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Experimental Research for Passive Solar Design and Energy Efficiency in Practical Net Zero Energy Buildings

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Abstract— The theory of passive solar design suggests that between 20 and 70 per cent of all household energy needs can be satisfied by simply designing the house in a naturally sound way, keeping the laws of the sun in mind. This experiment tested the validity of the above claim by retrofitting a regular apartment in suburban Mumbai. The results showed a considerable fall in energy consumption with a few minor tweaks in an existing residential house's design. The conclusion is that Passive solar energy design, coupled with active solar and wind or solar/wind hybrid generators, could play a pivotal role in achieving the goal of a Net Zero Energy Building.

Index Terms—Design, Energy Efficiency, Green Buildings, Passive Solar, Zero Energy Buildings.

1. Introduction

CURRENTLY, architects and engineers are relying on the three-pronged approach to realize their zero-energy goals-, Design for Passive Solar, Design for Energy Efficiency, and Design for Renewable Energy [9]. The hypothesis is that such an approach could be applied successfully in the hot tropical cities of India.

2. Methods

This experiment was conceived with the aim to compare the energy usage of a 1-BHK house, with and without retrofitting for Energy Efficiency and Passive Solar design [8]. The experiment commenced on the 1st of March and concluded on the 31st of March, 2012. The energy-meter reading for the house was noted at 8 AM in the morning, on the aforementioned dates.
The details of the unaltered apartment are as listed below:

2.1 Apartment Details

Orientation of house: Along the E-W Axis, windows on N-S Axis, Occupancy: 3, Carpet Area: 500 sq. ft.

- Living room: 180 sq. ft.
- Opposite bedroom: 144 sq. ft.

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Window Type: French Windows
Living room Window Area: 6.084 sq. m (65.487631 sq. ft.)
Adjacent Bedroom window area: 5 sq.m(53.927 sq.ft.)
Opposite bedroom window area: 1.81 sq.m (19.51 sq.ft.)
Appliances used (Kindly refer to table 1 for wattages):

Incandescent bulbs	x8
Ceiling Fan	x3
Refrigerator(260 litres, Non-ES)	x1
Air conditioner(Non-ES)	x2
Computer desktop(Non-ES)	x2
Television(32 inch LCD)	x1
Oven	x1
Geyser	x1
Washing machine(Automatic)	x1

The modifications made to the apartment are as follows (whether theoretical or practical are indicated by T and P respectively):

Window Type: Modified French windows using bamboo chicks		(P)
Living Room Window Area: 16 sq. ft.		(P)
Appliances Used:		
CFL bulbs	x8	(P)
Ceiling Fan(ES Rated)	x3	(T)
Fridge(260 liters, ES rated)	x1	(T)

Air conditioner (ES rated)	x2	(T)
Computer desktop(ES rated)	x2	(T)
Television(32 inch LCD)	x1	(P)
Oven	x1	(P)
Geyser	x1	(P)
Washing machine (Automatic, ES rated)	x1	(T)

2.2 Input Costs

For the practical aspect of the research, the only significant investments were three sets of bamboo chicks, covering the windows by their respective areas.
These were acquired at the cost of 7200 Rupees.
The CFL bulbs were changed practically too, costing a total of 800 rupees.
The total investment, thus, for the practical aspect of the experiment turned out to be 8000 rupees.
The theoretical aspect of the research makes the following assumptions:

- A solar water heater of 2kw power and 100liters per day capacity, costing 17,500 rupees is installed in the ZEH.
- All the appliances in the ZEH are assumed to be energy star rated, reducing consumption by 20% each.

Besides this, it's possible to factor in the surplus energy produced from a solar power system, installed at the cost of 5 lakh rupees. This would help significantly in the ZEH goal.

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2.3 Design Modifications

The apartment had ideal orientation, exactly along the E-W axis. The living room windows faced the south while the opposite bedroom window faced the north. [1]
This allowed us to utilise the natural rules of convection and thermodynamics to set up convection systems in the house for cooling purposes. [7]
The system used was direct-gain passive solar system, whereby the high afternoon summer sun heated the surface of the veranda and created a low pressure region, forcing air to move towards it and into the house.
The living room window area had to be re-ascertained using Steven Winter's table [1]. An approximate surface area was arrived at using details of current floor area of the living room, the latitude of the location and the ambient winter temperatures of the city.

