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Energy Savings Benefit from Passive Architecture

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Abstract

Passive Architecture is a climate responsive building that provides comfortable indoor conditions, naturally. In hot and humid tropics, this can be achieved by strategising the building elements namely: orientation, form, opening and sun shading devices to avoid solar radiation, promote ventilation from the prevailing wind and ensure daylight into the building. Consequently, the building operation would require less mechanical cooling and artificial lighting to be independent from commercially supplied energy. The resultant "savings" in the operational energy is termed as Energy Savings Benefit. This idea was demonstrated by comparing the energy use of a house built without any consideration of Passive Architecture (Actual Case) and a simulated version that incorporated Passive Architecture design strategies (Improved Case). It was found that the living/dining area in the Improved Case claimed significant Energy Savings Benefit from mechanical cooling and artificial lighting. Such information can be used to anticipate the long term benefits of a property that applies Passive Architecture design strategies.

Keywords: Passive Architecture, Energy and Energy Savings Benefit

1. Energy Requirement in Building

In hot and humid tropics, building needs Operational Energy (OE) mainly to cool the living space besides generating artificial lighting. This is captured as operational cost and exists throughout the building lifetime which can be up to 50 years (Fig. 1).

Building's OE varies from one property to another depending on its design, use and occupants. The bulk of OE supply comes from fossil fuel energy or commercially supplied energy (Buchanan, 2005). In time, the cost of OE will rise due to tariff hike and this can be a burden to the owner, tenant or operator. Unfortunately, information on OE is hardly available to the buyer when committing to a purchase and most buyers only become aware of building's OE when they are paying the energy bill.

There are several ways for building to reduce its operational cost. A sustainable approach is to utilise natural resources such as solar power, wind power, etc., or commonly known as Renewable Energy (RE) (Szokolay, 2006). Solar power is a popular RE but it requires high capital investment. Its main component, namely silicon, is still relatively expensive (Smith, 2005). Inevitably, the payback time is too long and the return on investment is hardly recouped by the building's first owner.

Another method to reduce operation cost is by using Energy Efficient (EE) equipment (Smith, 2005). EE equipment has high coefficient of performance such that it needs less energy to run when compared to other typical equipment. However, comprehensive application of EE products could be too expensive for building owners. For example, a typical EE compact fluorescent costs several times more than the incandescent bulb. The construction cost will eventually rise as more EE products are applied.

Building should be sensibly designed to be independent from commercially supplied energy by way of Energy Conservation (EC). This is a step before RE or EE.

2. Passive Architecture

Passive Architecture is a climate responsive building that provides comfortable indoor conditions, without relying on mechanical cooling or artificial lighting. In hot and humid tropics, the aim of Passive Architecture is to avoid solar radiation, promote ventilation from the prevailing wind and ensure daylight into the building. The maximum impact can be achieved by strategising the building elements such as orientation, form, opening and sun shading devices to achieve the said goals (Olgyay, 1963, Hyde, 2000).

Passive Architecture is not a new idea. Local traditional houses in the tropics have exemplified Passive Architecture by means of raised floor, low thermal mass envelope and raised/jacked roof to facilitate ventilation (Fig. 2).

Generous openings like windows, doors and ventilation outlets are deliberately positioned to encourage natural ventilation (Olgyay, 1963, Hyde, 2000). Traditional house also put emphasis in encouraging daylight as much as possible into its rooms. Nonetheless, the openings are well shaded, thus reducing heat gain.

Other studies found that in the hot and humid tropics, building with shallow rooms elongated from east to west and facing north performs better in achieving comfortable indoor conditions (Hyde, 2000). It was also found that natural ventilation is more successful in slender room since prevailing wind in the tropics does not have high velocity (Olgyay, 1963). Generally, Passive Architecture is elementary as it asserts Energy Conservation (EC) at the design stage to reduce OE in building (Fig. 3).

3. Thermal Comfort and Visual Comfort

A building can be made independent from mechanical cooling when the occupants feel thermally comfortable. There are two components of variables that influence thermal comfort, namely microclimate and occupant's personal adaptation (Auliciems & Szokolay, 1997). Meanwhile, to be independent from artificial lighting, occupants must sense visual comfort. Good amount of daylight enables occupants to carry out their activity in the house without resorting to artificial lighting. Generally, too much daylight may cause glare and too little may be too dark for a particular task; and both instances cause visual discomfort (Majoros, 1998).

Having said that, comfort encompasses both thermal and visual performances; each is a broad and complex subject. Comfort variables affect the indoor conditions differently at various times and these factors do not work in isolation (Table 1). For example, alleviating the heat gain using sun shading devices can affect the amount of daylight entering a room.

Despite the complex relationship, it is important to present the potential of Passive Architecture with reference to the combined effects of both thermal and visual comforts. This is because in reality, the shifting balance between getting thermal comfort and attaining visual comfort happens at any time in relation to all variables, simultaneously.

