Review

Enhancing the Potential of Smart Building for General Hospital: A Case Study in Malaysian Hospital

Mohd Faisal Baharuddin*, Chin Haw Lim and Ahmad Fazlizan

[1] Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia; chinhaw.lim@ukm.edu.my (C.H.L.); a.fazlizan@ukm.edu.my (A.F.)
*Corresponding author: p110062@siswa.ukm.edu.my

Abstract: Hospital Pulau Pinang is the general hospital in Malaysia which targeting energy savings of 10% within five years from 2015 and other sustainability targets such as 3-star Energy Management Gold Standard and Green Building Certification. The targets are beneficial for the hospital itself to establish the Smart Building Program to improve its energy efficiency concurrent with the green policy of the Ministry of Health Malaysia and Sustainable Development Goals by the United Nations.
This paper reviews the background of Hospital Pulau Pinang energy data , energy consumption trending, energy-saving trending, and energy conservation measures taken for the hospital from 2015 to December 2021.The yearly energy consumption baseline taken in 2016 was 27,496,731.00 kWh. It reduced significantly to 21,356,063 kWh in 2021 due to energy conservation measures. As a result, Hospital Pulau Pinang has achieved energy-saving about 16% at approximately RM7.3 million reduction in operational expenditure. The main objective of this paper is to provide further potential energy savings by studying the energy reduction by implementing solar photovoltaics using the simulation method. The simulation method can predict that Hospital Pulau Pinang can achieve another 5,130,000 kWh energy savings annually. This type of simulation has never been done before at a public hospital, and it will give further enhancing strategies to the Smart Building Program itself.
Furthermore, the potential of smart building can be maximized to the next level by simulation, which helps the hospital energy committee make the potential decision on the energy-saving investment.

Keywords: digital twin; energy saving; simulation; solar energy; smart building

1. Introduction

1.1. Background

To achieve established smart building for Hospital Pulau Pinang, the Energy Management Program (E.M.P.) and Sustainability Program (S.P.) are essential and concurrently with requirements in the Concession Agreement (C.A.). Today the entire world has realized the importance of being sustainable, smart building and energy-efficient building, and the hospital must also change eventually. The early 1980s was the starting point of research on making buildings intelligent. (J. Wong, H. Li, S. Wang, 2005). Through the Ministry of Health (M.O.H.), Hospital Pulau Pinang is bound to the Concession Agreement. The contract signed from 2015 until 2025 aims to achieve 10% energy saving for all hospitals in Malaysia and a few other key performance indicators that are subject to terms & conditions. (Ministry of Health Malaysia (M.O.H.), 2015).

The World Summit on Sustainable Development in Johannesburg in 2002 identified health as one of the five big priorities for the future. In summary, hospital buildings should be sustainable, healthy, and technologically aware, meeting the needs of the occupants and building, and should be flexible and adaptable to deal with change. This leads to achieving a building that has with combination of environmental, social and economic values. (Shaza Rina Sahamir, Rozana Zakaria, 2014).

Hospital is using a lot of energy to operate the hospital to meet its healthcare standard. Energy consumption in hospital is relatively high, while energy savings and cost reduction are some of the biggest challenges considered by mist designers, engineers, and decision-makers. Hospital has the highest building energy index (B.E.I.) compared to other building types due to its non-stop 24/7 operations, especially in the pandemic season of Covid-19. (Moghimi, S., Azizpour, F., Mat,2014)

1.2. Smart Building Program Of Hospital.

In line with the national vision to create more green buildings within government building, this concession agreement also included with the Sustainability Program including Energy Management Program (E.M.P. The World Summit on Sustainable Development in Johannesburg in 2002 identified health as one of the five big priorities for the future. In summary, hospital buildings should be sustainable, healthy, and technologically aware, meeting the needs of the occupants and building, and should be flexible and adaptable to deal with change. This leads to achieving a building with the best environmental, social and economic values. (Shaza Rina Sahamir, Rozana Zakaria, 2014).

