SOLAR ICE CREAM: ACHIEVING NET-ZERO THROUGH AN INTEGRATED RETROFIT APPROACH

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ABSTRACT

Many strategies, standards, and policies have been proposed to minimize the environmental and economic costs associated with building energy inefficiencies (1-3). One such strategy is Net-zero energy design (NetZED), which can be applied to new construction and, more importantly, retrofits of existing buildings. The NetZED retrofit approach requires thoughtful and data-driven design decisions, which aim both to minimize energy consumption and to produce enough energy to offset unavoidable energy expenditures. This paper presents a case study examining energy performance of an ice cream shop in Eugene, Oregon. We hypothesized that energy audit data can be used to develop a net-zero retrofit for this establishment which integrates onsite renewable energy sources. Onsite data collection included a plug load survey, field readings of name plates of lighting, pumps, and fans, and acquisition of utility data to determine peak energy use. Data from this audit indicate seasonally-dependent high process and cooling loads, a leaky envelope, and relatively high solar and wind potentials. These results were used to develop retrofit measures aiming to bring the building to net-zero by both improving the existing structure and incorporating on-site renewable energy production. Our assumption is if energy audit data is obtained prior to the design process, architects and engineers will recognize consumptive hotspots and identify the potential for onsite renewable energy production.

1. INTRODUCTION

In 2009, the US Environmental Protection Agency reported that buildings account for 38.9% of the total national energy consumption and for 71% of the total national electrical consumption, and these numbers are only projected to rise through 2025 (4).

This rising demand on an increasingly limited supply also presents large financial implications: Data from the U.S. Energy Information Administration, illustrated in Figure 1, show a trend of increasing energy spending since the U.S. energy crisis of the 1970s.

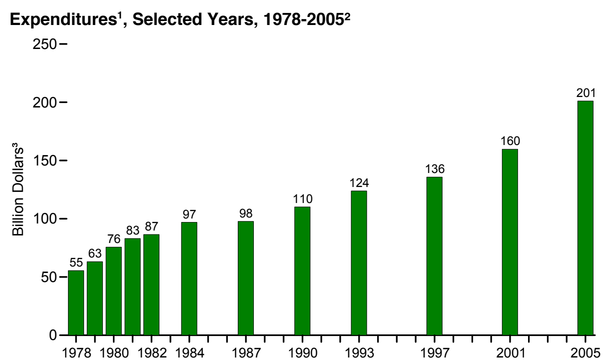

Fig.1: US energy spending from 1978 to 2005.

These data describe a bleak reality: The inefficiencies associated with building occupancy tap a rising share of global energy resources and, consequently, an increasing financial burden. While daunting, this grim picture presents an exploratory opportunity for architects and engineers. Designers much explore synergetic relationships between aesthetics, minimized environmental and financial impacts, and, above all, occupant comfort. Net-zero energy design (NetZED), or the method of designing buildings which use no more annual energy than is provided by on-site renewable energy sources, is one of many approaches to overcoming this challenge.

While the demand for NetZED is obvious, the path to its rapid implementation is not. Case studies, which assess current building energy performances, optimize these performances through deep energy retrofits, and explore the potential for architecturally integrated, on-site renewable energy production will both set precedent and increase the awareness and accessibility of NetZED. This paper contributes energyperformance data, effective retrofit proposals, and analysis of on-site renewable energy production potentials for a popular ice cream shop in Eugene, Oregon.

As with any case study assessing energy performance, an audit must first be performed, and the relevant metrics must be established prior to the energy audit performance period. Energy audit data identify high-impact zones, thus indicating where design improvements would most effectively diminish total energy demand. The primary metrics included in this study were adapted from NREL (6) and are shown in Table 1.

