INCORPORATING MICROSCALE RENEWABLE ENERGY TECHNOLOGY INTO ARCHITECTURE AND URBAN DESIGN

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ABSTRACT

The importance of localised power generation, heating and cooling from renewable energy sources is becoming increasingly necessary. Domestic power generation may also lead to less travel searching for fuel and paying for it too. This is especially relevant now in this time of the current pandemic with its quarantine and restriction on outdoor activities. This research will focus on incorporating specifically microscale renewable energy technologies into the fabric of newbuild architecture and urban design. Microscale generation technologies covered will include the utilisation of micro-wind turbines, photo-voltaic window panels, solar space and thermal heating. The scope of the technologies also covers; hydroelectric (stream or tidal); geothermal; ground source heat pump; combined heat and power (CHP); bio-fuel and biomass sources. Off-peak excess energy storage technologies are also discussed (batteries; super capacitors and pumped storage). Recommendations are finally given based on regional factors with a conclusion that nuclear-renewable micro-hybrid energy systems (N-R MHES) is the optimal solution.
Urban designs near streams harnessing micro-hydro power units combined with pumped storage are described. Depending on the local ground thermal activity, geothermal sources can be exploited. New builds can benefit from ground source heat pumps and air source heat pumps. The need for effective insulation of buildings needs to be considered for the efficient usage of heat pumps.
Reliance on the power grid need and foreign import of fuel and energy need to be reduced. The need to install combined heat and power (CHP) will be discussed. Along with communal bio-fuel and biomass generators.
Houses built should be designed with energy storage technologies from the use of building materials with high specific heat capacities to architectural changes. Some newer technologies such as the use of super capacitors will be explained.
Recommendations based on regional factors will be discussed and given. The research will conclude with the need to incorporate micro-hybrid energy systems into the building architecture and the setting up of micro-grids and local energy storage systems.

KEYWORDS: micro-wind turbine, photovoltaic windows, solar, microscale renewable energy

INTRODUCTION

This paper gives an overview of some of the latest renewable energy sources that should be considered for new builds and where possible as a retrofit solution to already constructed architecture. The technology presented is given from the viewpoint of an electronics-computer engineer. The research was conducted by searching the Internet for the latest

advances as announced by the researchers, builders and manufacturers. The paper follows the sequence covering the earliest known exploitation of renewable energy, that is, wind towers, then moving onto the latest technologies. Examples of these newer technologies are given including how they may be incorporated into the fabric of the building. The paper concludes with the recommendation to utilise a microgrid linked to a nuclear-renewable micro hybrid energy system.

It is important to see the worldwide per capita energy consumption, this is shown for a diverse range of selected countries in Figure 1, below. The majority of the countries' electricity consumption is due to thermal requirements, that is, the need for heating, cooling and cooking. Since the 1980s, the demand for electricity has in fact tripled with the majority of the production relying on fossil fuels (Alves, 2022).

