Does Zero Energy Pay Back in Hot Humid Climates?

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ABSTRACT

An energy simulation and net present value study of six commercial buildings is described in this paper. The buildings were designed by Kirksey Architecture for green certification in the Texas Gulf Coast. The objective was to assess net-zero energy potential for these buildings, and determine whether net-zero makes sense from a financial standpoint. The financial value of significant energy efficiency upgrades required to bring the buildings to zero energy was also assessed. Simulation results suggest that net-zero has positive returns when looked at over the lifetime of the building, which was assumed to be 25 years. The significant energy efficiency measures alone have positive returns at between 10-13 years.

Keywords: net-zero energy, hot and humid, commercial buildings

1 METHODOLOGY

An energy simulation study was undertaken, using actual buildings as baseline. These buildings were designed to achieve LEED certification in the Texas Gulf Coast. The software used for simulation was eQuest version 3.0[1]. The study included a range of building types and sizes. For each building, the cost and payback of strategies required to bring the buildings to zero energy was determined. Net Present Value (NPV) calculations were then used to judge the value of the financial investment required to make the buildings zero energy. NPV analysis was done to determine what an investment in net-zero energy buildings is worth in today's dollars over 10 years and 25 years[2]. Ten years is an arbitrary period over which many investors would want to recover a profit, and 25 years was used as the presumptive life of these buildings.

To achieve zero energy, a series of energy savings strategies was first applied to each building with the aim of reducing building energy use to the lowest level achievable with readily available technologies. In general, the strategies employed reduced building energy use 30-60% over the buildings previous performance modeled per Appendix G of ASHRAE90.1 2004. In the next step, grid-tied on-site solar energy was added to generate 100% of the building energy.

The energy saving strategies studied included only those which are commercially available, occasionally if not commonly used in the Texas Gulf Coast region, and which have proven performance in this climate.

Cost information for energy savings strategies and renewable energy was acquired from local contractors. Costs figures assume the net-zero strategies are added to the building as a part of the original design and construction, not for retrofitting an existing building.

2 EQUATIONS

NPV analysis compares the value of money now with the value of money in the future: a dollar today is worth more, because inflation reduces the buying power of future money, while money available today can be invested[3]. In general, a positive NPV is a profitable investment, and a negative NPV is a losing investment.

The net present value (NPV) over a period of time is calculated using a series of cash flows, both incoming and outgoing. In this calculation, each cash inflow and outflow is discounted[4] back to its present value (PV). Then they are summed. NPV is the sum of all terms

$$\frac{R_t}{(1+i)^t} \tag{1}$$

where

t - the time of the cash flow
i – the discount rate

[1] eQuest. Vers. 3.64. 53MB. 25 August, 2010, US Department of Energy, James J. Hirsch and Associates, <http://doe2.com/equest/>

[2] Note that these calculations included federal tax incentives only. For energy efficiency measures, the Energy Policy Act of 2005 provides a tax deduction of $1.80 per square foot if energy efficiency measures achieve 50% savings over ASHRAE 90.1-2001. For renewable energy, the American Recovery and Reinvestment Act of 2009 allows a 30% tax credit.

[3] Note that all costs considered are increases over the base case, which was the original design of the building before ZEB strategies were added.

[4] A discount rate of 5%, and an inflation rate of 2% were used to be conservative.

R_t - the net cash flow (the amount of cash, inflow minus outflow) at time t.

3 BUILDING TYPES

The six buildings studied were a mid-rise office building, a low-rise office building, a residence hall, a warehouse, an elementary school, and a park pavilion.

Building Type	Area (SF)	WWAR	EUI as Originally Designed	EUI of ZEB Design
Mid-Rise Office	253,000	43%	39.9	17.0
Low-Rise Office	33,000	32%	42.1	28.0
Res. Hall	126,000	19%	45.3	28.6
Elementary School	87,000	18%	36.9	24.8
Warehouse	60,000	20%	22.5	16.5
Park Pavilion	3,000	70%	38.7	21.0

Table 1: Buildings Used in Zero-Energy Simulation Study

3.1 Mid-Rise Speculative Office Building

The ten-story LEED building used as the baseline for this study was a speculative office building utilizing a 25,000 square foot rectangular floorplate with a central core very typical for buildings of this type in the Texas Gulf Coast. This building configuration is not well suited to passive energy saving strategies including effective daylighting and natural ventilation. The floorplate has a depth of 43 feet from the windows to the core. The central core and 110 foot depth of the building prevent effective cross ventilation regardless of the season; therefore natural ventilation was not considered.

