INTEGRATIVE SUSTAINABLE DESIGN STRATEGIES FOR ENERGY AND WATER EFFICIENCY: THE CASE OF THE EWHA CAMPUS COMPLEX IN KOREA

Jinkyun CHO Senior Engineer [1,2]
Minho HONG Director, P.E.[1]
Taisub LIM Senior Researcher [2]
Byungseon Sean KIM Professor, PhD [2]

[1] R&D Institute, Hanil Mechanical Electrical Consultants, 15-1 Yangpyeong-dong, Yeongdeungpo-gu, Seoul, Korea, jinkyun.cho@himec.co.kr
[2] Building Science Laboratory, Department of Architectural Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea, maxjcho@yonsei.ac.kr

Keywords: sustainable design, energy/water efficiency, eco-friendly systems, energy-saving technology

Summary

The Ewha womans university Campus Complex (ECC) is designed to be a completely eco-friendly underground campus building that will symbolize the vision of sustainable design for the 21st century. In order to achieve this objective, the building is planned to reduce energy costs and the environmental load as well as to promote energy/water efficiency by applying optimal eco-systems such as a thermal labyrinth, geo-thermal energy, concrete core activation and others in order to use less primary energy. Furthermore, the envelope is effectively designed to save energy required for cooling and heating by providing an earth berm, a massive construction and a green roof system for the top of the building. In addition, windows that can be opened located on the valley side (opposite side to the earth-sheltered envelope) will improve natural ventilation during mid-season. Various water sources such as ground water, rainwater, and de-watering, etc. will also be applied to the building complex. As explained above, the ECC is a low-tech building designed with a focus towards saving energy and water and maximizing the recycling of the spent energy and water.

Figure 1 Ewha womans university Campus Complex (ECC) in Seoul, Korea (January 2008)

1. General Building Description

Table 1 Building information

Project	Ewha Campus Complex		
Architects	DPA Dominique Perrault Architecture (France) and Baum Architects (Korea)		
Engineers	HLPP Consult (Germany) and HIMEC (Korea)		
Location	Seodaemun-gu, Seoul, Korea		
Services	- Academic program: learning and sport-term project space, libraries, cafeteria - Administration - Commercial area: cinema, theatre, shops as well as external sporting spaces and car parks (20,000 ㎡)		
Site area	19,000 ㎡	Built-up area	70,000 ㎡
Structure	RC + SS	Estimated completion	2008

Above and below the land previously occupied by the Ewha square and the athletic field, the new campus valley provides both Ewhaians and prospective female leaders with the much-needed space for continuing education and student services. The concept design proposed by Dominique Perrault (France) was accepted at an international design competition held by the Ewha womans university in 2004, in order to develop the massive educational-cultural complex. The campus complex to be constructed is designed to offer a new sense of direction for higher education in the 21st century. It will establish organic relationships between the new building and the surrounding areas of the campus as well as between the above ground and underground spaces. The entire campus complex comprises six floors of underground structure. The 20m wide x 300m long campus valley connects the front gate and the main building and is composed of two floors of parking lots and four floors of educational-cultural welfare establishments.

2. Central Plant and HVAC Systems

The central plant systems of the ECC are designed as ecosystems that maximize energy and water saving. The various eco-friendly systems are also organically unified.

Cooling systems comprise heat pump type chillers, absorption chillers and a thermal storage system. In the night charging mode, the cooling system is operated by storing heat in the thermal storage tank using the less expensive night thermal storage power service during the night and using the discharging mode in the daytime. It is intended that the cooling systems will be operated in the order of the stratified thermal storage tank, the absorption chiller and the heat pump type chiller, according to the rate of the cooling load.

Heating systems serve the heating spaces and the heat pump units, which are reversed in the operating mode into the heating and the hot water boilers, produce domestic hot water. Numerous heat exchangers are installed separately in accordance with the amount of hot water required for each area, while the primary loop pumps are constant speed pumps and are controlled by the return water temperature in order to reduce the pump power. The secondary loop pumps are adapted to a variable speed either by the inverter control or by the quantity-related control, according to the heating load.

