Energy Saving Effect and Economy Feasibility of Office Building with regard to Geometries and Orientations

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(Received December 10, 2008; Revision received January 30, 2009; Accepted March 16, 2009)

Abstract

The energy usage and the economical feasibility of the typical two story office building in the three urban locations of South Korea are evaluated as the eight orientations. The smallest energy consume is shown at the true south. The ranges of the low energy consume are -315°~0° and -135°~-180°. There are obvious advantages of passive solar designs such as using a fully glazed facade at the true south in the building. The General Low voltage plan is the effective way for the office building when does not required the high voltage electricity. The energy cost of KEPCO is compared to that of XCEL ENERGY. The portion of the customer charge of XCEL ENERGY is about 10% but it is about 50% of the total tariff of KEPCO. The effective way to save the energy cost is by reducing the operating energy of XCEL ENERGY plane but the most effective way is reduce the contracting energy of KEPCO plane.

Key words: Orientation, eQUEST, LCC(Life-Cycle Cost), NPV(Net Present Value)

Nomenclature

A : periodic payments for t years
e : Escalation rate
i : Discount rate
t : Life cycle period

1. Introduction

In this paper, the energy saving effect by the orientation and geometry is evaluated at the initial designing step. The modeled building is a typical two story office building at three urban locations of South Korea. The operating energy and the economical feasibility of the building are evaluated in regard to the eight orientations. The research questions posed are as follow:

1) Is able to save the proficient energy by the only suitable selection of orientation?
2) Is there any good orientation range to save the building energy?
3) Are there potential overheating periods during warm seasons at the low latitude location?
4) Which is the effective way to reduce the electricity energy charge to control the contract charge(fixed charge) or the energy charge (variable charge) in the electricity plan of KEPCO?

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2. Modeling methods

The operating energy of the building is hourly calculated by a building energy analysis program and a detailed energy evaluation is analyzed. This detailed analysis can be used to evaluate an accurate economic feasibility analysis at the initial building system designing step. This information is then used to determine the optimum capacity of the building system or types of the building system.

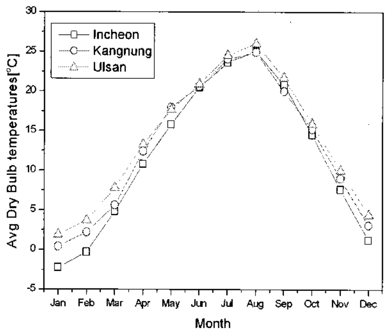
A virtual reference building was created, as to design and energy performance.[1,2,3] For this building a parametric study of energy use was carried out, where in the simulations the building construction, HVAC system and the type of controlling were described in detail. The orientations of the building are changed while other parameters such as the building's shape, the light, the occupants' activity and schedules, etc. were kept the same. Parametric studies were carried out regarding the energy use during the occupation stage of the building. The energy use of the building is analyzed based on the weather data of Incheon, Kangnung and Ulsan, as Fig. 1 and Table 1 at the eight orientation angles. The direct normal solar radiations are shown on peak cooling and heating days as Fig. 2. The heating loads at Incheon and Kangnung are relatively bigger than they are at Ulsan which is at the lowest latitude.

The simulation tool used is eQUEST(QUick Energy ESTimation)[(4)], a dynamic energy simulation tool, used by consultants and researchers for advanced building energy analysis. It is able to analyze the hourly energy evaluation in regard to the thermal storage effect of the thermal mass by the irradiation and internal heat gain and the temperature differences. eQUEST is selected by the building energy evaluating program for this paper as the suitable tool for the reasonable modeling program of the heat pump cooling and heating system with the various solar energy effects for the modeling.

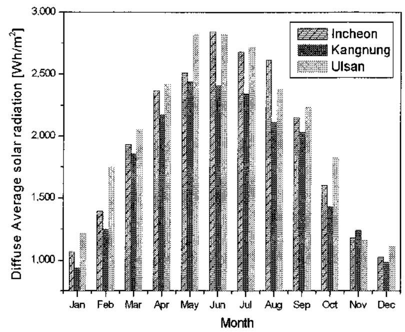
3. Building model

3.1. Description of the reference building

The modeling building is the typical two story office building in South Korea as Fig. 3 and the characteristics of building are described as Table 2. The total height of the building is 8.0m, the height of floor to floor is 3.96m, the height of floor to ceiling is 2.7m, and the floor space is 1,879 m²/story. The long façade