The program from 2015 until 2021 has started with data collection and energy countermeasure. This paper gives a better understanding of how to maximise the solar photovoltaic potential tailored suit with the Hospital Pulau Pinang building. It can be achieved through building energy simulation, using I.E.S. iCD and VE where the software can generate a digital twin of the hospital. It can simulate the potential energy saving, carbon emission, P.V. electricity yield and P.V. radiation from the interactive dashboard. Determining the potential and calculating the performance of renewables in an urban environment is essential for the design of future urban areas and the retrofit of existing structures. Accurate modelling is essential to achieve this objective. (Jonas Allegrini, Kristina Orehounig, 2015)

2. Methodology

2.1 Case Study Background

Hospital Pulau Pinang is the biggest hospital in the northern region and second-largest hospital in Malaysia which offer clinical services, training & research centre. It is located at latitude 5.42 N and longitude 100.31 E of Peninsular Malaysia. This multiple-building hospital is categorized as a state hospital that first started its operation in 1812 and is managed by the Ministry of Health (M.O.H.) Malaysia. This hospital has a building gross floor area of 119,383.77 $\boldsymbol{m^2}$ with a total air-conditioning area about 37% at 44,799.17$\boldsymbol{m^2}$ with total energy consumption at 27,496,731.00 kWh from 2016 baseline. Most of the buildings are designed with natural and mechanical ventilation with windows.

Hospital Pulau Pinang is a specialist state hospital that acts as a medical referral centre for the northern region of Peninsular Malaysia with multiple disciplines of medical departments with 15 secondary specialist, 34 tertiary specialist, and 16 clinical support services. Its facilities include 1,163 beds, 4749 staff and 24 hours operation. Total electricity consumption for year 2020 is 22,412,620.00 at RM9,600,974.30. Hospital Pulau Pinang is classified as a High Energy Consumption Hospital. The energy consumption in Malaysia increased rapidly every year, with an average of 2,533 GWh per year involving hospitals as major energy users (Sung C.T.B., 2016).

Three methods were involved: Data collection from various documents such as Monthly Energy Report, Detailed Energy Audit (D.E.A), etc. Secondly is the empirical evidence approach by on-site measurement using the Energy Monitoring System as per shown in Figure 1. Furthermore, to enhance the potential saving for the hospital, building energy simulation is used by implementing of the I.E.S. Intelligent Community Lifecycle, which contains iCD & VE software.

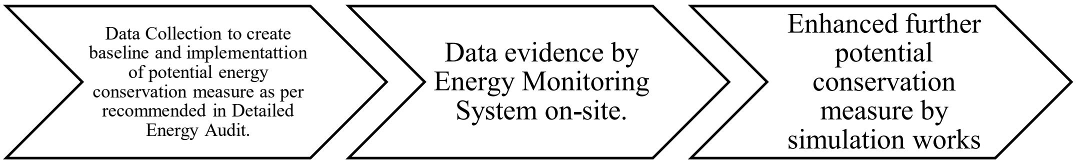


Figure 1. Methodology of enhancing the potential smart building for hospital.

Based on the review, the benefit of this paper has become relevant due to the impact of the energy performance contracting and energy management on the sustainable and smart building solution. Green building has become one the most widespread focus area in scholarly studies, governmental agencies, civil society, and building industries. Many countries have set up their own green rating systems according to their appropriateness for the benefit of the populace and this progress is seen as a world's target in greening the earth. (Shaza Rina Sahamir, Rozana Zakaria, 2014).

3. Building Energy Index (B.E.I.)

In normal condition to determine the performance of the E.M.P. activities at each building or facility, the Gross Floor Area (G.F.A.) is being used as a factor for the calculation of the Building Energy Index (B.E.I.), and it is measured in the unit of kWh/m2/year. The B.E.I. can be used as an indicator to compare the building energy consumption against the floor area. By the end of every interval, the hospital's management will know the hospital's energy performance based on the B.E.I. as the indicator. From the figure 2 below, Hospital Pulau Pinang has shown a significant decrease in B.E.I. This trend can prove the implementation of energy-saving measures. The Hospital B.E.I. is usually higher than a typical office building. The new trend to design and build hospitals using sustainable technology, renewable resources and systems to reduce energy consumption and carbon emissions make it possible to achieve higher building performance.