Table 2 Designed as a highly efficient heating and cooling system to deliver services

Equipments		Capacity	Quantity	Operation	Services
Cooling	Geo-thermal energy	100 kW	-	24 hours	CCA (concrete core activation)
	Ground water	40 kW	-	24 hours	CCA & condensate water
	Absorption chiller	1,266 kW	1 EA	24 hours	Day time: AHU, CHR & CCA Nighttime: CCA & nighttime zone
	Heat-pump type chillers	745 kW	2 EA (Stand-by)	24 hours	Daytime: AHU, CHR & CCA Nighttime: thermal storage tank
	Water thermal storage system	6,680 kWh	750 ton	24 hours	AHU, CHR & CCA
Heating	Geo-thermal energy	150 kW	-	24 hours	Heat-pump type chillers (chilled water)
	Hot water boilers	1,163 kW	2 EA	-	AHU, CHR, CCA & domestic hot water
	Heat-pump units (hot water)	958 kW	2 EA (Stand-by)	-	AHU, CHR & CCA

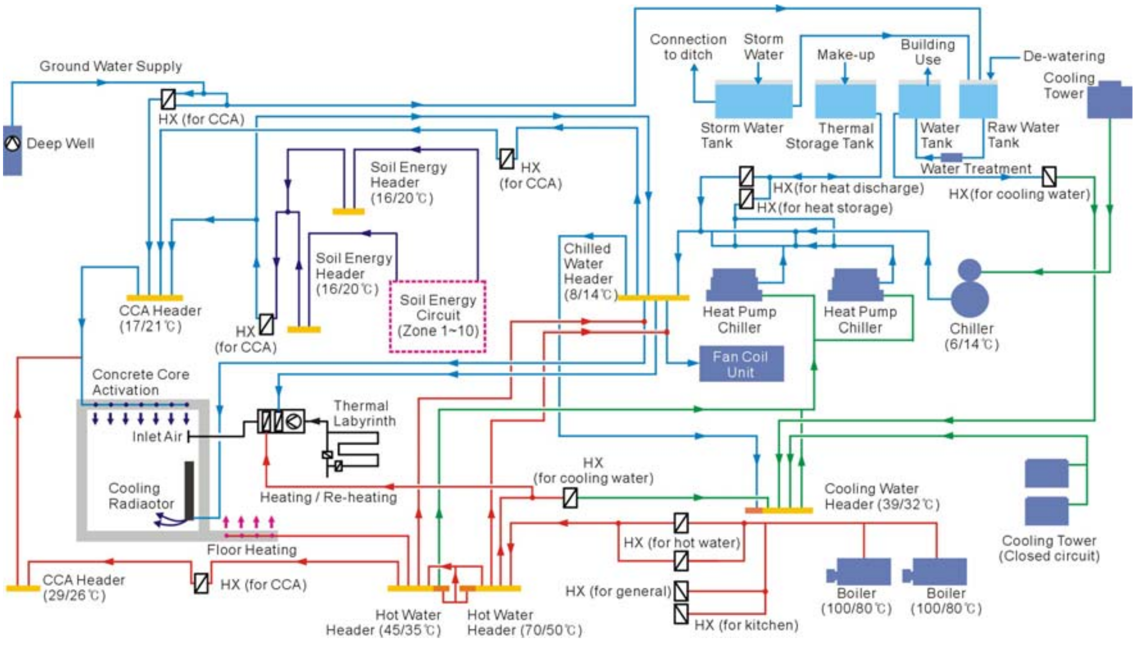


Figure 2 Central plant system diagram and equipment used for energy and water recovery

Re-cooling systems are prioritized to supply the condensate water that is exchanged with the domestic cold water and to use the waste heat from the AHU re-heating system in the summer season. In addition, if there is an insufficient capacity, the system is built to be able to control the quantity-related control of the closed circuit cooling tower.

