Toward Zero Net Energy (ZNE) Super High-Rise Commercial Buildings

CABA

Continental Automated Buildings Association

CABA White Paper

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The Continental Automated Buildings Association (CABA) (**www.caba.org**) is an international not-for-profit industry association dedicated to the advancement of intelligent home and intelligent building technologies. CABA's mandate includes providing its members with networking and market research opportunities.

CABA also encourages the development of industry standards and protocols, and leads cross-industry initiatives. The organization is supported by an international membership of nearly 300 companies involved in the design, manufacture, installation and retailing of products relating to home automation and building automation. Public organizations, including utilities and government are also members.

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Section 1

Executive Summary

The Energy Independence and Security Act passed by the U.S. Congress in 2007 (EISA 2007) set ambitious energy goals:

- Zero net energy (ZNE) for all new commercial buildings by 2030;
- Zero-energy target for 50% of U.S. commercial buildings by 2040;
- Net zero for all U.S. commercial buildings by 2050.

Can these goals be achieved, in particular, for super high-rise commercial buildings above 50 stories in height? This white paper first reviews the driving force from the U.S. government, both federal and state. Then, different definitions of ZNE are discussed. State-of-the-art technologies that could possibly help buildings fulfill a target of EUI=21 kBtu/sf/yr or 239 MJ/m^2/yr or less to become ultra low energy buildings are briefly introduced. A simple estimation shows that this goal for a super high-rise office tower is impossible by relying on on-site renewable energy generation. This paper presents a concept for a feasible net-zero solution applied to a building cluster consisting of an office building and the homes of the managers at the companies located in the building. In this way, an ultra low energy super high-rise building could be integrated as a component of the ZNE community or cluster consisting of the office building plus the houses and apartments of the managers who work for the companies in the building. (This proposal is limited to managers since it may be too complicated to involve all building occupants in such a program.)

The lead author of this paper, Albert So, was inspired to explore this topic by the February 2010 presentation on "Zero Net Energy Buildings" of Dr. Dru Crawley at the ASHRAE Hong Kong Chapter. This paper is dedicated as a compliment to Dr. Crawley. Some use the term NZEB (Net Zero Energy Building), but in this article we consistently use the term "ZNEB," which has the same meaning but was defined in EISA 2007.

Section 2

The Pressing Demand

Limitation in energy resources became apparent in 1973 with the first global oil crisis. In October 1973 members of the Organization of Arab Petroleum Exporting Countries publicly announced an oil embargo. By the end of the embargo in March 1974, the price of crude oil had increased from US$3 per barrel to $12. Although that was mainly a political issue, people around the world were alarmed by the consequences of an oil shortage. In 1979, a second oil crisis occurred in the United States because oil production was reduced during the Iranian Revolution. Though the supply was not that inadequate, the price of crude oil had increased to $39.50 per barrel over a period of one year. Building automation suppliers worldwide expanded their products from simple sensing with thermostats to more complex energy management systems (EMSs).

In the early 1990s another global phenomenon shocked us in addition to the inadequacy of oil supply. Scientists discovered a substantial increase in "Global Warming," which refers to the continuing rise in the average temperature of the Earth. Since the beginning of the 20th century, the average temperature of the Earth surface has increased by about 1.4 °F (0.8 °C) with about 1.0 °F (0.6 °C) of such warming occurring over the past three decades (NRC 2011). Natural factors, like orbital variations, solar output, volcanism, plate tectonics, etc., may influence global temperature variations. However, human activities are prime culprits of "Climate Change" and the foreseeable disasters that may ensue. We therefore learned that even if there is an adequate supply of crude oil, mankind still needs to conserve energy that is produced by either fossil fuel or other greenhouse gas (GHG)-emissive ways because GHGs are considered a key contributor to global warming.

At the same time, terms like "environmentally friendly activities," "green technologies," and "sustainability" have been discussed on a daily basis because the rapid growth of our economy over the past half-decade has exhausted resources, not just energy. One popular definition of "sustainable development" by the Brundtland Commission's 1987 report of the World Commission on Environment and Development of the United Nations is "the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs." As a result, the need for "Zero Net Energy Buildings" is an imperative.

According to Section 422 of EISA 2007, "Zero Net Energy Commercial Buildings Initiative," High Performance Green Building Partnership Consortia were to be established by the Commercial Director. Also, the term "Zero Net Energy (ZNE)

Commercial Building" is defined to be a high-performance commercial building that is designed, constructed, and operated:

a) to require a greatly reduced quantity of energy to operate;

b) to meet the balance of energy needs from sources of energy that do not produce GHGs;

c) in a manner that will result in no net emissions of GHGs; and

d) to be economically viable in all climate zones of the nation: marine, hot-dry, hot-humid, mixed-dry, mixed-humid, cold, very cold, subarctic.

The goal of EISA is the realization of ZNE for:

a) any commercial building newly constructed in the U.S. by 2030;

b) 50% of the commercial building stock of the U.S. by 2040; and

c) all commercial buildings in the U.S. by 2050.

