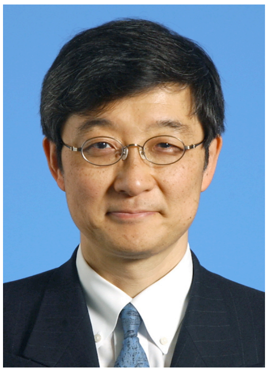
Zero Energy Building project in the University of Tokyo

Tomonari.YASHIRO,
Professor, Institute of Industrial Science, the University of Tokyo,
Japan
yashiro@iis.u-tokyo.ac.jp



Ryozo Ooka,
Professor, Institute of Industrial Science, the University of Tokyo,
Japan
ooka@iis.u-tokyo.ac.jp

Research fellow, Bumpei.MAGORI, the University of Tokyo, Japan, magori@iis.u-tokyo.ac.jp
Research fellow, Hiroshi Sako, the University of Tokyo, Japan, sako@iis.u-tokyo.ac.jp
Dr. Hiroyuki Shida, the University of Tokyo, Japan, shida@iis.u-tokyo.ac.jp
Dr. Kyosuke Hiyama, the University of Tokyo, Japan, hiyama@iis.u-tokyo.ac.jp
Research fellow, Daiki Yasuda, the University of Tokyo, Japan, daiki@iis.u-tokyo.ac.jp
Former Graduate School Student, Hirofumi Ikeda, the University of Tokyo, Japan, h-ikeda@iis.u-tokyo.ac.jp
Professor Takashi Nagata, the University of Tokyo, Japan, nagata@cluster.c.u-tokyo.ac.jp
Professor Michio Kato, the University of Tokyo, Japan, kato@idea.c.u-tokyo.ac.jp
Professor Kazuo Chikushi the University of Tokyo, Japan, chikushi@idea.c.u-tokyo.ac.jp

Summary

This is a case illustration of experimental pilot project to research, develop, design and construct net zero energy building (hereafter ZEB) by the authors in the campus of the University of Tokyo. The paper describes technologies invented and applied in the building as well as how the technologies are integrated to functionalize the building.

Keywords:zero energy building, double skin, heat pump, ground water utilization, radiation cooling, thermal mass utilization, natural ventilation, desiccant dehumidifier, energy management system, energy monitoring

1. Introduction

The idea of zero energy building is getting to be popular concept in various countries all over the world. Japan is not exceptional; The Ministry of Economy, Trade and Industry of Japanese Government is supportive to develop and diffuse the idea of net zero energy building. The research committee organized by METI [1] defined net zero energy building as;

A building that consumes zero or nearly zero energy on an annual net basis by reducing primary energy consumption in the building through enhanced energy efficiency performance of the building envelop and facilities, networking of neighbouring buildings, on-site utilization of renewable energy, and so on.

Associated with METI, New Energy and Industrial Technology Development Organization (hereafter NEDO) initiated the project to subsidize to the experimental pilot projects of ZEB. The University of Tokyo had the opportunity to get the subsidy for design and construction of ZEB buildings in its campus. This paper introduces technologies applied in this experimental pilot project. It also presents how technologies are integrated to enhance higher energy use performance.

2. Project description

2.1 Outline of the building

The building was constructed in Komaba campus, one of the three major campuses of the University of Tokyo. The building is called as “The building for innovative education”. It has five floors and one underground level floor. The total floor area of the building is 4,477m2. It includes several studios and convention rooms such as halls and meeting rooms.

2.2 Design team for ZEB

Original version of conceptual design of the building has nothing to do with the idea of ZEB. The University of Tokyo, as a client, decided to introduce the idea of ZEB after the first version of conceptual design has been completed. Consequently, design process of ZEB is a series of change orders from client side.

Various experts committed in the process of design development process during which the building has been transformed from ‘ordinary building’ to ZEB. The design team of the ZEB is interdisciplinary and is composed of architects, building service engineers, users and administrators, contractors and researchers in Institute of Industrial Science, the University of Tokyo.

Various design issues are mutually interdependent, thus, change and modification relating to some issues draws bunches of changes of other issues. The interdependency required tough design management process. Consequently, design process includes not only success but also failures. Members of the team held periodic meetings where information has been exchanged and the design has been discussed and coordinated based on design documents made by team members. Thus, the periodic meeting provided the opportunity for design integration.

2.3 Scenario for net zero energy

The design team defined reference level at 1830MJ/m2/ywar as a standard reference level in comparison. Then the team aimed to reduce 35% from the reference level within three years since its start of operation. The inventory of the reduction is;

50% reduction in heating
30% reduction in cooling
20% reduction in lighting
20% reduction in clean water use
30000kwh/year (i.e. 1880GJ/year) generation by PV

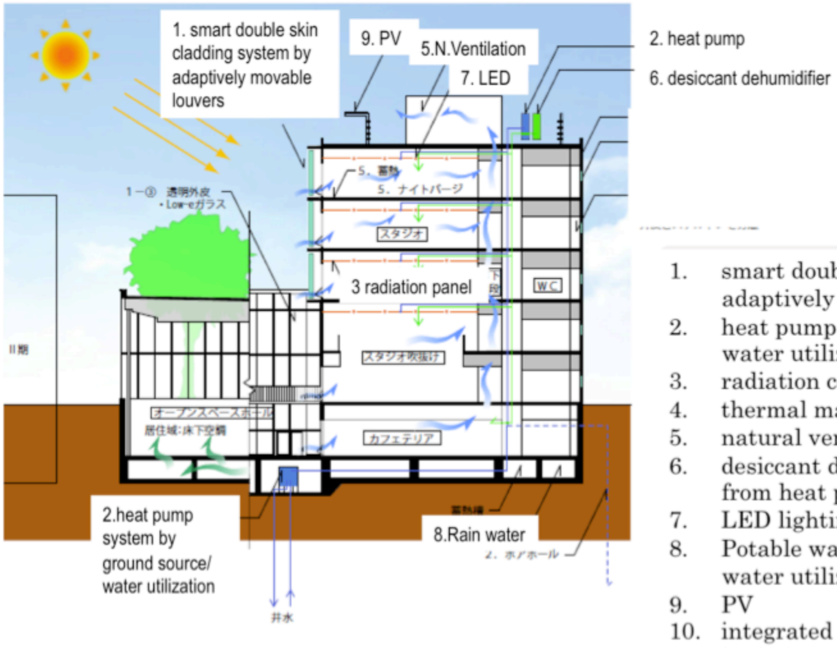
Then the design team estimate another 20 % reduction no later than 2020 by proactive demand control and optimization based on energy use monitoring system. Furthermore, respecting on rapid improvement in efficiency of building service equipment, another 20 % reduction by 2030 is supposed to be expected by replacement of exiting equipments by those with higher efficiency in future. In addition, conversion efficiency of PV would be doubled by 2030, Consequently, if those assumed conditions would be realized, the building could be net zero energy building.

2.4 List of technologies applied

Various technologies are invented and developed respecting on specific conditions and requirements of the building. Fig.1 presents technologies installed and integrated in the building, which includes;

1) smart double skin cladding system by adaptively movable louvers
2) heat pump system by ground source/water utilization
3) radiation cooling/heating panel system
4) thermal mass utilization
5) natural ventilation by chimney effect
6) desiccant dehumidifier by exhaust heat from heat pump
7) LED lighting system
8) Potable water saving including rain water utilization
9) PV

10) integrated building operation system by AI based control



1. smart double skin cladding system by adaptively movable louvers
2. heat pump system by ground source/ water utilization
3. radiation cooling/heating panel system
4. thermal mass utilization
5. natural ventilation by chimney effect
6. desiccant dehumidifier by exhaust heat from heat pump
7. LED lighting system
8. Potable water saving including rain water utilization
9. PV
10. integrated building operation system by AI based control