TABLE 1. ENERGY END-USE METRICS

Metric	Definition	Unit
Total facility energy use	Total of all energy consumed at the facility.	kWh
DHW energy use	Energy used to heat water for use other than HVAC or process loads.	kWh
Installed lighting energy use	Electrical energy consumed by hardwired lamps, ballasts, control devices, or transformers.	kWh
Process energy use	Energy consumed in a building to support a manufacturing, industrial, or commercial process other than conditioning spaces for occupants.	kWh
HVAC energy use	Energy consumed by heaters, chillers, fans, pneumatic controls.	kWh

Energy use intensity (EUI) provides a convenient way to compare energy efficiencies in buildings of all sizes; however, the metric excludes process loads. The nature of NetZED demands that the most comprehensive metrics are considered. Commercial energy consumption data in Figure 2 indicate that these process loads contribute significantly to the total energy use (7). This is especially true in the food service sector, of which this case study is a part. Considering this information, exclusive consideration of EUI is not sufficient for the achievement of NetZED, which requires minimization and offset of all energy demands.

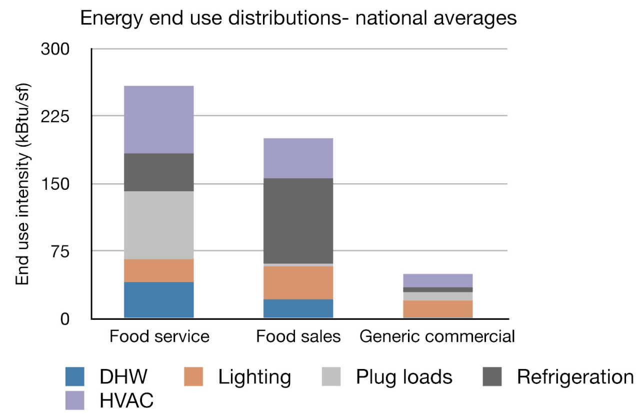

Fig. 2: Nationally averaged energy end-use data

Emphasis will therefore be placed on measurement and offset of energy associated with both regulated and non-regulated process loads.

Process loads become especially relevant in specific occupancy types, such as the food service industry, of which the case study building is a part (8). These process loads will be measured and minimized.

All unavoidable energy loads must be offset through the use of on-site renewable energy sources. This integrated design approach provides an aggressive path to achieving net-zero by designing for both the minimization of total energy consumption and the incorporation of on-site renewable energy production to offset all plug loads.

2.0 SCOPE & OBJECTIVES

This paper seeks to identify the energy end-use distribution for a small food service establishment in Eugene, Oregon. Field testing and computer simulations will be used to assess both the envelope performance and the implications of process-related energy loads on maintaining thermal comfort in the space. Results from the energy audit and the simulation will be used to identify major inefficiencies in the space and to develop multiple retrofit measures, which ultimately aim to bring the space to net-zero annual energy use.

3.0 SITE BACKGROUND INFORMATION

The 950 square-foot space is one of three adjacent retail spaces in the commercial building of interest. The space, shown in plan in Figure 3, has housed an ice cream shop since it was built in 1946.

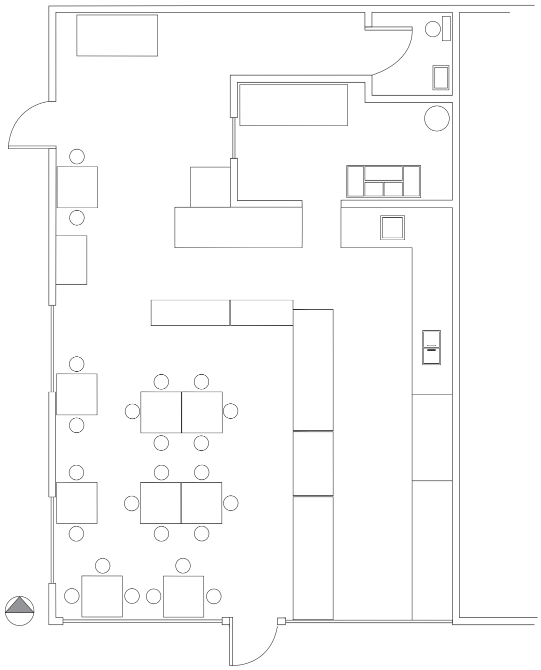

Fig. 3: The case study space shown in plan.