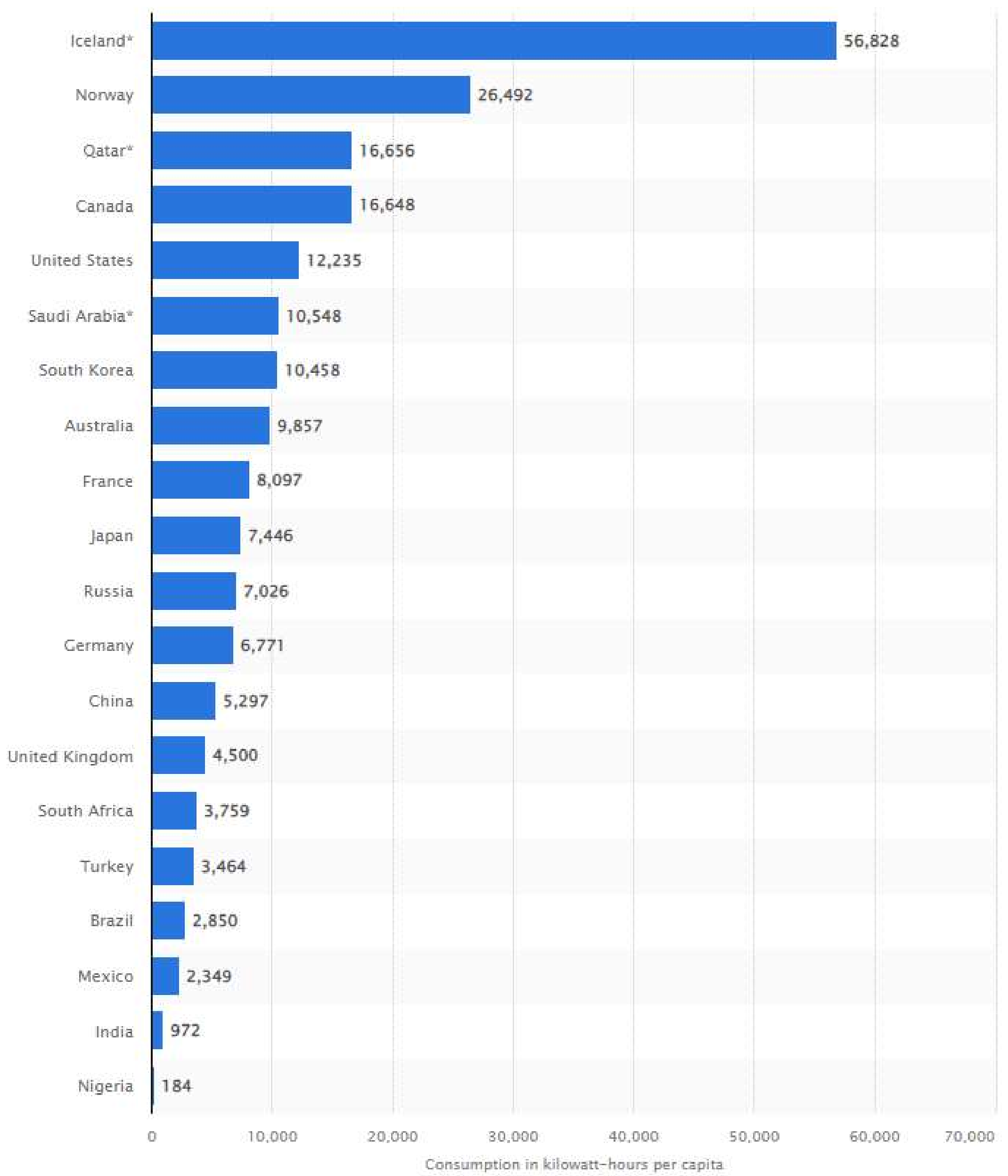

Figure 1: Electricity Consumption per Capita Worldwide 2020 (Alves, 2022).

The identification by Alves (Alves, 2022) that a large proportion of electricity is used for thermal purposes, shows the importance of construction of buildings with better insulation. The increasing importance of renewable generation is also evident, as reliance on fossil fuels have not diminished since the 1980s.

RENEWABLE ENERGY SOURCES

These renewable sources of electricity generation are covered: micro-wind turbines, photovoltaic concrete, photovoltaic windows, solar heating, pico-hydroelectric power, ground source heat pump, micro-CHP (Combined Heat Power) generator. The first example of thermal control without using electricity is an historical case of the use of wind towers for air conditioning in hot arid regions.

The Wind Towers of Iran (Ancient Air Conditioner)

The need to survive comfortably in harsh environments by utilising the prevailing climatic conditions can be seen from architecture built over a thousand years ago. A classic example is the wind towers of Iran. The concept is to trap and divert the prevailing higher elevation cooler air downwards into houses via tall wind towers. A summary is given in the paper by Ghaemmaghami and Mahmoudi (2005). Figure 2, below shows the concept of operation. Wind towers may be used for cooling in hot arid and hot damp climates.

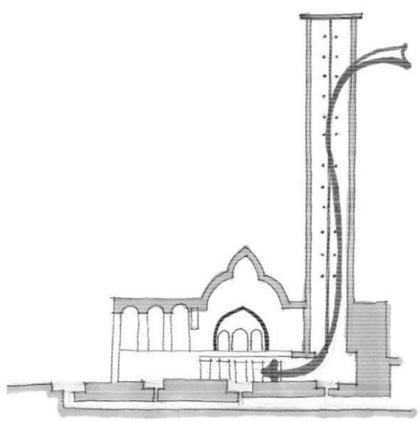

Figure 2: Function of Wind Tower in Yazd, Iran (Ghaemmaghami and Mahmoudi, 2005).

