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Design of Control Model for Multi-User Preference and Activity in Smart Building System for Energy Saving

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Abstract: The environmental adaptability of the smart building is required for energy efficiency. The scheduling-based control model that widely implemented, have a user dependence and assumes maximum occupancy regardless of the occupant's desire in the energy usage requirement during the activity (i.e., ignoring user preferences). In this paper, we present our study on a building control model based on user preference, presence, location, and activity. We present it in a formal model, including conflict resolution techniques on multi-user preference (minimum, maximum, and average preference models). The contribution of this study is the optimization of control model for energy efficiency that also meet multi-user preference. The evaluation of the proposed control model is done through simulation and is compared with the scheduling-based control models. The results show that the minimum, maximum, and average preferences have an energy consumption of 73.5 kWh/day, 44.5 kWh/day, and 58.9 kWh/day, respectively, which are more efficient than the scheduling-based control model. If the Euclidean distance is used to estimate the error value between temperature and light actuation to multi-user preference, the lowest error is the average preference.

Keywords: Smart building, User preferences, Activity, Energy efficiency, Multi-user.

1. Introduction

Intelligent buildings are adaptive, non-reactive, energy-efficient, durable, and comfortable buildings [1]. The adaptation of the building system to the environment such as occupant characteristics, building function, comfort level, and external weather conditions becomes a characteristic that must be satisfied in addition to energy efficiency [1]. The HVAC control system has been a prime target for reducing energy consumption [1, 2] and is one of the convenience controls to occupants. Lighting controls are based on presence in an office environment [3], and daytime operating times in classrooms within the university environment [4] have been conducted for energy efficiency. Voice recognition for user presence information has been utilized for building control in an apartment building for energy efficiency [5]. In [6], user activity detection using door sensors in smart home environments has been done for energy savings through dynamic thermal simulations. Meanwhile, activity recognition has been utilized for energy management systems and user convenience in buildings using ontology [7]. Device control based on occupant behavior, according to the conditions and size of the building and weather [8] and predicting the user behavior using embedded and wearable sensors [9] have been done for energy efficiency.

The scheduling-based control models have been implemented in many home automation systems. In [10], an automation system has been built based on user schedule using a wireless sensor actuator network (WSAN) in an office environment. The scheduling-based control model has been also developed with smart meeting scheduling [11], and monitoring and controlling systems in an office environment to minimize operational costs [12]. The meeting scheduling algorithm in the room has made the automation system aware of energy consumption because is able to automate meeting scheduling based on the time and space capacity [11]. Monitoring and control of devices using operating schedules within buildings have been able to perform energy efficiency in accordance with user-defined policies to minimize operating costs of devices in an office environment [12]. The remote control system of electrical devices using user schedules in office environments have been providing convenience to users in controlling devices anywhere to improve energy efficiency [10].

Nevertheless, these studies have some disadvantages. For instance, energy efficiency based on the scheduling has a user dependence on device control when inputting user schedules into the system (semi-manually) and assumes the maximum number of occupancy [10]. In addition, energy efficiency based on scheduling have not been thought of the preferences of many users to keep up their comfort [10 - 12]. So that the electrical device operation settings do not meet the current environmental conditions.

Multi-user preference and activity are a major problem in smart buildings because it is not only for energy efficiency but also for the convenience of multi-user. Smart building systems will be easy to control based on single user preference when compared to multi-user preference. This study proposed a model for handling device control based on multi-user activity preferences using rule and providing and provide resolution when there is a conflict between each users preference, also uses the user's position when performing the activity.

The rule-based has the potential to achieve energy efficiency based on multi-user, since it has the following advantages: (a) The rule engine is an essential component in smart building system that can provide flexible control; (b) The knowledge base in the rule engine is used to support control logic and decision-making, which can be utilized for more effective energy management; (c) Rules have the advantage of setting the actuator function to control the device and not user-dependent. Therefore, the actuation process in the building is not semi-manual. Hence, the smart building can accommodate according to multi-user preference, activity, and location. The contribution of our study is to provide a formal model of device control based on multi-user preference and activity, as well as resolution when a user preference conflict occurs. The aim of this study is to obtain the optimum value of energy efficiency as well as accommodate of multi-user preference.

The paper is organized as follows: Section 1 is an introduction. In Section 2, we provide related work. The design of the proposed control model which is based on multi-user preference and activity is presented in Section 3. Section 4 and Section 5 are presents the discussion and result. Finally, in Section 5, we present conclusions and future work.

2. Related work

Some studies concerning device control in the smart building have been conducted to provide energy efficiency. The scheduling-based control model makes the process of maintaining the operation of electrical devices through the schedules entered into the system [11, 12], and energy efficiency is performed using remote control [10].

Nevertheless, these studies have some restrictions on energy efficiency as follows: (a) energy efficiency using the scheduling-based control model has a user dependence for building control (b) the electrical device operation settings do not meet the current environmental conditions, such as the use of energy that corresponds to the preferences of users when doing the activity or the number of occupants in the room. According to the explanation above, there is a gap in the previous study: the scheduling-based control model has a dependence on the user for device control and assumes maximum occupancy regardless of the occupant's desire in the energy usage requirement during the activity. So the adaptive capability in the smart building system does not survive.

Multi-user preference in the activity become a significant problem because of an influence on energy consumption and service in the building environment, especially in an office. If the occupant in a room is only one person, the smart building system does not have a conflict in the building. Building system can easily assign commands to actuators to perform actions. Nevertheless, it gets harder for the system if at the same time and location many users are having different preferences. It becomes one of the problems in the building system to work intelligently, where the system can give action command to the actuator in deciding to control devices in the building that can fulfil the demand of many users and their activities.

Our study differs from the previous studies in which it focuses on energy efficiency and meets multi-user preference at once. To achieve this goal, we proposed a model of devices control based on multi-user preference when performing activities, device automation decisions using location to achieve energy-saving, and handle conflicts when there are differences in the user preferences. Resolutions are performed utilizing the minimum, maximum, and average preference methods. The contribution of this study is to present the formal model of multi-user preference and activity, and conflict resolution of actuation in buildings, in order to determine the optimum value of energy efficiency and user convenience. The benefit of the study is that building systems can be more tolerant to multi-user demands while sustaining energy efficiency. We evaluate our control model and compare it with the scheduling-based control model as a baseline through simulation.