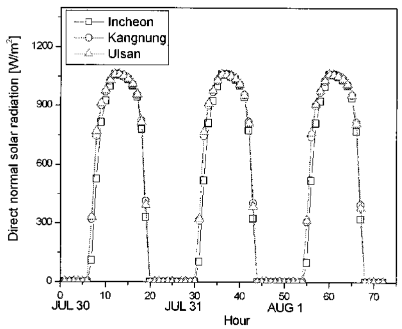


(a) Average temperature[℃]

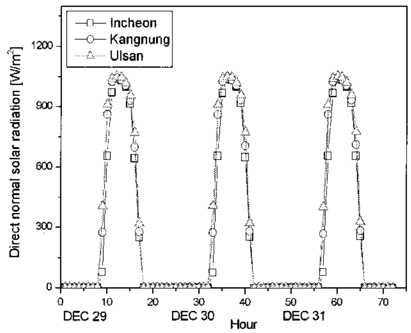


(b) Diffuse Average Solar radiation[Wh/m²]

Fig. 1. Weather data of the modeling locations.



(a) Jul. 30~Aug. 1(cooling season)

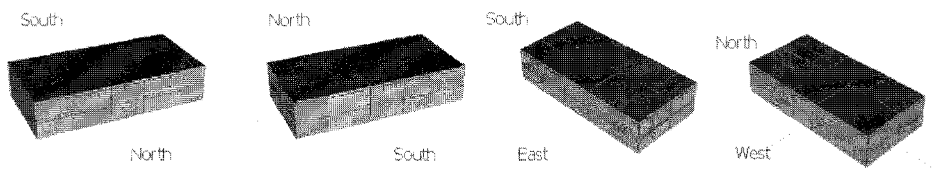


(b) Dec. 29 ~ Dec. 31(heating season)

Fig. 2. Direct normal solar radiation on peak days.

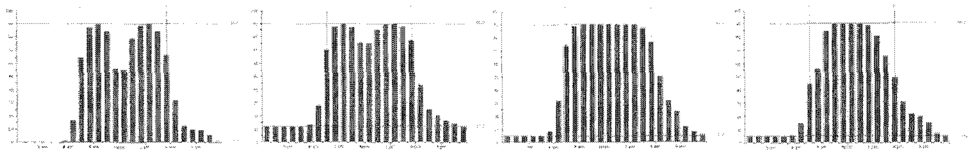
Table 1. Locations of modeling building.

Location	Latitude	Longitude	Altitude	time zone
Incheon	37°29′N	126°38′E	70 m	GMT +9
Ulsan	35°55′N	129°32′E	33 m	GMT +9
Kangnung	37°45′N	128°54′E	27 m	GMT +9



(a) North(-180°) (b) South(Base line) (c) East(-270°) (d) West(-90°)

Fig. 3. Shape and orientation of the Building.



(a) Occupancy (b) Office equipment (c) Lighting (d) Domestic hot water

Fig. 4. Internal load profiles (Week days).

Table 2. Characteristics of building.

Category	Notes
Gross area	3,757.6 (m²)
Occupants	105 People
Heat pump	Split system, Cooling EER: 8.5, Heating COP: 2.9
Domestic Water Heater	CAPACITY : 23.43kW TANK : 100ℓ (UA 1.899 kJ/HR-℃)
Exterior wall	R-18
Control	Design-Heat= 22℃, Design-Cool= 24℃

is 44m and the short façade is 22m in the a shape of a rectangle. The portions of window are 56% of the front long façade, 44% of the back long façade, and 58% of the short façade. The usages of the building are 70% of the offices, 10% of the aisle, 5% of the lobbies, 5% of the rest rooms, 4% of the meeting rooms, 4% of the machine room, and 2% of the copy room. Generally, the office building is not required to spend a big capacity of the district hot water and the air conditioning load also is not continuous, but it is an interval load during the day time only. The selected type of the air conditioning system for the building is the heat pump and the electric water heater with the storage tank for the schematics of the building.

3.2. Loads

As shown in Fig. 4, approximately 55%~90% of occupants are in the building from 8 am to 6 pm except the Saturday, Sunday and holidays. The maximum occupancy is 105 persons in the building and the average occupied space is 35.8 m²/occupant and the office occupied space is 19.7 m²/occupant. The energy use density of the light is 11W/m² at the offices, the meeting room, and the lobby, 6.1W/m² at the aisle, 8.3W/m² at the rest rooms, and 8.7W/m² at the machine room.

