Toward Future: Positive Net-Energy Buildings

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***Abstract*—For a positive net energy building (PNEB), the paper presents its need, definition and elements. The most important is that the PNEB should provide the maximum thermal comfort with a minimum of energy, primary energy, and exergy consumption, and a minimum of CO2 emission throughout its life. Then, the paper presents the software for a energy simulation and optimization of PNEB. After that, the paper describes the five examples connected to the PNEB. The first example is a simulation of a residential PNEB, second the optimization of the photovoltaics in the residential PNEB, third the description of an the building as a power plant initiative, fourth the description of an office PNEB, fifth description of an archive PNEB and finally a description of a headquarter PNEB.**

Introduction

Daniel M. Kammen, Director of the Renewable and Appropriate Energy Laboratory, University of California, Berkeley wrote the following in Nature[1]. "By 2020. humankind needs to be solidly on to the path of a low-carbon society — one dominated by efficient and clean energy technologies. Several renewable technologies are ready for explosive growth. Energy-efficiency targets could help to reduce demand by encouraging innovations such as PNEBs and electric vehicles. Research into solar energy — in particular how to store and distribute it efficiently— can address needs in rich and poor communities alike. Deployed widely, these kinds of solutions and the development of a smart grid would mean that by 2020 the world would be on the way to an energy system in which solar, wind, nuclear, geothermal and hydroelectric power will supply more than 80% of electricity."

Globally, the drive for PNEB is necessity and urgency to decrease carbon emission, and relive energy shortage.

Several worldwide targets are established. First, the Energy Performance of Buildings Directive of EU states that all buildings built after 31 December 2018 will have to produce their own energy onsite [2]. Second, from beginning of 2020 in USA, all new Federal buildings will be designed to consume zero-net-energy and be zero-net-energy buildings (ZNEBs) by 2030 [3]. Third, to progress with the development and adoption of high performance buildings in USA, there is the Net Zero Energy Commercial Building Initiative. The initiative aims to achieve marketable net-zero energy buildings by 2025 through public and private partnerships [4]. Finally, UK Government sets out improvements to energy requirements in Building Regulations to include that all new homes has to be 'zero carbon' by 2016[5].

The objective of this paper is to introduce definitions and general characteristics of PNEB that go beyond ZNEB, show software for their design and give their several examples.

Definitions

The schematic of a PNEB is shown in Fig.1.

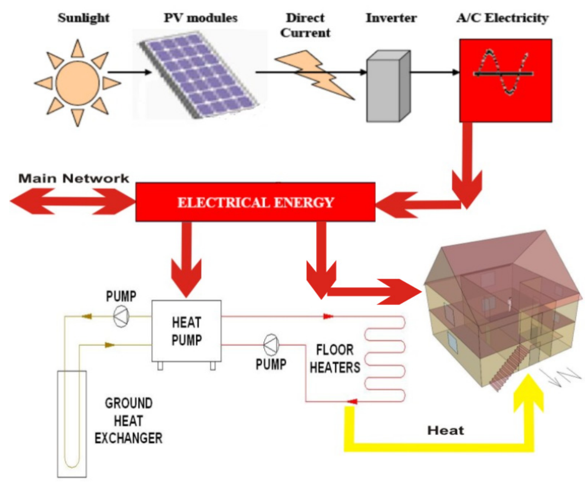

Fig.1 Schematic of a PNEB

A. *Ordinary Definitions [6]*

Positive-Zero Site Energy — PNEB generates more energy than it consumes. It usually produces electrical energy through PV modules and is connected to the grid. The building may either consume electrical energy from the PV modules or from the grid. The generated electrical energy may either feed the building or the grid. The electric energy supplies the grid when there is the electrical energy surplus. When there is electrical energy shortage the grid supplies electrical energy to the building. The ''positive-net'' concept means that yearly the excess electrical energy sent to the grid is larger than the amount received from the grid. The PNEB uses the power grid as an electrical storage battery.

Positive-Zero Source Energy — A building that produces and exports more energy as the total energy it imports and uses in a year, when accounted for at the source. "Source energy" refers to the primary energy required to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.