Fig. 1 Technologies applied to the building

3. Technologies developed and applied

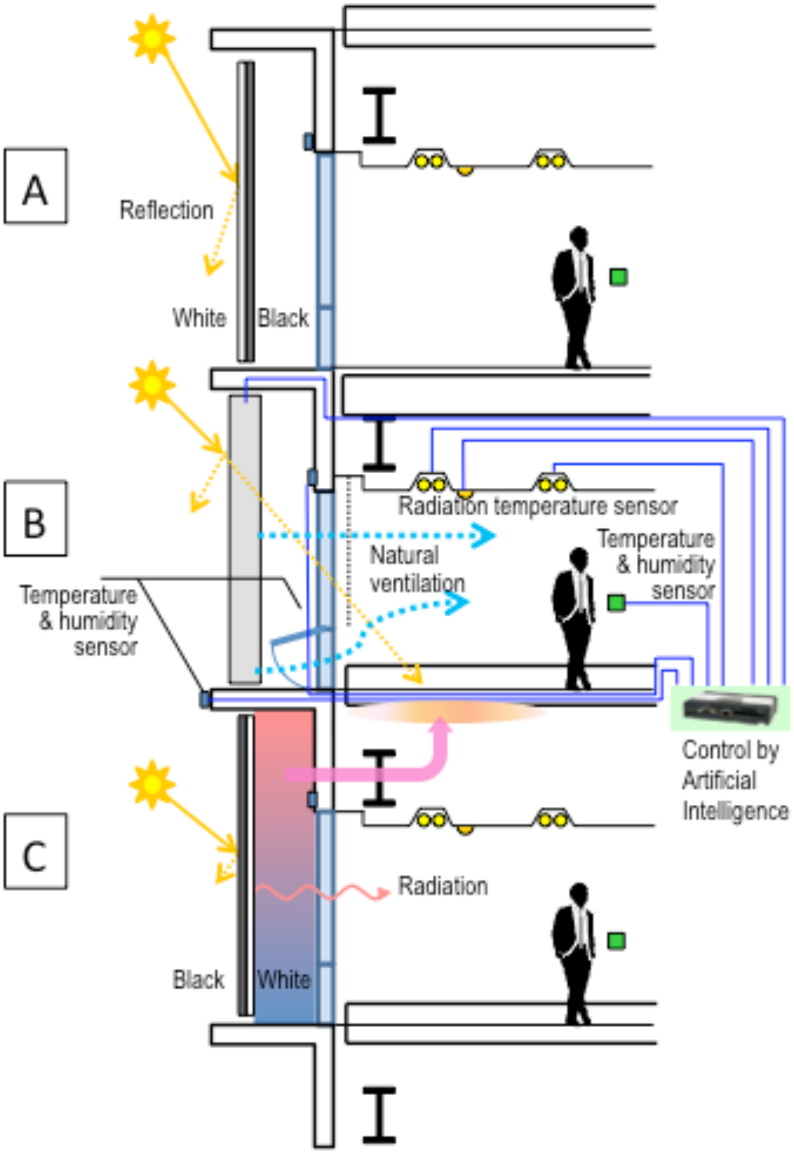
This chapter presents outline of technologies developed and used in the building through collaboration of the interdisciplinary design team.

3.1 Smart double skin cladding system by adaptively movable louvers

The west and east elevations of the building have considerable thermal load as well as an opportunity to utilize natural ventilation, natural light and heat radiation from sunrays in winter. In order to solve the contradict requirements on selective control of light heat and airflows, design team invented and developed smart double skin cladding system with adaptively movable louvers. In case of fixed windows, triple glazing sashes with inlet for natural ventilation are installed together with external sun shading.

In case of openable windows, invented double skin system is applied; the system consists of movable vertical louvers and their frames. Each vertical louver unit is composed of double layered slat panels and a double glazed panel. (Respecting on that this double skin is installed in the west and east elevation, slats are installed vertically.) The unit can be rolled around vertical axis. Consequently, as it is shown in Fig.3, both slat panels and glazed panel can face outside/inside selectively depending on outside conditions. In addition, white coloured side of slat and black coloured side of slat are also turned around, thus, both sides of slat can face outside selectively as well.

Fig. 2 shows three modes of movable louvers. The mode A aims to minimize thermal load by sunrays in summer by letting white coloured side of slat face to reflect sunray rays. The mode B aims to maximize natural ventilation and natural light utilization in spring and in fall (i.e. when thermal load from outside is low) by letting slats and glass give maximum way to airflow and natural light from outside. The mode C intends to heat gains from sunrays in winter by letting black colour side of slats faces outside. Fig. 3 presents detailed mechanism how the double skin system works in summer and in winter.