3. The proposed control model: Control design based on multi-user preference and activity

In this study, the concept of controlling in the smart building based on user preferences, user location, activity, and detection of occupancy. Then the device will operate in accordance with the user location and preference users and will not be based on maximum occupancy. This differs from the scheduling-based control model where occupancy in the room is considered maximum and ignore user preferences even though the device operation is based on the user schedule.

In the formal model of the building, the building has some floors, each of which has a two or more rooms. The room has some coordinates, each of which has a sensor to spot the location of occupants when sitting in a chair (pressure sensor). Each coordinate has a sitting device for occupants, except for certain areas that do not have seats. If coordinates that do not have a pressure sensor then actuation based on attendance only. The architecture of control design based on multi-user preference and activity in more details is described in Fig. 1.

In this study, we define user preferences as similar to user profiles. The user preference in performing the activity is the context that forms the rule in giving action commands to an actuator. User comfort generated from user preferences is generally affected by temperature and lighting. This is because the temperature and lighting can be explicitly described in the context of user preferences. However, satisfying user's convenience in real time is an arduous task as it depends on the user's mood.

The model of the control device on the smart building by utilizing multi-user preference is supported by three systems which include occupancy detection, indoor localization, and activity recognition. The yields of these three systems are used as contexts or parameters in the control design to generate actuation decisions for energy efficiency. Nevertheless, this study does not discuss user presence, indoor localization, and activity recognition in particular. We assumed that our system received output from each of the three systems, and they were considered as the context in the control design of our control model. The three contexts are user identifier $(userID)$, location (loc), and Activity (act). However, we will explain the general working mechanism of the three systems.

The mechanism of presence systems works through presence sensors (e.g., radio frequency identification (RFID) tags and reader's sensors). RFID tags are worn by the user. When the user enters the room, the RFID tag transmits signals that are read by the RFID reader installed in the room.

The localization system aims to estimate the location obtained from measured data values collected in a vector and received from a mobile device. Bluetooth, RFID, Zigbee, UWB and IEEE 802.1x are examples of technologies applied for indoor localization [13].

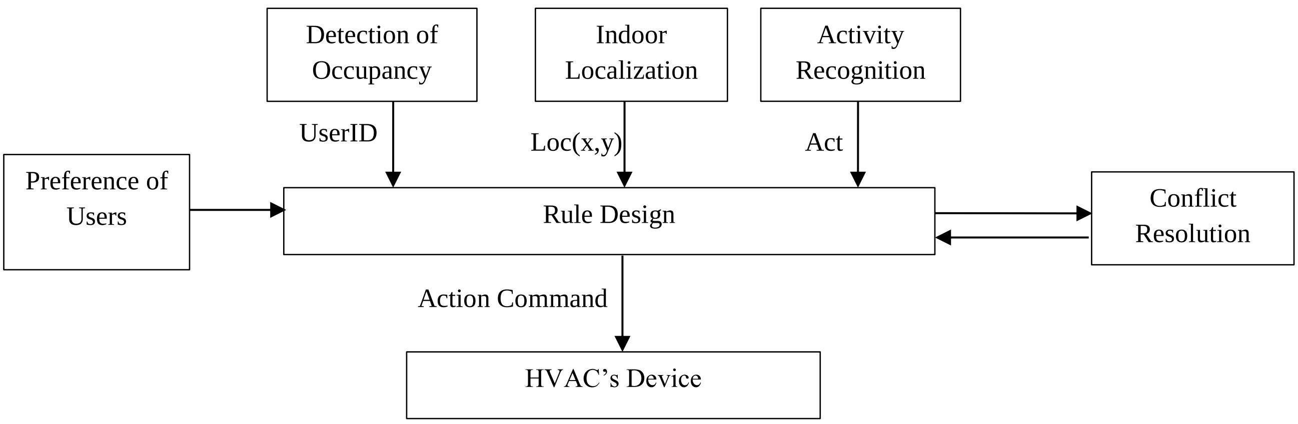

Figure. 1 An Architecture of Control Design Based on Multi-User Preference and Activity

Activity recognition can be performed by utilizing the built-in camera sensor, wearable sensors, or object sensors. Furthermore, the activity recognition algorithm will perform the detection process to inform the system regarding user activity [14].

3.1 The concept of actuation based on location user

To further clarify the rule for the automation devices of the building, the followings describe the formulation of the rule. The defined floor syntax expresses a set of variable building $B = \{f_1, f_2, f_3, \dots, f_n\}$; where f is a floor. Set $f_j = \{r_{1j}, r_{2j}, r_{3j}, \dots, r_{mj}\}$; where r_{ij} is room of a floor. Detailed visualization is described in Fig. 2. The graph of Fig. 2 describes that the direction of the arrow of each edge shows the ownership of the floor node for the room node.

Each room $r_{1j}, r_{2j}, r_{3j}, \dots, r_{mj}$ to $r_{1j+n}, r_{2j+n}, r_{3j+n}, \dots, r_{mj+n}$ has locations that are described as:

$$\begin{bmatrix} loc_{(x,y)} & \cdots & loc_{(x,y+n)} \\ \vdots & \ddots & \vdots \\ loc_{(x+n,y)} & \cdots & loc_{(x+n,y+n)} \end{bmatrix} \tag{1}$$

Some devices have an essential role in meeting user preferences (especially lighting), we used the location of the lamp to represent the coordinates. Each light position was a coordinated where RFID sensors were installed in the coordinates to recognize the user. The assumption was the area of each coordinate matched the range of signals acceptable to the RFID reader without interrupting the RFID reader in the surrounding coordinates. Each RFID reader records all user id data.

