Night Ventilation Strategies in Korean Apartment Units

- Ventilated Apartment and solar chimney

by

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A Dissertation submitted in part fulfilment of the
degree of Master of Science Built Environment:
Environment Design and Engineering

University of London
15. SEP. 2005

ACKNOWLEDGMENTS

This dissertation is dedicated to my wife Miran, who deserves an award for her patience, understanding and prayers during my MSc study and the writing of this report. I am also grateful to my parents, who provided spiritual support.

I wish to thank my supervisor, Dr. Ben Croxford, for his encouragement, guidance and support during my entire MSc study and this dissertation at the EDE. Next comes a group to whom I wish to thank for their advice and time, which gave me experience and knowledge in this course and dissertation. First, I wish to mention Dr. Alan Young for making my MSc study possible in the first place and taking good care of everything. Secondly I wish to thank Dr. Mike Davies and Mr. Hong for helping me with various topics of dissertation and for very useful discussions which led to improvements in my knowledge and dissertation.

ABSTRACT

This paper is aimed at estimating the effect of various factors on the heating energy consumption and introducing night ventilation strategies to reduce cooling load in Korean apartment using TAS Modeller, TAS Ambiens and QuickSTREAM. The factor considered this paper type of remodelling, insulation level, window type and reset an internal temperature. The natural ventilation strategies considered here night ventilation, night flush cooling and solar chimney. Base on some assumption, an actual apartment unit is simplified into a model that is used for heating load in winter and looking into internal condition in summer night. The simplified model is validated by showing a good agreement with the actual one in heating load result. Refurbished balcony has a benefit in reducing heating load by 15%. Remodelled apartment is sharply increased in thermal load which must be avoided in view of energy conservation as well as structural problem. The most efficient and the easiest way of reducing heating load in current apartment are to set the internal temperature at 20°C. In second part of the simulation, we confirmed that it is possible to use natural ventilation for physiological cooling, night flush cooling to cooled structure and cooperating with solar chimney during the summer night time to reduce PAC's operating hours. The best case exceeds the bench mark temperature which is based on all windows being open all day. The CFD and Psychrometric chart results support to use of natural ventilation strategies in Korean apartments and shows that when Korean apartments adapt the night ventilation strategies, the occupants does not feel turning on the PAC system during cooling period time.

Key Words: Heating Load, Cooling Load, PAC, Night ventilation Strategies,
Refurbished Balcony, Night Flush Cooling, Solar Chimney

Word Counts: 10,380

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1. INTRODUCTION

Improved quality of life and raised demanding of amenity, in Korea, consumers have started to adapt cooling systems in their houses such as, installing air condition system, which is PAC (Package Air Conditioning system) and electric fan. In Korean houses requirements for cooling has seen increased demand of PAC and in future it is forecasted to grow ever further. In terms of heating in dwellings, various energy sources are uses which are oil, gas and electricity, however, for cooling only electricity is use and unfortunately, PACs consume an enormous amount of energy, draining much of the available electric power during the summer. Therefore, peak load have been monitored during cooling season sometime leading to power cut. To prevent power cut, Korean government has planned to make more power stations to cope with the peak load electricity consumption. However, construction of new power stations will make Korea world biggest energy consuming and largest CO2 emitters in the world.

An analysis of Korea's energy consumption for domestic sector is greater than commercial sector. With apartment housing becoming the general housing style in Korea, apartments now consume approximately 33% of the entire domestic sector energy [1]. We must give attention to energy saving in the domestic sector, in particular, apartment buildings. Therefore, this paper will study about heating energy consumption in current balcony apartment and introducing night ventilation strategies in current balcony system in order to reduce cooling load.

In this paper, it has two different simulations, which are the first one looks into the effects of various factors on the energy consumption of Korean apartments. Based on some assumptions, an actual apartment in simplified into a model that is used for thermal load calculations. The factors considered here include type of remodelling which are original balcony, refurbished balcony and remodelling apartments, and window types and check the various insulation levels which are old insulation level, current building regulation level and super insulation levels and one more simulation will be carried out for heating load which is change indoor target temperature from 24°C to 20°C during heating season in Korea.