Various states actively supported EISA and followed with legislation. According to the New Buildings Institute (NBI 2014), California requires all new residential construction to be ZNE by 2020. All new California commercial buildings must achieve this ZNE goal by 2030; 50% of the square footage of existing state-owned buildings must be ZNE by 2025 (Title 24, the energy efficiency portion of the building codes of California). Washington State requires a 70% reduction in energy consumption by 2031 relative to the 2006 Washington State Energy Code (2012 Washington State Energy Code). The U.S. Department of Energy also established a goal of creating the technology and knowledge base for cost-effective net-zero energy commercial buildings by 2025. In the European Union, a March 2009 resolution required that by 2019 all newly constructed buildings produce as much energy as they consume on-site.

In Canada, similar efforts to reduce energy in office buildings are underway. An Ontario Feed in Tariff (FIT) similar to the one in Germany has provided the stimulus for a large increase in renewable energy projects including many with solar (photovoltaic, PV) rooftop installations. These PV projects were initially paid more than 80 Canadian cents / kWh for grid-connected projects under 10 kW and now, as PV costs drop rapidly, the MicroFIT rates are much lower at 39.6 Canadian cents / kWh for the roof top solar. Also, larger FIT projects now receive lower rates and the FIT program is limited to less than 500 kW for 20-year fixed-rate contracts. In order to receive the FIT payments and the energy efficiency incentive, the recipient must hand over any environmental credit to the Ontario Power Authority. The Authority is using the revenues of all electricity customers to fund these programs and intends to trade or to retire these credits as part of their overall GHG reduction commitments.

In the Canadian office building sector, the Real Property Association of Canada (REALpac) has set a significantly low energy target of 20 ekWh/sf (68.2 ekBtu /sf) by 2015. While the objective was not to meet a Zero Net Energy building target, it does make existing buildings more energy efficient while lowering energy costs and emissions. The following summary from their website describes their 20 by 15 program:

> In September 2009, REALpac, in collaboration with the Canada Green Building Council ("CaGBC") and the Building Owners and Managers Association of Canada ("BOMA Canada"), adopted an energy consumption target for office buildings of 20 equivalent kiloWatt hours of energy use per square foot of building area per year ("20 ekWh/ft^2/year"), to be achieved by 2015.

More details about the challenges and the energy benchmarking are available at: http://www.realpac.ca/?page=RPEBP1Intro

While the target is much greater than the EUI=21 kBtu/sf/yr for Zero Net potential, it is the recognition that many existing buildings cannot be Zero Net, but they can reduce their energy intensity considerably. New construction meeting LEED and Green Globes ratings promotes greater improvements in energy performance and incorporates renewables where beneficial. New buildings are pursuing GREEN and High Performance objectives while realizing the climatic conditions in Canada may make on-site Zero Net Energy office buildings of any significant size improbable without modification to the definition. Maintaining lower energy usage requires that buildings operate properly. The Continental Automated Buildings Association (CABA) developed the Building Intelligence Quotient (BiQ), which is a rating program complementary to the GREEN building and Energy Star programs. BIQ helps keep the owners and operators of building automation systems aware of building performance, thereby contributing to the Net Zero Energy objectives.

The issue of climate change and the opposing views are as strong in Canada as elsewhere. While Canada is a producer of fossil fuels for export, the electric power is mostly provincially owned and low in GHGs since it is based on hydro and nuclear sources. Carbon reporting for some government buildings is now required, and there is a Carbon Neutral Program with a registry for exchanging credits.

Canada, U.S., and Mexico have an environmental commitment under the North American Free Trade Agreement (NAFTA) to reduce environmental impacts of buildings and in other areas such as transportation and collaboration on programs like the C40 for cities to reduce energy. *Challenge and Sustainable 2030* cities include Canadian members. While not having a similar Zero Net Energy Building mandate or law as the U.S., Canada has many Chapters in the AEE, BOMA, CABA, IFMA, and other North American associations affecting the office building sector. ASHRAE, Green Globes, LEED, and other standards for High

Performance Buildings are also used in Canada with modifications to local conditions where applicable.

The Solar Net Energy Building Research Network (SNEBRN) is currently the major Canadian research effort in smart zero net energy buildings. It brings together 29 Canadian researchers from 15 universities to develop the smart zero net energy homes and commercial buildings of the future. The Network also includes researchers and experts from Natural Resources Canada (NRCan) and Hydro-Québec. Industrial partners from the energy and construction sectors are involved in most projects, developing the know-how that will help them compete in the global market. The Web site at http://www.solarbuildings.ca/index.php/en/ has a wealth of information on these activities and conferences.

We only have sixteen years to meet the U.S. federal target by making sure all new commercial buildings are ZNE. This is challenging especially since commercial buildings vary considerably in height, size, and purpose. Can the goal of EISA 2007 be achieved, in particular, for those super high-rise office buildings? This is the central theme of this white paper. The statistics of tall buildings in North America are available at www.skyscraperpage.com.