Each of these coordinate encompasses electrical devices that are related to some user preferences (we call them devices of preference). Except with the window air conditioning (window AC), because windows AC is used by all users. So each location represented by the coordinate has the electrical equipment and is declared as:

$$loc_{(x,y)} \ni (l_i, ac_i, d_i, p_i) \tag{2}$$

Where:

$loc_{(x,y)}$ = coordinates (x, y) where $x = 1,2,3, \dots, n$ and $y = 1,2,3, \dots, n$ in each room on each floor

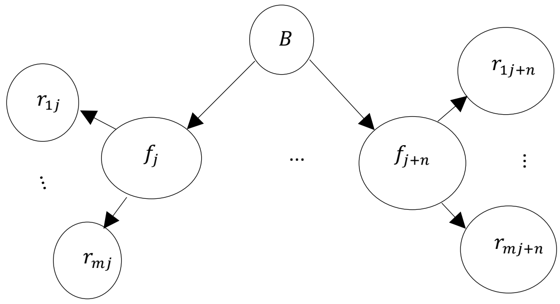

Figure. 2 Visualization of the building B has to floor f_j to f_{j+n} and each floor has room

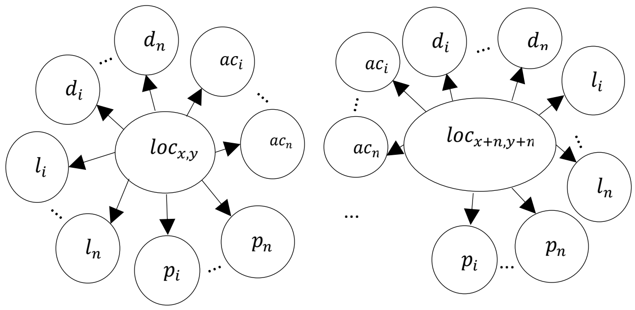

Figure. 3 Visualization of the coordinates and following attributes on the one-floor space j=1 (r_{1j}).

l_i = the lighting device where $i = 1,2,3, \dots, n$

ac_i = the device of air conditioner where $i = 1,2,3, \dots, n$

d_i = the electrical device where $i = 1,2,3, \dots, n$

p_i = the pressure sensor where $i = 1,2,3, \dots, n$

The visualization of the coordinates and following attributes can be seen in Fig. 3.

The outputs of the user presence, indoor localization, and activity recognition systems are user identification ($user$), coordinate (loc), and activity (act). These three outputs are processed by the rule system to apply the action command to the actuator. The relationship between the user, location, activity, and multi-user preference to actuator operations is described in Subsections 3.2.

Rows of matrix describe the available coordinate x, and the columns of matrix show the available coordinate y in each room. Each (x, y) incorporates a pressure sensor (p) placed on a chair. The pressure sensor operates as the receiver of the condition if there is a weight according to Eq. (3). The condition will give the light actuation command (l) to be able to operate (on or off). Lighting is one of the most important devices that must be present at each location. The lights in each coordinate can be utilized by multiple users at the same time. Each coordinate has electrical devices associated with the preferences users, for example, lights and air conditioner. Electrical devices that are linked to preference users when performing activities are called devices of preference. The devices of preference have several conditions to the location (e.g. lighting). Among others: relationships $loc_{(x,y)}$ to $loc_{(x,y-1)}$, relations $loc_{(x,y)}$ to $loc_{(x,y+1)}$, the relationship $loc_{(x,y)}$ to $loc_{(x-1,y)}$, and the relationship $loc_{(x,y)}$ to $loc_{(x+1,y)}$, etc. The relationship $loc_{(x,y)}$ to $loc_{(x,y-1)}$ occurs when the lighting preference device at $loc_{(x,y)} == empty$, and is present in the location $loc_{(x,y-1)}$ or the nearest location, and so on.

For example, the coordinates $loc_{(x,y)}$ do not have a light device, then the pressure sensor function p_i at the coordinates $loc_{(x,y)}$ will trigger the light actuation at the location $loc_{(x+1,y)}$ and $loc_{(x,y+1)}$. These conditions are named as independent coordinates ($iloc$). Other conditions If $loc_{(x,y)}$ has a lighting device, then $loc_{(x,y)}$ becomes dependent coordinates ($dloc$) since the actuation of lighting l in the coordinate depends only on each sensor pressure p_i at that location. The following is a formal description of the independent and dependent relationship of locations.

3.2 Relationship between users, location, activity, and preferences

Some possible conditions that will occur in real life are one or more user have similar preferences, one or more user have different preferences, one or more users have one similar preference parameter and other preference parameters are different, and or a combination of possible conditions. Users can have various preferences when doing specific activities, or it could be the same. For example, Ana has a lighting preference level of $1000\ lux$ and temperature of 24°C when reading and working using a PC, while Rosy wants $1500\ lux$ lighting with a temperature of 23°C when reading, but she has different preferences for working using a PC, such as a lighting preference of $1200\ lux$ with a room temperature of 25°C when using a PC.

In this study, we determined the primary relation between user, activity, and preference. The primary relations were the user generates the activity, and the activity generates user preferences. Furthermore, user preferences are stored in the smart building system into the database preference. Preference (p) consist of temperature (t) and luminance (l). User preferences are different or the same as other users.

Here is a formal model of user preference when doing the activity:

Definition 1: User relationship with activity: The user is a nonempty set with finite state and has membership function $U = \{u_1, u_2, u_3, \ldots, u_p\}$; with $u_p \epsilon\ U$ and $1 \leq p \leq n$. Activity sensors are placed in objects that are related to the activity. If the sensor in the object receives a value, then the activity is identified. The sensor variable is a non-empty and finite state set. The sensor membership function is $Sensor = \{s_o, s_a, s_b\}$. s_o is the occupancy sensor, s_a is the activity sensor, s_b is a building sensor. Occupancy sensor membership function is $so = \{o_1, o_2, o_3, \ldots, o_n\}$, $o_i \epsilon\ s_o$. Sensor building membership function is $sb = \{b_1, b_2, b_3 \ldots, b_n\}$,

$$iloc_1: loc_{(x,y)}\big((p_i == defined)\&\&(l_i == empty)\big) \rightarrow act_1 = \left(loc_{(x+1,y)}(l_i)\right)\&\&\left(loc_{(x,y+1)}(l_i)\right) \tag{3}$$

$$iloc_2: loc_{(x+n,y)}\big((p_i == defined)\&\&(l_i == empty)\big) \rightarrow act_2 = \left(loc_{(x+n,y+n)}(l_i)\right)\&\&\left(loc_{(x+(n-1),y)}(l_i)\right)\&\&\left(loc_{(x+(n+1),y)}(l_i)\right) \tag{4}$$