4. Energy Savings Benefit

The consequent effect of Passive Architecture is "savings" in the operational energy, termed as Energy Savings Benefit. This could be made tangible by comparing the energy consumption in buildings of similar type. For the purpose of this study, a house had been chosen as a sample of a building. Theoretically, a house designed for maximum daylight needs less artificial lighting, hence uses less commercially supplied energy when compared to another that has no consideration for daylighting (Baker & Steemers, 2000). In this instance, the Energy Savings Benefit claimed by the former occurs when it does not need to use artificial lighting (Fig. 4).

Similarly, a house with good natural ventilation would require less mechanical cooling as compared to the one with poor ventilation. Nonetheless, such comparison is only valid when it is made on a levelled platform, whereby the two houses must be of the same locality and size. In addition, the behaviour of the occupants in both houses has to be the same.

5. Methodology

The sample house for the study was a newly completed detached double storey house in Bangi, Selangor that did not have much consideration for Passive Architecture. It had a built up of 3000 sq ft (279 sq m) and sat on a land area of about 4800 sq ft (446 sq m). It was constructed using post and beam concrete with brick and mortar wall infill.

This sample was labelled as Actual Case. The total effect of orientation, form, openings and sun shading devices was treated as one cause for one definite value of indoor comfortable conditions.

As a comparison, Passive Architecture design strategies were being simulated onto the Actual Case to create an Improved Case (Fig. 5). As suggested by the name, the Improved Case is actually a design enhancement of the Actual Case; specifically with regards to the orientation, form, opening and shading devices. The Improved Case, nonetheless, maintained all other construction elements such as method of construction, material, etc. so that both the Actual and Improved Cases have the same construction cost.

The value of Energy Savings Benefit in the Improved Case was determined by comparing its resultant energy requirement with the Actual Case. For this paper, the study area was limited to the living/dining area only.

6. Measurement

The two scenarios had the occupants, microclimate, and material as constants. The simulation readings in the two houses were taken on every 15th day of the month for a year. Based on Auliciem's equation, $T_n = 17.6 + 0.31T_m$, where T_n is Thermal Neutrality and T_m is the mean temperature for the study area, i.e., 27.4°C; T_n is 26.1°C (Sh. Ahmad, 2004). It was assumed that when the building offers Comfort Zone in the region of 2.5K from T_n (for 90% acceptability), the occupants would not require the aid of mechanical cooling.

The illuminance (lux) readings for visual comfort were compared with recommendation by the International CIBSE (Chartered Institution of Building Services Engineers) Standard; for living/dining area is 300 lux (CIBSE, 1994). It was assumed that when the space gave such illuminance reading, it would not require artificial lighting and that personal adaptation would not involve any operational energy.

6.1 Actual Case

The form of Actual Case house was a square and rooms were arranged in a concentric manner. This is distinctive of Malaysian detached houses as it reflects the optimum use of the usual square-shaped land area (Fig. 6). Important rooms such as living area and master bedroom normally faced the main access road, regardless the sun path (Fig. 7).

The openings in the Actual Case house were of the same size, regardless the elevation. It was also observed that the Actual Case had only roof eaves to shade the rooms, and these were not effective at west and east elevations.

It is a fact that by adding sun shading elements and adjusting the size of openings of the Actual Case house, a better reading on the indoor comfortable conditions would be obtained (Auliciems & Szokolay, 1997). However, an important aspect of the study was that the application of Passive Architecture design strategies should be done holistically and should not effect for any additional construction cost.

6.2 Improved Case

Improved Case was simulated from Actual Case with reference to the literature review on Passive Architecture and an actual Passive Architecture house in the vicinity (Fig. 8). The living/dining area in the Improved Case was drawn to match the measurement of the living/dining area in the Actual Case but has the following variations (Fig. 9):

- North orientation;
- Slender form elongated east-west;
- Large openings on the north facade; and
- Recessed floor plan on the north and south sides.

7. Results of Solar Shading Analysis

Both cases were tested for solar shading on their elevations. For Actual Case, most part of the living/dining area faced west. As a result, it was well shaded in the morning but received direct sunlight every afternoon (Fig. 10). At this point, it was deduced that without intervention, the living/dining area in Actual Case would be fairly shady and cool in the morning and rather bright and hot in the afternoon.

On the other hand, the Improved Case did not get much solar gain because of its orientation. In addition, the less important rooms placed at the east and west sides "insulated" the living/dining area from solar gain. Consequently, the space received direct sunlight for only two hours early in the morning and appeared to be well shaded throughout the day (Fig. 11). The large openings on the north and south facades promised ample daylight into this space.

The simulations of solar shading on every 15th day of the month showed that the Actual Case received direct sunlight in the living/dining area for five hours in the afternoon. Meanwhile, the Improved Case received only few hours of direct sunlight in the early morning (Table 2).

It appeared that the Actual Case would require substantial intervention via mechanical cooling to reduce the effect of heat gain due to inappropriate orientation of the house. Furthermore, the Actual Case appeared to need assistance from artificial lighting in the morning hours.