Figure 3, shows a photograph of a typical construction of a wind tower in Iran.

Figure 3: The Wind Catchers of Yazd, Iran (Green, M., 2010).

This architectural design should again be considered for other similar geographical locations of the world. It requires no electricity in operation, requiring minimal cleaning maintenance.

Micro Wind Turbines

The utilisation of micro wind turbines in a domestic setting is now possible to generate electricity without the use of towers. American Wind Inc. have released several products that could be placed in balconies, verandas and rooftops to capture monodirectional wind flows for electricity generation. A typical example is shown below, the Horizontal WindWall®, in Figure 4, where an array of individual wind turbines in a grid formation has been placed along an open hall. Each turbine is housed in a MicroCube® which is described as having a maximum power output of 1 kW.

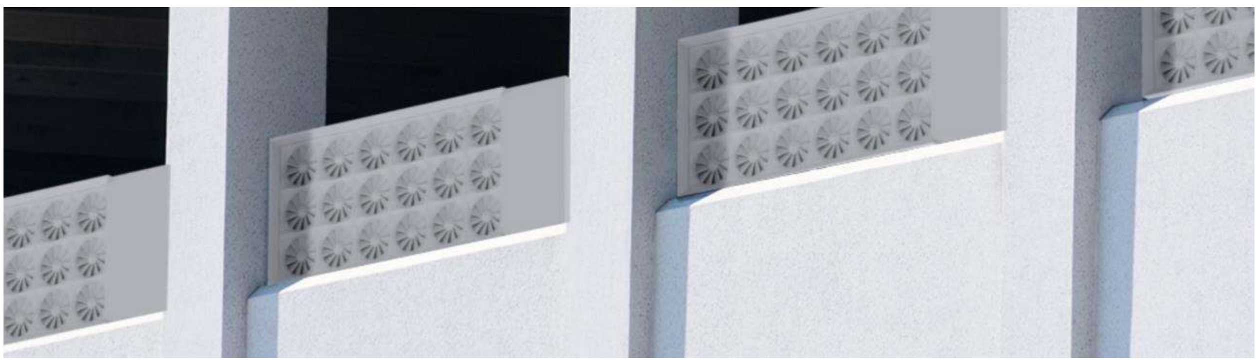

Figure 4: A Horizontal WindWall®, 18 kW Maximum Output (AmericanWind®, 2022).

For one individual structure shown in Figure 4 above, consisting of an array of 3×6 MicroCube®, these are some of the operational parameters:

- Max Output – 18 kW at 35.2 km/h
- Voltage - 220/440 V
- L | W | H – 1.98 m × 2.08 m × 0.61 m
- Weight – 271.5 kg
- Cut In Speed - 2.4 km/h
- Maximum Operational Speed – 225 km/h (+140 mph)

Smaller scale systems are also available producing 6 kW output power for domestic installation. This can be coupled with other renewable energy generating systems and off-peak power storage (batteries or capacitors). A case study of the power output of their MicroCube® is given on their website [MicroCube®].

Photovoltaic Concrete

In November 2017, LafargeHolcim a Swiss multinational building materials manufacturing company and Heliatek a German photovoltaic (PV) solutions company for building surfaces - presented a prototype for a new photovoltaic concrete façade system. The novel system combined LafargeHolcim's Ductal concrete panels, as shown in Figure 5, with Heliatek's lightweight thin solar film called HeliaFilm, as shown in Figure 6. This created the possibility to use prefabricated concrete Ductal panels for buildings without requiring rooftop solar panels to be installed. As potentially all the building walls were now PV solar panels which could be integrated into a solar energy-generation system. Using this combined technology

means every square metre of a building surface is an energy generating surface and not just the rooftops only. Using prefabricated solar PV film concrete panels also reduces the installation cost and building time.

Figure 5: LafargeHolcim and Heliatek's Prefabricated Cladding with PV Film [Heliatek1].

Figure 6: HeliaFilm - Heliatek's Lightweight Thin Solar Film [Heliatek2].

A building may not only utilise PV concrete but also photovoltaic windows. This will maximise the utilisation of a building's entire surface area for electricity power generation. Windows may also be replaced in existing buildings. If this is not possible, then possibly the PV window

glass pane could be retrofitted as a triple layer to make a triple glazed windows for additional thermal insulation of the building.

Thus further savings in electricity required for heating or cooling of the rooms. The windows have a thin film coating of amorphous light sensitive Silicon, which converts optical energy into electricity. Due to the film, UV and IR radiation entering the building is also reduced, thus offering thermal insulation too. Figure 7, shows an actual installation of photovoltaic glasses with almost 100% light transmittance.

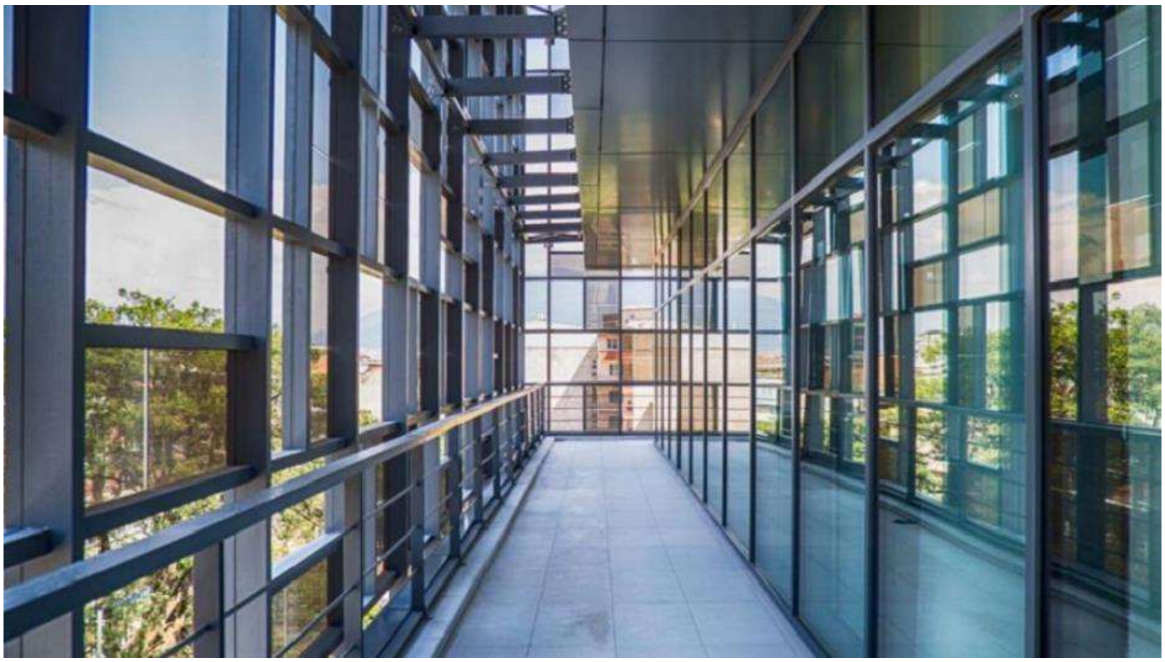

Figure 7: Atria Innovation's Photovoltaic Windows [Atria Innovation].

No case studies are available that incorporates both solar concrete and photovoltaic windows for energy saving comparisons over traditional buildings using just fossil fuels for HVAC (Heating, Ventilation and Air Conditioning). The cost savings are expected to be substantial in terms of reliance over fossil fuel.

Solar Heating

Solar heating encompasses designing the building taking into account the heating of a room by the sun, the placement of windows and the circulation of the air throughout the building. Allowance needs to be made for the placement of solar collectors for heating water on the roof and the structural weight bearing for the placement of the heat exchanger, heat store and water cylinder. A typical room incorporating passive solar heating is shown in Figure 8. It is important to ensure that no hot spots or hot rooms occur due to excessive sunshine. Thus it is important to ensure adequate flow and control of air movement throughout the room and building. Automated binds should be incorporated to keep the passive heating of rooms within a comfortable range of temperatures. The motors controlling the binds may be powered by solar cells back-up with battery storage.