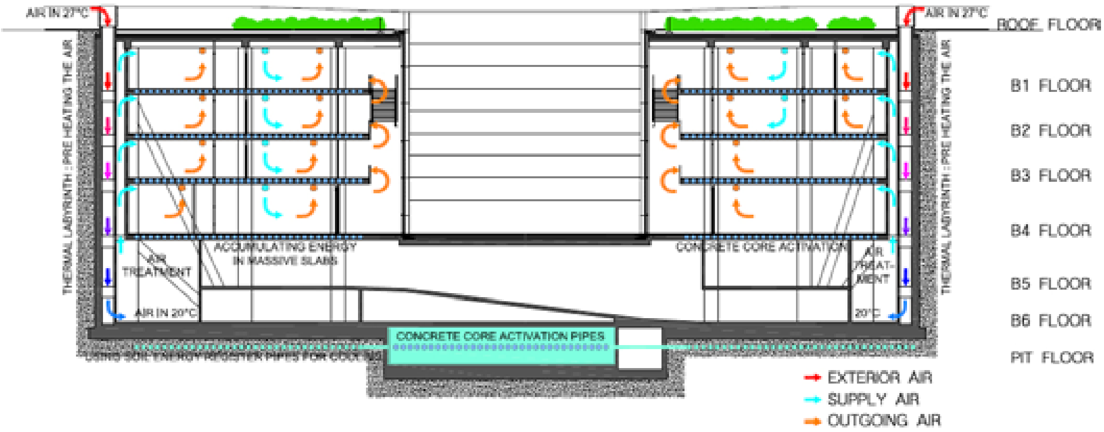
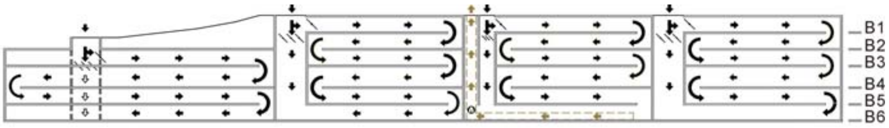


Figure 3 Section of ECC and how the design provides paths for air (cooling mode)

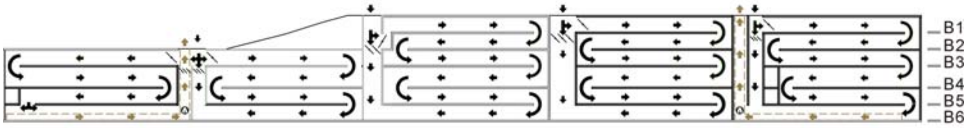
3. Eco-friendly and Energy Conservation Technologies

3.1 Thermal Labyrinth

The thermal labyrinth is a pre-cooling and pre-heating system supplying fresh outdoor air by taking advantage of building underground where there is a regular temperature all year round. There is no burden of extra construction cost for labyrinth structures because of the saving made in the use of a double layered space, which is necessary to install for the base structural system of earth coupled buildings. An analysis revealed that there is an approximate 10℃ pre-heating effect in winter and a 7℃ pre-cooling effect in summer, demonstrating that this system can save the energy that is otherwise required in HVAC systems for the pre-cooling and pre-heating of fresh outdoor air and can downsize the capacity of the boilers and chillers of central plants. Due to the air resistance of the labyrinth concrete structure, these benefits are greater than those gained by increasing fan power consumption.



East Wing



West Wing

Figure 4 Schematic diagram of thermal labyrinth (fresh outdoor air inlets and paths)