Mode A

Mainly in the morning in summer, white coloured side of slat panels in movable louvers faces outside and the angle of louvers follows diurnal motion of the sun to prevent inclusion of sunrays to inside.

Mode B

Mainly in spring and in fall, movable louvers are open to outside to maximize natural ventilation. If outside temperature should be lower than inside in night in summer, natural ventilation is introduced through inlet within slat panels to facilitate night purge effect. The moving mechanism of louvers is manupirated by artificial intelligent controller which is introduced in 3.7.

Mode C

Mainly in the morning in summer (i.e. duration of time when sun altitude is relatively low), black coloured side of movable louvers faces outside in order to collect radiated heat from the sun and to stock them in upper flower slabs by utilizing its thermal mass. Even in the time when louvers are shut, visibility from inside to outside is assured by deliberate detailing of punching metal shape of slats.

Fig. 2 Three modes of 3.1 Smart double skin cladding system with adaptively movable louvers (developed by Shida and Magori et.al.)

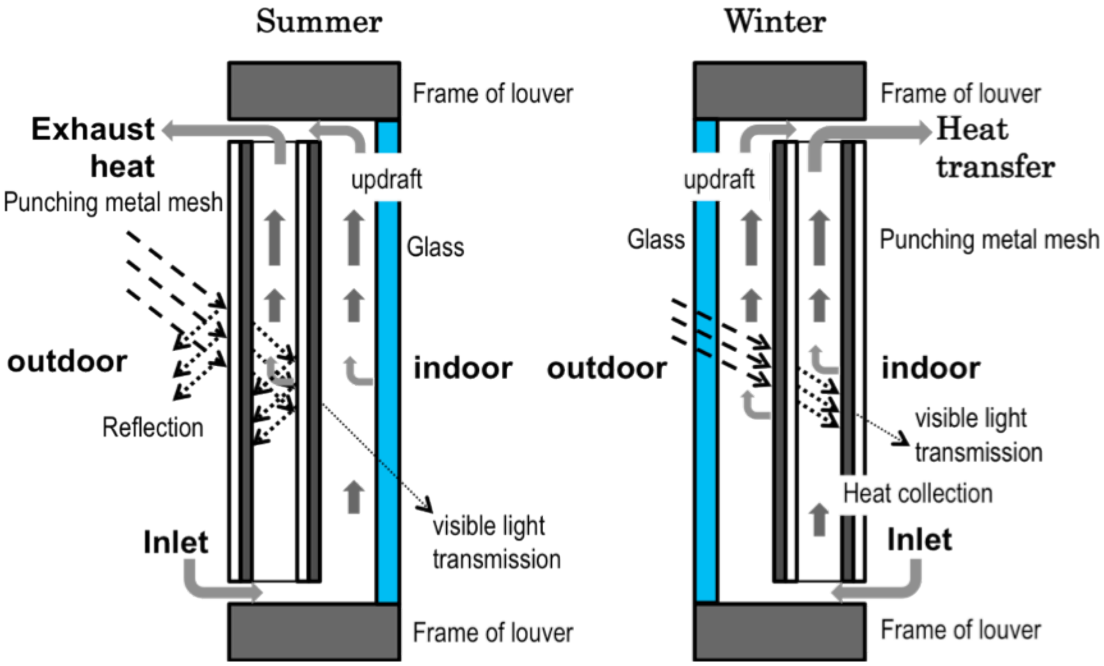


Fig. 3 Mechanism of smart double skin cladding system with adaptively movable louvers (developed by Shida et.al.)

3.2 Heat pump system by ground source/water utilization

In general, ground temperature is stable in all four seasons (in Tokyo, 16-17 degrees). Thus, utilization of ground and/or ground water as heat sources enables higher energy efficiency in heating and cooling of building. To utilize the potential of ground heat, the building applies ground source/water based heat pump system by installing 10 tubes of 100 meter length U shaped heat exchangers as well as a pair of wells in the underground of the building.

Respecting on previous researches by Ooka, one of the co-author of this paper, possibility of clogging in well was predicted. This is a reason why a pair of well is used; clogging could be prevented by exchanging the role of pumping well and returning well periodically.