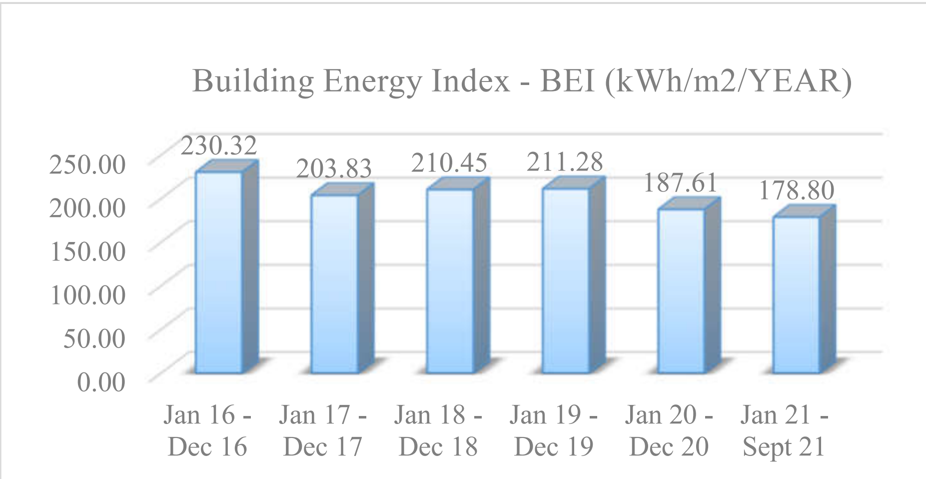


Figure 2. Building Energy Index for Hospital Pulau Pinang from 2016 to 2021. (Monthly Energy Report,2021).

Therefore, the hospital could respond in terms of reducing energy consumption, improving indoor air quality and creating a supportive healing environment. (Shaza Rina Sahamir, Rozana Zakaria, 2014). Electricity consumption in commercial buildings requires serious attention as electricity is the predominant energy source used in these buildings. With increasing fuel price, consumers are now using electricity more wisely. (Ahmad Sukri Ahmad, M. Y. Hassan ,2012)

4. Energy Monitoring System for Smart Building

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 20 September 2022 doi:10.20944/preprints202209.0302.v1

Intelligent buildings, historically and technologically, refer to the integration of four unique systems: Building Automation Systems (B.A.S.), Telecommunication Systems, Office Automation Systems and Computer Building Management Systems. The increasingly sophisticated B.A.S. has become the “heart and soul” of modern intelligent buildings. Integrating energy supply and demand elements has become an important energy efficiency policy concept, often known as Demand-Side Management (D.S.M). (João Figueiredo, João Martins,2010). In the Sustainability Program, the monitoring system is limited to the energy or kWh as per shown in Figure 3. The energy monitoring system installation was first started in 2015.

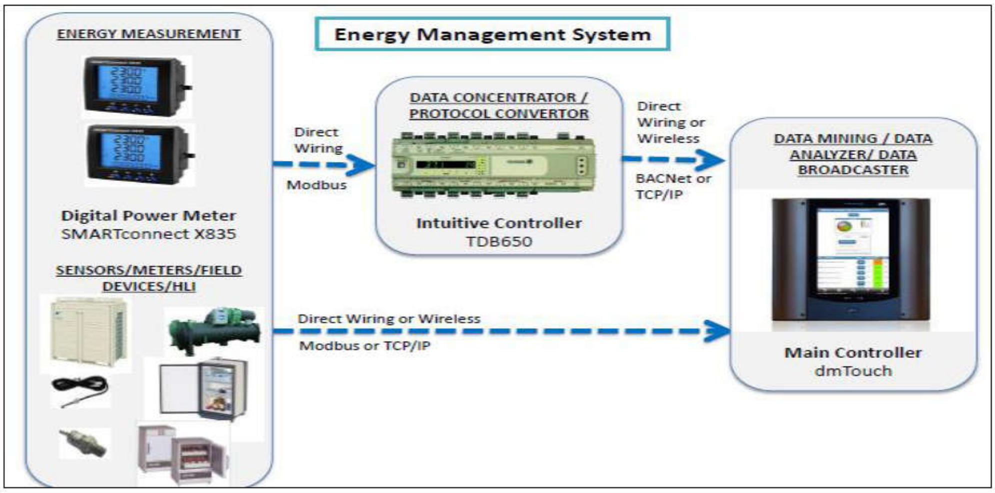


Figure 3. Type of Monitoring System for Energy at Hospital. (Monthly Energy Report,2021).

