Article
A Study on Control Strategy for Air Conditioning of Western Exposed Rooms in Subtropical Region

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Abstract: Recently, energy saving has been a major issue in all aspects. In buildings, air conditioning is one major part of power consumption. In this study, we examined the effect of an intermittent control strategy for air conditioning on energy saving in western-exposed rooms under subtropical weather conditions. The strategy applied periodic deactivation and reactivation to the air conditioners. Room temperatures, power consumption, and readings from sensors of air conditioners of two identical rooms were monitored and analyzed. For indoor temperatures, we found that the deactivation of the air conditioner for 15 min resulted in temperature peaks that were 4 to 5 °C higher than the control room. The reactivation of the air conditioner was able to cool down the room within 10 min based on the built-in sensor. However, due to the location and resolution of the sensor, the overall temperature from the four temperature and humidity sensors was still higher than the target setting, which may cause thermal discomfort. For power consumption, the strategy led to power peaks while reactivating, but the summation was 2.9% lower.

Keywords: energy saving; air conditioning; control strategy; electricity consumption

1. Introduction

In recent years, people have begun to focus on energy conservation. Energy consumption includes the use of industrial electricity, residential electricity, commercial electricity, etc. Among them, residential electricity and commercial electricity are both considered to be building energy [1]. From 1990 to 2020, building electricity usage significantly increased by 144% and accounted for nearly 50% of the annual electricity. In the total electricity consumption of Taiwan in 2020 [2], the residential sector was 53.81%, the residential sector was 17.92%, and the service sector was 16.51%. The building energy (residence and service sectors) was 34.43% of the total consumption. As shown in Figure 1, globally and locally, we found that building energy consumption accounts for a large proportion of the overall energy use. Many researchers have conducted studies regarding the distribution of electricity consumption by department.

Pérez-Lombard et al. [3] analyzed the available information concerning energy consumption in buildings, particularly related to HVAC (Heating, Ventilation, and Air Conditioning) systems. Their results showed that the energy consumption of buildings in developed countries comprises 20–40% of the total energy use and is above the industry and transport sectors. In China, Huo et al. [4] proposed a set of building energy consumption calculation methods. The results showed that the percentage of building energy consumption to total energy consumption remained relatively stable at between 17.7% and
20.3%. Furthermore, Allouhi et al. [5] surveyed recent data on global energy consumption in residential and commercial buildings. The past situation, current status, and future trends were analyzed and discussed for several countries. It is necessary to decompose building energy consumption to determine the key parameters that affect it. Therefore, the importance of energy-efficient buildings cannot be ignored. Reducing building energy consumption has gradually become an important energy-saving and emission reduction strategy in countries around the world.

Figure 1. Total electricity consumption of Taiwan in 2020. (Data from Reference [2]).

As mentioned above, the use of building electricity is increasing on an annual basis. Therefore, many countries have begun to develop low-energy consumption buildings, achieving their goals through passive building energy-saving technologies and the use of low-energy electrical equipment and, even further, introducing renewable energy sources to achieve energy self-sufficiency. However, the most critical factor that affects building energy consumption is air conditioners.