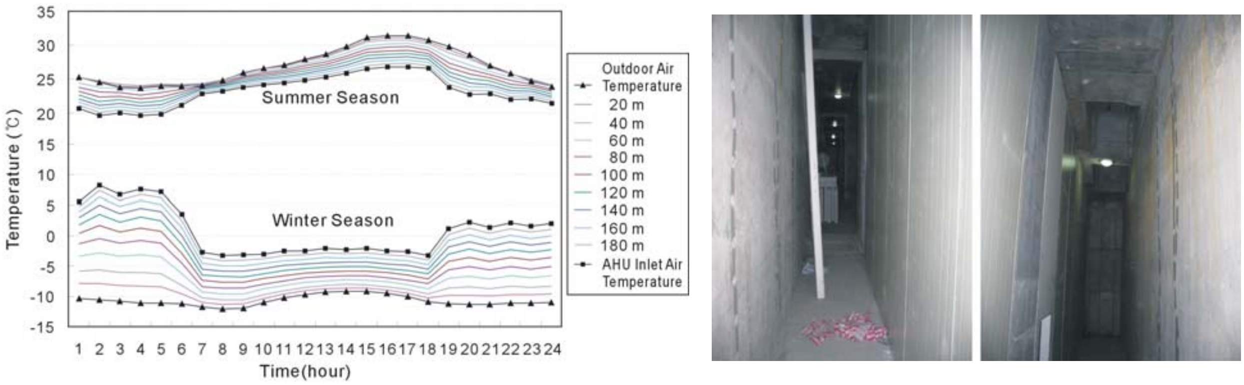


Figure 5 Effects of thermal labyrinth in summer / winter and actual figures of thermal labyrinth

For HVAC systems, during mid-season, when the outside temperature ranges from 12 to 18℃, the outdoor air is directly introduced through the vertical shaft. Conversely, a thermal labyrinth is composed of nine sections and eight outdoor air inlets. Because the ECC comprises a west wing, an east wing and a valley in the middle, the thermal labyrinth is divided into five sections in the west wing and four sections in the east wing. It is designed so that the fresh outdoor air is supplied to the two-storied mechanical room in the 6th underground floor and the heat is exchanged with the earth via the approximately 240m long soil duct connecting to the air handling units. The factors that affect the efficiency of the thermal labyrinth are thermal conductivity, density, heat capacity of the soil and the superficial area on the soil surface, resistance, the duct path of the thermal labyrinth, and the speed of air, etc. The results of an energy simulation taking these factors into account, demonstrate that it is possible to reduce the approximate 411kW peak heating load and the approximate 324kW cooling peak load. The equipment capacity of both the boilers and chillers can therefore be downsized.

3.2 Geo-thermal Energy

The main concept of the geo-thermal energy system is the use of cooling and heating source energy obtained from heat exchanged with the soil via the buried small-caliber pipes in the concrete floor slab of the 6th underground floor. During the summer season, the chilled water that has been heat exchanged with the soil is used for part of the cooling systems of the CCA and should be operated within 24 hours for thermal mass storage. The geo-thermal energy system comprises 10 different zones. In the cooling mode, the chilled or hot water is supplied through the CCA pipes for thermal mass storage and will be supplied to the hot water supply header in the heating mode. In Korea, it is known that the underground temperature regularly ranges from approximately 14 to 15℃ above a soil depth of 6~7m. The building was therefore designed so that the cooling system uses heat exchanged by the buried pipes between the concrete floor slab and the sand and gravel above the building foundation under the 6th underground floor. The temperature of the water is estimated to be about 16℃ after passing through the buried pipes and is supplied at about 17℃ via geothermal heat exchange before it is supplied to the CCA. The diameter of the pipe for the geo-thermal energy buried under the floor slab is 25mm and the pitch is 500mm.

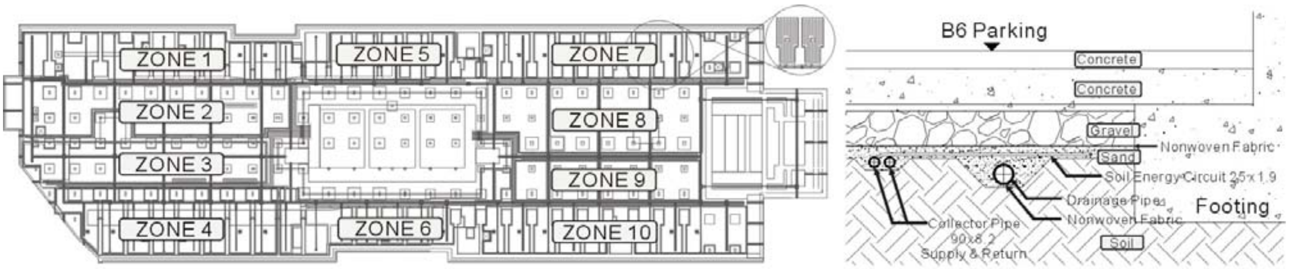


Figure 6 Plan of the geo-thermal energy system zonings and detailed schematic diagram of buried pipes

