Solar decathlon Europe 2019: The resilient nest as a solar powered and energy efficiency rooftop house for urban density

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Abstract. This paper presents the design concept, and monitoring results of the Resilient Nest which was participated in the Solar Decathlon Europe 2019 competition. The Resilient Nest has been designed as a lightweight rooftop house which can be placed on top of a row house in Bangkok, Thailand to respond an increased urban density. This additional rooftop house does not only increase the living space on an existing building, but it also ensures that the existing building become more viable, comfortable and eco-friendly. A solar energy, both electrical energy from photovoltaic panel and thermal energy from solar collector which are renewable energy, can accommodate the Resilient Nest rooftop as well as the existing building. The monitored results during 10 days competition results showed that the energy balance of the Resilient Nest was net positive of 171.81 kWh which was the highest value compared to other 9 competitors. The Resilient Nest generated 277.78 kWh as the first runner-up for the Energy generation. The power consumption for the HVAC system of the Resilient Nest during 10 days was only 37.65 kWh. Comparing to the suitable air conditioned house recommended by the Government Public Relations Department of Thailand, the Resilient Nest consumed over 14 times less energy because of its high performance thermal insulation, heat recovery system and solar thermal system. The low HVAC power consumption gave high performance for indoor comfort. As a result, the Resilient Nest won a second place in Comfort conditions contest.

1. Introduction
Solar Decathlon is an international collegiate competition initiated by the US Department of Energy [1] which has 10 contests associate with the solar powered and energy efficient house design, construction and operation [2]. The Solar Decathlon Europe (SDE) competition was introduced to Europe since 2007 and was held in Spain and France. The Solar Decathlon competition is not just only the competition in field of architecture but also needed to be integrated with engineering, energy efficiency, sustainability, market viability, and communications as a multidisciplinary project [3-4]. The fourth SDE, Solar Decathlon Europe 2019 (SDE19) was held in Szentendre, Hungary and organized by ÉMI Non-profit LLC. Compared to the other Solar Decathlon competition, SDE19 had
an innovative scope as a value-added renovation of an existing building. KMUTT team from King Mongkut’s University of Technology Thonburi was selected as one of the ten participants with the house named the Resilient Nest. During the competition, the house was monitored with a goal to reach the positive electrical balance [5-6]. The objective of this study was to design, construct, and monitor the Resilient Nest as a net positive electrical balance house which can be placed on top of a row house in Bangkok, Thailand to respond an increased urban density.

2. SDE19 contest

2.1 Contest: Energy balance

The electrical appliances were categorized by power consumption into 2 types which were a fixed load consumption (\(E_f\)) and a variable load consumption (\(E_v\)). The fixed load consumption included the electrical appliances, lighting, and home automation systems. The load consumption for the heating, cooling, ventilation and hot water systems was the variable consumption. There were 5 AC electricity meters (single phase multi-function energy PRO1-Mod and PRO380MOD from INEPRO) [5] installed in the house which were energy production from the photovoltaic panels (\(E_p\)), two for the energy-consumption from the fixed load, the energy-consumption from the variable load, and the grid consumption. The electrical balance (\(E_b\)) can be calculated by using an equation (1). Teams are encouraged to reach the positive electrical balance [6]. If teams’ electrical balance exceeds the upper limit \(E_{BU}\), teams will get full score. If it is less than the lower limit \(E_{BL}\), teams will receive no point. Else, score will be linearly interpolated. These values depend on team’s installed photovoltaic power which is 4.875 kWp. Thus, the \(E_{BU}\) and \(E_{BL}\) values are 54.6 kWh and 35.1 kWh respectively.

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E_b = E_p - (E_f + E_v) \geq 0
\]  

2.2 Sub-contest: Temperature

The sub-contest: temperature monitoring was evaluated within the Comfort conditions contest. The interior air temperature of air-conditioned rooms of living room and bedroom were measured by provided AM2315 sensors from AOSONG (resolution of 0.1 ± 0.2°C, range 10 - 50°C) [5]. The target temperature was 24°C with ±1°C tolerances. If the measured temperature was in the range of 21-23°C or 25-27°C, the linearly scaled reduced points would be applied.