From the statistics of office buildings in Taiwan [6], in terms of the annual electricity consumption of the major energy-consuming equipment, air conditioning accounted for 47.9% and was followed by lighting: 19.55%, office appliances: 9.93%, air supply and exhaust: 4.27%, water supply and sewage: 3.38%, elevator: 6.85%, refrigeration: 0.76%, and other equipment: 7.35%. As shown in Figure 2, air conditioning equipment accounted for the largest part of electricity usage. There have been some studies on energy consumption in various countries related to air conditioning. Through the available data and market research in Ghana, Opoku et al. [7] found that 60–80% of the electricity consumption of commercial and public buildings comes from air conditioning, which is to provide employees with a comfortable environment. The results of the study showed that more than 85% of air conditioners used in Ghana have the lowest energy efficiency ratio (1-star). There is the potential to save 260 and 1170 GWh for 2020 and 2030 with 4-star-equivalent air conditioners. According to a financial analysis, if the existing air conditioners were replaced with a higher energy-efficiency ratio air conditioners, it would save about 1.96 billion US dollars in electricity consumption costs from 2018 to 2030. Randazzo et al. [8] pointed out that households on average have to spend 35–42% more on electricity when air conditioners were adopted. Through analysis, we found that climate change and the increasing demand for air conditioning will exacerbate energy poverty. Those who spend a high percentage of their income on electricity continue to increase, and households with lower incomes are the most negatively affected.
In terms of air conditioners in buildings, the most basic, simple way to save energy is to adjust the temperature setting, which will effectively save energy, but it is relatively necessary to reduce the indoor thermal comfort for people. Wang et al. [9] introduced a South African model for estimating energy consumption due to air conditioning at different temperature settings. The air conditioning energy consumption at 24, 25, and 26 °C from January to December were recorded. Comparing the actual measured energy consumption of a data center with the energy consumption calculated by the model, the coefficient of variation of the root mean square error between the estimated data and measured test data was 11.5%. To maximize occupants’ acceptance of the indoor thermal environments, Mui et al. [10] proposed a concept for a new Bayesian control algorithm. This new algorithm uses the smallest predicted percentage dissatisfaction (PPD) to optimize the air temperature of a space, where the optimum air temperature setting data for the air conditioner systems were obtained from some Hong Kong offices to prove that the new algorithm can be used to control the sample air temperature set to between 0.2 °C and 1 °C. This algorithm would be useful for adaptive control for thermal comfort in large, occupied, air-conditioned spaces. Zhang et al. [11] systematically investigated occupants’ thermal sensations in buildings equipped with separate air conditioners in hot, humid areas of China using a longitudinal design. Adjusting clothing choices, opening windows, and adaptive behavior involving the use of fans were found to be closely related to indoor thermal sensations. The usage time of split-type air conditioners was mostly distributed from May to October, where the units were most often turned on at midnight. The average indoor air temperature was 30.1 °C, and the average setting was 26.1 °C. Yan et al. [12] discussed the air conditioner habits of occupants in bedrooms and living rooms. Through an analysis of big data, the bedroom was classified into five modes, and the living room was divided into six modes. The air conditioner setting and adjustment method for each mode was different. Finally, these authors concluded that, in the bedroom, the air conditioner is most often set from 24 to 26 °C.

Chiou et al. [13] studied a model of fuzzy control for the energy savings and steadiness of air-conditioning systems compared with ON/OFF control methods. The temperature change and power change with the ON/OFF control method was set at 27 °C. The control logic of ON/OFF is that, when the indoor temperature is higher than the set temperature by 1 °C, it should start the compressors. When the indoor temperature is lower than the set temperature by 1 °C, it should be shut down the compressors. The result showed that the fuzzy controller control can save 8.92% energy compared with traditional ON/OFF methods. Chen et al. [14] studied the effect of an energy-saving device (ESD) on the performance of a split-type air conditioner and the proposed low-cost approach design for decreasing the shell temperature and power consumption of a compressor. The ESD
was fabricated using a moisture-transferring and quick-drying textile and then coated on the shell surface of the compressor to absorb the condensate expelled by a condensate pipeline and distributor to enable evaporative cooling of the compressor. The split-type air conditioner was tested with various outdoor air conditions (29, 32, and 37 °C temperature; 55% relative humidity) and a fixed indoor air condition (26 °C temperature; 50% relative humidity) to compare the function of the air conditioner with ESD installation before and after. The results indicated that the shell temperature of the compressor, high-side pressure, and power consumption of the air conditioner was 15.1 °C, 2.7%, and 9.2% lower, and the dehumidification capacity and EER were 25.4% and 7.3% higher, respectively, compared with those of the original split-type air conditioner under the optimal conditions.

