Design and Energy Analysis of Green Villa Compared with Conventional Villa Using Virtual Design Modelling

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1 Introduction

BIM stands for building information modelling which is an upcoming concept for information handling in large projects. It involves a simultaneous design process across all involved disciplines, thereby removing the possibility of conflicts, as well as any ambiguity in the execution phase. Large building projects such as multipurpose dams and planned cities always generate a massive amount of data in the form of plans, contracts, documentation, etc. They also involve multiple disciplines aside from civil engineering such as mechanical, electrical, environmental engineering, etc. The centralized handling of this data, from the planning stage to the execution stage is one of the main concepts of BIM [1–4].

Green buildings are defined as projects which give high priority to environment conservation, control of pollution, and energy saving during construction as well as during service life. Green buildings are certified and recognized by Indian Green Building Council (IGBC) nationally and by Leadership in Energy and Environmental Design (LEED) internationally [5, 6]. Energy analysis of buildings is carried out using certain software (such as Autodesk Revit, Energy +) to find the energy consumption of the building and the effects of the materials used on the same. With this analysis, we can get energy efficiency solutions to minimize energy consumption as well as the use of materials that cause environmental damage [7].

The application of green building concepts in small residential buildings such as villas on a larger scale will have a positive effect on the national and global energy consumption and help to alleviate the pressures of energy crises. Since the green building concepts encourage the use of natural energy sources like solar power and

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wind, it not only reduces the load on commercial grids but also reduces pollution since the energy is produced cleanly. Another significant advantage of villas made using green building concepts is the reduction of pollution and the reduction of usage of harmful materials in construction. Retention and recovery of green cover, as defined by IGBC guidelines, improve the aesthetic quality of the neighbourhood, and heightens the ecological value as well [8, 9].

The use of BIM in small-scale projects such as villas not only helps in the more effective application of the aforementioned green building concepts but also minimizes delays, ambiguities in the interpretation of plans and design mistakes, and also reduces construction time and cost. With the help of this tool, the engineers can easily identify mistakes, while a layman can visualize the progress of construction [6, 7, 10–13].

2 Analytical Programme

2.1 Project Methodology

Autodesk AutoCAD is used for the creation of the plan drawings as well as the detailed diagrams of the structural elements. Bentley Engineering STAAD.Pro is used for structural analysis and load simulation. Autodesk Revit software is used for building modelling and energy analysis. For this study, BIM model creation and the energy simulations for the building are carried out using Autodesk Revit.

- Study on building information modelling and its applications
- Collection of data for conventional building:
- Structural analysis and design of the conventional building
- Modelling of conventional building
- Energy analysis of the conventional building
- Conversion of conventional to green building
- Modelling of the green building
- Energy analysis of the green building
- Comparative study

2.2 Parameters Studied

The parameters considered for the energy analysis were taken from IGBC Affordable Housing codebook. Samples were taken as per their relevance to the context of the report and applied as per the stipulations of the guidebook [14]. The total credits accredited are taken against the median of the overall credit breakup given in the IGBC Affordable Housing codebook, and the expected level of certification is awarded. The parameters were considered in the evaluation of both villas and are given in Table 1.

Table 1 Major parameters studied for energy analysis

Site selection	Proximity to construction material sources
	Proximity to transportation facilities
	Avoiding ecologically high-value areas
Social infrastructure	Access to basic amenities
	Proximity to the urban environment
On-site green cover	Minimal damage to local ecosystem during construction
	Retain/recover as much green cover as possible
Heat island effect	Reduce damage to the local ecosystem
	Provide shades of paths, roads, etc
	Provide roof garden
Efficient appliances	Use of 5-star-rated appliances
	Strategic installation to maximize efficiency
Efficient lighting	Use of LED lights
	Strategic installation to maximize efficiency
	Reduce the energy bill
Day lighting	Use of large windows
	Lower energy bill
	Maximize the use of natural lighting when available
Efficient materials	Use of thermally efficient materials
Transplanting of trees	Transplanting of valuable trees, if any
HVAC	Controlling interior air quality
	Removal of indoor pollutants
	Cycling of fresh air into the building
Environmental effect	Use of low-VOC (volatile organic compound) materials
	Use of eco-friendly and reusable construction materials

2.3 Data Collection and Analysis

The following data was collected for the purposes of design and analysis of the two villas and is given in Table 2.

