Moving Towards Net Zero - Improving Thermal Comfort and Energy Performance of Prototype Supermarket Stores in India

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Abstract

The demand for supermarkets and centralized shopping spaces is growing rapidly in India. Reducing the energy use impact of these buildings is significant from both the owners as well as global environmental perspectives. Energy consumption in a typical supermarket is mainly dominated by HVAC and lighting, which make these systems the ideal candidates for energy efficiency opportunities. Indoor thermal comfort is also a key factor for supermarket designs as the end user spends a considerable amount of time once inside and peak occupancies can be high. This paper presents an approach for meeting end user thermal comfort with minimum operational energy within the constraints of capital investments. Simple payback analysis has been done to select the most optimum strategy in a three-tier approach to achieve Net Zero Energy Building (NZEB) goals. Several design recommendations have been developed into three packages based on energy efficiency, first cost impact, energy saving, thermal comfort, and payback. The three packages are:

Package-1: Optimized design (low cost);

Package-2: Enhanced thermal comfort, and

Package-3: Achieving NZEB goals

The simulation results show that Package-1 results in 27% energy savings with a slight improvement in thermal comfort compared to a typical supermarket store. Package-2 results in enhanced thermal comfort along with 30% energy savings. Package-3 saves 34% energy and provides significantly better thermal comfort. The cost analysis shows that the capital cost increased by 32%, 40%, and 63% with a simple payback period of 1.3 years, 1.4 years and 2.0 years for the three packages respectively.

Introduction

Supermarkets are amongst the most electricity-intensive types of commercial buildings, using an average of about 50 kilowatt-hours (kWh/sqft/yr) of electricity (Facility Type: Supermarkets & Grocery Stores, 2008). India is the fifth largest preferred retail destination, and its retail sector is expected to increase at the compound annual growth rate of 17% by 2020 (Care Ratings 2017). Tier-II and Tier-III cities are also catching up with the metros in terms of demand for supermarkets.

Supermarkets require a design which is not only visually appealing but comfortable for the customer to spend longer periods. Energy efficiency is crucial not only from an economic perspective, but it also enhances the customer's overall shopping experience comfort. Refrigerated goods and walk-in refrigerators pose a challenge to energy efficiency and comfort. For example, too much cold air escaping from refrigerated displays may decrease comfort and increase the cooling demand. (Timmer et al., 2016). Thus, optimized control strategies for Heating Ventilation and Air Conditioning (HVAC) systems are required to achieve acceptable environmental conditions for customers and optimized operation of the refrigeration system.

Kampelis et al. (2017), Fanney et al. (2015), and Moran et al. (2017) found that improved building designs include enhanced thermal insulation, higher levels of airtightness, optimized orientation/shape, solar shading, etc. Studies by Thygesen et al. (2017) and Lu et al. (2015) mention that adopting energy-efficient lighting and efficient appliances not only directly reduce the electricity consumption but also lower the cooling load imposed on HVAC systems.

Mylona et al. (2018) presented a study demonstrating the cooling benefits of night ventilation for supermarkets with high cooling demands. Energy and environmental data from two stores with a high percentage of frozen and chilled goods and with different HVAC systems are presented. It was documented that night ventilation in combination with a high building mass has the potential to reduce the working hours and thus the cooling energy use of the active cooling system on the following day.

Watcharapongvinij and Therdyothin (2017) performed a study on VSD installation in refrigeration system for retail and wholesale buildings. The VSD system needs to set additional functions to turn off at night or turn off at no load/demand.

Wu et al. (2018) investigated and compared the energy, comfort and economic performance of commercially-available HVAC technologies for a residential NZEB. Heat Recovery Ventilator (HRV) and Energy Recovery Ventilator (ERV) reduced the HVAC energy by 13.5% and 17.4% respectively for different ventilation options.

Khan et al. (2015) described the performance and estimated the energy savings potential of a radiant cooling system installed in a commercial building in

India. A comparison of energy consumption indicated that the radiant system was 17.5% more efficient than a conventional all-air system.