Taiwan is located in the Tropic of Cancer. This subtropical climate is high in temperature and humidity. According to Taipower Company (TPC, major power supplier of Taiwan), the electricity usage for air conditioning rises greatly during the summer, which could impact the power quality. Demand control is a common strategy for energy worldwide. For industries of high energy consumption, the peak power (kW) and total power consumed (kWh) can both be lowered by 5–10%. The demand control focuses on avoiding peaks by shifting the time of power usage. In practice, TPC would have its customers lower their power usage at a given time for 15 min [15–17].

For air conditioning systems, the use of cycling on/off control instead of normal on/off control can also lower the power consumption. This intermittent control may apply to ducted central systems, packaged systems, and piston compressor systems but not for screw and centrifugal compressor systems [15,16]. TPC offers the option of intermittent control to the users of central systems over 20 horsepower or packaged systems over 10 refrigerating tons. TPC will set up timers for air conditioning systems: in central systems, turn off 15 min for every 60 min; in packaged systems, turn off 8 min for every 22 min, as shown in Figure 3 [18]. TPC will also set the users into groups based on locations and system types. Different groups would be turned off alternately to lower the peak usage [17]. TPC claims that intermittent control can lower the power consumption in medium and large systems [15–19]. However, the effects on home use window units and split-type systems remain unclear.

![Figure 3](translated.png)

**Figure 3.** The intermittent control scheme of TPC for central systems and packaged systems (translated) [18].
In this study, this control strategy was applied on split-type air conditioning systems, and the power consumptions of different times were analyzed to examine the effect on power saving under subtropical weather conditions. The main objective is to test the intermittent control of air conditioners and evaluate the energy-saving effect on home use devices that were originally designed for large central or packaged systems by TPC. The present work is structured as follows: Section 2 states our experimental equipment and setup. We simulated a common office with western exposure to be subjective. Finally, in Section 3, we first discuss the effects on indoor temperature and then examine the influence on energy consumption.

2. Experimental Equipment and Method

The experiment was conducted at SPINLab (Subtropical Performance-testbed for Innovative eNergy research in buildings) in Shalun, Tainan, Taiwan. The exterior of SPINLab is shown in Figure 4a. There is a monitoring room in the back and two test rooms with a glass curtain opening in the front. The two test rooms were set up as an office scene with the same configurations. Figure 4b shows the interior of one test room. The inner dimension of one test room is 6.5 m × 4.8 m × 3.8 m. Tables 1 and 2 are the structure of SPINLab and the thermophysical properties of the materials. Each test room is equipped with one split-type air conditioner; the model is HITACHI RAD-140NX1 (Taiwan Hitachi Asia Pacific Co., Ltd., Taipei, Taiwan), which has a max cooling ability of 14 kW. It is an inverter air conditioner (variable frequency) with CSPF (Cooling Seasonal Performance Factor) of 5.13 kWh/kWh.

![Figure 4. (a) Exterior and (b) interior of SPINLab.](image)

| Parts            | Structure                                      |
|------------------|------------------------------------------------|
| Exterior wall    | 2.5-cm aluminum panel                          |
|                  | 6-cm rockwool                                  |
|                  | 2.5-cm aluminum panel                          |
|                  | Air gap                                        |
|                  | 6-mm calcium silicate board                    |
| Roof             | 15-cm reinforced concrete                      |
|                  | 1.2-mm steel deck                              |
|                  | Air gap                                        |
|                  | 6-mm calcium silicate board                    |
| Glass curtain    | 6-mm + 6-mm laminated glass                    |

Table 1. The structure of SPINLab.
Table 2. Thermophysical properties of the materials.

| Materials               | Density (kg/m³) | Thermal Conductivity (W/m-K) |
|-------------------------|-----------------|------------------------------|
| Aluminum panel          | 2700            | 210                          |
| Calcium silicate board  | 1000            | 0.15                         |
| Steel deck              | 7860            | 45                           |
| Reinforced concrete     | 2200            | 1.4                          |
| Rockwool                | 60              | 0.042                        |

| Thermal transmittance (W/m²-K) |
|--------------------------------|
| 6 mm + 6 mm Laminated glass    | 4.88            |

The overall layout is shown in Figure 5. There are 4 office tables and chair sets numbering 1–4 with dividing partitions in each room. The opening of the rolling shutter on the glass curtain wall is set to adjust the window-to-wall ratio at 40% on this side of a room. Only 40% (in height) of the glass is allowed for incident sunlight. In this study, the glass curtain wall was set to face west to induce sunlight in the afternoon and examine the influence of “western exposure”. A temperature and humidity sensor was located on the roof to obtain the outdoor temperature. Both room A and room B were also equipped with 4 temperature and humidity sensors located at seats 1–4, as shown in Figure 5. The sensor model was eYc THS130. The measuring range and accuracy were 0–50 °C ± 0.2 °C (temperature) and 0–100% ± 2% (humidity). Data were recorded every 1 min. In order to obtain the actual perceptions of the indoor occupants, the sensor was suspended 1.6 m above the ground which is the height of the human head. For the heat load, we referred to the general human body heat dissipation data provided by several references [20–22] and set a scene where there were two people using two computers in each office. The heat load was simulated by 2 heaters for the computers and another 2 heaters for the humans. The total heat generation was 1000 W for each room. The inlets and outlets of the air conditioners were located near the window and in the middle of room, respectively, as shown in Figure 5. The sensors of the air conditioner are at the back of the rooms.

Figure 5. Experimental setup of the temperature and humidity sensors, air conditioning (AC) equipment, and heaters in test rooms A and B.

Intermittent control is a method proposed to customers by TPC to reduce air conditioner energy consumption [18]. The control strategy is to turn off an air conditioner for
15 min after every 60 min in one room. The other room remained in the control (i.e., constant temperature setting) for comparison. The temperature setting for both rooms was 26 °C, which refers to an energy-saving regulation in Taiwan [23]. The test time was from 08:00 to 18:00, and the control started after 10:00 in room B. The experiments were conducted on 21 and 22 April, and the weather was typical sunny days in Taiwan. The climate of Taiwan is hot, steady, and dry from March to May. Then, the rainy season starts in late May (plum rain). Typhoons start to appear from June/July. It may be the hottest days, but the weather would be too unsteady to perform experiments that require sunlight.

3. Results and Discussion

The indoor environment of the rooms was strongly influenced by sun exposure. With two identical setups in rooms A and B, the effects of the air conditioning strategy can be examined.

3.1. Effects on Indoor Temperature

Figure 6 shows the temperature variations from different sensors of outdoors, room A (A1–A4), room B (B1–B4), and their own air conditioners (Aac and Bac) on day 1. The outdoor temperature showed a typical variation during the daytime that increased before noon and then gradually decreased in the afternoon. The indoor temperatures can be divided into the A1A2, B1B2 group (near window) and A3A4, B3B4 group (away from window).

In room B, in which the intermittent control strategy was applied, the temperatures showed great differences from room A after direct sun exposure began. In room B, the temperatures could also be grouped by the distance from the window (B1B2 and B3B4), but all temperatures were affected by the deactivation of the air conditioner. Once the air conditioner was deactivated, all sensors ramped up rapidly and then lowered by the re-activated air conditioner within 10 min. The peak temperatures reached maxima values of 28, 28, 30, 32.5, 34, and 30.5 °C from B2 at 11:00, 12:30, 13:40, 15:00, 16:15, and 17:40, respectively. From B1 to B4 between 11:00 and 18:00, the overall temperature kept rising until sunset at around 17:00. It required more time and power for the air conditioner to remain the target temperature.

Comparing sensors at the same location in room A and B, all the max temperature differences were 4 °C, regardless of location.