An Energy Management System (E.M.S.) is a set of software tools used to monitor, control, and analyse a building’s energy consumption. Any building should be considered an installation of EMS for building with air-conditioned space ≥ 4000 m2 (Malaysia Standard on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings, 2014). This make Hospital Pulau Pinang included as the air-conditioned space inside the building is 37.0%. The Energy Management System consists of several components: the main controller, intuitive controller, and set of energy measurement meters, as shown in the following figure. Monitoring, analyze, and optimizing building’s energy consumption is of central importance for the renovation and energy-efficient operation of buildings since it allows the identification and correction of inefficient energy usage. Generally, E.M.S. has three main functions: control of equipment, monitoring of equipment, and integration of equipment sub-systems. The primary purpose of the control equipment is to save energy by (preferably real-time) optimisation system controls. The amount of digital power meter that has been installed for Hospital Pulau Pinang is 178. The data from the digital power meter (D.P.M.) will be transmitted to the intuitive controller. The intuitive controller will then transmit the data to the main controller for further E.A.C analysis for each D.P.M. Scientist across the world is working on energy modelling and control to develop strategies that would reduce a building's energy consumption (V.S.K.V. Harish, Arun Kumar,2015).

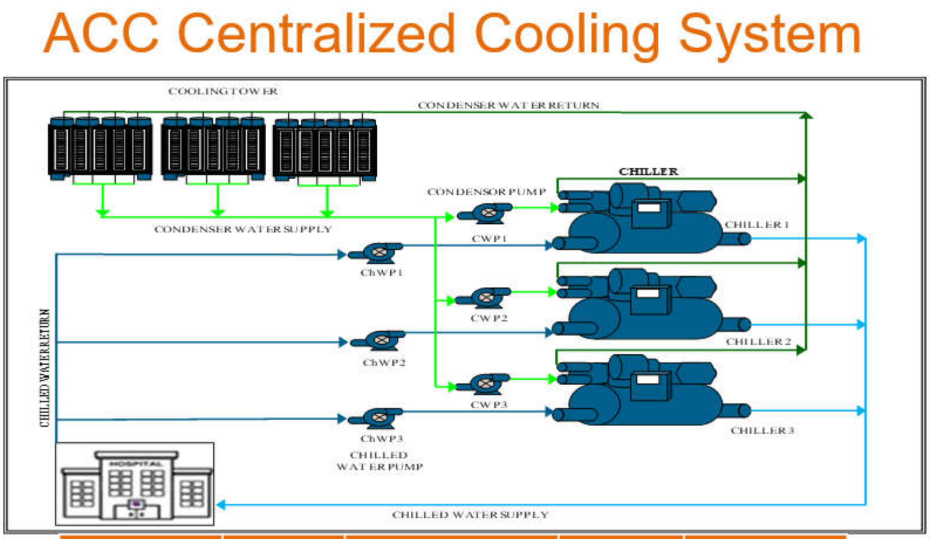
 doi:10.20944/preprints202209.0302.v1

5. Energy Conservation Measure. (E.C.M.)

Hospital Pulau Pinang has benefited a lot from the program of Sustainability Program since a large amount of money has been invested wisely which helps energy saving such as air-conditioning and lighting retrofitting.

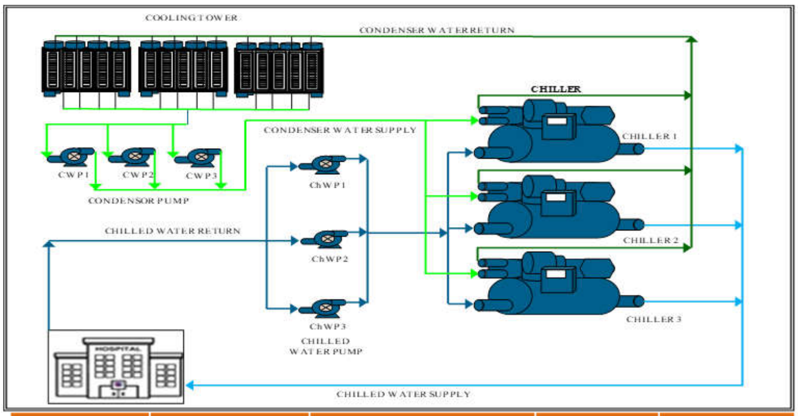
Figure 4. Oil-Free Compressor for Chiller System during Retrofit Program by Energy Performance Contracting with zero initial capital cost.

More than RM2.8 million has been invested in the Energy Management Program. Figures 4 and 5 show a few examples of the activities that have been done to make sure energy saving is achieved.



Description	Brand	Type	Cooling Capacity	Operation Mode
Chiller 1	SMARDT	Magnetic Bearing	250 RT	2 Running 1 St andby
Chiller 2	York	Screw Chiller	250 RT	
Chiller 3	SMARDT	Magnetic Bearing	250 RT	

BLOK B Centralized Cooling System



Description	Brand	Type	Cooling Capacity	Operation Mode
Chiller 1	SMARDT	Magnetic Bearing	500 RT	2 Running 1 Standby
Chiller 2	Dunham Bush	Screw Chiller	350 RT	
Chiller 3	Dunham Bush	Screw Chiller	350 RT	

Figure 5. Chiller retrofit program through E.P.C.

