Methodology to Achieve Safety and Energy Savings in Laboratory Buildings

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ABSTRACT

Most of laboratories are highly energy consuming buildings, which have many mechanical exhaust equipments to ensure safety of human body from toxic substances. Air change rate of fresh air intake caused by exhaust for lab facility comes up to 20 ～ 60 air-change/h, compared to office building of only 1 ～ 2 air-change/h. Conventionally, because safety takes precedence, it was allowed that great volume of ventilation consumes much energy, however, recent demand for sustainability strongly requires coping with both proper safety and energy saving. A primary cause, which makes lab exhaust greater, is installation of many spot exhaust devices such as fume hood to prevent human body from suffering chemical exposure. However, codes and regulations require that constant and adequate face velocity to be maintained at sash opening of fume hood, it would be a problem if exhaust amount were simply reduced. In recent years, VAV system is introduced for fume hoods which operates together with sash, still, to take demand factor into system design for energy saving becomes more important.

On this paper, we introduce a case where 55% reduction of energy consumption was achieved by introducing VAV and design optimization, compared with conventional system. Furthermore, we propose a methodology targeted to detect fault and optimization by on-going commissioning. And we also propose the visualizations about fault detection system for end users. The visualizations are friendly tool that end users are able to recognize possibility of fault. This methodology would contribute to energy saving, reduction of CO_2, and improvement of sustainability.

FEATURE OF LABORATORIES

“Safety ”and “Energy saving”

When experiments are conducted in a laboratory, materials such as chemical substances, which are harmful to the human body, are used in research processes. Therefore, when researchers handle such toxic substances, it is required that the safety for the human body to be properly maintained.

To ensure safety in laboratories, large amount of indoor air is ventilated by mechanical ventilation. That is why laboratories are the buildings where the energy consumption is much higher than that of average office buildings. In other words, seeing from an energy point of view, how to maintain “Safety ” with “Minimized Energy Consumption ” should be important issue to be resolved.

Devices for safety and codes requirements

To prevent researchers from taking toxic substances into their lungs, special mechanical ventilation devices such as fume hoods are used in laboratories. Regarding controlling air in front of researcher, Codes and Regulations prescribe air velocity through sash opening of fume hood. (Figure 1). The above is a reason why ventilated air volume could not be simply reduced. Table 1 lists requirements of Codes and Regulations for face velocity.

Energy Consumption in Laboratories

Because a lot of fume hoods are installed in laboratory, much amount of energy is consumed to treat fresh air for air conditioning supply. About air change rate of fresh air treatment, laboratories and average office buildings are compared to grasp aspect of energy consumption. Figure 2 shows that fresh air change rate of average office building is around 1 ～ 2AC/h for CO_2 Control, and around 5 ～ 10AC/h for Temperature Control. On the other hand, in laboratories, it is 20 ～ 60AC/h because of exhaust by fume hoods and so on. Therefore energy consumption is huge in laboratories

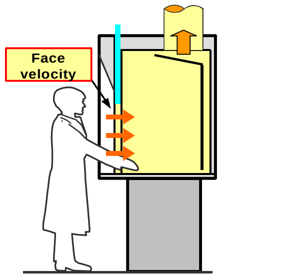


Figure 1 Face Velocity

Table 1 Codes and regulations for face velocity

Code	Face velocity
Labor low (Japan)	Min. >0. 4m/s Min. >0. 5m/s (Gas)
OSHA (Occupational Safety & Health Administration)	Ave. : 0. 3～0. 51m/s
ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers)	Ave. 0. 51m/s±10%
ANSI (American National Standards Institute) AIHA (American Industrial Hygiene Association)	Ave. 0. 41～0. 61m/s
SEFA (The Scientific Equipment and Furniture Association)	Ave. 0. 51±0. 1m/s
NFPA (National Fire Protection Association)	Ave. 0. 4～0. 6m/s

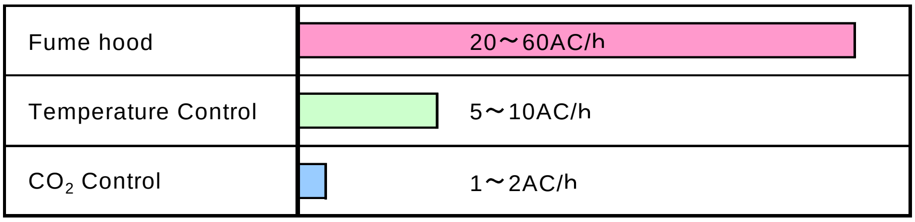


Figure 2 Comparison of Air Change Rate

PROPOSED SYSTEM TO REDUCE ENERGY CONSUMPTION

Recently, it is strongly requested to minimize energy consumption in view of energy saving and sustainability. However, safety is most important issue to be treated with top priority. In addition, under the circumstance where research processes are changing to be complicated, number of fume hood installed is increasing, and the operating time in laboratory becomes irregular.

<u>Optimum Design and Operation based on Demand Factor</u>

In conventional independent exhaust system, constant air volume is exhausted regardless of the opening height of fume hood sash. (Figure3) Even when the fume hood is not in use, indoor air is exhausted from the opening provided at the upper part of the sash. Each exhaust from one or two fume hood is connected to one exhaust fan. (Figure4)

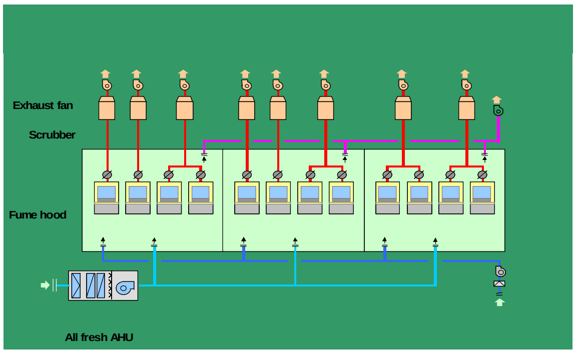


Figure 4 Conventional independent exhaust system

First step of energy saving is introducing VAV system. Because exhaust air volume is regulated by VAV system, which is controlled based on the opening area of the fume hood sash, air of necessary is exhausted properly. (Figure5) In addition, during Standby Mode and Night Mode, exhaust air volume can be changed to perform minimum ventilation. Furthermore, an exhaust a fan is not installed for each fume hood, besides manifold duct, which gathers exhaust air from many fume hoods, is installed.