Positive-Zero Energy Costs — A building where the amount of money a utility pays the building's owner for the renewable energy the building exports to the grid is larger than that the owner pays the utility for the energy services and energy used over the year.

Positive-Zero Energy Emissions — A building that produces and exports more emissions-free renewable energy as it imports and uses from emission-producing energy sources annually. Carbon dioxide, nitrogen oxides, and sulfur oxides are common emissions that PNEBs offset.

B. Embodied energy [7]

Life positive net energy building (L-PEB) is defined that during entire life it produces more energy than it spends for the embodied energy of building components and its energy use [6].The net energy ratio (NER) is a as the ratio of the decrease on annual energy use to the increase in annualized embodied energy. The higher NER better more effective is move toward L-ZEB.

II. ENERGY

A. Energy consumption

In ZNEHs, energy may be used for space heating, space cooling, DHW heating, lighting, and appliances, etc.

Technologies for lighting and appliances should be energy efficient to minimize use of electrical energy that has to be generated by the building.

In future buildings, space heating should be efficient. In this direction, technologies for space heating are usually ground coupled heat pumps (GCHP) as they give around 3 times greater amount of heat energy than that of electrical energy with which it was run. The heat pumps may be used for heating and cooling when the direction of refrigeration fluid is reversed. The most often it is a GCHP with hydronic floor heating or air space heating.

B. Energy generation

Technologies for heat & cold generation from geothermal energy use electrical energy to operate. These devices are called heat pumps. They should be energy efficient and have the highest COP (to use as low amount of electrical energy as possible).

Technology used for DHW heating may be heat used by solar collectors and electrical energy produced by the PV modules, or the heat pump driven by electrical energy. The most efficient heating may be performed by either solar collector with electric backup.

Technologies that are used for energy generation should be energy efficient and to use as low surface area as this is possible. These technologies are generation of heat energy by solar collectors, and electrical energy by the PV modules and wind power. When there are energy generation with the PV panels and solar collectors, one should determine the ratio between areas of the PV modules and of solar collectors. However, there is also simultaneous generation of heat and electricity by hybrid PVT panels.

C. Building envelope

In future buildings, a building envelope should minimize heat transfer. In cold climate, the building envelope has to be super insulated and air tight. Special double glazed windows are used at the south wall that are filled with argon and have low heat emissivity film coating.

D. Rule of thumb

However, the amount of energy generated by the PV modules and solar collectors located on the building roof is limited as there is shortage in surface (space) needed for energy generation. Consequently, the rule of thumb of design of ZNEH is to minimize energy consumption in the building. This would minimize required energy generation and surfaces required for this energy generation.

E. Cost effectiveness

Energy saving and producing technologies should be cost effective. That means minimum construction costs for these houses and their fastest penetration into practice. The highest cost is the cost of its GCHP heating system and the PV modules. To minimize these costs, the designer has to minimize heating and cooling loads to these homes. For designer, the most interesting questions are that of area of the PV modules and financial attractiveness of their installation. As these technologies are still relatively expensive, the government should enhance financial attractiveness of the investment in such devices.

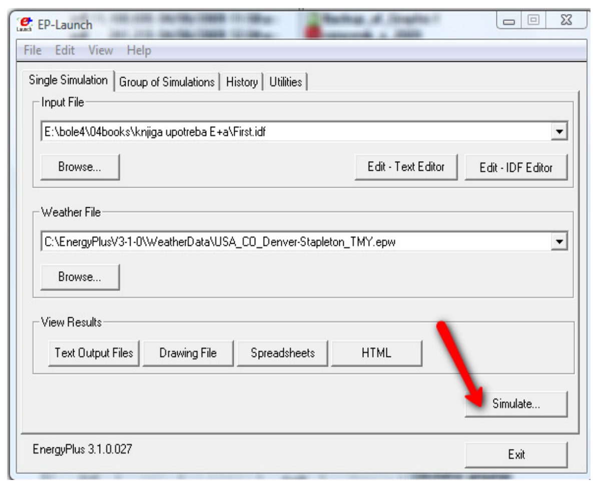

Fig.2 EnergyPlus interface

SIMULATIONS AND OPTIMIZATIONS

A. Simulation software - EnergyPlus

EnergyPlus is made available by the Lawrence Berkley Laboratory in USA [8]. EnergyPlus interface is shown in Fig.2. EnergyPlus development began in 1996 on the basis of two widely used programs: DOE-2 and BLAST. The software serves to simulate building energy behavior and use of renewable energy in buildings. The renewable energy simulation capabilities include solar thermal and photovoltaic simulation. Other simulation features of EnergyPlus include: variable time steps, user-configurable modular systems, and user defined input and output data structures. The software has been tested using the IEA HVAC BESTEST E100-E200 series of tests. To model, the building and renewable energy systems in