$$iloc_3: loc_{(x,y+n)}\big((p_i == defined)\&\&(l_i == empty)\big) \rightarrow act_3 = \left(loc_{(x,y+(n-1))}(l_i)\right)\&\&\left(loc_{(x+n,y+n)}(l_i)\right)\&\&\left(loc_{(x,y+(n+1))}(l_i)\right) \tag{5}$$

$$ilocC_4: loc_{(x+n,y+n)}\big((p_i == defined)\&\&(l_i == empty)\big) \rightarrow act_4 = \left(loc_{(x+(n-1),y)}(l_i)\right)\&\&\left(loc_{(x+n,y+(n-1))}(l_i)\right)\&\&\left(loc_{(x+(n+1),y+n)}(l_i)\right)\&\&\left(loc_{(x+n,y+(n+1))}(l_i)\right) \tag{6}$$

$$dloc: loc_{(x,y)}\big((p_i == defined)\&\&(l_i == defined)\big) \rightarrow act_q = \left(loc_{(x,y)}(l_i)\right) \tag{7}$$

$b_i \epsilon\ s_b$. In general, the sensor activity membership function is $sa = \{sa_1, sa_2, sa_3, \dots, sa_n\}$, $sa_i \epsilon\ sa$; and $1 \le i \le n$. If $sa_i = NotNull$ then $sa = sa_i$. The definition of activity is $A = \{a_1, a_2, a_3, \dots, a_n\}$, $a_k \epsilon\ A$ and $1 \le k \le n$.The relationship between the user (u) and activity (a) is:

$$R(u,a) = \begin{bmatrix} u_p, a_k & \dots & u_p, a_{k+n} \\ \dots & \dots & \dots \\ u_{p+n}, a_k & \dots & u_{p+n}, a_{k+n} \end{bmatrix} \quad (8)$$

Definition 2: The function of the activity a with the user u was given with a value of 1 if a user performs the activity and filled with 0 if there is not performing the activity.

$$f_{(u \to a)} = \begin{cases} 1, & u_p, a_k = 1 \\ 0, & u_p, a_k = 0 \end{cases} \quad (9)$$

Definition 4: User preferences consist of temperature (t) and light (l) in conducting activities.

$$\begin{matrix} p(t) = [t_i & \dots & t_j] \\ p(l) = [l_i & \dots & l_j] \end{matrix} \quad (10)$$

Each user $u_p, \dots, u_n$ performs the k-th activity (a_k) until n-th activity (a_{k+n}) has a preference (p) described as follows:

$$u_p\big(a_k(p)\big) \quad (11)$$

Definition 5: Since preference (p) consist of temperature (t_i) and luminance (l_i), so the formula description of the user preference of the activity as follows:

$$u_p\big(a_k(t_i, l_i)\big) \quad (12)$$

Thus the relation of user u_p with activities a_k and preferences p of the conditions become:

$$\begin{aligned} & u_p\big(a_k(t_i, l_i)\big) = 1 \\ & \to u_p\Big(a_k\big(t_i, l_{i+1,i+2,i+2,\dots i+j}\big)\Big) = 0 \\ & u_p\big(a_k(t_i, l_{i+1})\big) = 1 \\ & \to u_p\Big(a_k\big(t_i, l_{i,i+2,i+3,\dots,i+j}\big)\Big) = 0 \\ & u_p\big(a_k(t_i, l_{i+2})\big) = 1 \\ & \to u_p\Big(a_k\big(t_i, l_{i,i+1,i+3,i+4,\dots i+j}\big)\Big) = 0 \end{aligned} \quad (13)$$

and so forth, where $\forall\ [i,k,p] = [1,n]$ and n is an integer.

Definition 3: User performs an activity in time (τ), where Time is a non-empty set that has a Time membership is $Time = \{\tau_z, \tau_{z+1}, \dots, \tau_{z+n}\}$ and $1 \le z \le n$. The user performs an activity in time (τ) that is described as follows:

$$u_p\big(a_k(t_i, l_i)\big)(\tau) \quad (14)$$

where:

u_p = user-p where p = 1, 2, 3, ..., n
a_k = is an activity performed by each user. The activity consists of: a_1 = reading, a_2 = writing, a_3 = typing, etc until the last activity a_n
t_i = temperature i (°C)
l_i = luminance i (lux).

Definition 6: User activity in a building with more than one person is called multi-user activity. Multi-user activity is done at the same time and place, and many activities. Variable location is used to describe the place, and given initials loc. loc is the finite set with membership $loc = \{loc_{(x,y)}, \dots, loc_{(x+n,y+n)}\}$, where $loc_{(x,y)} \epsilon\ loc$, $1 \le x \le n$ and $1 \le y \le n$.

$$u_p\big(a_k(t_i, l_i)\big)(\tau) \wedge \big(loc_{(x,y)}\big) \quad (15)$$

Based on the formal model definition in Eq. (1) to Eq. (15) the design of rules for the devices control command is as follows:

$$\begin{aligned} & rule_{i..n}: \big((user = u_p)\&\&(act = a_k)\big) \\ & \to pref\Big(u_p(t)\Big) = p(t)\ \&\& \\ & pref\Big(u_p(l)\Big) = p(l) \end{aligned} \quad (16)$$

$$\begin{aligned} & rule_{(n+1)..m}: coor = loc_{(x,y)} \\ & \to \big(d_{1i(x,y)} = l_i\big)\&\&\big(d_{2i(x,y)} = p_i\big) \end{aligned} \quad (17)$$

$$\begin{aligned} & rule_{(m+1)..z}: \big(user = u_p\big)(\tau) \\ & \&\&(act = a_k)(\tau)\ \&\&\big(coor = loc_{(x,y)}\big) \\ & \to temp\big(d_{1(x,y)}\big) = pref\Big(u_p(t)\Big) \\ & \quad temp\big(d_{2(x,y)}\big) = pref\Big(u_p(l)\Big) \end{aligned} \quad (18)$$