The literature review indicates that even with advanced envelope construction, the HVAC system remains responsible for the largest share of energy use in buildings. Although prior research has analyzed the advantages & disadvantages of different HVAC systems (AlAjmi, 2016), the HVAC options studied were limited, and the evaluation criteria mainly focused on energy performance or economic benefit without considering thermal comfort. Several studies have demonstrated that radiant cooling, high-efficiency Variable Refrigerant Flow (VRF) systems, Variable Speed Drive (VSD) controllers and displacement ventilation are good strategies to reduce energy consumption and enhance comfort.

Net Zero Energy Building (NZEB) is a powerful concept and a key solution to carbon neutrality and the elimination of fossil fuel use. A building can become a net zero energy building by minimizing the energy demand through improved building design, efficient HVAC systems, smart control technologies, & encouraging energy-efficient occupant behaviour (Zhou et al. 2016; Marszal et al., 2011).

This paper presents the results of a multivariate analysis for optimizing energy use and thermal comfort for a prototype supermarket design. The research is carried out using dynamic simulations for the evaluation and the optimization of building energy performance. The typical design of a supermarket store was evaluated for parameters of thermal comfort and energy efficiency to recommend design strategies. Each design measure affecting these parameters was analyzed individually as well as in conjunction with others to evaluate the effect on annual operational energy costs and thermal comfort. The approach was aimed at achieving a Net Zero Energy Building (NZEB) with building-level integration of renewables. Recommendation have been made based on a simple payback analysis.

Evaluation Approach

Design measures for achieving maximum thermal comfort and Net Zero Energy goals were analyzed in a three-tier approach to strategically study the impact of each measure.

Tier-1: Envelope Optimization – Focuses on strategies which can be implemented during the early design stage like envelope, glazing, insulation, shading, radiant barrier and use of solar PV to reduce the cooling load.

Tier-2: Lighting Reduction – Focuses on design strategies for lighting schemes. This includes efficient lighting fixtures etc., which reduce cooling load and costs.

Tier-3: HVAC Techniques – Focuses on various HVAC systems and air supply configurations. Efficient refrigeration techniques were also investigated.

Based on these Tiers; Energy Conservation measures were analyzed using hourly simulation software to

investigate their impact on operating Cost and thermal comfort. Design recommendations have been made in three packages based on energy efficiency, capital cost impact, operating energy cost, thermal comfort, payback and practicality of operation:

Package-1: Optimized design (low cost);

Package-2: Enhanced thermal comfort, and

Package-3: Achieving NZEB goals

Figure 1 below summarizes the three packages:

Figure 1: Flow chart of design recommendations

Grid-tied Rooftop PV was added to make up for the deficit in energy savings to bring the building closer to the Net Zero Energy Building target.

Energy Analysis

Base Case – Prototype Building

Prototype Model for the supermarket store was developed and modeled in Design-Builder Software. The prototype store has Back of House (BOH) spaces, retail spaces and Office/Pantry spaces for store administration. The retail area has low-temperature refrigeration storage enclosures for vegetables, fruits and other perishable items. Figure-2 shows the prototype model of the store modeled in Design-Builder software.

Figure 2: Prototype model 3-D design

Building parameters for the prototype design are given in Table-1 below:

Table 1: Prototype supermarket store design parameters

Prototype supermarket store		
Area (Sales+BoH)	4,490 m ²	
Envelope	Walls	Up to 3.2 m: 18mm Plaster*2 + 230 mm Brick. U-value = 1.854 W/m ² -K
		Above 3.2 m: 50 mm PUF Panel + 2*0.5mm Steel. U-value = 0.427 W/m ² -K
	Roof	50 mm Glass Wool + 2*0.5mm Steel U-value = 0.432 W/m ² -K

Lighting	Sales Area	LPD: 6.3 W/m ² , 150W/Luminaire
Skylights	2% SRR	U-value: 3.2 W/m ² K SHGC: 0.5, VLT: 0.4
HVAC	Retail and BOH	Chilled Water System with AHU in retail and CSUs in BOH. Chiller efficiency: 1.8 kW/TR
	Office	Split Units
Operation	9 AM to 9 PM	
Setpoint	26°C	
Fresh Air	Per ASHRAE 62.1-2010	