Figure 6. Temperature and temperature differences of rooms A and B (day 1).
In room A, both A1A2 and A3A4 were regulated to 26 °C by air conditioning before 13:00. After 13:00, the sun started to have direct exposure from the west (window). As a result, the indoor temperature A1A2 started increasing to 29.7 °C at the max, but A3A4 remained at about 25 °C. The increase of A1A2 continued until 1.5 h before sunset. Due to the location of the sensor of the air conditioner also being far from the window, its reading (Aac) was similar to A3A4 with a lower resolution of 1 °C. The result showed local hotspots that occurred despite the air conditioner that was activated by default. In room B, in which the intermittent control strategy was applied, the temperatures showed great differences from room A after direct sun exposure began. In room B, the temperatures could also be grouped by the distance from the window (B1B2 and B3B4), but all temperatures were affected by the deactivation of the air conditioner. Once the air conditioner was deactivated, all sensors ramped up rapidly and then lowered by the reactivated air conditioner within 10 min. The peak temperatures reached maxima values of 28, 28, 30, 32.5, 34, and 30.5 °C from B2 at 11:00, 12:30, 13:40, 15:00, 16:15, and 17:40, respectively. From B1 to B4 between 11:00 and 18:00, the overall temperature kept rising until sunset at around 17:00. It required more time and power for the air conditioner to remain the target temperature. Comparing sensors at the same location in room A and B, all the max temperature differences were 4 °C, regardless of location. Figure 7 shows the temperature variations from another day. The results were similar, but the max differences between room A and B increased to 5 °C.
It is found that temporarily deactivating the air conditioner increased the overall room temperature beyond 1 °C, which triggered an increase of the power output from the air conditioner. Besides the normal heat load (people and computers), there was an extra heat input from sunlight. The incident sunlight caused differences in the indoor temperature based on the distance to the window. Sunlight directly heats up the location where it lightens. In room A (no intermittent control), when A1 and A2 kept rising at 13–15 p.m., the air conditioner did not activate. Only when the sensor was heated, the air conditioner would be activated. It could be heated up by sunlight, as in room A, or by the temperature increase of the whole room, as in room B. The temperature-related phenomena were mainly attributed to the sensor and, subsequently, air conditioner on/off. Table 3 summarizes the average and difference of the indoor temperature at different time sections. The temperature increased more near the window (A12, B12) when the rooms started to have incident sunlight in the afternoon. Overall, the appliance of intermittent control increased the indoor temperature by 1.4–2 °C.

Table 3. Average and difference of the indoor temperature at different time sections.

| Time (p.m.) | Average Temperature (°C) | Difference (°C) |
|-------------|---------------------------|-----------------|
|             | A12 | A34 | B12 | B34 | B12–A12 | B34–A34 |
| 12 to 13    | 25.9 | 24.2 | 27.4 | 25.7 | 1.5      | 1.5      |
| 15 to 16    | 28.3 | 25.6 | 30.2 | 27.6 | 1.9      | 2        |
| 16 to 17    | 28.9 | 25.9 | 30.3 | 27.7 | 1.4      | 1.8      |

3.2. Effects on Power Consumption

During the normal operation of the air conditioner, the power output mainly depended on the built-in temperature sensor. To examine the effects of intermittent control, the power consumption from the air conditioners in each room is shown in Figure 8 with their sensors and the nearest sensors. The curves of different days show a similar trend.

![Figure 8. Temperature and instant power consumption of rooms A and B.](image-url)
In room A, the room temperature of A3 and A4 was regulated at 25 ± 1 °C. In contrast to the continuously zig-zagging curves A3 and A4, the sensor of the air conditioner (Aac) showed a curve with discrete peaks due to its low resolution. The instant power monitoring showed the corresponding peaks of the air conditioner to increase the power output. When the sensor was near the target temperature, the power was at 1 kW to remain the current temperature. At the peaks, the power output can reach 2.5–2.8 kW.

In room B, the curves were similar to room A before the western exposure and application of intermittent control strategy. At 11:00, 12:30, 13:40, and 17:40, the reactivation of the air conditioner caused power peaks of about 2.5 kW to compensate for the reactivated (0 kW) periods. The deactivations in the early afternoon resulted in the sensor (Aac) being 1 °C higher than the target temperature. As for 15:00 and 16:15, the strong sun exposure caused temperature differences of 2 °C, and the power peaks reached 5 kW.

Figures 9–11 are temperatures and power consumptions at the different deactivated periods.