Where $rule_{i..n}, rule_{(n+1)..m}, rule_{(m+1)..z}$ are the rule from i to n, $n+1$ to m, and $m+1$ to z, respectively. $user$ is the condition variable of the user value compared with the u_p variable, where $p = 1,2,3, \dots, n$; act is the condition variable of the activity value compared with the a_k variable, where $k = 1,2,3, \dots, n$; $pref\Big(u_p(t)\Big)$ is a variable of temperature preference value (t) of the user u_p;

$pref\left(u_p(l)\right)$ is a variable of luminance preference value (l) of the user u_p ; $coor$ is the condition variable of the location value compared with $loc_{(x,y)}$; where $x = 1,2,3, \dots, n$ and $y = 1,2,3, \dots, n$; $d_{1i(x,y)}$ is the identity variable of the light device at the location (x, y), $d_{2i(x,y)}$ is the identity variable of the pressure sensor at the location (x, y), where $i = 1,2,3, \dots, n$; (τ) is a function of time; $temp\left(d_{1(x,y)}\right)$ and $temp\left(d_{2(x,y)}\right)$ are the luminance and temperature preference variables of each coordinate.

3.3 The concept of conflict resolution of preference users.

A multi-user activity is an activity by many people at the same time in the same location, but not bound by the activity. They can do different or similar activities, especially in terms of energy usage. Their preferences can also be similar or even different. Multi-user preference at the same time can cause trouble to the control system when making decisions for device actuation in the smart building. The control system must be able to provide decisions in device actuation that can satisfy all user preferences. This situation is called preference conflict.

In this section, we describe the formal model and concepts when many user preferences have to be met by the building control system and conflict resolution. Fig. 4 describes the concept of multi-user preference and activities as well as the resolution conflicts of preference. For example, in the period τ_0 to τ_4 in one location occurs a condition as follows: the initial state of the building environment conditions following the rules set by Standar Nasional Indonesia (SNI) [15], such as, air conditioning will be 'ON' half an hour before business hours begin, and others. SNI explains the standard of energy consumption for energy saving in Indonesia considers its tropical climate. The situation is at the initial time (τ_0) with initial environmental arrangements in accordance with SNI $\left(set_{env_0}\right)$. set_{env_0}will change if there is a change of condition like a presence of a user. The u_p arrival time is visualized at τ_1 and performs activity i (a_k) has a lighting preference level (l) of 1000 Lux and temperature (t) of = 19°C.

The building system set the environmental conditions to set_{env_1} , according to the u_p preferences that stored in the building system.

The system continues moving without any change until the time τ_2, u_{p+1} comes with the activity of a_{k+3} and has a lighting preference level (l) of 1500 lux and temperature (t) of = 24°C; then the u_p does another activity at the time that is a_{k+1} has a lighting preference level (l) of 1300 Lux and temperature (t) of = 22°C. Activity and preference information from u_p and u_{p+1}will be accepted by the system through the sensors. At the time τ_2, the system will change the environmental condition to set_env_2. Since there is more than one user and have different preferences, set_env_2 causes conflicts in determining appropriate environmental conditions to satisfy all user preferences without eliminating the goal of energy efficiency. The proposed conflict resolution method in Eq. (19), Eq. (20) and Eq. (21) are applied to resolve the conflict. The conflict resolution methods of user preferences proposed in this study use the average, minimum, and maximum preference values. Furthermore, the building control will set the environment setting on set_env_2 based on the minimum, maximum, or average of the existing user preference, and it continues until the closing time of the system. Action for multi-user conditions: In determining the temperature and luminance of multi-user preference in their activity (assumes all users in the room have agreed to one of the options in action).

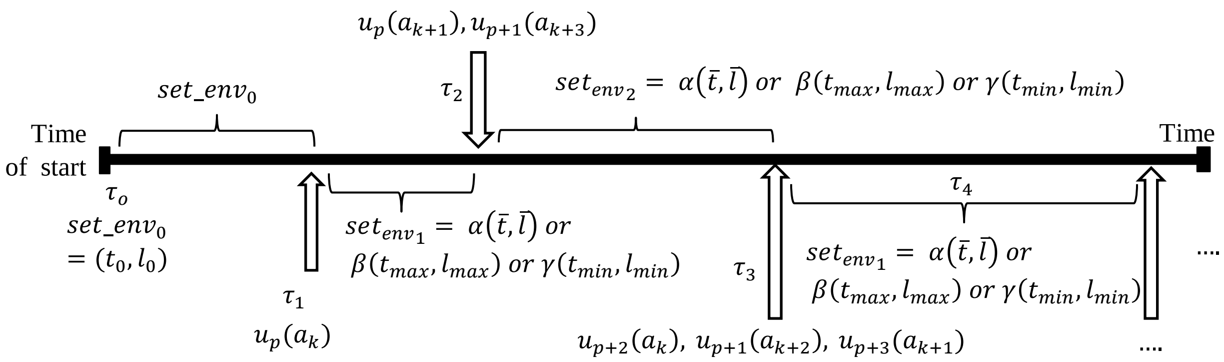

Figure. 4 The concept of the resolution conflict of user preferences and activity

$$\alpha(\bar{t},\bar{l})(\tau) = \frac{\sum_{q=1}^{n}\left(u_p\left(a_k(t_i,l_i)\right)\right)_q}{n} \quad (19)$$

$$\beta(t_{max},l_{max})(\tau) = \max\left[\left(u_p\left(a_k(t_i,l_i)\right)\right)\right] \quad (20)$$

$$\gamma(t_{min},l_{min})(\tau) = \min\left[\left(u_p\left(a_k(t_i,l_i)\right)\right)\right] \quad (21)$$

Where:

$\alpha(\bar{t},\bar{l})(\tau)$ = Actuation of average temperature and luminance at time τ

$\beta(t_{max},l_{max})(\tau)$ = Actuation of maximum temperature and luminance at time τ

$\gamma(t_{min},l_{min})(\tau)$ = Actuation of minimum temperature and luminance at time τ

with $\forall(i,j,p,k) = [1,m]$; where m is an integer.

4. Discussion

This study used energy plus simulation tools to estimate energy consumption. Multi-user activities consist of office activities, such as reading (seated), writing, and typing.