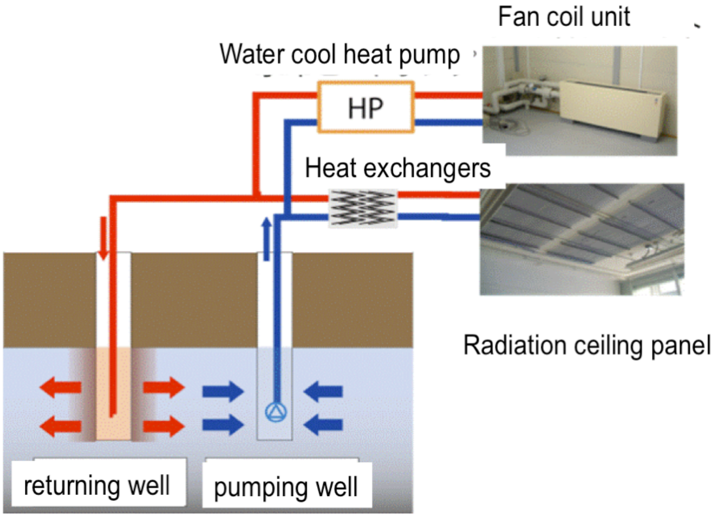


Fig. 4 Heat pump system by ground source/water utilization (developed by Ooka et.al.)

3.3 Radiation cooling/heating panel system with desiccant dehumidifier

Conventional air conditioning method changes the temperature of air to warm or cool human’s body. This indirect warming and cooling via air includes waste and inefficiency in energy use. Contrarily, warming and cooling by radiation panel is a method to warm or cool human’s body directly. It does not need the energy for bringing air and for activating fans. It also avoids needless draft as well as upgrades indoor air quality and comfort. The installed ceiling panels have function of radiation panels. Before application to the building, performance of the radiation panels had been verified through experiments in laboratories.

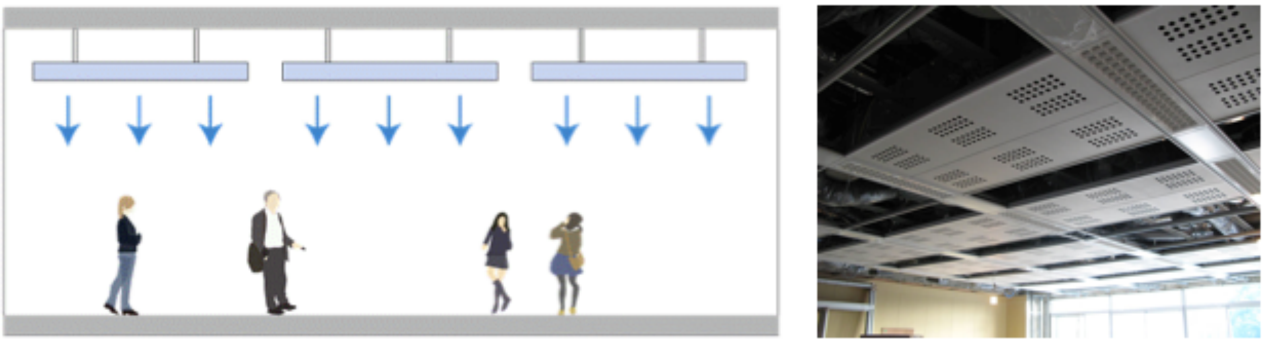


Fig. 5 Radiation cooling/heating panel system (developed by Sako et.al)

When radiation cooling system by ceiling panels is introduced, water drops by dew condensation around ceiling panel could be happened. In order to prevent such kind of dew condensation disaster, accurate control of indoor humidity is necessary. Desiccant dehumidifier system is effective measure for non condensation. However, conventional desiccant technique has low energy use efficiency because of consumption heat for recovery of desiccant materials. To solve this problem, solar heat and/or exhaust heat needs to be utilized for recovery of desiccant materials. Desiccant dehumidifier system installed in this building utilizes exhaust heat from heat pump air conditioning system.

