# Study on energy conservation in experimental facilities by changing users' behavior

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**Abstract.** In 2021, Japan announced its aim to reduce greenhouse gas emissions by 46% in FY2030 than in FY2013, and universities were expected to contribute to the conservation of energy. The current study focused on ventilation systems in laboratories, which are among the most energy-intensive areas in universities, with the aim of reducing overall electricity consumption. The amount of electricity consumed by the draft chamber in a laboratory was determined based on the chamber opening. Result confirmed that the amount of electricity consumed by the 12 draft chambers to be 63,263 kWh/year. Using the relationship between chamber opening degree and power consumption by air conditioners and exhaust fans, we implemented a method to induce users of the draft chamber to take action toward controlling the chamber opening degree, using real-time information on chamber opening degree. A screen was set up to provide information to draft-chamber users in the laboratory using real-time monitors, and the induction of behavior was investigated over a 5-week period. Results confirmed that information displayed on the tablet device indeed reduced the chamber opening, the reduction rate being 21–48% compared to that before the information was displayed.

## 1 Introduction

According to a survey on the energy consumption in each campus of Osaka University in 2013, the primary energy consumption per unit area in science departments was reported to be more than three times higher than that in arts departments [1]. In addition, several studies have proved that energy consumption tends to increase due to the increase in the number of experimental equipment and the longer usage time of such equipment as research becomes more sophisticated, compared to other commercial facilities [2][3]. Based on these findings, reduction of power consumption by experimental facilities in science departments were considered to potentially contribute greatly to an overall reduction of power consumption in all universities. There has been a great discussion about draft chamber, an energy-intensive facility in a university laboratory facility [4][5]. Because, the ventilation provided by draft chamber require high air exchange rates, the energy required to draw air in can sometimes account for more than 60% of the energy used in a laboratory [6]. In order to reduce the energy consumption of draft chamber, it is important to

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implement operational improvements to close chamber sash when not in use [7]. One way of operational improvements is to apply nudges to induce energy-saving behavior among users by providing information [8][9]. Itoigawa focuses on electricity bill statements and considers information design that increases the likelihood of inducing energy-saving behavior [10]. Based on the above, the present study was undertaken in order to consider energy consumption reduction focusing on draft chamber in university experimental facilities. Specifically, the present study examines the changing chamber user's behavior by providing information through real-time monitors.

## 2 Electric power consumption modelling

First, power consumption due to the draft chamber was estimated, and relationship between the variation of chamber sash opening height (hereafter referred to as "chamber opening") and power consumption was modelled.

### 2.1 Composition of the laboratory studied

As shown in figure 1, information on power consumption by air conditioner and exhaust fan and draft chamber sash opening was obtained from a laboratory having 12 draft chambers. Information was gathered using a 0–10 V DC voltage, varying with the sash opening surface, by creating a parallel circuit in the draft chamber control panel. As figure 1 indicates, information was transmitted from a wireless communication node inside each draft chamber to a cloud server via a gateway in the laboratory through a closed-network communication. This enabled real-time and remote monitoring of chamber openings. One of the 12 draft chambers was excluded from the measurement in this study, since it could not acquire an opening signal. In addition, the data recording interval between power consumption by air conditioner and exhaust fan and information on chamber opening was 1 time/minute, allowing detailed measurement of minute-by-minute changes.