8. Results of Daylight Analysis

The illuminance reading measured daylight opportunity under standard overcast sky as defined by the CIE (Commission Internationale d'Eclairage). The duration was approximately 12 hours from 7:00 a.m. to 7:00 p.m. every day, except during winter solstice. The daylight analysis was carried out onto an imaginary working plane of 0.85 metre-high in the living/dining area to reflect the operational level.

Generally, it was found that the illuminance readings in the space were not consistent. For example, on 15th June, area closer to the window had high illuminance reading compared to the centre of the space. In this instance, even if one-third of the space read 300 lux, it was assumed that the occupant would still need artificial lightings in order to compensate for the insufficient luminaire at the other part of the space. When this happened, the area would be generalised as having inadequate daylight (Fig.12 and Fig.13).

On the other hand, when two-third of the space gave illuminance reading exceeding the minimum requirement of 300 lux, the living/dining area would be considered as well lighted and did not need artificial lighting (Fig.14 and Fig. 15).

The fluctuation in the luminance reading on the 15th June can be translated into the need for artificial lighting in the living/dining area (Figure 16).

On this particular day, both the Actual and Improved Cases required artificial lighting at night time. However, during daytime the Actual Case needed artificial lighting several hours longer in the morning and late afternoon when compared to the Improved Case. Assuming that in both cases the living/dining area was unused after midnight till 6:00a.m., the Energy Savings Benefit claimed by the Improved Case occurred when it did not require artificial lighting for five hours as compared to the Actual Case. When simulated for every 15th day of the month, the Actual Case had insufficient daylight for no less than five hours per day (Table 3).

On the contrary, the Improved Case had inadequate daylight for a minimum of two hours per day. The simulation showed that the lighting level in the living/dining area of Actual Case was always too dim in the morning; thus, required artificial lighting even if the sun was shining bright outside the house. Meanwhile, the daylight illuminance reading in the living/dining area of the Improved Case had maintained to be above 300 lux for most part of the daytime. Assuming readings on every 15th day represent a typical day of the month; Improved Case could claim Energy Savings Benefit up to 155 hours per month or 1158 hours per year.

9. Results Of Thermal Comfort Analysis

The reading on 15th June showed that the minimum indoor air temperature in the Actual Case was 28.9^{o}C and this had exceeded the thermal comfort range of 2.5K from Thermal Neutrality, T_n of 26.1^{o}C (Fig.17).

It was assumed that when the space temperature exceeded the comfort range, occupant would require mechanical cooling. Inevitably, the Actual Case would be highly dependent on mechanical cooling throughout the day and night to bring the room air temperature down into the thermal comfort zone.

Meanwhile, the indoor air temperature of the Improved Case was in the range of thermal comfort in the morning. However, during post-meridiem the indoor air temperature only slightly exceeded the thermal comfort zone (Fig. 18). As the maximum indoor temperature was only less than 1^{o}C above 28.6^{o}C, the occupants may or may not require mechanical cooling at this time.

Simulations on every 15th day of the month showed that the Actual Case would require 24 hours mechanical cooling to bring the room temperature down into the comfort zone. Whilst the Improved Case appeared to need only 12 hours of mechanical cooling because the space was in the thermal comfort zone during ante-meridiem (Table 4).

Nevertheless, the above readings had to be ratified because generally no one uses the living/dining room after midnight till 6:00 a.m., hence both cases did not need mechanical cooling at that time. It was also found that the indoor air temperature appears to be fairly consistent everyday because of the little climate change in the tropics.

Based on the above, the Energy Savings Benefit claimed by the Improved Case happened when it did not need to use mechanical cooling for 6 hours per day as compared to the Actual Case (Fig. 19).

Taking 15th June to represent every day of the year, the Energy Savings Benefit from mechanical cooling claimed by the Improved Case could be up to 186 hours per month (i.e., 6 hours x 31 days) or 2190 hours (i.e., 6 hours x 365 days) per year.

10. Conclusion

A property that applies Passive Architecture design strategy would indeed become less dependent on commercially supplied energy and consequently offered Energy Savings Benefit. The study showed that the annual Energy Savings Benefit from mechanical cooling and artificial lighting could be 2190 hours and 1158 hours, respectively – and that was for the living/dining area only. It was also found that substantial gain was due to the form and orientation of the Improved Case and this was achieved without incurring any additional construction cost.

Energy Savings Benefit would appeal to building owner because it deliberates on the long term economic gain of owning or operating a property. However, information on Energy Savings Benefit is hardly offered for potential buyers' consumption. If such information is made available, it could affect the buyers' judgment. Thus, if all remain equal, it is commonsensical for one to opt for property that costs less to run. In addition, information on Energy Savings Benefit would enable potential buyers to cautiously exercise their purchasing powers against the present awareness of global warming and unsustainable energy consumption (Mustapa & Yusop, 2007).

