Energy Efficient & Sustainable Buildings: Integration with solar assisted air-conditioning technology in Qatar – A Step towards Grid Free Zero Carbon Living.

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Abstract

The air-conditioning systems in hot countries like Qatar consumes around 60-80% of the total energy demand in buildings. This triggers researchers and industry experts in the built environment to explore new avenues towards reducing the cooling load on buildings to enhance energy efficiency under such extreme conditions. [2] The carbon foot print of buildings can be minimized by reducing cooling load through passive design, using high efficiency equipment and incorporating renewable energy technologies such as solar systems, air and ground source heat pumps, which are few to name among many other concepts and technologies.

This paper focuses on optimization of passive house building design alternatives for different blocks of residential buildings as essential components for establishing sustainable and modern agro-industrial communities in Qatar.

Two different designs of multifunctional residential buildings were considered; a block of 3 Apartments (one apartment per floor), as an example of labor housing, and a block of 18 Apartments (six apartments per floor), both spread over three floors, as an example of a community living. Three dimensional (3D) energy models were created for both types of buildings using the IES software (Integrated Environmental Solutions) in virtual environment and thermal analysis was carried out using the Qatar's weather data. Two different criteria were applied to the model of each block of apartments, i.e. Passive house design vs. Conventional design. Energy analysis was carried out to optimize building design, in terms of best thermal comfort and minimum energy consumption to identify/select optimum building materials.

The simulation results revealed that optimized passive house design concepts can significantly reduce the cooling load and lighting loads, which saves 60 to 70% of the total energy consumption in both small labor residential block and large community residential block respectively. This energy savings can translate into equivalent cost savings and the available flat roof area on top of each block can be utilized for installation of the innovative solar PV cooling plant which has the capacity to meet the cooling and domestic hot water demand of the building. It will also help in achieving grid free zero carbon buildings in future.

Keywords: Passive house design, Building energy efficiency, Solar cooling, Grid free zero carbon building

1. Introduction

The building sector consumes more electricity than any other sector worldwide, on average 42 per cent. Most people spend more than 90 per cent of time in buildings, i.e. either at work in the office or at home. Energy used in buildings (residential and commercial) accounts for a significant percentage of a country's total energy consumption. This percentage depends greatly on the usage of electricity, the level of urbanization, the specific building area per person, the surrounding climate, as well as local and national policies to promote energy efficiency [7].

Air-conditioning systems in hot countries like Qatar consumes around 60-80% of the total energy demand in buildings. This triggers researchers and industry experts to explore new methods and technologies to improve building's energy efficiency in the built environment [2].

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In industrialized countries, most of the energy consumed in buildings is used for space cooling, ventilation, heating and lighting. This energy usage depends not only on the energy effectiveness of temperature control and lighting system inside the building but also on the design of the building and its outer envelope to minimize heat losses and maximize natural lighting and ventilation to satisfy the human comfort conditions. For a selected set of end uses, the building design and selection of construction materials play a significant role in energy consumption of the building. The purpose of energy efficiency in buildings is to exploit different opportunities and take measures for reducing energy usage in buildings without sacrificing occupant‘s thermal comfort. [7]-[8].

Building regulations influence the selection of construction materials for buildings and set appliance standards that have a significant effect on energy efficiency. The Gulf Organization for Research & Development (GORD) has developed Global Sustainability Assessment System (GSAS) which is a green building certification system developed for the State of Qatar and the GCC region. The primary objective of GSAS is to minimize ecological impact by creating a sustainable built environment while addressing the specific regional needs and environment of Qatar. GSAS has developed star rating system for building‘s certification. It has six levels of certification to measure the project’s environmental impact. Each level of certification corresponds to a star rating from a minimum of 1-star up to a maximum of 6-stars [1].

This work is part of an ongoing research project of Qatar Environment & Energy Research Institute (QEERI), which is focusing on integration of solar PV power and air cooling system for future buildings in the agro-industrial communities of Qatar. The research project aims to assess the energy consumption of passive house community apartments and agricultural greenhouses in the built environment of Qatar and the feasibility of meeting the building‘s cooling and domestic hot water demand by integrating with an innovative hybrid solar thermal collector (PV/T).