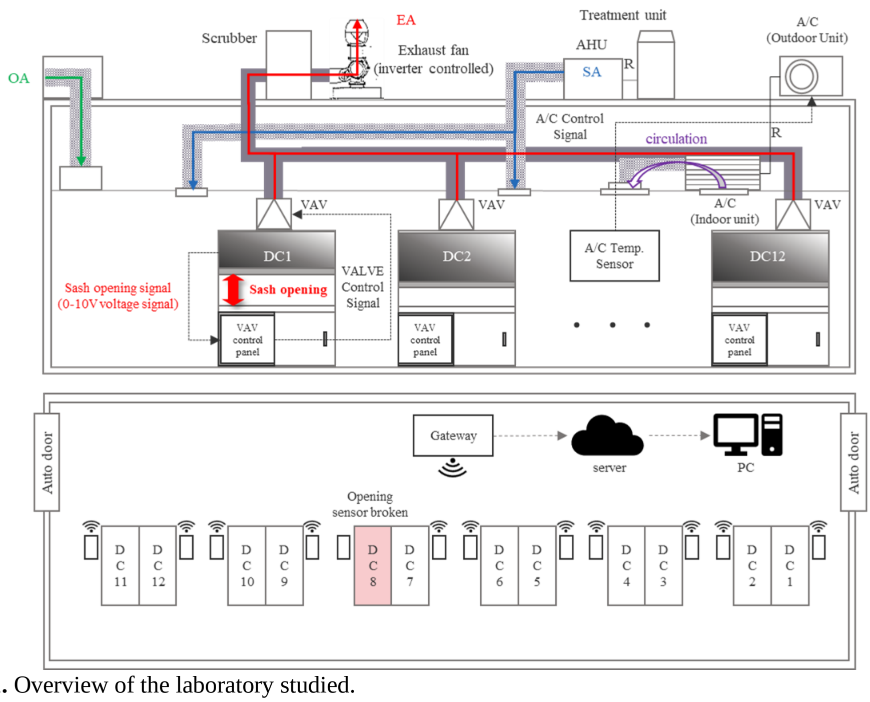


**Fig. 1.** Overview of the laboratory studied.

As shown in figure 1, the draft chamber used in this study was equipped with valves that allowed variable air volume (VAV) control. The latter can be defined as a control that regulates the airflow to be exhausted, according to the opening of the chamber's sash, and keeps the airflow constant at the opening surface. Draft chambers were controlled using a VAV to achieve a surface wind velocity of 0.25 m/s. Width of the sash in the draft chamber was 164 cm. Therefore, when the glass window was opened continuously for 1 h at 1 cm, the exhaust air volume was 14.76 m3/h.

## 2.2 Installation of human detection sensors

An infrared motion sensor was installed to analyze the chamber opening when users of the draft chamber are not using it. Installation of sensors could enable checking of the status of the user's draft chamber. In addition, using the response history of the sensor, the number of days the user worked, and duration of the same, could be estimated based on the user's enrolment time. Although the draft chamber was not actually used, the sensor was installed with the chamber facing 90° downward from the horizontal plane to minimize misjudgements due to users' passing through the front of the chamber.

## 2.3 Electric power consumption model due to draft chamber

This study aimed to induce energy-saving behavior by displaying chamber opening to the user. The main electric power consumed by the draft chambers can be classified into two categories. The first category was incremental air-conditioning load caused by exhaustion of the conditioned air. The second category was the electric power consumption by exhaust fans. First, the air conditioning load per unit volume was calculated based on the difference in specific enthalpy between indoor and outdoor air, which was then converted to power consumption by multiplying it by the amount of air exhausted in accordance with the chamber opening by VAV control. For the calculation of specific enthalpy of the room, target temperature setting of the air conditioner was set as the room temperature and humidity was considered to be 50%. The specific enthalpy differences for 2022 are shown in figure 2. Second, power consumption by the exhaust fan was measured every minute using a computed tomography (CT) sensor for current measurements and a data logger. Relationship between the chamber openings measured simultaneously with exhaust fan power consumption is shown in figure 3.

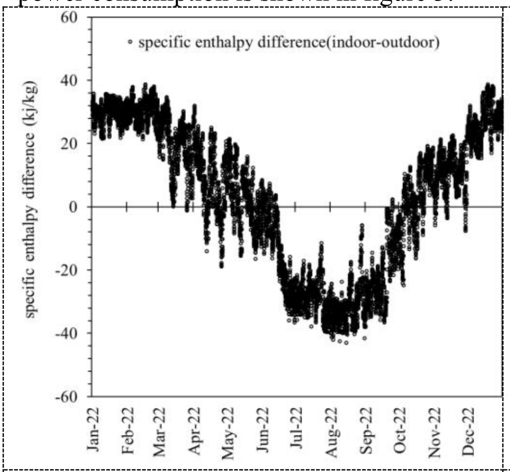


**Fig.2.** Specific enthalpy difference between indoor and outdoor.

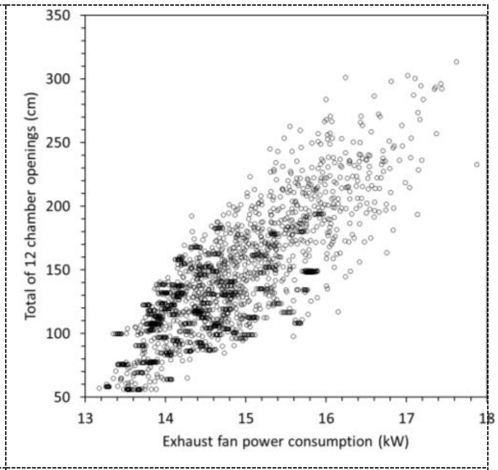


**Fig.3.** Relationship between exhaust fan power and chamber opening.

Equation 1 shows the relationship across the specific enthalpy difference, exhaust fan power consumption, and chamber opening. However, the equation requires the use of different constants depending on the sash width of the draft chamber, surface air velocity, number of chambers, exhaust fan efficiency, and differential pressure between the inside and outside of the room.

$$Wd = (0.012 + 0.021) \times \sum_{t=1}^{T} Hc \times t \qquad (1)$$

In equation 1, *Wd* is the amount of electricity consumed by the draft chamber (kWh), *T* is the observation period (h), and *Hc* is the one-hour average (cm) of the chamber openings (total of 12 units). Table 1 lists the results of estimation of total power consumption of all units by factor using equation 1. To calculate the value equivalent to 12 units, the average value of 11 units was added as the value for the 12th unit. For annual conversion, the value equivalent to 12 units was divided by 301 days, which was the observation time, and then multiplied by 365 days.