Business operates from noon to 11:00 PM, seven days per week, 50 weeks per year. Heat rejected from the refrigeration units provides sufficient heat in the winter, while an air conditioning system maintains occupant comfort during the cooling season. The summer is thus the period of peak energy use, as shown in Figure 4, which plots the business's monthly building energy consumption and average outdoor temperatures between 2010 and 2011 (9).

4.0 HYPOTHESIS

Energy audit data can be used to bring a small, internal-load dominated commercial building in Eugene, Oregon to net-zero through the use of on-site renewable energy sources.

5.0 ASSUMPTIONS

We assume that the obtained billing data from 2010-2011 are representative of typical month-by-month energy consumption for a given year. Similarly, we assume that the occupancy schedules, business, and outdoor weather conditions during the measurement periods are typical for July. We also assume that energy consumption in the space can be roughly divided into four general categories: domestic hot water (DHW), hardwired lighting, plug (process) loads, and HVAC.

6.0 METHODOLOGY

6.1 Billing Data

Monthly utility billing data were obtained from the occupant. The local utility provides average daily energy consumption (kWh) for the given billing period, which ranges from 30 to 34 days in length. These data were then broken down into four primary end-use categories:

$$E_{TOTAL} = E_{DHW} + E_{LIGHTING} + E_{PLUGLOADS} + E_{HVAC}$$

Data are shown in Figure 4.

6.2 DHW

The energy required to heat hot water for uses other than HVAC and process loads was obtained from the nameplate on the Ruud™ hot water heater. The plate lists a maximum and minimum annual load in kilowatt-hours . These values were averaged and divided by 365 to determine the daily energy demand associated with domestic water heating.

6.3 Hard-wired lighting

The energy consumption associated with hardwired interior and exterior illumination was calculated using estimated occupancy schedules and wattages read directly from the lamps in the space. Four lighting zones were identified in the space, and the energy associated with lamps for each of these zones was determined using the following equation.

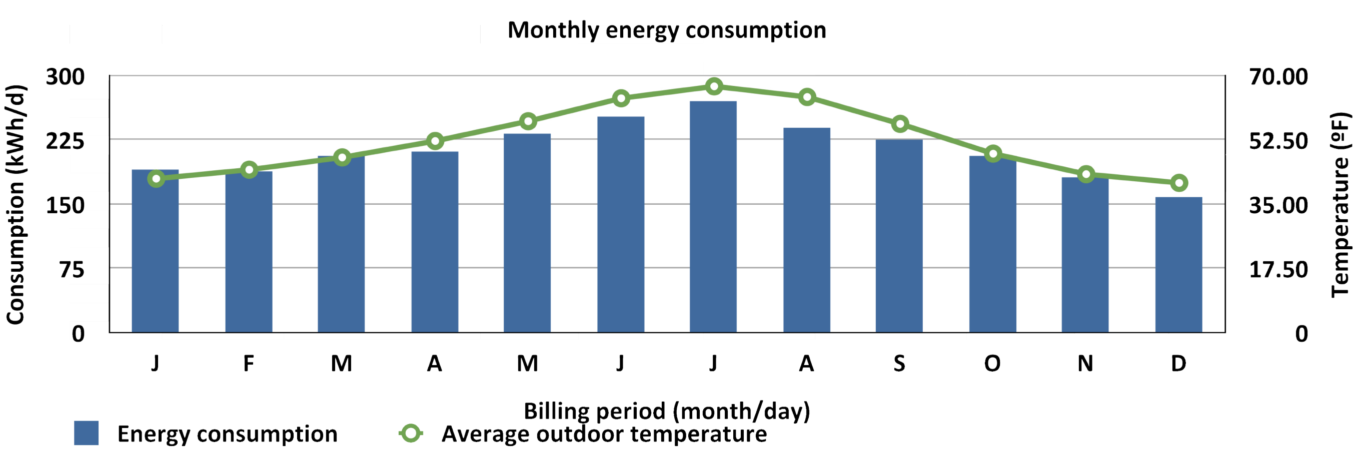

Figure 4. Billing and temperature data for the space.

$$E_{LIGHTING} = (\text{watts/lamp}) \times (\#\text{lamps}) \times (\#\text{hrs})$$

The values from each of the four lighting zones were summed to give the total lighting energy demand.