Section 3

Definitions and Characteristics of ZNEBs

There are many definitions for a ZNEB. According to the National Renewable Energy Laboratory (Torcellini *et al.*. 2006), a U.S. Department of Energy facility, there are up to four definitions.

a) Class 1: Net-Zero Site Energy: produces as much renewable energy as it uses annually within the footprint of the building, when accounted for at site.

b) Class 2: Net-Zero Source Energy: produces (or purchases) as much renewable energy as it uses annually, when accounted for at the source. Source energy refers to the primary energy used to extract, process, generate, and deliver energy to the site. An appropriate set of site-to-source conversion multipliers is applied to the calculation of imported and exported energy.

c) Class 3: Net-Zero Energy Costs: a building in which the amount the utility pays the building owner for the renewable energy the building exports to the grid is at least equal to amount the owner pays the utility for energy services and energy used annually.

d) Class 4: Net Zero Energy Emissions: produces (or purchases) enough emissions-free renewable energy to offset emissions from all energy used in the building annually. Carbon, nitrogen oxides, and sulfur oxides are common emissions that ZEBs offset.

The U.S. Department of Energy National Renewable Energy Laboratory (NREL) (Pless *et. al.* 2010) also proposed a classification grading system for options of ZNEBs based on the renewable energy sources that a building uses, from ZNEB:A to ZNEB:D, as shown below:

a) ZNEB:A buildings generate and use energy through a combination of energy efficiency and renewable energy collected within the building footprint. They certainly belong to Class 1. Qualifying as Class 3 may be difficult, depending on the multipliers used.

b) ZNEB:B buildings generate and use energy through a combination of energy efficiency, renewable energy generated within the building footprint as well as within the site. They also belong to Class 1. Qualifying as Class 3 may be difficult, depending on the multipliers used.

c) ZNEB:C buildings use renewable energy strategies as ZNEB:A and ZNEB:B buildings as far as possible but uses off-site renewable resources that are brought on-site to produce energy. They may be classified as Classes 1, 2, and 3 depending on the carbon-neutral renewables used.

d) ZNEB:D buildings use energy strategies of the three mentioned above but can purchase certified off-site renewable energy such as utility-scale wind from certified sources. They could be qualified as Classes 2 and 4, but not 1 and 3.

According to a white paper from Johnson Controls (Nesler et al.. 2009), there are various common characteristics of zero-energy buildings, including:

a) They are not large, usually one or two stories tall;

b) Efficiency comes first and every bit counts in terms of load reduction, systems efficiency, regenerative systems, and renewable systems;

c) Integrated design and operation are necessary because a successful ZNE building should be based on a joint effort of owners, designers and architects, contractors and operators;

d) On-site renewable energy, mainly in terms of solar power and wind, is a priority;

e) Grid connection is a must to achieve an annual energy balance; once an ZNE building is connected to a grid, it becomes a Demand Responsive Building (DRB) but an attractive utility pricing model must be available to promote excess power generated on-site be fed back to the grid (CABA 2012);

f) A good monitoring and verification process is necessary to validate the achievement continuously.

Feature (a) is no longer true, but at present ZNE buildings are still limited in height. Feature (d) actually poses a limit to the height of the building. In coming sections, we will examine the current status and technologies that enable ZNE buildings.

Section 4

Current Status of Commercial Buildings and the Gap

The most popular benchmarking parameter for measuring the efficiency of energy utilization of buildings is EUI (energy utilization index) expressed in either kBtu/sf/yr (IP unit) or MJ/m^2/yr (SI unit), which refers to the total energy consumption of the entire building divided by the total floor area over a year. Here, energy refers to all kinds of non-renewable energy such as electricity and gas. The latest report of NBI (NBI 2014) reveals that by the end of 2013, nationwide, there are 33 ZNE verified buildings or districts distributed across the nation at different climate zones and 127 emerging buildings or districts (i.e. projects with a target to ZNE). And there are 53 ultra-low energy buildings whose EUI is comparable to ZNE building. In other words, if renewable energy sources like PV panels are installed, it is not difficult for these ultra-low energy buildings to become ZNE buildings. NBI (NBI 2014) also reports that the EUI of a list of 24 verified ZNE, emerging and ultra-low energy office buildings lies within a range from 13 (148 MJ/m^2/yr) to 33 kBtu/sf/yr (375 MJ/m^2/yr). The average EUI of verified ZNE office buildings is 21 kBtu/sf/yr (239 MJ/m^2/yr) versus 93 kBtu/sf/yr (1056 MJ/m^2/yr), the 2003 average national EUI of all commercial buildings. This represents a huge reduction of almost 80%.

Therefore, it is obvious that load reduction is the prime means for achieving ZNE. Table 1 shows the EUI roadmap of heading towards the goal for commercial buildings.

