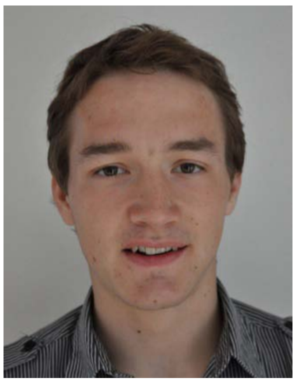
Design of Air-conditioned Houses in Hot Humid Areas

How to reduce energy consumption



Jakub Popela
Student
School of Architecture, Lund University, Sweden
jakubpopela@seznam.cz
June 2012

1 Urban Shelter Design Development

It is a well known fact that world population growth has recorded immense development in recent decades and will continue even further. In 1960s there were 3 billion people in the world and now it counts even 7 billion[1]. We can say that in western countries this growth is more or less linear but the problem is in developing countries, where the growth is almost exponential and according to UN there are two possible ways of further situation in year 2050. One is if all UN-agreed population policies are implemented and then we should expect around 8 billion people living on our planet. The other one says 12 billion if everything fails[2].

Another side of this population growth is an economical growth all over the world. Even though, there are still about 2 billion people beyond poverty line cooking on fire, there are also about 5 billion people who have access to electricity and who can afford new and different electrical appliances. There are also new unwritten standards for every person in the number of these appliances which are also very tightly connected to income group (graph 1.1).

---

[1] Hans Rosling and the magic of washing machine on www.ted.com
[2]www.sustainablescale.org

Graph 1.1

Source: www.gapminder.com

If we combine this knowledge with current speed of development and population growth, we can clearly see that energy consumption is growing exponentially and even now-a-days there is not enough energy for everyone. In western countries, there is motion towards lower energy use, higher energy efficiency and long term sustainability so their energy consumption is lower and lower. However we can't expect this happening in developing countries and we should expect the exact opposite. This is clearly visible in graph 1.2 for electricity consumption in Sweden and China between years 2005 and 2008.

Graph 1.2

Source: www.gapminder.com

For developing countries, energy access and consumption is very important matter and for families with low income it is a crucial part of their monthly budget. These families can easily spend more than 10% of their income just for electricity and because of that energy consumption should be one of the most important issues during design proces.

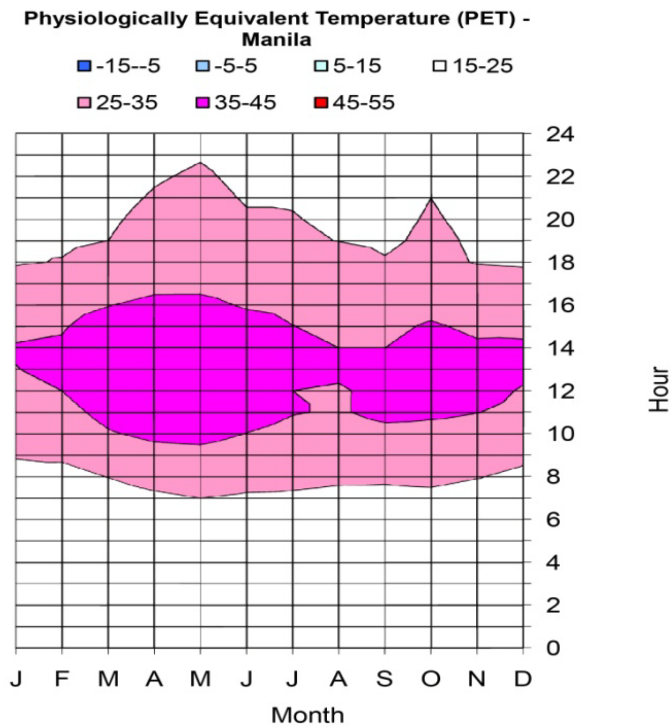
2 Factors Shaping Urban Shelter Design

Before going deeper into a problem it is important to clarify that this work is based on a field trip to Philippines, METRO Manila in February 2012. All tables and calculations are made as a reaction to observations from existing projects or projects under construction and interviews with beneficiaries of these programs or people who are behind the construction like governmental organizations, NGOs or contractors.

Today in Philippines everything in urban shelter projects is just about unit construction cost. It is also major value for measuring affordability of living and success or failure of different projects and different construction principles. When the project is designed, there is a very simple way to calculate monthly mortgage and for how long the beneficiaries are expected to pay for their new home. However, in the real world it is not that simple. With new possibilities come new expenditures. With the possibility of electrical socket, there is a high chance of buying new electrical appliances and with bad material or design there is higher chance of buying new appliances as means to achieve thermal comfort inside the building. This is especially important in hot humid climates, where there is very high humidity, almost no air movement and high outside temperatures.