The focus of this paper is on an innovative passive house design concept for future residential buildings for establishing modern agro-industrial communities of Qatar. The carbon foot print of buildings can be minimized by reducing the cooling load and energy demand through passive building design. This can be achieved via highly insulated building envelope, lower infiltration rates, effective solar shading, natural ventilation, daylight harvesting system, ventilation heat recovery system, utilizing high efficiency equipment and incorporating renewable energy technologies such as PV panels, air source heat pumps and ground source heat pumps are a few to name that are widely used among many other available renewable energy technologies in the market [3], [4] & [10].

This research work assess and compare the annual energy consumption of passive house design and conventional design for two different blocks of residential apartments for future agro-industrial communities in Qatar. The passive house design shows significant reduction in cooling load and energy consumption compared to conventional design. The lower cooling loads and the available flat roof area on top of the roof of each block provides an opportunity for future to install the integrated solar PV cooling plant on top of the roof and link the apartments cooling and domestic hot water system with it [5]- [6].

2. Methodology

In order to carry out comparative energy analysis, the same building type was simulated with two different designs i.e. passive house design and conventional building design. For this purpose, two different blocks of multifunctional residential apartments were considered; a block of 3-Apartments (one apartment per floor), as an example of labor housing shown on figure 1&2, and a block of 18-Apartments (six apartments per floor) shown on figure 3&4, both spread over three floors, as an example of community living. The apartment’s floor areas range between 88m^2 and 100m^2 with 2 to 3-bedrooms per apartment and large open plan kitchen, living and dining area. Dynamic energy models were created for both type of buildings using the IES software (Integrated Environmental Solutions) in virtual environment and dynamic thermal analysis was carried out using hourly weather data of Qatar. For each building type, two different criteria were applied to the model, i.e. Passive house design vs. Conventional design. The conventional design was based on the Qatar GSAS (Global Sustainability Assessment System) one star rating, and the passive house design was based on the Qatar Green Building Council (QGBC) passive house design developed for Qatar. Energy analysis was performed to optimize building design, in terms of best thermal comfort and minimum energy consumption to identify/select optimum building materials and design parameters [1], [3] & [4].

