10 Recommendations for Adopting Lifestyle in a Green and Energy Efficient Building

In the last edition of Roof & Façade (12/2013) success or failure to adopt higher temperatures pointed to the implementation of a green lifestyle. Practising it is the main enabler to tolerate and encourage a higher Tropical Thermal Comfort-set point of up to 28.6ºC in our homes and 26.6ºC in offices. Have you ever tried that out? In the following deliberations we will write what it means to adopt to a greener lifestyle. These are 10 interconnected ideas emerging like the secret recipe to enjoy our "habitat" in a tropically adopted energy efficient building during the day and nighttime:

1. A green lifestyle jives in tandem with a healthy lifestyle: It Is an old rule independent of cultures **not to eat later than at least 3 h before you intend to sleep**. Our digestion will appreciate that and instead of sweating due to late heavy meal we can easily stand and appreciate the higher comfort temperature. We don't have to be nutritionists to switch the eating clock forward. If we feel oversaturated after a belated meal, a walk through the park or more intense evening exercises can work miracles to burn the inadvertent surplus of calories.

2. Try to **cultivate a 1/3 ratio eating mentality**: come from a typical common 50+ percent coal hydrates to 33%, and from 0-10% vegetables to 33% with another 33% of proteins (as e.g. proposed by Metabolic Balance ® healthy lifestyle nutrition). After some initial training, you will be amazed how easily vegetables and proteins can substitute the consumption of coal hydrates and provide you with much better health and fitness at the same time. **Metabolic Balance ®** determines a list of foods that will retrain and optimise your metabolism. It is an easy to follow, four-phase program coupled with a healthy diet and nutrition plan offering individualised coaching and training

3. Whenever you feel hot, typically in temperatures of above 28-6 - 30ºC when coming from outside, take a more **extensive shower** of 2-3 minutes, and dry only what is sociably necessary (evaporative cooling). Water on the Peninsula and in Borneo is at a refreshing temperature of 23-27ºC and hence lower then the maximum thermal comfort borderline. In the commercial application, offices can provide conventional **cool air condition "chill-in" rooms** with work stations and WIFI near to the entrance for staff to cool down when they entered from outside. They can spend some time there until they feel cold and can enjoy a warmer temperature in their office. Instead of having a generally too low temperature or one which is dependent on weather conditions, they provide a more flexible solution.

4. In sleeping rooms, **do not longer use thick comforters** which act like a vicious circle (research by UPM, Centre of Housing, Zaky, 2010) – except for decoration. Accepting tropical thermal comfort also means the demise of the usage of bed comforters which make sense to northern countries where they first came in. In an aircon cool arena, they create a vicious circle. The colder the aircon, the more we feel in dire needs putting the set-point of the A/C very low, and the thicker the comforter, the more we sweat without a remarkably cold set point. Conversely, people from the North would not believe that rural people sleep almost half-

naked with thin bed sheets against the odds of the comforters. One related issue is where to purchase thin bed sheets instead of the comforters which only give comfort in a very cool room. Some of the traditional tailor shops in malls still provide the curtain fabric which is around 1/10 cheaper than comforters and just need to be cut according to the customer's preferences.

5. It sounds weird, and then its clear: Usually, in a green & energy efficient home we should only dress up with necessary cloths, which of course must be in line with our **cultural habits and regulations**. Orang Asli with less clothes (CLO=0.2) will find it easier to stand the temperatures in green and energy efficient buildings as devised here. The temperature can then be easily be increased to 25 - 26.5° C in work areas and to nocturnal 28.6° C in residential areas. As there will be a minority of occupants who still typically fall out of the range of thermal comfort, it is the target to define a band-with of 4° C to make 85% of all occupants happy. Those people whose BMI is too low or too high (meager and obese people) will probably still feel uncomfortable, but thermal conditions at least can make it right for the overwhelming majority.

6. As the temperature logs comparing indoor and outdoor temperature during the hot late morning and afternoon hour tell us, apart from proper ventilation, it is absolutely necessary to **keep the windows and doors of the GEEB closed during the daytime at sunny/cloudy conditions**. If you have children, the usage of door closers is absolutely advisable, to keep the coolness inside. If you open the windows during evenings, make sure you have an efficient mosquito protection like a mounted mosquito net or electrical blades. Practised consequently, it will also help to reduce the more rampant and still increasing threat of Dengue-fever in Singapore and Malaysia.

7. **When not at home, switch off all unnecessary electrical device and replace CO2-triggering devices** like thermo-flasks or electrical water heaters. **Decide together on a monthly or annual budget for green expenses for reinvestments (**e.g. 1/5 of the monthly family cash flow). EXAMPLE: Household income RM 5,000. Monthly cash flow RM 1,000 => green cash flow 250 RM. Energy savings due to automated air condition that had been budgeted earlier 250 RM per months. Therefore, the money available for further green investments is 500 RM per month and 6,200 RM per year. This is already the price of e.g. one inverted air-condition (that will save up to 45% of a conventional split unit) and sun protected windows in 2 rooms, depending on which kinds of windows/frames or shading tools you are using.

8. **If you have a typically uninsulated house, leave the house during the hot indoor afternoon hours whenever possible.** Offices, shopping malls and other public places are great get-aways. They are cooled down to digestible thermal comfort zones anyway, and going out for shopping and other daily needs will both increase your stamina and fight obesity (if this is an issue). If you are a mental worker or an Iphone / Ipad person, you are independent of your desk back home. If you have children who suffer especially from afternoon and hot evening temperatures with unsatisfactory school performance, provide one cooler place in your house for them provides a great saving potential as well. I remember the case of a Sarawakian family with 2 school kids rooms facing both the hot afternoon sun in the first floor under the hot attic heat tank each running

8h of 1 horse power conventional air condition split unit with switch on and off mode. During the school holidays, the monthly electricity bill was RM 800 lower then during school periods.

9. **Adopt your life style to other related areas** such as visiting green seminars (e.g. for planting your own, non-chemically treated food in the previously empty garden areas, balcony or even indoor), combining shopping mall visits with recycling center visits , using motorcycles or public transport instead of cars, or bicycles instead of motorcycles. When it comes to green your building further, depending on your time and aptitudes you can contribute to retrofitting with your own labour (e.g. easy green wall insulation or coating).

10. **Join and create social media forums and chat rooms** (twitter, facebook and blogspots) in order to share your ideas and experiences with others (you can visit us at our own blog at http://triplegreenandhealthylifestyle.blogspot.com/ to provide us with a feedback. It is an ongoing journey to improve the awareness and implementation of a more natural definition of thermal comfort.