Graph 2.1 shows that indoor climate comfort is important, since for outdoor conditions there is no comfort during day, there is a slight discomfort all year from early morning till late afternoon and around noon, there is always discomfort.

Graph 1.3



Source: HDM, Lund University, Sweden

In table 2.2, there is a simplified calculation of electricity consumption of different appliances, based on how long people use the appliances listed. For this particular purpose the most important part is cost per month. In calculation it is assumed that cooking takes around 1 hour a day, all entertainment is on ¼ of a day, fridge goes nonstop, light is on during night, table fan in hours of slight discomfort and that they have to use air-conditioning only in time of discomfort. Price of energy is given by Meralco electricity company of Philippines and in March 2012 it was 9,04 PHP/kWh[3].

Table 2.2

Appliance	Consumption in Watts	Hours/day	kWh/day	kWh/month	PHP/month
Air-Conditioning	2000	4,1	8,2	250,1	2261
Cooker	1000	1	1	30,5	276
CRT TV	150	6	0,9	27,45	248

3 www.meralco.com.ph

Desktop computer	130	6	0,78	23,79	215
Laptop computer	40	6	0,24	7,32	66
Fridge 120 l	60	24	1,44	43,92	397
Light bulb	60	4,5	0,27	8,235	75
Rice-cooker	1000	1	1	30,5	276
Radio	15	6	0,09	2,745	25
Stereo	30	6	0,18	5,49	50
Table fan	25	11,7	0,293	8,92	81

It is obvious that entertainment takes relatively small amount of electricity except for older CRT TV and desktop computer. The second most important part of a bill are appliances handling food like cookers and fridge. Having a fridge is almost comparable to cooking one hour a day which can be quite surprising. Never the less, the most important energy consumer is an air-conditioning unit and even though it runs only four times longer than a cooker it takes eight times more energy.

This is a clear message, that taking energy consumption into account during design process is more than reasonable and it can also change the affordability of a unit a lot. If we realize that average monthly mortgage is around 3000 PHP and less, then 2200 PHP just for air-conditioning makes a huge difference and can be a huge problem when people move from informal settlement into newly built houses made of wrong materials and in a wrong way. Living costs can become unbearable and can result in tremendous complications for people who should have been beneficiaries at the first place.

3 The Parametric Study

For architects there are, among others, two main options how to think about indoor climate. There is a passive way or active way. Of course passive way, where the nature is used to create indoor climate, is most suitable from sustainability point of view, but there are also huge limitations. Now-a-days it is very hard to achieve passive cooling in the building with the materials used today as concrete, corrugated iron sheets and such and there are also security issues. It is much easier to let machinery create comfort for us. If we decide for active cooling, there is still a lot of place for our creativity. There are still ways to achieve better results and we can still lower cooling loads which will save someone's money.

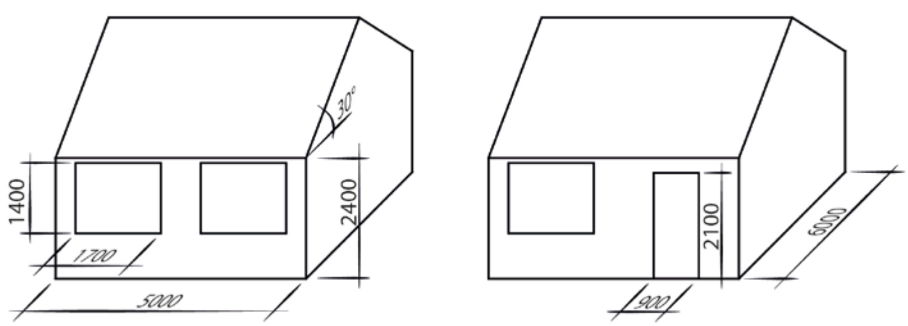
Computer simulation

For better understanding of parameters influencing cooling loads, computer simulation with Ecotect Analysis 2011 software is presented. This study should show the difference and effect of minor changes, which are presented as a simple case study.

Case study

Calculations are made on a simple one-storey row house, which is between two houses of same dimensions and characteristics. Exact dimensions are shown in figure 3.1. Design of this unit is done according to Mahoney Tables for Philippines and today's building techniques in Metro Manila. Windows on back side take exactly 40% of wall surface and pitched roof is chosen according to weather resistance recommendations. Windows are facing North and South.