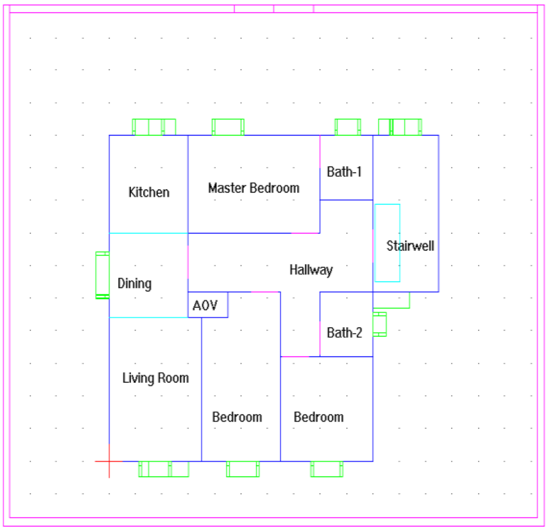

Fig 1: Plan View of Block of 3-Apartments

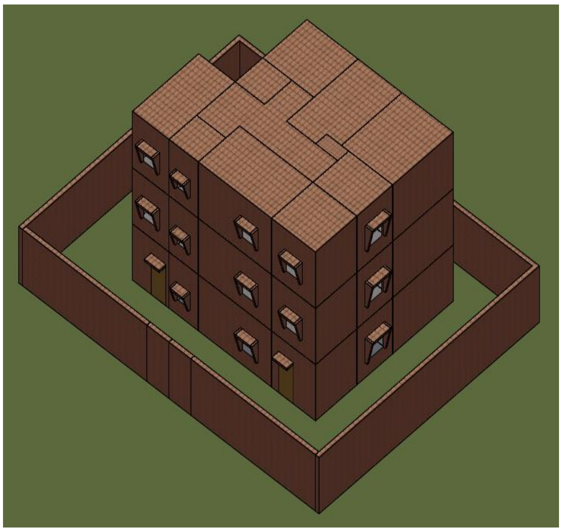

Fig 2: 3D-View of Block of 3-Apartments

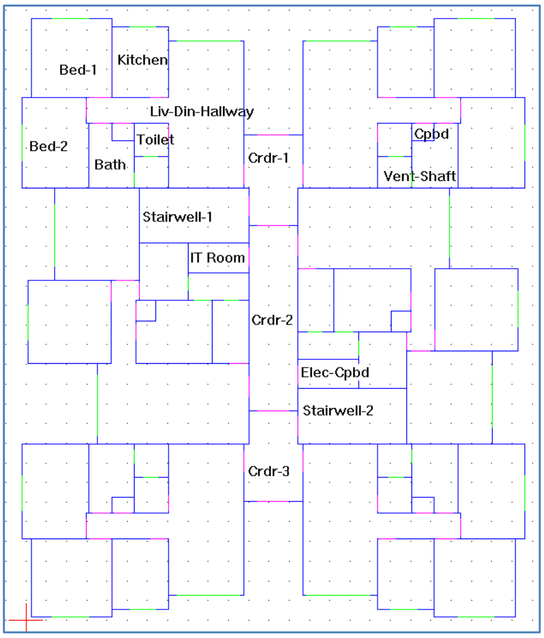

Fig 3: Plan View of Block of 18-Apartments

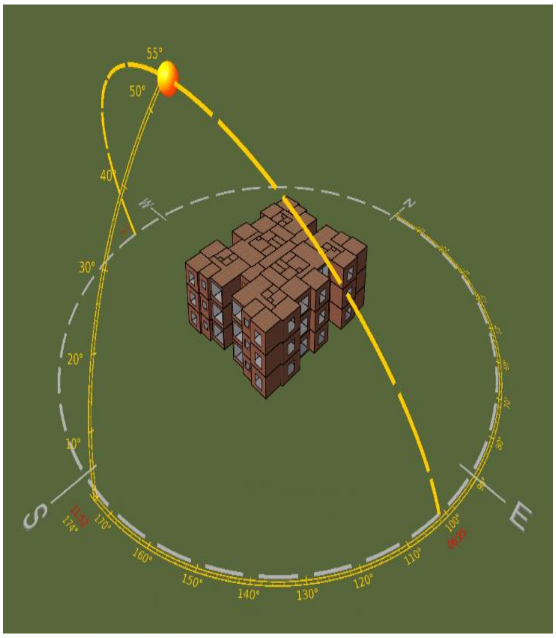

Fig 4: 3D-View of Block of 18-Apartments

Table 1 below summarizes the input parameters applied to the energy models [1], [3] & [4].

Tab. 1: Model Input Data

U-Values ($W/m^2.K$)	**Passive-house Building***	**Conventional Building****
External Walls	0.083	0.35
Internal Partitioning Walls	1.7	1.7
Doors	2.2	2.2
Roof	0.084	0.25
External Windows	1.17	2.84
Glazing g-value	0.20	0.73
Internal Floors/Ceilings	1.1	2.2
Ground/Exposed Floor	0.11	0.25
Internal Gains		
People	Sensible – 90 W/Person Latent – 60 W/Person	
Fluorescent lighting	8.5 W/m^2	
Miscellaneous gain (Equipment etc.)	2.90 W/m^2	
Occupancy density		
Apartments	50 m^2/Person	
Communal Areas	25 m^2/Person	
Air Permeability ($m^3/hr.m^2$)	3	10
Cooling set point (°C) with 50% RH	21	21
Weather Data: Doha Weather Data		

*QGBC Passive-house Design.
**Based on GSAS one star rating for Conventional/Impassivhaus Design.

A building's energy efficiency is the extent to which the energy consumption per square meter of floor area of the building is compared with the established energy consumption benchmarks for that particular type of building under the defined climatic conditions for that region. Energy consumption benchmarks of buildings are representative values for common building types against which a building's actual performance can be compared. The measure of heat loss or gain through a material, referred to as the U-Value or unit thermal transmittance, is also used as a way of describing the energy performance of a building or any of its structural element. The U-value refers to how well a structural element of the building conducts heat from one side to the other by rating how much the heat the component allows to pass through it [9].

The thermal resistance, R, of a structural element can be calculated from:

$$R = \frac{d}{\lambda} \quad (1)$$

Where:
$d =$ thickness of element (m)
$\lambda =$ thermal conductivity of the material (W/mK)
The basic formula for calculating the U-value of an element or structure is:

$$U = \frac{1}{R_T} \quad (2)$$

Where: $$R_T = \frac{R_{Upper} + R_{Lower}}{2} \quad (3)$$

Therefore: $$U = \frac{2}{R_L + R_U} \quad (4)$$

Where:
R_U = Upper bound thermal resistance (m^2K/W)
R_L = Lower bound thermal resistance (m^2K/W)

R_T = Thermal resistance of section (m^2K/W)
U = Thermal transmittance (W/m^2K)

The U-values are the standards used in building codes for specifying the minimum energy efficiency values for windows, doors, walls and other building components. U-values also rate the energy efficiency of the combined materials in a building component or section, for example a bridged wall. A low U-value indicates good energy efficiency. Windows, doors, walls and skylights can gain or lose heat, thereby increasing the energy required for cooling or heating. For this reason most building codes have set minimum standards for the energy efficiency of these components [9]- [10].