Practising these or other green & energy efficient lifestyle modules does not require a grand change of mindset. However, the family set point of the temperature must not be too debatable: Every degree C we allow the temperature to decrease equals more expenses, and a shorter operation hours of the cross ventilation. If you like 26ºC, there will be only few hours left to harvest fresh outside air. If you prefer 24ºC with humidity <60%, you would not need to purchase the combination system, but invest in much more expensive wall and windows installation measures that will never pay off, like the cool tec house in Malacca with its sensational RM 2 electricity bill per day running four automated 1 horsepower air conditioners for this matter.

However, green lifestyle modules are just interwoven recommendations. They are NOT and can never mean "10 commandments" creating a dogma. The event of a new dictatorship of family leaders asking people to suffer with a decreed unreasonably set high or low set point (e.g. lower than 24°C or higher than 28 °C does not jive with liberal open persons in a family who should look at green lifestyle as a testing ground to practice basic democratic principles back home.

Hence, internally adopting to a green lifestyle results may prove that by tolerating and encouraging higher TTC-set points by adopting a greener lifestyle (and the utilisation of fresh aided ventilation) can substitute or, in some cases, even replace split air condition units. In the wake of soaring energy prices (Malaysia has just recently stipulated a one time rise of 15%) healthy cooling savings to protect our environment comes at a good time to practice green lifestyle back home.

How to achieve Tropical Thermal Comfort in Green & Energy Efficient Residential Buildings

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1. Roadmap: HX-Diagram and Tropical Thermal Comfort

Whether it is hot or cold it matters: Thermal comfort belongs to the family of ***basic*** *human needs. If temperature and humidity are not within a certain band-with, we feel not comfortable and any of our actions pursuing higher levels of needs can be hampered. Children who can't perform their homework, escapism to shopping malls with cool air or separate sleeping rooms for married couples* *where one cannot stand the air condition belong to these innumerous examples. Gerhard Mollier's more sophisticated hx-diagram points out the "comfort zone" in dependence of two main parameters, temperature and humidity.*

Following the logics of the diagram, thermal comfort almost never will be achieved in the outdoor and non-air conditioned environment of a tropical country. The problem is not big, but: Temperature or humidity and sometimes both at the same time are a slightly too high to adhere to the requirement of the diagram. How can lasting thermal comfort in a tropical built modern environment be attained? Is it possible to save energy at the same time?

First, the optimum human thermal comfort for a standard residential building in tropical countries has to be revisited, questioning the still prevailing Northern ASHRAE-standards. Recent lead-user studies comparing the prevailing standard of colder countries with the concept of the TTC (tropical thermal comfort) unveiled that about 85% of the population can be pleased within a band-with of 4 °C. But where is the range? Let us have a look only at the temperature, leaving aside the humidity.

Applicability	*Minimum*	*Optimum*	*Maximum*	*Source*
*Northern Countries (**general**)*	*19.1°C*	*21.1°C*	*23.3°C*	*ASHRAE-Standard, e.g. 2005*
*All countries (new standards for **offices**)*	*22.5°C*	*24.5°C*	*26.5°C*	*e.g. set-point not lower than 24°C. Malaysian regulation for offices (2011)*
*Tropical Countries (standard for **residential**) (e.g.Malay Peninsula)*	*24.6°C*	*26.6°C*	*28.6°C*	*e.g. research team at UTM 2007, Haryarti Shafii, 2012*

Table 1: Comparison of different thermal comfort definitions

*Interestingly, the standards in **offices** converge in colder and warmer countries, even though in regions of the North lots of energy would have to be consumed to reach the medium level of 24.5 °C during the cold seasons. In tropical countries in between 0 and 5 °C, the gap between desired and real temperature is much less, but slight cooling has to be provided throughout the whole year.*
*In private **residential** households, the standards of cold and warm countries automatically deviate. This is due to the fact that every degree C in a cold country that needs to be heated up costs energy and money, whereas in warm countries the temperature is cheaper if the allowable end of the band-with is as high as possible. However, the Western standards nowadays appreciate also*

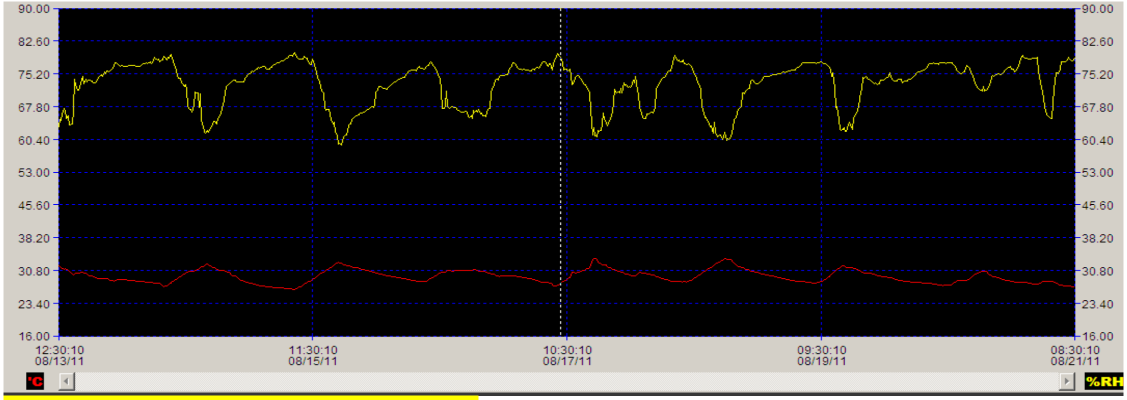
higher temperatures as the table suggested. No one likes to live with energy saving 17 °C or 18 °C which were still the prevailing standards in the 1930s.

The tropicalised 28.6 °C are derived from different researches carried out independently throughout locations along the Malayan Peninsula. They serve as a litmus and benchmark for the following considerations in residential areas. These standards do not question or replace the office standards which are 2.1°C lower, as we wear less clothing in our houses and move less around.

2. *Activation: Three Gadgets to Provide Thermal Comfort*

Electrical air condition systems are getting more common, as they can serve for a lower temperature and humidity creating ventilation at the same time. They account for more than 1/3 of the present tropical CO2-emissions. By a growing number of consumers, who ever spent extra-money into it, life without aircon can hardly be imagined. We bear in mind their high operational costs and sometimes negative impact on our health. No fresh air will enter the room, but the coolness pretends that the air is fresh which is only possible with a quite expensive ventilation system. Hence, green building architects and engineers alike have gone "back to the roots" looking for eco-friendlier alternatives and substitutes. Based upon own experiments for low-energy and passive houses, the best solution reconciling environmental and human needs is an affordable combination including a minimum of smart aircon. To achieve thermal comfort, we will check in how far a smart residential system consisting of 3 elements (split air condition units, fans and cross ventilation) work hand in hand to enable a greener cooling concept.