EnergyPlus environment, we used models of different components that are embedded in EnergyPlus such as that of PV-array, inverter, flat-plate solar collector, storage tank, tempering valve, and instantaneous water heater. Water in the storage tank was heated by solar energy and water in the instantaneous water heater by electricity.

B. Simulation software - Google SketchUp

Google SketchUp is a free 3D software tool that combines a tool-set with an intelligent drawing system. Building in Google Sketch-up environment is shown in Fig.3. The software enables to place models using real-world coordinates. Most people get rolling with SketchUp in just a few minutes. There are dozens of video tutorials, an extensive Help Centre and a worldwide user community.

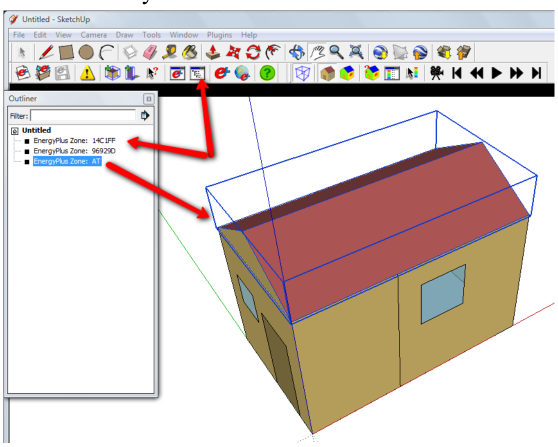

Fig.3 Building in OpenStudio environment

C. Simulation software - OpenStudio

The OpenStudio is free plug-in that adds the building energy simulation capabilities of EnergyPlus to the 3D SketchUp environment. A house in OpenStudio environment is shown in Fig.3. The software allows you to create, edit and view EnergyPlus input files within SketchUp. The plug-in uses the standard tools provided by SketchUp. The software adds as much extra detail as you need to zones and surfaces. The plug-in allows you easy to create a building geometry from scratch: add zones, draw heat transfer surfaces, draw windows and doors, draw shading surfaces, etc. You can save what you have drawn as an EnergyPlus input file. The plug-in also allows users to launch EnergyPlus simulations and view the results from within SketchUp.

D. Optimization software - GenOpt

GenOpt is an optimization program for the minimization of a cost function evaluated by an external simulation program [9]. Optimization and simulation data flow paths by using Genopt are shown in Fig.4. GenOpt serves for optimization problems where the cost function is computationally expensive and its derivatives are not available or may not even exist. GenOpt can be coupled to any simulation program that reads its input from text files and writes its output to text files. The independent variables can be continuous variables (possibly with lower and upper bounds), discrete variables, or both, continuous and discrete variables. Constraints on dependent variables can be implemented using penalty or barrier functions. GenOpt is written in Java so that it is platform independent. GenOpt is applicable to a wide range of optimization problems. GenOpt has a library with adaptive Hooke-Jeeves algorithm.