Figure 7 Construction pictures of geo-thermal buried pipes and supply header (B6F)

3.3 CCA (Concrete Core Activation)

The CCA system is the radiation cooling/heating system that controls the inside temperature by using the surface temperature of the radiation of the thermally activated building system. The system was proposed in order to save energy and to shift the peak load times due to the effect of thermal storage. Since the CCA system controls the space cooling/heating by using the radiation of thermal mass, residents are able to feel more comfortable at a higher indoor set temperature than when the conventional all air HVAC system is used. In addition, because of the low airflow rate compared to that of all-air systems, the duct works could be downsized along with the air delivery system energy. A total of four CCA zones are accommodated in accordance with the different load profiles between the inner zone and the outer zone. The inner zone is the valley area that faces the outside, while the outer zone faces the soil and the chilled/hot water loop pump zoning is separately installed. The CCA pipes buried in the concrete slab are of polyethylene material with a 20mm pipe diameter, a 150mm pitch, and are buried at a depth of 125mm from the ceiling (350mm of the thickness of the slab). It is intended that the entering/leaving chilled water temperature will be 17/21℃ for cooling and that of the entering/leaving hot water temperature for heating will be 29/26℃. Each zone area of the CCA is approximately 50~60 ㎡. From the results of simulation, considering the day time discharge efficiency (30W/㎡) and the night time charge efficiency (10W/㎡) at the early stage of design, a 60mm burial depth for the CCA in the concrete slab was proposed. A CCA system that utilizes various eco-friendly and natural energy methods uses geo-thermal energy primarily for the chilled water supply. When geo-thermal energy has insufficient capacity to serve the system, the chilled water will be supplied from the ground water or chillers. The reverse valves will control the exchange between chilled water and hot water seasonal supply in each season. In addition, a regular temperature of the CCA chilled water is maintained by primary variable speed pumps and 3-way valves in order to prevent dew condensation forming on the ceiling surface. In each room, the CCA that has buried pipes in the concrete slab controls sensible cooling and heating loads, while OHUs (outdoor air handling units) control the latent loads that are related to ventilation and dehumidification. VAV units control the airflow rate of ventilation according to the number of people in each area.

Figure 8 Detailed schematic diagram of CCA and construction pictures of CCA pipes

Figure 9 Indoor spaces of CCA system and cooling radiator

Using this method, any direct drafts from the cold air and shock from the difference in temperatures between the indoors and outdoors can be prevented. In addition, the heat generated from the human body is not rapidly eliminated, as it is with forced convection HVAC systems. Furthermore, this system can reduce the risk of dew condensation, via the latent heat load removal and ventilation. The finishing method for the ductwork is designed to reveal the ceiling in accordance with the interior concept, while the supply and return air ducts are arranged in a row. The VAV units are installed in the mechanical room in order to harmonize with the interior concept and to improve the convenience of maintenance.

3.4 Total Water Recycling System

Ground water maintained at a regular temperature is used for the heat source of the CCA operating 24 hours; after the ground water has been used for the CCA, it is collected in the water tank and is finally used for the domestic water through various steps, after being used for the heat sink of the condensate water of the cooling towers. As using ground water, the rainwater and de-watering are collected in the raw water tank, since after water clarification the heat sink for condensate water can save energy within the system. Using ground water also helps to improve the COP (coefficient of performance) of the chiller because the chiller can generate a lower temperature than that of the normal entering/leaving water temperature of cooling water. During the design stage, it is intended that the well sinking capacity will be 8.5 tons per hour and it is anticipated that the de-watering will be about 150 tons per day. The re-cooling capacity generated by the total water resource-recycling system is expected to be about 500kW.