Let us look at the temperature and humidity log at a typical sunny and in part cloudy day on the tropical peninsula. At first sight it seems that the indoor temperature in an uninsulated, but not airtight residential house is quite stagnant. It is hardly lower than 28°C and rarely exceeds 30°C. However, according to the framework laid out above, the temperature passes the decisive borderline between comfortable and uncomfortable on ***every*** *sunny-cloudy by 1-3°C. The humidity in suburban areas without much greenery is more rampant between 60 and 80%. The cold mainstream and the hx-diagram requests us to provide much lower temperatures. According to tropical research humidity which is rampant and not in a quite predictable tiny range like the temperature can be easily reconciled.*

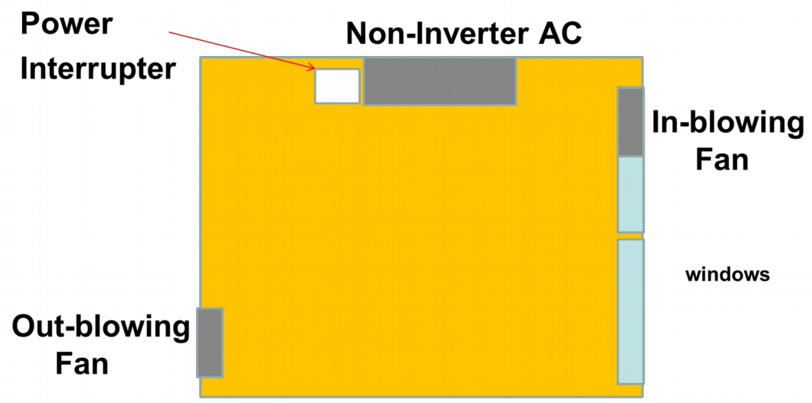


REPLACE BY BISTARI 10 DAYS during dry season

Since during these 10 days the temperature exceeds 28.6 °C only slightly, cooling does not have to perform a great job. However, most non-inverted air conditioners are set on 16°C when occupants enter from "hot" outside and remain there. Even if they never reach 16 due to non-existing insulation, their direct blow in many instances is felt as uncomfortable and much too cold by its occupants.

3. How to gain green and energy-efficient thermal comfort

The whole system which is still in the research & development stage comprises of the 3 elements mentioned above: Conventional air condition (A/C), power interrupter and cross ventilation which on request breezes in the lower night time temperature and transports the hot air outside the building during hot periods.



Picture: Thermal Comfort with a Green & Energy Efficient Smart System in a 3*4m mid-sized sleeping room

The three gadgets work interactively. Whenever the temperature rises above a certain "upper" space limit, the air condition will work automatically. When

the temperature reaches the thermal comfort zone, it will be switched of by the smart power interrupter. Basically, if the occupants can agree on the tropical set-point of 28.6°C and do not question a bit higher relative humidity, in 50-100% of all gained data the night-time cross-ventilation ALONE served for thermal comfort.
The most cost saving measure in this system is, of course, to leave the house during the daytime, and focus mainly on the cheaper and healthier cooling modes of mainly cross ventilation during the nighttime.

The idea and practice to provide cross ventilation is not new. Malay kampong houses thrive on the idea since many centuries. Before concrete was added and made most of the buildings almost inhabitable during heat peak hours, attics, rooms and the stilted areas below the houses were passively cross-ventilated.

The new necessary element in a concrete house where the heat is stored is ACTIVE electrical ventilation. It derives from the European passive and low energy buildings since the late 1970s and 1980s. In a concrete houses with the problem of high walls heat storage the smart system and the active breeze of outside ventilation will complement the A/C and make it less indispensible.

The outside temperature log in the sequence of seven tropical nights with five sunny-cloudy days and two after rain (blue and black) underpins the viability of night time cross ventilation. Below the dotted brown line, it is used as the sole tool responsible for ventilation PLUS cooling (compared with 1.7-2°C HIGHER indoor temperatures):

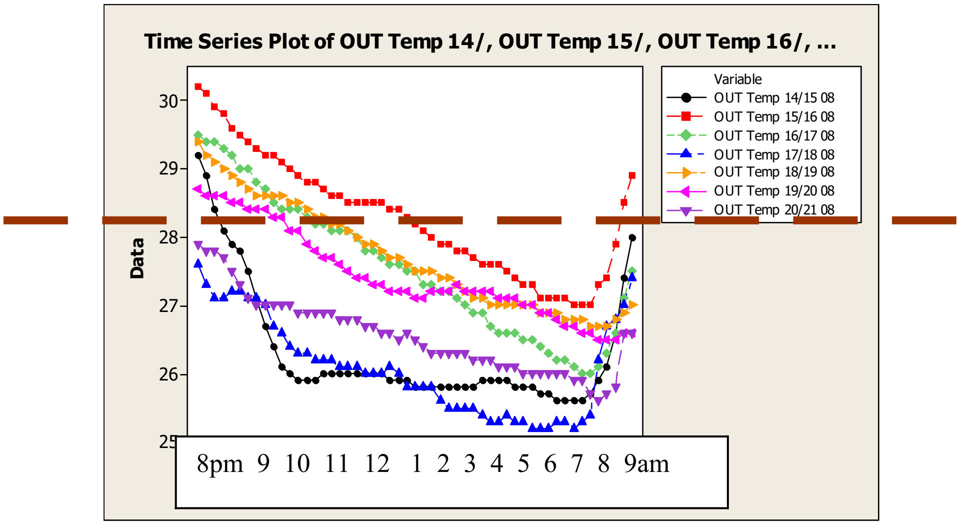


Figure : Time Series Plot of Outside Temperature over 7 Nights in a Cross-Ventilated Room without AA/C

It depends on the weather situation whether the target of 28.6º C is achievable during the daytime by cross-ventilation alone, after 9 pm or at (the latest) after 12am after the hottest day during the dry season (August). As the chart shows, the critical hours where coolness from outside is not yet achieved, in all cases (except after rainy conditions) are between 8 pm and midnight with the smart system in motion: and a set point of 28 °C. between 12 a.m. and 2 a.m. the latest, the yielded outside temperature will be often in range with 28.6 º C as the upper space limit for residential tropical thermal comfort.
The effectiveness of mere cross-ventilation without A/C also depends on the insulation during the day time. Even without insulation, during the same days of observation at least 2/3 of the colder outside night-time temperatures could be harvested. Our observations yielded the following average scores in the early morning with these temperatures and DELTAs (differential between desired and real temperature):