The above plan was created for the conventional villa design as per IBC given in (Figs. 1 and 2). It focuses on giving large open spaces and is characterized by the considerably large living room, combined kitchen and dining room, and the patio. The upper floor is focused on residents of the house, for whom several sizable bedrooms are provided. The garage can comfortably accommodate two family sedans with extra storage space to spare.

Table 2 Property details of the site

Description	Details
Area	464.5 m^2
Location	Engineers Park, Phase–III, Kandigai, Chennai South
Groundwater depth	Feasible at 40–50 ft
Social infrastructure	All religious places, departmental stores, banks, restaurants
Floor area	204.4 m^2
No. of floors	2
No. of bedrooms	5
Additional amenities	Open patio, terrace, attic storage space, spacious balconies

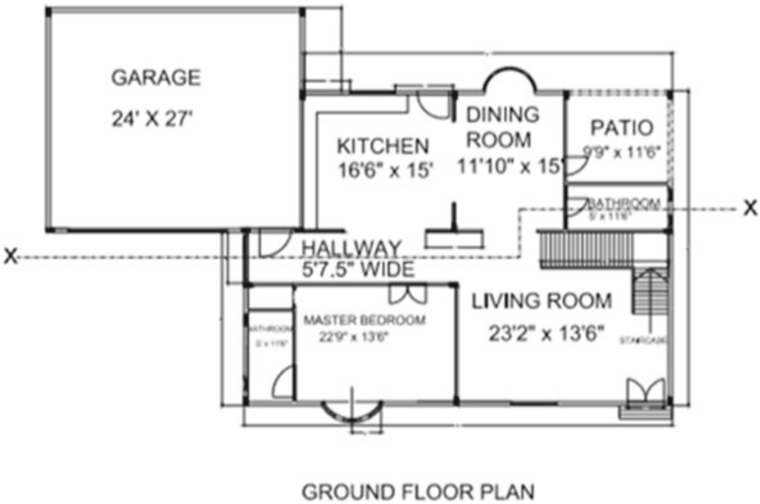

Fig. 1 Plan for conventional villa: Ground floor plan

2.4 Structural Analysis

The structural analysis is done to ensure the serviceability and safety of the design, as stipulated by the Limit State Design Method in IS456. The simulated loads, as taken from IS875, show potential points of failure in the structure, and therefore indicate the structural elements to be designed as shown in Fig. 3.

- The framed structure of the house was analysed using STAAD SPro V8i SS6.
- Using the bending moment, axial force, and shear force analysis results, the structural elements undergoing the highest of these values were selected.
- Manual calculations were performed to obtain dimensions of structural elements.