![Figure 9. Temperature and instant power consumption of rooms A and B at 12 to 13.](image-url)
Figure 9 is at the deactivation in the early afternoon (12:00–13:00), which the sun started when entering the rooms. In room A, the air conditioner regulated the temperature of the sensor (Aac) within a 1 °C fluctuation. Meanwhile, the room temperatures A1–A4 were separated into two groups by the distance from the window, as aforementioned. The average of A1A2 and A3A4 are shown as A12 and A34 in Figure 9, respectively. The two curves show identical small fluctuations due to the automatic regulation of the air conditioner, but A12 is at 25.5–26.5 °C and A34 is at 24–25 °C. The corresponding power output rose to 2.5–2.8 kW at peaks for additional cooling and maintained at 1 kW. When the temperature dropped below the target, the air conditioner entered temporary standby periods at 0.1 kW power consumption. In room B, the deactivation caused the sensor temperature (Bac) to rise mostly by 1 °C. However, B12 and B34 greatly increased to 29...
and 27.5 °C, respectively. The corresponding power is similar to room A, except that the deactivated period is 0 kW.

As the time proceeded to 15:00–16:00, the incident sunlight became more intense. In Figure 10, Aac remained at 25 °C, and A12 and A34 slowly increased from 27.6 to 28.5 °C and 25.1 to 26 °C, respectively. In room B, Bac was kept at 26 °C and reached a peak of 28.5 °C during the deactivation. B12 greatly increased to 32.1 °C, which was equal to the outdoor temperature, and then cooled down by air conditioning within 10 min. The trend of B34 was similar to B12, but the maximum only reached 30 °C. Comparing rooms A and B, the automatic regulation was not triggered in room A, and the power consumption remained at 1 kW. In room B, the large 3 °C difference from the target temperature led to a 5-kW output for 5 min after reactivation and then remained at 1 kW, as in room A.

Figure 11. Temperature and instant power consumption of rooms A and B at 16 to 17.
In the late afternoon (16:00–17:00), the outdoor temperature started decreasing from 31 to 29.5 °C, as shown in Figure 11. While Aac and A34 remained at 25–26 °C, A12 was still strongly affected by sun exposure, which reached a maximum of 29.5 °C. In room B, the effect of sunlight was even more apparent. Bac was kept at 26 °C but reached 28.5 °C during the deactivation when the outdoor was cooler than in Figure 10. B12 significantly increased to 33.4 °C, which was much higher than the outdoor temperature (31 °C), and then also cooled down in 10 min. The trend of B34 was similar to B12 with a maximum of 31 °C. As for the power consumption, both rooms A and B were similar to the previous period in Figure 10. The power consumption was at 1 kW in room A and a 5-kW peak in room B.

As the outdoor temperature lowered the afternoon time, the amount of incident sunlight through the west window increased with the solar zenith angle. The local time of sunset was 18:22. Therefore, the sunlight was still intense at 16:00–17:00 and caused a strong greenhouse effect that heated up room B.

To compare the overall effects of the intermittent control, the instant power and electricity consumption (i.e., accumulated power used) are shown in Figure 12. Similar results were attained from two different days. In room A, the instant power of the air conditioner was mostly kept at 1 kW, except for the short regulating actuation, which switched between 2.8 kW (cooling) and 0.1 kW (standby). Therefore, the corresponding electricity usage was nearly linear to the operation time. As for room B, the electricity consumption was identical to room A before the control strategy was applied. By starting the strategy, the instant power showed the three stages of “power off”, “restarting peak”, and “sustain”, as shown in Figures 9–11. The intensity of restarting peaks depends on room temperature, which was affected by the incident sunlight. It showed lower peaks at 11:00–15:00, as in Figure 9, and higher peaks at 15:00–18:00 (Figures 10 and 11). Comparing the electricity consumption in the rooms, the total consumption was slightly lower in room B. The final consumption of the day was 9.63 kWh in room A and 9.35 kWh in room B. The effect on energy saving occurred at 11:00–15:00 when the sun exposure was weaker. The maximum difference reached 16.9% by 15:00. However, at 15:00–18:00, the strong exposure caused higher power consumption while restarting the air conditioner. As summarized in Table 4, the average electricity consumption in the three time sections corresponding to Figures 9–11 shows that less energy was saved when time proceeded, and the incident sunlight became stronger. Thus, the final electricity consumption was only lower by 2.9% in room B.