The Energy Service Company (E.S.C.O.), are responsible for designing, supplying, installing, and maintaining the E.P.C. project for Hospital Pulau Pinang. The E.P.C. Contract Period starts from 1st October 2019 until 31st March 2025. For the record, the Physical installation period started 1st October 2019 to 31st March 2020. It was followed by a Performance Period from 1st April 2020 to 31st March 2025 with an expected guaranteed saving of 5,664,691 kWh/year or RM 2.3 million. This attractive and practical option can extensively contribute to energy savings and environmental benefits. It has been reported that such an intelligent building monitoring and control system can result in an approximately 20% savings in energy usage, a substantial step toward the realisation of smart building automation and management. (James, D., Marcus, K., Vladimir, B, 2008)

6. Digital Twin Technology

Traditionally, digital twins were used to improving the performance of a single asset such as a car, but more recently, digital twins have been applied to systems of assets or an entire organisation. (Mohsen A. Jafari, 2020). A significant portion of the energy consumed in buildings is wasted because of the lack of controls or the failure to use existing building automation systems (B.A.S.s) properly. Much of the waste occurs because of our inability to manage and control buildings efficiently. Over 90% of the buildings are either small-size (<5,000 sf) or medium-size (between 5,000 sf and 50,000 sf); these buildings currently do not use B.A.S.s to monitor and control their building systems from a central location. (Katipamula, 2012). Over the past decades, detailed individual building energy models (B.E.M.) on the one side and regional and country-level building stock models on the other side have become established modes of analysis for building designers and energy policy makers, respectively. (Christoph F. Reinhart, 2016). Hospital Pulau Pinang does have an energy monitoring system, but it is only limited to data presentation with no analysis or simulation can be generated from the system. It will be significant if the energy data can be analyzed, simulated, and presenting the data in the interactive platform. This attractive and practical option can extensively contribute to energy savings and environmental benefits. It has been reported that such an intelligent building monitoring and control system can result in an approximately 20% savings in energy usage, a substantial step toward the realisation of smart building automation and management. (James, D., Marcus, K., Vladimir, B, 2008)

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 20 September 2022 doi:10.20944/preprints202209.0302.v1

Nowadays, modelling and simulation are standard processes in system development, e.g. supporting design tasks or validating system properties. Firstly, simulation-based solutions are realized during operation and service for optimized operations and failure prediction. In this sense, simulation merges the physical and virtual worlds in all life cycle phases. (Boschert S., Rosen R.,2016) For this case study, building modelling through digital twin technology uses software such as I.E.S. Intelligent Community Lifecycle (I.C.L.) software can generate data and provide information to enhance energy performance analysis. The I.C.L. consists of Intelligent Community Information Model (iCIM), Intelligent Portfolio Information Model (iPIM), Intelligent Community Design (iCD), Intelligent Control and Analysis (iSCAN) and Intelligent Virtual Network (iVN). Scientist across the world is working on energy modeling and control to develop strategies that would reduce the building's energy consumption (V.S.K.V. Harish, Arun Kumar,2015).

Hospital Pulau Pinang building-related information can be collected and visualized as the digital twin of the hospital to the energy management committee with an interactive platform. Now, building energy modelling and control is an inter- disciplinary area of study, that involves concepts and studies of electrical and electronic engineering, mechanical engineering, civil engineering, and architecture (V.S.K.V. Harish, Arun Kumar,2015). Miniaturization and price decline enable the integration of information, communication, and sensor technologies into virtually any product. Products become able to sense their state and the state of their environment. Paired with the ability to process and communicate, this data allows for the creation of digital twins. The digital twin is a comprehensive digital representation of an individual product that will play an integral role in a fully digitalized product life cycle.(Sebastian Haag, Reiner Anderl,2018)