Figure 1: Floor Plan of the apartment

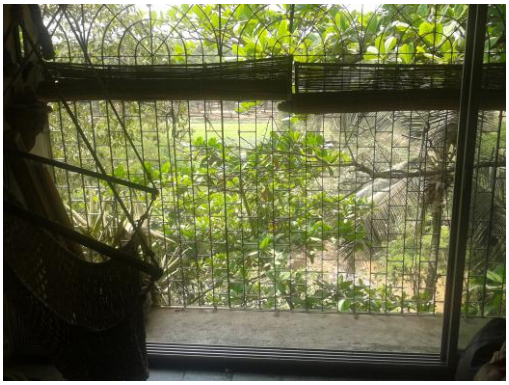

Figure 2:Living room window(French Window) before rolling down chicks

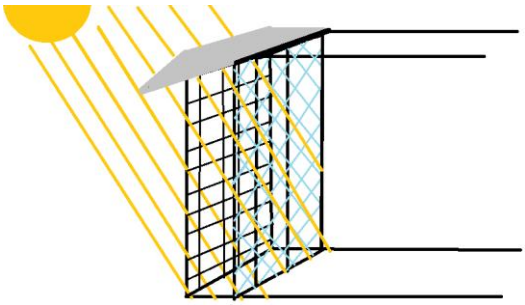

Figure 3: Solar action in living room without chicks. Notice the heating of veranda thermal mass due to sunrays.

Figure 4: After installation and rolling down of chicks to reduce window area.

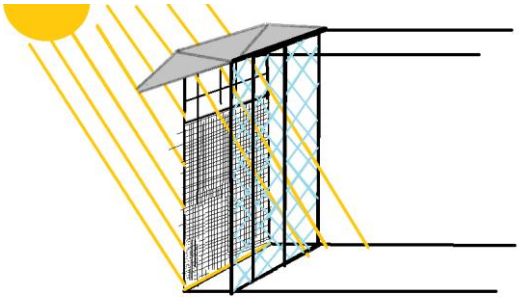

Figure 5: Solar action post-installation of chicks. Minimum light enters through the window aperture, shielding the house from high summer sun.

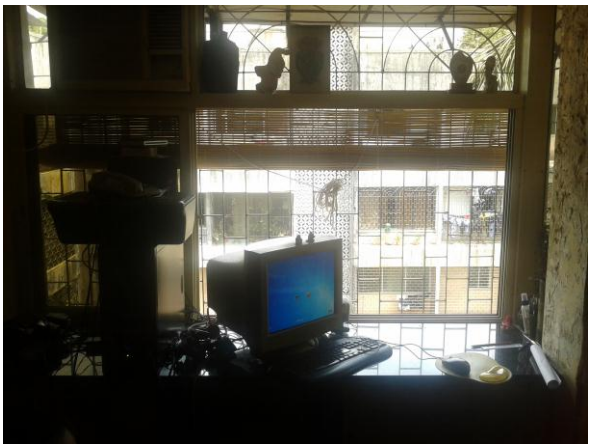

Figure 6: Opposite bedroom window before rolling down/installing bamboo chicks.

Figure 7: Opposite room window after rolling down/installing bamboo chicks

3 FINDINGS

Sr. No.	Appliances	Quantity		Power Rating		Hours per day		Energy units consumed	
		O.H.	ZEH	O.H.	ZEH	O.H.	ZEH	O.H	ZEH
1	Incandescent/CFL bulb	8 Incan.	8 CFL	8x60=480 watt	8x16=128 watt	5	5	2.4kwh	0.640kwh
2	Ceiling Fan	3	3	40x3=120	36x3=108	12	8	1.44kwh	0.864kwh
3	Refrigerator(260 litres)	1 non-ES	1 ES rated	200w	160 w	24	24	4.8kwh	3.36kwh
4	Air conditioner	2 non-ES	2 ES rated	1850 w+990w	1480+792w	9	9	25.56kwh	20.448kwh
5	Computer desktop	2 non-ES	2 ES rated	260 watt	208 watt	12	12	3.12kwh	2.496kwh
6	Television(32 inch LCD)	1	1	80 watts	80 watts	4	4	0.32kwh	0.32kwh
7	Oven	1	1	1200 watt	1200 watt	10 min	10 min	0.2kwh	0.2kwh
8	Geyser	1	0	3000 watt	Solar heater	40 min	40 min	2kwh	0kwh
9	Washing machine(Automatic)	1	1	500 watts	400 watts	15	15	0.125kwh	0.1kWh
10	Large AC Off-grid Solar Home Power System	0	1	0	4230 watts	0	5	0	upto 20kWh
					Total daily consumption:			39.965kwh	28.428kwh(without SPS), 8.428kWh(with SPS)
					Total monthly consumotion:			1198.95kwh	852.84kwh(without SPS), 252.84kwh(with SPS)
					Difference(without solar power system): 1198.95-852.84=346.11kwh=28.86%				
					Difference(with solar power system): 1198.95-252.84=946.11kwh=79.9%				