3. Integrated design of architecture and solar system

3.1 Architecture design

The demand for residence in urban especially Bangkok, Thailand is increasing in contrary to the inadequacy of space and the increasing of the estate price. Moreover, the existing buildings inside the city are needed to be renovated. With the huge amount of the row houses or commercial buildings in Bangkok that are abandoned and in un-renovated conditions. KMUTT team proposed the Resilient Nest as an alternative solution instead of demolishing the existing row houses or expands the city to the suburb. The Resilient Nest was designed to be placed on the rooftop of the existing row houses like a bird builds its nest on top of the existing tree. Inspired by the concept of the bird nest, the Resilient Nest does not only increase the living space on the existing building and use the existing row houses for the supporting structure and circulation, but it also ensures that the existing buildings become more viable, comfortable and eco-friendly by the renewable solar energy generation including the electrical energy and the thermal energy. With the Resilient Nest on the rooftop of existing row houses, it will protect the heat that is directly radiated by the sun. In addition, the Resilient Nest was raised and leaves the gap of 60 cm which is able to passively ventilate the heat out from the existing building. These benefits provide a symbiosis relationship between the buildings as shown in figure 1. Apart from the design concept, the neighbourhood integration and urban design have been considered. The installation of the Resilient Nest will increase the urban density and innovatively ensure that the existing row houses will be more viable and sustainable.
To maximize the energy production and minimize the energy consumption, the energy efficiency concept was considered by taking the bioclimatic aspects into account. The Resilient Nest was not designed just only for Bangkok, Thailand, but also for the competition in Hungary which has extremely different climate. The poly-isocyanurate (PIR) insulation with low thermal conductivity of 0.021 W/m²K has been selected as an envelope. The insulation was manufactured as prefabricated elements which not only reduces the effect of thermal bridges but also increase ease of construction. Every sides of the air-conditioned rooms including walls, partitions, floor, and roof were constructed with this prefabricated insulation. With the symbiosis concept and the integration design, the row houses with the Resilient Nest on their rooftop could reduce the grid electrical consumption up to 30% with the clear sky and fully efficient condition.

3.2 Electrical and PV system
The electrical system was designed in accordance with the International Electrotechnical Commission (IEC) standards and local standards of Thailand and Hungary. Electrical loads were classified into three groups which are grid load, prioritized load, and heating, ventilation, and air-conditioning (HVAC) system load as shown in figure 2. The grid load is the electrical appliances generally used but not essential in case of blackout such as outlets, home electronics, kitchen appliance, or cloth washer and dryer. The prioritized load is the essential appliance which should be available in case of blackout including lighting, automation system and refrigerator. The prioritized loads were backed up by batteries and could be continuously operated up to 30 hours without grid supply. The summation of the power measured from meter 2 of grid load and meter 5 of prioritized load was the fixed load in compatible with the rule [2]. The HVAC load is the variable load which was measured by meter 3.

According to the rules [2], fifteen heterojunction monocrystalline cell-photovoltaic panels (PV panel, HIT Panasonic) with 325 Wp production per panel, have been used to produce 4.875 kWp of electrical power. The optimized orientation of the photovoltaic panels was simulated by PVGIS software. The result shows that the optimum azimuth is -2° to the south and the inclination of 17° for Bangkok which will achieve the maximum annual electrical energy production. For the competition in Szentendre, Hungary the optimum azimuth is -5° to the south and the inclination of 36°. However, the team had strategy to maximize the energy production during the competition period which was in summer. With the considering of PV shading analysis, the inclination of 36° may cause magnificent production reduction due to the shading effect. Thus, the inclination during the competition was reconsidered and yielded the most efficient result of 15° inclinations. The inverter used with the Resilient Nest was ABB REACT UNO-4.6-TL with integrated 3 units of 2-kWh battery BATT-AP1. The generated energy was measured with meter 1 as shown in figure 2.
3.3 Mechanical, heating and cooling system

The mechanical, heating and cooling system of the Resilient Nest consisted of HVAC system, hot water system, and ventilation system. Heat Recovery Ventilation (HRV) system was used to exchange heat between the incoming air and exhausted air in order to reduce energy consumption to condition the incoming air directly. The water heating system was designed for the sanitary and air-heating system. To reduce the electrical energy consumption, solar collector and waste heat recovery tank were raised. Three flat plate solar thermal collectors with 5.7 m² gross surface area were installed on the roof to heat up water with solar radiation. The heated water was stored in the hot water storage (HWS) for 300 litres which was integrated with air source heat pump with the heating capacity of 4.0 kW. The heat pump was programmed to be operated as a backup system in case of low solar radiation. The wasted heat recovery tank was installed to recover the heat from the cooling system’s working fluid instead of releasing to the ambient environment. Not only reduced the electrical energy used to heat up water, but the advantage of heat recovery system also increased the coefficient of performance (COP) of the cooling system. The heating and cooling system of this house had the COP value of 4.0 and 4.14. The heating and cooling loads of living room were 6,890 btu/h and 5,327 btu/h respectively. Relatively for living room, the heating and cooling loads were 4,210 and 3,928 btu/h.