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Table 1. Cause and effect of Passive Architecture design strategies in the tropics.

CAUSE	**EFFECT**		
Primary Design Strategies in Passive Architecture	**Get breeze for ventilation**	**Avoid direct heat gain**	**Get Daylight**
Orientation	✓	✓	✓
Form	✓	✓	✓
Openings	✓		✓
Sun Shading Devices		✓	✓

(Note: ✓ means relationship for favourable effect)

Table 2. Time and hours of direct sunlight into the living/dining area of Actual and Improved Cases on every 15th day of the month.

	15th Day	**Jan**	**Feb**	**Mac**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Actual	Time of direct sunlight / day	3pm to 7pm	3pm to 7pm	3pm to 7pm	2pm to 7pm	2pm to 7pm	2pm to 7pm	2pm to 7pm	2pm to 7pm	2pm to 7pm	2pm to 7pm	2pm to 7pm	2pm to 7pm
	Hours of direct sunlight / day	4	4	4	5	5	5	5	5	5	5	5	5
Improved	Time of direct sunlight / day	nil	nil	8am to 9am	8am to 9am	8am to 10am	8am to 10am	8am to 11am	8am to 10am	8am to 9am	nil	Nil	nil
	Hours of direct sunlight / day	0	0	1	1	2	2	3	2	1	0	0	0

Table 3. Time and hours when daylight illuminance below 300 lux in a third of living/ dining area of Actual and Improved Cases on every 15th day of the month and the resultant Energy Savings Benefit (ESB).

	15th Day	Jan	Feb	Mac	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Actual	Time illuminance below 300 lux	7am, 8am, 9am, 6pm, 7pm.	7am, 8am, 9am, 6pm, 7pm.	7am, 8am, 9am, 6pm, 7pm.	7am, 8am, 9am, 6pm, 7pm.	7am, 8am, 9am, 5pm 6pm, 7pm.	7am, 8am, 9am, 10am, 5pm 6pm, 7pm	7am, 8am, 9am, 10am, 5pm 6pm, 7pm	7am, 8am, 9am, 5pm 6pm, 7pm	7am, 8am, 9am, 6pm, 7pm	7am, 8am, 9am, 6pm, 7pm	7am, 8am, 9am, 5pm, 6pm, 7pm.	7am, 8am, 5pm, 6pm, 7pm.
	Hours illuminance below 300 lux (A)	5	5	5	5	6	7	7	6	5	5	6	5
Improved	Time illuminance below 300 lux	7am, 8am, 7pm.	7am, 8am, 7pm	7am, 8am, 7pm	7am 7pm	7am 7pm	7am, 7pm	7am 7pm	7am 7pm	7am, 7pm	7am 7pm	7am, 8am, 7pm.	7am, 8am, 7pm
	Hours illuminance below 300 lux (B)	3	3	3	2	2	2	2	2	2	2	3	3
	Hours of ESB /day claimed (A-B)	2	2	2	3	4	5	5	4	3	3	3	2
	Hours of ESB / month (A-B) x days in a month	62	56	62	90	124	150	155	124	90	93	90	62

Table 4. Time and hours when air temperature in living/dining area of Actual and Improved Cases exceeding Thermal Comfort (TC) range on the 15th day of every month.

	15th Day	Jan	Feb	Mac	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Actual	Hours exceeding TC range	24	24	24	24	24	24	24	24	24	24	24	24
Improved	Time exceeding TC range	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am	12pm to 12am
	Hours exceeding TC range	12	12	12	12	12	12	12	12	12	12	12	12

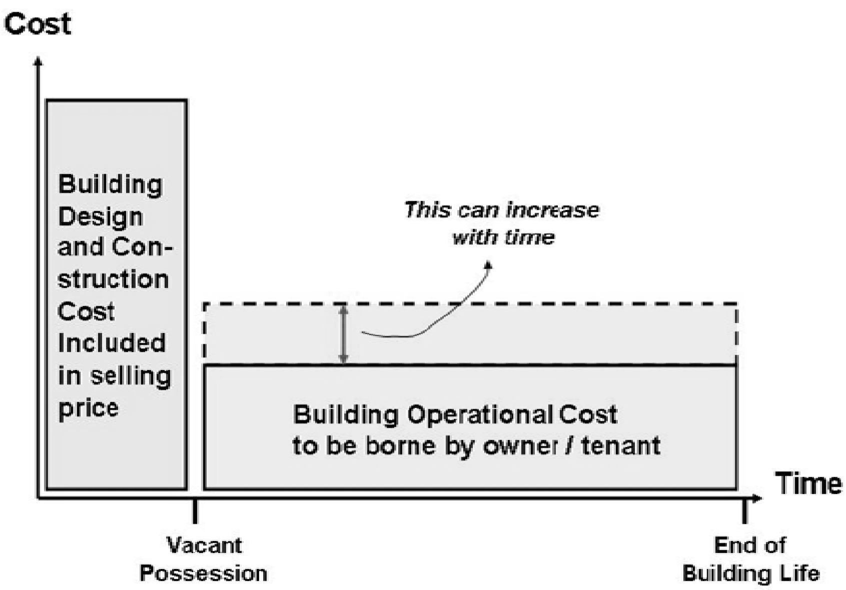


Figure 1. Building operational cost lasts throughout its lifetime.

