Energy Autonomous Buildings: A Review

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Abstract

Because of growing worldwide population, the increase of CO_2 emissions and energy costs, the need to create sustainable and efficient buildings is greater than ever. Energy autonomous buildings, which rely on clean ambient sources, can help to create extreme Low-Carbon (LC) buildings. However, resilience-housing and energy design, trigger the radical thinking for Autonomous Buildings (ABs). This ABs idea focused on particular interest for 'independent building and energy autonomy'. This is a zero-carbon building that utilises 100% clean energy. Moreover, the building responsible to maintain internal and external environmental comfort. This paper analyses several examples for ABs developed over the past five decades. For instance, Robert and Branda Vale demonstrated their 'autonomous house' in the 1970s [Vale & Vale, 2000]. Over ten years later, Building Research Established in the UK, built 'Integer House' in 1998, was known as 'Intelligent and Green' building [Wood, 2011]. This ABs assessment aim to provide a comprehensive literature review, to identify the definitions and boundaries of 'autonomous'.

Keywords: Self-sufficient house, Zero carbon building, Off-grid building, Energy efficiency, Energy design.

1. Introduction

This report introduces the concept of energy Autonomous Buildings (ABs), and the focusing on energy autonomy. First, autonomous buildings are defined within the context of a range of increasingly stringent building energy performance standards. Next, the context for autonomous buildings within the wider framework of a changing energy system is established. Key examples of autonomous buildings in the world are highlighted.

The built environment learning the lessons of Zero-Energy Buildings (ZEB) and building design are moving towards low carbon energy |Torcellini, 2006]. These can help accelerate the adoption of technologies into the marketplace and enhance resilience in developed world and improve access to basic energy services in the developing world.

1.1.Energy Use in Buildings

Humans have a basic need for shelter/a place to live, and housing development has been one of the ongoing challenges. Those challenges including energy production, energy distribution and grid connections, costs, geological and environmental impacts, etc. In addition, home standard services such as; heating, cooling, lighting and appliances plus comfort, required energy consumption regardless of building location. This indicates; 'A building can be seen as a stationary energy consumer, irrespective of time and location. In the UK, domestic sector accounts for approximate 29% of final energy consumption, of which 80% is heating demand [Energy Strategy, 2017]. Supply of hot water is second energy consumption in a building. [CIBSE, 2004]. "Educational buildings accounted for 12% of all energy used in commercial buildings in the United States in 1995" [Pless, 2006].

The building sector occupies an important role in national economies. It is estimated one-third of the private household disposable income spent on housing (including energy, mortgage, etc.) [Paliwal, et al. 2014]. Moreover, Buildings are responsible for 40% carbon emissions, 60% waste production and 14% water consumption worldwide. Buildings also require water during construction and occupancy) [Shaahid, 2011].

1.2.Problem statement

The current problems include; 1.2 billion people in the world have no access to electricity. Moreover, A huge amount of fossil fuel energy consumption worldwide creates Green House Gas (GHG) in the world. This leads to air pollution and climate change [Union, 2014]. The combined local and global climate change creates tremendous stress on the urban environment and numerous humanitarian disaster in the form of heat waves, urban floods, hurricanes, droughts and thermal discomfort. This results in financial costs and destroyed quality of life in many regions worldwide (Demuzere, 2014).

2. Autonomous Buildings

2.1. The Fundamental principle of autonomous building

The AB attitude as shown in Figure 1 describes the fundamental principle in autonomous building is under five major phases.

1. Off-grid

2. Renewables

3. Storage

4. Technology Integration (solar heat, battery, geothermal, etc.)

The main principle of Autonomous Building is the capability for off-grid performance. Autonomous buildings are design for stand-alone routine, and the highest energy efficiency capability. [Vale et al. 2000], and [Voss et al. 1996], reports electricity demand could be reduced with additional 'Energy Efficiency (EE). Moreover, supplementary EE decreasing the long-term costs of energy consumptions. Significant savings can be made from shifting to add energy efficient lights, refrigerators and other low-cost measures.

The size and selection of renewable technology depends on local (micro) climate and different locations. The sizing methodology also depends on the buildings scope including the number of floors and units, but the basic principle (Fig.1) remains constant. 'There are: fundamental principle energy efficiency, off-grid houses, and off-grid energy generation and energy storage systems. Therefore, ABs need energy integrated technologies, to convert ambient energy into green electricity.

2.2. Definition of ABs

Various definitions for autonomous buildings exist. Vagn Korsgaard Zero Energy Home in Denmark [Bliss et al. 1955], and the Saskatchewan Conservation House [Esbensen et al. 1977], and [Vale et al. 2000]. These pioneers defined the concept in the 1970s as one that can function independently from the support of services and facilities.