The energy density of the office equipment at the office, meeting room and the copy room is 3.2 W/m². As the result of the building energy analysis, the annual energy consumptions are 5,640kWh of the lights and 19,972kWh of the office equipment. The maximum electricity capacities are 17.1kW for the lights, 5.8kW for the office equipment. The energy consumption of the HVAC systems, pumping and piping vary with regard to the eight orientations and each location.

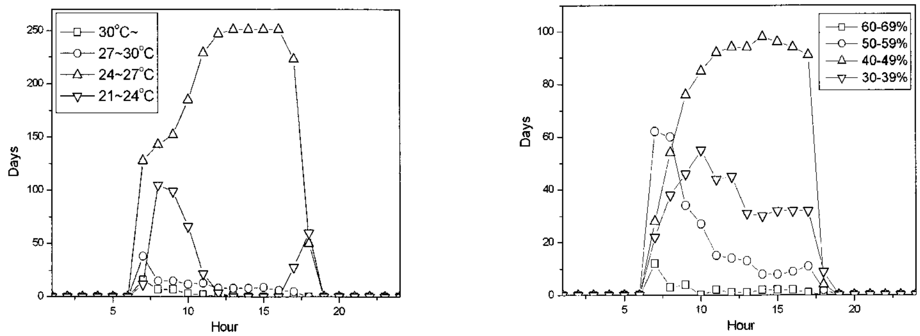
3.3 HVAC system

The pattern of the air conditioning is the intermediate cooling and heating by the air-cooled packaged multi-zone type heat pump unit. The EER is 8.5(Cooling) and the COP is 2.9(Heating). Normally, after the air conditioning unit shuts off, the indoor temperature is affected by the outdoor temperature. The temperature of the thermal mass is changed by the heat transfer at the external wall in the intermediate air conditioning. If the system starts at this point, the air conditioning is operated at a different state with the idle air conditioning. It needs the cooling or heating energy for the thermal mass which is not reached at the steady state, and the air conditioning unit starts to operate before the office is opened.

Therefore, in this study, the air conditioning unit starts at 7 am which is one hour before the office opens and the operation of the air conditioning unit finishes at 6 pm as the building closes. The air change ratio is 0.07~0.33 with regard to the purpose of each space. The design temperatures of indoor are 24℃ for the cooling and 22℃ for the heating. The air conditioning unit is operated based on the conditions of outdoor and indoor. It is keeping as temperatures are 21~27℃ and the relative humidity is 30~69% as shown Fig. 5 and Fig. 6.

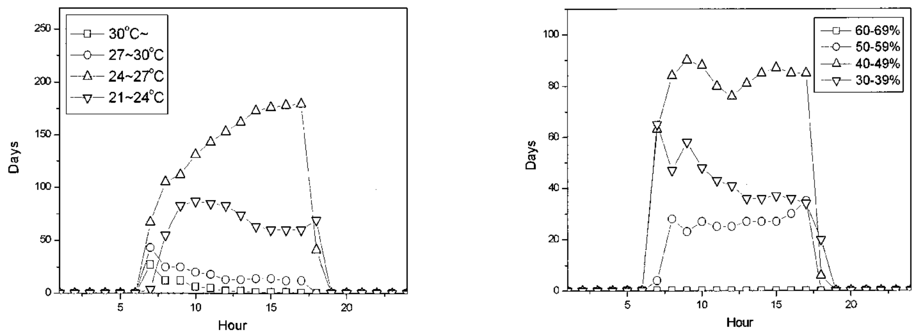
3.4 Energy costs and standards of LCC analysis

The electricity plans are able to select the General High-voltage (A) option I or the General Low-voltage



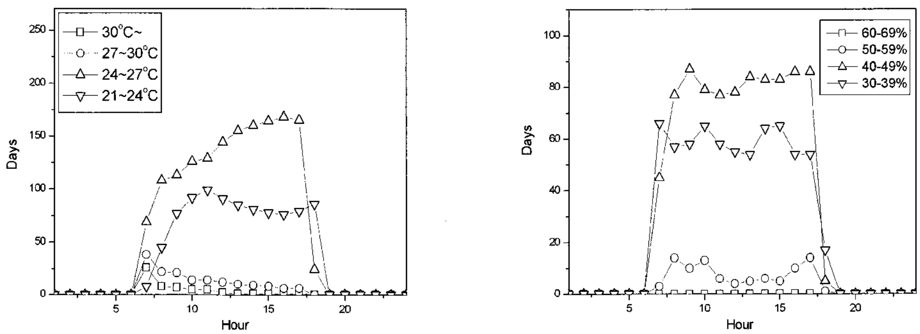
(a) Temperature level (b) Relative humidity level