Table 1 – EUI roadmap

EUI in kBtu/sf/yr ($MJ/m^2/yr$)	Standard adopted	Source
100 (1136)	ASHRAE 90-75 & 90A-80	NBI Selected Policies (2014)
93 (1056)	CBECS	NBI (2014)
89 (1011)	ASHRAE 90.1-1989	NBI Selected Policies (2014)
84 (954)	ASHRAE 90.1-2001	NBI Selected Policies (2014)
70.7 (803)	ASHRAE 90.1-2004	Griffith et al. (2007)
58 (659)	ASHRAE 90.1-2010	NBI Selected Policies (2014)
40.3 (458)	Max Tech energy efficient scenario	Griffith et al. (2007)
21 (239)	Verified office ZNE buildings	NBI (2014)
12.2 (139)	Max Tech energy efficiency scenario with PV	Griffith et al. (2007)

The verification process of NBI is detailed in the NBI references below from 2012 and 2014. The "Max Tech energy efficient scenario" was a theoretical maximum in the NREL simulation (Griffith 2007), which is the basic scenario for analyzing the opportunities for ZNE buildings. This scenario includes improvements in the building envelope, lighting systems, plug and process loads, HVAC, and on-site generation, with the best estimated projections for what would happen in 2025. How could the steps shown in Table 1 be achieved? State-of-the-at technologies that help to lower the EUI are discussed in the next section.

Section 5

Technologies to go Zero and Concerns

In Table 1, the "Max Tech energy efficient scenario" was proposed (Griffith et al. 2007) where it is possible for an office building to approach ZNE by adopting current technologies. Such technologies help lower the EUI of an office building significantly until it is close to 20-30 kBtu/sf/yr (227-341 MJ/m^2/yr). Such buildings are described as "zero energy comparable" or "ultra-low energy". With the introduction of renewable energy sources like solar power and wind turbines, such buildings may be turned into ZNE. Table 2 shows a list of technologies that are currently available and have been applied to existing ZNE buildings.

Table 2 – Current technologies for ZNE buildings

Type	Name of Technology	Brief Description	Remark
Passive	Thermal insulation	Insulation with higher R values are used for floor slabs (R-20+), walls (R-45+) and roofs (R-60+) (unit is sf.F.hr/Btu; + means equal to or higher than). Heat conduction through such wall can be significantly reduced.	Steel frame is insulated under the concrete footings
	Low-E glass	Such glass allows visible light to go through but highly reduces the transmission of infrared and ultraviolet radiation. U-values are preferably at or below 0.2 Btu/hr.sf.F (1.14 W/m^2K). Greatly reducing the window-to-wall ratio to 25% or lower helps.	Curtain wall design for office buildings is no longer the fashion
	Passive solar	The house is designed to collect, store and distribute much more solar energy in the form of heat in winter and reject heat in summer by considering window placement, clerestories, glazing type, thermal insulation, thermal mass and shading. Its effectiveness is very dependent on the local climate.	Less flexible for high-rise office buildings.
	Utilization of daylight, and light colored interior paint.	Introduce more daylight (the visible spectrum only) into the building by window placement, suitable building geometry and light shelves to save energy for artificial lighting. A high reflectance of interior pain can increase overall illumination with the same amount of luminous flux. Low or no partitions improve the effect.	Glare and uniform illumination are concerns.

Type	Name of Technology	Brief Description	Remark
Passive	Use of green. cool roof and walls	Covering the roof and walls with plants maintains a constant and low temperature on the surface of the façade, thus reducing the amount of heat penetrating into the building interior and eliminating the "Heat Island Effect" of cities. Evaporative cooling a given element of the building, say the roof, by a shaded roof water pond can maintain the ceiling temperature closed to the web bulb.	Green roof is applicable to high-rise office buildings but green walls and roof ponds may not be.
	Natural ventilation	When the enthalpy of outdoor air is slight lower than the desirable enthalpy of indoor air, fresh air could be introduced into the building naturally without any treatment by suitable architectural design but issues with cleanliness, enthalpy variation, air speed, acoustics and security should be considered.	Not necessarily applicable to high-rise office buildings.
	Stairways	Make stairways an attractive and highly accessible part of mobility in a building. This effect is obvious for short up- (1-3 stories) and down- (up to 1-6 stories) walks. The reliance on elevators could thus be reduced.	Attractive stairways may occupy more useful space.
Active	Demand controlled and energy recovery ventilation	The rate of ventilation is subject to occupant's demand based on schedules, occupancy and indoor density of carbon dioxide etc. so that the right amount of fresh and circulated air drawn. Thermal wheels and heat pump thermal exchangers are used to cool down or warm up fresh air based on seasons.	A desirable comfort level is a necessity.
	Dynamic blinds and windows	Dynamic blinds are automatically lowered or raised subject to the incident sunlight. Dynamic windows can change transparency to manage solar heat gain, glare and day-lighting.	To reduce cost of installation, the window-to-wall ratio must be low.
	Night purge	When the outdoor air enthalpy is very high at daytime and low at nighttime, substantial fresh air in drawn in either naturally or by forced ventilation to flush warm air out of the building and cool down the thermal mass for the next day, thus saving HVAC energy consumption.	Again, this method very much depends on the local climate and cleanliness of fresh air.
	Dedicated outside air supply (DOAS)	By DOAS, the delivery of ventilating air must be separated from the space conditioning systems for proper air distribution. If possible, the outdoor air should be conditioned to handle all indoor-latent load and part of sensible load. The remaining sensible load is to be handled by warm/chilled beam/floor.	Good for offices with low load variation and at suitable climate zones.
	Radiant heating and cooling.	This is associated DOAS. With warm/chilled beams and DOAS, up to 60% saving in energy consumption of the HVAC system is possible.	Again, this is for steady state operation.
	Ground source heat-pump	The deep ground is a geothermal heat buffer because its temperature is almost constant. Refrigerants or water in buried copper tubes can extract heat from or inject heat into the ground with heat exchangers.	The civil work may be expensive but worth.
	Air conditioning means	Variable refrigerant flow (VRF) units are a better option than conventional DX machines. Variable Air Volume (VAV) without reheating is still considered one energy efficient air conditioning means. Chillers with high COP (at least 7 or above) are still useful contemporarily but the DOAS approach may be the trend.	VRF system may not be suitable to high-rise offices.
	Ice storage	This is for preparing thermal energy storage when the electricity demand or cost is low, which can help to improve chiller efficiency and meet peak demand.	This system may mainly reduce cost, not energy.