Heat loss equation:

$$Q_t = [F_{1cu} \, X \sum(AU) + F_{2cu} \, X \, C_V] \, X \, (t_c - t_{ao}) \qquad (5)$$

Where:
Q_t = total heat loss (W)
t_c = dry resultant temperature (°C)
t_{ao} = outside air temperature (°C)

C_v is the ventilation conductance of the room:

$$C_V = NV \div 3 \qquad (6)$$

Where:

Cv = Ventilation Conductance (W/K)
N = air change per hour (/h)
V = volume of the room (m^3)

Two correction factors F_{1cu} and F_{2cu} are needed to calculate the total heat loss from a space.

$$F_{1CU} = \frac{3(C_V+6\sum A)}{\sum(AU)+18\sum A+1.5R(3C_V-\sum(AU))} \qquad (7)$$

$$F_{2CU} = \frac{\sum(AU)+18\sum A}{\sum(AU)+18\sum A+1.5R(3C_V-\sum(AU))} \qquad (8)$$

Where:

R = radiant fraction of the heat source
∑A = total area through which heat flow occurs (m^2)
∑(AU) = sum of the products of surface area and corresponding thermal transmittance (W/K) [9]- [10].

The following measures were taken in light of QGBC passive house design and Passivhaus trust to improve the building energy efficiency and reduce the cooling load of both the residential blocks [3]- [4].

- Effective solar shading over external windows with internal blinds
- Triple glazed windows
- Lower infiltration rates
- Supply of natural ventilation linked with external temperature and relative humidity sensor
- Mechanical ventilation heat recovery
- Minimum acceptable U-values for all structural elements (Walls, Doors, Windows, Roof, Ground and partioning walls)

3. Simulation Results

3.1 Block of 3-Apartments (One apartment per floor)

Five different cases were simulated to optimize the apartments' design and reduce the cooling loads, increase the energy efficiency and improve the quality of living.

Case A. Impassive/Conventional design with whole house mechanical ventilation

Case B. Impassive/Conventional design without whole house mechanical ventilation

Case C. Passivhaus design without natural and mechanical ventilation

Case D. Passivhaus design with natural ventilation through wind catcher

Case E. Passivhaus design with whole house mechanical ventilation linked with a weather Sensor

Tab. 2: Comparison of cooling load and annual energy consumption of five simulation cases

Reference	Peak Summer Cooling + Dehumidification Plant Load (kW)	Annual Cooling +Dehumidification Plant Load (MWh)
Case A	49.86	153.23
Case B	49.86	154.13
Case C	14.8	48.07
Case D	14.8	45.85
Case E	14.4	44.18