Figure 3.1



Basic unit is constructed out of reinforced concrete walls with single-glazed windows and roofed by corrugated iron sheets. Rest of used materials and some of their properties are shown in table 3.2.

Table 3.2

Basic description	Components	U-Value	G-Value	Solar Absorption
Walls				
Reinforced concrete	-100mm of reinforces concrete	5	-	0,506
Reinforced concrete	-100mm of reinforces concrete	5	-	0,248

with reflective paint	-outside layer of reflective paint			
Insulated reinforced concrete	-100mm of reinforced concrete -50mm of rock wool	0,57	-	0,506
Roofs				
Corrugated metal roof	-corrugated metal sheet	5,53	-	1
Corrugated metal roof with reflective paint	-corrugated metal sheet -outside layer of reflective paint	5,53	-	0,245
Insulated corrugated metal roof	-corrugated metal sheet -50mm of rock wool	0,61	-	1
Ceilings				
Wood	-20mm thick planks	3,77	-	-
Insulated wood	-20mm thick planks -50mm of rock wool	0,58	-	-
Windows				
Single-glazed, timber frame		5,1	0,94	-
Double-glazed Low E, aluminium frame		2,41	0,75	-

Comfort criteria

Comfort criteria are very important part of calculations, because with those data it is possible to show cooling loads, which are produced to create ideal indoor climate. In air-conditioned buildings the upper comfort level is 25-27°C depending of clothing; the higher value assumes as little clothing as socially acceptable and the lower value a light business suit. During house cleaning the temperature should not exceed 25°C if the person is properly dressed (Adamson and Åberg 1993:6). It is why the thermostat in the unit is set between 25 to 27°C.

Changes

For satisfying result 13 different units are measured and submitted to computer simulation; one basic unit and 12 minor adjustments, always only one different material or adjusted dimensions of one component, etc. The list of adjustments is based on a simple equation used to calculate cooling loads for room:

$$P_{cooling} = P_{indoor} + P_{solar} + P_{transm.} + P_{vent.} \pm P_{storage}$$

where $P_{storage}$ is heat stored in or removed from inner walls, fittings, furniture, etc.; P_{indoor} is the heat produced indoors by people, electrical appliances, etc.; P_{solar} is the solar transmission through windows; $P_{trans.}$ is the specific heat transmission G through the building envelope; $P_{vent.}$ is the heat transfer between outdoor and indoor air (Adamson and Åberg 1993:7).

Whole list of changes is in table.3.3.