A composite climate condition has been selected for simulation. This Climate type is characterized by high temperatures and low humidity in Summers, a cold Winter and high humidity levels during Monsoon. Mean temperature during Summer midday ranges from 32°C to 43°C, while Summer nights are between 27°C and 32°C (BEE 2009). The simulation was performed in Energy Plus using the Design-Builder interface. Thermal comfort has been analyzed with the help of the CBE Thermal comfort tool (Tyler et al. 2017) using ASHRAE Standard-55 Predicted Mean Vote (PMV) method. (ASHRAE Standard 55, 2010)

Cooling Load and Annual Energy analysis were carried out for the prototype design and energy conservation measures models. External climate conditions were sourced from ISHRAE 2014 for analyzing Cooling System sizing using the heat balance method (ASHRAE, 2009) and performing yearly energy simulation.

Figure 3: Prototype model cooling load components

Figure-3 shows coincident peak cooling load for the baseline prototype design, signifying the major contribution of the envelope in the peak load.

The analysis shows that there are three significant components: Roof, fresh air, and occupants which account for 76% of the total cooling load. The roof alone contributes around 22% of the entire cooling load, followed by Walls at 9% and Skylights at 7%.

It can be seen from Figure-4 that the peak load occurs at 3:30 pm. Occupants do not contribute significantly to peak cooling loads as occupancy peaks in the late evening hours.

Figure 4: Sales area hourly heat gain profile: Prototype design

Tier-1: Envelope Optimization

The Tier-1 approach is to reduce the cooling load by incorporating efficient building design and construction as it has the most significant impact on cooling demand. Simulations have been performed for roof and wall options to find the optimized design. A summary of the envelope parameters is given in Table-2.

Table 2: Envelope parameters: Tier-1

Parameters	Prototype Design	Proposed Design
Walls	Up to 3.2 m: 18mm Plaster*2 + 230 mm Brick. U-value = 1.854 W/m ² -K	Up to 3.2 m: 100mm PUF panel U-value = 0.303 W/m ² -K
	Above 3.2 m: 50 mm PUF Panel + 2*0.5mm Steel. U-value = 0.427 W/m ² -K	Kept the same due to constraints of the supermarket
Roof	50 mm Glass Wool + 2*0.5mm Steel U-value = 0.432 W/m ² -K	100mm insulation + 2*0.5mm Steel U-value = 0.223 W/m ² -K

It can be seen from Figure-5 that the contribution of roof to the overall cooling demand has dropped from 22% to 8%. Due to reduction in envelope loads; the peak load has shifted towards the evening when there is a higher consumer footfall (occupant load component has increased to 41% from 19%)

Figure 5: Tier-1 measure - Optimized cooling load

Figure-6 shows that the coincident Peak cooling load in the optimized design occurs at 5:30PM, as envelope is shaded and optimized, it does not contribute significantly to the peak cooling load. Further, fresh air loads also reduce due to lower ambient temperature at time of peak load.

Figure 6: Sales area hourly heat gain profile: Tier-1

Other parameters which have been analyzed to reduce the cooling load are correct sizing of loads based on the heat balance method, loading deck airlock, installation of solar PV on the rooftop and albedo paint. Table-3 shows the effect of envelope measures on the cooling load.

