach based on meteorological data was attempted by Mahoney in 1965 (cf. Koenigsberger, et al., 1974).

The CEI developed by the SME partner is an attempt to quantify the 'climatic burden' on a building by outside air. It has four component loads: two sensible energy loads (heating and cooling) and two latent energy needs (humidification and dehumidification). The CEI is defined thus:

CEI = Sum of (Sensible Cooling, Sensible Heating, Humidification, dehumidification).

It is expressed in kWh/yr for a given volume of air (in m^3/hr). Table 1 presents the CEI values for 14 representative geographical locations from around the world.

Table 1: CEI values for selected representative locations

Location	CEI	Sensible Heating	Sensible Cooling	De-humidification	Humidi-fication
Fairbanks	31.96	26.83	0	0	5.12
Minneapolis	19.25	16.01	0.39	0.35	2.49
Boston	14.19	12.18	0.14	0.06	1.81
Baltimore	14.11	11.08	0.79	0.79	1.44
Glasgow	13.4	13.04	0	0	0.36
London	10.11	9.97	0	0	0.13
Los Angeles	5.06	4.85	0	0	0.21
Sydney	4.72	4.28	0.27	0.14	0.03
Phoenix	6.26	3.18	2.44	0.04	0.6
Houston	12.35	6.54	2.75	2.88	0.19
Abu Dhabi	14.77	3.35	5.94	5.48	0
Miami	12.01	4.05	4.13	3.83	0
Bangkok	22.43	4.79	8.05	9.58	0
Singapore	25.72	5.43	7.56	12.73	0

The Building Energy Index (BEI) developed by the SME partner expresses the CEI in terms of energy need of a given building.

$$BEI = CEI \times OA/FA$$

where, BEI= Building Energy Index (kWh/yr/m^2);
OA= Outside air intake (both infiltration and auxiliary ventilation (m^3/hr);
FA = Floor area (m^2)

Validity tests

In order to validate the CEI/BEI, we followed the following approach:

Compare the CEI against a previously developed and validated attempt to quantify the 'climatic burden;'
Compare the BEI outputs provided by the SME partner against the output from a simple parametric building energy simulation tool.

The index chosen for the comparison of CEI is the Mahoney's Table (cf. Koenigsberger et al., 1974). A detail overview of the chart is presented in Appendix 1.

We used DEROB-LTH (Kvist, 1999) to compare the outputs from the BEI.

Validity of the Climate-Energy Index (CEI)

The CEI is directly comparable in its approach to Mahoney's Chart (cf. Koenigsberger, et al., 1974). Mahoney's Chart combines Air temperature (AT), Relative Humidity (RH), Wind and precipitation data to gauge the necessity for pre-determined passive / low energy building responses to climate.

However, Mahoney's chart is not a single number, it therefore needs to be converted to such if we are to compare it with a single number provided by the CEI.

We used the following approach to 'quantify' the Mahoney's Chart. The chart attempts to quantify the 'climatic burden' of a given set of weather data in terms of six indices:

H1 – Ventilation essential
H2 – Ventilation desirable
H3 – Rain protection essential
A1 – Thermal mass essential
A2 – Outdoor activity possible
A3 – Heating essential

Based on these indices, the Chart recommends design strategies in terms of the following passive design options:

ventilation
rain protection
thermal mass
Heating

As could be seen from the description of these categories, all of them cannot be of equal weight (for example, H1 and H2 are not of the same weight; H1 being an 'essential' criteria should have a higher weightage than H2 – a desirable criteria). For our current purpose, we performed the following modification:

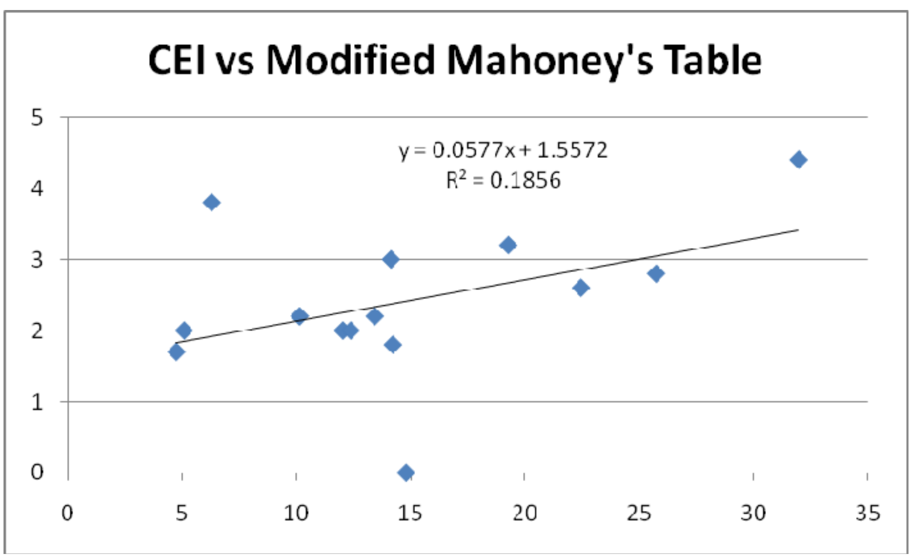
Modified Mahoney Chart = [(H1 x 2) + (H2 x 1) + (H3 x 2) + (A1 x 2) + (A2 x 1) + (A3 x 2)]/10

Our approach to validate the CEI therefore used a modified Mahoney Chart to 'predict' the CEI (by simple regression) and then examine the anomalies, if any, against a bioclimatic chart to explain the 'severity' of the climatic load. For this purpose we chose the most widely used bioclimatic chart – Givoni's thermal comfort chart (Givoni, 1989). Givonis Chart plots monthly maximum/minimum air temperature/relative humidity onto a modified psychrometric chart showing zones of influence of nine passive/active building design options.