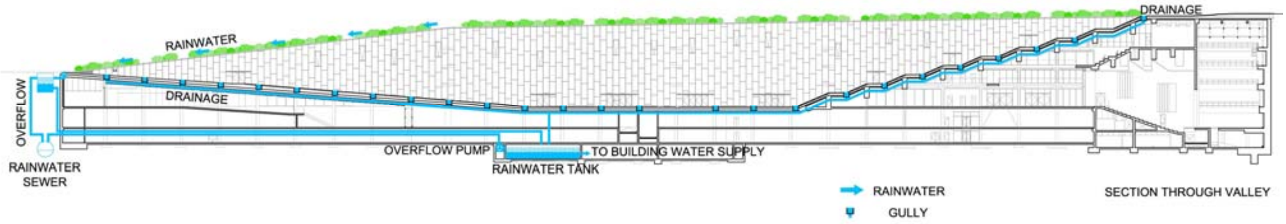


Figure 10 Use of rainwater for flushing toilets, irrigation, vegetation watering

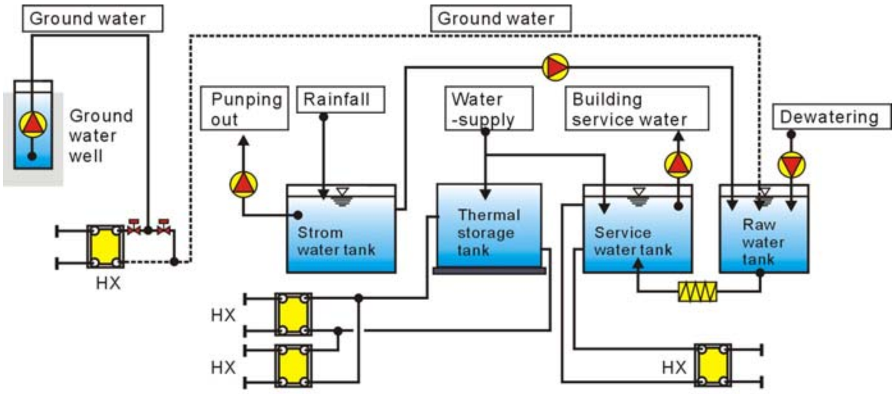


Figure 11 Schematic diagram of total water recycling system

3.5 Earth Berm: Earth-sheltered Building

As mentioned above, the optimum feature of the ECC is its massive construction for thermal storage and the application of soil energy as the source of energy. Because most of the exterior walls of the ECC are underground, the solar radiation and envelope load are effectively reduced. From an analysis of the building peak load, it is estimated that the load will be reduced by more than 20% of that of a similar sized building constructed above ground and that it is possible to reasonably downsize the capacity of the central plant equipment.

3.6 Waste Heat (from Exhaust Air) Reuse of Underground Car Parks

The air in the 6th underground floor car park is composed of the exhaust from the AHU and the fresh outdoor air for ventilation. In order to recycle the exhaust (waste) heat from the AHU into the re-cooling heat sink of the heat pump type chillers, the cooling towers for the chillers are installed on the 6th underground floor. To prevent an increase in the indoor temperature of the 6th underground floor, it is charged by heat-exchange of the soil with the underground car parks. The results of the simulation considering this condition show that during rush hour, when the maximum heat is generated from car engines, the indoor temperature of the underground car parks is maintained at under 27℃, which is the same as the entering wet bulb temperature of the closed circuit cooling tower. Therefore, the entering/leaving water temperature for the cooling tower is set at 32/39℃ and the re-cooling capacity is about 1,000kW.

Figure 12 Louvers for the waste heat reuse of the HVAC and the closed circuit cooling tower in the underground car parks

3.7 Re-heat System and Heat Recovery System for AHUs

Humidity control is very important in order to prevent dew condensation on the surface of the concrete slab, which is one of the problems of the CCA system. Dehumidified and over-cooled air is passed through the cooling coil in order to control humidity during the summer season. Hot and wet outdoor air is supplied to the indoors after again passing through the re-heating coil to meet the indoor set temperature. The re-heating energy is the recycled waste heat from the heat pump type chillers and the capacity of the re-heating coil is designed to be about 200kW.