6.1. Smart Building Energy Simulation

Hospitals in Malaysia have been exposed to the idea of Industrial Revolution 4.0 to operate the buildings with sustainable approaches. Align with the government's intention to reduce greenhouse gas emissions, converting the existing hospitals into smart hospitals will contribute largely as the buildings that operate in hot and humid climates are currently using enormous amounts of energy consumptions to maintain the thermal comfort level reduce infection control rate. As the public hospitals have already implemented the energy management program across Malaysia, they barely need a platform that enables monitoring and simulation. B.I.M. energy consumption analysis can compare different materials, examine the performance of various materials, and select the most suitable and most energy-efficient materials for building structure maintenance. (Weixi Wang, 2022). A new phase of energy monitoring is to leverage the digital twin technology, which will bring a new phase of the internet of things (IoT) to the energy management program itself. The building energy simulation tools perform the heat balance calculation based on the physical properties of the building, such as the material, orientation, the mechanical systems operating in the building, and the dynamic inputs such as occupancy, lighting, weather, etc. Building energy simulation tools have become a popular method to predict the behaviour of a building during the initial design stage. The building designers can optimise the building energy performance from predicted values early in the design stage. (Mohd Ashhar M, Haw L,2022)

 doi:10.20944/preprints202209.0302.v1

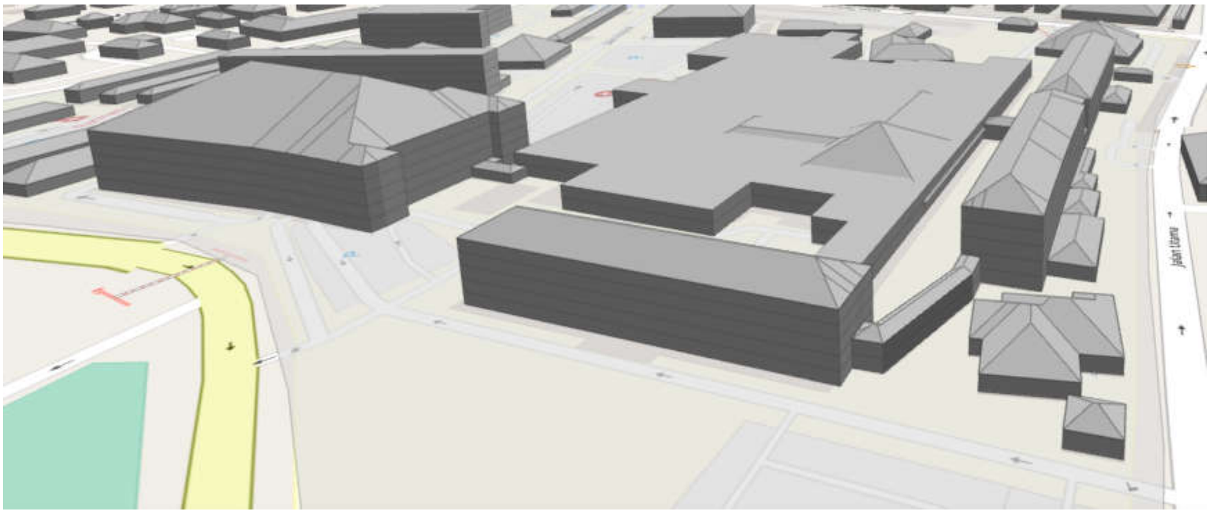


Figure 6. Digital Twin of Hospital Pulau Pinang.

Energy efficient Building Digital Twins (B.D.T.s) are researched using Building Information Model (B.I.M.) to explore the key techniques of Digital Twins (DTs) (Weixi Wang, 2022). By using the I.E.S. Intelligent Community Lifecycle software to create the three-dimensional digital twin of the hospital as per shown in Figure 6, the energy simulation can be produced and thus the Building Energy Index (B.E.I.), Cooling, Energy Consumption, Lighting energy consumption in kWh/m2/year and Annual Carbon Emission of the hospital in tCO2 for Hospital Pulau Pinang are generated in an interactive platform that can be accessed from web browser. Apart from active measures, many more energy-saving potentials can still be explored through passive strategies. The simulation method is used to establish an energy baseline as the basis for predicting energy saving potential for passive strategies that cannot not be measured through an energy audit. Combining of these methods is essential to optimise the potential of energy saving through active and passive strategies that have so far never been implemented in any public hospital in Malaysia. (Abd Rahman N, Lim C, Fazlizan A, 2021)

All information was generated by I.C.L. software and the digital twin for hospitals was modelled according to Autocad & google maps. Some information was taken with the help of a drone view. The results of energy simulation by software can be shown in table 1.

Table 1. The Attributes Summary Of The Hospital Pulau Pinang by simulation.