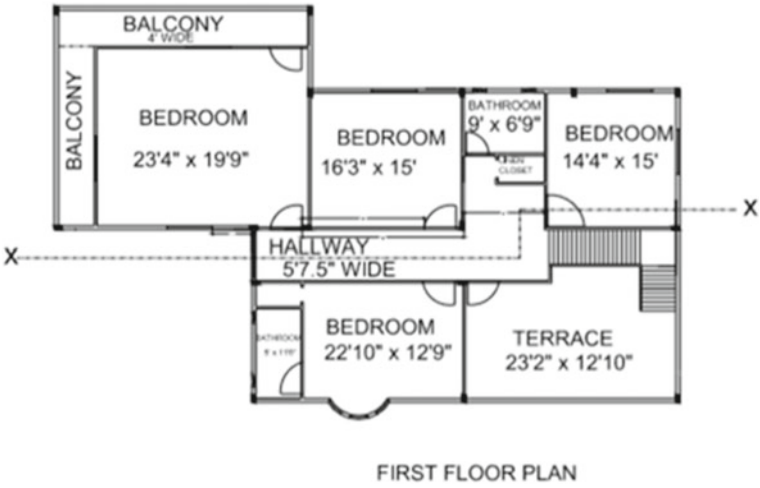

Fig. 2 Plan for conventional villa: First floor plan

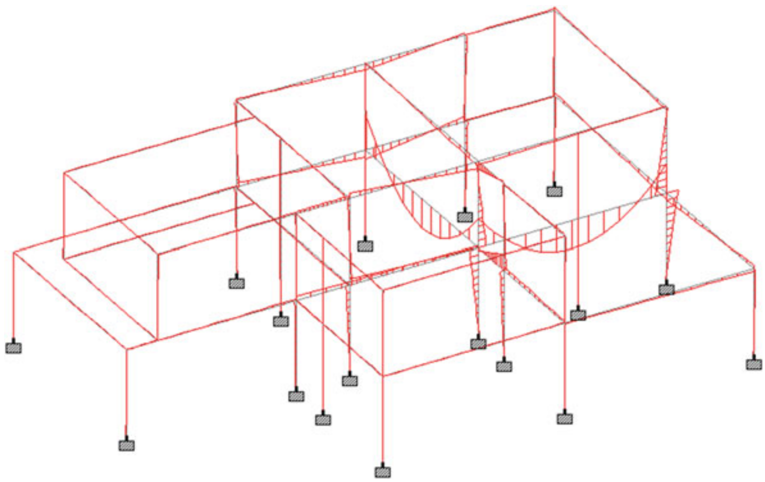

Fig. 3 Bending moment diagram

2.5 Energy Analysis

The model of the villas is created by importing the "cad" files from AutoCAD and given doors and windows. The rooms are designated and the materials are assigned in Revit, after which the energy analysis tools are used to obtain energy consumption results (Figs. 4 and 5).

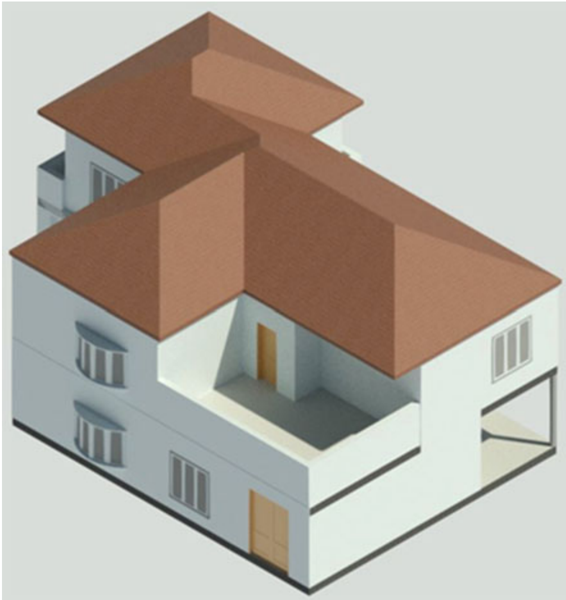

Fig. 4 Model of the conventional villa

Fig. 5 Model of the green villa

- The two villas were analysed using Autodesk Revit 2018.
- The villas were modelled separately in the software, and the inbuilt energy analysis tool was used to determine the energy consumption.
- These results along with several other factors defined by the IGBC Affordable Housing codebook were considered for the total green rating.

3 Results and Discussions

The results obtained in the analyses give crucial information used for the IGBC review criteria (Figs. 6 and 7). The factors relevant to energy analysis are considered