Figure 1 shows a comparison of CEI numbers with the modified Mahoney Chart number for 14 cities from around the world. Weather data for our calculations were obtained from a source independent (Weatherbase, 2010) of the one used for the calculation of CEI:

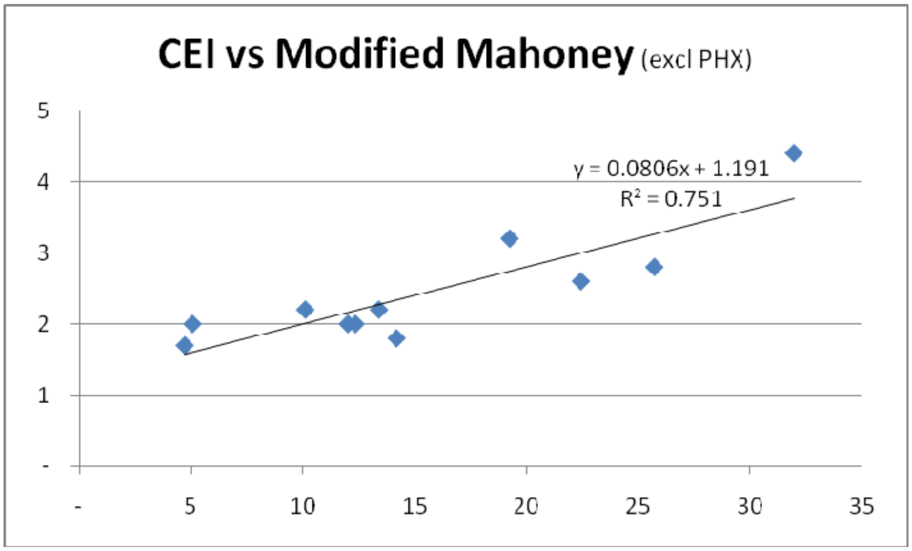
Fairbanks
Minneapolis
Boston
Baltimore
Glasgow
London
Los Angeles
Sydney
Phoenix
Houston
Abu Dhabi
Miami
Bangkok
Singapore

Figure 1: Comparison of 'climate burden' imposed by 14 cities from around the world



As can be seen from Fig 1 the match between the two indices is very poor. However, the situation improved dramatically when an outlier (in this case, Phoenix, USA) was removed (see Figure 2)

Figure 2: Improved predictive ability of CEI



We suspect the reason for this anomaly could be one or both of the following:

1. The humidification energy need estimated by the CEI for Phoenix (0.6 kWh/yr/m^3/hr) is too low (perhaps a data error). This seems a reasonable suspicion given the relatively high values for other cities known to be wetter – for example, the energy needed for 'humidification' in Glasgow is said to be 0.36 kWh/yr/m^3/hr).
2. Perhaps 'sensible' and 'latent' energy needs of a climate should be 'weighted' differently, on account of their unequal effects on human perception of thermal comfort (a fact accentuated by high levels of humidity or temperature)

In addition to the above, the 'extreme' nature of the climate of Phoenix too needs to be factored in. Figure 3 plots the monthly weather data for Phoenix on Givoni's Bioclimatic chart. As can be seen from Fig 3, the monthly climatic conditions vary widely (from very hot, dry in July and August daytime to very cold and humid nights in December to February). Thus, any attempt to look at the 'annual' climatic burden will tend to gloss over the extreme variations in monthly climatic requirements (i.e. the de-humidification need in the winter will be cancelled by the humidification need in the summer). On the other hand, a more 'mild' climate such as that in Glasgow, Scotland or Sydney, Australia (Figure 4) has less seasonality and therefore a more uniform 'climatic burden.'

We therefore recommend the following:

1. CEI is a good indicator of the 'climatic burden' imposed on buildings by 'mild' external climates (i.e. climate that have a more predictable variation in their monthly climatic burden on buildings)
2. It's performance may be improved by examining any data anomaly (especially with respect to 'humidification' and/or 'de-humidification'
3. If point no. 2 does not adequately address CEI's performance in extreme climates (i.e. climates with wider monthly variations) perhaps a weighting factor could be introduced

to either increase or decrease the importance of latent energy need (i.e. humidification or de-humidification).

Figure 3: Bioclimatic need in an 'extreme' climate (Phoenix, USA)