Type	Name of Technology	Brief Description	Remark
Active	Low lighting power density (LPD)	T5 fluorescent tubes and LED lamps are to be used. In the near future, all will be LED-based, with an efficacy from the current 60 lm/W to a target of over 200 lm/W by 2020. Then, the LPD in W/m^2 or W/sf could be lowered significantly.	
	Occupancy sensors	For good housekeeping to turn on lights only when they are needed.	
	Daylight photo-sensor controls	The luminous flux of daylight is not constant due to sun movement and overcast etc. while a constant indoor illumination is required. Artificial lighting is needed to supplement daylight automatically.	Sophisticated control is needed.
	Lighting environmental controls	Functions of rooms inside an office building change from meetings to presentations to workshops etc. with different desirable illuminations. Addressable ballasts and automatic dimming are needed to provide what is needed.	
	BMS and KPI energy dashboards	Energy management is one key function of modern building management and automation systems. Dashboards showing key performance indicates of all building systems, energy consumption in particular, are important tools for the facility management professionals to operate the building.	
	Advanced plug strips	NBI (NBI 2014) discovers that plug load may account for 50% of total energy consumption of a low-energy or ZNE building. So, plug loads must be greatly reduced by advanced strips or receptacles controlled by occupancy and schedules.	This load profile is beyond the control of building codes.
	Advanced elevators	Permanent magnet synchronous machine (PMSM) drives, vectored VVVF drives, regenerative braking, parking mode and artificial intelligence based dispatching are saving energy for elevators.	
Renewable	Photovoltaic panels	PV panels are the major renewable energy sources at present. They are installed on the roof, on walls, on overhung shades and on parking lot covers. The module efficiency is usually below 20% but technology is advancing. Another efficiency, i.e. conversion of power from DC to AC for connection to the grid, needs to be considered as well, which is in the seventies to eighties at present.	
	Wind turbines	They are not practical for use on building roof in cities (wind speed in megacities is usually low) while their efficiency is high at wind farms. Some vertical axis design seems suitable for buildings but the power capacity is relatively low.	
	Biomass	The fuel is not local, thus transportation being a problem.	

Not all technologies available and described above may necessarily be applicable to super high-rise commercial and office buildings. In an office, human comfort that ensures high productivity is the key concern.

First, a uniform and constant lighting environment, 500 lux at a level 32 inches above floor level, has to be maintained. Glare, with a glare index above 16, is always unacceptable. Day-lighting of course can help to save energy consumed by artificial lighting. The problem of daylight, coupled with the avoidance of unwanted solar gain and glare, has to be resolved. Possible solutions include attention to building orientation, window-to-wall ratios, varying window size, shape on different sides of buildings, and the incorporation of highly efficient glazing and exterior shading devices to cut off peak-day sun angles. The indoor daylight factor must not be too high so that proper dimming of artificial light is able to supplement and result in a constant illumination level. Illumination control with light shelves pipes is not an easy task.

Natural ventilation, though desirable from an energy point of view, may not be applicable to office buildings due to inadequate air movement, temperature and humidity variation over the day, security problems, cleanliness of outdoor air in cities, and acoustic problems. Human thermal comfort is measured by a predicted mean vote (PMV) that combines six parameters, namely metabolic rate, cloth thermal insulation, dry bulb temperature, humidity, radiant temperature, and air speed as detailed in international standard ISO 7730. An indoor HVAC system for offices needs to address human comfort precisely, whichever methods is used because productivity is always the priority in an office.

Plug loads include workstations, laptops, mobile phones, office machines such as scanners and copies, etc., appliances inside the pantry like hot/cold water dispensers, coffee makers, microwaves, refrigerators, etc., and appliances in the bathrooms. Many of these loads are beyond the control of building codes, building designers, and facility operators. Occupants must be assisted and alerted whenever possible to lower the plug load demand. An energy dashboard readily shown on the web page for the building and accessible by all managers may be a good motivation.