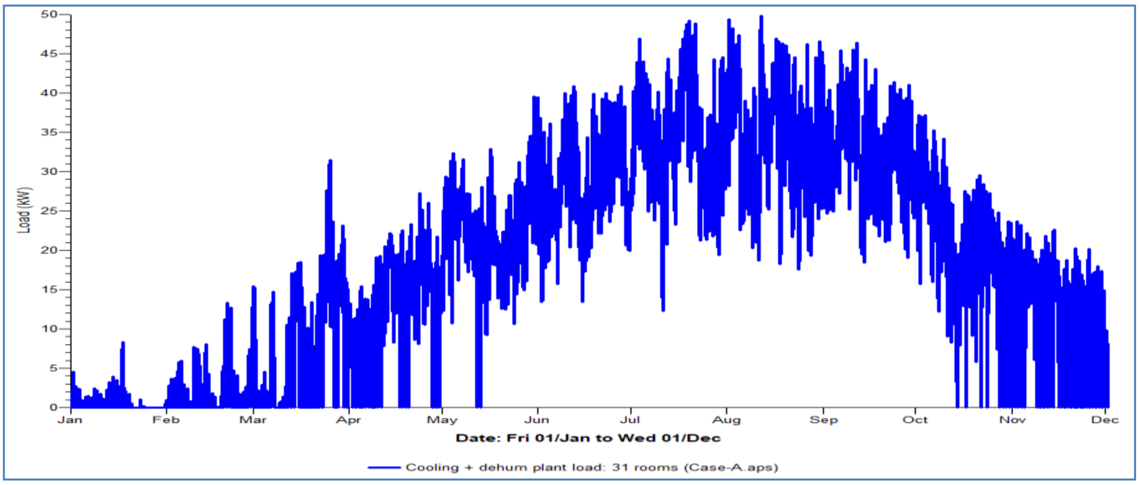

Fig. 5: Case A - Cooling plant annual profile

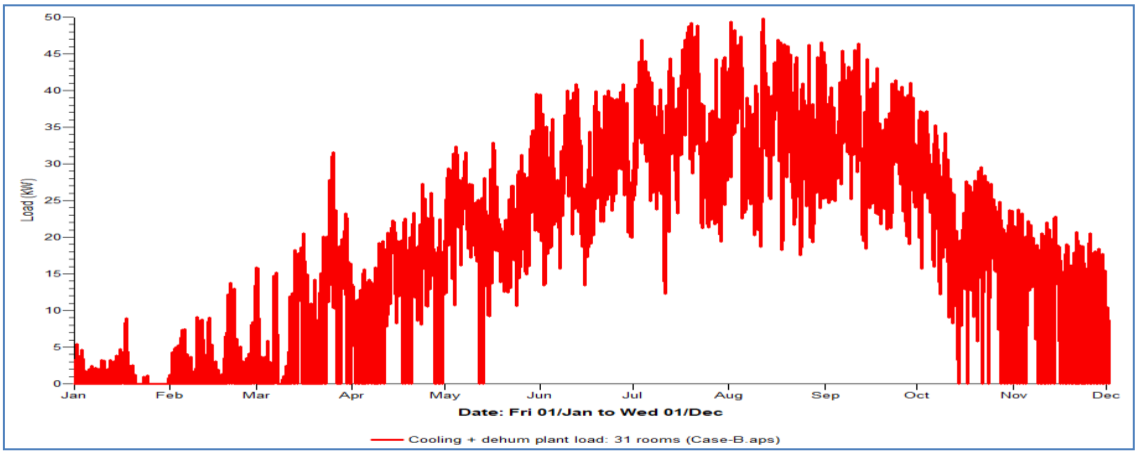

Fig. 6: Case B - Cooling plant annual profile

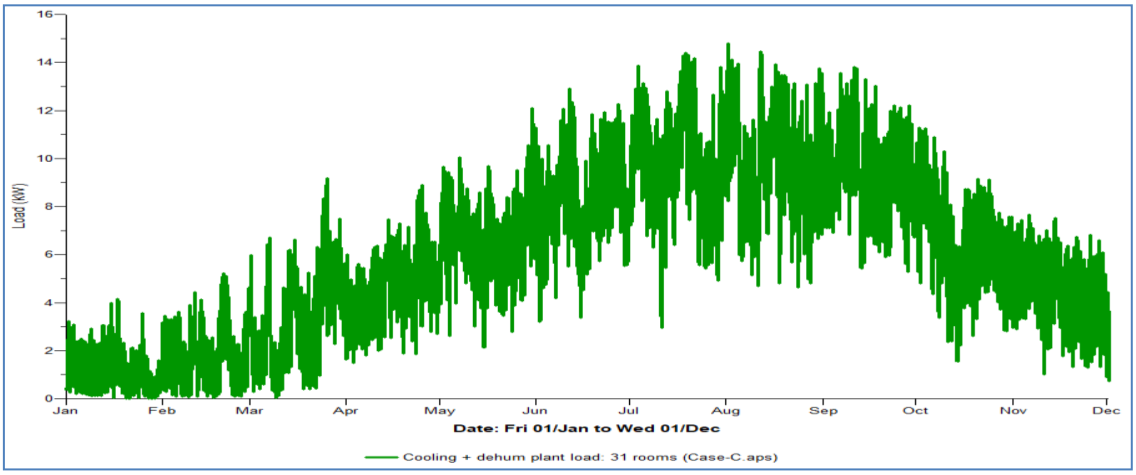

Fig. 7: Case C - Cooling plant annual profile

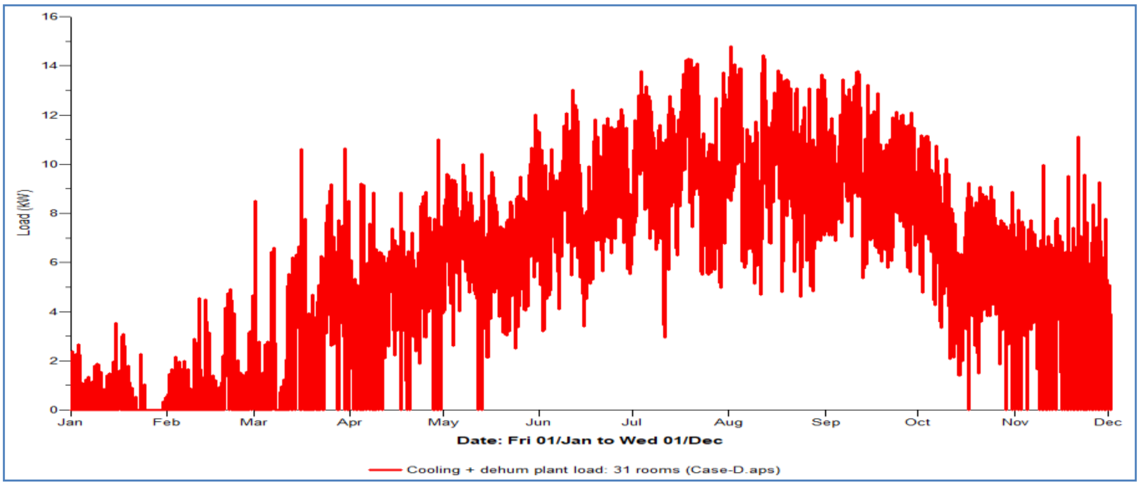

Fig. 8: Case D - Cooling plant annual profile

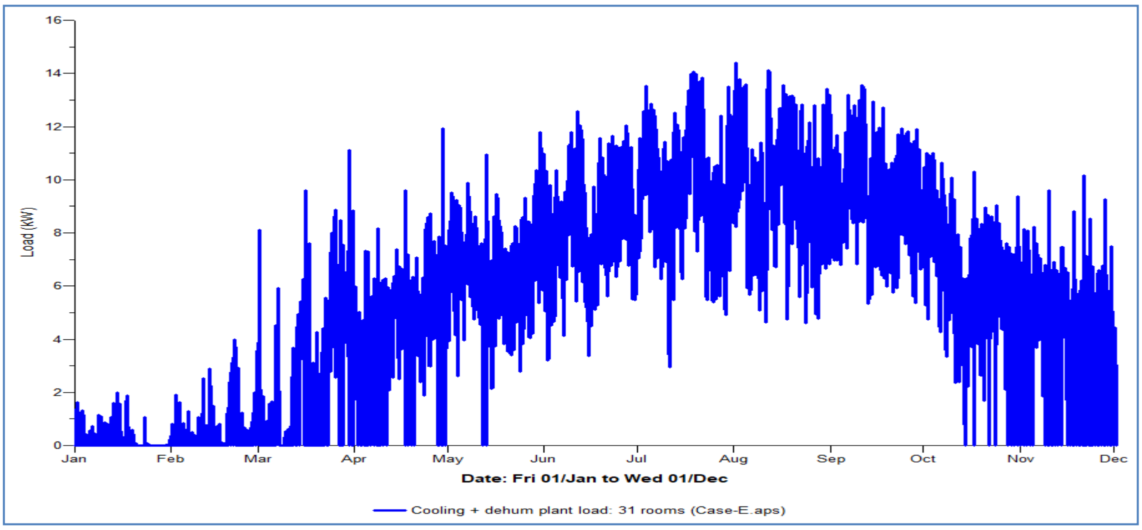

Fig. 9: Case E - Cooling plant annual profile

Case B is the worst and Case E is the best case scenario. Case E not only reduces the cooling load, saves energy but also ensures better living quality via continuous fresh air supply to the building through whole house mechanical ventilation. Case E shows 71.12% reduction in cooling load compared to Case B.

3.2 Block of 18-Apartments (six apartments per floor)

Three different cases were simulated to optimize the community apartments building and reduce the cooling loads, increase the energy efficiency and improve the quality of living.