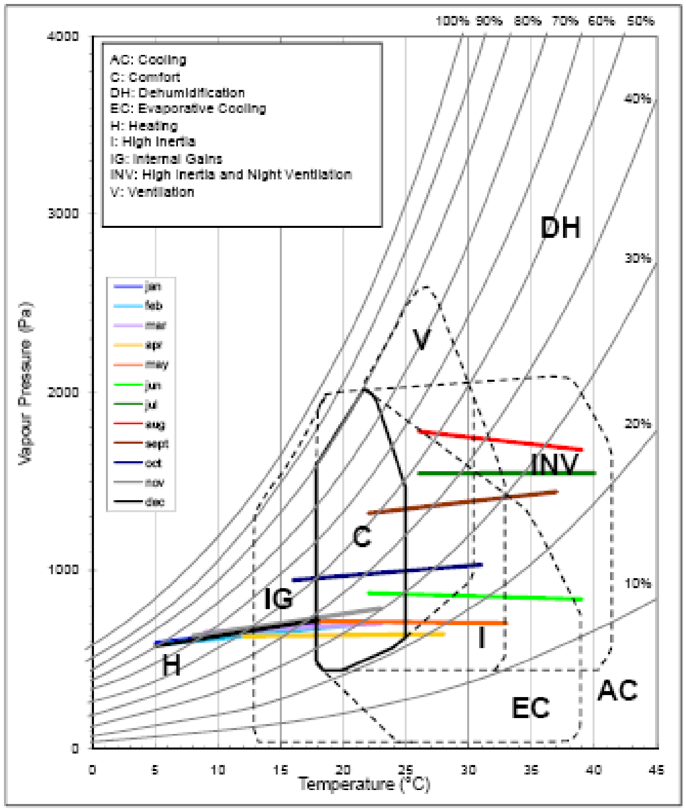
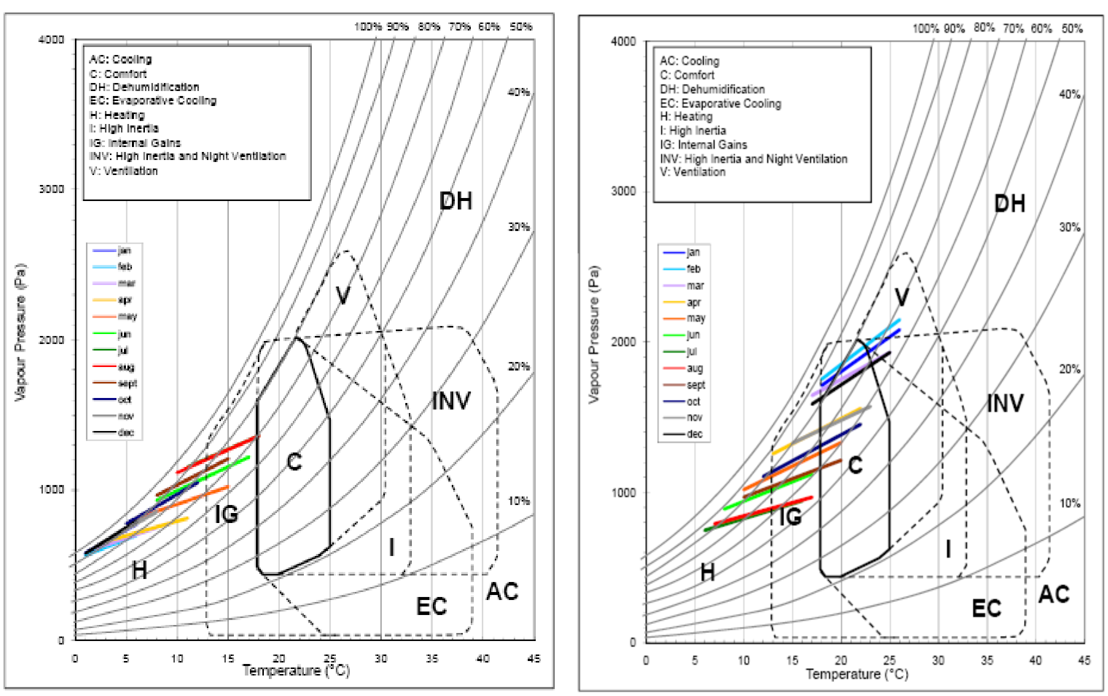


Figure 4: Bioclimatic need in more uniform climates (Glasgow on left and Sydney on right)



Validity of the BEI

The SME partner provided performance data for the BEI index in terms of the following:

1. Building energy performance for three categories of buildings

    a. Buildings designed to meet the 'Best' practices in the developed world (i.e. assuming an indoor condition where the predicted mean comfort vote – PMV lies within -0.50 to +1.00). This category of buildings is called 'GREAT' buildings;
    b. Buildings designed for basic code standards as applicable in most developed countries (i.e. Designs fulfilling the adaptive comfort stands – ASHRAE 55 -2004 (ASHRAE, 2004) and is defined by ASHRAE 55: 2004, Figure 5.3 with 80% acceptability. Such an approach is also allowed in many 'sustainable building' assessment methodologies, for example LEED IEQ 7.1 [USGBC, 2010) and Green Star IEQ 9). This category of buildings is called 'GOOD' buildings;
    c. Buildings designed for basic standards currently prevalent in the developing world (i.e. within an internal PMV of ±1.5). This category of buildings is called 'POOR' buildings.

2. Simulation of building energy performance of 10 buildings in 14 different locations

    a. The energy performance of ten different buildings (See Appendix 2) ranging from single family residential buildings to very large office and institutional buildings were simulated for each of the 14 cities listed in page 4.

Our approach to validate the BEI was as follows:

1. Compare BEI of the ten different types of buildings shown in Appendix 2 for each of the 14 cities, against building energy performance for 'Poor' and 'Great' buildings
2. Attempt to explain variations
3. Compare all of the BEI supplied by the SME partner with energy performance estimated by a generic building simulation software outputs (DEROB-LTH, see Kvist, 1999)
4. Suggestions for improvement

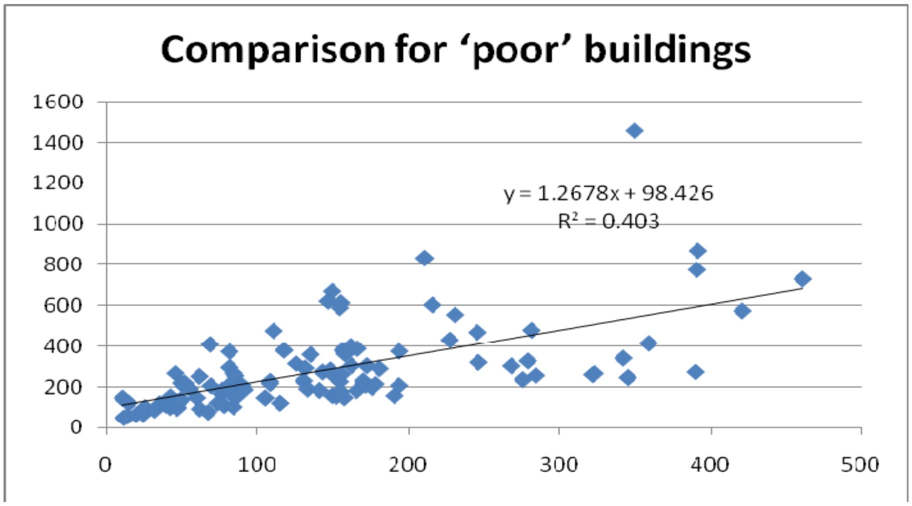
For the purposes of Task 3 above, we used a parametric building energy simulation software called DEROB-LTH developed by the Lund University, Sweden (Kvist, 1999). DEROB-LTH is capable of simulating the indoor thermal comfort and building cooling/heating energy needs. It needs following climatic inputs:

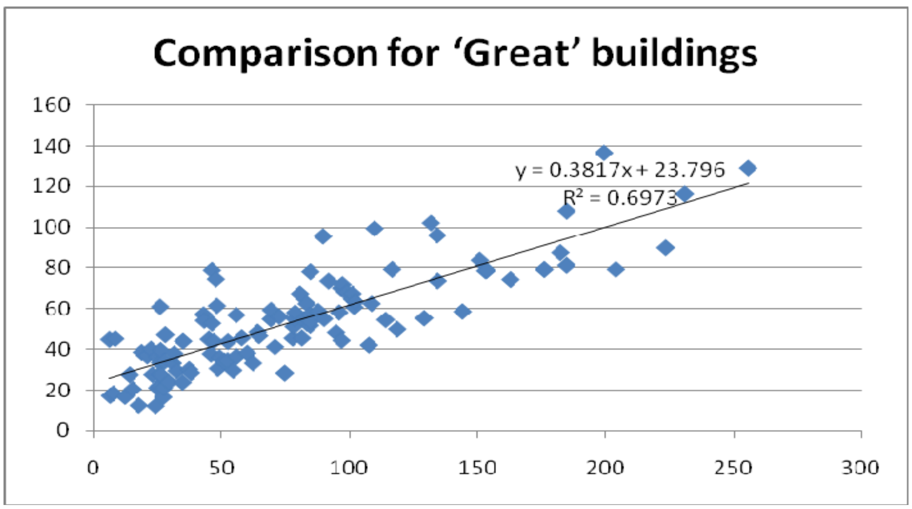
Outdoor average daily maximum and minimum air temperature;
Outdoor average daily maximum and minimum relative humidity;
Average daily cloud cover (or total global radiation)
Average monthly rainfall

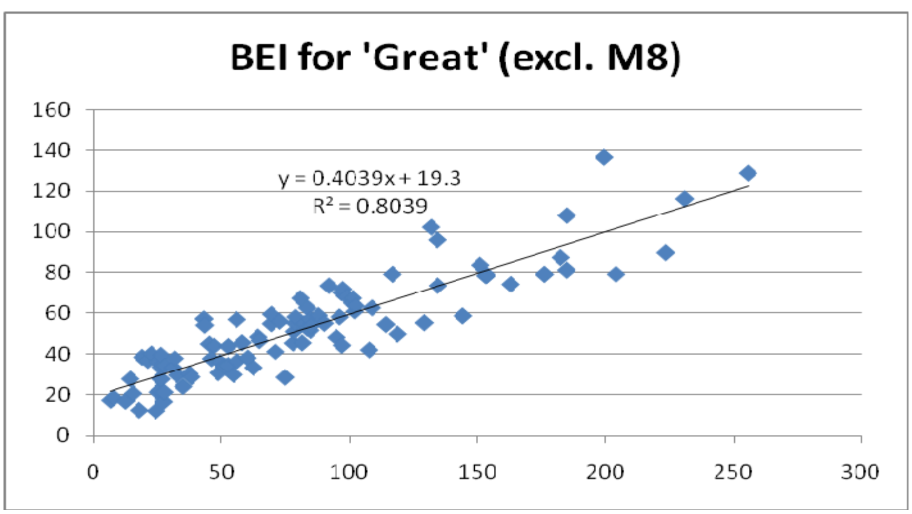
Figure 5a shows the comparison of energy performance vs. BEI for 'POOR' buildings in the 14 climatic locations selected for the study. As is to be expected the predictive ability of the BEI in terms of a building's energy needs is rather poor (R^2 = 0.403). BEI's predictive ability improved significantly in the case of 'GREAT' buildings (Figure 5b). The case improves even further when energy performance data for hot, humid locations (Singapore, Miami and Bangkok) for one of the more outlandish designs (a building called M8 – mostly glazed and a design more suited to temperate conditions) is removed (Figure 5c). This is to be expected, given the low likelihood of all design types being constructed in all selected climatic locations. It is therefore safe to say that the

BEI index is a good predictor of the likely energy performance of buildings that fulfils the current best practices in the developed world. In this sense, the BEI therefore fulfils its intended purpose (i.e. a simple and universal predictor of building energy performance of 'sustainable' buildings).