Practical Results:	Theoretical Results:
March 2011 usage=762kwh	March 2011 usage=1198.95kwh
March 2012 usage=504kwh	March 2012 usage=852.84kwh
Difference=258 units	Difference=346.11kwh
%difference=33.85%	%difference=28.86%

Table 1: Theoretical Calculations. Notice Energy savings with and without solar panel [10]

3 INFERENCES

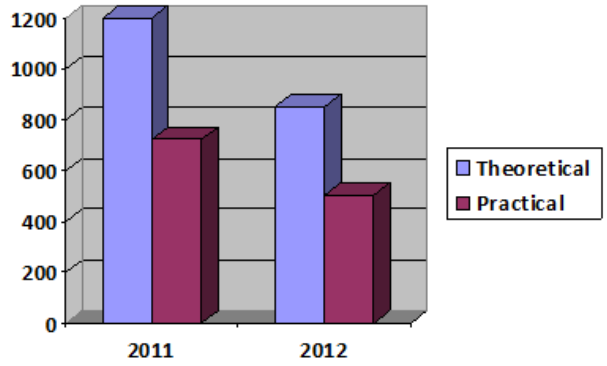

Figure 8: Theoretical VS Practical energy consumption for March 2011 and March 2012. Units are in kWh.

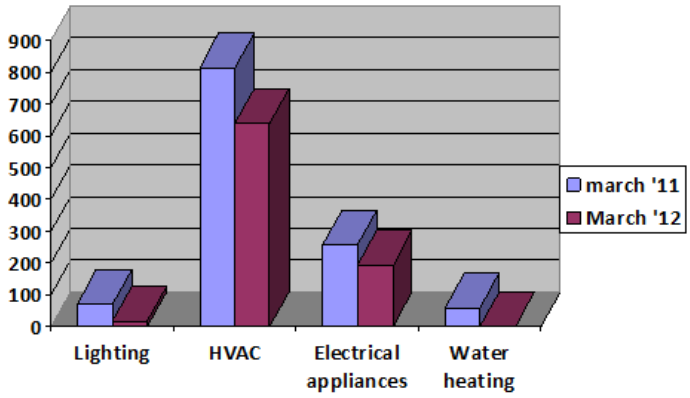

Figure 9: Energy consumption by purpose (Theoretical breakdown)

Fig. 8 indicates that the theoretical consumption for both the months was significantly greater than the practically noted consumption. These could be for a host of reasons as listed below:

2. The consideration of the fridge being placed in a highly efficiently ventilated area is not made. The cross ventilation cools the fridge faster, decreasing excessive over-heating and energy consumption in turn.
3. The estimated use of lighting may be a maximised situation. The probability of usage of all lights in all rooms is low.
4. The same point (#2) applies to the use of ceiling fans.

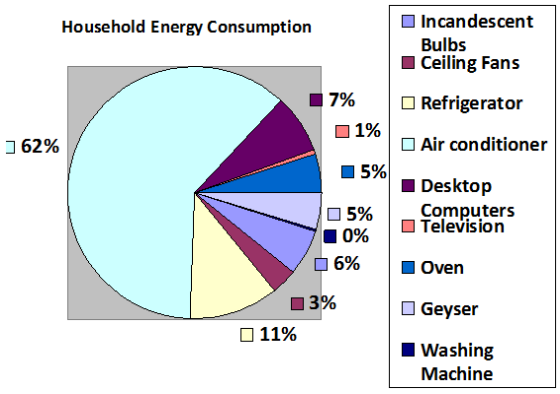

Figure 10: Household energy consumption per appliance/gadget in an ordinary home

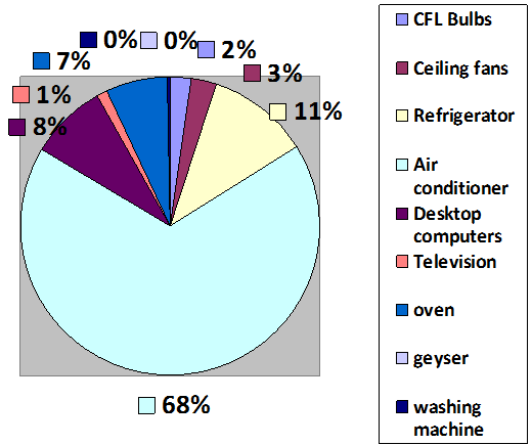

Figure 11: Household energy consumption per appliance/gadget in a modified hom

The above pie charts show that energy consumption breakdown for both, a passive solar house as well as an ordinary home, remains more or less similar. The significant differences are:

1. Since the lighting consumption decreases in an energy efficient house due to use of CFLs, the same is reflected in fig. 10.
2. Though the charts look similar, the primary difference is the decrease in units consumed, which are reflected in the bar graph (fig. 8).
3. The proportion of consumption for cooling is significantly greater in case of the solar house, but this can be attributed to the overall energy efficiency of the house as well as to the limitation of keeping windows shut at night to prevent mosquitos from entering, thereby compelling the inhabitants to use the Air Conditioner in the sweltering heat.

5 CONCLUSIONS

It can be concluded from the findings that the results prove the claims of benefits of passive solar design and energy efficiency.

For the small suburban apartment in which the research was carried out, the initial investment for a basic retrofitting for passive solar design can be recovered within 24 months' time considering annual savings of 21% for HVAC alone. If an annual bill is 30000 rupees, HVAC usage is 62% of it, i.e., 18600. Therefore, HVAC savings is 21% of 18600, which is 3906 rupees. [2]

Switching from incandescent to CFLs, CCFLs or GFL bulbs might seem relatively expensive at first, but the savings are evidently incredibly high.

Perhaps the most expensive step towards a truly Zero-Energy house is the installation of an energy producer, in this case a solar panel.

The solar panel under consideration in the research, a large AC off-grid solar home power system, costs about 10000$ (approx. 5 lakh rupees), producing around 600kwh a month. The solar water heater too helps save 60kwh of energy a month with relatively lesser input costs which may be recovered much faster than that of the solar power system.

6 A APPENDIX OF DESIGN CONSIDERATIONS

6 A. 1 For Initial Apartment

1. Living room window area:

Height of windows: 1.95 m
Length of windows: 3.12 m
Net area: 1.95 m x 3.12 m
= 6.084 sq. m. (65.487631 sq. ft.)

2. Adjacent Bedroom window area:

Height of window: 1.98 m
Length of window: 2.53 m
Net area: 1.98m x 2.53 m
=5.0094 sq. m. (53.927 sq. ft.)

3. Opposite bedroom window area:

Height of window: 0.88 m
Length of window: 2.06 m
Net area: 0.88 m x 2.06 m
=1.8128 sq. m. (19.5128 sq. ft.)

6 A. 2 For Modified Apartment [1]

1. Living Room Window Area:

Surface area of window to surface area of room floor ratio, as per Steven Winter's handbook for passive solar technology:
1:10 =0.10(considering latitude=19 and ambient winter temperature=65 degree Fahrenheit)
Hence, final window area for living room:
0.10 x (Area of living room floor-space)
=0.10 x 180 sq. ft. =18 sq. ft.

2. Opposite Bedroom Window Area:

Opposite bedroom windows are covered similarly, with a ratio of 1:10.
0.10 (Area of bedroom)
=.10 x 144 sq. ft. = 14.4 sq. ft.

6 B. 1 APPENDIX OF SAVINGS POST-RETROFITTING

Note: All Calculations Done With Reference To Table 1.0:

HVAC:
Monthly consumption for non-retrofitted house: 810 kWh (AC+fan)

Daily savings	=	5.688 kWh
Monthly savings	=	170.64 kWh
Percentage savings	=	170.64/810
	=	21.06%

Lighting:
Monthly consumption for incandescent lighting: 72 kWh

Daily savings	=	1.76 kWh
Monthly savings	=	52.8 kWh
Percentage savings	=	52.8/62

= 85.16%

Other electrical appliances:

Monthly consumption for other electrical appliances: 256.95 kWh

Daily savings = 2.089 kWh

Monthly savings = 62.67 kWh

Percentage savings = 62.67/256.95

= 24.39%

Water heating:

Monthly consumption for geyser: 60 kWh

Daily savings = 2 kWh

Monthly savings = 60 kWh

Percentage savings = 60/60

= 100%

ACKNOWLEDGMENTS

Many thanks are due to the giants that have worked in the field of passive solar energy before, allowing me to build on and verify their work.

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