Table 3: Cooling Load optimization through the envelope

Parameters	Reduction in Cooling Load kW _r (TR)	Revised Cooling Load kW _r (TR)
Prototype design case	548 (156)	
Sizing based on heat balance method	42 (12)	506 (144)
Wall, All PUF 100mm	21 (6)	485 (138)
Roof, 100 mm Insulation	38 (11)	447 (127)
Solar PV on Roof	35 (10)	412 (117)
Albedo Paint	17 (5)	395 (112)
Loading deck airlock	14 (4)	381 (108)
Optimized Case: Tier-1	167 (48)	381 (108)

Analysis of Tier-1 measures show that increasing roof insulation to 100mm from 50mm results in cooling load reduction of 39 kW_r (11TR). No significant reduction in cooling load was observed on further increasing the insulation above 100mm (the increase in capital cost was very high). Addition of rooftop PV reduced around 35 kW_r (10TR) of cooling load demand due to its shading effect on the metal roof. These measures combined into different packages reduced not only the initial capital cost but also reduced the operational cost of the store. Utilizing space above refrigeration rooms for offices can also help in reducing the air volume to be conditioned. These design strategies coupled with efficient envelope; and PV shading helps in reducing cooling load demand by approx. 167 kW_r (48TR).

Tier-2: Lighting Reduction

Lighting is considered as one of the most important parameter in reducing the energy consumption of a building. (Li and Lam 2001). Also, lighting has secondary impacts on cooling energy consumption due to the heat produced by electric lights. Generally, reducing lighting energy results in increasing heating and decreasing cooling energy demands of a building (Shishegar and Boubekri 2017).

Different strategies have been applied to reduce the lighting load and to increase visual comfort. The strategies include the removal of skylights, efficient lights fixture with controls. The prototype system has skylights in the design, but according to its current

design, it increases the energy consumption due to higher heat gains. So, it has been recommended to remove it from prototype design case and use the area of skylight to install the rooftop PV.

Lighting fixtures were recommended to improvement of view in vertical illumination as well. Two lighting schemes were analyzed to reduce the lighting load and to improve vertical illuminance on the storage racks. Table-4 shows lighting scheme options:

Table 4: Lighting scheme options

Lighting initiative	Prototype	Proposed Option-1	Proposed Option-2
Average Lux Levels on Vertical Surface	150	300	200
Wattage	150	120	100
Energy consumption (kWh)	2,04,000	1,63,200	136,000
Cost increase (USD)		6,322	2,100
% Savings		20%	33%
Yearly energy savings (USD)		4,630	7,590
Payback (Years)		1.4	0.3

The reduced lighting load of 4.5W/m² from the existing 6.3W/m² subsequently reduce cooling load demand by 7kW_r (2TR) as well as the operational costs. Table-5 shows the effect on cooling load by applying various lighting and daylighting optimization measures.

Table 5: Cooling load optimization through lighting

Initiative	Reduction in Cooling Load kW _r (TR)	Revised Cooling Load kW _r (TR)
Prototype design case	548 (156)	
From Tier-1 approach	167 (48)	381 (108)
Removal of skylights	28 (8)	353 (100)
Efficient lights	7 (2)	346 (98)
Optimized Case: Tier-2	204 (58)	346 (98)

Tier-3: HVAC Techniques

Prototype building simulation results highlighted that HVAC consumes about 30% of the overall yearly energy use (Figure-7). Typically, refrigeration in a supermarket store is second highest parameter of the total energy usage, which consumes approximately 1/4th energy of the store. (Klemick, Kopits and Wolverton 2015).

Figure 7: Energy end-use breakup of a prototype supermarket

For further reducing operational costs and achieving better thermal comfort, Tier-3 measures were analyzed for HVAC techniques (VRT technology, efficient water-cooled chiller, radiant cooling, Demand control

ventilation, efficient refrigeration) and air speed control (displacement ventilation, and HVLS fans).

Prototype design systems were simulated with the cooling load as well as with optimized cooling load achieved using Tier-1 measures. Below is the brief description after applying energy-saving technologies on the HVAC:

- Variable Refrigerant Temperature (VRT) is a technology by which energy efficiency can be improved in part load conditions by increasing the evaporating temperature in cooling. It was found 32% more efficient than the chiller coupled with optimized heat loads.
- Demand control ventilation has been used and it showed 16% cooling energy savings.