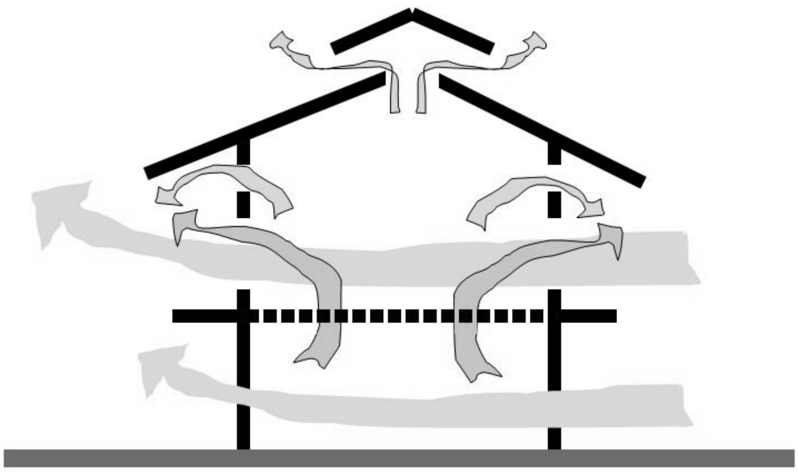


Figure 2. Ventilation concept of traditional house in cross-section

whereby the arrows depicted the flow of air.

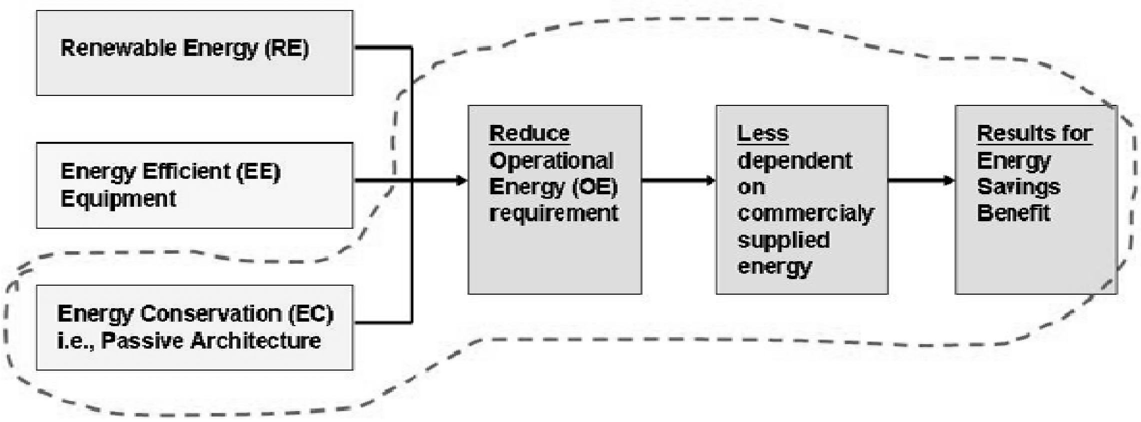


Figure 3. Passive Architecture asserts Energy Conservation that reduces Operational Energy in building.

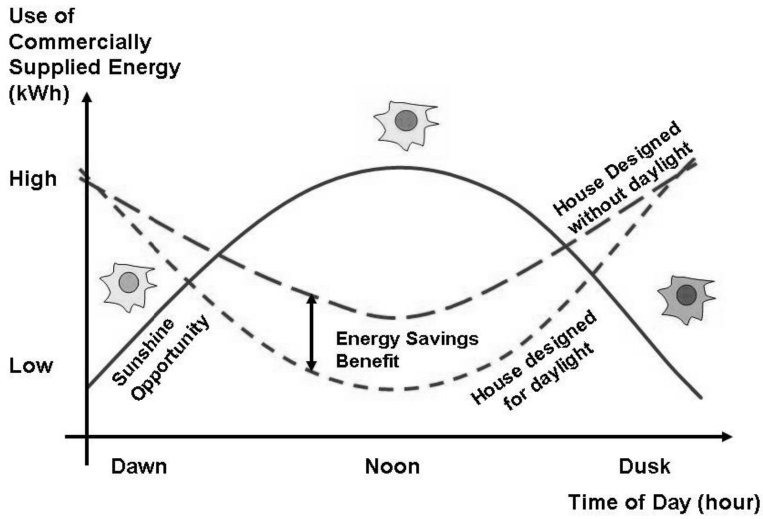


Figure 4. Use of commercially supplied energy.