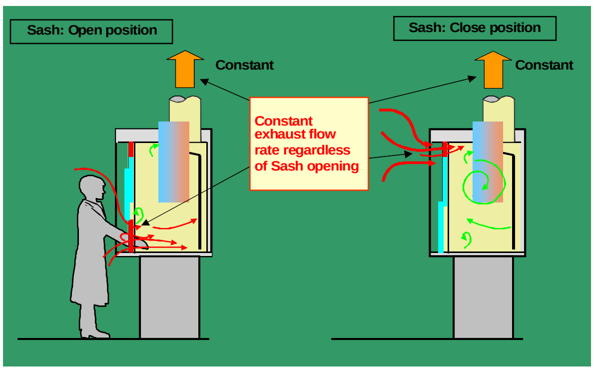


Figure 3 Conventional type Fume hood

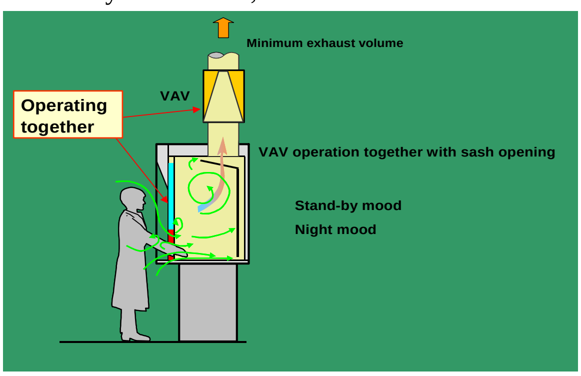


Figure 5 VAV exhaust system
Operating with sash

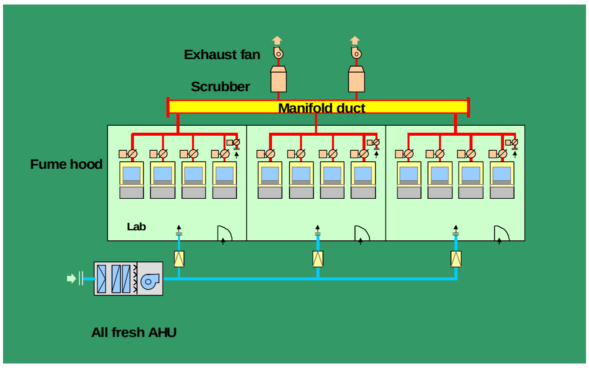


Figure 6 Manifold duct
＋ VAV exhaust ＆ supply system

Figure7 is the graph of 'probability of simultaneous use' (i.e. demand factor) of fume hoods in laboratory. Statistical approach for ten Fume hood was set to be initial condition, and demand factor was calculated. It is binomial distribution, with demand factor of 10%. In this case, probability of one or less fume hood in use is more than 70 %. Accordingly, it is not necessary to install exhaust fan based on flow rate of maximum fume hoods operation.

Keeping proper face velocity at sash opening to maintain safety, with proper Cx and warning systems, which inform researcher such as excess number of fume hoods in use, sash auto closer with human sensor, it is important to find optimum point where total exhaust air volume is controlled to be minimum.

Figure8 shows the point. The horizontal axis is exhaust air volume, and the vertical axis is safety performance. In this figure, the point of intersection of curves is considered to be Optimum Point for Safety and Energy Saving.

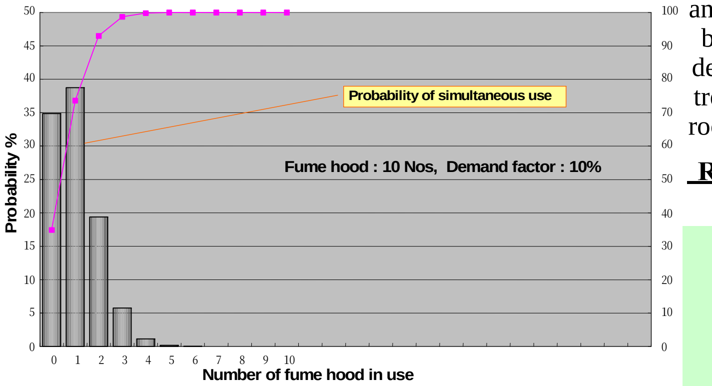


Figure 7 Probability of simultaneous use

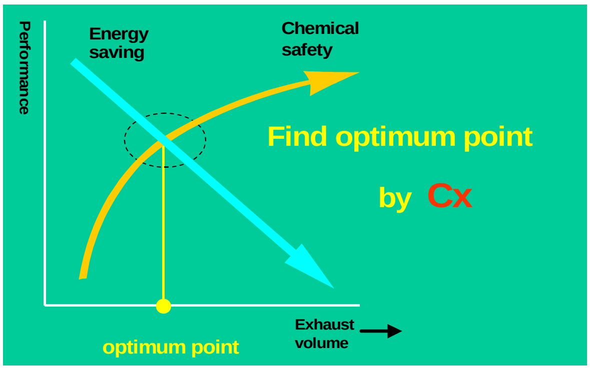


Figure 8 Chemical safety and Energy saving

Generally, a large number of fume hoods are installed in the laboratories. Actual usage of fume hoods was grasped by monitoring. Figure9 shows a floor plan of a building where actual survey was conducted. Figure10 shows the monitoring system. A monitoring sensor was installed on each fume hood, and actual operations of fume hoods were recorded.

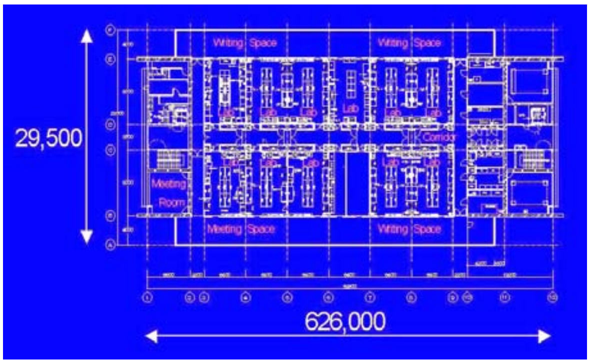


Figure 9 Floor Plan

In addition, the exhaust air volume by the VAV and the treated fresh air volume were also recorded by monitoring system. By this monitoring system, demand factor was found out. Figure11 shows trend chart of each fume hood operation in one room.