By 2025, we should have high confidence that all these problems can be solved, as stated in the NREL "Max Tech energy efficient scenario."

Section 6

How High Can Commercial Buildings Go? – Limitations of Renewable Energy Sources

NREL (2007) did a comprehensive study on a large set of building models derived from the 2003 Commercial Buildings Energy Consumption Survey and found that the ZEB goal is largely achievable. Based on projects of future performance levels from currently known technologies and design practices, they found that 62% of buildings could reach net zero. In the executive summary, it was mentioned that "Achieving the ZEB goal on a given building project depends on four characteristics: (1) number of stories; (2) plug and process loads; (3) principal building activity; and (4) location. Single-story buildings are the most likely to achieve net zero energy consumption. According to 2003 CBECS, 40% of the nation's commercial buildings are single story."

In 2012, Arup carried out a series of building simulations to determine the technical feasibility of ZNE buildings in California (Arup 2012). In the report, another benchmarking parameter, Time Dependent Valuation (TDV), was adopted in addition to the common EUI but the two values accidentally are quite close to each other. They concluded that the California ZNE goal is not easily achievable. Steps to reach ZNE include load reduction, passive systems, active efficiency, energy recovery, on-site renewables, and cogeneration. Very often, the parking lots have to be utilized by installing PV panels on the roof on the lots. Their findings are shown in Table 3 below.

Table 3 – Summary of exemplar samples of Arup's study (Arup 2012)

Type of Building under simulation	Possibility of NZE
Single family residential (1 story)	Possible across all climate zones
Multi-family low-rise (3 stories)	Possible across all climate zones
Multi-family high-rise (10 stories)	Impossible unless with parking lot PV
Medium office (3 stories)	Possible across all climate zones
Large office (12 stories)	Impossible unless with parking lot PV
Strip mall (1 story)	Possible across all climate zones
High school (2 stories)	Possible across all climate zones
Large hotel (6 stories)	Impossible unless with parking lot PV and CHP
Grocery (1 story)	Possible across all climate zones
Sit down restaurant (1 story)	Impossible
Hospital (5 stories)	Impossible
Warehouse (1 story)	Possible across all climate zones

From an international point of view, an office building with 12 stories cannot be considered a super high-rise building, which should be at least 40-50 stories in height.

In 2009, Phillips (2009) assessed the ZNE possibility purely by means of PV panels.

Here are the conclusions in the article:

a) The facade is responsible for approximately 25% to 30% of sensible building loads in a hot climate in addition to occupants' load such as lighting, equipment and air-conditioning. So, reduction in internal gains, latent load, and facade insulation should be done at the same time.

b) The height of a building that can achieve ZNE is two or three stories.

c) The climate of Abu Dhabi is hot and humid while regions of Middle East, Asia and North America could be similar.

d) The reality of the analysis highlights that solar energy harvesting alone does not permit tall ZNEBs.

Here, a simple estimation is conducted for three cities: Seattle WA, San Jose CA, and Las Vegas NV. We base our calculation on officer towers of 50 stories each erected in these three cities with a gross floor area of 7000 sf (650 m^2) per story (100 ft E-W x 70 ft S-N). Suppose the EUI per story of these exemplar ultra-low energy buildings is 21 kBtu/sf/yr (239 MJ/m^2/yr) by the year 2025 with a variety of technologies to reduce consumption. The street level is not considered a story, and the roof is at the 51st story while all refuge and mechanical stories are not counted. On the roof, a fixed PV panel of array size 5,376 sf (500 m^2) is erected with an optimal tilt angle (location by location) to the horizontal and faces south, i.e. 180^o. We are going to estimate the "solar budget" of this PV panel at all three cities. Although these three cities do not represent all North American cities, they show that PV panels on the roof of a super high-rise commercial building cannot make the building ZNE.

The "solar budget" is the renewable annual solar opportunity on-site, varying from city to city. It can be calculated by using the PVWatts Calculator of NREL. The efficiency of common modules is 16% and the capacity of the PV system is 80 kW under this size. The DC-to-AC derate factor is 0.77. It should be noted that although the solar budget is still expressed in kBtu/sf/yr or MJ/m^2/yr, the meaning is different. The area refers to the exact physical size of the PV array, not the floor area of the building. Table 4 shows the results.

Table 4 – Solar budget of exemplar building at 3 cities

City	Tilt Angle	Solar budget in kBtu/sf/yr (MJ/m^2/yr)
Seattle, WA	34°	49 (560)
San Jose, CA	31°	73 (827)
Las Vegas, NV	34°	81 (920)

Since the gross floor area of our exemplar office building is 7,000 sf per story with an EUI of 21 kBty/sf/yr, the total consumption of every story is 147 MBtu/story/yr. The PV array can produce 49 kBtu/sf/yr x 5376 sf = 263 MBtu/yr in Seattle, 73 x 5376 = 393 MBtu/yr in San Jose and 81 x 5376 = 436 MBtu/yr in Las Vegas. A simple division shows us that the solar renewable energy can only turn a building of 2 stories to ZNE in Seattle, 3 stories in San Jose, and 3 stories in Las Vegas.