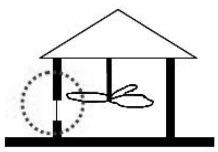
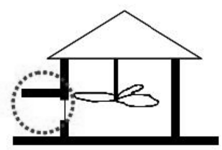
SAMPLE	CAUSE	EFFECT
A local detached house disregards Passive Architecture  **Actual Case**	Building elements were merely construction elements with no consideration for Passive Architecture design strategies	=> short period of comfort => need mechanical cooling => high operational energy => need more commercially supplied energy
Improvement on the Actual Case incorporating Passive Architecture design strategies  **Improved Case**	Building elements (orientation, form, openings and sun shading devices) were simulated to achieve Passive Architecture goals	=> long period of comfort => need less mechanical cooling => low operational energy => need less commercially supplied energy => claims Energy Savings Benefit

Figure 5. Cause and effect of Actual and Improved Cases.

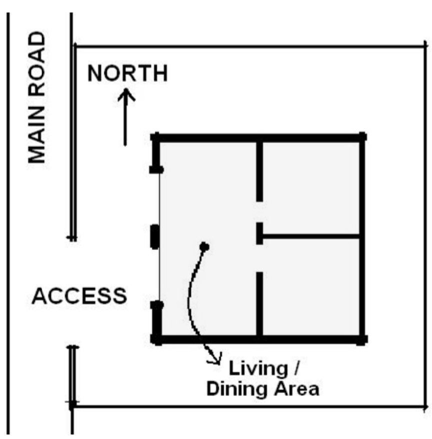


Figure 6. Actual Case - conceptual site plan showing concentric space arrangement.

Figure 7. Actual Case - living area, family room and master bedroom facing west.

Figure 8. A Passive Architecture precedent in the vicinity.

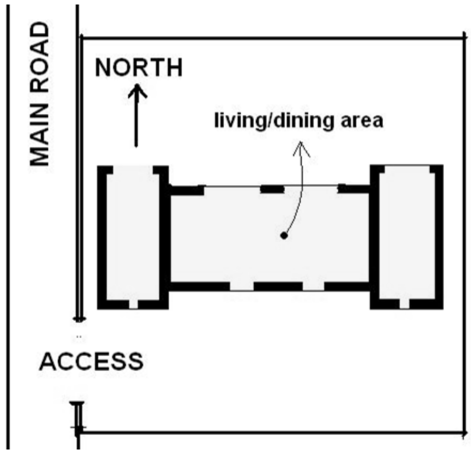


Figure 9. Simulated site plan of Improved Case showing elongated form.

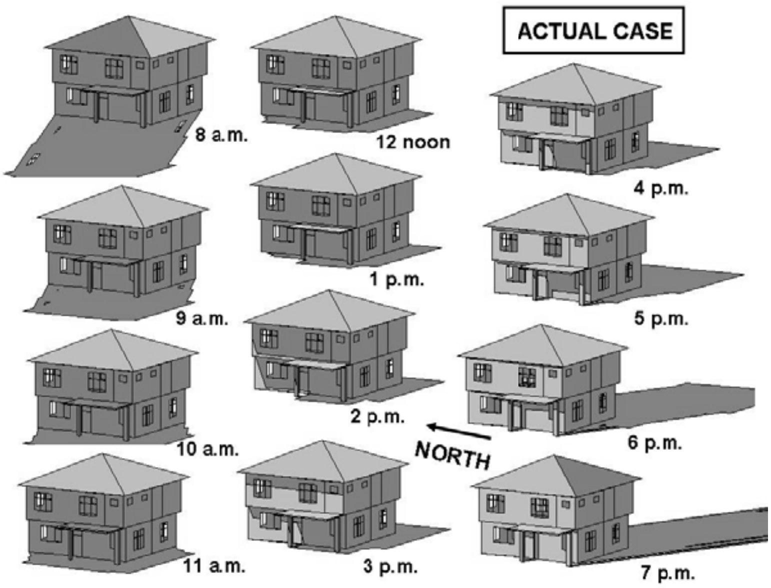


Figure 10. Actual Case - solar shading on 15th June.