Result of Monitoring

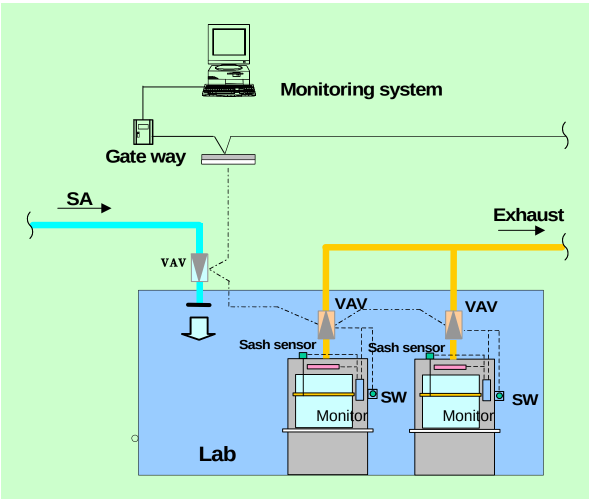


Figure 10 Verification of diversity factor
by monitoring system

Number of fume hoods used simultaneously is seven at the maximum. Demand factor is around 40% of the whole. About 'fume hood – h', in this chart, it is found that the sash of fume hood was left in open position.

Table 2 shows comparison of Peak air conditioning load and volume of fresh air intake. Figure 12 and 13 show the trend of demand factor in 24 hours.

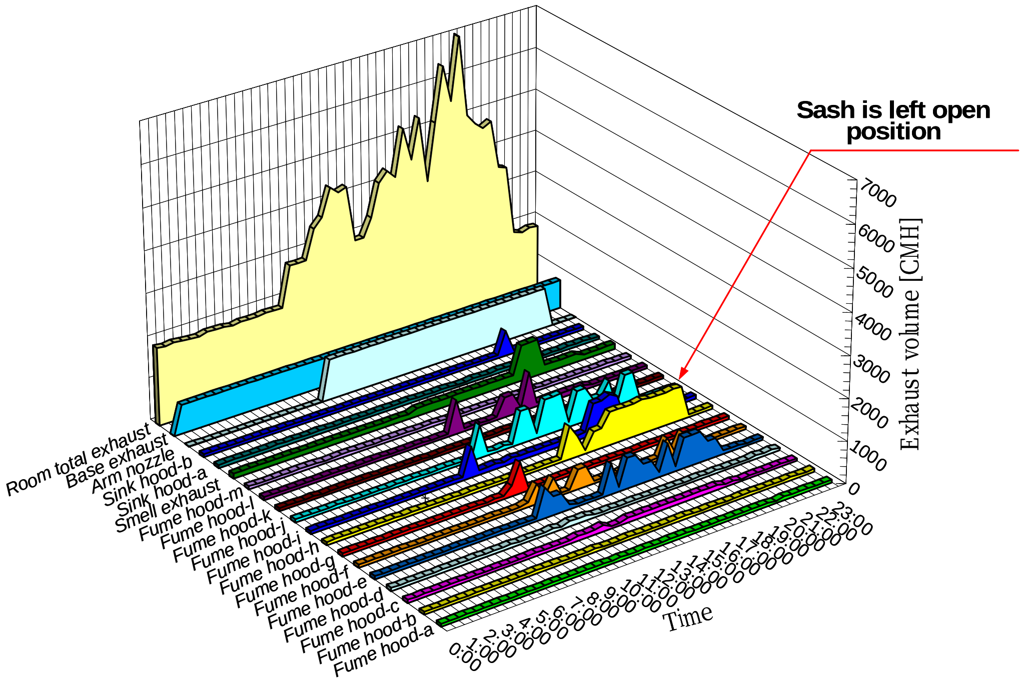


Figure 11 Usage of each Fume hood

Table 2 Comparison of air conditioning peak load and fresh air intake

No.	system	Peak Load (W／㎡)		Fresh Air Intake (AC／h)
		Cooling	Heating	
1	Conventional independent exhaust system	680	528	51(Lab) 25(Lab+Office)
2	Manifold duct + VAV exhaust & supply system	476	364	34(Lab) 17(Lab+Office)
3	Manifold duct + VAV exhaust & supply system ＋ **Comissioning**	305	227	19(Lab) 10(Lab+Office)