3. Examples of Autonomous Buildings

Brenda and Robert Vale, 2000, reports, "the autonomous house on his site is defined as a house operating independently. This means without connection to a national grid. In some ways, it resembles a land-based space station designed to provide a suitable environment, using the life-giving capabilities of the Earth without interfering or altering them.

3.1. Dymaxion House

[Müjde, 2013], reports Buckminster Fuller was an architect and the inventor and theorist of Dymaxion House which was completed in 1930 after two years of development. The house inhabited round 30 years and represent the first conscious effort to build an autonomous building in the 20th century. Dymaxion dynamic home as shown in Figure 2, with the unique structure as the first 4D house, full metal (aluminium) with wood flooring capitalized on wartime research and redesigned in 1945, taking advantage of the housing shortage the USA experienced after World War II.

3.2. The Autonomous Building

Brenda and Robert [Vale, 2000], definition of an autonomous house is an independent house operating without any input, except those of its immediate environment. The house is not linked to the main service of gas, water, electricity or drainage, but instead uses the income-energy source of sun, wind and rain to service itself and process its own waste. The initial design idea started in 1975, but the autonomous house completed in 1990, based in South-well, Nottingham-shire, England as shown in Figure 3. This shows that zero-carbon houses do not have to in a rural area or appear radically different from conventional homes [Martin, 2011].

3.3. Autarkic House

Littler, 1979 introduce the principles of the autarkic house. His report mentioned harvesting wind power and solar energy to provide its own energy. He believes that independent house can be built even in cloudy Britain. In fact, a Cambridge team have designed a house that would be complete independent of all types of mains services. This means; an autarkic house is complete self-sufficient and off-grid in all respects as shown in Figure 4. The autarkic house goal was to formulate a low energy building where ambient energy sources could meet the demand. The demand reduced in different ways such as; passive and active methods. Passive measures include the reduction of standard space, use of insulation and solar gain. Active measures included heat recovery via an aero-generator [Tanaka, 1992].

3.4. Earthship

[Godrey, 2011], Earthships are autonomous and self-contained houses. Earthship features include passive solar heating and cooling, rainwater harvesting, photovoltaic power systems and solar hot water heating as shown in Figure 5. Earthship construction includes utilisation of recycled materials such as black and grey water treatment systems.

3.5. Freiburg house

The Freiburg House is a self-sufficient solar house as shown in Figure 6 operating since 1992 in Germany. The building has independent solar-energy supply and features a hydrogen storage system for high demand and a grid back up during a short-term breakdown of a fuel cell. This building is known as a Self-sufficient solar house and/or Plus energy settlement. [Stahl et al. 1994], special attention is given in the Freiburg house to covering all aspects of energy demand. For instance, instead of the reduction of space heating was prioritised. Because in a Central European space heating around 80% of total energy consumption in residential buildings.

3.6. Norwegian Row House

[Winther et al. 1999], describes a wooden row house with very low energy consumption. The features design included solar panels, green building design while emphasising the use of resource-friendly materials and very low energy consumption. The row house as shown in Figure7 has no battery storage but is connected to the grid. It is located in southern Norway and features both active and passive solar designs.

This type of Norway house is compared to four other types: two where the building design was based on the requirement of the new Norwegian Building Code; One type where the building was designed according to current Norway standards; One type where the building was designed based on the principles used by the architects present building "green" buildings in Norway. The results show that solar buildings have a lower energy demand when both energy consumption during operation and embodied energy are taken to account.

3.7. Izu-Atagawa House

[Tanaka, 1992], describes the project of building an autonomous house in Japan. The self-sufficient system built on the Izu-Peninsula, 80 km southwest of Tokyo known as; Izu-Atagawa as shown in Figure 8.The site area is in a valley with approximately 5000 m2. The mountain area provides other resources for residence such as food and clothing, etc. and minimising the impact on the environment as small as possible. The climate is humid in summer and warm in winter. Hot water supplied from hot springs at approximately 70'C in the neighbouring resort area. He reports that autonomous houses are generally classified as; (A) Dwellings, self- sufficient for energy; thermal energy needed in house for heating water, and electricity for lighting, computer and running equipment, etc. The energy supplied by renewables in the form of solar energy used direct (active and passive systems, solar photovoltaic generation) and indirect; (wind power conversion to electricity. These houses are high insulated with a high degree of air-tightness, harnessing natural lighting and ventilation. (B) Dwellings self- sufficientfor energy and resources; these houses have their own supply of water in addition to building class (A). They use rainwater as well as recycled water. There is agriculture land, produce fruit, vegetables and their bakery products are homemade. (C) Complete self- sufficient Dwellings; these houses are self-sufficient for energy, foodstuff, resources and maintain a recycling environment. Generally, as a community, taking in a minimum of industrial goods. Heating: passive measures adopted; direct solar gain and 100 mm insulation and double-glazing doors. The ground floor made of concrete with heat storage capacity. The hot spring water can be used for baths. Even in a cloudy climate, the house is 100% selfsufficient using a catalytic high-performance cast-iron stove from fallen branch and woodland as fuel. Cooling: with passive ventilation, but there is hardly any need. Heatfor cooking during winter a wood burning cooking stove is used, and in summer a self-generated electricity is used a power source. Source of electrical is a normal hydraulic generation of 300 W, and a back-up solar cell with an output of 1.5KW (approximately 15 m2) positioned in die roof.