Figure 2 also shows that there are 2 fan coil units (fcu) in each conditioned room for heating and cooling systems. The system was designed to be suitable for both Thailand and Hungary which have totally different climate. Unlike Hungary, Thailand has hot climate with no need of the heating system. This HVAC system was purposed since it would be easy for modification. The heating fan coil unit can be removed for the condition of Thailand without much effect on the overall system.

4. Monitored results and discussions

The cumulative electrical energy was measured and represented in figure 3. During the 10 days competition, the Resilient Nest consumed energy for fixed load and variable load of 68.31 and 37.65 kWh respectively. Since the fixed load appliances were used and monitored 24 hours, the fixed load consumption was gradually increased. However, the variable load consumption seemed constant during July 22nd - 23th because it was passive day or the day without using the active HVAC system. The figure also shows that the Resilient Nest generated 277.78 kWh. Comparing with the other competitors, the Resilient Nest was the first-runner up for energy generation as shown in figure 4 with only 2.18% lower than the winner team. The generated energy was much higher than the total consumption, therefore the electrical energy balance became positive of 171.81 kWh. However, at the beginning of the competition, the result shows that during the first day the electrical balance was
negative because the battery was discharged to be empty at first as stated by the competition rule. The grid was consumed to operate the appliances just only when the battery was charging at the beginning. As a result, the Resilient Nest received full score for energy balance sub contest with the highest electrical energy balance. Moreover, the Resilient Nest had the least peak-load consumption compared with the other competitors and won the first place for power-peak sub-contest.

Figure 3 also shows that during the night time where the cumulative electrical generation became constant, the variable load was barely increased. The heating system was needed at night, but the water was already heated during the day and was enough to be used for heating the entire night as resulted in figure 5 that the temperature met the expectation. During the day time, the Resilient Nest was opened for exhibition and the measured temperature was not scored. The active HVAC system was not operated at the moment. So the indoor temperature raised up to the maximum value of 34.1°C. Nonetheless, before the monitored period which was 9PM - 10AM, team had strategy to extremely reduce the temperature lower than the expected range and let the system operated during the scoring period. Also during the passive days, the passive ventilation design of the Resilient Nest gave the results within the scored zone. The Government Public Relations Department of Thailand recommends to use the air-conditioner with power consumption of 600 BTU/hr per square meter for the room under roofs with 2.5-3.0 floor-to-ceiling height [7]. The required power needed for air-conditioning system of an area-equivalent conventional house during 10 days is 530.34 kWh. The Resilient Nest consumes over 14 times less energy because of its high performance thermal insulation, heat recovery system and solar thermal system. Nevertheless, the low HVAC power consumption gives high performance for indoor comfort. With these strategies, the Resilient Nest was scored as the second runner-up in sub-contest: temperature and first runner-up in Comfort conditions contest. Finally, not just only the monitored energy and comfort condition contest, the Resilient Nest is also an alternative solution for urban density issues which was described in the architecture design, as proof by the second runner-up prize in Neighbourhood integration and impacts.

![Figure 3. Measured electrical energy of the Resilient Nest during the competition period](image1)

![Figure 4. Cumulative electrical energy generation](image2)
5. Conclusions
This paper presents the design concept, and monitoring results with a discussion of the Resilient Nest which was participated in the Solar Decathlon Europe 2019 competition, as following:
1) The HVAC system with solar thermal collector, air source heat pump, and waste heat recovery tank saved the electrical energy for water heating. The HVAC system of the Resilient Nest consumed 14 times less energy than the recommendation by Department of Public Relation of Thailand.
2) The fifteen heterojunction monocrystalline cell-photovoltaic panels of the Resilient Nest house generated highest electrical energy of 277.78 kWh during the 10-day competition period. Nevertheless, the Resilient Nest was the net positive electrical balance house.
3) The Resilient Nest is an alternative solution for urban density as proved by the second runner-up prize in Neighbourhood integration and impacts, and first runner-up prize in comfort conditions.

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