Solar Lighting

The costs associated with lighting often takes a second place to the cost due to HVAC requirements. The use of sunlight for lighting may utilise either skylights or a light pipe to reach the interior of buildings, such as down to the basement. Figure 9, shows an example of a 36 m light tube to illuminate the interior of a 12-storey building. Such a design feature needs to be incorporated more in designs to further save electricity.

Figure 8: Solar Passive Heating of a Room [Aitken].

Figure 8 shows the use of skylights for both illumination and solar heating. Whereas Figure 9, shows a light tube for interior lighting.

Figure 9: 36 m Solar Light Pipe in Washington DC, USA [Greendiary].

Pico-hydro Electric Power Generation

Using the kinetic energy of flowing water is nothing new. The innovation is in the miniaturisation of the hydro power generator into a highly efficient pico-hydro generator capable of producing 1 kW of power from streams. This technology is ideal for rural communities situated on land with streams, rivers and other types of flowing water. A case study for a rural deployment in Kenya is given in (Maher, P, 2002). Figure 10 shows a portable hydro-turbine system deployed in Pakistan. Even in urban environments, flowing drainage water from buildings can be used to generate power.

Figure 10: Portable Pico-hydro Power Generation [Paksolarservices].

A case study is described (Velazhagan et al., 2019), where pico-hydroelectric power is generated using consuming water distributed inside a multi-storage building from a water tank and the power stored in rechargeable batteries.

Ground Source Heat Pump

The ground source heat pumps use the warmer and stable underground temperature compared to the above air temperature by burying pipes underground conveying a liquid, such as water. Cold water flows into the ground and is heated or warmed by the underground soil which is then pumped back into the ground-source heat pump to extract the thermal energy. A typical system can be implemented either by burying the pipes horizontally at a shallower depth or burying them deep vertically. This is shown in Figure 11. Typically 50 m (10 m of slinky) pipe is required to generate 1 kW of power. The pipes are usually buried 1-2 m deep in a trench and if buried in a borehole configuration then the depth can be down to 100 m. More energy can be extracted for deeper depth or longer lengths of pipe deployment. Several case studies by the Ground Source Heat Pump Association of the UK is given on their website (GSHPA, 2022).

Figure 11: Ground Source Heat Pump Implementation: Horizontal (left) and Borehole (right) [Kensa].

Micro-CHP (Combined Heat and Power) Generator

Most governments of the world are now encouraging the public to generate their own power on site. Using the Stirling Engine which is a heat engine to convert the differential heat temperature of a fluid into energy. Though no major structural changes are required, installation of micro-CHP systems in domestic settings may simply be the replacement of current conventional boilers and connecting them into the electrical network of the home. Figure 10 shows a simplified block diagram of a micro-CHP system. It shows that it can run on natural gas whilst producing electricity for domestic appliances and thermal energy for heating of the homes. The system also shows the potential to sell-back the excess electricity back to the grid too. A case study showing the benefits of micro-CHP is given in (Micro-CHP, 2015).

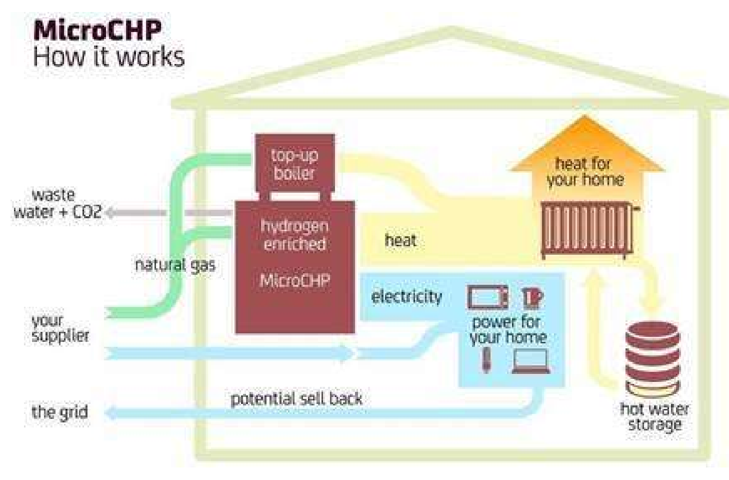

Figure 12: Micro-CHP Generator [Betterworldsolutions].