3.8. Self-Sufficient Homes

[Moench, 2004], reports "independent home" typically refers only to its energy use, but selfsufficient homes are different because they can produce and distribute food to sustain its occupants. Mel Moench, who designed a totally "Self-Suffident Homes" (SSH) in Arizona, USA as shown in Figure 9.He believes in colder locations, generating energy from wind power would be more important. Moreover, while heating the home is a primary consideration in cold regions, required greater insulation for the main rooms or the primary heating zone. The report mentioned about the short- and long-term benefits of self-sufficiency. These include security from global unrest, climate change natural disasters, etc. The long-term global benefits are; a) general transition to SSH and green energy technology globally, b) reduction of energy need for housing, c) slow the advance of soil problem and global warming.

4. Findings and Autonomous Buildings Attribute

In order to make sure our ABs are energy autonomy and working simultaneously, integrating technologies (Figure 10) and energy design architecture must be fit for purpose, and depends on both size and location of die building.

4.1 Future works

Currently, I am working and calibrate on realistic operational scenarios in small-scale autonomous buildings and energy design architecture by computer simulation modelling. This will be finalised before end of 2019. The future will replicate current knowledge and skills into the medium and large-scale ABs in different design and locations. Overall resilience and successful energy ABs require high resolution, featurerich models.

5. Taxonomy

Comparison of current autonomous buildings and evaluation criteria for model characterization. The results of the taxonomy process led to 8 distinct autonomous buildings worldwide. I did not follow any ABs classification, because no taxonomy exists in this field. Hence, I design the first ABs taxonomy. The 8 types of ABs are listed in chronological order, from 1930 till now, according to their initiation time, as shown in Table 1.

6. Conclusion

This review indicates the fundamental characteristics and design elements of ABs worldwide. ABs have number of critical aspects including a) there are not many, b) high cost, c) very limited uptake, d) ABs are not usually based in city centre. However, I believe these issue can be solved. However, ABs have number of public and environmental benefits. Although, ABs must be including; 1) high energy efficiency, 2) consider ambient energy to meet demand supply, 3) integration technologies (renewables), 4) smart control system, 5) energy storage system (battery).In addition, this research paper is matter because indicates the common points and different design in autonomous buildings. This paper is an important reference that for the first time create taxonomy of autonomous buildings worldwide. Knowledge is the key to innovation. This knowledge contribution and guidance can be used for energy companies interested in built environment and organising lessons for students of energy design architecture, climate change, manufacturing and providing organised information for those interested to visit ABs in different countries and gain a better understanding of ABs engineering. For instance; this research learned around 20% ABs have small site and close urban area, but 80% have large sites and based in rural area. Also, indicates ABs features and their main common point, which is not relying on fossil fuel and/or national grid. This means; ABs are not adding Co2 emissions or air pollutions. Therefore, the history of ABs indicates; capability of lowering the environmental impacts including (GHG). Moreover, it is obvious the new energy autonomous buildings are representing extreme low carbon buildings. Therefore, it can assess the sustainability impacts of built environment duty.

More effort is needed to enhance and realise the potential of 'Autonomous Buildings'.

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NOMENCLATURE

AB Autonomous building
ABs Autonomous buildings
EAB Energy Autonomous Building
EE Energy efficiency
ESS Energy system storage
CO_2 Carbon dioxide
CIBSE Chartered institution of building services engineers
GHG Greenhouse gas
IoT Internet of things
kW / kWh Kilowatt / Kilowatt hour
LC Low carbon
PV Photovoltaics
P5 Page 5
RE Renewable energy
SSH Self-sufficient homes

TI Transparent insulation
ZEB Zero energy building

DUAL UNITS

100 тл2 = 1076.39 fU2 = 155000.31 inch^
100 mm = 0.33 ft = 3.94 inch
33 ft = 10.05 m = 396 inch
$ 2-3 m-us = 2 to 3 Million U.S. dollar
1.6 M-DM = 1.6 Million Euro

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