(1) Incheon-south orientation



(a) Temperature level (b) Relative humidity level

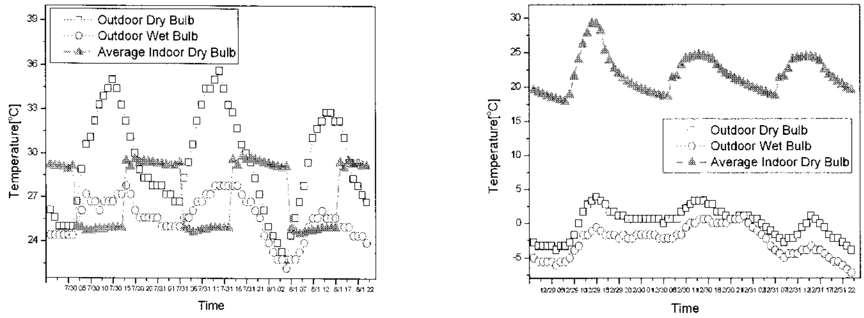
(2) Ulsan-south orientation



(a) Temperature level (b) Relative humidity level

(3) Kangnung-south orientation

Fig. 5. Total hours and time of day in the building.



(a) Jul. 30~Aug. 1(cooling season-Ulsan)　(b) Dec. 29~Dec. 30(heating season-Incheon)

Fig. 6. Indoor and outdoor air temperatures for time period.

Table 3. General electricity rates: 4kW or more and less than 1,000kW.

Classification.	Demand charge ($/kW)	Energy charge ($/kWh)		
		summer	spring/fall	winter
		Jul.1~Aug.31	Mar.1~Jun.30/Sep.1~Oct.31	Nov.1~Feb.28
High-voltage(A) option I(from 3,300V or higher to 66,000V)	5.320	0.0911	0.0607	0.0676
Low-voltage(220V, 380V)	5.160	0.0914	0.0609	0.0679

as the Table 3. In comparing these analyses, it can be determined which is the effective saving plan for the office building among the General electricity plans at the step of the building design. These plans dependent upon the complicated internal calculation such as a basic charge with the peak loads and an energy charge with seasonal options. So, for more accurate estimation, the hour by hour analysis of the operating energy cost is required. The average inflation rate is 3.5% and the electricity tariff inflation rate is 2.37%[8]. They are cited by the 25 years data of KEEI[7]. The period of LCC analysis is from January 1st, 2008 for 25 years. This is the time for the replacement of the HVAC system. The expense is the net present values are calculated by Eq. (1).

$$NPV = \sum_{t=1}^{N} A \frac{\left(\dfrac{1+e}{1+i}\right)^{t} - 1}{1 - \dfrac{(1+i)}{(1+e)}} \qquad (1)$$

The office is rotated from 0° (the true south) to -315° at each 45° as clockwise. The results indicate that in order to get maximum energy saving in winter, the main solar glazing should face south. If for some reason a true south orientation is not adopted, it is better to orient the window more to the west than to the east. For the same office building at Incheon, we find that the -90° orientation is much better than the -270° one. It is even better by 3.4% than the one facing the true south and 1.8% at Kangnung. The results for the summer are completely different. In summer, the exact north orientation is the best one, but the energy consumption in the south orientation is higher by only 2.9%. On the other hand, the total energy consumption in the north orientation is higher by 3.6%.

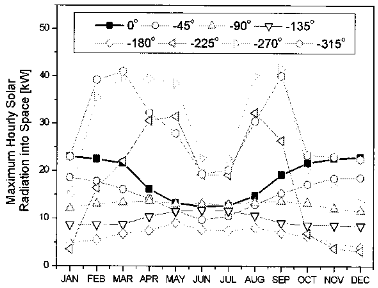
When the main glazing is facing west, it allows the penetration of the SW(-45°) radiation into the building during the hottest period. As a consequence, T_{max} increases and with it the total energy consumption for cooling. Also, the higher deposition of radiation energy in the house demands a bigger air-conditioning unit as its energy consumption should be determined according to the worst case. On the other hand, if the main glazing is facing north, the maximum isolation happens when the building is still cool. As a result, no high T_{max} inside the building is induced. This allows the use of a smaller air-conditioning unit or eliminates it completely. The combined total energy consumption for summer and winter shows minimum energy consumption for the true south orientation. The total energy consumption increases by about 3.6% when facing -180° and by 21.5 % for -225° and -270° of true south.