Efficient Refrigeration

Refrigeration system consumes approximately 24% of the total Supermarket Energy. In this case, the Energy consumption of the refrigeration system is optimized using:

- Reducing Heat loads through reduced infiltration by providing strip curtains in the freezer room and strip curtains near the entrance as the ante room are removed
- System Design optimization using VFD on both the LT and MT compressors and using EC motors/fans on all Evaporators Condensers. This reduces the fan speed when compressors cycle off. Reducing speed reduces the heat load from the fans themselves.
- Motion sensors for display cases which operates lights when someone is near-by.
- MPX-Pro controller gives good defrost management and better Rail Heater Management.

These strategies can achieve 30% savings over the prototype design refrigeration system.

Cooling system with the following efficiency figures (Table-6) were analyzed in this tier:

Table 6: Proposed cooling system efficiency

Proposed Cooling System	Efficiency
VRF	ikW/TR: 0.86 COP: 4.10
Efficient Chiller	VFD Water Cooled Screw Chiller ikW/TR: 0.61 (AHRI conditions) COP: 5.7 (AHRI conditions)

There are several energy-saving cooling technologies have been analyzed to optimize the air flow for comfort. Some of them are explained below:

Radiant Cooling

Coupling of water-cooled chiller with radiant pipes embedded in the Sales floor area helped to reduce the floor surface temperature to 21°C. This reduced mean zone radiant temperature of the space, thereby improving thermal comfort. Figure-8 shows the temperature distribution of radiant pipe inside radiant slab installed at 50mm from the floor and water is flowing at 16°C.

Figure 8: Temperature distribution of radiant pipe inside the floor slab

Displacement Ventilation

In the prototype store, cool air from the Air Handling Unit (AHU) is being supplied from 7m height at 18°C. It has been simulated with the help of Computational Fluid Dynamics (CFD) to analyze the temperature gradient at the occupant level which comes in the range of 26-27°C. This configuration achieves air speed of 0.1-0.2 m/s at occupant level. Figure-9 and Figure-10 shows the temperature gradient and velocity vector respectively.

Figure 9: Temperature gradient, Supply duct at 7m

Figure 10: Air velocity gradient, Supply duct at 7m

Displacement ventilation is an air distribution strategy where conditioned air is supplied at low velocity from air supply diffusers located near floor/occupant level and extracted above the occupied zone. This technique helps the cooling provided only in the vicinity of the occupant. In this case, the air has been supplied at 1.5m above ground level in prototype case and simulated. Figure-11 shows that the achieved air temperature has been found in the range of 22-23°C.

Figure 11: Temperature gradient, Supply duct at 1.5m

This setup of air supply reduces the load by 40TR from the cooling load. Also, this configuration achieves air speed of 0.3-0.4 m/s at the occupant level (Figure-12).

Figure 12: Air velocity gradient, Supply at 1.5m

Cooling energy savings over the water-cooled chiller were compared with more efficient technologies like VRT, and energy efficient water-cooled chiller. It has been found that efficient water-cooled chiller operating with radiant scheme and optimized loads saves around 50% of the cooling energy cost, while the same chiller with conventional AHUs saves 44% cooling energy with less increment in capital cost but with less comfort level than radiant scheme. Table-7 shows the cost savings due to Tier-3 approach.

Table 7: Cost savings analysis: Tier-3 Approach

Equipment	% Energy Improvement	Increase in Cost (USD)	Savings (USD)
Existing Water-cooled Chiller	Prototype design		
Current VRF with existing heat loads	17%	28,100	6,750
VRT/VFR Technology with revised heat loads	32%	-12,650	12,250
Water cooled chiller with revised heat Load	44%	7,025	17,000
Water cooled Radiant with revised heat load	50%	26,700	19,500

Thermal Comfort Analysis

Thermal comfort is a cumulative effect resulting from a series of environmental (air temperature, air velocity, relative humidity) and personal factors (Clothing, metabolic heat). (ASHRAE Standard 55, 2010)

For optimal comfort, Mean Radiant Temperature (MRT) and air speed must be managed. MRT is defined as the temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure. Lowering the MRT and control over air speed can be achieved through a combination of:

- Optimized envelope
- Displacement cooling
- HVLS fans

With the help of CBE thermal comfort tool (Tyler et al. 2017), Predicted mean vote (PMV) and Predicted percentage dissatisfied (PPD) has been calculated for each case. The value of Metabolic rate (MET) and Clothing value (CLO) have been fixed as 1.7 (walking) and 0.5 (typical summer) for all cases.