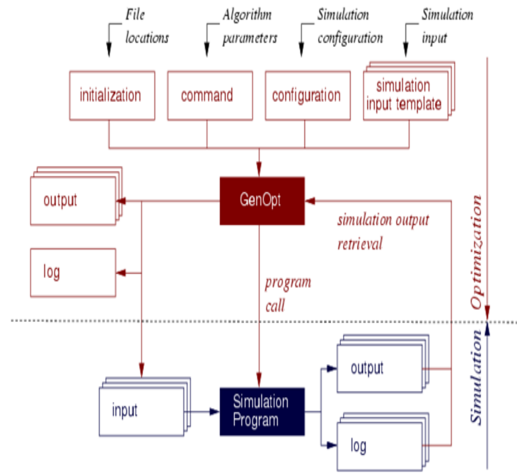

Fig.4 Optimization by using Genopt

4. EXAMPLES

A. Residential PNEB in Serbian conditions [11]

This article reports investigations of a residential building in Serbian conditions energized by electricity from photovoltaics (PVs), and the electricity grid. The building uses electricity to run its space heating system, lighting and appliances, and to heat domestic hot water (DHW). The space heating system comprises floor heaters, a water-to-water heat pump, and a ground heat exchanger. The schematic of this PNEB is shown in Fig.1. The PV system generates electricity that either may be consumed by the building or may be fed-in the electricity grid. The electricity grid is used as electricity storage. Three residential buildings are investigated. The first residential building has PVs that yearly produce smaller amount of electricity than the heating system requires. This is a negative-net energy building (NNEB). The second building has the PVs that produce the exact amount of electricity that the entire building annually needs. This is a zero-net energy building ZNEB. The third building has PVs that entirely cover the south-facing roof of the building. This is a PNEB. These buildings are presented by a mathematical model, partially in an EnergyPlus environment. For all buildings, simulations by using EnergyPlus software would give the generated, consumed, and purchased energy with time step, and monthly and yearly values. For sure, these buildings would decrease demand for electricity during summer, however they will increase this demand during winter when there is no sun and start of space heating is required. Depending on the size of PV array this building will be either NNEB, or ZNEB, or PNEB. However it is crucial for such a building to be connected to the electricity grid. The smaller payback for investment in the PV array is obtained for buildings with larger size of PV array. The feed-in tariff for the generation of electricity in

Serbia should be under the constant watch to be corrected accordingly for larger penetration of this technology in the Serbian market.

B. Optimizing performances of photovoltaics in Reunion Island – tilt angle [12]

As in Reunion Island, France, around 61% of electricity is produced by using coal and fuel oil with high greenhouse emissions. It is beneficial to the environment to produce electricity from solar energy. Therefore, there is a large push to generate electricity from solar energy by use of photovoltaic (PV) arrays. However, it is important to have high efficiency of electricity generation, that is, to locate PV arrays in an optimal direction. The investigated PV systems may take 1, 2, 4, and 12 tilts per year. For the PV arrays facing the north–south direction, this paper reports investigations of their optimum tilts and the maximum amounts of generated electricity. The investigated PV arrays are located in the towns of Saint-Benoit, Les Avirons, Piton Saint-Leu, and Petite-France in Reunion Island. To obtain optimal tilt of the PV arrays for electricity production from solar energy, EnergyPlus software and GenOpt software are used with Hooke–Jeeves optimization routine. For the investigated PV arrays, the percentage gains in energy, exergy, avoided fossil energy, and the percentage decrease in CO_2 emission are around 5% when compared with that of the PV array that takes only one optimum tilt per year.

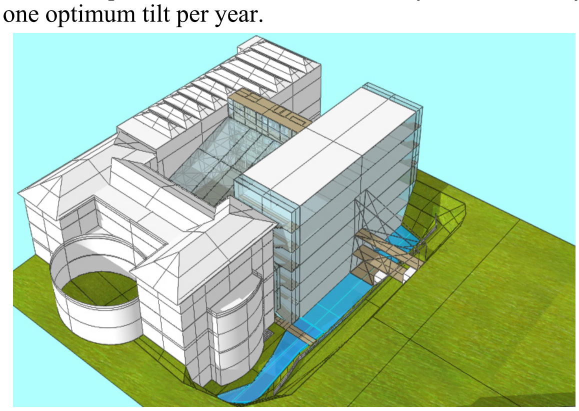

Fig.5 BAPP initiative object

C. The building as Power Plant initiative[13]

The Building as Power Plant (BAPP) initiative seeks to integrate advanced energy-effective building technologies (ascending strategies) with innovative distributed energy generation systems (cascading strategies), such that most or all of the building's energy needs for heating, cooling, ventilating, and lighting are met on-site, under the premise of fulfilling all requirements concerning user comfort and control (visual, thermal, acoustic, spatial, and air quality). BAPP is shown in Fig.5. This will be pursued by integrating a "passive approach" with the use of renewable energies. BAPP is designed as a 6-story building, located in Pittsburgh (a cold climate with a moderate solar potential), with a total area of about 6000 m2 which houses classrooms, studios, laboratories, and administrative offices. At present, the combined cooling, heating, and power generation option that is being considered for the demonstration building is a Siemens Westinghouse 250-kW solid oxide fuel cell (SOFC).