Some have proposed that PV panels can be installed on the vertical façade of the office building or on the covers of parking lots. Suppose the four vertical walls of the building in San Jose were covered with PV panels. The respective generation per sf per year is shown in Table 5.

Table 5 – Generation of PV panels on 4 vertical walls of exemplar building at San Jose

Facing Direction	KBtu/sf/yr	MJ/m^2/yr
South	42	486
East	34	381
West	36	407
North	11	128
Total	**123**	**1402**

If the slab-to-slab height of every story were 13 ft (4 m), the overall PV generation on each wall for every story would be as shown in Table 6.

Table 6 – Generation of PV panels on 4 vertical walls for every story at San Jose in IP unit

Facing Direction	W (ft), H (ft), Area (sf)	Unit Generation (kBtu/sf/yr)	Total Generation (Mbtu/story/yr)
South	100, 13, 1300	42	55
East	70, 13, 910	34	31
West	70, 13, 910	36	33
North	100, 13, 1300	11	14
Total			**133**

Table 6 shows that even under an ideal situation, after the roof PV panels supply the first few stories in San Jose, the vertical PV panels can only produce 133 MBtu/story/yr at most while the demand is 147 MBtu/story/yr. The goal of a ZNE building is still marginally not accomplishable. However, this ideal situation, practically, is not feasible at all. The reason why super high-rise office buildings have to be constructed is that in commercial business districts (CBD), land is often so limited and expensive that super high-rise office buildings have to saturate the downtown. All these buildings are technically sun shades for the surrounding buildings, and therefore PV panels on the vertical facades cannot really receive adequate sunlight. Also, the fact that PV panels on vertical facades block all external views of the occupants is totally unacceptable. Finally, since land is limited, where is the parking lot? That has to be built underground or occupies the first few stories of a super high-rise office building, implying that the erection of PV panels covering the parking lot is also not feasible.

Section 7

The Suggested Solution

Let's re-examine the definitions of ZNEBs. An ZNEB:C uses renewable energy sources as described in ZNEB:A and ZNEB:B, but also uses renewable energy sources available off-site to be transported to generate energy on-site. An ZNEB:D uses renewable energy sources as described in ZNEB:A, ZNEB:B and ZNEB:C, but also purchases certified recently added off-site renewable energy sources. Such definitions have inspired us to propose a solution to realize the goal of ZNE super high-rise commercial buildings.

It is apparent from the literature and the simple estimations in the previous section of this article that a super high-rise building always consumes much more energy than it can generate on-site. This is due to the limited roof area for installing photovoltaic panels and wind turbines, but an ZNEB:C or ZNEB:D is allowed to get help from off-site renewable energy sources.

Office buildings provide a work environment for the managers who run the businesses on behalf of their companies. These managers, of course, live in their own residential houses or apartments and travel to work in these office buildings. We propose to consider such an ultra low-energy super high-rise office building (ULEB) as a component of a ZNE community or cluster consisting of the office building plus all the houses and apartments of these managers. Most houses and apartments in North America and Europe are low-rise, at most three stories high. It is much easier to develop residential NNEBs (Negative Net Energy Buildings – those that generate more electrical energy than consumed annually). The resultant summation of energy consumption and generation of all these NNEBs and the dedicated ULEB can provide us with an equivalent ZNEB cluster or community, as shown in Figure 1. Since all these managers contribute to the business operated in the

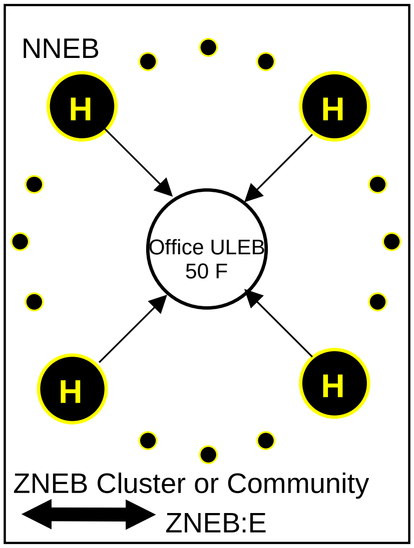

Figure 1 – Concept of ZNEB Cluster

particular ULEB, they should also contribute to that ZNEB cluster in terms of achieving the annual energy goal. The owner of that ULEB then purchases the excess electrical energy generated by all NNEBs of these managers to fulfil the overall requirement of the ZNEB. We call this concept ZNEB:E. To fit into the existing four definitions of ZNEBs, we propose ZNEB:E buildings, which are ultra low energy buildings with an overall EUI = 21 kBtu/sf/yr (239 MJ/m^2/yr) or less and rely on on-site renewable energy sources plus renewable contribution from certified houses or apartments of occupants.