Figure 5: BEI Performance validation



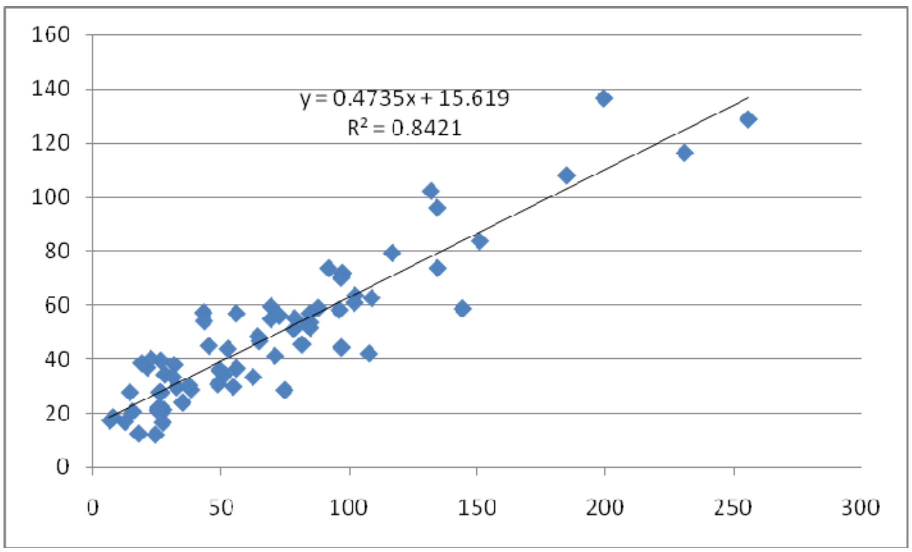




Robustness of the BEI

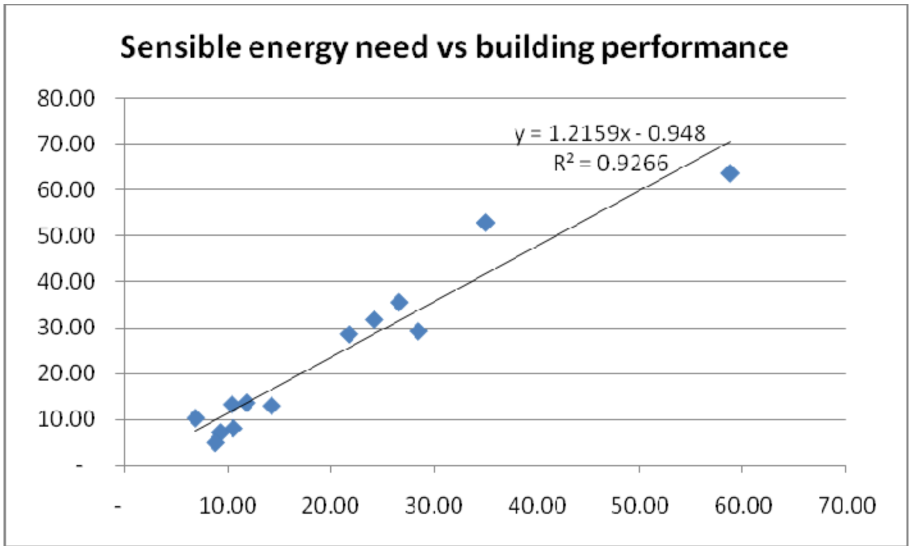
As indicated in the previous section, we compared the BEI values for all 10 buildings in all 14 climatic locations. The rationale for selecting these buildings is that these are considered 'sustainable' on account of their assessed scores under a building sustainable assessment methodology such as the BREEAM. It is highly unlikely that all of these buildings will ever be built in all of the selected locations, given the wide variations in local climate. For example, heavily glazed and un-shaded buildings are highly unlikely to be considered 'sustainable' in a warm, humid climatic contexts. We therefore removed the unlikely combinations (mainly, those in the hot, humid cities of Miami, Singapore and Bangkok). Figure 6 shows the BEI vs. Energy consumption data for 'Great' buildings in all cities excluding the 'hot, humid' cities (i.e. excl. Miami, Bangkok and Singapore). As can be seen from Figure 6, the predictive ability of BEI is improved even more.

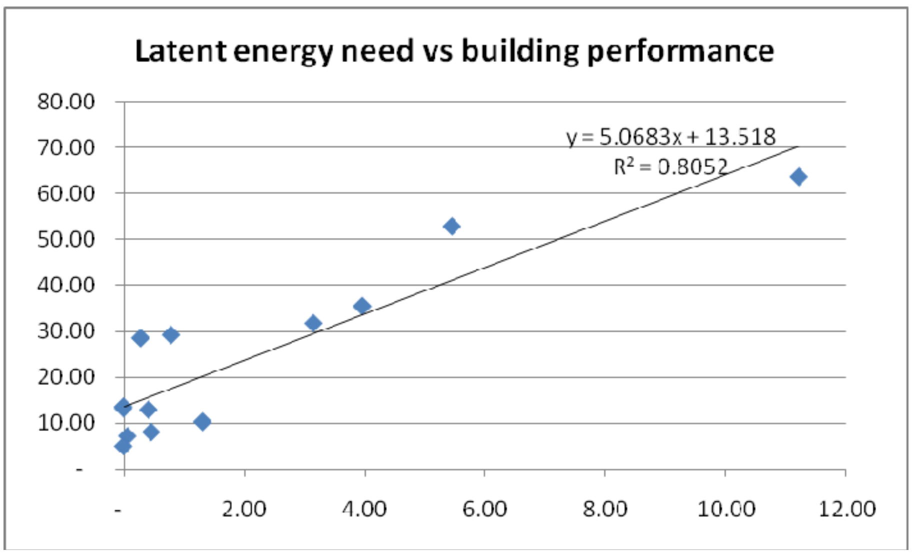
Figure 6: Building energy consumption and BEI for non hot, humid cities



A possible explanation for this improved predictive ability is the pooled (sensible plus latent) nature of the building energy data used for the exercise. We suspect the removal of hot, humid cities from the mix reduces the importance of latent energy needs, thus the improved performance. Such a hypothesis is supported by Figure 7. Figure 7a shows the relationship between BEI and sensible building energy need (sensible heating or cooling) while Figure 7b shows the BEI vs. Latent building energy needs (humidification and/or dehumidification). The improved R^2 values for the former might indicate that the BEI is a better predictor of sensible energy needs. This again points to the need for a separate (or a weighted) approach to the problem of moisture, much as the discussion on CEI previously indicated.