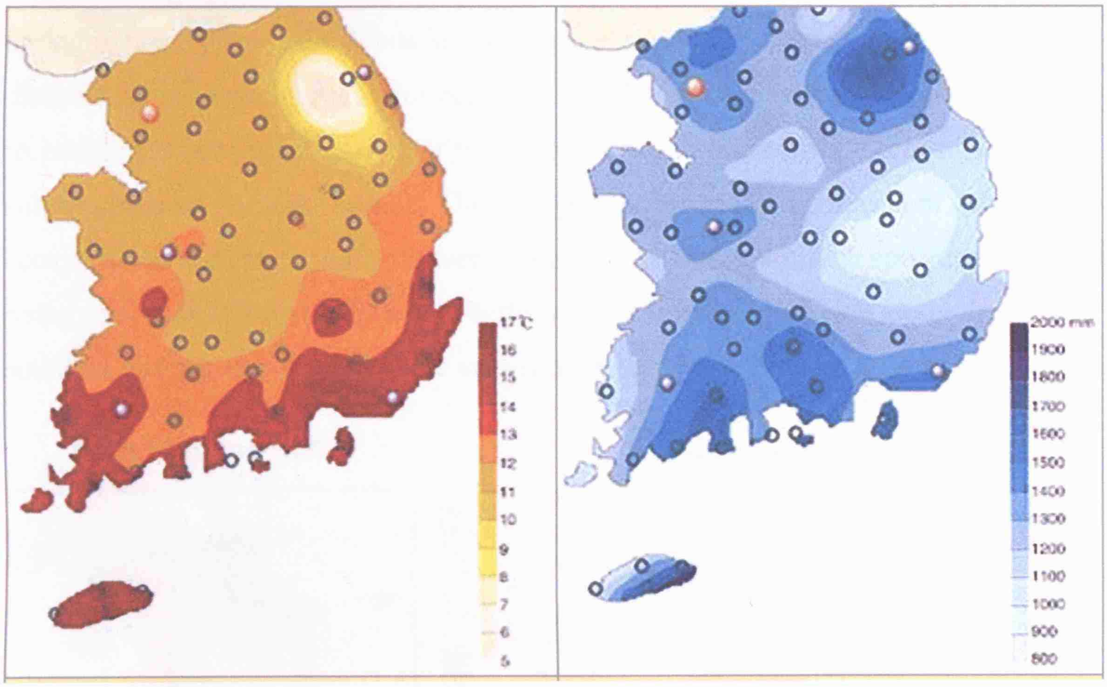
Secondly it looks into an appropriate night time ventilation regime if available for the cooling season in Korea in order to reduce electricity consumption during cooling season. It will only look at night time which is used for PAC in Korea and when some changes will be happen how the indoor temperature response and how many hours will be place in thermal comfort zone especially within summer recommended comfort zone on Psychrometric chart of Korea.

2. CLIMATE CHANGE IN KOREA

2.1 CLIMATE AND WEATHER

The annual mean temperature ranges from 10 to 16° C except in the high mountain areas (figure 1(a)). The warmest month is August, whereas January is the coldest one. The monthly mean temperature ranges from 20 to 26° C in August and from -5 to 5° C in January.

The annual precipitation is about 1,500mm in the southern part of Korea and 1,300mm in the central part (figure 1(b)). More than half of the annual precipitation falls during the Changma season when a stationary front lingers across the Korean peninsula for about a month in summer. The winter precipitation is less than 10% of the total.



(a) Annual Mean Temperature (b) Annual Precipitation

*Source: KMA(Korea Meteorological Administration)

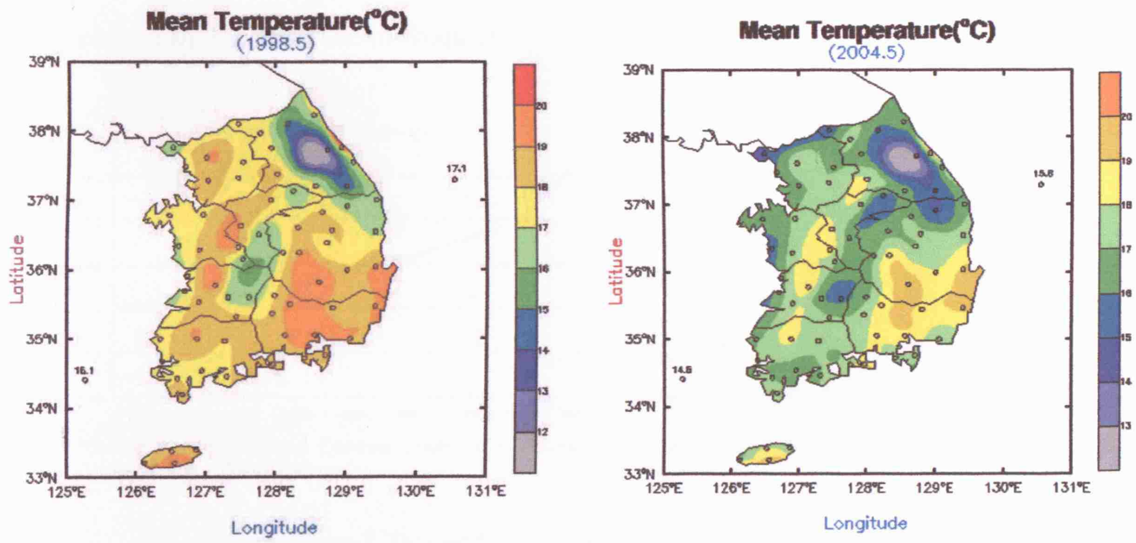
Figure 1. Annual Mean Temperature and Precipitation in Korea

The prevailing wind systems are south-westerly in summer and north-westerly the winter. The speed of the latter is higher than the former in general. During the transition period from south-westerly to north-westerly region in September and October, a well developed land-sea breeze emerges as a prominent feature.

Humidity peaks in July, reaching 70-80 % nationwide. On the contrary, the lowest means of monthly humidity are 30-40 % in January and April. Meanwhile, the pleasant humidity of September and October contributes to a plentiful harvest. Changma, the summer Asian Monsoon systems, starts in the southern area of Korea in late June and gradually proceeds northward. On the average, Changma continues for 30 days, when frequent heavy rains and flash floods result in great natural disasters. Two or three typhoons out of about 28 generated annually in the Northwest Pacific influence the Korean peninsula from June to October.