In our exemplar office tower at San Jose, if the roof PV panels can adequately supply the annual consumption of the first three stories, the remaining 47 stories have to rely on the NNE homes of the managers. A simple estimation is conducted here. A 7,000-sf story can accommodate 50 managers and the whole building 2,500 managers who live in, to be conservative say, 1,000 houses. Not all managers working in the super high-rise office tower can afford or choose to live in a house. Therefore, a conservative figure of 1,000 houses for 2,500 managers is proposed here. We shall demonstrate below that we do not even need 1,000 houses.

Ignoring the first three stories which are supplied by on-site PV panels, the remaining part of the whole building consumes 147 MBtu/story/yr x 47 stories = 6,909 MBtu/yr. It is assumed that a standard 8 kW PV panel, with an array size of 538 sf (50 m^2), with a tilt angle of 31^o facing south, is installed on top of the roof of every house of an officer at San Jose (climate zone 4). The house is a single family model, 2,116 sf detached home with 3 bedrooms and 2 bathrooms. The site EUI according to Arup (Arup 2012) is around 13 kBtu/sf/yr. That means, the total on-site load is 27.5 MBtu/yr. According to PVWatts Calculator, 39.2 MBtu (11,484 kWh) of electrical energy can be generated per year. If a fair rate is adopted with the utility company, a net 11.7 MBtu/yr can be fed into the grid by each house, or 11,700 MBtu/yr for 1,000 houses. This is obviously good enough to turn the whole 50-story ULE office tower into an ZNE community.

Society is not driven by mathematics; it is mainly influenced by economics. The major obstacle currently to ZNEB is from the electric utilities. Their business is to sell electrical energy to customers, but now, the ZNEB model forces them to buy electrical energy back from customers. Obviously, these suppliers are unhappy with buying power from customers. There are public policy debates about imposing some cost (or reduced benefit) on electrical energy fed into the grid from customers' renewable energy sources because resources are needed to stabilize the whole grid when everybody tries to feed power into it. The government must play a strong role to make sure laws and codes facilitate such exchanges and leverage the technology of the utilities to help install and interconnect smart grid systems for consumers.

Section 8

Conclusion and Recommendations

The trend toward ZNE buildings is not just a national drive but also a global drive. Mankind needs to do whatever is necessary to reduce the emission of GHGs and to reduce reliance on fossil fuels that are not renewable. Definitions of ZNEBs are discussed. It is evident from both literature and simple exemplar buildings at three cities that it is impossible to turn a super high-rise office building to ZNE by on-site generation of renewable energy.

The EUI of these super high-rise office towers must be mitigated with a target of 21 kBtu/sf/yr (239 MJ/m^2/yr) or less. State-of-the-art technologies that are currently available to help buildings achieve this targeted EUI are described. Then, a solution is proposed that every manager working inside the office building has an obligation to contribute to the goal of making it ZNE. They feed electrical energy generated at their homes, thus forming a ZNEB cluster. Mathematically and technically, this is totally feasible when the house is one to two stories high, as is common. However, concerns from electric utilities must not be neglected. Without their support, it is difficult to implement this proposal.

The recognition by utilities and public regulators of the need to transform the 100-year-old electrical and gas regulated utility business model is evident by the recent GridWise® Architecture Council (GWAC) issuance of the Transactive Energy Framework (www.gridwiseac.org). It starts to address the challenge of transforming the electric industry from centralized production to distributed energy resources including renewable energy sources. Transactive Energy is a set of economic and control tools intended to maintain grid stability as renewables proliferate (Wacks 2013). Some renewables may be large solar and wind farms operated by existing utilities; others may be local generation by consumers, both residential and commercial, who sell excess production by inserting it into the grid. ZNE and Transactive Energy are both important methods for reducing carbon emissions while providing clean, reliable energy as we transition from the industrial to the informational age.

In compliance with EISA, it is the responsibility of commercial building managers in the U.S. to pursue the ZNE goal by 2030. Employers may give incentives to their staff to erect PV panels on the roof of their houses and feed electrical energy into the grid. Incentives may include financial support for installation and maintenance, electricity rate compensation, and sustainable employee awards, etc. The government must provide incentives to these utilities and to energy consumers to encourage cooperation for a successful system. Codes in all states must be enforced so that super high-rise buildings are more widely separated in order to increase solar energy absorption. If these buildings are not congested in the commercial business districts, PV panels on the vertical façade and on parking lot covers will then become practical. Nevertheless, this initiative is not easy to accomplish. An impetus from public policy is required. The government should reward building owners with tax incentives, density bonuses, expedited permitting, grants, loans, insurance, etc. to achieve the EISA goal for all super high-rise office towers.

Finally, the willingness of corporate managers in these buildings to participate in this scheme is essential. The implementation of this scheme requires significant co-ordination between building owners, company employers, and managers, as well as the government, utility suppliers, and the general public. Further research is recommended since the deadline for achieving NZE building is approaching.

Section 9

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