These results show that for a country with a hot and humid climate, the best orientation of the main solar glazing is the south (as in cold places). When no south orientation is possible (or if non-monotonic design solutions are desired), it is better to orient the building -135° and -180° of true south than west or east of it.

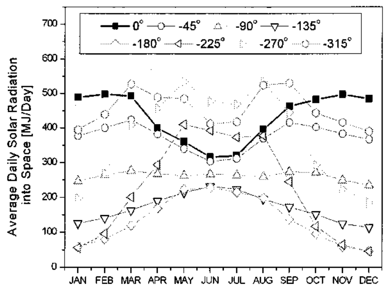
4. Results and discussion

4.1 solar radiation and building load

Fig. 7 is the solar radiation of the office A at the first floor of the façade side. At Incheon, the daily solar radiation energy during the cooling season (Jul. 1~Aug. 31) is 216 MJ/day, the smallest solar radiation at the true north (-180°) and 535MJ/day, the biggest at the true east (-270°). The solar radiation during the cooling season increases of the cooling load and then is added the total energy consumption of the building. The solar radiation during the heating season(Nov. 1~Feb. 28) is 498MJ/day, the maximum energy at the true south(0°) and 81MJ/day, the minimum energy at the true north(-180°) and the true south is the best

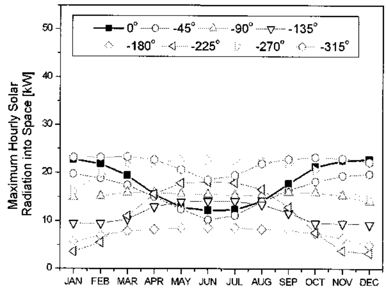


(a) Maximum Hourly Solar Radiation

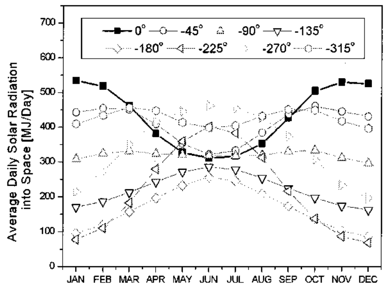


(b) Average Daily Solar Radiation

(1) Incheon

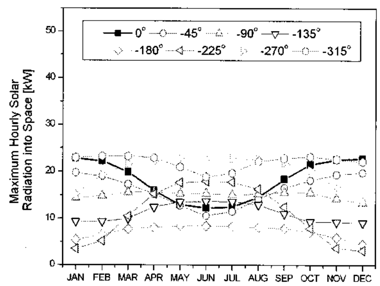


(a) Maximum Hourly Solar Radiation

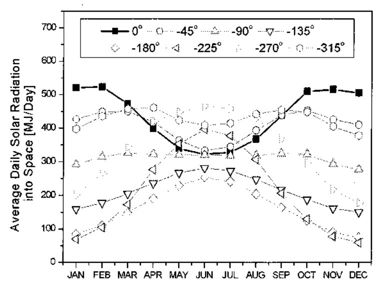


(b) Average Daily Solar Radiation

(2) Ulsan



(a) Maximum Hourly Solar Radiation



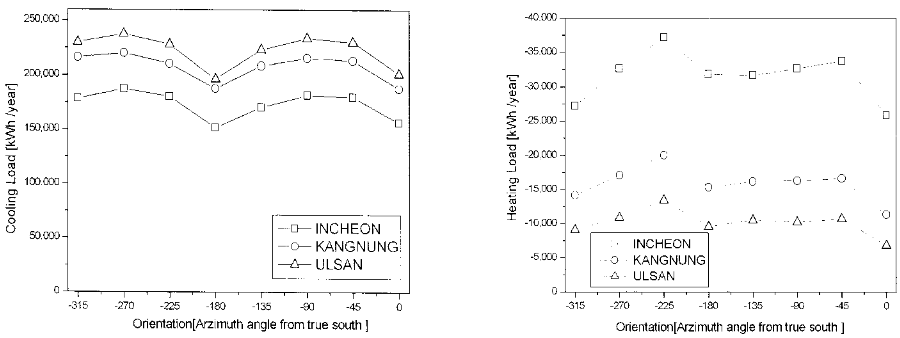
(b) Average Daily Solar Radiation

(3) Kangnung

Fig. 7. Variation of the solar radiation intensity on the façade side Space (office A at 1st floor).