Figure 7: BEI and the sensible/latent building energy needs

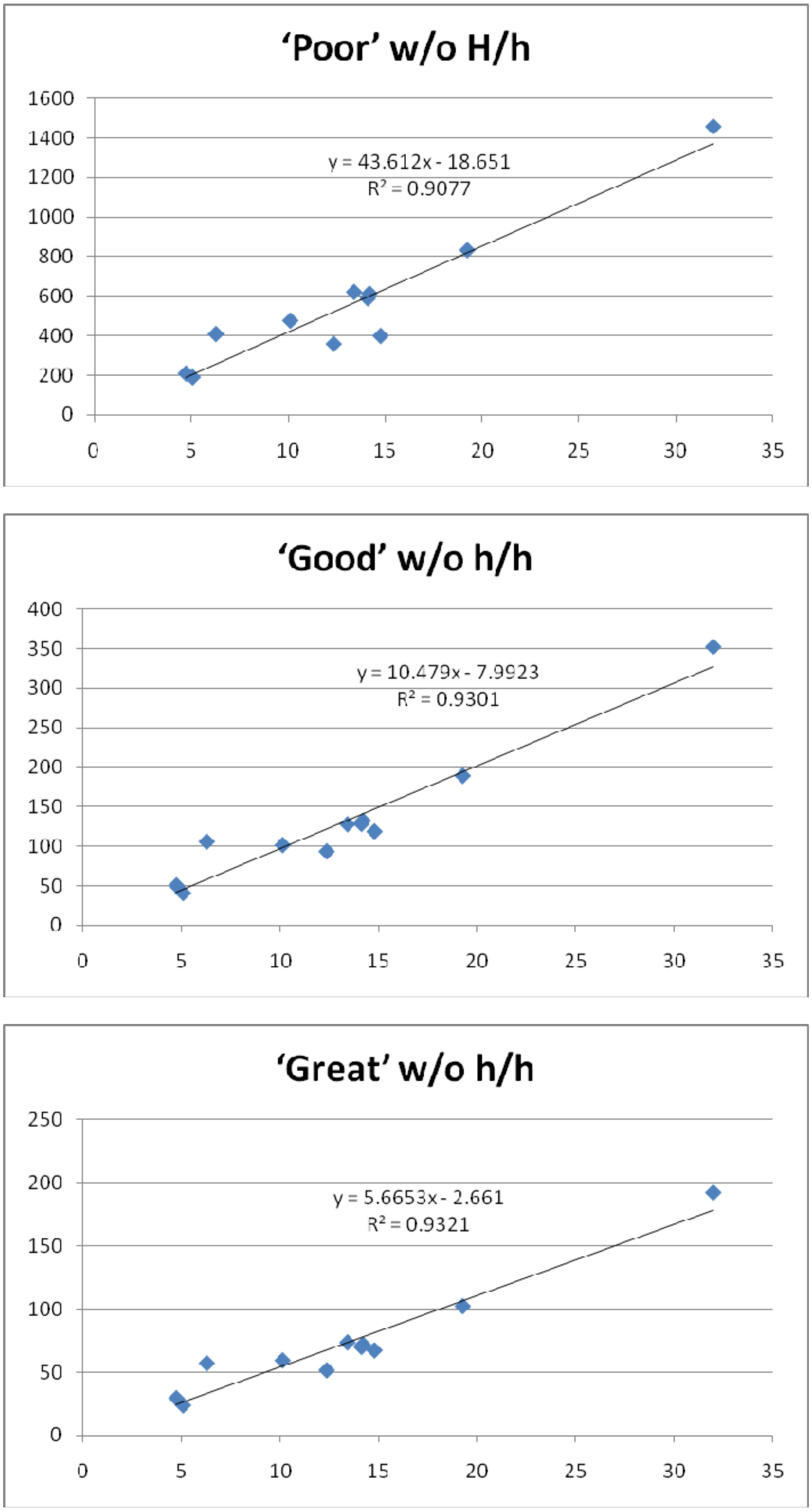




We also analysed the predictive ability of the BEI index of the building energy performance of 'POOR' buildings. Given the global ambitions of the CEI/BEI indices (see page 1), such a robustness test is important. Most buildings (especially in the developing world0 are yet to reach the superior indoor thermal environmental standards demanded by the best practice regimes currently in operation. In other words, a vast majority of buildings designed and built in the current context remain within our 'POOR' category and therefore, professionals from around the world will find it of immense value if the BEI index could predict the energy performance of these buildings.

Figure 8 shows the BEI vs building energy performance comparison for all buildings in all cities excluding the three hot, humid cities (Miami, Bangkok and Singapore). It is clear that the predictive ability of the BEI is very good even in the case of 'POOR' buildings. (R2 value for 'POOR' and 'GREAT' buildings were 0.9077 and 0.9321 respectively). This further reinforces our earlier conclusion that the BEI index is a very good predictor of the building energy performance, even if the buildings are constructed to a 'POOR' thermal comfort standard.

Figure 8: BEI performance in all climates excluding the 'hot, humid' cities



Concluding remarks

Our review in this exercise comprised of a validity test for the Climate Energy Index (CEI) and the Building Energy Index (BEI) developed by the SME partner, IES Ltd., Glasgow. We compared the efficacy of the CEI against previously developed and tested climate quantification indices (in this case, the Mahoney's chart). We also analysed the performance of the BEI against three categories of buildings (those conforming to best practice standards in the developed world; basic standards in the developed world and those not conforming to current thermal comfort regulations) for 10 different building types in 14 different cities from around the world. Furthermore, we performed robustness tests in terms of climate and building sub-types as well as latent and sensible energy needs to better understand the performance of the BEI.