**Table 1.** Estimated power consumption by factor calculated by the model.

| | Cumulative opening (cm*h) | Electricity consumption (kWh) | | |
|---|---|---|---|---|
| | | Exhaust fan | Air conditioning | Total |
| Total 11 units (301 days) | 1,447,173 | 17,366 | 30,391 | 47,757 |
| Equivalent to 12 units (301 days) | 1,578,735 | 18,945 | 33,153 | 52,098 |
| Equivalent to 12 units (annualized) | 1,917,066 | 23,005 | 40,258 | 63,263 |

## 3 Implementation of real-time monitors

Two types of monitors were prepared for this demonstration, namely shared monitors and individual monitors. The shared monitor was intended to create an environment in which the status of all draft chambers can be monitored simultaneously and to encourage users to control the opening of the chamber based on social norms. To make these monitors accessible to many users, they were installed near the entrance and exit of the laboratory. Individual monitors were installed near each draft chamber, where users can easily check the monitors themselves, for developing appropriate behavior toward the draft chamber users. The information displayed on the shared monitor included the real-time opening value of the chamber, chamber-user absence time and opening ranking for the day. The intention of each method was to enable users to determine whether they can change the chamber opening by displaying the real-time opening rate and time of absence. Further, by displaying the ranking, it would be possible to work toward the social norm, which is the purpose of shared monitoring. Individual monitors displayed the amount of money, opening history, opening evaluation, and advice or appreciation according to the chamber opening status. The intention of displaying the amount of money was to show that it was the only effective method, among the methods proposed in this study, in terms of benefit/cost evaluation; therefore, it was considered to be highly effective when combined with other elements. One example of real-time monitors is that the screen configuration of the shared monitor is shown in figure 4.


**Fig. 4.** Screen configuration of the shared monitor.

## 4 Results

Chamber openings were measured in real time, and the opening information and various other related information were displayed on the screen every minute. Whether installation of the monitor caused a change in chamber opening was determined by comparing the total data on chamber openings of the chamber openings over a week. In addition, days with the same level of response from the human detection sensors were defined as days with the same trend in draft chamber usage time and were referred to as equivalent days. As shown in figure 5, the average chamber opening rate of the 12 draft chambers resulted in reductions ranging from 21% to 48% compared to that in the equivalent days; the average reduction was 34%. Considering the annual electric power consumption estimated in Section 2, a reduction of 21,509 kWh per year was expected. However, as the demonstration progressed, the reduction rate compared to that on an equivalent day was found to be lower. This could be because the demonstration peaked in the second week of the year, possibly resulting in a lower reduction rate for openings, due to familiarity with the demonstration.

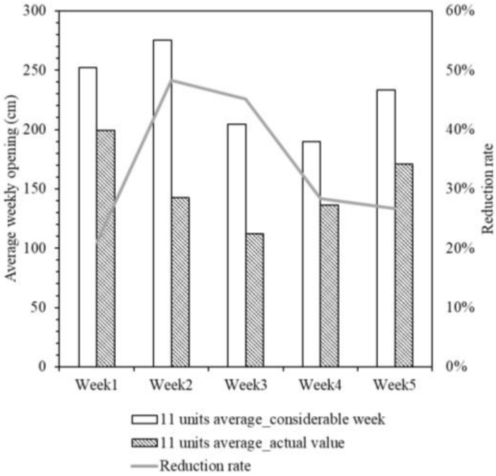


**Fig. 5.** Comparison of average weekly openings before and after introduction of the monitor.

## 5 Conclusion

The present study was undertaken in order to consider energy consumption reduction focusing on draft chamber in university experimental facilities by changing users' behaviour. First, focusing on chamber opening, it can be formulated the energy consumption of draft chamber from incremental air-conditioning load caused by exhaustion of the conditioned air and the energy consumption by exhaust fans. Using this equation, we estimated the energy consumption by draft chambers in the target laboratory over the course of a year and found the amount of electricity consumed by the 12 draft chambers to be 63,263 kWh/year. Next, the present study examines the changing chamber user's behavior by providing information through real-time monitors. Two types of monitors were prepared, chamber opening, chamber-user absence time, opening ranking for the day, the amount of money, opening history, opening evaluation and advice or appreciation. Results of five-weeks demonstration, the average chamber opening rate of the 12 draft chambers resulted in reductions ranging from 21% to 48% compared to that in the equivalent days.

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