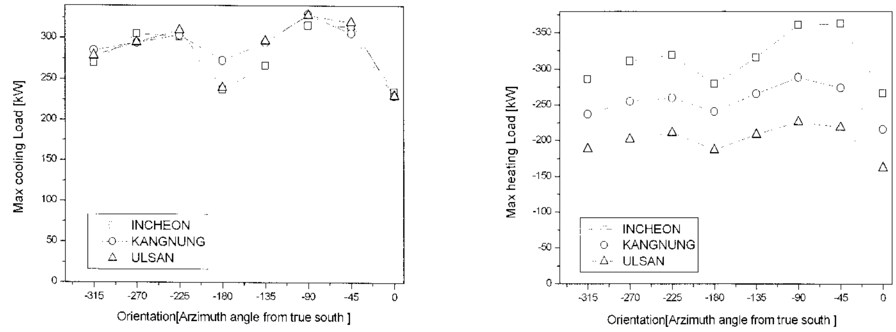
orientation for the saving of the heating energy. At Kangnung, the daily solar radiation during the cooling season is 242MJ/day, the smallest at the true north (-180°) and 458MJ/day, the biggest at the true east (-270°). The solar radiation during the heating season is 523MJ/day at the true south(0°) and 111MJ/day at the true north(-180°).

Because the solar energy is radiated a small amount at the cooling season and a bigger amount at the heating season on the true south, the energy consumption on the other orientations is bigger than it is on the true south. As shown in the Fig. 8, the total cooling load is the smallest at the true south and became bigger until at the true west each 45° rotating clock wise and then the load became small again at the true north and the load became bigger again at the true east. At Ulsan which is the lowest latitude, the cooling load is the biggest, and the cooling load is the smallest at Incheon which is the highest latitude. The pattern of the cooling and heating load is similar at the true north with the true south because the building shape is rectangular and the fraction of windows at the front and back façade are 54% and 45%. So the effect of the solar radiation is shown as having almost the same pattern at the true north with the true south. The total heating load is the smallest at the true south too. However, it is the biggest heating load at the -225°(NE). The maximum cooling and heating load is shown at Fig. 9. The cooling and heating load is biggest at -90°(True west) and is smallest at the true south. Refer to the maximum cooling and heating load, the air conditioning units were designed and is determined the capacity of the electricity facilities. The customer charge is determined by the capacity of the building electricity facilities, and it is fixed as an annual customer charge. The Annual energy consumption and the maximum electricity at each cities were shown in Fig. 9 and Table 4 in detail. The energy consumption is big as an order of the lights, cooling, ventilation and etc. The maximum electricity is used as an order of the heat pump supplements, cooling, heating and etc. At Ulsan which is located at



(a) Total cooling load [kWh] (b) Total Heating load [kWh]

Fig. 8. Effects of orientation on the annual total cooling load & the Heating load.



(a) Max cooling load [kW] (b) Max heating load [kW]

Fig. 9. Effect of orientations on the max cooling load & the Heating load.

the lowest latitude, the energy consumption for the cooling is the bigger than the lights with different to the Incheon which is located at the highest latitude. The maximum required electricity is the cooling, too. The pattern of an energy consumption for the lights and the cooling is similar with its the true south of Kangnung. At the other orientations, the energy consumption for the cooling is 14% bigger than the lights.