Based on our work we could conclude as following:

1. CEI has a good match with previous attempts at quantifying the 'climatic burden' with respect to buildings with one exception: Phoenix (PHX)
2. The outlier case may be explained by the unusually low humidification energy need for PHX and/or the equal weighting given to both the 'sensible' and 'latent' energy loads of a given climate.
3. The BEI seem able to predict well the performance of 'Great' buildings than 'Poor' buildings.
4. The performance of 'Poor' buildings improves dramatically if 'hot, humid' climates are excluded (i.e. Miami, Singapore and Bangkok cases)
5. This again indicates a possible link to 'latent' energy needs, given the importance of moisture in these climates

Future directions

The prototype Index has the potential to form the basis of a unique design tool (product) that will allow the comparison of designs worldwide in a simple and independent fashion. As an easy to develop index, the BEI (and the CEI) has the potential to provide a common method to compare the energetic performance of buildings (and different design strategies) in different climatic regions.

Given the global aspirations of the CEI/BEI approaches, it is necessary to enhance the predictive ability of the BEI in hot, humid climates as well. Based on our results we suggest that the developers consider improvements to the indices (to reflect the unequal human comfort effects of sensible and latent energy needs) in the 'problem' climate areas (i.e. hot, humid and hot, dry climatic regions). This might involve having different weighting factors for these two energy needs, depending on the climatic conditions and perhaps increased 'value' (i.e. weightage) for 'passive' design approaches (i.e. ventilation, thermal mass and perhaps solar radiation) in 'POOR' buildings.

References

Acharya PK. 1979. Indian Architecture According to Mänasära-Šilpasästra, Patna, India: Indian India, 268 pp.

ASHRAE, 2004. ANSI/ASHRAE 55 – 2004: Thermal Environmental Conditions for Human Occupancy. Atlanta, GA: American Society for heating Ventilating and Air Conditioning Engineers (ASHRAE)

Dept for Communities and Local Govt (DCLG). 2006. Code for Sustainable Homes: A step-change in sustainable home building practice. London: DCLG, 31 pp (available at: http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf last accessed 08 October 2010)

Feist W. 2008. What is a Passive House? Passive House Institute. http://www.passivhaustagung.de/Passive_House_E/Passive_House_in_short.html (last accessed 08 October 2010)

Givoni B. 1989. Urban Design in Different Climates. World Meteorological Organization Technical Note, WMO/TD- 346, WCAP-10. Geneva: World Meteorological Organization

Koenigsberger OH, Ingersoll TG, Mayhew A, Szokolay SV. 1974. Manual of Tropical Housing & Building, Part I: Climatic Design, London: Longman

Kvist H. 1999. DEROB-LTH for Windows, Lund, Sweden: LTH

Morgan MH. (trans.) 1960. Vitruvius: The Ten Books on Architecture, New York: Dover

Weatherbase, 2010. Weather records and averages. Available at: http://www.weatherbase.com/ (last accessed 08 October 2010)

Yannas S. 1990. Passive solar heating and energy efficient housing design, Proc. 2nd European Conference on Architecture, Kluwer, Dordrecht, pp. 548-556

Yannas S. 1994. Solar energy and housing design, Vol. 1: Principles, objectives, design Guidelines. London: Architectural Association Publications

Yannas S. 1996. Energy indices and performance targets for housing design, Energy and Buildings. 23, 237-249

Appendix 1 – Mahoney’s Chart: an example for Singapore

Mahoney Tables

Location	**Singapore**
Longitude	104 °
Latitude	1 °
Altitude	15 m

You have to fill out temperature, humidity and rainfall data for all months before you can make the Mahoney evaluation!

Air temperature °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	High	AMT	(annual mean temp)
Monthly mean max.	29	31	31	31	31	31	30	30	30	30	30	29	31	28	
Monthly mean min.	23	24	25	25	25	25	25	25	24	25	24	23	25	####	
Monthly mean range	6	7	6	6	6	6	5	5	6	5	6	6	Low	AMR	(annual mean range)

Relative humidity %	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean max am	92	92	92	93	92	90	90	89	92	92	92	93
Monthly mean min pm	74	69	72	74	76	72	73	73	75	73	77	80
Average	83	80.5	82	83.5	84	81	81.5	81	83.5	82.5	84.5	86.5
Humidity group	4	4	4	4	4	4	4	4	4	4	4	4

1 <30%
2 30–50%
3 50–70%
4 >70%

Rain and wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall mm	200	150	170	140	160	140	150	140	180	170	250	300	2150
Wind, prevailing	17	16	14	9	9	9	9	12	9	8	6	8	
Wind, secondary													

N, NE, E, SE,
S, SW, W, NW

Mahoney

Diagnosis °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AMT
Monthly mean max	29	31	31	31	31	31	30	30	30	30	30	29	28
Day comfort, upper	27	27	27	27	27	27	27	27	27	27	27	27	
Day comfort, lower	22	22	22	22	22	22	22	22	22	22	22	22	
Thermal stress, day	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	
Monthly mean min	23	24	25	25	25	25	25	25	24	25	24	23	
Night comfort, upper	21	21	21	21	21	21	21	21	21	21	21	21	
Night comfort, lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress, night	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	

H = Hot
O = Comfort
C = Cold

Comfort limits	AMT >20°C				AMT 15–20°C				AMT <15°C			
	Day		Night		Day		Night		Day		Night	
Humidity group	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	26	34	17	25	23	32	14	23	21	30	12	21
2	25	31	17	24	22	30	14	22	20	27	12	20
3	23	29	17	23	21	28	14	21	19	26	12	19
4	22	27	17	21	20	25	14	20	18	24	12	18