The microgrid

A microgrid is a localised, energy system that covers a small geographical footprint encompassing a university, hospital or village. Figure 13 shows a typical microgrid.

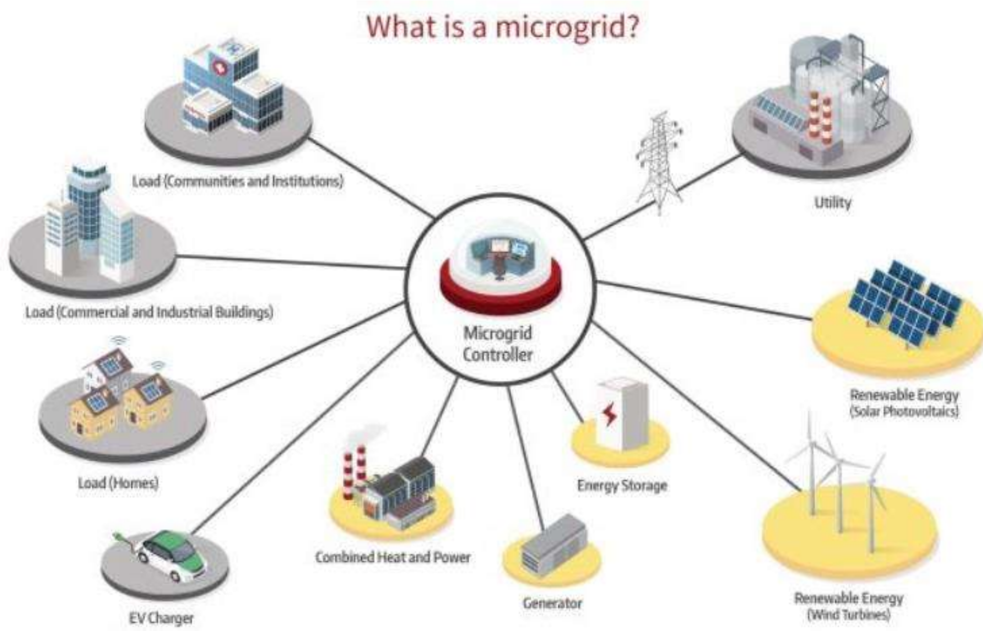

Figure 13: A Generic Microgrid [Microgridknowledge].

The microgrid itself consists of various distributed energy sources, often renewable, such as PV arrays, wind turbines, CHP generators. CHP generators are seen as "virtual power plants" with fast start-up times which can be easily aggregated into the microgrid (Micro-CHP, 2015). Modern housing estates and apartments that are being planned should be set-up on a microgrid basis. The microgrids are eventually linked to the national utility grid.

Storing Excess Energy

When electrical energy is not being utilised, it should ideally be stored for local consumption during peak demand, such as in times of cooking, heating water or cooling (air conditioners). The excess energy could also be exported to the grid. Houses being built should allocate space for the storage batteries and or the ultra-capacitor energy storage system cabinets. Houses should also provide electric vehicle (EV) power outlets for charging. Energy may also be stored as heat in water tanks. A concept house utilising some of the concepts discussed here is shown in Figure 14, below.