6.4 Plug loads

Every appliance that was plugged in to a standard 120-volt outlet was considered in a plug load survey. Brand, model number, and nameplate information, including watts or amps used, were obtained for each appliance. Energy usage was continuously metered on each appliance in the space. Twelve WattsUp?™ PRO meters logged energy consumption for each appliance separately. These meters have tunable logging intervals. Each logged datapoint represents a snapshot of energy consumption at the end of the given time interval (i.e. the datapoint does not represent an average of energy consumption over the interval). To see if this might make a difference in determining plug load energy consumption, two data sets were obtained: The first used a five-minute logging interval over a two-week performance period, while the second used a five-second logging interval over an eight-hour period during regular business hours. No significant differences between data sets were observed. Utility billing data from previous years indicate that peak energy demand occurs in July and August; therefore, the performance periods were held in this time. The WattsUp?™ data were used to calculate the daily energy demand associated with each appliance. These loads were summed to give the total daily plug load demand; this calculation is described in the following equation:

$$E_{PLUGLOADS} = \Sigma\, E_{APPLIANCE} = \Sigma(\text{measured energy consumed}) / (\text{length of metering period})$$

Some appliances required higher operating voltages and therefore could not be measured using the WattsUp?™ meters. The daily energy demands of these appliances were instead estimated using product specification sheets provided by the manufacturer.

6.5 HVAC

The totals of each of the process, lighting, and domestic hot water energy loads were then used to back-calculate the average daily energy consumption associated with conditioning the occupied space:

$$E_{HVAC} = E_{TOTAL} - (E_{DHW} + E_{LIGHTING} + E_{PLUGLOADS})$$

6.6 Infiltration testing

A blower door test was conducted to examine the airtightness of the envelope. These data were used to both augment the utility data and provide envelope information for the computer simulation. Infiltration rates were measured using a Retrotec™ 1000 blower door. The blower door assembly was inserted into the door on the west side of the building. All HVAC diffusers were sealed. The volumes enclosed in the interior walls were included in the total volume calculations, as these walls are mostly hollow enclosures.

The blower door fan was used to both pressurize and depressurize the space.. A series of increasing pressure differentials, as well as initial and final “zero flow” pressure values were obtained for a total of nine points per test. The “zero-flow” values represent the pressure differential across the envelope without any additional pressurization from the fan. The airflow through the fan that was required to establish a given pressure differential was measured and recorded for each point. Daylight was observed between the south door and its frame; we therefore decided to run a second set of pressurization and depressurization tests, with this opening completely sealed.

6.7 Modeling

Baseline HVAC zoning, exterior conditions, envelope construction, and occupancy were modeled using DesignBuilder. Results from this simulation as well as energy use data from the plug load survey were used to develop a list of small retrofit measures aimed toward net-zero energy. These modifications were then modeled both individually and in combination to assess the energy performance implications associated with the changes.

7.0 RESULTS

7.1 Billing data

Figure 4 shows the monthly billing data that were used to determine both the total monthly energy demand and the periods of peak energy consumption. Data indicate peak energy consumption in July, which aligns with peak outdoor temperature. This result is expected, considering the occupancy of the building.

7.2 DHW

The average daily energy load from domestic hot water heating was estimated as 14 kWh/d using annual average data listed on the nameplate.

7.3 Hardwired lighting

Table 2 shows location and several characteristics of each light fixture in the space. These data were used to determine the total lighting load.

TABLE 2: HARDWIRED LIGHTING SURVEY

Location	Main space	Store room	Bathroom	Facade
Lamp type	T8	T8	CFL	T8
Quantity	16	4	32	12
Wattage (W)	32	32	13	32
Use (hrs/d)	12	24	24	4
Consumption (kWh/d)	6.1	3.1	0.6	1.5

The total lighting load for the space was calculated as 11.3 kWh per day. This total does not consider ballast factor.

7.4 Plug loads

Energy loads of metered appliances are listed in Table 3.

TABLE 3: METERED PLUG LOADS

Appliance	Consumption (kWh/d)
Ice cream freezer	24.4
Display freezer	15.6
Hot fudge heater	4.5
Storage refrigerator	3.0
Espresso maker	2.8
Storage refrigerator	2.0
Mini-refrigerator	0.7
Credit card machine, phone, mp3	0.4
Cash register	0.2
Milkshake maker	0.2
Total	**54.4**

Those appliances whose daily consumptions could not be metered are listed in Table 4. The estimated daily energy consumptions associated with each appliance are also listed.

TABLE 4. ESTIMATED PLUG LOADS

Appliance	Frozen storage	Frozen storage	Ice maker	**Total (kWh/d)**
Voltage (V)	220	120	-	
Current (A)	10	16	-	
Use (hrs/d)	12	12	40 lbs/d	
Consumption (kWh/d)	26.4	23.0	3.3	**52.7**
Notes	50% run time	50% run time	8.2 kWh/ 100 lbs	

The grand total for peak energy consumption associated with plug loads is 107.3 kWh per day.

7.5 HVAC

The HVAC energy load was calculated as follows.

$$E_{HVAC} = E_{TOTAL} - (E_{DHW} + E_{LIGHTING} + E_{PLUGLOADS})$$

$$E_{HVAC} = 270\ kWh - (14\ kWh + 11.4\ kWh + 106.7\ kWh)$$

$$E_{HVAC} = 137.9\ kWh/d$$

7.6 Infiltration testing

The measured volume of the space was 8750 ft^3. A blower door was inserted into the west door and was used to both pressurize and depressurize the space. Data from these tests were used to calculate the ACH_{50}. The resulting infiltration rate was 5.8 ACH at 50 pascals. The test was repeated with the leaky south door completely sealed. This resulted in a 25% decrease in the infiltration rate. These results were used in later computer simulations of energy use in the space.

8.0 ANALYSIS

The first column in Figure 5 shows the energy end-use distribution for the case study space. HVAC and process refrigeration loads present the most significant energy demands.

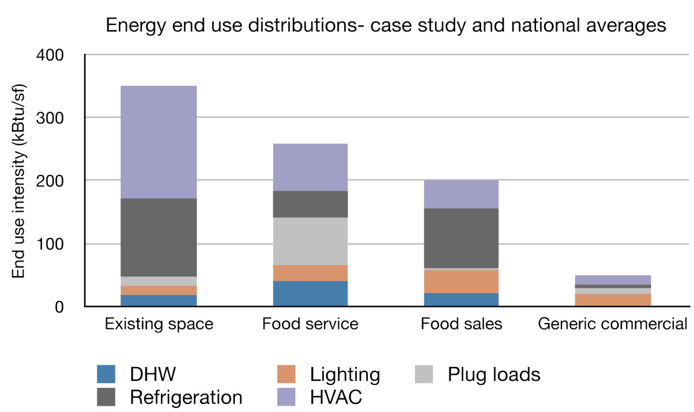

Fig. 5: A comparison between nationally averaged energy end-use data and the energy profile obtained from this case study.

These relative values can be compared to middle and right column, which show end-use distributions for food service and food sales, respectively (9).

HVAC and refrigeration collectively account for considerably more energy consumption in the case study than in the national average data. This is not surprising, considering the high energy intensity associated with refrigeration equipment. Process plug loads include cooking, computers, and other electrical equipment. While still technically “plug loads”, we define “refrigeration loads” as those loads dedicated to cold storage, which includes both freezers and refrigerators.

Such energy-intensive refrigeration equipment also contributes heavily to internal heat gain, and therefore indirectly raises the cooling energy demand. This is observed year-round. The amount of heat gain attributed to refrigeration units was simulated for the months of April through September, along with other factors influencing thermal balance in the space. These simulations were performed by DesignBuilder and EnergyPlus energy modeling software. The results of these simulations are shown in Table 5.