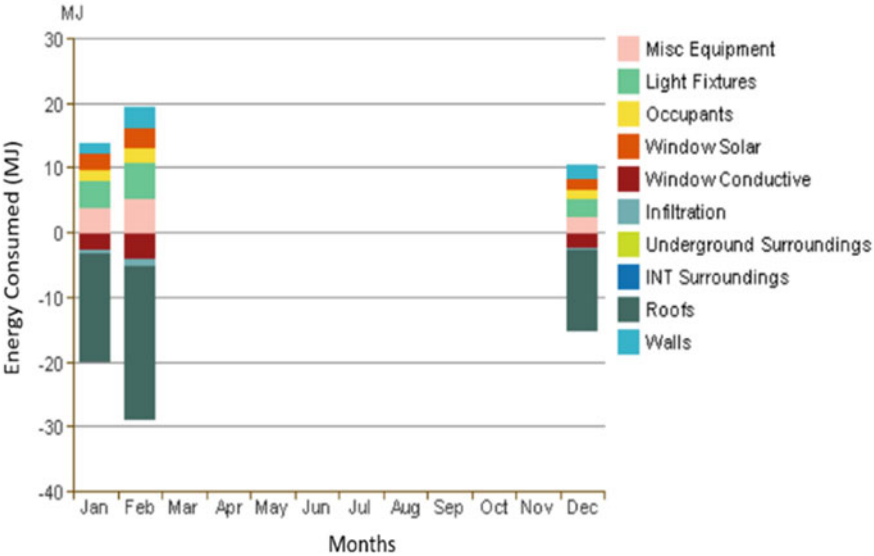

Fig. 6 Heating load of the conventional villa

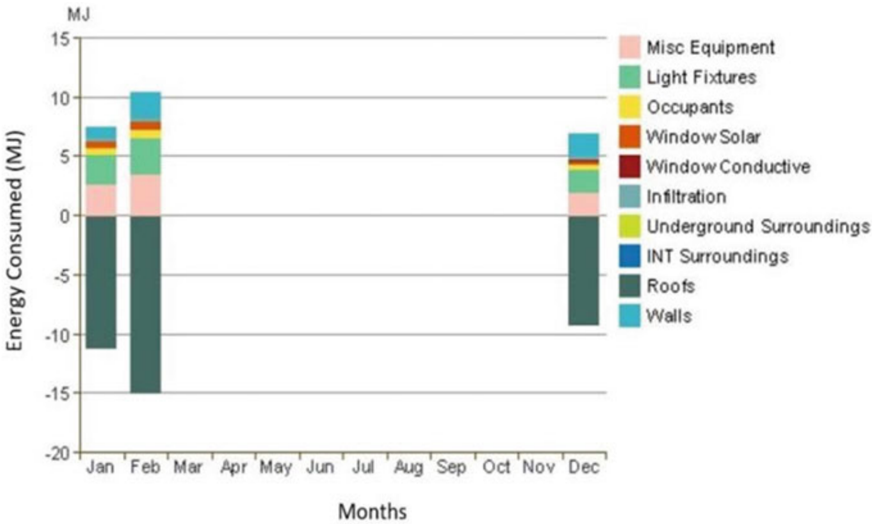

Fig. 7 Heating load of the green villa

for both villas, and the houses are rated accordingly. Several construction techniques used in the construction of green villa also improves its rating [15–19].

Figures 8 and 9 show the reduced heating loads for the winter period for the green villa. This is due to improved heat retention, thermal insulation, and optimized ventilation, designed with the annual local wind patterns. The lower heat loss (represented by the negative side of the chart) and the energy required to bring the interior to a comfortable temperature (represented by the positive side of the chart) is seen to be lesser for green villa [17, 20, 21]. The above charts represent the cooling loads for