2.2 CLIMATE CHANGE IN KOREA

There is growing evidence that Korea is vulnerable to the impacts of climate change. As seen in figure 2 (a) and (b), the year 1998 in Korea was marked by the hottest spring in history, severest floods in summer and an autumn hotter than summer. The distinctions between Korea's four beautiful seasons which have been a great pride for its people are becoming blurred, with the southern part of the nation turning into a subtropical area without winters. The change resulted in the disruption of the ecosystem as seen in the early flower blossoms and changes in fish species. Moreover, rising sea-level will certainly pose a serious threat to the marshlands along the southern and western coasts whose values have been recognized worldwide.



(a) spring in 1998, May (b) spring in 2004, May

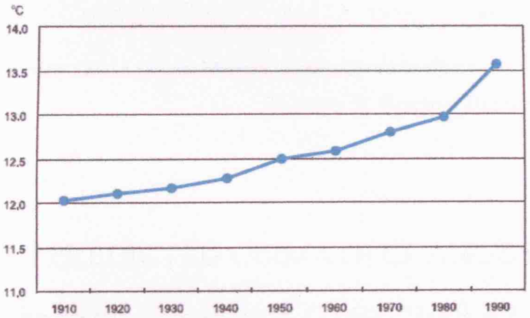
*Source: KMA (Korea Meteorological Administration)

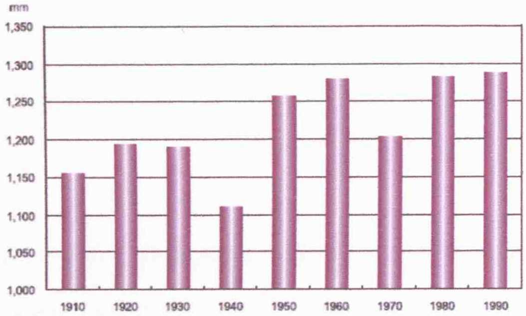
Figure 2. Spring in 1998 and in 2004

2.2.1 TEMPERATURE AND PRECIPITATION

The temperature observational record for Korea indicates that the average temperature has been rising gradually during the past 90 years. Historically, the temperature rise was highest in the 1990s. The decadal average precipitation has been increasing; however the level of precipitation was comparatively low in the 1910s, 1940s and 1970s, resulting in relatively dry periods. Extreme analysis for the daily maximum and minimum temperatures shows that frequencies of extremely low temperatures in the winter have sharply decreased whereas the frequency of extremely high temperatures in the summer has slightly increased. Such tendencies are more pronounced in the inland region than the coastal [2].

The data recorded for the southern region of the Korean Peninsula shows that in the recent 20 years, the rainfall intensity has increased by 18% resulting from increase of annual rainfall by 7% and decrease of annual number of rainy days by 14%. Accordingly, frequency of extreme heavy rainfall has also increased. Days with heavy rainfall of over 50 mm have increased by 22~25%. The increase of rainfall amount in the summer season and the decrease of number of annual rainfall days in the fall season clearly result in the increase in frequency of heavy rainfalls, overall increase in rainfall amount, and decrease in frequency in non-heavy rainfall. In the southern region, the decrease in the number of rainy days has been caused by the decrease in the number of days with non-heavy rainfall, and the increase of rainfall has been caused by the increase in frequency of heavy rainfalls.



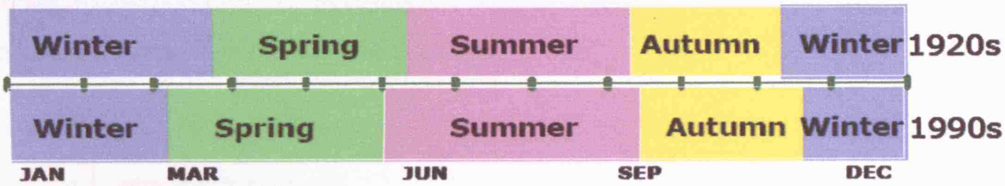


*Source: Second National Communication of the Republic of Korea Under the Nations the United Nations Framework Convention on Climate Change

Figure 3. Overall Changes Mean Temperature and Precipitation

2.2.2 SEASONAL CHANGE

Result of mean temperature change it has effected seasonal change which is represented below figure 4. In Korean government climate change reports, it has studied about 100 years Korean weather data and it found the mean temperature has gone up by decades during that time; the most dramatic temperature raised 0.6° C in 1980s to 1990s and it affects seasonal length which means winter in 1990s is shortened by 27 days relative to 1920s.

