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Green science: Independent building technology to mitigate energy, environment, and climate change

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ABSTRACT

All residential and commercial buildings are connected to conventional electricity, gas, and water supply lines to meet their vital needs, which causes severe environmental crises. Therefore, a green science application is proposed in this article to meet the total energy, water, and gas demands for a building, which can be produced by the building itself without any outside connections and is also 100% clean. To meet 100% of the energy demands of a building, a design theory is implemented wherein at least 25% of the exterior curtain wall skin and roof is used as a blackbody assisted photovoltaic (PV) panel to capture solar energy and convert it to electricity. The domestic water supply is provided by in-house treatment processes (filtration, chlorination, UV treatment and purification) from in-situ groundwater extraction by PV-panel-assisted pumping. Subsequently, the domestic waste undergoes a transformation process wherein sludge, consisting mainly of human feces, is collected in a closed anaerobic detention tank in a cellar and introduced into a bioreactor, enabling the production of biogas by *methanogenesis*; this biogas is then stored and used for cooking and HVAC equipment. Finally, the separated wastewater is treated in the cellar by applying primary, secondary, and tertiary processes and is then used for gardening, irrigation, and landscaping. The combination of these technologies, wherein a building can produce electricity, water, and gas without outside connections, is a major scientific innovation expected to dramatically mitigate the global energy, environmental, and climate change crises.

1. Introduction

Buildings have a significant impact on climate change since they account for almost 40% of energy consumption due to burning fossil fuels [1,2]. To estimate how much energy this represents, let us calculate the value based on annual global energy consumption: world energy consumption in the year 2015 was 5.59×10^{20} J (559 EJ), and nearly 2.236 EJ was consumed by residential and commercial buildings, producing nearly 8.01×10^{11} t CO_2 (218 gtC from construction out of a global total of 545 gtC; 1 gtC=10^9 t C=3.67 gt CO_2) [2]. The amount of energy used by buildings continues to increase due to the new development is occurring rapidly throughout the world. Energy consumption by buildings will continue to increase until buildings can be designed to produce sufficient renewable energy through sophisticated technology. Interestingly, light emitted by the Sun that reaches Earth is one of the most plentiful renewable energy resources [3,4]. The deployment of solar technology must come with clear and defined requirements to ensure that reliable photovoltaic (PV) systems are implemented [5]. Recent research conducted by Anish Mode et. at and presented a thorough numerous literature review on solar energy based electricity, and heat and power production as a renewable energy source [39]. Another study performed by Huihui et. at to investigate the biogas production from wastewater obtained from HTL of straw for bio-crude production, with focuses on the analysis of the microbial communities and characterization of the organics where they found methane yield production is reasonable to utilize it as an energy source [44]. Though several research has been performed to convert solar energy into electricity energy, biogas production from the *methonegenis*, but no research has been conducted as a combined effort to produce solar, gas, and water by an building itself to meet its total energy, gas, and water demand.

Thus, the present research conduction on combined technology application (energy, gas, water) for confirming a zero-emission building (ZEB). It will indeed be the highly innovative technology to balance its energy demands if the building's skin and roof are designed with at least 25% blackbody-assisted PV panels to capture solar energy to meet its total energy demand, which will reduce emissions by 8.01×10^{11} t CO_2 per year [2,6]. It is estimated that 402 ppm CO_2 is currently

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present in the atmosphere, causing global warming; this must be reduced to 300 ppm CO_2 to achieve global cooling at a comfortable rate [7,8]. The use of blackbody-assisted PV panels in each building will eliminate 40% of CO_2 production per year. Interestingly, it will take only $\{\int_{300}^{402} (1-0.4)dx\}$ =61.2 years to cool the atmosphere, resulting in the reversal of climate change after 62 years.

It is well known that water reservoirs play a significant role in the Earth's ecosystem and may contribute to changes in Earth's climate once they become stratified due to water extraction for domestic water supplies [9]. Subsequently, reservoirs warm and generate methane, a greenhouse gas, in the bottom layers that are anoxic (i.e., they lack oxygen), leading to the degradation of biomass through anaerobic processes. In some cases, where flooded basins are wide and biomass volumes are high, the amount of biomass converted to methane results in a pollution potential 3.5 times greater than that of an oil-fired power plant for the same generation capacity. Methane gas is one of the most significant contributors to global climate change [1,9]. It is costly to use reservoir water treatment, supply, and maintenance of city water lines to supply each building to meet our daily water demands. Since groundwater is available within the 200 m energy line everywhere in the world and is mostly purified by natural processes by aquifers, it can be pumped and further treated at a low cost on-site to meet a building's water demand without harming the climate.

The use of a biochemical platform for the production of biofuels (ethanol) and value-added compounds (antioxidants) from grain and tree-pruning as feedstock has been studied by several researchers in the past, but it was found that the production of grain-based and/or tree-pruning bioenergy can have detrimental consequences for soil carbon sequestration, nitrous oxide emissions, nitrate pollution, biodiversity and human health [10–12] and that domestic waste is the best option to produce biogas. Thus, in this research, building domestic waste, including wastewater, that can be collected in a closed detention tank and then separated into two different chambers (for wastewater and feces) was chosen. For context, a person produces 0.4–0.5 kg/day of human feces (solid waste), which can produce 0.4 m^3 biogas/day, which can cook three meals per day for a family of four [44]. Treated wastewater can be used for rooftop gardening and for a building's landscape irrigation. It would truly be an independent building technology that can meet all of its energy, water, gas demands; thus, this capability is expected to play a key role in reducing climate change.