3.8 Natural Ventilation and Green Roof System

At the main entrance of the ECC, the glass walls that face the valley are designed to facilitate natural ventilation. In addition, the green roof system on the top of the building is designed to provide places for relaxation and to reduce the cooling and heating envelope load of the indoors through the roof.

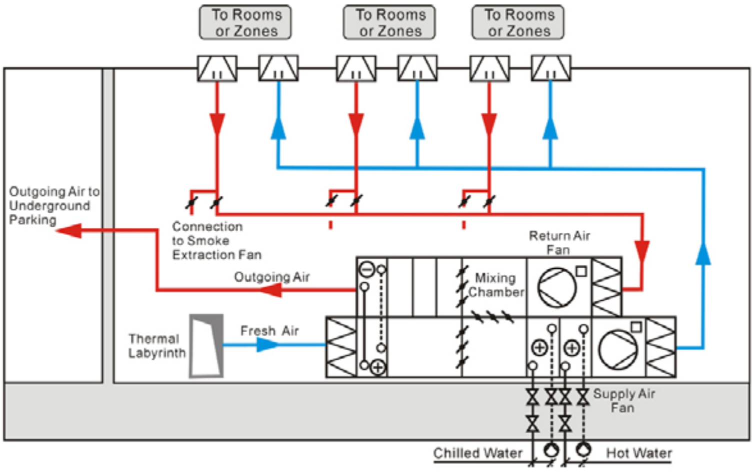


Figure 13 Schematic diagram of the re-heat and heat recovery system for air handling units

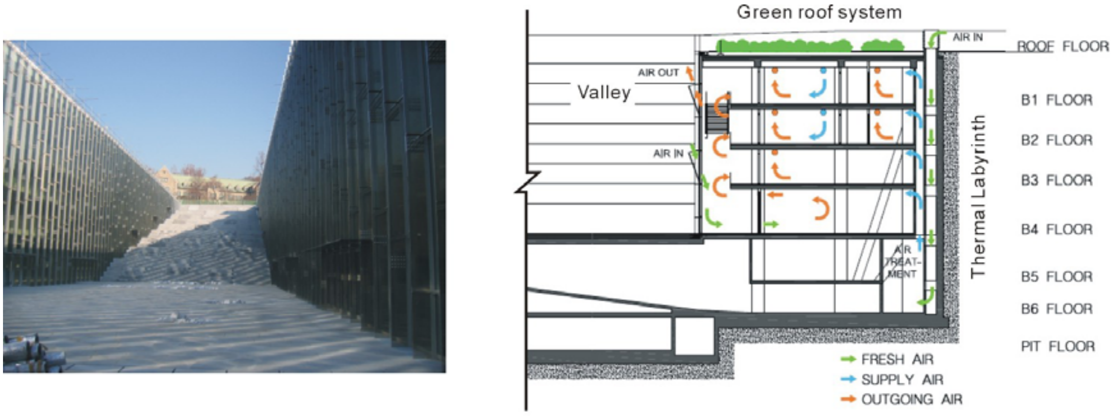


Figure 14 Outdoor air inlet windows for natural ventilation and green roof system of ECC

3.9 Water Thermal Storage System

The water thermal storage system stores (and charges) the chilled water, which is heat exchanged with the low temperature chilled water generated by the heat pump type chillers, in the stratified thermal storage tank installed under the 6th underground floor. This helps to reduce the operating cost by using the less expensive night thermal storage power service and by rapidly reacting to the load profiles. The temperature of the stratified thermal storage tank is charged at under 6℃ by the heat pump type chillers. A heat exchanger with a capacity of 840 kW for discharge is adapted.