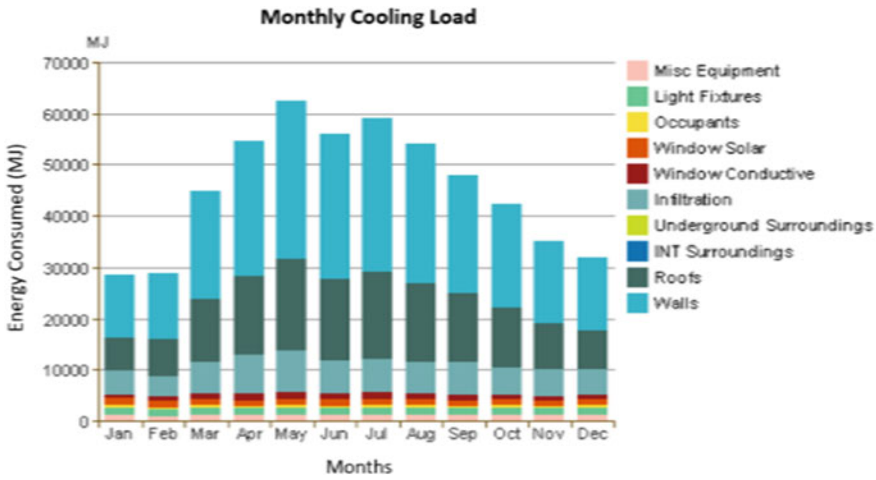

Fig. 8 Cooling load for conventional villa

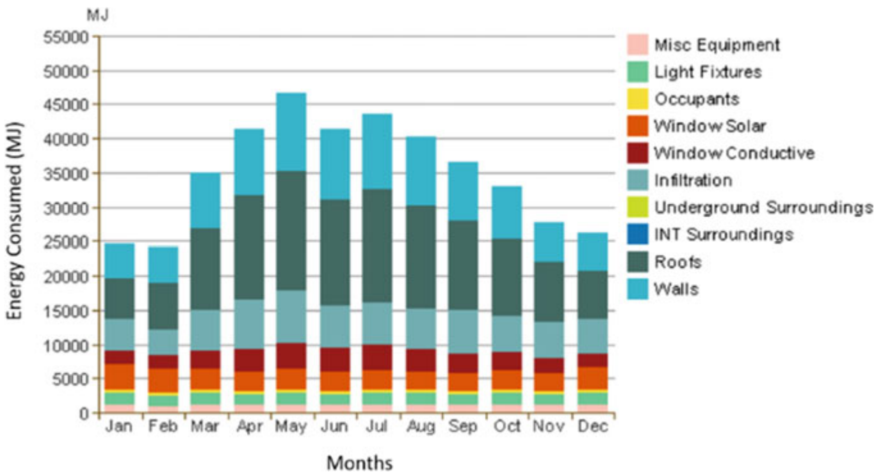

Fig. 9 Cooling load for green villa

the respective villas. It is seen that the improvements made in the green villa reduce the cooling energy requirements [22–24].

Table 3 shows the comparison of the energy analysis outputs for both villas. The green villa shows a marked reduction in energy consumption, due to the aforementioned modifications [21, 24–26].

The complete list of all factors considered for the comparative study and the credits awarded to each villa are shown in Table 4. Green villa consistently shows lower energy consumption and greater environment-friendliness. Besides the changes in design and the inclusion of a skylight and roof garden, these results can be attributed to improved construction materials and the use of optimized ventilation solutions.

Table 3 Comparative results of energy analysis

Inputs	Conventional Villa	Green Villa
Area (m^2)	327	325.57
Volume (m^3)	995.48	793.87
Cooling setpoint	23 °C	23 °C
Heating setpoint	21 °C	21 °C
Supply air temperature	12 °C	12 °C
Number of people	4	4
Air volume calculation type	VAV- Single Duct	VAV- Single Duct
Relative humidity	44.00% (Calculated)	46.00%
Psychrometrics		
Psychrometric message	None	None
Cooling coil entering dry-bulb temperature	28 °C	28 °C
Cooling coil entering wet-bulb temperature	19 °C	20 °C
Cooling coil leaving dry-bulb temperature	12 °C	12 °C
Cooling coil leaving wet-bulb temperature	14 °C	13 °C
Mixed air dry-bulb temperature	28 °C	28 °C
Calculated results		
Peak cooling load (W)	98,595	18,884.8
Peak cooling month and hour	May, 15:00	July, 17:00

(continued)

Table 3 (continued)

Inputs	Conventional Villa	Green Villa
Peak cooling sensible load (W)	96,075	15,983.6
Peak cooling latent load (W)	2520	2901.2
Peak cooling airflow (L/s)	5242.7	826
Peak heating load (W)	3506	34,799.9
Peak heating airflow (L/s)	223.2	1590
CHECKSUMS		
Cooling load density (W/m^2)	301.57	58.01
Cooling flow density (L/(s-m^2))	16.04	2.54
Cooling flow/load (L/(s-kW))	53.17	43.76
Cooling area/load (m^2/kW)	3.32	652.62
Heating load density (W/m^2)	10.72	106.89
Heating flow density (L/(s-m^2))	0.68	4.88

4 Conclusion

The following conclusion can be drawn from the analytical work:

- The energy analysis shows the marked reduction in cooling energy requirements of the green villa, as compared to the conventional villa (98 kW for the conventional villa to 18 kW for the green villa).
- The use of environmentally friendly materials and ecologically conscious construction procedures which the green building concepts give high priority to produce far less pollution and harmful effects on the environment.
- The IGBC rating system easily quantifies the ecological value of the two villas, and clearly shows that the green villa is superior (14 out of 40 credits for conventional villa, and 36 credits for green villa).

Table 4 Factors considered for the comparative study

Parameters	Conventional villa	Green villa
Site selection (SM1) Proximity to construction material	Point not awarded	Point awarded
Site selection (SM1) Proximity to social infrastructure	Point awarded	Point awarded
Site selection (SM1) Avoiding high-value areas	Point awarded	Point awarded
On-site green cover (SM2)	2 Credits	4 Credits
Recover green cover (SM2)	0 Credit	4 Credits
Heat island effect (SM4)	2 Credits	6 Credits
Energy-efficient appliances (EC1)	2 Credits	4 Credits
Day lighting (EC3)	2 Credits	6 Credits
Efficient materials (EC4)	1 Credit	2 Credits
HVAC (EC6)	3 Credits	6 Credits
Environmentally friendly materials	1 Credits	4 Credits
Total	14 Credits	36 Credits
IGBC certification level	Certified	National excellence

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