2. Methods and materials

2.1. PV array modeling

In this article, a mathematical model is analyzed that describes the operation and behavior of a PV generator in which the maximum power output can be calculated for a module once the PV solar irradiance on the PV module and temperature is determined [13]. Interestingly, the model can be simplified in terms of the maximum power output, which has a reciprocal relationship with the temperature module and a logarithmic relationship with the solar radiation absorbed by the PV module [14–16]. This model, with the associated calculation procedures, accuracy and parameters of a current–voltage relationship, is presented in Fig. 1) and in more detail in the single-diode equivalent circuit of a PV cell model module (Fig. 2 and 3).

with $I_{pv\text{-}sim}$ is calculated from the model with a diode, using a wide range of variation of the illumination received by the photovoltaic p.

$I_{pv\text{-}sim}$ is calculated based on a model with a diode, using a wide range of variation in the illumination received by the PV panel; p contains various parameters to determine P_1, P_2, P_3, P_4, A, R_s, and R_{sh} and was therefore used as the control for the minimal control strategy to simultaneously achieve a green active and reactive power source with active filtering capability [15,17].

The power output of a PV array is based on solar irradiance and ambient temperature; thus, the model is calculated as follows:

$$P_{pv} = \eta_{pvg} A_{pvg} G_t, \tag{1}$$

where η_{pvg} is the PV generation efficiency, A_{pvg} is the PV generator area (m^2), and G_t is the solar radiation in a tilted module plane (W/m^2). The parameter η_{pvg} is further defined as

$$\eta_{pvg} = \eta_r \eta_{pc}[1 - \beta(T_c - T_{cref})], \tag{2}$$

where η_{pc} is the power conditioning efficiency, which is equal to one when MPPT is used; β is a temperature coefficient (0.004–0.006 per °C); η_r is the reference module efficiency; and T_{cref} is the reference cell temperature in units of °C. The reference cell temperature (T_{cref}) can be obtained from the relation

$$T_c = T_a + \left(\frac{NOCT-20}{800}\right)G_t, \tag{3}$$

where T_a is the ambient temperature in °C, NOCT is the nominal operating cell temperature in °C, and G_t is the solar radiation in a tilted module plane (W/m^2). The total radiation in the solar cell, considering both normal and diffuse solar radiation, can be estimated as

$$I_t = I_b R_b + I_d R_d + (I_b + I_d) R_r \tag{4}$$

The solar cell, which is the building block of the solar array, is essentially a P-N junction semiconductor capable of producing electricity via the PV effect [18–20]. PV cells are interconnected in a series-parallel configuration to form a PV array, and graphene is integrated in the PV module to improve the efficiency of the resulting PV device [16,21].

Using an ideal single diode, as shown in Fig. 2, for an array with N_s series-connected cells and N_p parallel-connected cells, the array current can be related to the array voltage as follows:

$$I = N_p\left[I_{ph} - I_{rs}\left[\exp\left(\frac{q(V+IR_s)}{AKTN_s} - 1\right)\right]\right], \tag{5}$$

where

$$I_{rs} = I_{rr}\left(\frac{T}{T_r}\right)^3 exp\left[\frac{E_G}{AK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{6}$$

and q is the electron charge (1.6×10^{-9} C), K is Boltzmann's constant, A is the diode ideality factor, and T is the cell temperature (K). I_{rs} is the cell reverse saturation current at T, T_r is the cell reference temperature, I_{rr} is the reverse saturation current at T_r, and E_G is the band gap energy of the semiconductor used in the cell. The photo current I_{ph} varies with the cell's temperature and radiation as follows:

$$I_{ph} = \left[I_{SCR} + k_i(T - T_r)\frac{S}{100}\right], \tag{7}$$

where I_{SCR} is the cell short-circuit current at the reference temperature and radiation, k_i is the short-circuit current temperature coefficient, and S is the solar radiation (mW/cm^2). The single-diode model includes an additional shunt resistance in parallel to the ideal shunt diode model. The *I-V* characteristics of the PV cell can be derived using a single-diode model as follows:

$$I = \quad I_{ph} - I_D \tag{8}$$

$$I = \quad I_{ph} - I_0\left[\exp\left(\frac{q(V+R_sI)}{AKT} - 1\right) - \frac{V+R_sI}{R_{sh}}\right], \tag{9}$$

where I_{ph} is the photo current (A), I_D is the diode current (A), I_O is the inverse saturation current (A), A is the diode constant, q is the charge of the electron (1.6×10^{-9} C), K is Boltzmann's constant, T is the cell temperature (°C), R_s is the series resistance (Ω), R_{sh} is the shunt resistance (Ω), I is the cell current (A), and V is the cell voltage (V). The output current of the PV cell, using the diode model, can be described as follows [20,22,23]: