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Energy Audit and Management System for Smart Classroom of Green Design Building

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Abstract. The design of an energy audit is the first step in the energy management process to support the 12th SDGs program on responsible consumption and production in achieving energy sustainability. The energy audit plan is applied to the smart classroom equipped with SPEM (Smart Plug Energy Monitoring) by considering thermal comfort based on the results of the CFD simulation using the CLTD calculation approach and finding the proper number and position of the air conditioning location. To maintain the comfortable condition of a smart classroom that has 9.3 m in length, 8.3 m in width, and 3 m in height, and 21-person capacity plus various types of equipment inside with a cooling load of 11364,169 Watt or equivalent to 38776,159 Btu/hour, 2 units of 2 HP air conditioning with a capacity of 19000 Btu/hour per unit are required. EMAS (Energy Audit and Management System) is a program designed by combining the results from CFD calculation concepts with conventional energy audit concepts to calculate Energy Using Intensity (EUI) and find the potential for energy savings while maintaining the thermal comfort of the room continuously in real-time. The ideal position for the smart classroom was determined to be on the south wall, which meets the thermal comfort standards and has 24 out of 27 airflow velocity measurement points that comply with SNI 03-6572-2001.

1. Introduction

Like many countries around the world, Indonesia faces challenges related to population growth. Population growth will have an impact on various things, including energy consumption. Electricity is an energy consumption that will increase due to the rising population and expanding economy. More energy usage will lead to more greenhouse gas (GHG) emissions and pollution, seriously impacting the global environment. Based on Indonesia's Environmental Status, the proportion of PLTU activities to air pollutants in the form of NO₂ gas is 169,041.99 tons/year, SO₂ gas is 245,759.95 tons/year, and TSP is 174,112.93 tons/year[1]. Thermal power plants primarily



rely on fossil fuels, including coal, to convert water into superheated steam. This implies that greenhouse gas emissions (GHGs) from electricity production can be reduced, and coal consumption as a fuel source can be minimised[2][3]. Natural resource reserves of fossil fuels are depleted day by day; therefore, energy saving is an important thing to do in all fields. Energy savings, switching to the use of renewable energy fuels like solar cells [4], and the use of green technology, in manufacturing [5], [6], machinery [7], and buildings [8] are some of the efforts to achieve this goal. Apart from saving energy, safety, and comfort have also become a concern since the industrial era of 4.0. Currently, various related research results have been implemented in various matters such as the development of smart manufacturing [9][10], smart homes, smart buildings[11], and smart classrooms in educational buildings[12].

A smart classroom is commonly part of a smart building with a green building oriented too. A smart classroom was built to create comfortable room conditions while studying with good lighting and proper air conditioning without ignoring the concept of energy saving. Research has reported that employing digital technologies in smart rooms could reduce energy consumption by 10% by exploiting real-time data to improve operational efficiency[13]. In contrast to the smart room, which has a very varied variety of electrical equipment, in the smart classroom, there are relatively fewer, and the electrical equipment that requires the most power is the air conditioning (AC). According to this reason, then the capacity, number, and position of its placement in the classroom need to be planned as optimally as possible. Optimization is done by considering the number of lights, the power required, the number of people in the room, the position, and several other things that need to be considered. Electricity is wasted in classrooms where all the lights are on and even air conditioning is installed, even when there are no students or faculty. To reduce power consumption in the classroom and save even more, the power-saving smart classroom project will automatically turn off lights and fans or air conditioners when the last person leaves the classroom. A classroom at XYZ Education and Training Centre building in Jakarta will be prepared to be a smart classroom. The design of the smart classroom will be simulated and analysed for preliminary study. The energy audit system is designed to assess the energy usage of a smart classroom and explore ways to improve energy efficiency. This is achieved using tools developed as part of the Energy Audit and Management System, which serves as the innovation of the research.

2. Literature Review

2.1. Energy Management and Energy Audit

Based on PERMEN ESDM No. 14 of 2012, the definition of energy management is an integrated activity to control energy consumption to achieve effective and efficient energy utilization to produce maximum output through structured and economical technical actions to minimize energy use including energy for the production process and minimize consumption of raw materials and supporting materials. The initial step of energy management is an energy audit. Energy audits are deemed the first step in increasing energy efficiency within an organisation[14]. According to the European technical standard EN 16247[15]. An energy audit is a systematic and comprehensive analysis of the energy performance of an organisation, its equipment, systems, or processes. The energy audit aims to identify and propose energy savings opportunities.

2.2. Energy Audit

The energy audit is a technique used to calculate the amount of energy consumption and identify ways to save it. The Energy Audit aims to identify a picture of energy use and seek efforts to

improve energy use efficiency. Referring to the Indonesian National Standard (SNI) Number 03-0196:2010[16]. A short energy audit is an energy audit activity that includes historical data collection, available building documentation data and observations, calculation of Energy Using Intensity (EUI) and its trends, potential energy savings, and preparation of audit reports. The initial energy audit is an energy audit activity that includes historical data collection, available building documentation data, instantaneous observations and measurements, EUI calculations, and trends, energy-saving potential, and preparation of audit reports. Detailed energy audit (detail audit) is an energy audit activity that is carried out when the EUI value is greater than the specified target value, including the collection of EUI calculations and trends, potential energy savings, technical and financial analysis, and preparation of audit reports. Energy audits can be implemented in various fields with various objectives. An example of implementing an energy audit at a tyre manufacturing facility in Tangerang focuses on identifying areas of energy consumption and detecting oversupply or inefficient power use. The energy audit implementation in high-rise buildings at one of the universities in Jakarta aims to map the installation of electrical networks and analyse the results of electrical energy audits and opportunities for implementing energy management systems based on ISO 50001:2011[17]. In this research, the energy audit design system will be built in a short energy type. The design system will then be used as a guide to building smart energy audit tools is a novelty of the research.

3. Experiments

3.1. Methodology

The methodology used in this research involves both analytical methods and CFD simulations. The heat load in the Smart Classroom and the total cooling load required will be calculated using the analytical method. This process helps establish the specifications for the cooling capacity and the air output velocity of the air conditioning system, ensuring that the room reaches and maintains a comfortable condition.

Then the model of the airflow generated by different evaporator placement variations in the room will be simulated by CFD software, and the parameters and boundary conditions will be set based on actual conditions, as done in previous research [18][19], while the environmental conditions are adjusted to reflect those in the surrounding area of the room. Once the simulations are completed, each result from the different evaporator placements is analysed. Data on temperature and airflow velocity are collected at predetermined measurement points. This data then, compared with the comfortable temperature limits and the maximum airflow velocity recommended by SNI 03-6572-2001. The ideal evaporator position is determined based on the room's average temperature and the number of measurement points that meet the SNI 03-6572-2001 standard [20]. The data from the simulation and the calculation result will be used to make the layout design a smart classroom.

The smart classroom layout will become input for EMAS, a program which is used to audit energy autonomously. EMAS will calculate the prediction of power consumption and electrical costs that must be paid. The program will recommend improvement of the layout until achieves the optimum layout according to technical, ergonomic and economical parameters.

3.2. Classroom Data

The initial classroom data drawing that will be built to be a smart classroom can be seen in **Figure 1**. Smart Classroom walls are included in the type D wall type, namely brick lining with concrete

blocks and plaster. There are concrete columns on each side of the wall. In addition, there is also a window with a single sheet glass type of 10 mm thickness equipped with bright roll curtains as a cover. The height of the window is 1.2 m from the base of the room (Figure 2.). The average outdoor temperature (T_m) is 29.7°C and the room temperature to be achieved, (T_i) is 22°C.

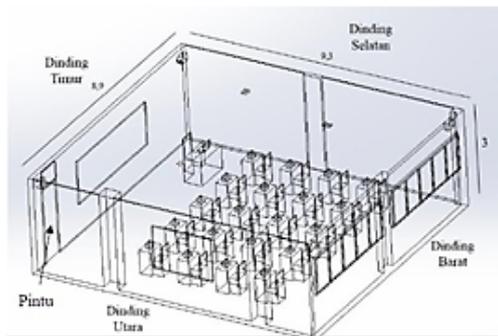


Figure 1. Smart Classroom Layout

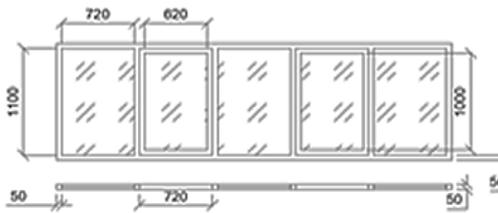


Figure 2. Smart Classroom Window Dimension

In this Smart Classroom concept, there are heat loads from outside the room, heat loads from inside the room, and heat loads from infiltration and ventilation as in Table 1.

Table 1. The Source of Heat

The sources of heat load	The source of indoor heat load	The sources of infiltration and ventilation heat load
<ul style="list-style-type: none"> • Wall • Glass • Partition (room divider) 	<ul style="list-style-type: none"> • 25 pieces of 36-Watt TL lamp • 21 occupants (teacher&20 students) • 3 pieces 7-Watt LCD Smart Boards • 25-Watt 15-Watt Smart Tablets • 50-Watt teaching laptop • 2 pieces 10-Watt sensor cameras • 4 pieces 6-Watt wall speakers • Wi-Fi router 10-watt 	<ul style="list-style-type: none"> • Inner wall • Ceiling • Door • Electric socket • Window with frames

The air properties used in this simulation are Outlet Temperature (T_o)= 295 (°K), Initial Temperature (T_i) -300 (°K), Density (ρ)=1.225 (kg/m³), Velocity (v)= 4.6 (m/s), Absolut Viscosity (η) = 1.79 E-05 (N.s/m²), Ratio of Specific Heats =1.4. The parameters of the simulation are auto

mesh meshing, gravity= -9,81 m/s², energy equation models, K-Epsilon Viscous Model, and Initialization Standard.

3.3. The Phases of the Design Process

The phases of the energy audit system design process in this research will follow the flow diagram in **Figure 3**.



Figure 3. The steps of the energy audit system design process

1. Smart Classroom AC Layout Design

Smart class AC layout design using CLTD analysis method and CFD simulation with ANSYS Fluent. The simulation results will determine the position of the AC, data on temperature, and airflow velocity at measurement points and compare them with the limit values of comfortable temperature and maximum airflow velocity recommended by SNI 03-6572-2001. The summary of the simulation results will be the input for the proposed audit system.

2. Energy Audit and Management System (EMAS) Design.

In this phase, the short energy audit system will be designed. The steps of input data from preliminary study results will be processed and analyzed in terms of economic aspects such as estimation of power consumption and electrical cost. The IoT needs for smart classroom operational monitoring and the scheme of cyber-physical systems will be determined.

3. Verification of EMAS

The last stage to be carried out is the verification process of the EMAS system design. The design will be verified by the logical relation test method.

4. Results and Discussion

4.1. Smart Classroom AC Layout Design

Based on the results of the CLTD calculation, which is calculated at the highest heat load, the total heat load value (total) is the result of the sum of Effective Room Sensible Heat (ERSH) and Effective Room Latent Heat (ERLH).

Outdoor sensible heat load	= 4633,333	W	Indoor latent heat load	= 1949,8	W
Indoor sensible heat load	= 2511,24	W	Latent heat load of	= 1192,575	W
Sensible heat load of infiltration	= 536,070	W	infiltration and ventilation		
<u>and ventilation</u>					
<u>Total</u>	= 7680,643	W	<u>Total</u>	= 3142,375	W
Safety Factor 5%	= 384,032	W	Safety Factor 5%	= 157,119	W
<u>ERSH</u>	= 8064,675	W	<u>ERLH</u>	= 3299,494	W

Then the total calorific load in the room is Grand Total = ERSH + ERLH, 11364,169 W or 38776,159 BTU/h. The value of the calorific load is the heat that must be removed by the air

conditioner (AC) or can be called the cooling load. The number of air conditioners needed to achieve and maintain comfortable conditions is 2 units with a cooling capacity of 19000 Btu/hour, AC power capacity of 2 PK, and air velocity output of AC of 4.6 m/s. Based on SNI 03-6572- 2001 to maintain comfortable conditions, the speed of air falling over the head should not be faster than 0.25 m/s. The result of the CFD simulation can be seen in **Figures 4 and 5.**

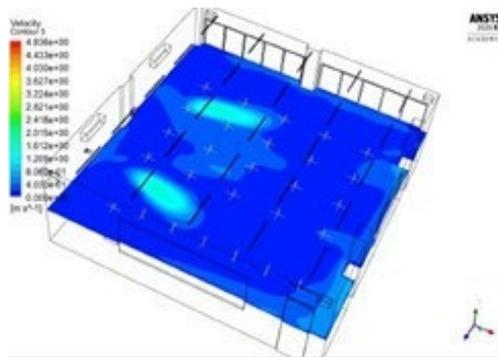


Figure 4. South wall airflow distribution of evaporator at height 1.35 m from floor

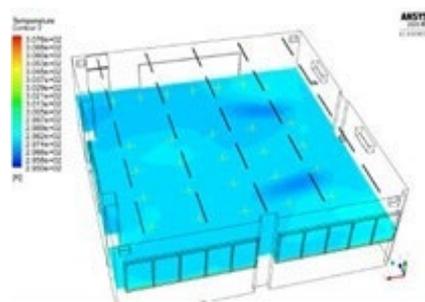


Figure 5. South wall temperature distribution of evaporator at height 1.35 m from the floor

4.2 Determining the Ideal Evaporator Position

The ideal evaporator placement position will be determined based on the results of the average room temperature and the results of the air velocity at each measurement point that meet the recommended standards of SNI 03-6572-2001 in the case of thermal comfort. A comparison of the results of the average room temperature can be seen in **Figure 6.**

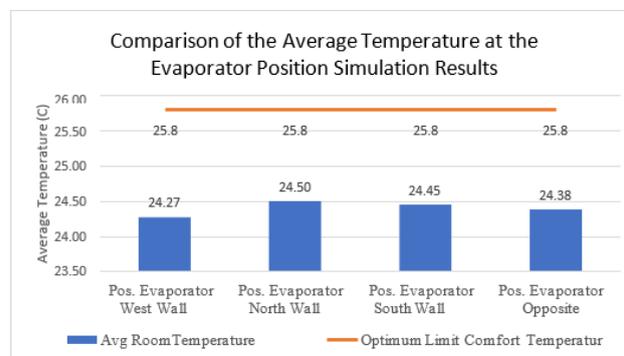


Figure 6. Comparison of average room temperatures from simulation results

Based on the comparison of the average room temperature from the simulation results in **Figure 6** above, all average temperature results for each simulated room fall within the optimal comfort category according to the thermal comfort standard SNI 03-6572-2001. Therefore, it can be concluded that the four planned simulation results meet the thermal comfort standard in terms of average room temperature. A comparison of the number of airflow velocity measurement points that meet the recommended velocity standards in SNI 03-6572-2001 can be seen in **Figure 7** below

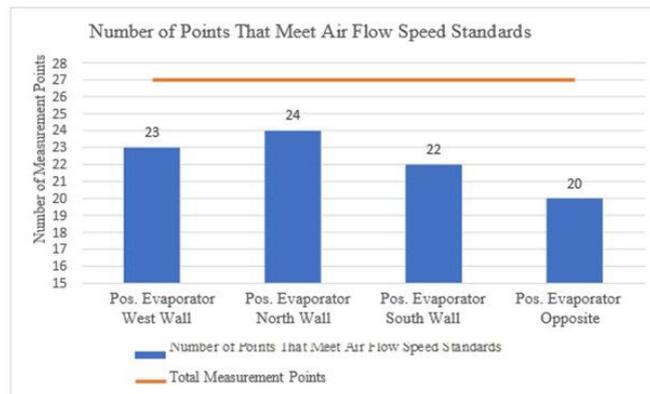


Figure 7. Comparison of the number of points that meet the airflow speed standards from the simulation results

Based on the comparison of airflow velocity measurement points meeting the recommended standards of SNI 03-6572-2001 for each evaporator position, as shown in **Figures 7** and **8**, the evaporator placed on the south wall had the highest number of compliant points, with 24 out of 27. Thus, the south wall position is deemed the most ideal for implementation in the Smart Classroom concept at the XYZ Training Center, based on CFD simulations. This placement meets both the optimal thermal comfort category and the highest number of airflow velocity points that comply with SNI 03-6572-2001

4.3 . Energy Audit and Management System (EMAS) Design

This phase involves designing an Energy Audit and Management System (EMAS) that will be used to audit smart classrooms. The classroom layout will be based on recommendations from Computational Fluid Dynamics (CFD) simulation results. Data from the simulation will serve as input for EMAS. EMAS will process the predicted energy consumption of the smart classroom using a calculator (C) and estimate the associated energy costs. Additionally, EMAS will compare the results with the standard parameters database (DB) to ensure comfortable conditions are achieved. Once the physical classroom is built and operational, real energy consumption data will be collected and calculated in EMAS.

Unlike common energy audits, EMAS can get energy consumption data that is sent in real-time from Smart Plug Energy Monitoring (SPEM) installed in electrical appliance sockets to the application program. In EMAS, this data will be used as input for data processing to find Energy Use Intensity (EUI). EMAS can also be linked to CFD simulation programs to improve energy

efficiency and thermal comfort in smart classrooms. EMAS is also expected to be able to give orders to electrical appliances to reduce or stop the electric current from them when needed to improve energy efficiency. Data from SPEM will be collected through SPEM applications into a cloud database using a wireless network and will then be processed in EMAS for auditing and energy management processes (Figure 8.)

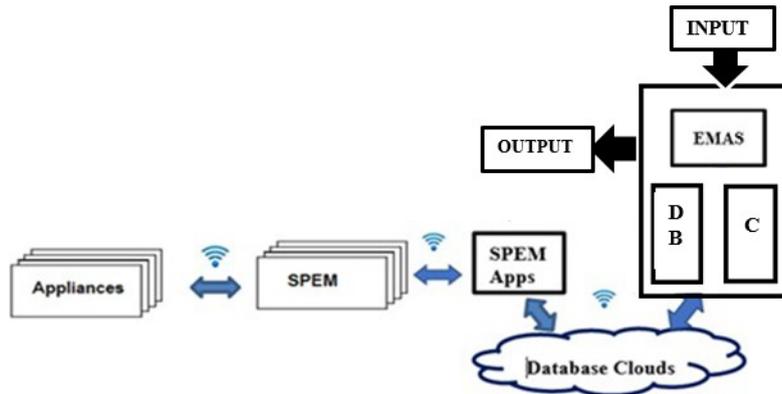


Figure 8. Scheme of A Energy Audit and Management System (EMAS) Data Processing

EMAS typically facilitates four audit steps, namely preparation, data collection, analysis, and reporting, as in a short energy audit process commonly. There is a page in the preparatory stage for determining the scope of activity, required documents, checklists, and scheduling. During the data collection stage, SPEM and its cloud-based application will collect the installed power of all electrical equipment, building occupancy loads, and visual simulations. EMAS will process the data at the data processing and analysis stage to calculate Energy Using Intensity (EUI) and potential energy savings while considering thermal comfort based on the results of CFD simulations in smart classrooms. Following that, a report will be created with energy consumption portraits and recommendations as an outcome of the audit process. The display of EMAS application can be seen in Figure 9.

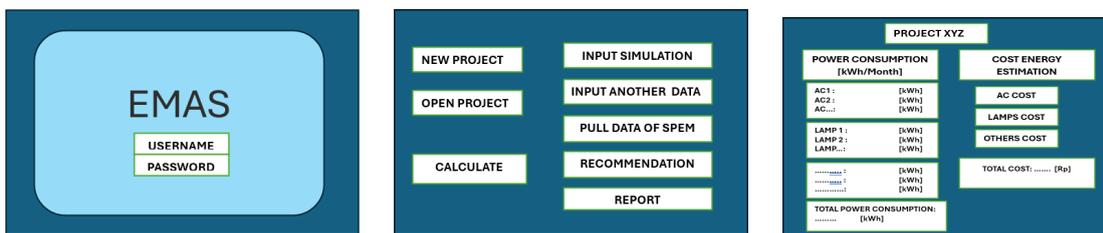


Figure 9. Display of Energy Audit and Management System (EMAS) Application

4.4. Energy Audit and Management System (EMAS) Verification

The last stage to be carried out is the verification process of the EMAS system design. The design will be verified by the logical relation test method. The computer model is verified by testing

logical relations showing that the computer program is an appropriate implementation of the logical model.

Verification can be conducted by examining the airflow streamlines, represented as velocity vectors. The accuracy of the airflow simulation can be evaluated based on the direction of the airflow. If the simulation shows airflow exiting the room despite the absence of openings in the walls and the doors being closed, it indicates inaccuracies in the simulation. In the current airflow simulation, no air exits the room. The airflow is shown to move between the equipment or furniture within the room. It exits only through the evaporator outlet duct (the air inlet into the room). It re-enters via the evaporator inlet duct (the air outlet from the room), as demonstrated in the simulation images in the previous section. The Inlet and outlet duct can be seen in **Figure 10**.

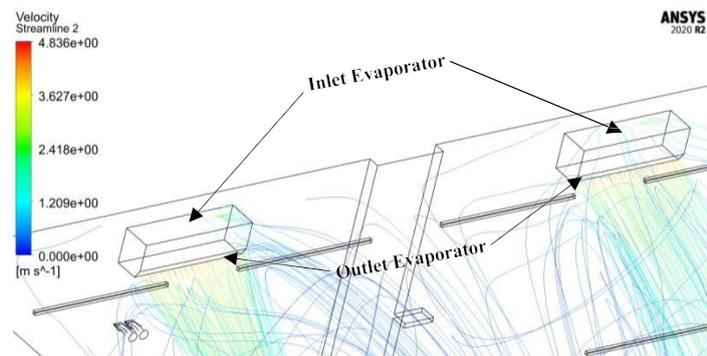


Figure 10. Inlet and Outlet Duct Evaporation

Verification is conducted by observing the temperature distribution results in the simulation, particularly around the room's walls, which exhibit higher temperatures compared to their surroundings. This is caused by heat transfer from outside the room through the walls. The temperature contours of the walls and the temperature distribution around them can be seen in **Figure 11**.

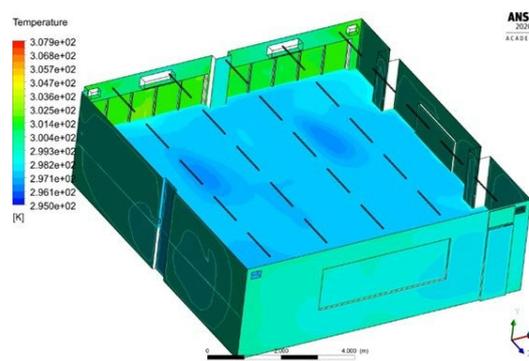


Figure 11. Wall temperature and the temperature around the wall

Conclusion

EMAS Energy Audit and Management System is a system that is designed to conduct energy audits and management in a smart classroom in an educational building. The system differs from the general short audit system because it combines a static conventional preliminary audit process with a continuous real-time data collection process into a cloud database for processing and analysis. In addition to calculating the IEU and potential energy savings, the system considers the thermal comfort of the room obtained from the CFD simulation. Based on the results of the simulation using the CFD method for each planned evaporator position, the most ideal position was determined to be on the south wall. This position meets the thermal comfort standards and has 24 out of 27 airflow velocity measurement points that comply with SNI 03-6572-2001.

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