Case A. Impassive/Conventional design without whole house mechanical ventilation
Case B. Passivhaus design with whole house mechanical ventilation linked with a weather Sensor
Case C. Passivhaus design without mechanical ventilation

Tab. 3: Comparison of cooling load and annual energy consumption of the three simulation cases

Reference	**Peak Summer Cooling + Dehumidification Plant Load (kW)**	**Annual Cooling +Dehumidification Plant Load (MWh)**
Case A	329	841
Case B	126	296
Case C	126	308

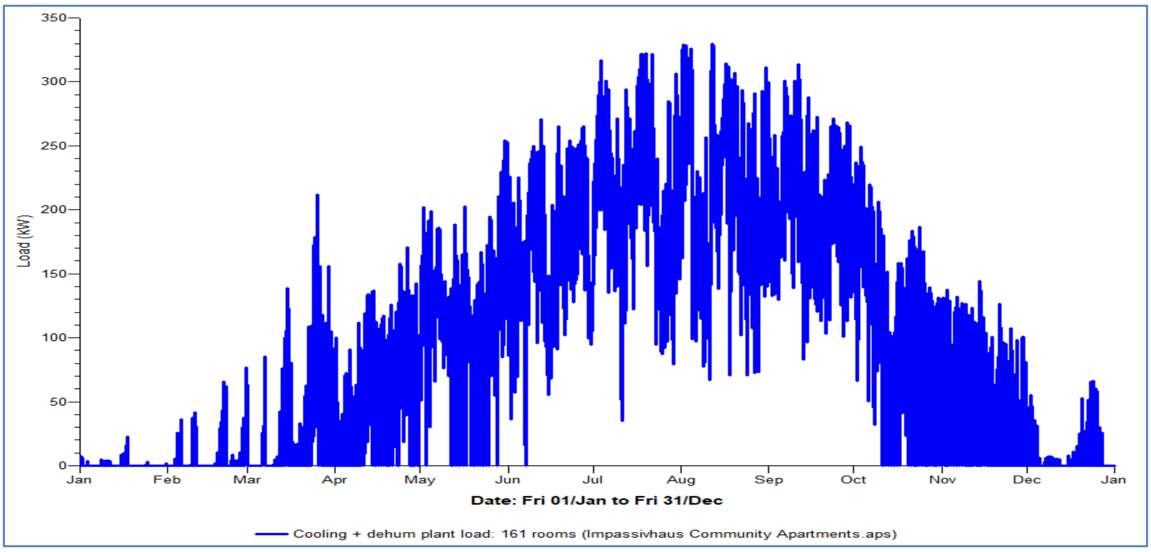

Fig. 10: Case A - Cooling plant annual profile

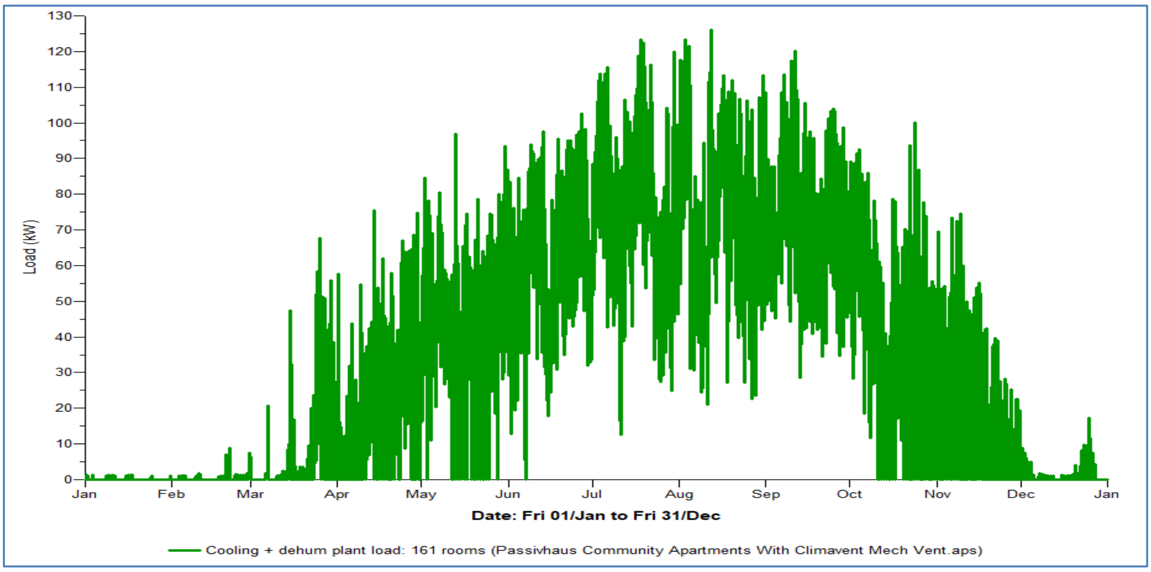

Fig. 11: Case B - Cooling plant annual profile

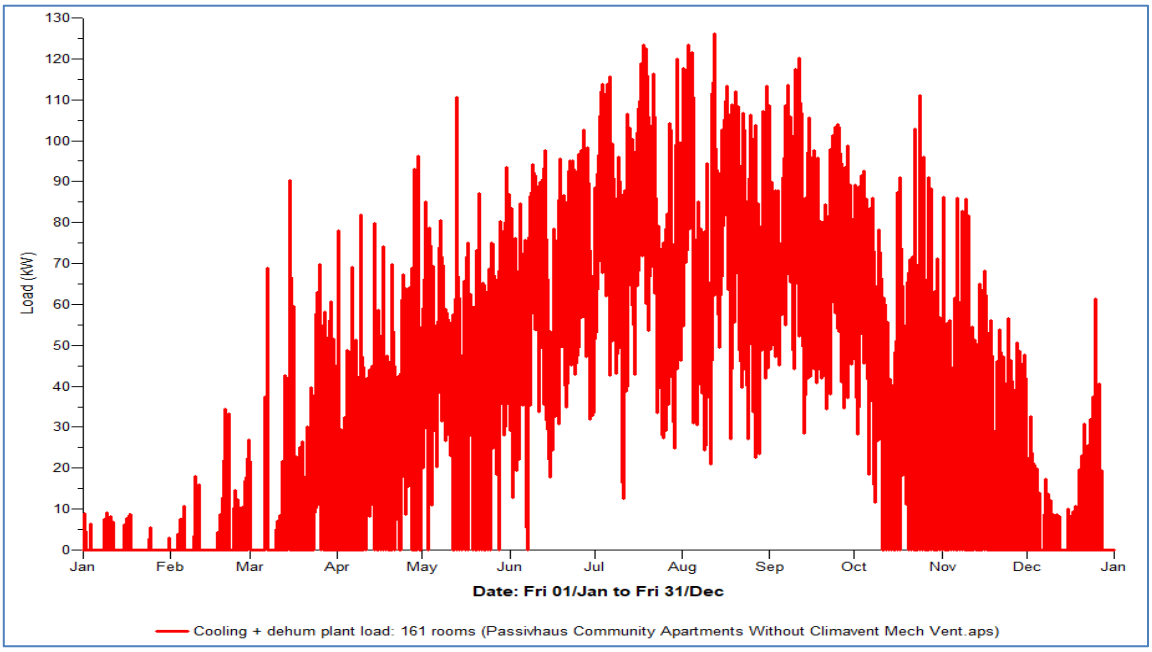

Fig. 12: Case C - Cooling plant annual profile

Case A is the worst and Case B is the best case scenario. Case B not only reduces the cooling load, saves energy but also ensures better quality of living via continuous fresh air supply to the building through whole house mechanical ventilation. Case B (Passivhaus design) shows 65% reduction in cooling load over Case A (Conventional/Impassive design).

4. Conclusion

The simulation results revealed that optimized passive house design can significantly reduce the cooling load and saves 60 to 70% of the total energy consumption in both small labor residential block and large community residential block respectively. This energy savings can translate into equivalent cost savings and the building‘s roof top area can be used for solar system installation that can help to achieve grid free zero carbon buildings in future. This energy saving will also reflect in reducing the as installed cooling plant size and associated infrastructure cost. This will also reduce the annual operational and maintenance cost of the building with just an extra 15% in construction cost for passive house design compared to conventional design.

For future, the energy model based on passive house design can be improved by application of daylight harvesting system that will help reduce the cooling load of the building and further energy saving. To validate the energy models, QEERI has initiated collaboration with QGBC and discussions are underway to install the innovative hybrid solar thermal collector on top of the roof of passive house villa situated at Barwa city. This will not only provide an opportunity for real life experiment on the passive house villa and hybrid solar thermal collector but will also help validate the buildings simulation models.

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