Prototype Design Case

In the prototype design store, the simulated peak zone MRT is found to be 33°C due to high surface temperature of metal insulated sandwiched panel of envelope. Figure-13 shows the temperature profile of the store.

Figure 13: Prototype store zone temperature profile

Standard Effective Temperature (SET) has been calculated considering uniform air temperature of 26.0°C and an air speed of 0.1m/s. SET achieved was 32.6°C with PMV value of 1.6 (Tyler et al. 2017), which do not comply with ASHRAE standard-55. It has been calculated that 60% occupants feel uncomfortable in these conditions.

Optimized Envelope

Using efficient envelope design, simulated peak zone MRT has been found as 28.6°C, which is 4°C less than the MRT achieved in prototype design. (Figure-14)

Figure 14: Efficient envelope zone temperature profile

SET using efficient envelope measures, considering uniform air temperature of 26°C and achieved air speed of 0.1m/s is 31.3°C, thereby not complying with ASHRAE standard 55. Achieved PMV was 1.3 while 40% of the occupants feel uncomfortable in these conditions.

There is a slight variation in MRT has been achieved with the following design of envelope:

- Increasing Roof insulation to 100mm from existing 50mm results in a reduction of 1.3°C in MRT.
- Addition of Rooftop PV further reduced 1°C in zone MRT.

The cumulative effect of high Albedo paints combined with Roof insulation and Rooftop PV in reducing Zone mean radiant temperature was observed to be around 4°C.

Displacement Cooling

Displacement cooling strategy has been analyzed along-with the optimized envelope. It has been seen from Tier-3 approach that it helps reducing the cooling consumption. It lowers down the SET from 31.3°C to 26.9 °C with an air speed of 0.3 m/s and air temperature of 23°C. It complies with ASHRAE standard 55. PMV achieved in this case is 0.29, while only 7 % of the occupants feel uncomfortable in these conditions.

HVLS Fans

A high-volume low-speed (HVLS) fan is a type of mechanical fan greater than 2.1m in diameter. HVLS fans move slowly and distribute large amounts of air at a low rotational speed. CFD simulation of HVLS fans has been carried out to find the optimum air flow speed, which was 0.8m/s at occupant level. SET has been achieved in this case is 25.9°C, thereby complying with ASHRAE standard-55. PMV is achieved 0.14 while only 5% of the occupants feel uncomfortable in these conditions. Figure-15 shows the comparison of all the three combination in terms of SET and PMV.

Figure 15: Comparison of all cases for thermal comfort

Table-8 summarize the input and output parameters for each option to achieve the desired thermal comfort.

Table 8: Parameters for thermal comfort

Combinations	MRT (°C)	SET (°C)	Air speed (m/s)	PMV	PPD (%)
Prototype	32.0	32.6	0.1	1.66	59
Optimized Envelope	28.6	31.2	0.1	1.30	40
Displacement cooling	28.6	26.9	0.3	0.29	7
HVLS fans	28.6	25.9	0.8	0.14	5

Path to Net Zero

Energy efficiency measures for achieving net zero design are used from current design best practices for

supermarket (BEE, 2017). System efficiency inputs of proposed cooling systems are summarized below in Table-9:

Table 9: Best practices design inputs (BEE 2017)

Net Zero model inputs	Values
Water Cooled Chiller	0.586 kW/TR (COP 6.0)
AHU	Motor Efficiency: IE4, 70%
Cooling Tower	0.017 kW/kWr
Chilled Water Pumps (Primary+Secondary)	14.9 W/kWr with VFD on secondary pump, Pump Efficiency: 70 %
Condenser Pump	14.6 W/kWr, Pump Efficiency: 85 %
Wall	U Factor: 0.22 W/m2K
Roof	U Factor: 0.20 W/m2K
Cool Roof	All exposed roofs (not covered by solar or other utility) are cool roofs

Cost analysis has been done to explore the financial feasibility of net zero energy buildings. The analysis provided here demonstrates that net zero buildings are a viable and cost-effective investment, as compared to prototype building. Table-10 shows the energy consumption for all the year and load to cater Net zero building demand.