TABLE 5. SIMULATED THERMAL CONDITIONS

Period	Solar radiation (kWh/ft^2d)	AC energy (kWh)
January-February	0.208	198
February-March	0.306	291
March-April	0.394	374
April-May	0.454	431
May-June	0.502	477
June-July	0.548	521
July-August	0.583	554
August-September	0.548	521
September-October	0.445	423
October-November	0.276	262
November-December	0.166	158
December-January	0.165	157
	Total	**4367**

Solar potential data from PV Watts indicate that about 40% more energy is generated than is needed on an annual basis.

In Figure 6, data in the right-hand column of Table 9 are super-imposed on the billing and temperature data graph previously shown in Figure 4.

As shown, energy consumption is offset for every billing period except for the early winter months. This net-positive summer months more than accommodate these slight shortcomings of the winter months.

8.2 Redesign

A retrofit should do more than cover a rooftop with a PV array. Results from the energy audit are used to determine appropriate redesign measures, which aim to minimize total energy load in the space prior to sizing and specification of PV panels. Ideally, these retrofit strategies will reduce the size of the array required for the net-zero energy offset.

The energy audit results indicate high HVAC cooling load due to the internal gains from the exhaust heat of the refrigeration equipment.

Five relatively small modifications to the existing space are proposed in Table 7; these modifications seek to minimize the HVAC cooling load in the space.

These are proposed in no order of priority but can be seen as either incremental changes or in combination with each other. The associated energy consumption implications of such design decisions are tabulated as well. Energy savings, expressed as a percentage, represent the percent change from the simulated existing HVAC cooling load.

TABLE 7. IMPACTS OF REDESIGN MEASURES

Modification	Energy savings (%)	DB T_{max} (ºF)	RH at T_{max} (%)	Cfm/ft^2
Remove west windows	0.14	82.83	44.50	1.23
Install mini-split with separate mechanical ventilation	-20.8	82.70	41.92	1.55
100% natural ventilation	100	94.30	27.41	
Naturally ventilated at 70ºF; Cooling setpoint = 86ºF	15.7	88.12	35.07	0.80
Naturally ventilated at 70ºF; Cooling setpoint = 86ºF; Additional operable glazing on the north side	14.0	88.36	35.02	0.81

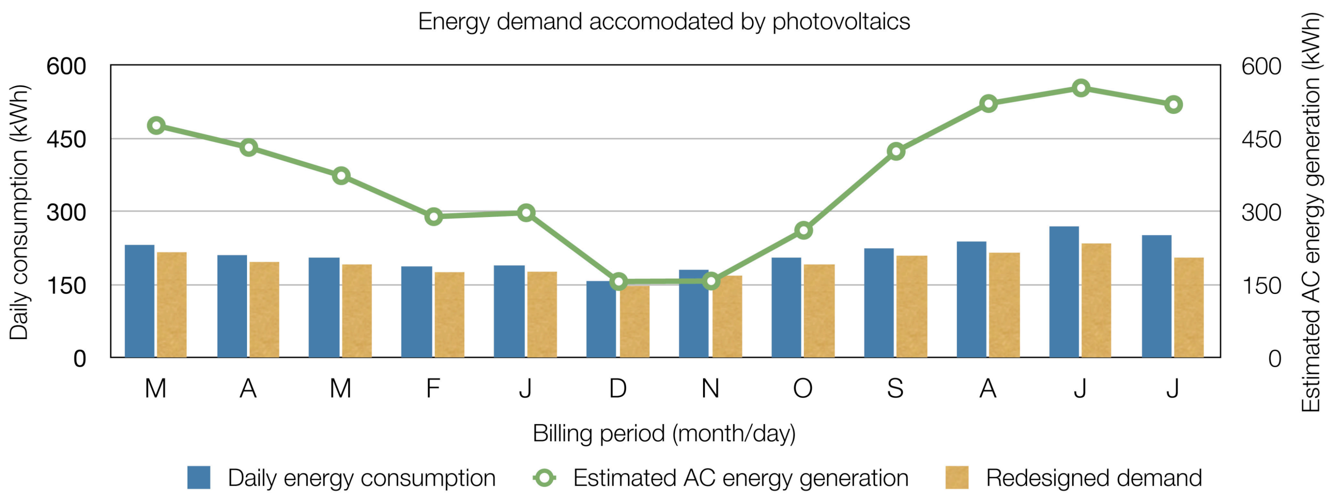

Fig. 6: Energy demand accommodated by rooftop PVs.