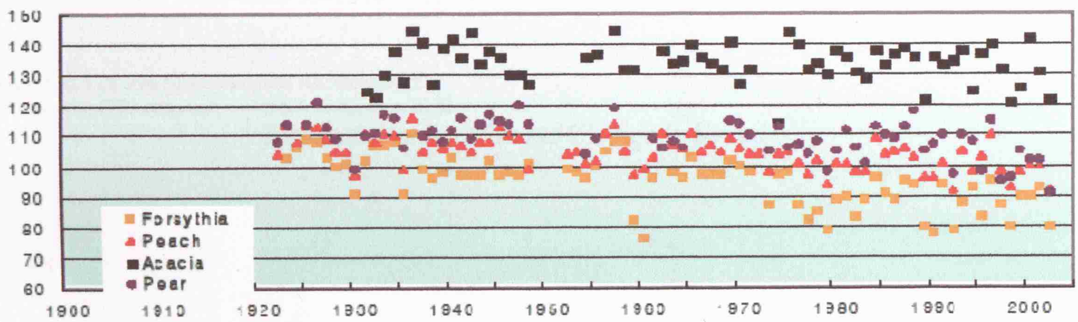


*Source: KMA (Korea Meteorological Administration)

** The mean temperature of day below 5°C is winter and over 20 °C is summer in this report and between them are spring and autumn

Figure 4. Seasonal Change in Korea

It has changed spring flower blooming date. Since 1960s, spring flower blooming is almost 10 days early than before 1960s.



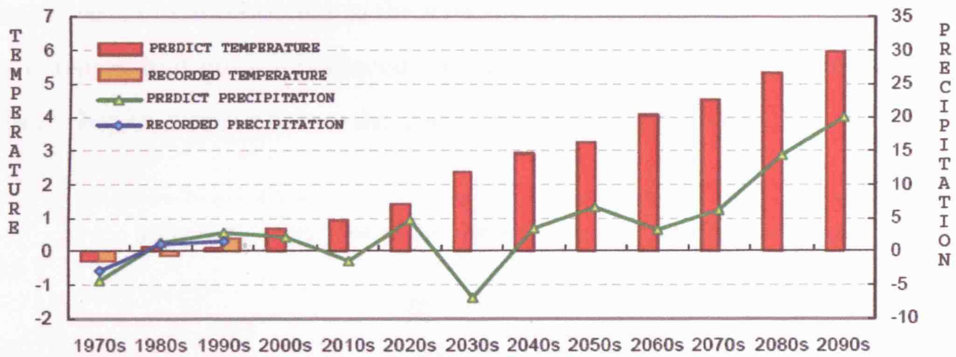
*Source: KMA (Korea Meteorological Administration)

Figure 5. Spring Flower Blooming Date in Seoul

2.3 PREDICTED CLIMATE CHANGE IN KOREA (2040 AND 2090)

The result of long-term (1860~2100) A2 scenario simulation using a coupled Climate Model performed by the Meteorological Research Institute shows that at the end of the 21st century, the global temperature will rise by approximately 4.6°C with CO2 concentration of 820 ppmv, which is higher than the present level. The average rainfall in 2100 will increase by approximately 4.4%.

An ensemble analyses with various future climate change scenarios were carried out to project temperature and precipitation trends in Korea region in the 2040s and 2090s. The result indicates that the temperature change based on A2 scenario shows a 3°C increase in the 2040s, an increase of 6°C in the 2090s. The average rainfall in Korea shows an increase of 3.6% and 20% for scenario A2. Seasonal projection indicates that the rise of temperature in the winter and spring is slightly higher than that of the summer. Furthermore, it is projected that the rise in temperature will be the highest in the north-western region of Korea, and increase in rainfall will be the greatest along the coastal regions of Korea in the summer.



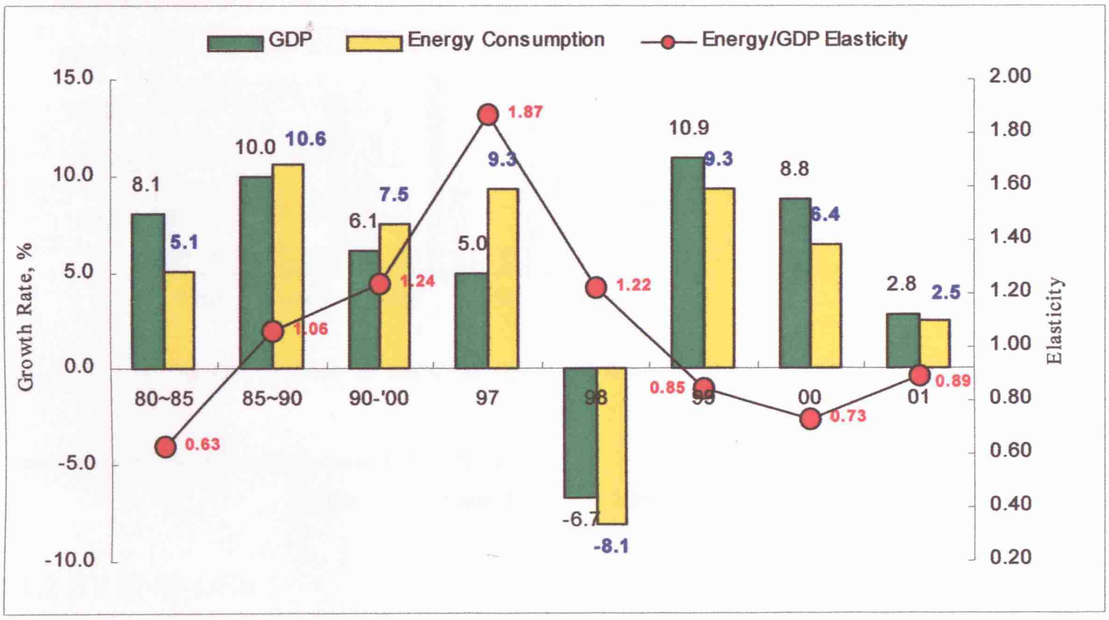
*Source: KMA (Korea Meteorological Administration)
**A2 scenario: CO_2 emission will reach 820ppm in 2100.