D. The office project (commercial building) [14]

In the green office project (commercial building) in Meudon outside Paris, FRANCE, by Bouygues Immobilier, energy consumption is reduced to the strict minimum with the bioclimatic design of the building and a high-performance natural ventilation system (shown in Fig.6). The building has a north-south building orientation; its outer walls have enhanced external insulation, with wood and aluminum joinery for improved performance, and motor-controlled vents for natural ventilation; the open-plan office space is 13.50 metres deep, making it easier to make full use of natural lighting and ventilation; air circulating fans enhance comfort levels in summer; the motor-controlled external blinds provide good solar protection. The thermal inertia of the floor slabs is made more readily accessible by dispensing with false ceilings and raised floors. Lighting in the building has been designed to contribute to energy savings while still providing maximum comfort levels. Control of lighting has been optimised to reduce power consumption by automatically turning lights off when the office is not occupied. Energy balance says that this building produces more energy than it consumes.

Fig.6 The Green Office in Meudon

Green office will reduce power consumption by 60% compared to a standard building constructed to the RT 2005 thermal regulations, and by 30% relative to the most energy-efficient buildings on the market today. More than 5,000 sq. metres of solar panels produces energy for the building. They are installed on walls; and as "car ports" in outdoor parking areas. The building also uses a biomass combined heat and power system fuelled by wood or oil. The produced heat covers the building's entire heating requirement, and the electricity produced covers power needs above and beyond the capacity of the solar panels. The project is carbon-neutral. In addition, the special attention is given to reducing its carbon footprint by limiting carbon emissions during construction.

E. An archives building [15]

The archives building for the Nord administrative district is built by Bouygues Construction, in Lille, northern France (Fig.7). In addition to archives rooms, The building has the total floor space of more than 13,000 sq. metres that include extensive work areas.

To keep future energy consumption down, the building has enhanced insulation (walls, roof, glazing), superior air and water tightness, and the innovative, energy-efficient equipment and technologies. Since its overall priority is to store archives under the optimum temperature and humidity conditions, a special innovative, high-performance air-conditioning system (desiccant-based) is applied. The applied systems achieve a record low level of primary energy consumption, at 12.9 kWh/sq. metre/year compared to the average consumption of 105 kWh/sq. metre/year for a conventional building of the same type.

Fig.7 An archives building

Heat and electricity will be produced by a combined heat and power plant running on plant oil and by 350 sq. metres of solar cells.

F. The Masdar Headquarters, Abu Dhabi [16]

In Chicago, architecture firm Adrian Smith + Gordon Gill is chosen to design a positive energy, mixed-use building for the world's first zero-carbon, zero-waste, car-free city called Masdar (Fig.8). As a "positive energy" building, the design aims to generate more energy each day than it consumes. The 130 thousand m^2 ($300 million) headquarters will serve as the centre of Masdar City, which will end up being about a $22 billion development in Abu Dhabi. The headquarters are the lowest energy consumer per square meter for a modern class A office building in an extremely hot and humid climate. They feature one of the world's largest building-integrated photovoltaic arrays. They employ the largest solar thermal driven cooling and dehumidification system.

FIG.8 MASDAR HEADQUARTERS, ABU DHABI

CONCLUSIONS

The paper shows that PNEBs are in strong need worldwide. The most important fact is that throughout their life, the PNEBs should provide the maximum thermal comfort with the minimum of energy, primary energy, and exergy consumption, and the minimum of CO2 emission. The different definitions of the PNEBs are present. They can account for the site energy, source energy, CO_2 emissions, costs, and embodied energy. The PNEBs require up-to-date technologies for efficient energy consumption and energy generation from solar and geothermal energy. The PNEBs may be designed by using software for energy simulation and optimization. The PNEBs would be successfully used for residence, research, office, archive, and business.

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