The first modification aims to minimize thermal gain through the west glazing, though simulation data for the existing space predict that this will be a low-impact decision. The next three simulations propose various modifications to the mechanical system. The final simulation modifies both the mechanical system and the north wall: Operable windows were added to take advantage of the north prevailing wind in the summer and to increase overall airflow in the space.The ultimate goal for simulations three through five was to increase airflow in the space. Previous studies indicate that occupants can tolerate elevated temperatures when higher airflow rates are introduced (11). This realignment of the comfort zone is shown graphically in Figure 7, which plots thermal conditions on the psychrometric chart (11) for both the existing and redesigned spaces. The redesign does not bring these conditions out of the comfort zone.

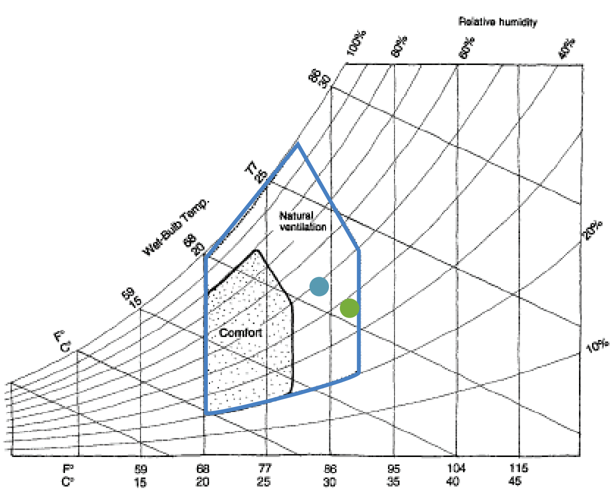

Fig. 7: Thermal conditions for both the existing (blue) and redesigned (green) space.

Simulation data of proposed redesigns indicate that raising the cooling setpoint and maintaining thermal comfort by increasing airflow is a relatively simple way to reduce HVAC loading in the space. As shown in the table, adding north glazing had no effect on the cooling load. This result is surprising, as this should increase cross-ventilation.

9.0 CONCLUSIONS

The 15.7% energy savings from the HVAC cooling load of the existing space corresponds to a 7.1% overall energy savings. These data are compared to energy end-use distributions of the existing space and of national averages in Figure 8.

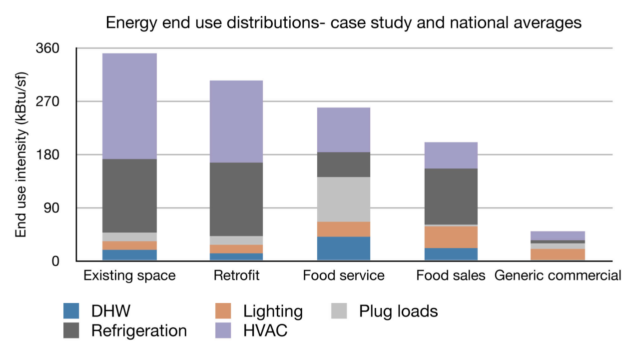

Fig. 8: Comparison of energy end-use data for the existing case study space, the retrofit, and national averages.

Increasing natural ventilation in the space decreases the necessary renewable energy offset. This might be done seasonally, without compromising comfort. Depending on the relative costs of the redesign and photovoltaic arrays, this integrated design approach may be a more cost-effective path to net-zero energy use.

Dozens of other redesign strategies can be employed. The authors would like to more thoroughly explore comprehensive retrofit measures, which bring both plug loads and HVAC cooling to a true minimum through modification and upgrade of mechanical systems, appliances, envelope, and spatial organization.

10.0 ACKNOWLEDGEMENTS

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