Table 10: Net Zero feasibility

	Proto type	Optimized envelope	Enhanced comfort	Net Zero
Total kWh/yr	11,55,141	8,41,933	8,07,267	7,65,629
Solar kWh/yr	- 4,05,000	- 6,75,000	- 6,75,000	- 6,75,000
Remaining kW for Net Zero	- 7,50,141	- 1,66,933	- 1,32,267	- 90,629
Installed Cooling kW (TR)	685 (195)	492 (140)	422 (120)	422 (120)
Energy savings (%)	-	27%	30%	34%
Additional Solar required for Net Zero (kWp)	355	125	100	65

After full utilization of space available for solar rooftop PV, additional solar power required to achieve net zero building is 65 kWp. The potential to meet this additional demand exists in the store parking area.

Simple Payback Analysis

Efficient Water-cooled Chiller operating with Radiant scheme and optimized Loads saves around 50% of the cooling Energy cost with a payback period of 1.4 Years, while the same chiller with conventional AHUs saves 44% cooling Energy with less increment in Capital Cost but with less comfort level than Radiant scheme. Payback analysis has been done for each of the options with and without considering solar PV. Table-11 shows the payback analysis for all three cases.

Table 11: Simple payback analysis

Packages	Package-1: Optimized Envelope	Package-2: Enhanced Comfort	Package-3: Net Zero
Energy Savings	27%	30%	34%
Additional Capex (USD)	44,960	54,790	88,511
Opex Savings (EE+Solar) (USD/Year)	35,000+19,000	39,050+19,000	43,700+19,000
Total Savings (USD/Year)	54,090	58,024	62,660
Payback (years) EE / Solar	1.3 / 0.8	1.4 / 0.9	2.0 / 1.4
Comfort/Quality	Good	Better	Best

*Capex: Capital Expenditure *Opex: Operational Expenditure

It can be seen from Table-11 that Package-1 gives 27% energy saving with payback of 1.3 years over prototype design case. Packages-2 gives 30% energy saving with slightly higher payback of 1.4 years, while a payback period of 2-years with energy saving of 34% was calculated to achieve Net-Zero building.

Conclusion

NZEB research is developing worldwide and represents a novel multi-disciplinary approach toward building physics. Minimizing the building energy demand includes improving building design, integrating a more efficient HVAC system, using efficient appliances, smart control technologies, and encouraging energy-efficient occupant behaviours. A case for achieving Net Zero Energy Building (NZEB) goal has been analyzed with the integration of Renewables within the existing infrastructure. Design recommendations have been made into three packages based on energy efficiency, first cost impact, energy saving, thermal comfort, and payback which are: 1) Optimized design; 2) enhanced thermal comfort, and 3) achieving net zero goals.

The simulation results showed that Optimized Case achieves a 27% cost savings with a slight improvement in thermal comfort over the prototype design. Enhance Comfort package provides better thermal comfort with 30% energy savings over the prototype case. Net Zero case achieves a Net Zero target with over 34% energy saving along with better thermal comfort in conjunction with a renewable energy service providing a grid-tied rooftop PV system.

Cost analysis of proposed systems showed that the capital cost increased by 32%, 40%, and 63% with a simple payback period of 1.3 years, 1.4 years and 2.0 years for the three packages respectively.

The current design practice for supermarket is governed by a desire to reduce first cost. Sometimes; it leads to inefficient designs and equipment selection. However, cost-effective NZEB supermarkets are possible with the right design, selection & operation of HVAC and lighting systems. There is considerable potential for improvement in the refrigeration systems as well as demonstrated by the detailed analysis in this paper.

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