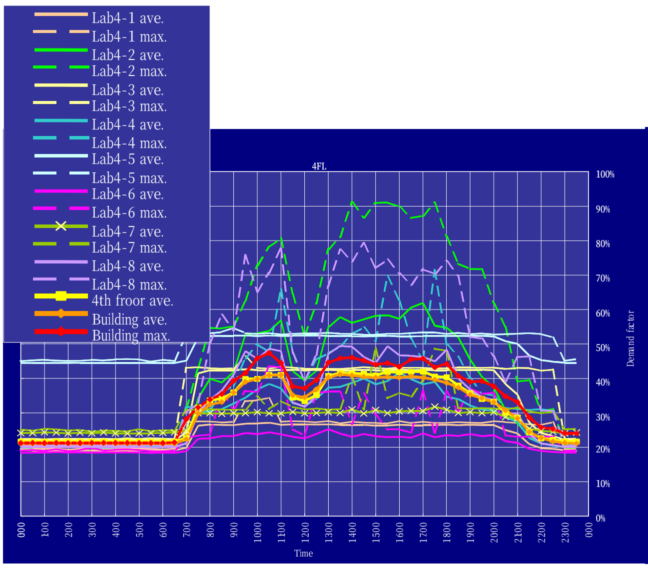


Figure 12 Demand Factor （1）

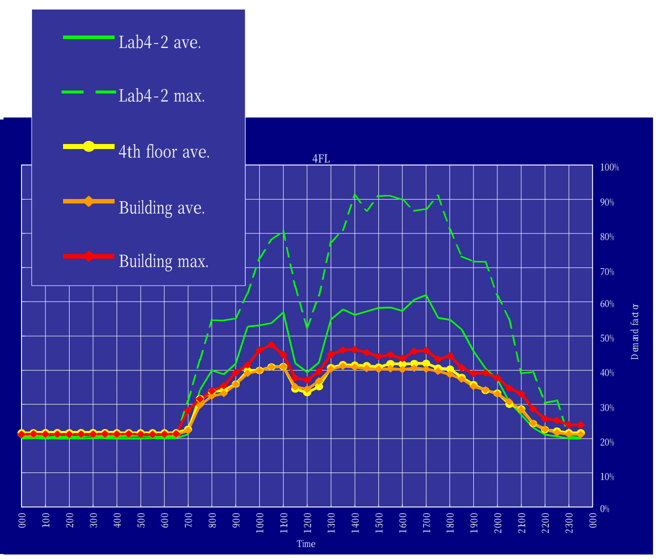


Figure 13 Demand Factor （2）

System tuning with Statistical Method and On-Going-Cx was put into practice. Figure14 shows a result of the cooling load with Cx. The reduction effect by Design phase Cx is 30%. The reduction effect by Construction & Operation phase Cx is 36%. When it was compared with original load, reduction of 55% was accomplished.

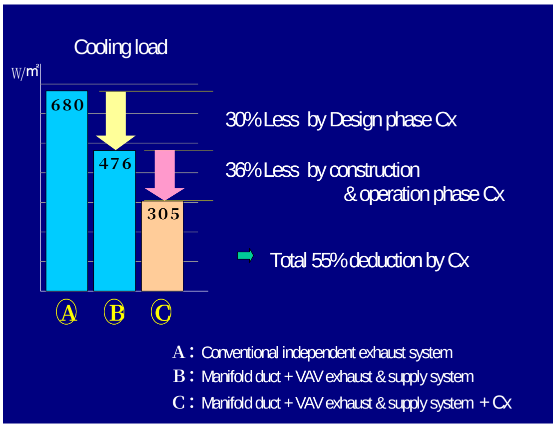


Figure 14 Comparison of Cooling Load

METHODOLOGY THAT AIMED AT FAULT DETECTION AND OPTIMIZATION BY ON-GOING CX

For the further improvement of the air conditioning system that leads energy saving, fault detection systems by Building Management System or Building Energy Management System (BEMS) were studied. There are two approaches. First one is from indoor environment; second one is from operational condition of the fume hoods.

Approach from indoor environment

This is a fault detection approach where fault is detected by process values of indoor environment.

Temperatures, relative humidity, air pressure deference between rooms, cleanliness are nominated items to be monitored. Alert level (upper level / lower level) is settled in building management system. When a process values of the items deviate from alert level, warning is made on time. Sensors installed for automatic control purpose are utilized for the monitoring purpose mentioned above. It is necessary that the validity of the located place of the sensors to be properly examined.

Approach from fume hood status of operation

Air volume passing in a duct, is monitored by sensors. If it is considered too mach compared with design value, which is based on demand factor, alarm to be made. Besides above, each fume hood has sash opening sensor, then number of fume hoods in operation and opening height of each sash to be monitored for fault detection.

The undesirable condition is caused by both mechanically and human error. Human error means careless mistake or users offending against rule, S.O.P (Standard Operating Procedure).

For example, in case S.O.P. requested user close a sash of a fume hood every time after experimental activities, and if it was not done properly, exhaust air volume would be greater than designed set value. That means excess air is exhausted and energy is wasted, either.

Visualization of Faults for User's easy recognition

Since activities of users affect energy consumption directly and seriously, it is thought important to have a USER FRIENDLY TOOL complete with visualization. That helps researchers in laboratory realize extraordinary condition immediately by themselves, as well as the facility manager of the building does.
"Recognizing immediately" leads fast correction of improper usage, and to establish revised S.O.P.
Energy saving and safety are not attained until hard ware and soft ware are settled properly.
In large energy consuming facilities such as laboratories, how to improve activities of end user is one of the key issues to be solved.

About visualization, there are two categories, as follows.

a) The category, about the condition of the device
- ON or OFF status of devises
- Alarms by trouble of devises
- Alarms by unusual number of operating equipments in use at the same time

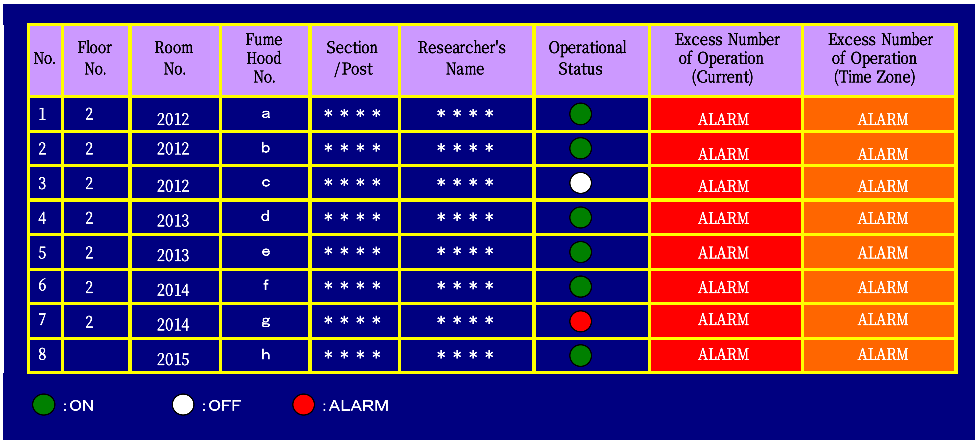
b) The category, about the energy consumption status
- Alarms by monitoring of current energy consumption (Alarms when the actual value exceeds the expected value)
- Energy consumption of every day, every week, every month (Visualization of the data of last year as the comparison.)

Figure15～ 17 show the image of visualization. Figure16 shows the current condition of fume hoods usage. User as well as facility manager are able to be aware of the user's name who causes unusual energy consumption.

To make user pay attention to status of usage and energy saving, visualization is made with colors. (Ex. orange or red color). Demand factor and number of fume hood in operation is set, on the basis of actual survey value.

If some sashes were left open, warning would be made to inform researcher for rectification. These systems are useful for education and to prepare guideline or S.O.P for end users.

Figure16 shows floor plan of the building to monitor the current status of fume hoods in use. Figure17 shows the list that make researcher recognize the usage of fume hoods of the day. With the accumulated data, S.O.P will be revised. And it is possible to adjust the energy consumption of the building to proper and minimized value.