The simulation shows that an active chilled beam HVAC system including a single dedicated outdoor air handling unit with energy recovery was one of the most effective strategies for energy savings. In this system, the dedicated outdoor air handling unit conditions outside air separately from return air, effectively separating temperature and humidity control. Conditioned outdoor air is delivered via ductwork to the chilled beam, which induces room air across the chilled coils; the space undergoes convective and radiative cooling simultaneously. Chilled beams save energy by minimizing fan use. With this system, controlling humidity is absolutely critical to avoid condensation. Therefore the building must be completely airtight. Because of this, chilled beams are incompatible with natural ventilation in humid climates.

Another effective strategy on this building is triple glazed windows. Traditionally, triple glazed windows are most effective in cold climates where there is a large temperature differential between outside and inside air. In a warm humid climate the temperature differential is small, therefore the potential energy savings from choosing triple-pane glazing over double-pane usually don’t justify the investment. Office buildings like this one are an exception, as they often have higher window to wall ratios; this building has a 43% window to wall area ratio.

A geothermal[5], or ground source, heat pump was also simulated for this building. This is a central heating and cooling system that pumps heat to or from the ground, using the earth as a heat sink in the summer or a heat source in the winter. In this building, the use of the geothermal system resulted in near zero use of heating energy in the winter months. Geothermal is often classified with renewable energy sources[6] and like these, it is a relatively expensive technology with long paybacks when considered in isolation from other strategies.

3.2 Low-Rise Owner Occupied Office Building

The baseline building was a two story building with a rectangular floor plate, 80’ x 205’, oriented with the long sides facing north south.

Windows on the north and south facades, along with shading devices, allow the spaces to be substantially daylit. Using triple glazing for these windows yielded a 4.7% overall energy savings for the building. Daylight accessibility is increased further by open plan workstations which make up a large portion of the floor area. Adding daylight harvesting controls yielded a 7% savings over the original design of the building.

Because of the narrow and relatively open floor plan, cross ventilation is possible and saved 5.7% of overall building energy in the simulation.

For the applicable buildings in this study, seasonal natural ventilation was studied, and it was assumed that windows would be open whenever outside conditions were in the comfort range. The comfort range we used was a compromise between ASHRAE 55-2005 PMV (Predicted

[5] Note that for all the geothermal heat pumps in this study, cost information was for vertical loops, 250’ in depth, 20’ spacing, 6” in diameter.
[6] We did not include it as a renewable energy source in this study.

Mean Vote), in which 7% of hours are in the comfort zone in Houston, and the ASHRAE 55-2004 Adaptive Comfort Model[7], in which 29% of hours are in an expanded comfort range for buildings with natural ventilation. The Adaptive Comfort range includes temperatures between 65.2°F to 84.3°F, and assumes that people will wear clothing suitable for the season (i.e. clo values are climate adaptive). To be conservative, in this study a compromise was reached between the two standards by assuming that 16% of hours are in the comfort range.

3.3 Residence Hall

The baseline building is a four story, 384 bed residence-hall with two students per bedroom.

Residence Halls follow a residential occupancy schedule; they are mostly occupied at night. They are often sparsely occupied during the hottest part of the day, and thus heating loads are more important than for other building types in this study. As residential buildings without significant equipment and lighting heat loads, residence halls are dominated by envelope loads. Given this, triple glazing yielded an overall energy savings of 3.1%.

The HVAC system originally designed for the baseline building was a central chilled and hot water plant serving individual room fan-coil units. Air to air heat recovery by enthalpy wheels was added to this design which yielded 12.6% additional overall energy savings.

Hot water use is significant in residential uses, and this study study found respectable energy savings through the use of a 6500 gallon solar water heating system.

3.4 Warehouse

The baseline building was a conditioned warehouse of 60,000 sf, consisting of eight 7500 square foot structural modules, one of which contains office space. The warehouse has a very low occupancy, and minimal window area. The original design of this building was already quite efficient; because of this and the near zero occupancy of the building, the ability to achieve significantly greater energy efficiency toward the goal of net-zero energy was limited.

To enable daylighting of the structure, double-domed diffused skylights were added for 2.5% of the roof area, along with stepped daylight controls. This strategy results in 14% energy savings over the original design, with savings from lighting energy and reduced cooling loads.

Water source heat pumps were simulated to condition the space. These are small, high efficiency self-contained units, each of which serves a single module of the building. Water source heat pumps units save energy by using water for heat-exchange, which is more efficient than using air. For the water source heat pumps used in these calculations, heat was added and rejected from the loop using a boiler and cooling tower. A ground source or surface water source would double the efficiency of these units, though it would result in a much larger first cost.

3.5 Elementary School

The baseline building was a two story 87,000 sf building with an L-shaped floor plate.