Outside: Inside: Experimental Room (ER) Inside: Control Room
(CR)
with Cross-Ventilation with Ceiling Fan

DELTA **OUT-ER** = 1.4º C DELTA **ER-CR** = 2 º C

On average, despite the cooling effects of the night time temperature, the experimental room remained 1.2 º C warmer than outside. Conversely, a control room without cross-ventilation (just ceiling fan) still stays stuck at 1.4 º C hotter than the thermo-ventilated area respectively 2.4 ºC compared with the minimum outside temperature. With the smart system in operation, there is no more sweating issue as the air condition will perform its job well to the occupants' wishes as long as the temperature is still too hot. And the best is that other than with any split unit fresh and in most areas more healthy air will help to increase the indoor air condition and reduce harmful indoor CO2 and dangerous CO.
At the end, an integrated system saves costs tremendously and serves for much better thermal comfort as if the split unit just revolving existing air is the only cooling agent. As we will point out in our next edition, whether the system stands or falls results of the capability of the occupants to adopt a green and healthy lifestyle.

8-8 cv with PI
8-8 AC or nothing

This basic model varies, both on "colder" and "hotter" days, but as a matter of fact temperature can be saved.

The investment costs of this system, like any other green investment, are higher than using AC or of course the cheaper stand-alone fan solution. The operational costs, however, render the system even financially attractive in the long run. The main important thing, however, is that CO2 is reduced and the air is not only comfortable, but healthy in residential areas. Either AC or indoor fans in a combination with closed windows cannot avoid a high indoor CO2 concentration which can cause unhealthy air conditions.

The main issue to implement green cooling based thermal comfort is the green lifestyle, which can emerge as the guarantor of low electricity bills.

KEYWORDS: Thermal Comfort, Residential Buildings, CO2-Emission, Green Cooling

1. INTRODUCTION: Definition and Practice of Thermal Comfort Revisited

TC provides an acceptable temperature for human beings. We define TC as the state of mind that expresses satisfaction with the temperature, humidity and velocity of the surrounding environment (according to the SO 7730 or, likewise, ASHRAE Standard 55). Together with a) environmental sustainability and b) long-term cost saving, c) maintaining thermal comfort for occupants of buildings or other enclosures is the third of the three important objectives of TRIPLE Green building architecture and engineering. Thermal comfort belongs to the family of basic individual needs. Presuming it is taken for granted, TC enables us in a concerted effort with other physical needs to climb up further the ladder of Maslow's renowned pyramid of needs. Conversely, in its absence, mainstream research holds that any thermal gain or loss above or beyond the following generic borderlines may generate a sensation of discomfort.

A typical Western conception keeps on believing that the inside temperature for offices should be 21.1° C on average with variations of +- 2.5° C (Thermal Comfort, Fundamentals volume of the *ASHRAE Handbook*, ASHRAE, Inc., Atlanta, GA, 2005). Of course, in a cold country every °C that has not to be heated can save tremendously energy and budget. In recent years, this figure for thermal comfort has been even proposed to be altered for European *offices* to 24.5° C, which means an enormous deviation from the internationally renowned ASHRAE-standard (Braatz, 2008). For *tropical* countries, Busch (1990) carried out a pioneering field study for Thai offices in Bangkok and found that the neutral temperature or effective temperature for the air conditioned buildings and naturally ventilated buildings was 24.5ºC and 28.5ºC, respectively. A similar range of "neutral" conducive temperature was determined for a Malaysian School (Ibrahim Hussein, M Hazrin A Rahman (2009), Based on PMV regression is 25.9ºC with a comfort range between 24.4ºC and 27.4ºC. The trendy increase of temperature in offices and public cooled down areas also follows the in-part demise of the common dress code with suits and ties translatable into the 2011 policy by the Malaysian government requesting all state-owned buildings to set-point the temperature not lower than 24°C.

Abdul Rahman (1995) in his ground-breaking study found that the most comfortable indoor temperature in Malaysia (tropical region) for *residential* areas ranges even from 25.5-28°C compared to the general recommendation by World Health Organization (1990) ranging from 18-28°C. UTM's researchers Sabarinah Sh.Ahmad, Nor Zaini Ikrom Zakaria, Mohammad Shayouty Mustafa, Mohd Ghadaffi Shirat concluded that a 2.5°C range between 26.1°C and 28.6°C is optimum in tropical countries even for adopted people from Northern countries (2007). Others and our own findings clearly confirm that the optimum residential area temperature for most tropical occupants in their privacy at its highest comfortable end should not exceed 28.6º C. Therefore, the researchers at UTM state "the comfort band for the KL area for all building types is between 23.6° and 28.6° C with an optimum medium temperature in Malaysian *households* of 26.1° C" with the upper space limit (USL) set at ***28.6°C***". To conclude, two reasons can be sorted out. 1) the lower cost when putting the highest set-point in a tropical warm country. 2) the perception by people living in tropical regions is different from those in temperate and cold regions (Wang and Wong, 2007; Singh et al., 2009). The perception is based on lifestyle and habits, and based on economic necessities. All of them contribute to the explanation of the following comparative depiction:

Northern countries	19.1	21.1	23.1	ASHRAE, 2005 (general)
"new approach"	22.5	24.5	26.5	Braatz, 2008 (offices)
Malaysia (KL)	23.6	26.1	28.6	e.g. UTM, 2007

Table 1: Comparison of different thermal comfort definitions

Devising a tropically adopted concept for thermal comfort with these higher temperature banding can cause a steep increment in terms of energy saving potentials by 4-7% of less CO_2 and energy cost with each degree centigrade the temperature is increased (Green Efforts Start at 24°C. In: The Star, 12/08/2011, 2). Unfortunately, even if the USL (upper space limit)-temperature is set to its highest end at 28.6°C, in a typical uninsulated concrete building -with the walls, windows, ceiling and roof as permanent heat traps- TTC cannot be achieved during a sunny / cloudy day even in kampong areas (Sanusi, 2010).