No.	Floor No.	Room No.	Fume Hood No.	Section /Post	Researcher's Name	Operational Status	Excess Number of Operation (Current)	Excess Number of Operation (Time Zone)
1	2	2012	a	****	****		ALARM	ALARM
2	2	2012	b	****	****		ALARM	ALARM
3	2	2012	c	****	****		ALARM	ALARM
4	2	2013	d	****	****		ALARM	ALARM
5	2	2013	e	****	****		ALARM	ALARM
6	2	2014	f	****	****		ALARM	ALARM
7	2	2014	g	****	****		ALARM	ALARM
8		2015	h	****	****		ALARM	ALARM

Figure 15 Example of Visualization （ 1 ）

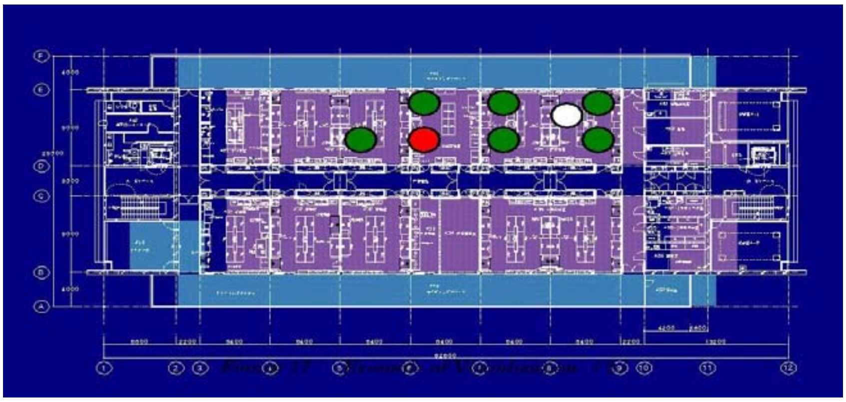
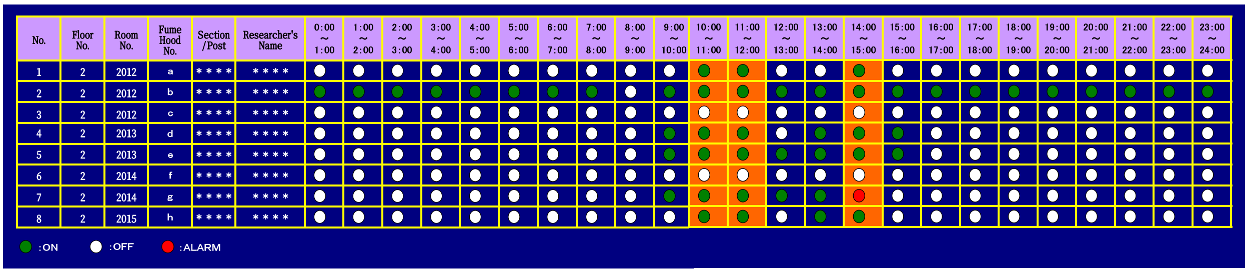


Figure 16 Example of Visualization （ 2 ）



No.	Floor No.	Room No.	Fume Hood No.	Section /Post	Researcher's Name	0:00 ~ 1:00	1:00 ~ 2:00	2:00 ~ 3:00	3:00 ~ 4:00	4:00 ~ 5:00	5:00 ~ 6:00	6:00 ~ 7:00	7:00 ~ 8:00	8:00 ~ 9:00	9:00 ~ 10:00	10:00 ~ 11:00	11:00 ~ 12:00	12:00 ~ 13:00	13:00 ~ 14:00	14:00 ~ 15:00	15:00 ~ 16:00	16:00 ~ 17:00	17:00 ~ 18:00	18:00 ~ 19:00	19:00 ~ 20:00	20:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 23:00	23:00 ~ 24:00
1	2	2012	a	****	****																								
2	2	2012	b	****	****																								
3	2	2012	c	****	****																								
4	2	2013	d	****	****																								
5	2	2013	e	****	****																								
6	2	2014	f	****	****																								
7	2	2014	g	****	****																								
8	2	2015	h	****	****																								

Figure 17 Example of Visualization （ 3 ）

CONCLUSION

On this paper, how to attain both safety and energy saving of laboratory was mentioned. Especially, in case of highly energy consuming facilities, it is important to make a careful consideration for both hard ware and soft ware such as users S.O.P. (Standard Operating Procedure)

To obtain proper S.O.P., On-Going-Cx is significant.

Visualization tool as a fault detection system, which helps user to recognize improper energy consumption, was proposed. This system and methodologies are useful for not only laboratories but also factories such as electric devise, pharmaceutical, food factories.

The proposed systems and methodologies may be utilized not only large facilities but also small facilities where no facility manager is controlling energy consumption. Socially to make gross energy consumption minimum, improvement in small facilities is a key issue.

In view of the above, it is expected that proposed methodology may contribute to reduce consumed energy and to achieve safety and proper operation.

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