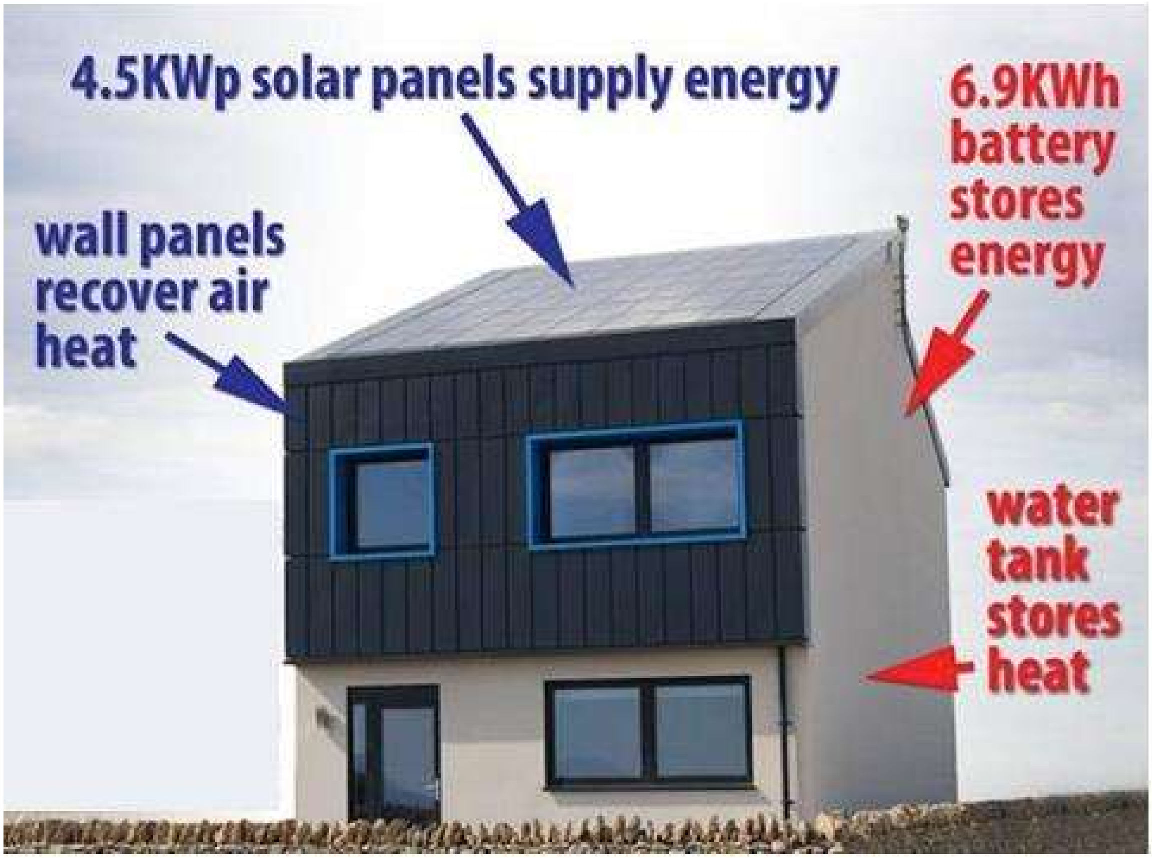

Figure 14: A Concept House Utilising Renewable Energy Sources [Mirror].

Nuclear-Renewable Micro Hybrid Energy System (N-R MHES)

To supply the increasing energy requirements of megacities, the use of nuclear energy should be seriously considered. Even if it is not used, the micro hybrid energy system should be implemented as shown in Figure 15, below. The figure shows how all the various renewable energy sources may be integrated into a microgrid system and finally linked to the electric grid. Figure 15 also shows how the electrical energy storage system is connected to the grid.

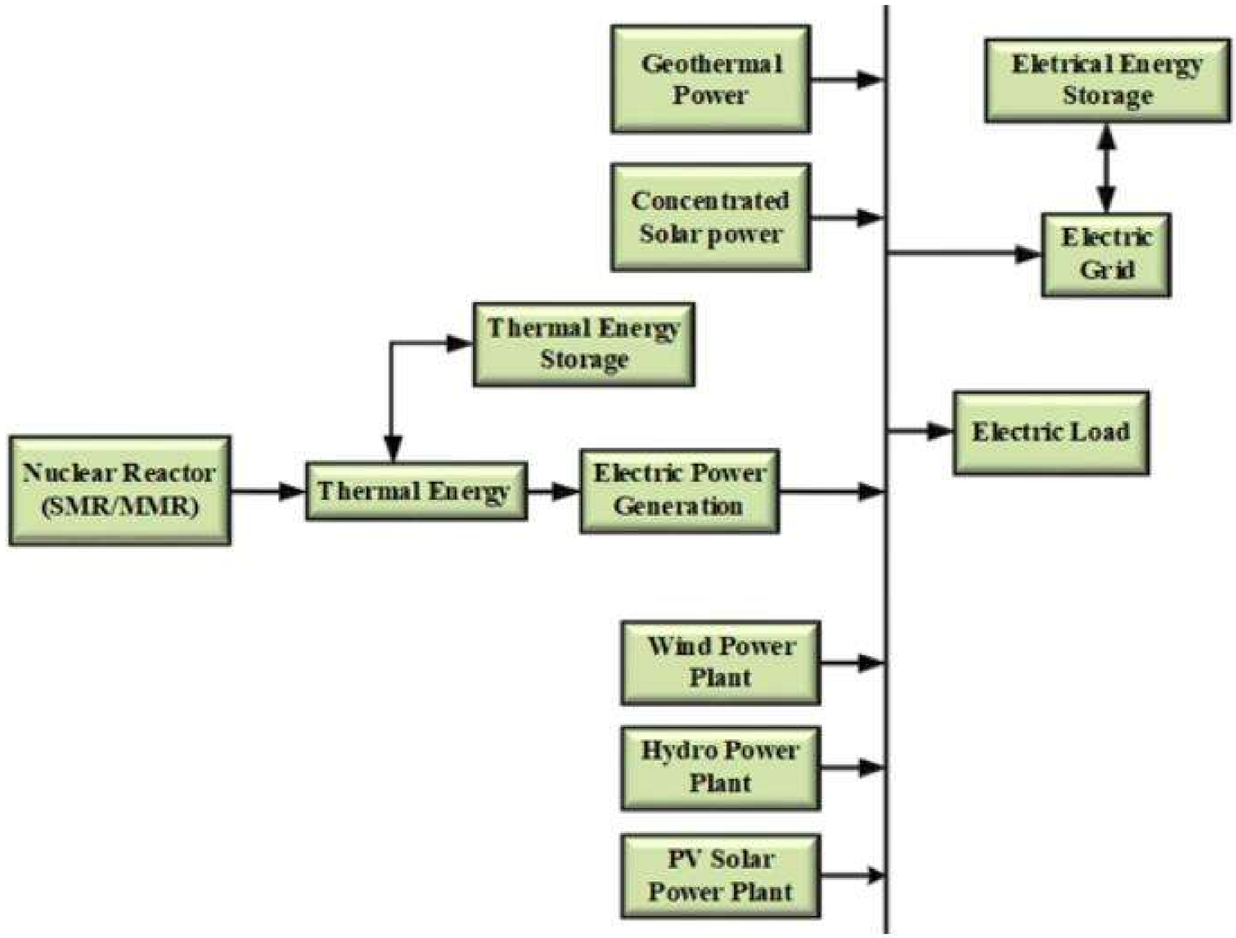

Figure 15: Nuclear-Renewable Micro Hybrid Energy System (N-R MHES) [Smartgrid].

CONCLUSION

The utilisation of energy generating materials in new build is a must to tackle the increasing cost of energy production. Wherever possible renewable energy systems should be retrofitted in already old buildings. The combination of multiple technologies such as PV panels, PV concrete and PV windows should all be utilised in the construction of new buildings whether domestic or corporate.
Geothermal and Ground Source Heat Pump also is a viable technology offering stable heating/cooling.
Insulation is essential for any technology employed to work efficiently. This is particularly true where air source heat pumps are to be installed in old buildings. This is to keep the electricity costs down in running the pumps.
Each house should also generate its own power using CHP systems. Bio-fuel and Biomass fuel sources need to be considered too along with natural oil.
When planning to construct the micro-grid, villages, hospitals and schools should all be linked to the Microgrid Network.
Implementing all these renewable energy sources into buildings will mean the need to go out for people under quarantine is lessened.
The future planning is to seriously consider the use of Nuclear-Renewable Micro Hybrid Energy System (N-R MHES) along with energy storage systems.

External references to case studies have been given wherever possible for each technology. They all show the cost benefits of utilising their respective technologies along with integration into the smart grid.

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