2. MATERIALS AND METHODS

Some ground-breaking experiments will find out in the near future which level of thermal comfort can be achieved by using different green building material and electricity for green cooling. We will start out and exemplify this set of researches with ventilating a typical residential area park = "Taman" house.
An estimated 60% of residential real estates in Malaysia consist of low-rise terrace, semi-detached and detached houses. Despite of whopping technological opportunities after 2000, these buildings are constructed the same way since the 1980s and 1990s when a growing number of residential areas were built with concrete and/or bricks. The growing minority is equipped with air-condition panels at least for the sleeping room. This system has a much higher emission, as one inverter driven unit consumes around 1,200W/h peak compared to those 55-85 W of a single ceiling fan to gain thermal comfort in a mid-seized living or sleeping room. Even in 2011, 1 ½ years after Malaysia's Prime Minister announced the commitment to save 40% of CO_2 in Malaysia until 2020, the increasing number of those taman buildings fitted with air conditioners, are non-withstanding emitting a growing level of CO_2 as ever. In this respect, most of Malaysian households emit 3-4 KW/month/m^2 which equals on average to 341 kg CO_2/ month per unit (Universiti Kuala Lumpur, unpublished research paper 04/2011).
Ordinary taman houses without air conditioners can only in part be considered "thermally comfortable" with rare well-being TC-temperatures below 28-28.6 ºC, as they can only be run with ceiling fans and some stand-fans changing just the felt "ambient" temperature on the spot of the body they are blowing onto. In terms of the cooing load they certainly are much greener compared to their air conditioned benchmark companions, but in terms of their building envelope they are not green as they are not able to provide TC. As the already existing houses in 2012 will certainly represent more than 90% of the whole built environment in 2020, how can they be greened by retrofitting and increase their thermal comfort at the same time?

As a reference building, an ideal type case study was chosen, with some distinctive elements compared with other types of residential buildings. However, basically it might stand for the bulk of creating thermal comfort in Taman houses and, as they are constructed with the same material, low-rise buildings throughout the country.

2.1. Description of Reference Building and Experiments

The reference building with a built-in area of 83.6 m^2 and 271 m^3 is a semi-detached standardised house in a suburban Taman area on the mainland near Penang. It was chosen because like such as for many of them, their envelope is highly standardised and natural or aided shading is not provided. Sun-lit locations can be typically found in many areas where the existing trees and plants were indistinctively chopped during the construction, and landscaping is restricted to sawing grass on more or less unfertile soil. Following the same logics, the windows at the south front of this semi-detached building will be hit by the sun path 11 a.m. onwards, shining in at different angles until the sun goes down at an angle of 15 degree before it will vanish behind the shape of the adjacent neighbouring building. As a result, the windows of the West front will be hit 1.30 onwards until 45-60 minutes before the sunset.

Figure 1: Picture of the Ideal Type Taman Reference Building

The minimum requirement the team had to achieve is simple insulation and slight air-tightness of the building to create an experimental design deemed necessary to compare with a building based on the open air principle.
Therefore, within the building, the master bedroom and the adjacent washroom were separated by insulating wall and door:

1. The hot permeable ***Southern part of the building*** is mainly equipped with open louver windows. It may be based on the utopian idea of bringing back traditional thermal comfort of kampong houses into a modern built environment. As recent researches have found out, this concept cannot be utilised for a stand-alone low-energy house creating its own thermal comfort because of the air leakages.

2. Following this approach, the compartment in the South with prevailing louver windows was separated towards the ***Northern part of the building*** which predominantly was equipped with closable tinted, but -at this first research stage- not laminated single-glazed windows (4mm). Working on a low budget, as a first minimum requirement to run the thermal comfort system, the air-tight part requires a closed partition wall dividing it from the permeable part, insulation material underneath the roof and airtightness of the existing windows. At a later (optional more expensive stage) the heat transmission rate can be reduced further by installing insulation atop the suspended ceiling. Set-up of the experiment: The walls, the windows and the door.

2.2. Planning of Sequential Experiments

Step-by-step, within a research period of 5 months, the researchers tested all the different elements in terms of tropical thermal comfort (especially temperature, humidity and velocity / ventilation). Based on the following 4 experiments, at a later stage, operational costs and ROI of retrofitting with less or no air conditioning units can be scrutinised.

Experiment 1: Measurement of inside and outside day-/ night time temperature / humidity in a sequence of 10 days (3.1)

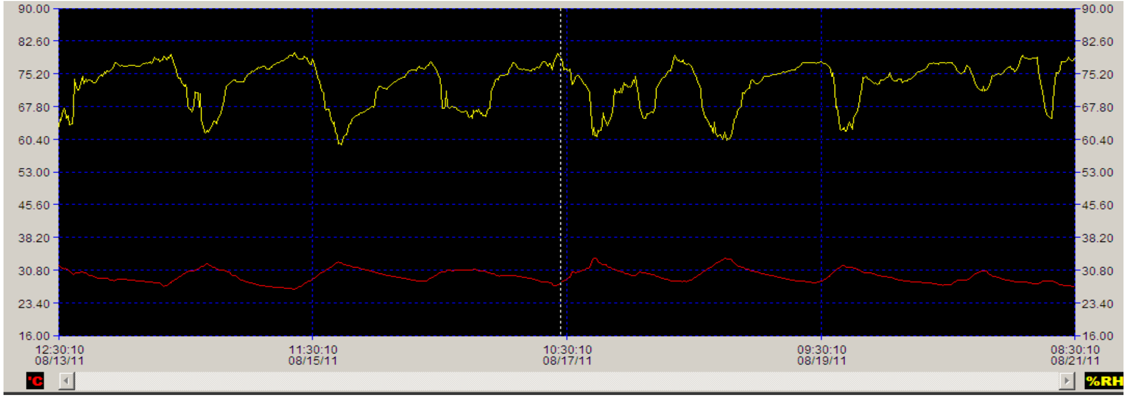
Experiment 2: Installation of Thermo Ventilation Tool -> Measurement with Cross-ventilation mode and suck-in mode during night time.
This experiment can be conceived of as an initial litmus test which can tell whether or not and to which extent an air-condition reduced future is feasible for the majority of residential houses (3.2).

3. RESULTS AND DISCUSSIONS: Analysis of Results

is performed by a statistical analysis with the software Minitab ® which is the prevailing tool for 6-Sigma-DMAIC-projects. The result will be presented together with recommended improvement measures and controlling tools to reduce deviation in terms of thermal discomfort.