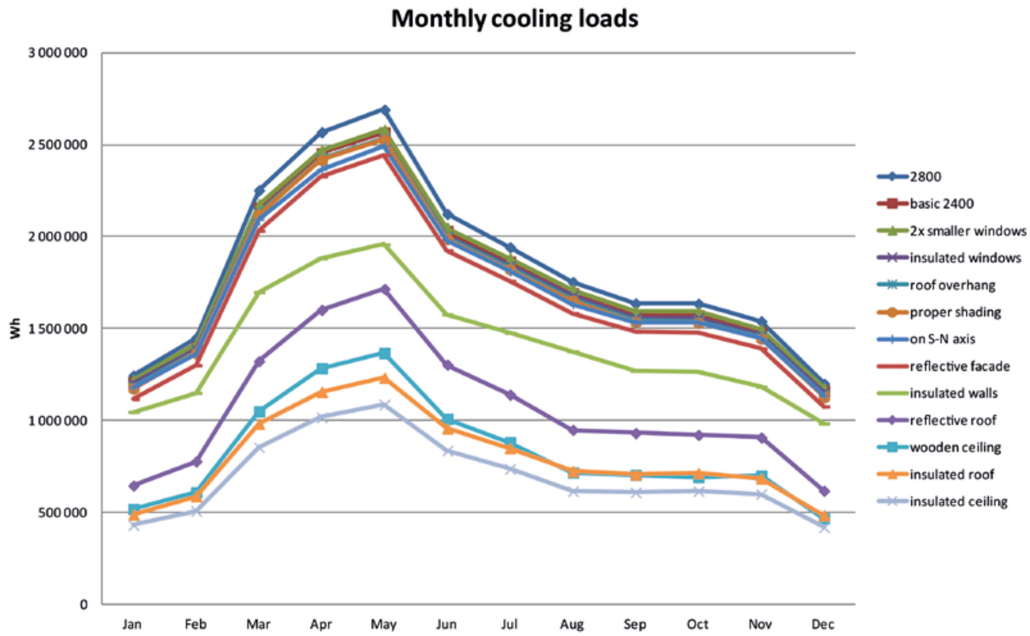
Table 3.3

No	Name	Note	Aim
1	Basic 2400	Basic unit on E-W axis	-
2	Insulated walls	-	Reduce $P_{trans.}$
3	Reflective facade	-	Reduce $P_{trans.}$
4	Insulated windows	Better window type	Reduce P_{solar}
5	2x smaller windows	-	Reduce P_{solar}
6	Insulated roof	-	Reduce $P_{trans.}$
7	Reflective roof	-	Reduce $P_{trans.}$
8	Wooden ceiling	Inserted ceiling under roof	Reduce $P_{trans.}$ and volume
9	Insulated ceiling	-	Reduce $P_{trans.}$ and volume
10	Roof overhang	Roof overhanging by 1m	Reduce $P_{trans.}$ and P_{solar}
11	Proper shading	-	Reduce $P_{trans.}$ and P_{solar}
12	2800	Room height 2,8m	Increase the volume
13	On S-N axis	Rotated by 90°	-

First results

First set of simulations is giving us very different values and it is obvious, that just small change can make a huge difference. Some of them are less effective, even though they might be more expensive, and some are very powerful with minimal investment. Graph 3.4 shows values for cooling loads in Watt/hours for all months. Names of units are already in order according to total cooling load per year.

Graph 3.4



As expected, if the room height is higher and there is a bigger volume to cool, cooling load is also higher than in case of lower height and the same principle works for integrated ceiling. In graph, there is also a group of changes which do not have a big impact. These are for example changes to windows, even though better windows give some positive values, but for high price. In the same group, there are also changes like overhanging roof and proper shading, which are reducing direct solar transmission through windows, but obviously it is not as important as reducing heat transmission trough envelope of the building. Quite a good result is for reflective facade, if we realize that the house is enclosed by two others and surface of the facade facing sun is rather small. Insulated walls reach even better value but of course for much higher price and technical demands.

In both graphs for first results it is obvious that most important part of the building is roof. It is also largest surface facing outdoor conditions. Insulated roof is better than roof with reflective surface, but reflective surface is much better than all previous treatments and changes to the house. However, simulation shows that most important is integrated ceiling, which lowers the volume of room and also separates room from heat accumulated under roof. Simple wooden ceiling can have the same advantage as insulated roof, except for hottest months of a year. The best solution is then insulated ceiling.

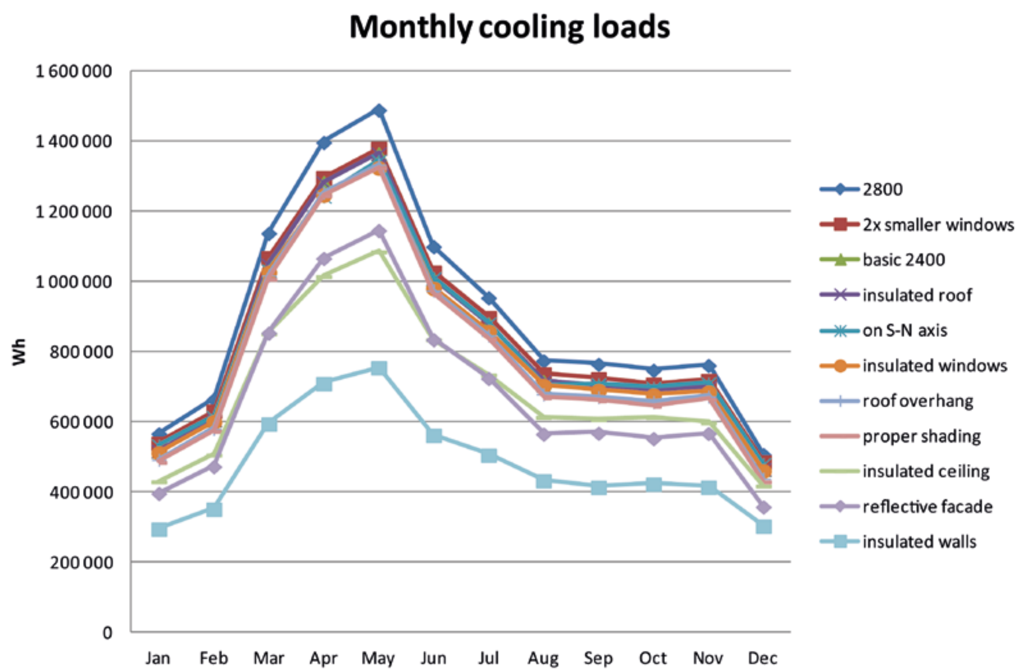
Graph 3.5

Graph 3.5 shows the absolute values per year in Watt/hours. Obviously some adjustments do not make a big difference, but then there is a huge improvement when the focus is on walls, roof and ceiling. Just simple ceiling can decrease cooling loads to 47% of original unit and insulated to 39%.