Hospital / Indicator	AVERAGE ENERGY USER INTENSITY (E.U.I.) kWh/m2/yr	AVERAGE CO0LING ENERGY (kWh/m2/yr)	AVERAGE LIGHTING ENERGY (kWh/m2/yr)	Annual CO2 emission (tCO2)
Hospital Pulau Pinang	249.66	62.51	27.05	28081

Further enhancement of the energy conservation measure is taking place with the implementation and integration of the renewable energy system in the hospital buildings. By simulation of I.E.S. iCD software, it can generate the best position of solar photovoltaic (P.V.) based on sun path, analyse the solar photovoltaic (P.V.) radiation, site solar photovoltaic (P.V.) electricity yield and furthermore simulate the potential total solar photovoltaic (P.V.) contribution. The capacity of the solar photovoltaic (P.V.) system will be sized according to the roof surface area of the Hospital Pulau Pinang as can be shown in Figure 7 below.

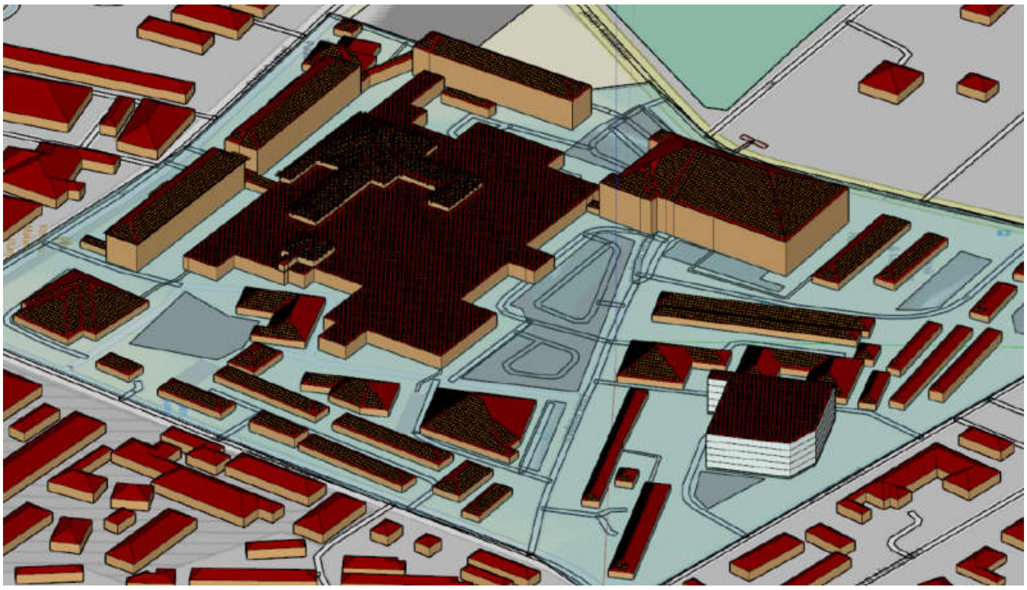


Figure 7. The Solar P.V. positions are generated by the iCD solar assessment simulation.

7. Results and Discussion

The energy report showed significant energy saving for the hospitals. The energy management system and utility bills show that the energy consumption from 2017 to 2021 is decreasing, and total energy saving can be summarized in the table below. Approximately RM 7.3 million has been saved from 2017, and it can be concluded that the program was successful and has achieved its target as per Table 2.

Table 2. Total saving since 2017 until 2021. (Monthly Energy Report,2021).

Year	Total saving in ringgit (RM) equivalent
2017	RM1,475,023.25
2018	RM827,700.25
2019	RM285,189.10
2020	RM1,844,557.40
2021	RM2,876,843.50
Overall	**RM 7,311,892.10**

A Smart Hospital model can be utilized by Energy Management Committee (E.M.C) for a particular hospital or even at the Ministry level in Putrajaya, and it can also be extended throughout the other hospital in Malaysia. For the result of the simulation works, implementing the solar photovoltaic (P.V.) at the best possible location as recommended in the software. It can be further improve energy saving by contributing about 5,130,000 kWh more to the existing saving that the hospital has achieved. In terms of carbon emission reduction, if the hospital implements the solar P.V. as per simulation, approximately about 3,801 tCO^2e can be offset from the total carbon emission. All the results from the simulation can be analyzed and visualized to the hospital management levels in an interactive dashboard.