Figure 6. Predict Climate Change in Korea

3. ENERGY CONSUMPTION AND CO2 EMISSIONS IN KOREA

3.1 ENERGY CONSUMPTION IN KOREA

Korea's energy consumption has shown a comparatively higher rate of growth during the 1990s as a reflection of the nation's large energy-consuming industrial structure, except in 1998 when the nation experienced its worst financial crisis.
In 2001, however, Korea's economy suffered from recession and recorded a lower growth rate, thus resulting in a merely 2.9 percent increase in energy use in sharp contrast with a 6.3 percent growth in the previous year. In 2002, energy consumption increased by 5.5 percent thanks to the nation's economic recovery, but it declined to 3.0 percent again in 2003 owing to the nation's sluggish economic activities.
Energy consumption growth outpaced the nation's annual economic growth rate until 1997, but it began dipping below the annual economic growth rate.



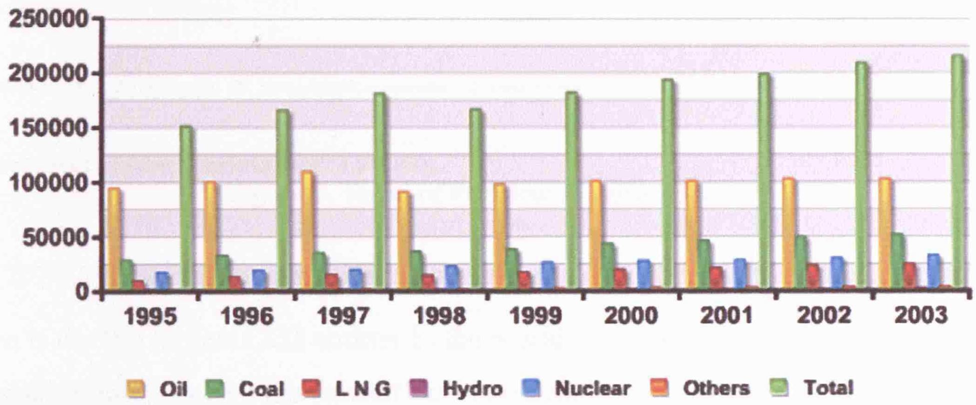
*Source: Korea Energy Economics Institute

Figure 7. Growth Trend of Economic and Energy Consumption

3.1.1 BY FUEL TYPE

Of energy sources, petroleum is still playing a major role in energy consumption in Korea by occupying the lion's share of 47.6 percent in 2003 even though the share shrank a lot from 62.5 percent in 1995. The gradual shrink in the role of petroleum was attributed largely to a fuel switch to other energy sources such as LNG encouraged by ever-strengthening environmental regulations and convenience in usage especially in the case of LNG. In view of the intensifying global efforts to reduce the green-house gases under the international convention on climate changes (Kyoto Protocol), large oil-consuming countries are required to cut down the use of fossil fuels such as petroleum. Korea has been also taking various actions to curb the domestic demand for fossil fuels, especially petroleum, and thus to reduce CO2 emissions. As a result of such efforts by the government and recent higher oil prices, the share of petroleum in the nation's energy consumption is expected to further decline gradually even in the future.

Even though its share may decrease in the years ahead, however, petroleum is anticipated to continue to hold the position as the nation's most important energy source for the time being in Korea since there are no economically viable substitutes for transport fuels and raw materials in the petrochemical sector.



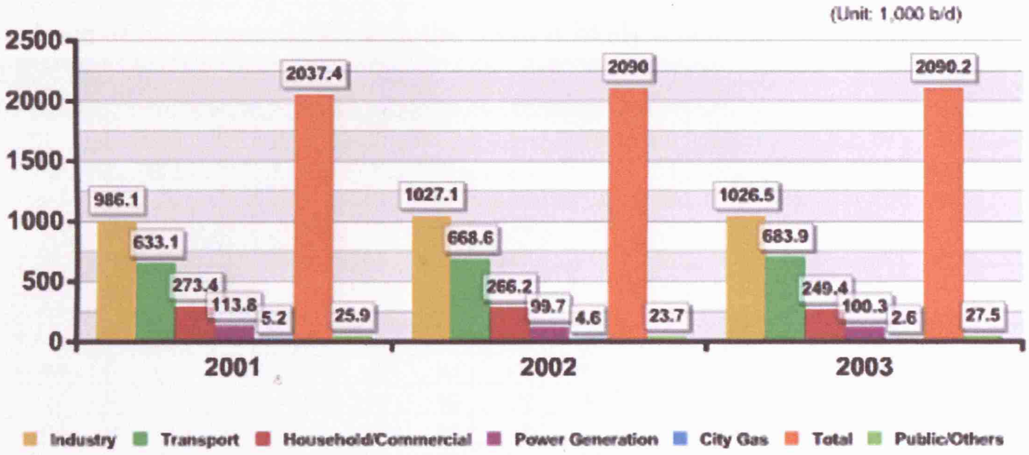
*Source: Korea Petroleum Association (unit: 1,000 TOE, %)

Figure 8. Demand Ratio by Energy Sources.