Table 4. Energy-saving efficiency at different time sections.

| Time    | Average Electricity Consumption (kWh) | Difference to Room A |
|---------|--------------------------------------|----------------------|
| Room A  | Room B                               |                      |
| 12 to 13| 4.29 3.96                            | −7.47%               |
| 15 to 16| 6.96 6.45                            | −7.41%               |
| 16 to 17| 8.30 8.02                            | −3.33%               |

The variation process of instant power for the cycling on/off of split-type air conditioning systems was different from the research of Chiou et al. After 11:00 in Room B, the air conditioner was turned off for 15 min and then on again for the air conditioner. The instant power of the air conditioner suddenly increased and then decreased. This result was different compared with the research of Chiou et al. The variation phenomenon of instant power was not very obvious in Chiou et al.’s research. It may be caused by the different air conditioner types and the on/off of control method. However, the results for the cycling on/off of the air conditioner in this study showed that the energy-saving benefits in some periods are similar to those of Taipower Company [23], but the energy-saving benefits will be reduced when sunlight shines in the room.
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Figure 12. Instant power and electricity consumption of rooms A and B.

In the intermittent control, the air conditioner was shut down, and room B had 0 kW power consumption for the selected periods. In contrast, the autoregulation in room A had a constant consumption near 1 kW. However, from the intermittent case in Figures 10–12, there were time lags between power off and the temperature increase of the sensor (Bac); after which, the air conditioner should respond to the increased output. Therefore, the part of power in maintaining the temperature while the room temperature was self-sustained by thermal inertia was saved. Furthermore, in our case of western exposure, the variation of the temperature was small until late in the afternoon (more incident). The strategy would be more effective and have less thermal impact in other window orientations. Additionally, the incident intensity of sunlight was found to dominate the power consumption of air

Figure 12. Instant power and electricity consumption of rooms A and B.
conditioning. The effects of shading could also be effective, which we may examine in future studies.

4. Conclusions

The effect of an intermittent control strategy for air conditioning on energy-saving was examined in western-exposed rooms. The strategy applied periodic deactivation and reactivation to the air conditioner. Room temperatures, power consumption, and readings from the sensors of air conditioners of two identical rooms were monitored and analyzed. The rooms were well-insulated from each other, and a glass curtain wall of 40% window-to-wall ratio was on the west side. The results can be summarized as follows:

The indoor temperatures of both rooms could be sorted into groups according to the distance from the window. Temperatures were found higher when near the window with air conditioning. Furthermore, while the outdoor temperature gradually decreased in the afternoon, the indoor temperatures kept rising in both rooms until 1.5 h before sunset. The greenhouse effect caused by sunlight exposure from the west is the dominating factor of the room temperature in the afternoon.

The deactivation of the air conditioner for 15 min resulted in temperature peaks that were 4 to 5 °C higher than the control room. The reactivation of the air conditioner was able to cool down the room within 10 min based on the built-in sensor. However, due to the location and resolution of the sensor, the overall temperature from the four temperature and humidity sensors was still higher than the target setting, which may cause thermal discomfort.

The deactivation and reactivation had a direct influence on power consumption. The strategy led to three stages in the power curve: “power off”, “restarting peak”, and “sustain”. Compared to the control room, which was mostly at 1 kW, the instant power switched between 0 kW (power off), 2.8, 5 kW (restarting peak, based on temperature difference), and 1 kW (sustain). The summation of the power curve showed a 2.9% lower total electricity consumption (kWh) while the strategy was applied. It showed less energy-savings with home use devices than claimed, which TPC originally applied on large central or packaged systems. It is worth noting that it may have a higher energy-savings effect with the window facing in other directions. The current “western exposure” setup would introduce the most heat by sunlight in the afternoon.

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