8. Conclusion

After all, achieving the energy-saving for at large hospital is not an easy task and it has been shown that large hospitals such as the Hospital Pulau Pinang needed almost five years to achieve such energy savings. The right policy and top management trust in the energy committee to fulfil the program are critical factors. Driven by the high standard in concession agreement requirement, a journey for the smart building is in the proper structure, and steady investment is needed to see this program continuously improve in the next phase, renewable energy, particularly solar energy. For more than a 5-year energy management program, this hospital need few more investments in retrofitting the HVAC. They can look for solar P.V. to improve energy saving in the future as recommended by the simulation to further enhance the potential for smart building.

The ability to assess, monitor, analyse and manage these public hospitals energy consumption throughout Malaysia is a sustainable approach to make the idea of Smart Hospital. Implementation of digital twin technology by I.E.S. software can help the committee decide on the suitable investment for energy-saving measures and monitor the energy data from the fingertips.

The enormous amount of energy-saving from large hospitals, which have never undergone any energy management program, will significantly succeed with the right and structured policy and management. Hopefully, the figure and exposure from this review can inspire any type of building to achieve the same goals as Hospital Pulau Pinang.

Acknowledgments: Thanks to all the person that involve in this review and case study that eventually will help the hospital in Malaysia to maximize their potential to become a smart building.

References

1. João Figueiredo, João Martins, Energy Production System Management – Renewable energy power supply integration with Building Automation System, Energy Conversion and Management, Volume 51, Issue 6, 2010, Pages 1120-1126,
2. Moghimi, S., Azizpour, F., Mat, S. et al. Building energy index and end-use energy analysis in large-scale hospitals—case study in Malaysia. Energy Efficiency 7, 243–256 (2014)
3. Ahmad Sukri Ahmad, M. Y. Hassan, H. Abdullah, H. A. Rahman, M. S. Majid and M. Bandi, "Energy efficiency measurements in a Malaysian public university," *2012 IEEE International Conference on Power and Energy (PECon)*, Kota Kinabalu, 2012, pp. 582-587, doi: 10.1109/PECon.2012.6450281
4. Shaza Rina Sahamir, Rozana Zakaria, Green Assessment Criteria for Public Hospital Building Development in Malaysia, Procedia Environmental Sciences, Volume 20, 2014, Pages 106-115, ISSN 1878-0296
5. J. Wong, H. Li, S. Wang, Intelligent building research: a review, Autom. Constr. 14 (1) (2005) 143–159
6. James, D., Marcus, K., Vladimir, B., "Specification of an Information Delivery Tool to Support Optimal Holistic Environmental and Energy Management in Buildings", National Conference of IBPSA-USA, pp. 61-68, 2008
7. Sung C.T.B., 2016, "Electricity demand, economic growth, and sustainable energy resources in Malaysia". Extraordinary mind discuss ideas, pp. 1-8
8. V.S.K.V. Harish n, ArunKumar, (A review on modeling and simulation of building energy systems), 2015.
9. Jonas Allegrini, KristinaOrehounig (A review of modelling approaches and tools for the simulation of district-scale energy systems), 2015.
10. Ministry of Health Malaysia (M.O.H.) (2015). "Concession Agreement in respect of provision of Hospital Support Services at Contract Hospital". Ministry of Health Malaysia, Putrajaya
11. Katipamula, Srinivas; Underhill, Ronald M; Goddard, James K; Taasevigen, Danny J; Piette, M A; Granderson, J; Brown, Rich E; Lanzisera, Steven M; Kuruganti, T (2012) Technical Report: *Small- and Medium-Sized Commercial Building Monitoring and Controls Needs: A Scoping Study*
12. Boschert S., Rosen R. (2016) Digital Twin—The Simulation Aspect. In: Hehenberger P., Bradley D. (eds) Mechatronic Futures. Springer, Cham.
13. Sebastian Haag, Reiner Anderl, Digital twin – Proof of concept, Manufacturing Letters, Volume 15, Part B, 2018, Pages 64-66,
14. Abd Rahman N, Lim C, Fazlizan A, - Optimising the energy saving potential of public hospital through a systematic approach for green building certification in Malaysia – 2021.
15. Christoph F. Reinhart, Carlos Cerezo Davila, - Urban building energy modeling – A review of a nascent field – 2016.
16. Weixi Wang, Han Guo, Xiaoming Li - Deep learning for assessment of environmental satisfaction using BIM big data in energy efficient building digital twins – 2022.
17. Mohsen A. Jafari, Esmat Zaidan - Improving Building Energy Footprint and Asset Performance Using Digital Twin Technology – 2020.