3.1.2 BY END-USE

By sector, petroleum demand in the industry, this accounted for nearly half of the nation’s total oil consumption at 49.1 percent in 2003, declined slightly by 0.1 percent in the same year owing to economic recession. The transport sector continued its rising trend of demand growth thanks to an incessant increase in the number of automobiles, but the growth rate slowed down to 2.3 percent in 2003. The transport sector accounted for 32.7 percent of total oil consumption in 2003.

Oil demand for the household and commercial sector went on to mark a minus growth since 2000 due to a continuous fuel switch to LNG, and so its share further declined to 11.9 percent in 2003. Its share peaked at 16.8 percent in 1999.The power generation sector registered a drastic suck back of 12.4 percent in demand in 2002 against the previous year mainly due to an increased fuel switch to LNG as a reflection of strengthened environmental regulations and lower cost, compared to heavy fuel oil . In 2003, petroleum demand of the sector inched up by 0.6 percent as tight supply situation of LNG arising from a steep hike in demand forced some power plants to use heavy fuel oil.



*Source : Korea Petroleum Association (unit : 1,000 B/D)

Figure 9. Trend of Petroleum Consumption by Sector

3.2 CO2 EMISSIONS IN KOREA

Korea is the 9th largest CO2 emitter in the world whose energy consumption is growing rapidly. Before the current economic crisis, especially the period between 1991 and 1995, annual average of economic growth rate was 7.4%, energy consumption 10% and CO2 emissions growth rate 9.1%. Although the sharp increase in the energy consumption was largely fuelled by the rapid economic growth, energy consumption grew much more rapidly than the economy (figure 7).

	Unit	1999	2005	2010	2015	2020
CO2Emission	MTC	111.3	146.4	170.6	188.8	205.3
Per capita CO2	TC	2.38	2.98	3.37	3.64	3.92
CO2/GDP	TC/won	0.25	0.24	0.21	0.19	0.17
CO2/Energy	TC/TOE	0.61	0.62	0.62	0.62	0.61

* Source: Korea Energy Economics Institute

Table 1. Energy and GHG indicator

Among the various greenhouse gases, the contribution of CO2 to global warming was 86%, with 94.1% of CO2 emissions generated by the use of energy. Without drastic changes like industrial restructuring, energy conservation, and increased use of renewable energy, these trends will go unabated.

The total CO_2 emissions are expected to increase from 237 million tons of carbons in 1990 to 472 million tons of carbons in 2002(5.3% increase, figure 10). If Korea will keep going on this growth ratio, this would make Korea one of the world's largest CO_2 emitters in the world with its ranking moving up from 16th to 9th in order of the U.S., Russia, China, Japan, Germany and Korea and to 4th respectively. Despite the slowdown of the economic growth, the trend is likely to remain unchanged.

		1990		1994	1995	1996	1997	1998	1999	2000	2001	2002		90-'02 Growth ratio
World		21,313	100.0	21,663	22,159	22,806	22,915	22,986	23,312	23,829	23,950	24,528	100.0	1.2
Annex I Countries		13,852	65.0	13,097	13,271	13,465	13,519	13,434	13,524	13,772	13,799	13,827	56.4	0.0
OECD		11,141	52.3	11,410	11,607	11,923	12,119	12,113	12,219	12,486	12,511	12,600	51.4	1.0
1	USA	4,852	22.8	5,108	5,138	5,263	5,422	5,440	5,538	5,699	5,643	5,705	23.3	1.4
2	China	2,431	11.4	2,836	3,024	3,176	3,191	3,118	3,117	3,171	3,123	3,432	14.0	2.9
3	Russia	2,131	10.0	1,570	1,586	1,513	1,492	1,449	1,498	1,521	1,527	1,515	6.2	-2.8
4	Japan	1,075	5.0	1,123	1,150	1,162	1,161	1,138	1,155	1,168	1,164	1,178	4.8	0.8
5	India	615	2.9	752	821	861	882	909	974	1,003	1,018	1,054	4.3	4.6
6	Germany	971	4.6	869	875	891	873	870	834	840	868	848	3.5	-1.1
7	UK	569	2.7	548	548	563	539	542	542	542	555	532	2.2	-0.6
8	Canada	421	2.0	441	452	464	480	489	495	516	513	507	2.1	1.6
9	**Korea**	**237**	**1.1**	**334**	**361**	**372**	**425**	**372**	**408**	**440**	**448**	**472**	**1.9**	**5.9**
10	Italy	397	1.9	395	412	411	411	421	421	427	428	430	1.8	0.7
11	Mexico	297	1.4	332	314	325	339	357	359	360	365	380	1.6	2.1
12	France	364	1.7	329	344	399	344	372	361	355	375	369	1.5	0.1
13	Ukraine	655	3.1	430	436	404	373	321	317	311	309	311	1.3	-6.0

*Source: CO_2 Emissions from Fuel Combustion 2004 IEA (unit: Million CO_2 Ton, %)

Figure 10. CO_2 Emissions in the World

3.3 OUTLOOK FOR ENERGY CONSUMPTION IN 2020

According to Korean government energy policy, total energy demand is expected to increase by 2.4% annually by the end of 2020. This figure is lower than the expected annual economic growth rate, which is 6%. The share of LNG and nuclear power consumption is growing due to increasing regulation and concerns on the environment, while the market share of oil and anthracite in decreasing.