For AMT = 28			
Day		Night	
L	U	L	U
26	34	17	25
25	31	17	24
23	29	17	23
22	27	17	21

Meaning	Indi-cator	Thermal stress Day	Night	Rainfall	Humidity group	Monthly mean range
Air movement essential	**H1**	H			4	
		H			2–3	<10°C
Air movement desirable	**H2**	O			4	
Rain protection necessary	**H3**			>200mm		
Thermal capacity necessary	**A1**				1–3	>10°C
Outdoor sleeping desirable	**A2**		H		1–2	
		H	O		1–2	>10°C
Protection from cold	**A3**	C				

Indicators	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
H1	1	1	1	1	1	1	1	1	1	1	1	1	12
H2													0
H3											1	1	2
A1													0
A2													0
A3													0

You have to fill out temperature, humidity and rainfall data for all months before you can make the evaluation!

Singapore
Latitude 1°N

Indicator totals from data sheet					
H1	H2	H3	A1	A2	A3
12	0	2	0	0	0

General recommendations

Layout

H1	H2	H3	A1	A2	A3		
			0–10			X	Orientation north and south (long axis east–west)
			11–12		5–12		
			11–12		0–4		Compact courtyard planning

Spacing

H1	H2	H3	A1	A2	A3		
11–12						X	Open spacing for breeze penetration
2–10							As above, but protection from hot and cold wind
0–1							Compact layout of estates

Air movement

H1	H2	H3	A1	A2	A3		
3–12						X	Rooms single banked, permanent provision for air movement
1–2			0–5				
1–2			6–12				Rooms double banked, temporary provision for air movement
0	2–12						
0	0–1						No air movement requirement

Openings

H1	H2	H3	A1	A2	A3		
			0–1		0	X	Large openings, 40–80%
			11–12		0–1		Very small openings, 10–20%
Any other conditions							Medium openings, 20–40%

Walls

H1	H2	H3	A1	A2	A3		
			0–2			X	Light walls, short time-lag
			3–12				Heavy external and internal walls

Roofs

H1	H2	H3	A1	A2	A3		
			0–5			X	Light, insulated roofs
			6–12				Heavy roofs, over 8h time-lag

Outdoor sleeping

H1	H2	H3	A1	A2	A3		
				2–12			Space for outdoor sleeping required

Rain protection

H1	H2	H3	A1	A2	A3		
		3–12					Protection from heavy rain necessary

Detailed recommendations

Size of opening

H1	H2	H3	A1	A2	A3		
			0–1		0	X	Large openings, 40–80%
			0–1		1–12		Medium openings, 25–40%
			2–5				
			6–10				Small openings, 15–25%
			11–12	0–3			Very small openings, 10–20%
			11–12	4–12			Medium openings, 25–40%

Position of openings

H1	H2	H3	A1	A2	A3		
3–12						X	In north and south walls at body height on windward side
1–2			0–5				
1–2			6–12				As above, openings also in internal walls
0	2–12						

Protection of openings

H1	H2	H3	A1	A2	A3		
					0–2	X	Exclude direct sunlight
		2–12				X	Provide protection from rain

Walls and floors

H1	H2	H3	A1	A2	A3		
			0–2			X	Light, low thermal capacity
			3–12				Heavy, over 8h time-lag

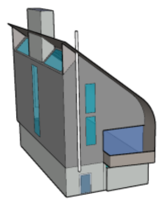
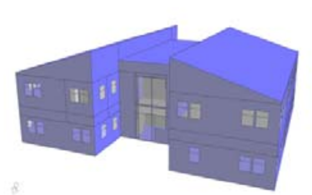
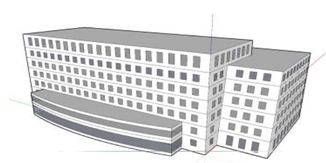
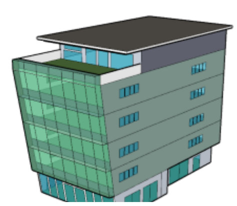
Roofs

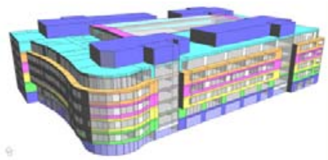
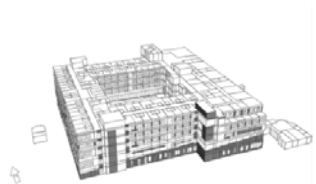
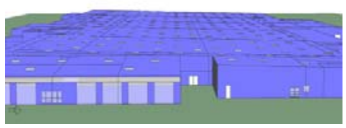
H1	H2	H3	A1	A2	A3		
10–12			0–2			X	Light, reflective surface, cavity
10–12			3–12				Light, well insulated
0–9			0–5				
0–9			6–12				Heavy, over 8h time-lag

External features

H1	H2	H3	A1	A2	A3		
				1–12			Space for outdoor sleeping
		1–12				X	Adequate rainwater drainage

Appendix 2 – Selected buildings used for the BEI exercise

Ref	Model	Model image	Type	Floor Area	Volume	No Rooms
1	BRE		Residential	309	1758	5
2	Newhouse		Residential	332	818	15
3	Helix		Small office	864	6671	46
4	M4		Large office	17195	66785	7
5	M8		Lab/Research	2089	7558	6
6	Walberton		Small school	2195	7101	55

7	Feather-stone		Large school	4305	15708	130
8	Hastings		College	39516	87755	764
9	Beaumount		Hospital	25603	90226	
10	Walmart		Retail	28641	127947	237