3.1. 1st Experiment: Temperature and Humidity Log Readings *with comparison of inside and outside temperature / humidity before any green intervention (10 days)*

Due to the Malaysianised definition of thermal comfort elaborated in part 1, we set maximum 28.6ºC and a humidity of not exceeding 70% as the tropical USL (upper space limit) borderline of thermal comfort, neglecting velocity. In our own tropical thermal model based on longitudinal participant observation, given ventilation, hot temperatures contributes to more then 90% of thermal discomfort, and humidity only to 10% at its high ends. This is due to the finding during observation and interviewing that the absence of thermal comfort is the temperature with humidity having second importance.
We used two thermo loggers in this experiment, one outside and one inside the building. (13-21/08/2011) measuring temperatures (red lines) and humidity (yellow lines):



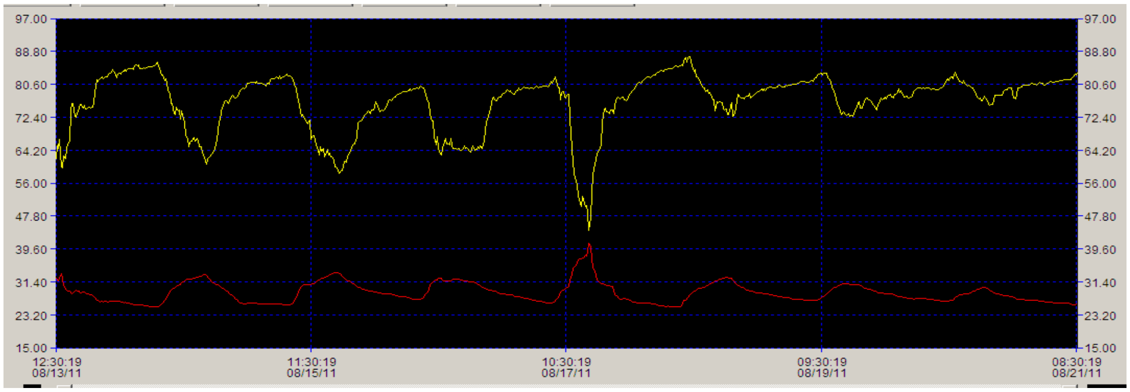


Figure 2: Inside and Outside Temperature and Rel. Humidity (RH)

These are the 3 major findings of comparing inside and outside temperatures:

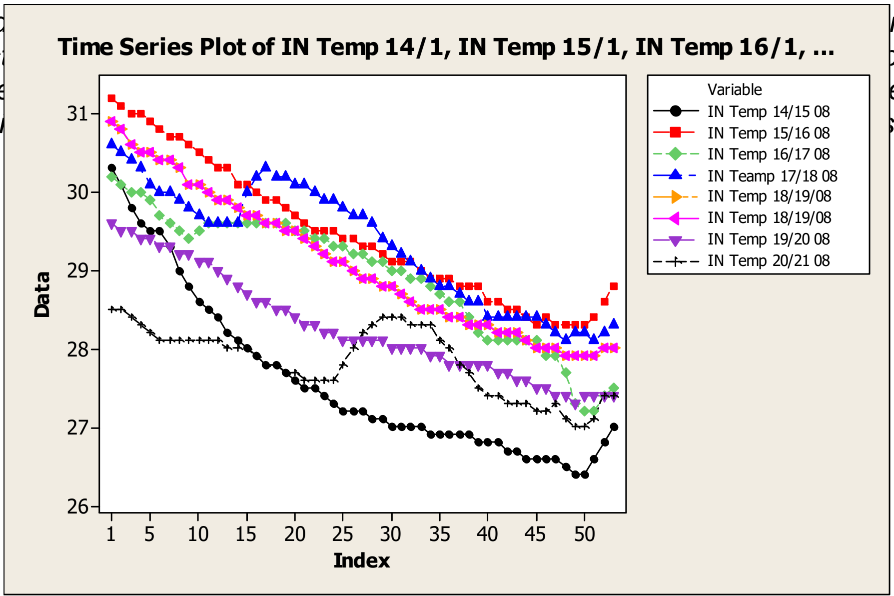
1. The average inside *temperature* is slightly higher inside the building (30.7ºC), with the outside standard deviation (SD) being four times higher than inside. Whereas the temperature inside this bricks and concrete building is continuously too hot, the outside temperature will increase to 3ºC hotter during the daytime, but decrease up to a even 5 ºC colder during the nighttime.
2. The outside *relative humidity* (RH) during the daytime is often lower than the upper space limit of comfortable 60% during peak periods of sun shine. It tends to be slightly higher than inside at cloudy and rainy conditions. However, the RH gets significantly higher after the sun sets and during the nighttime.
3. A high *negative correlation between temperature and humidity* (r= -0.90) could be reported. That means the higher the temperature, the less the humidity and the other way round. In its extremes, this can result in indigestible temperatures of 34 ºC in the afternoon with an acceptable RH of 50%.

The set of measurement is consistent with only 2 anormalcies: (1st chart) inside: when an extra dehumidifier was switched on (discussion in 2013) and (2nd chart) outside: when the measurement tool was exposed to the sun for one hour and then returned to its original position in the shade.

*Subsequently, in a 2nd analysis, the daytime data was removed in order to find out whether the inside or outside temperature **during the night time** (8 p.m. – 9 a.m.) could be cold enough to comply with the thermal comfort level of 28 ºC– 28.6 ºC.*

The nighttime outside temperature's average in 371 measurement points taken was 27.1ºC with a standard deviation of 1.101, whereas the inside temperature was 28.4 ºC (S= 1.078). If the theory of thermal comfort with the Upper Space Limit of 28.6 ºC is true, this 1.3 ºC might be the cutting edge in terms of creating better thermal comfort.

a) *The c* *ncy, by*
the s *oo high*
above *e early*
morn *s in the*
early



28.6 °C

28 °C

8 9 10 11 12 1 2 3 4 5 6 7 8 9

Figure 3: Inside Temperatures over 7 Nights

b) In contrast to the stack-effect represented during the readings of inside temperature, the look at the outside temperature varies as indicated below in figure 4. Like in a wooden Kampong house that cools down quickly after sun set it shows the same decreasing tendency with an average score of 28ºC compared to 29ºC inside. However, it depends on the weather situation whether the target 28ºC-28.6º C is achievable after 9 pm or at the latest after 12am after the hottest day:

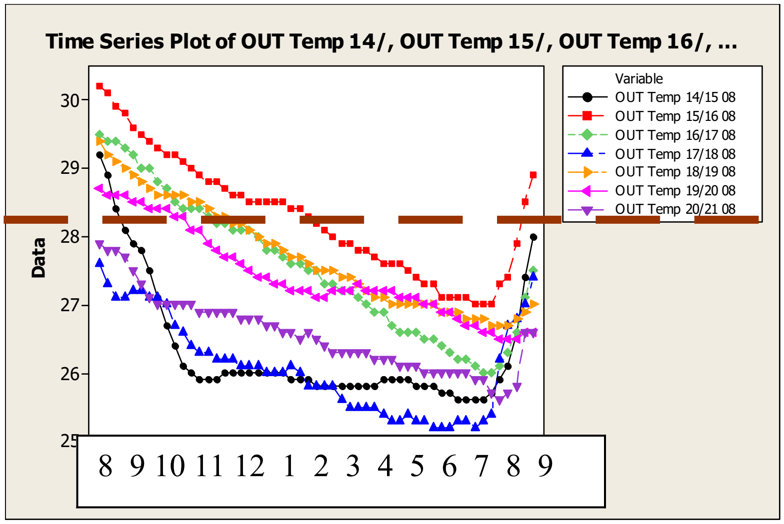


Figure 4: Outside Temperature over 7 Nights

As the chart shows, the critical hours where coolness from outside is not yet achieved, in all cases (except after rainy conditions) are between 8 pm and midnight. Between 12 a.m. and 2 a.m. the latest, the yielded outside temperature will be often in range with 28.6º C as the upper space limit for residential tropical thermal comfort. The following hypothesis has to be argued: "Nocturnal minimum air temperatures in night ventilated condition are still about 2.0 ºC higher than the ambient air" (Ahmad, Supian and Doris Toe, Hooi Chyee, 2008).

3.2 . 2nd Experiment: Measurement of inside and outside temperature with installation and operation of Thermo Ventilator

Apart from the local fan technology, the thermo-ventilator used to breathe in and out consists of a motor with 18W peak performance for the fan, heat retaining fins, inclusive of noise reduction and air filter.

Figure 5: Thermo Ventilator

This device is usually installed into European airtight houses providing fresh air. In a tropical country, the ventilator provides a purposeful hybrid combination of the traditional approach which goes “back to nature” (open air principle) and the prevailing air condition systems. Heavily or unequally chilled buildings with inverter-based air condition units account for more than about 18 times compared to ceiling or stand fans. At a scenario of an old air condition unit consuming 2 KW/h their operational costs and CO_2 emission even accounts for roughly 30 times higher as by traditional ceiling or stand ventilation systems.

For this experiment, two units of modified thermo ventilators were used. One stand-alone unit repeatedly reversed the direction of its air flow direction in the following experiment a). In experiment b) one unit breathed air from inside to outside and the second unit, the outside-inside ventilator, was built in into the wash room’s window grill adjacent to the Master Sleeping Room (SR) which became a real-life ***experimental laboratory***:

Figure 6: Location of Outside-Ventilators

The other rooms and the hall (living room (LR)) were used as ***control room*** with no intervention of inside-outside ventilation activities. Apart from a wide variety of other variations, only two modes of operation were chosen to be presented in this paper:

a) ***Two-way flow air mode with one device***

The thermo ventilator which worked as a stand-alone unit ran in an automated breathing-in/ out-mode with 18W: Every 50-80 seconds, the thermo ventilator changes its direction. As the results proved to have no impact on the temperature which stayed stably 3.09 ºC higher than the outside night temperature with no significant improvement compared to the control room, we abandoned this mode after 2 nights.

b) Two-way flow air mode (2 device, each 1-way-stream)

During 5 subsequent days, we installed one thermo ventilator to suck the inside air out, and a 2nd fan to harvest colder and fresh outside nighttime air into the test room. Within 2 nights, the temperature gap between inside and outside temperature with the ventilator sucking the colder outside air was reported at 1.49 ° C on average with S^2 of 0.71° C inside and 0.42 ° C outside. Conversely, the weaker 1-way operation nights had averaged in only 0.454437 ºC decreased temperature. This can be considered a ground-breaking result, and longitudinal studies adapted to several locations are being conducted at the same time could verify its validity at probably reasonable investment costs. The exemplified results show the headway of progress:

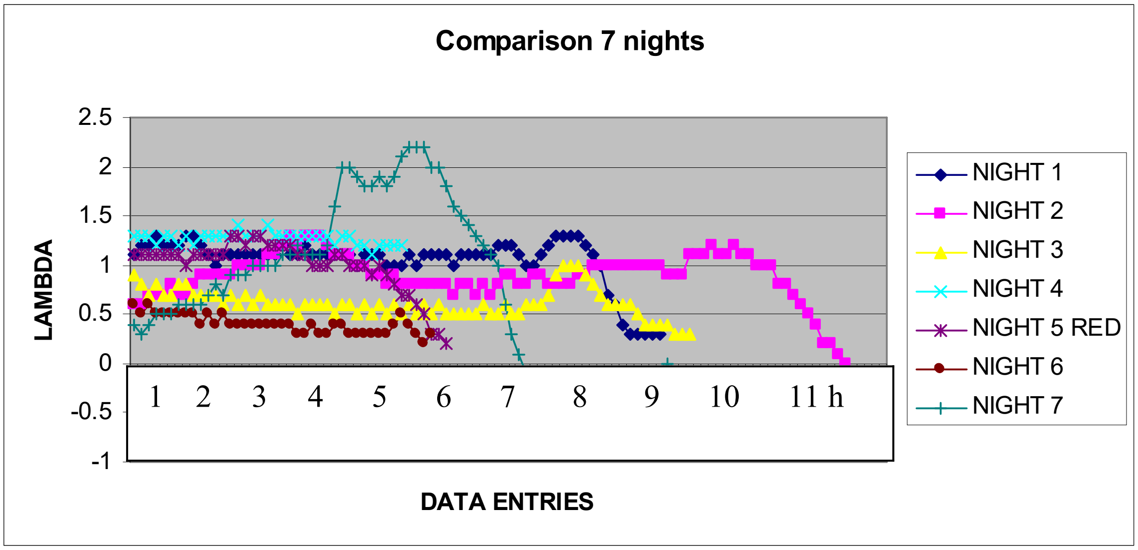


Figure 7: Duration of Below 28.6° C Values during Nighttime Ventilation: Thermo Ventilation Yield in Hours per Day

Typically, it took at LEAST 2 ½ - 4 h to harvest TC based compared to the already colder outside temperature. Depending on the cumulative outside temperature intake during the day, here are 3 typical examples of time lags until the thermo ventilator system yielded the target temperature of 28.6º C:
a) 10.38 p.m.– 1.08 a.m. (“green” night with heavy downpour before)
b) 2.18 a.m. – 4.58 a.m. (“yellow” night with typical sunny mornings followed by predominantly cloudy weather conditions during the afternoon).
c) In some remaining “red” nights, with stable mostly sunny / cloudy conditions during subsequent rain, that was only close to the upper space limit, but could not reach the targeted temperature.