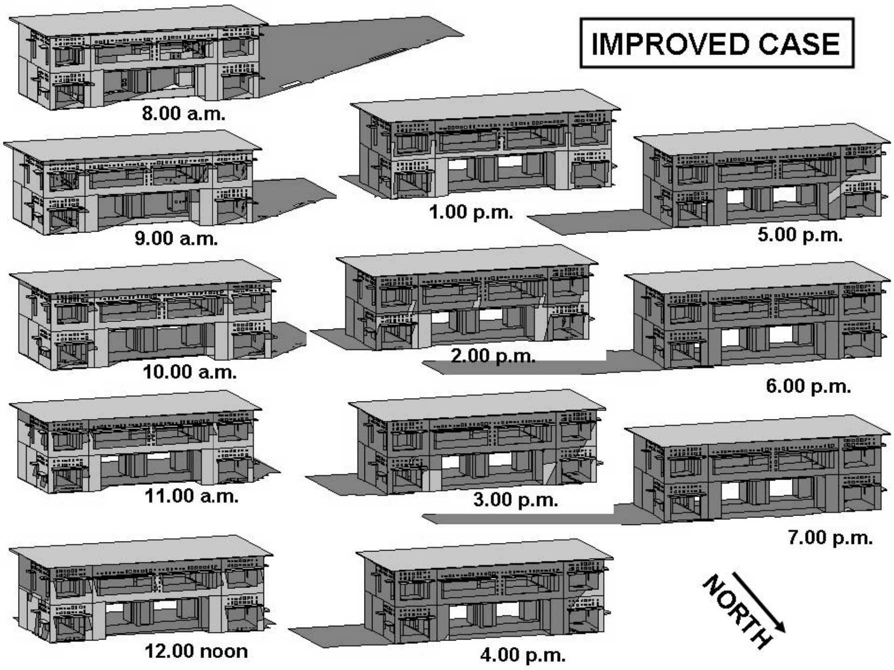


Figure 11. Improved Case - solar shading on 15th June.

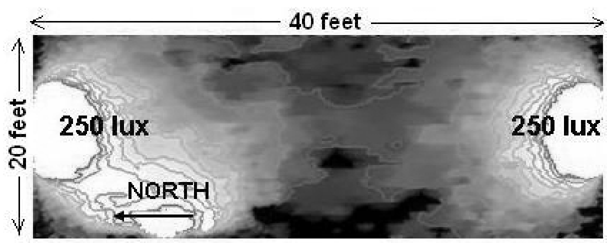


Figure 12. Inadequate daylight in Actual Case - room plan showing illuminance reading averaged at 250 lux in the living/dining area at 9:00 a.m. on 15th June.

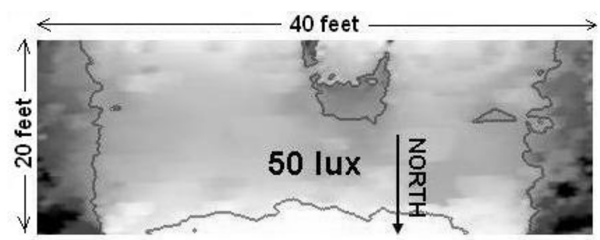


Figure 13. Inadequate daylight in Improved Case - room plan showing illuminance reading averaged at 50 lux in the living/dining area at 7:00 p.m. on 15th June .

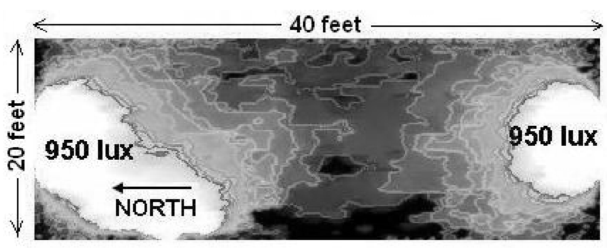


Figure 14. Adequate daylight in Actual Case - room plan showing illuminance reading averaged at 950 lux in the living/dining area at 3:00 p.m. on 15th June.

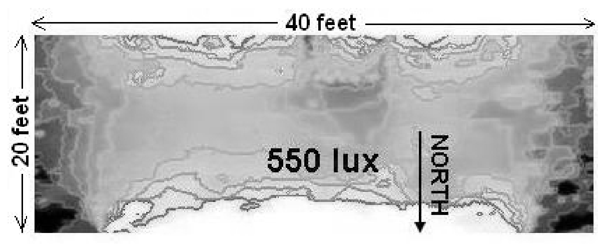


Figure 15. Adequate daylight in Improved Case - room plan showing illuminance reading averaged at 550 lux in the living/dining area at 3:00 p.m. on 15th June.

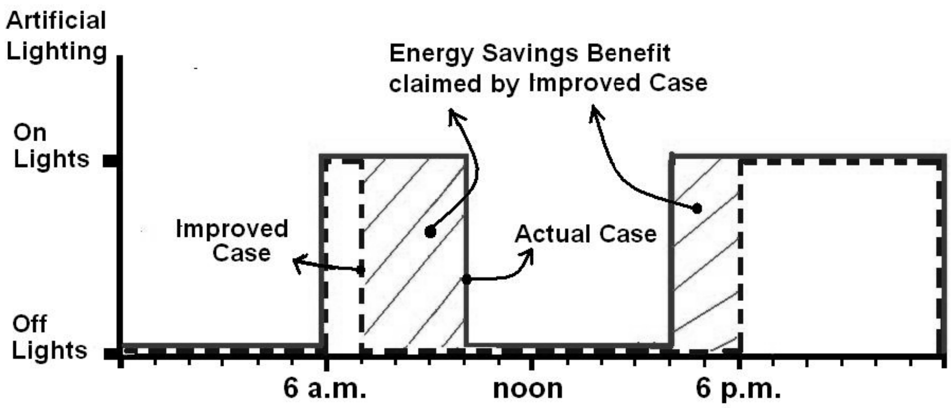


Figure 16. Use of artificial lighting by Improved and Actual cases on 15th June.