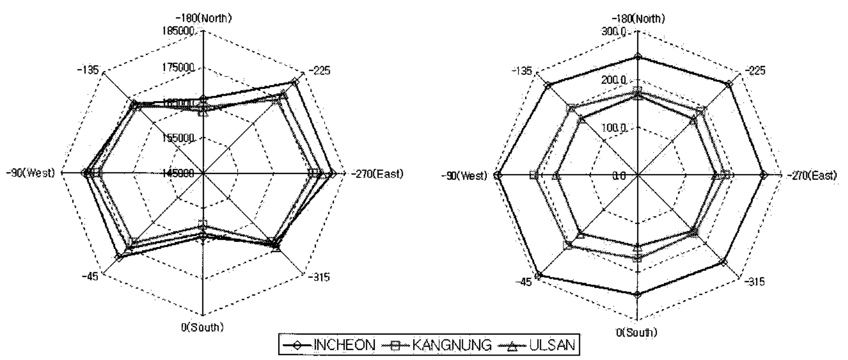
At the orientations of -225°, -270°, -90°, and -45°, the energy consumptions spent 21%, 21%, 17.6%, and 17.6% more than the true south at Incheon. At Kangnung the energy consumptions more spent 16.7%, 18.7%, 16.9%, and 17.6% compare with the

Table 4. The energy consumption for an office unit at different orientations.

Incheon.		0°(South)	-45°	-90°(West)	-135°	-180°(North)	-225°	-270°(East)	-315°
energy [KWH/year]	HEATING	10,365	15,695	15,158	13,540	12,677	17,149	15,031	11,705
	COOLING	46,227	54,288	54,672	50,804	44,925	54,393	56,438	52,899
	AUX	3,008	2,986	3,042	3,039	2,997	2,927	2,921	2,980
	FANS	21,473	24,539	24,929	23,417	22,467	25,592	26,097	24,458
	H/P SUPP	6,083	5,304	5,045	6,085	7,246	5,837	5,397	5,597
	Hot water	1,946	1,946	1,945	1,946	1,949	1,948	1,946	1,945
	Total	89,102	104,758	104,791	98,831	92,261	107,846	107,830	99,584
		Baseline	117.6%	117.6%	110.9%	103.5%	121.0%	121.0%	111.8%

Kangnung		0°(South)	-45°	-90°(West)	-135°	-180°(North)	-225°	-270°(East)
energy [KWH/year]	HEATING	4,946	7,907	8,008	7,839	7,271	9,403	8,146
	COOLING	55,865	64,499	65,208	63,150	57,061	63,770	66,501
	AUX	2,993	2,957	2,991	3,011	2,990	2,920	2,916
	FANS	18,926	20,210	21,228	20,214	19,395	20,752	21,249
	H/P SUPP	1,555	1,510	1,381	1,366	1,382	1,849	1,595
	Hot water	1,877	1,876	1,876	1,877	1,880	1,879	1,877
	Total	86,162	98,959	100,692	97,457	89,979	100,573	102,284
		Baseline	114.9%	116.9%	113.1%	104.4%	116.7%	118.7%

Ulsan		0°(South)	-45°	-90°(West)	-135°	-180°(North)	-225°	-270°(East)
energy [KWH/year]	HEATING	3,072	5,254	5,217	5,119	4,259	6,564	5,362
	COOLING	60,424	70,421	71,515	67,888	59,209	69,882	72,620
	AUX	2,694	2,658	2,685	2,698	2,693	2,627	2,632
	FANS	19,063	20,316	21,194	20,547	19,375	20,986	21,182
	H/P SUPP	859	866	780	896	1,153	1,156	951
	Hot water	1,814	1,813	1,813	1,814	1,816	1,815	1,814
	Total	87,926	101,328	103,204	98,962	88,505	103,030	104,561
		Baseline	115.2%	117.4%	112.6%	100.7%	117.2%	118.9%



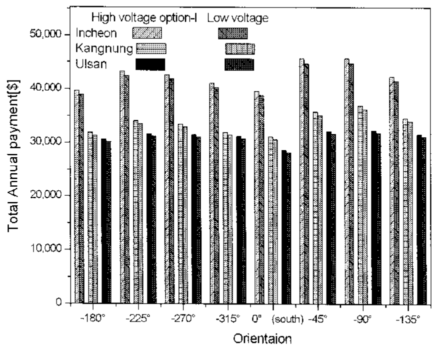
(a) Energy consumption[kWh] (b) Maximum electricity[kW]

Fig. 10. Annual energy consumption with regard to the orientations.