3.4 Thermal mass utilization

The building is designed to stock heat gain in floor slabs by utilization of its thermal mass. Together with internally generated heat such as heat from lighting and computers, the building aims to make zero-heat-load for air conditioning in winter. In other seasons, night purge mechanism is introduced; structural members and spaces between ceiling and floor panels are cooled by natural ventilation in night in order to minimize cooling load when mechanical cooling system starts its operation in the morning.

3.5 LED lighting system and integrated system

Needless to say, the use of LED has advantage in energy conservation compared with conventional lighting. This building aims more higher efficiency than simple, stand alone use of LED.
The building embodies integrated control system that maximizes use of natural light and facilitates complementary use of artificial light by LED with dimmer function.
Fig. 6 shows outline of the integrated system. Previously mentioned louvers in double skin cladding system moves based on evaluation of the data from pyranometer; In case pyranometer would suggest that it is raining or cloudy, louvers moves to introduce maximum quantity of day light to inside. In case it would suggest bright and no direct sun rays, louvers also settle to the direction to introduce natural day light as much as possible. In case of sunny day with direct sun rays that could increase cooling load such as in summer, the louvers are settled to prevent inclusion of sun rays to inside of the building. In case indoor space is warmed artificially, louvers are settled to proactively introduce heat gains. Together with and harmonised with adaptively controlled louver system, artificial light by LED is controlled. Motion sensors works to switch off and on LED lighting

which is controlled to assure sufficient illumination intensity based on illuminometer. The system is manipulated by artificial intelligent controller which is introduced in 3.7.

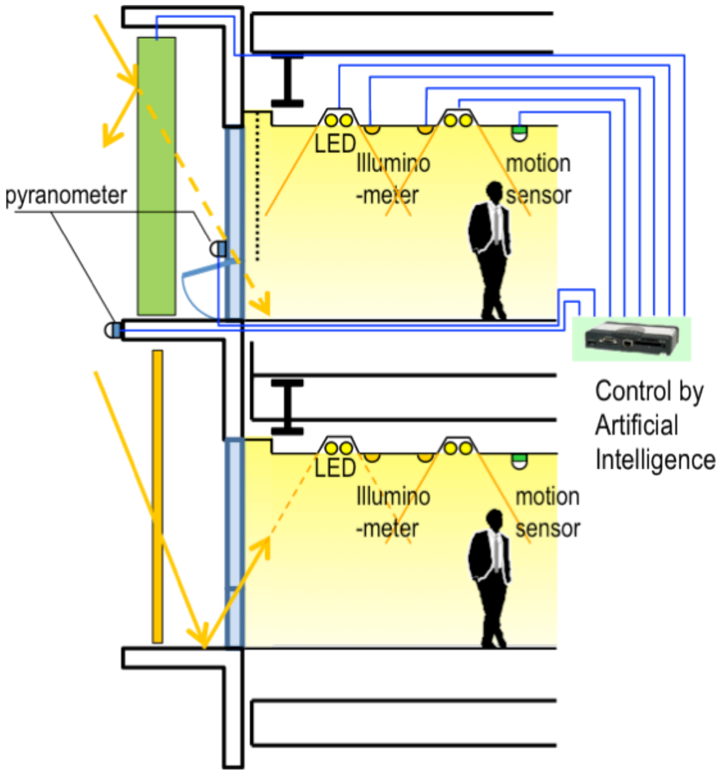


Fig.6 Integrated use of natural light and LED

3.6 PV (photovoltaic) system

Photovoltaic system by 300 meter square of thin-film solar modules are installed on the roof of the building. The maximum capacity of generation reaches to 30kw which is 10% of anticipated maximum peak load demand of electricity in summer. Annual total electric power generated by installed PV is estimated as 400GJ in primary energy basis. Generated electricity is designed to be used in the building (i.e. PV here is separated from network). The building also embodies continual monitoring system to measure site basis real efficiency of the PV.

3.7 Integrated building operation system by AI based control

The building embodies energy monitoring system based on the idea of information embedded building [2]; the monitoring system consists of sensors of energy use, temperature, humidity, indoor air quality, illumination intensity etc. The real time basis data is transferred from sensors as digital data to server which is located off-site. The stocked and input data in the sever is analysed through the process shown in Fig.7. The visualised real time basis reporting of the analysis is accessible to all stakeholders of the building through WEB site. Consequently, the system is used as a device of benchmarking for building owners and users. The major users of the building are students of the university of Tokyo. Thus, the College of Arts and Sciences of the University of Tokyo is now preparing environmental education by utilization of the energy monitoring system as a visualization device for education.