4.1 Simulation on model

The simulation of electrical device control strategy implementation is based on the proposed model done using the EnergyPlus software to estimate the energy savings achieved. Energy Plus is the industry standard tool for simulating building energy by considering parameters such as HVAC systems, shelter, weather, and building materials [16]. In general, we use the characteristics and settings of the room 2.2 located in the Head Office, Faculty of Engineering Universitas Gadjah Mada for simulation. The floorplan of room 2.2 can be seen in Fig. 5.

For window AC, the simulation used an existing HVAC for the EnergyPlus software. Window AC is a unit of equipment consisting of an outdoor air mixer, a fan, and a direct expansion cooling coil (DX) [16][17]. The weather conditions during the year followed the local climate of Jakarta, Indonesia. The detailed description of simulation parameters can be seen in Table 2.

4.2 Simulation of methodology

To evaluate the proposed control model, the scheduling-based control model is simulated as a baseline to ensure increased energy efficiency of the proposed control model. All control methods are simulated using the same environmental conditions as those recorded in Fig. 5 and Table 2.

The scheduling-based control model uses the mechanism of controlling the device in the room, according to the time specified in the schedule. The schedule of room use can be seen in Table 3. The scheduling-based control model assumes maximum occupancy in each room and every schedule. So we used the maximum cooling temperature setting for each schedule. In this study, we assumed the maximum cooling temperature value is 18℃.

The second simulation uses our proposed model, which controls device operation based on multi-user preference, activity, and location. The second simulation is applied based on the concepts and models we have described in Eq. (1) through Eq. (19), as well as Fig. 1 through Fig. 4. We use the random function to generate preference values for temperature and luminance users, 18℃ to 28℃ and 310 Lux to 2270 Lux, respectively, and use the rank function to avoid duplication of users at the same time.

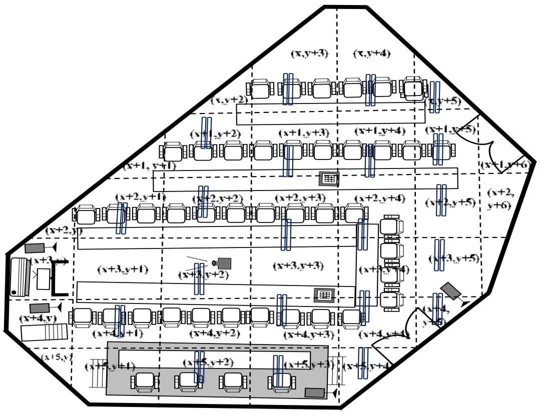

Figure 5. The floor plan of room 2.2 in the head office Faculty of Engineering Universitas Gadjah Mada.

Table 2. Parameter environment to energy plus

Parameter	***Value***
People	36 people
Lighting	21 fluorescent lamps of 40 Watt each
HVAC	Windows AC system
Device	46 chairs, 46 tables
Operation time	07:00 am to 06:00 pm, on weekdays (Monday to Friday), holidays and weekend are considered no activity
Equipment	36 Laptops of 530 Watt each
Location	Jakarta_Design_Condition
DesignDay	Sizing Jakarta
ground temperature	22℃
Area and Material	using WindACAuto.idf from the example file of Energy Plus.

Table 3. The schedule of the Room 2.2 Use/day

Time	Information	Explanation
07 am – 09 am	Session 1	Used
09 am – 10 am	-	Break
11 am – 12 am	Session 2	Used
12 am – 01 pm	-	Break
01 pm – 03 pm	Session 3	Used
03 pm – 04 pm	-	Break
04 pm – 06 pm	Session 4	Used
06 pm – 07 am	-	Break

Table 4. Estimate the error of temperature and luminance actuation to user preferences

Setpoint actuation preference	Total of Error value	
	Luminance (Lux)	Temperature (Celcius)
Minimum	5411	70
Maximum	5271	69
Average	3569	37

In this study, user presence patterns are made to vary with each session to simulate closer to real conditions. It session used in accordance with the scheduling-based control model in Table 3. In the first session, the users present are 8% every 10 minutes and continues until the 50th minute. In the second session, the users present are 22% in on time, the remaining of 53% and 25% are the users present every 10 minutes later. In the third session, 8% of the users present in on time. Furthermore, every 10 minute period the percentage of the users present as much as 8%, 8%, and 50%. Furthermore, 30 minutes before the session end, 8% of the users present are every 10 minutes. In the fourth session, the users present are 50% in on time, and the rest is present towards the end of the session.

To estimate error setting temperature and light against user preferences, we use Euclidean distance ($L_2 - norm$). Euclidean distance is the distance between two points (x and y) in the dimensional space n [18]. Description of Euclidean distance to estimate the error of temperature actuation to user preference can be seen as follows:

$$d(p(t), t_a) = \|p(t) - t_a\|^2$$

$$= \sqrt{\sum_{i=1}^{n}(p(t) - t_a)^2} \quad (20)$$

Where:

$p(t)$ = Temperature preference value

t_a = The actuation of temperature values

$d(p(t), t_a)$ = The distance between temperature preference and temperature actuation (error).

The same formula is also used to estimate the error of luminance actuation to user preference.

5. Result

The total energy consumed per day with the three conflict resolution techniques were 44.5 kWh/day using the maximum preference method, 58.9 kWh/day using the average method, and 73.5 kWh/day using the minimum method. To evaluation of the proposed control model, we made a comparison using the scheduling-based control model (as a baseline) to determine the energy efficiency. The scheduling-based control model worked regardless of user preferences, and the device operated according to the daily schedule of activities without any adaptation to the user at any time. With the same environmental conditions, the number of occupants, and the duration of the same activity, we obtained the energy consumption on the scheduling method of 80.2 kWh/day. A comparison of a total of energy consumption of the proposed model and the scheduling-based control model can be seen in Fig. 6. Energy consumption by cooling, interior lighting, interior equipment, and fans in the scheduling-based control model, average preference, minimum preference, and maximum preference methods can be seen Fig. 7.

Fig. 6 shows that energy consumption using the scheduling-based control model was still more extravagant compared to device automation using multi-user preference in the activity. The maximum preference method produced the lowest energy consumption compared to the other two preference methods. The error result of each parameter of preference (light and temperature) obtained by using the Euclidean distance formula can be seen in Table 4.

The lowest error of temperature and luminance actuation against user preferences is the average preference method. Meanwhile, the highest error of temperature and luminance actuation against user preferences is the minimum method of preference.

The difference between actuation of temperature to the temperature of user preferences can be seen in Fig. 8. The comparison of the difference of temperature actuation and preferences temperature can be seen in Fig. 9. The difference between actuation of luminance to the luminance of user preferences can be seen in Fig.10. The comparison of the difference of luminance actuation and preference luminance can be seen in Fig. 11. The patterns of energy consumption on each of the maximum, minimum, and average methods can be seen in Fig. 12 to Fig. 14.

6. Conclusion

From the results, we conclude that:

a. Building's HVAC control model concerning multi-user preference (minimum, maximum, and average preference methods) have better energy efficiency than the scheduling-based model. Besides, control models based on multi-user preference enables the smart building system to have an adaptive capability and more tolerance to multi-user preference.

b. The average method can be used to cover preferences of luminance and temperature to meet the multi-user preference because it has the lowest estimated error

c. If the smart building system wants to get higher energy efficiency, the maximum method can be used. Nevertheless, this method does not achieve the optimum user convenience if compared to the average method.

In the future, we will extend the study of making optimization models to further minimize the error value between the preference actuation of the building system against the actual user preferences.

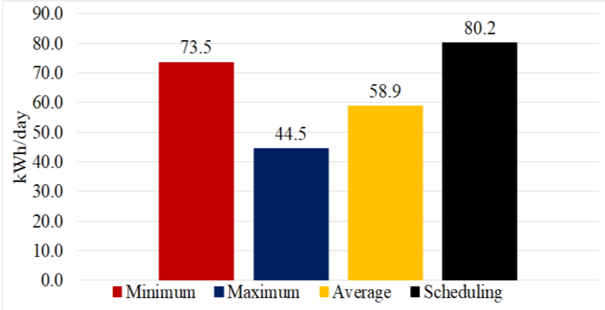

Figure. 6 Comparison of total energy consumption per day

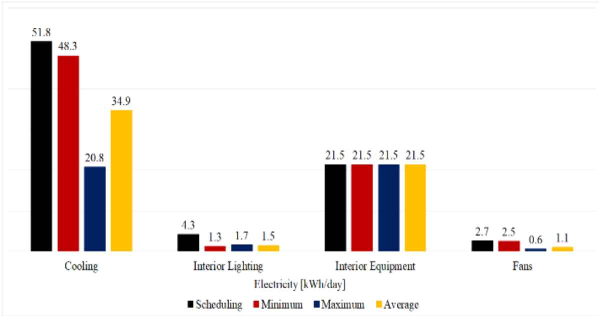

Figure. 7 Comparison of energy consumption from uses device electricity

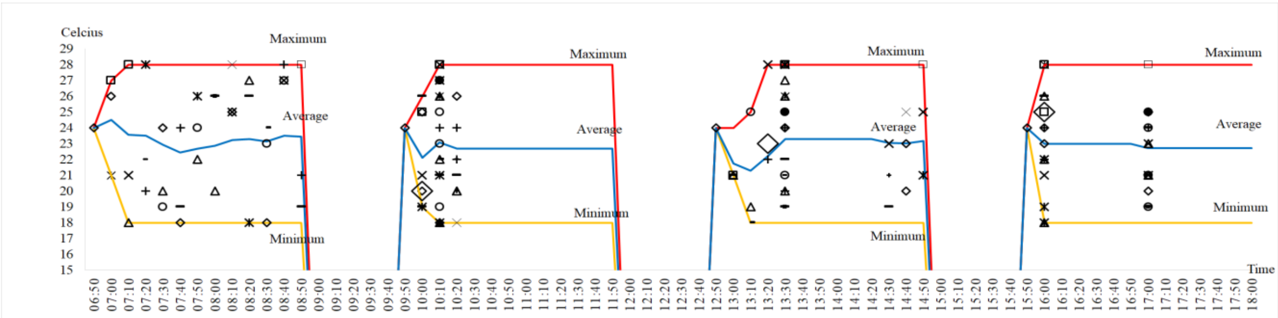

Figure. 8 Temperature actuation to users temperature preferences

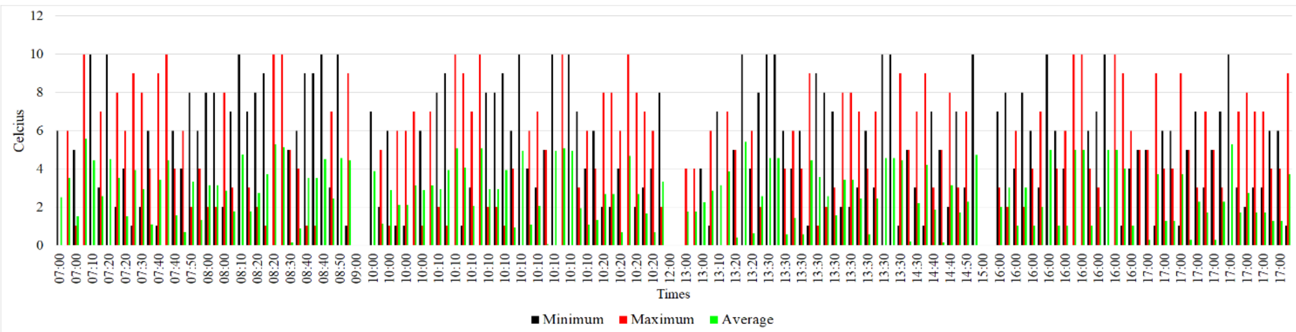

Figure. 9 The comparison of the difference of temperature actuation and preferences temperature

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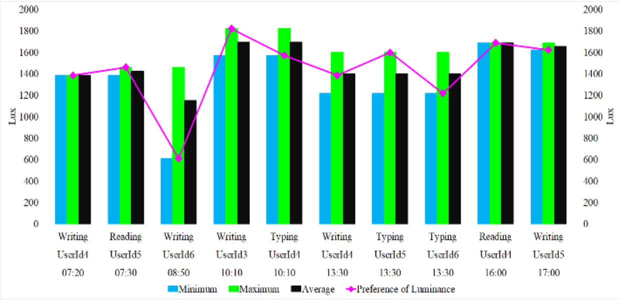

Figure. 10 The difference between actuation of luminance to the luminance of user preferences of LightingID:3

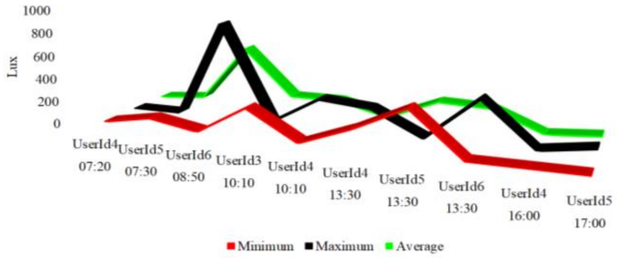

Figure. 11 The comparison of the difference of luminance actuation and preference luminance of LightingID:3

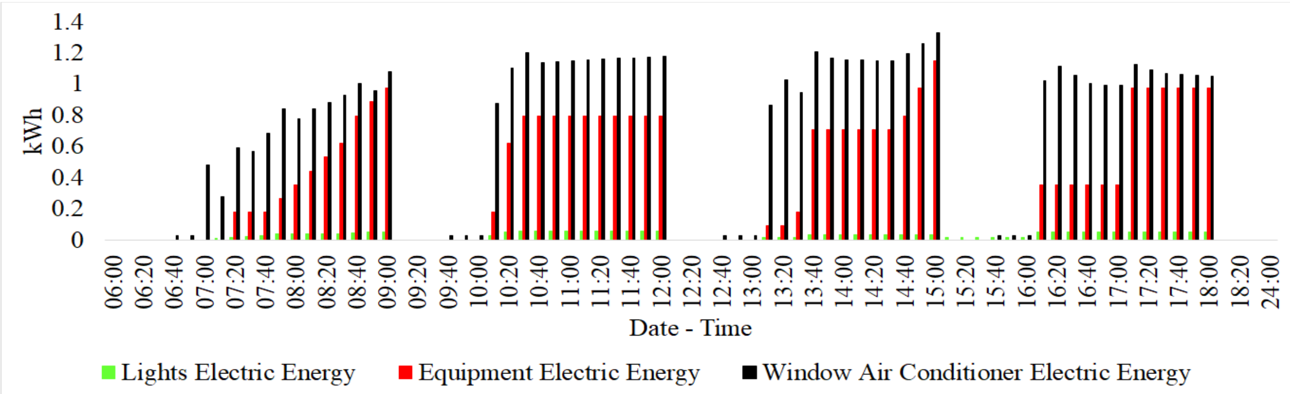

Figure. 12 The pattern of energy consumption used the average method

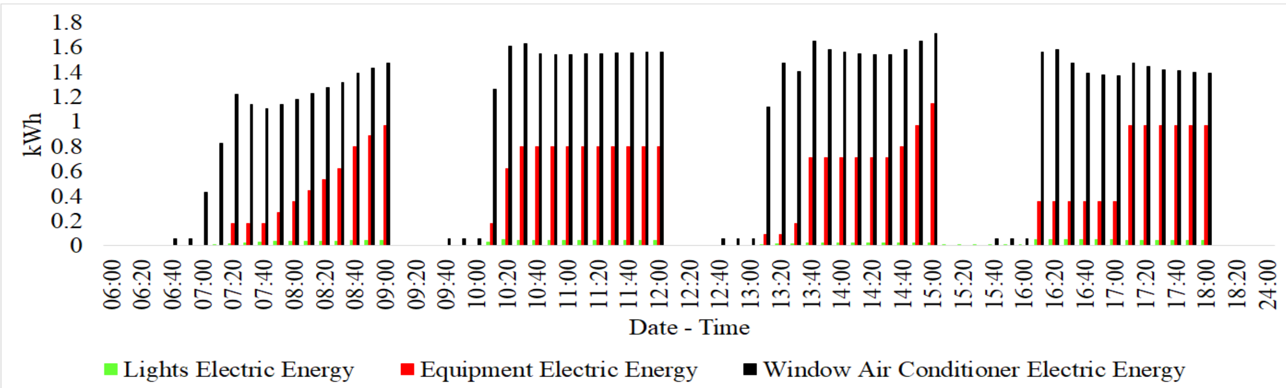

Figure. 13 The pattern of energy consumption using the minimum method

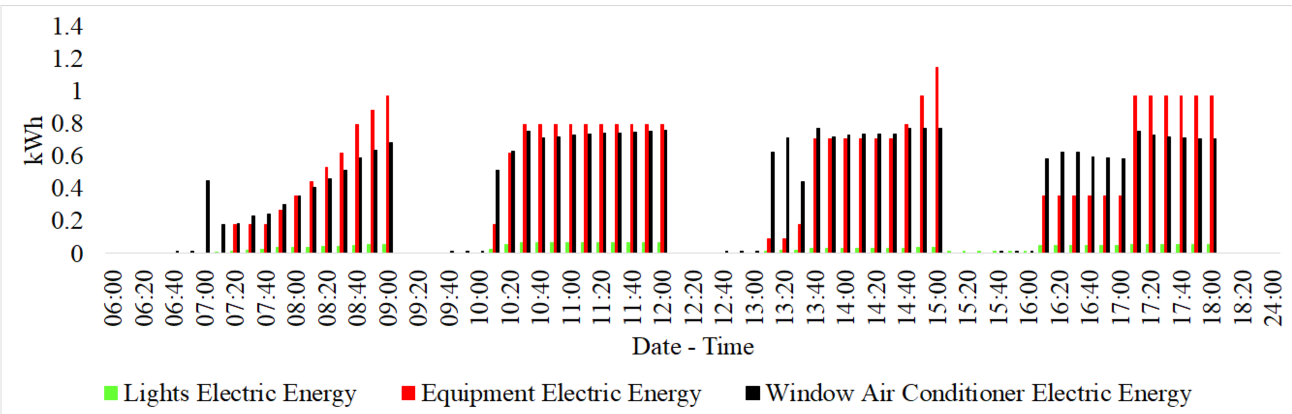

Figure. 14 The pattern of energy consumption using the maximum method

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