Thermal displacement ventilation was simulated, in which cool air is supplied at a low level and rises due to natural buoyancy as it heats up. Room air is stratified with the hottest air near the ceiling, and cool air near the floor where the occupants are. This strategy can be achieved with underfloor air distribution, or with low level supply grilles located in walls or against columns as permitted by the floor plan[8]. Displacement ventilation works well in buildings occupied by a single owner, where wall locations aren't likely to change often. Air delivered at a low level can be a higher temperature, since it isn't being blown down from the ceiling; therefore, energy is saved. Since the air is stratified and not mixed, polluted air is quickly exhausted and indoor air quality is improved.

The use of displacement ventilation requires specialized knowledge to analyze and avoid potential problems related to thermal decay, leakage, and thermal comfort. It should be noted that DOE2 commercial energy simulation softwares, like eQuest, do not fully support displacement ventilation system calculations[9].

3.6 Park Pavilion

The baseline building consists of a small enclosed area of 3120 sf shaded by a very large overhanging green roof. Interior spaces include a conference room with kitchen and restroom facilities. This building is unique in this study as it is the only structure originally designed to be zero energy. This very small building is occupied only intermittently, so its energy loads are modest in general.

The building envelope was designed to be as efficient as possible, with a large roof overhang to protect the window

[7] ASHRAE 55 models were accessed through Climate Consultant 5.0, Build 3, 32MB, 19 October, 2010, University of California, Los Angeles, <http://www.energy-design-tools.aud.ucla.edu/>

[8] Low-level supply grilles were used for the cost figures in this study.

[9] Energy simulations should be run along with air-flow simulations to increase accuracy of the modeled system.

glazing from heating loads, structural insulated panels used for the walls, and an insulating green roof. Six skylights in the conference space are designed to provide all daytime lighting.

The conference space was also designed to be naturally ventilated, with operable windows on three sides of the building to allow cross ventilation seasonally. For the minimal conditioning needs of the building, an efficient SEER 14 air cooled heat pump provides a cost effective solution.

In our observation, small buildings like this are the most likely to seek net-zero energy status, though this study indicates that net-zero energy does not have a positive NPV until 29.1 years. This is likely due to smaller upfront costs as compared to larger buildings.

4 RESULTS

Since renewable energy strategies often have long payback periods, a decision was made to study the profitability of the energy efficiency improvements alone in addition to studying net-zero, which includes the added renewable energy. The simulation results suggest that significant energy efficiency measures alone are a positive investment at between 10-13 years, and for five out of the six buildings, net-zero is a good investment when looked at over 25 years.

Energy Efficiency Improvements Only	NPV at 10 Years	NPV at 25 Years	First Profitable Year
Mid-Rise Office	-$189,539	$1,528,855	11.4
Low-Rise Office	-$10,043	$91,647	11.2
Residence Hall	-$6,892	$507,704	10.2
Elementary School	-$6,638	$146,000	10.6
Warehouse	-$33,100	$110,121	12.9
Park Pavilion	$1,550	$15,463	8.8
Net-Zero Energy (Solar **Plus** Energy Efficiency)	NPV at 10 Years	NPV at 25 Years	First Profitable Year
Mid-Rise Office	-$1,045,122	$1,956,188	14.5
Low-Rise Office	-$332,987	$40,778	23.0
Residence Hall	-$1,097,292	$511,061	19.5
Elementary School	-$754,731	$25,730	24.3
Warehouse	-$342,170	$58,312	22.4
Park Pavilion	-$35,202	-$4,774	29.1

Table 2: Net Present Value of Energy Efficiency Only and Net-Zero Energy Building Investment.

5 CONCLUSION

The results of this study indicate that owners willing to tolerate a 10-13 year payback should design buildings to be “net-zero ready” today. In coming years, as renewables become more efficient and affordable, these buildings can be converted to zero energy. An investment in zero energy today will take between 15-30 years to start generating positive cash flow.

Federal, state and local governments can have a great impact on the speed at which net-zero energy buildings will be adopted in the marketplace, since incentives can significantly reduce the payback period for these investments. For example, if the Federal commercial building tax deduction ($1.80 per square foot per the Energy Policy Act of 2005) for highly efficient buildings was changed into a tax credit, all of the buildings in this study would have a less than 10 year payback for extreme energy efficiency measures.

REFERENCES

[1] ANSI/ASHRAE/IESNA, "Standard 90.1-2001, Energy Standard for Buildings Except Low-Rise Residnetial Buildings," ASHRAE Standard, 2001.

[2] US Congress, "American Recovery and Reinvestment Act of 2009," Public Act, Sept 30, 2009.

[3] ANSI/ASHRAE/IESNA, "Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residnetial Buildings," ASHRAE Standard, 2004.

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