The system shown in Fig. 7 has another implication for building operation. Continuous collection of real time data and analysis facilitates to establish more precise and accurate prediction model of energy use of building through genetic algorithm, which can be called as a sort of artificial intelligence. It is an enabler of proactive demand control by feed-forward operation based on the precise prediction through artificial intelligence (hereafter AI). In another word, the integrated operation system is an AI based tool for continual improvement of building operation as well as environmental education. This is a mechanism of artificial intelligent (AI) controller which is shown in Fig.2 and Fig.6.

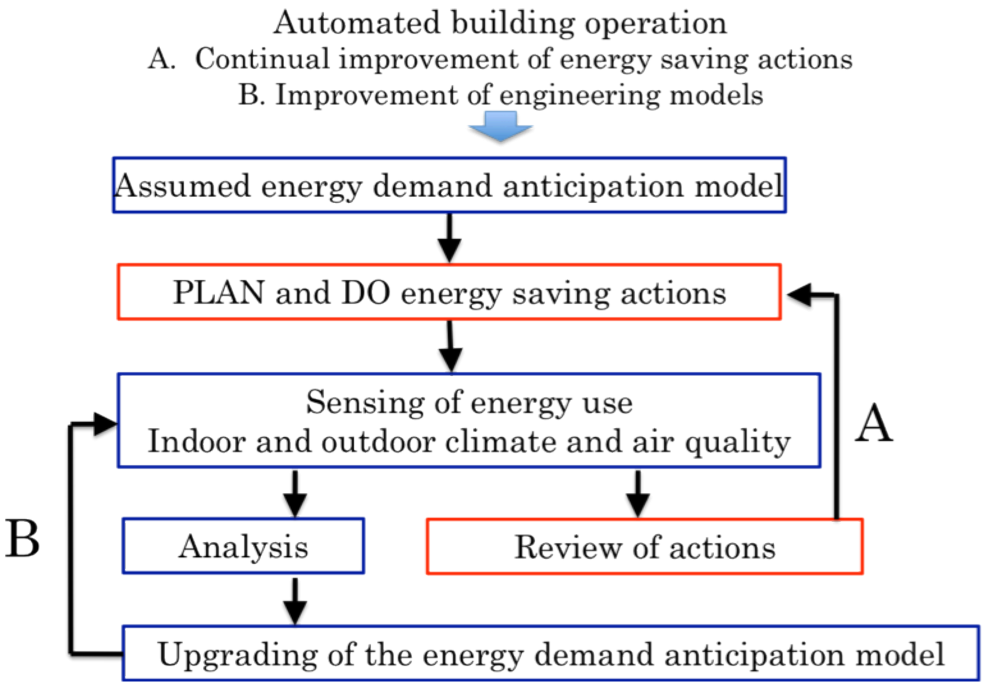


Fig.7 Proactive demand control system using real time energy monitoring and a sort of AI

4. Concluding comment

The design team of the building developed brand new technologies that could enhance the reality of the idea of ZEB. Though those are invented to respond to specific conditions of the project, the author believes it could be applicable in the other ZEB oriented projects. In addition, the method of design integration is expected be the template for following projects.
The building will be fully completed in May 2011. Thus, actual performance of building against net zero energy and target defined in the scenario in pre-design process is not yet reviewed and evaluated. The authors will commit in the process in building operation of the building as well as the educational activities using this building. The authors wish to report on the actual performance of the building continually through various opportunities in future.

References

The authors appreciated all collaborators of the reported experimental building projects and funding agencies including NEDO for their support and contribution

References

[1] The Ministry of Economy, Trade and Industry of Japanese Government Ministry of International Trade, “*Development and diffusion of net zero energy building – prospect toward 2030*”, 2009(in Japanese) http://www.meti.go.jp/report/downloadfiles/g91124d01j.pdf.

[2] YASHIRO T, “Information embedded building for sustainable living”, proc. of World SB08 Melbourne: World Sustainable Building Conference, CSIRO, 2008, p.1188-1195.