As can see table 2, oil is the globally-dominant energy source, and it is expected to maintain its current status. Oil consumption is expected to increase by annual 1.8% by the end of 2020. Considering the global oil supply and oil consumption forecasts, the dependence on the Middle East will deepen. The stabilization of oil imports will continue to be a major issue for Korea's policies, and efforts to expand oil supply capacity are necessary.

	2000	2005	2010	2015	2020	Growth ratio (%)		
						00-10	10-20	00-20
Oil	100.4 (50.6)	116.3 (48.9)	125.4 (46.5)	131.8 (45.7)	139.6 (44.8)	3.0	2.2	1.8
Coal	42.9 (22.2)	51.2 (22.2)	61.5 (23.3)	59.1 (20.5)	62.6 (20.1)	3.7	0.2	1.9
Anthracite	3.1	2.7	2.6	2.2	2.3	-1.8	-1.3	-1.5
Bituminous	39.8	48.4	58.9	56.8	60.3	4.0	0.2	2.1
LNG	18.9 (9.8)	29.6 (12.8)	32.1 (12.2)	41.7 (15.4)	48.0 (15.4)	5.4	4.1	4.8
Hydro	1.0 (0.5)	1.1 (0.5)	1.2 (0.4)	1.2 (0.4)	1.2 (0.4)	0.8	1.6	0.5
Nuclear	27.2 (14.1)	31.8 (13.8)	39.5 (15.0)	47.8 (16.6)	52.0 (16.7)	3.8	2.8	3.3
Firewood & Others	2.1 (1.1)	3.7 (1.6)	5.6 (2.1)	6.8 (2.3)	8.6 (2.7)	10.1	4.3	7.2
Total Primary Energy Supply	192.9 (100)	230.9 (100)	263.6 (100)	288.2 (100)	311.8 (100)	3.2	1.7	2.4
Total Final Energy Consumption	150.1	176.9	199.7	219.4	236.8	2.9	1.7	2.3

*Source: Korea Energy Economics Institute (unit: Million Toe)
**() Indicates shares in total primary energy supply

Table 2. Energy Forecast of Korea

Gas consumption is expected to increase globally due to growing concerns on the environment. Gas supply is more stable in comparison with oil supply, since it is deposited over a wide area and its reserves are relatively abundant. At present, the supply in natural gas exceeds demand, but uncertainty exists in the future balance between supply and demand. Continuous efforts are needed to ensure a stable supply, such as expanding storage facilities.

Renewable energy is expected to increase rapidly due to globally-strengthened environmental regulations such as the Convention on Climate Change, but the share of renewable energy expected to be lower than the global average of 7.2% in 2020. The government has set a policy goal for increasing the share of renewable energy, reaching 5% by 2010. Electricity consumption is expected to increase steadily, which means that continuous efforts are need to ensure a stable electricity supply base.

4. ENERGY CONSUMPTION IN KOREAN APARTMENTS

4.1 BACKGROUND OF KOREAN APARTMENTS

Korea has experienced rapid urbanization and housing shortage after World War II and apartments were introduced from western countries to supply houses for newly arrived people in cities. Thus, after the mass construction of apartment complexes in 1970s and 1980s apartments became the most popular urban housing type in Korea (figure 11).