Furthermore, comparing the outside temperature with the thermo-ventilated room (purple) and the control room with just an ordinary ceiling fan in operation (blue), the following result could be yielded in 3 ½ days of observation:

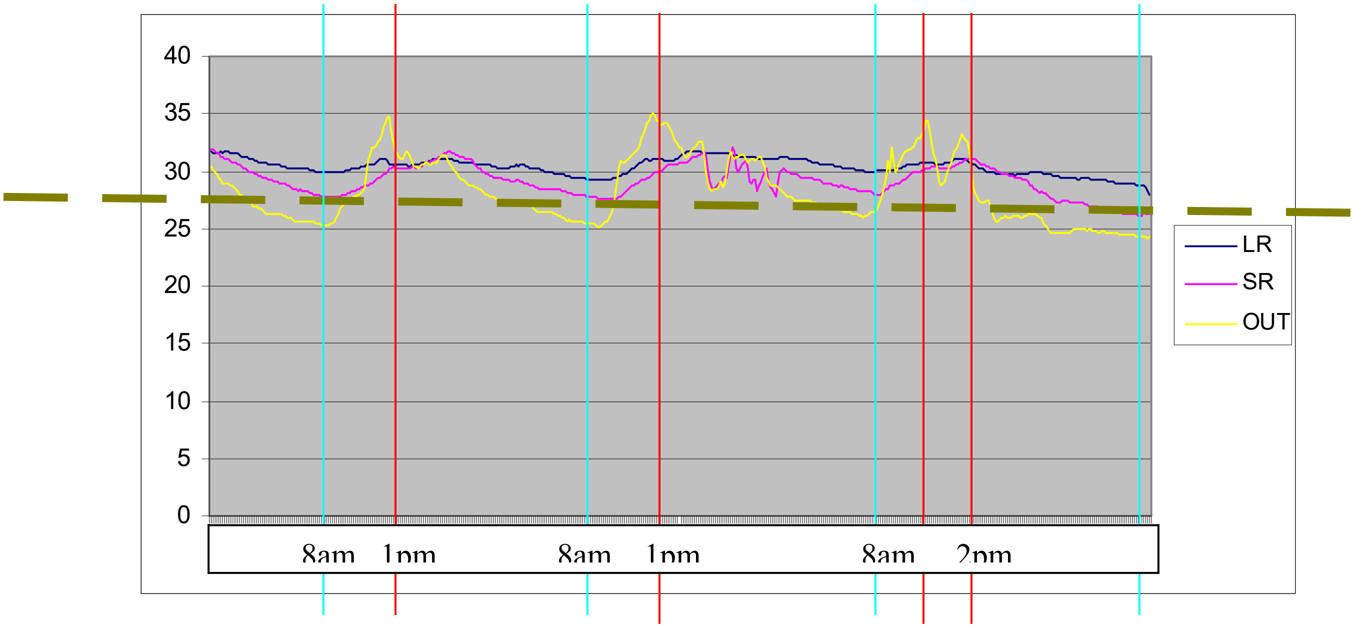


Figure 8: Run Chart Temperature 4 Days Comparison Sleeping = Experimental Room (SR), Living = Control Room (LR) and OUT-side temperature

As the figure shows again, the thermal comfort zone could be gradually reached for the thermo ventilator during the nighttime at different times between midnight and usually 4.30 a.m., whereas in case of the fanned control room it remained always above the upper space limit. When the heat of a new day set in again, the experimental room (SR) gradually still kept the coldness for a few hours typically until 11 a.m. During the mornings, the lower temperature below the set point could still be achieved before the effect of the non-insulated building envelope would soon rise the temperature up again out of the TC-zone.

Our observations yielded the following average scores in the early morning with these temperatures:

Outside:	Inside: Experimental Room with Cross-Ventilation	Inside: Control Room with Ceiling Fan
26.5 C	27.9 C	29.9

DELTA **OUT-SR** = 1.4° C

DELTA **SR-LR** = 2 ° C

On average, despite the cooling effects of the night time temperature, the experimental room remains 1.2 ° C warmer than outside. Conversely, the control room still stays stuck at 1.4 ° C hotter than the thermo-ventilated area respectively 2.4 °C compared with the minimum outside temperature.

3. Conclusion

1. Active night time harvesting of colder outdoor air temperature by thermo ventilators is possible at reasonable operational costs (see 5.). This system will actively breeze in fresh air and hence reduce the unhealthy indoor CO2-level caused by permanently closing the windows when fans or air condition units are in operation.
2. Outside night air harvesting alone will help to decrease the temperature only by 1.2 - 2ºC during 8 p.m. – 8 a.m. on average. By far, it will not always be capable to yield the derived Malaysian TC-zone of maximum 28.6ºC. Insulation measures of the windows, the roof, the ceiling and also the walls will help genuinely to reduce the temperature so that further cooling by electrical air condition is not longer required or can be substituted by a hybrid system.
3. Harvesting colder nighttime temperature naturally also implies a higher intake of humidity exceeding the official thermal comfort level as it does anyway during all nights in non-air conditioned rooms. In the five consecutive nights measured above, the average humidity was 75.8% and hence 3.9% higher than within the control room. Studies need to be conducted, how to reduce the humidity without increasing the temperature or – like in this experiment, to ignore / live with it and still feel quite comfortable.
4. At present, the obvious restrictions of the utilisation of the colder night time temperatures mentioned are still grounded in astonishingly high variations as well. On hot days with high heat intake in an uninsulated building, the cooling thermal comfort effect of the ventilation only started at 2.30-6.00 a.m. during our initial experiments. During longer hot periods, TC could nt achieved at all. However, it is expected by retrofitting enabling the building to reduce or even avoid the high daytime heat intake and make the system run effectively in at least 90% of all times between 10 p.m. and 12 p.m.
5. Finally, looking at the operational costs, cross ventilation is comparable to running a likewise operating ceiling fan, but –on the condition that occupants are always at home- the system incurs much less cost savings compared to different air condition solutions (peak):

a) Air Condition Unit	1,200 W/h (Inverter)- 2,000 W/h (non-inverter)
b) Ceiling Fan at speed level 4:	65-75 W/h
c) Cross ventilation with 2 gadgets	<50 W/h
Aid of ceiling fan during hot nights (max. at level 2)	25 W/h
TOTAL	75 W/h

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