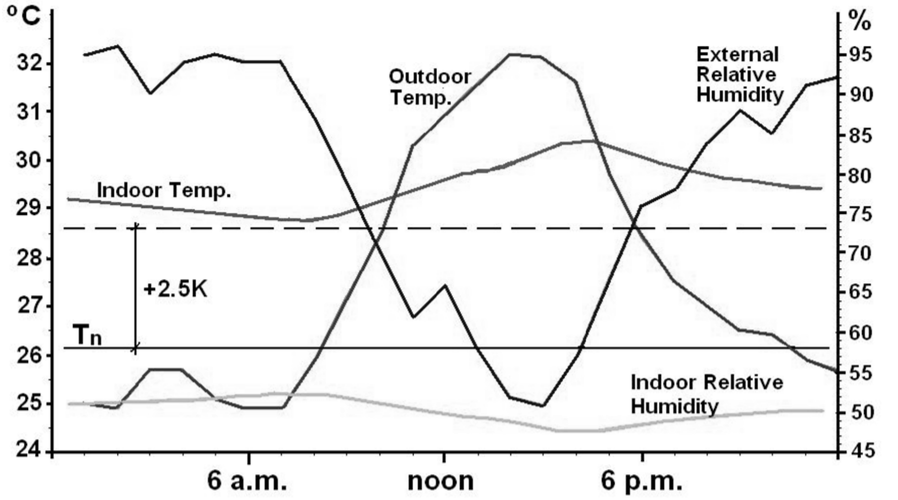


Figure 17. Actual Case - indoor thermal conditions in living / dining area on 15th June.

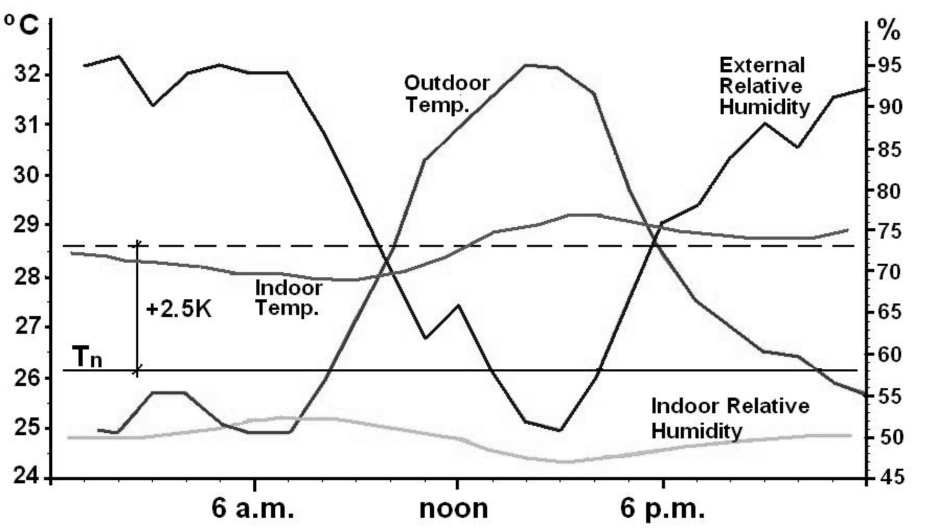


Figure 18. Improved Case - indoor thermal conditions in living/dining area on 15th June.

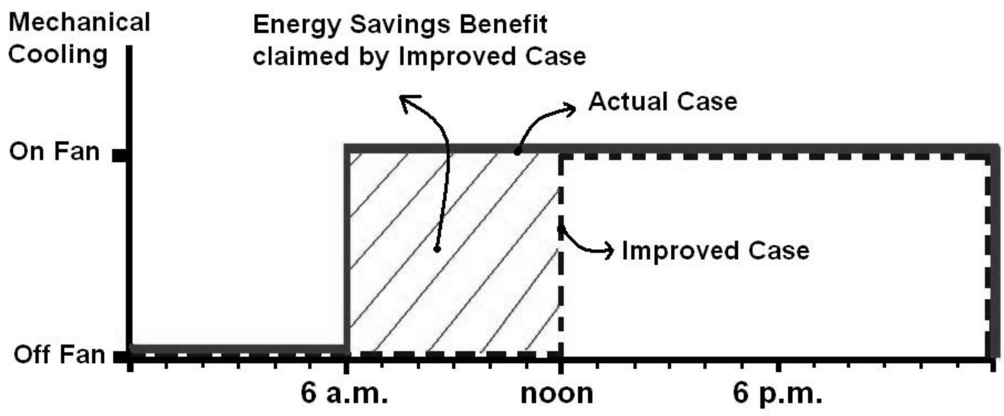


Figure 19. Use of mechanical cooling by Improved and Actual cases on 15th June.