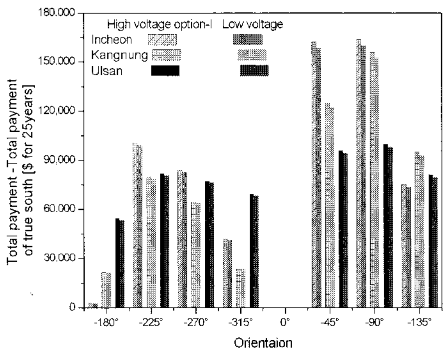
true south at each orientations. At Ulsan, 17.2%, 18.9%, 15.2% and 17.4% of the energy spent more than at the true south orientation. The tariff plans(5,6) for the office building are able to select among the two plans as the General High-voltage (A) option I plan and the General Low voltage plan. The General High-voltage (A) option I plan provides the electricity of 3,300V or higher to 66,000V and the General low voltage plan provides the electricity of 220V or 380V. At the General High-voltage (A) option I, the cost of the customer charge is higher than the General Low voltage plan instead of the low energy cost. As see the Fig. 12, the annual electricity cost of the General low voltage plan is about 2% lower than the General High-voltage (A) option I plan. Because the tariff plans of KEPCO consist of the high portion (over 50% of total cost) of the customer charge, it is the benefit to select to the lower customer charging plan. Therefore, the selecting of the General Low voltage plan is the effective cost saving way for the office building when it is not required the high voltage electricity such as the manufacturing facilities.

As shown in Fig. 11, the smallest annual energy cost is at the true south and the biggest cost is at the true west. The smaller ranges of the energy cost are -315°~0° and -135°~-180°. As the comparison of the energy cost of XCEL ENERGY and KEPCO, the portion of the customer charge of the XCEL ENERGY is just 10%, but the portion of the customer charge of KEPCO is about 50% as shown in Fig. 12. The effective way to save the energy cost is by reducing the operating energy of XCEL ENERGY plane but the most effective way is reduce the contracting energy of KEPCO plane.

The building energy saving methods are varied. The lower cost of the annual energy tariff reduce by reducing of the contracting energy in the insulating wall, the low-e windows, the energy efficient HVAC system, the energy efficient fan and the renewable energy systems.

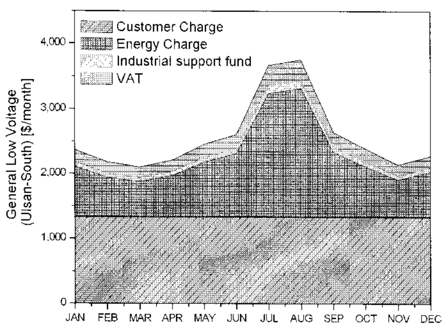


(a) Annual energy costs[unit :$/year]

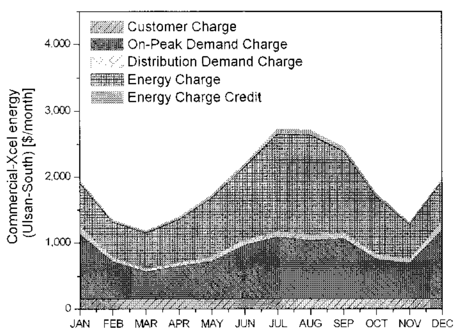


(b) Accumulate cost savings for 25years[unit :$]

Fig. 11. Energy costs with regard to the payment programs.



(a) General Low Voltage (KEPCO)



(b) Commercial & Industrial Service Rates *

Fig. 12. Monthly Detail Energy costs (Ulsan -South).

(* effective JAN. 9, 2008 for XCEL ENERGY Electric and Natural Gas Customers in Wisconsin)

5. Conclusion

In this paper, the energy usage and the economical feasibility of the typical two story office building in the three urban locations of South Korea are evaluated by using the eight different orientations. Based on the General electricity plans of KEPCO, it is looking for the effective cost saving plan. The structure of energy cost of KEPCO is compared to its of XCEL ENERGY.

(1) The pattern of the smallest energy consumption is shown at the true south. There are obvious advantages of passive solar designs such as using a fully glazed facade in building.
(2) The ranges of the low energy consumption are -315°~0° and -135°~-180°.
(3) The annual electricity cost of the General Low voltage plan is about 2% lower than the General High-voltage (A) option I plan. The selecting of the General Low voltage plan is the effective way for the office building that does not require the high voltage electricity for the any manufacturing facilities.
(4) The portion of the customer charge of XCEL ENERGY plan is about 10%, but the portion of the customer charge is about 50% at tariff of KEPCO plan. The effective way to save the energy cost is by reducing the operating energy of XCEL ENERGY plane but the most effective way is reduce the contracting energy of KEPCO plane.

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