Results with integrated ceiling

Another set of results is with already integrated wooden ceiling to find out what is the best combination out of all options; both technically and economically. As it was in previous case, higher room means increased cooling load, but now it is even more obvious. There is also a group of changes which make almost no difference for rather high cost. These are again windows, overhanging roof and shading system. Even though it makes no huge difference it is interesting that building position on S-N axis is slightly better than W-E. This works in both cases. However, W-E axis is better from a social point of view, because it is easier to achieve shade on porch during day.

Graph 3.6



With integrated ceiling it is obvious that roof treatment isn't that important any more. Therefore it is not important to focus on roof when there is a ventilated space between roofing and ceiling. In this case most important changes are those made with walls. Reflective facade can have the same impact as insulated ceiling and the best option is to combine simple wooden ceiling with insulated walls. And in this case amount of insulating material needed for wall treatment is 50% lower than for ceiling.

Graph 3.7

Combination of insulated walls and wooden ceiling results only in 58% of demands of basic unit with ceiling and just 27% of demands of basic unit without any treatment from previous simulation.

4 The Role of Architects

If an architect is in process of designing a building, the architect's first question should be who the client is. In case of urban shelter it is little bit more complex than this, because client is always some kind of organization; either governmental or nongovernmental. Then the question should be who the beneficiaries are. What are their needs and what do they have. One of the characteristics of the poor people is that they do not have much money to spare. That is why the question of affordability is so important, however, this should include much more than just the building cost. It should also count with living cost given by design. The architect cannot decide for the family if they want a TV or not but the design itself sometimes causes the need of extra power. It depends a lot on the type of building. Is it designed as passive or active building? In now-a-days conditions it is very hard to design working passive house so it is much easier to decide for active one, but with this decision comes great responsibility. The architect should remember again the reason and aim of the design and it should be to save someone's money and energy to make this kind of development sustainable at least in the part of energy consumption. Previous simulation is a proof that one good decision can change energy consumption by air-conditioning unit a lot and it can be just a minor investment. According to the simulation, clearly the most important thing is to separate hot air accumulated under roof and main cooled room. This extra heat is mostly produced by thin roofing layer like corrugated metal sheets, which are often used in developments of this kind. This separation can be done simply by thin wooden layer or maybe even some cloth. Significance of this step is its cost. There are also other steps like insulation of walls or ceiling itself, but the price is of course higher and some technical difficulties can occur.

References

Adamson, Bo; Åberg, Olle

1994 *Design for climatization; Houses in Warm-Humid Areas.* Lund: LCHS.
ISSN 1100-9446
ISRN LCHS-A3-BI--10--SE

Rosenlund, Hans; Jianqing, He; Guofeng, Sun

2005 *Housing Design for Lower Domestic Energy Use.* Lund: HDM.
ISSN 1100-9446
ISRN HDM-BI--34--SE

Adamson, Bo

1991 *Passive climatization of residential buildings in tropical climates.*
Lund: LCHS.
ISSN 1001-797X
ISRN LCHS-A3-MEM--3--SE

De Luna, John Z.

2000 *Low-Cost Housing Units in the Philippines.*
Lund: HDM.

Aktacir, Mehmet Azmi; Buyukalaca, Orhan; Yilmaz Tuncay.

2010 *Applied Energy, pp. 599-607: A case study for influence of building thermal insulation on cooling load and air-conditioning system in the hot and humid regions.*
Turkey.

B. Givoni

1994 *Renewable Energy, Vol.5, Part II, pp. 908-916: Building Design Principles for Hot Humid Regions.*
Los Angeles: University of California

Schiavon, Stefano; Melikov, Arsen K.; Sekhar, Chandra

2010 *Energy and Buildings, pp. 699-707: Energy analysis of the personalized ventilation system in hot and humid climates.*

Alpuche, Guadalupe; Heard, Christopher; Best, Roberto

2005 *Applied Thermal Engineering, pp. 507-517: Energy analysis of air cooling systems in buildings in hot humid climates.*

Mexico

HDM, Lund University, Sweden

www.meralco.com.ph

Hans Rosling and the magic of washing machine on www.ted.com

www.sustainablescale.org

www.gapminder