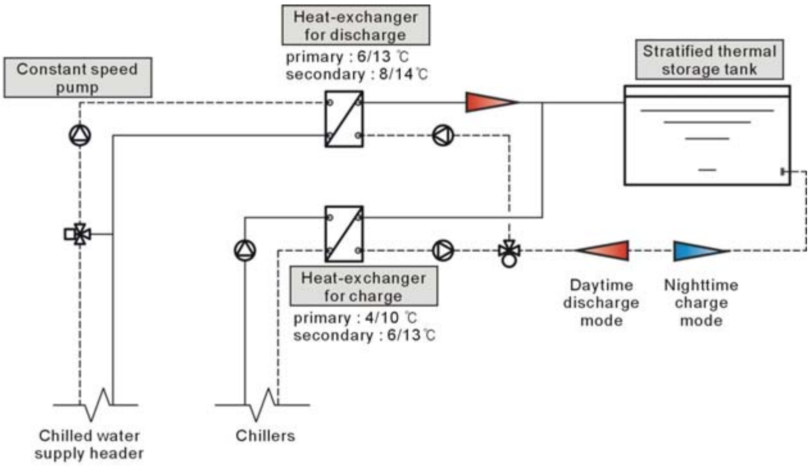


Figure 15 Schematic diagram of the water thermal storage system

4. Conclusion

In this study, the Ewha womans university campus complex (ECC), which organically connects eco-friendly and energy saving systems, is briefly introduced. The sustainability initiatives used in the design of the ECC encompass a range of well-integrated energy and water saving approaches, as well as a number of innovative techniques, such as a thermal labyrinth, CCA, and a geo-thermal energy system. Because the systems adapted in this building are somewhat unfamiliar, it is important to determine a method that will maximize the capacity to meet the climatic requirements and to be able to continuously monitor and analyze the operating data. Therefore, tests and verification of the systems are continuously required, as outlined below.

Firstly, the estimated capacity of the systems where eco-friendly and natural energy system design strategies have been integrated should be compared to the real capacity after the system has been in operation in order to detect and resolve any problems.

It is necessary to detect any problems related to the building control method by estimating the input/output energy of each organically connected system and to resolve such problems in order to create optimal operating systems.

In order to establish the concept of the design and construction of eco-friendly and sustainable buildings, it is necessary to investigate methods to improve such systems and to reduce the initial costs by improving the method of construction in order to protect the eco-system.

It is possible for eco-systems to be recovered to stable energy and water flows as macro environmental problems are solved through the removal of micro environmental problems within buildings. Consequently, when an integrative sustainable design is carried out, not only energy saving factors but also environmental factors need to be practically examined.

Acknowledgement

Technical support for this project has been provided by DPA (Dominique Perrault Architecture), HLPP Consult, Baum Architects, Samsung engineering & construction and Ewha womans university. Without their supports, this study would not be successfully achieved.

References

Cho J.K, Kim B.S, Lim T.S and Lee M.J. 2007, The energy and water circulating system shift by the eco-systems of buildings, CLIMA 2007 Finland, Proceedings of the 9th REHVA World Congress

Poul E. Kristensen, CK Tang, Gregers Reimann, Ahmad Zairin Ismail, 2007, Design strategies for energy efficiency in hot and humid climate: the case of the ZEO building, International Conference on Sustainable Building Asia, SB07, Seoul

Cho J.K, Chu S.K, Hong M.H. and Jeong C.S. 2005, A study on the system design strategies for sustainable housing, Proceedings of the SAREK 2007 Summer Annual Conference

Lee S.Y, Cho J.K, Hong M.H. and Jeong C.S. 2005, An analysis of reduction effect on energy consumption using thermal labyrinth in building, Proceedings of the SAREK 2005 Summer Annual Conference

Dietrich Schroer 2002, Concrete core cooling with supply air-better air-conditioning with less energy consumption, Special Print Edition of HLH

Eiji Maki, William A. and McDonough 2000, Sustainable architecture in Japan, Wiley-Academy

Figure 1 (a 3d rendering image) from Dominique Perrault Architecture (2004)

Figure 3 from sustainability: moderate climate ventilation shame / Dominique Perrault Architecture (2007)

Figure 6 (right) from HLPP Consult (2005)

Figure 8 (a 3d rendering image) from concrete core activation-technology of the future / Velta Contec (2005)

Figure 10 from sustainability: rainwater reuse / Dominique Perrault Architecture (2007)

Figure 14 (right) from Dominique Perrault Architecture (2007)