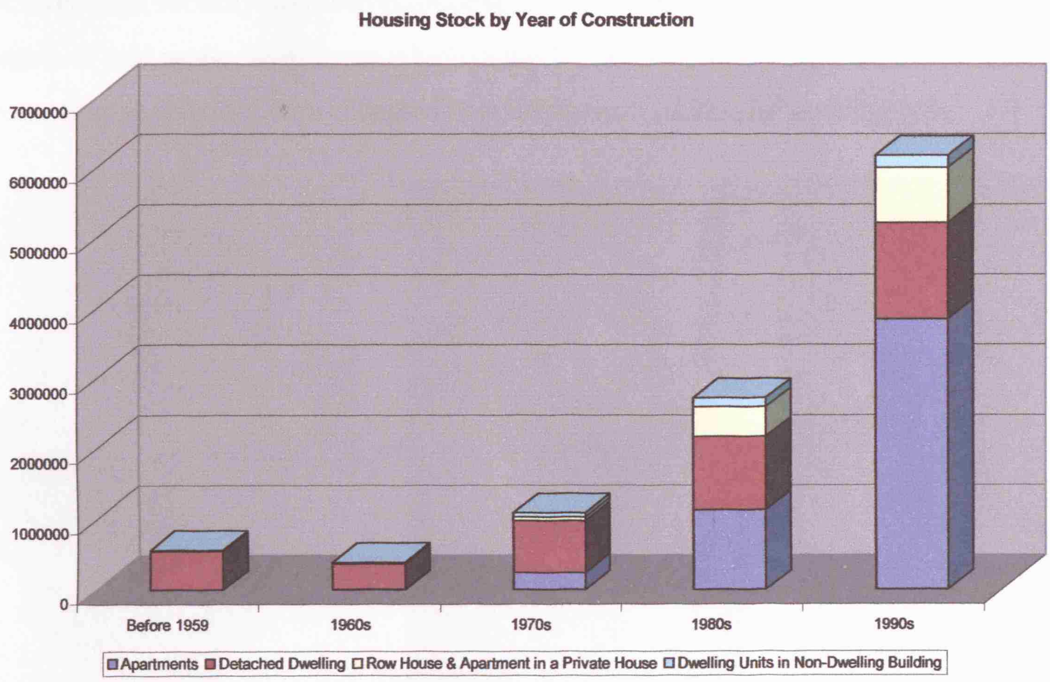


Figure 11. Hosing Stock by Year of Construction

The history of apartments in Korea might go back to as early as Japanese colonial period, construction of apartments under guidelines of land use plans and site plans started after 1960. Korea Housing Corporation played important roles in construction of apartments in Korea. Mapo apartment, which was constructed in 1962, was the birth of a modern apartment in Korea. After, Mapo apartment, many apartment complexes have been constructed.[3]

4.1.1 LIFE STYLE IN KOREAN APARTMENTS

In Korea, although the unit plans of apartments were based in western styled, ONDOL, a traditional Korean floor heating system, was introduced to apartments. Thus, ONDOL-typed rooms in apartments could afford to lead a traditional lifestyle of floor seating and a western life style with furniture. It seems true that current unit plans of apartments reflect traditional structures of Hanok (a traditional Korean House). Especially, a living room and front balcony were considered to replace a courtyard of Hanok with common quality. In addition, utility balcony accommodates the activities of backyards in traditional houses. Therefore, the unit-plans of apartments in Korea are the result from accommodation of traditional life to westernized apartments space.

Furthermore, apartments have a great appeal to the public due to its good environment for kids, high security and convenience to live. In addition, apartments were good targets of real estate investment which could be exchanged to cash assets easily. It seems that people in Korea accepted apartments as a successful housing type.

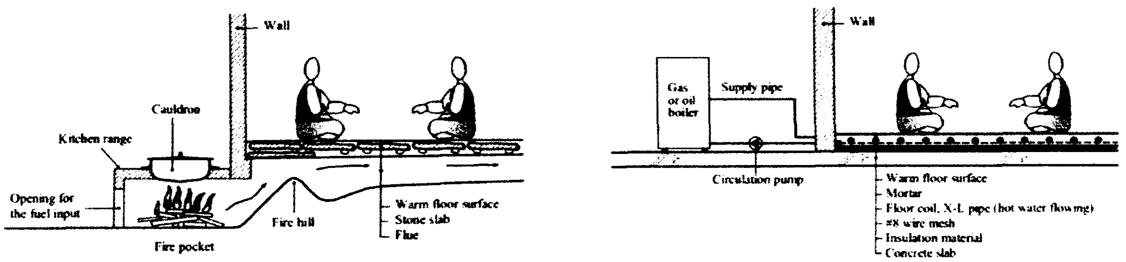
(a) Original Apartments (b) Refurbished front balcony (c) Refurbished utility balcony

Figure 12. Pictures in Korean Apartment

Living in Korean style apartments, it needs some special place for drying clothes, planting and stock room. Figure 12(a) shows the original Korean apartment's balcony, which does not have any sash in baloneys, and which is usually refurbished when the apartment is occupied. Figure 12(b) shows the refurbished front balcony, which is used for drying clothes and plating which traditionally took place in Korean House's courtyard. Figure 12(c) is the rear balcony which is used on utility room and stock room and taken the role of backyard activities in Hanok.

4.2 KOREAN HEATING SYSTEM

The ONDOL floor heating system has been used conventionally in Korea since 400 B.C. [4] As seen in figure 13(a), before the 1950s, firewood was used as fuel, and the opening for the fuel input was a gate where firewood passed. The heat generated by burning firewood in the fire pocket was simultaneously used for cooking and heating. The fire hill was designed to protect against adverse strong winds from the chimney, and the flue was a flame pathway. The stone slab was a thermal storage mass, which kept the floor surface and the occupants warm. This system ran twice a day in the early morning while preparing breakfast and in the evening in time for dinner. After the 1950s, the ONDOL system was modified when introduced in modern Korean apartments, which is represented in figure 13(b). The ONDOL system was modernized with a gas boiler instead of firewood and briquette fuel. Hot water from a boiler is supplied to the floor coil, which is the X-L pipe underneath the floor surface. The thermal storage mass was put in place of the stone slab as mortar. The principle of the ONDOL floor heating system has remained the same, even as its form has changed. From the floor surface, heat is radiated to warm up the air temperature and consequently keeps the occupants warm. [5]



(a) Before the 1950s (b) At present

Figure 13. The ONDOL Floor Heating System

4.3 COOLING AND HEATING ENERGY CONSUMPTION IN KOREAN APARTMENTS

The number of apartment houses in Korea has rapidly increased in a very short period making up about half of all housing types (figure 14). [6]

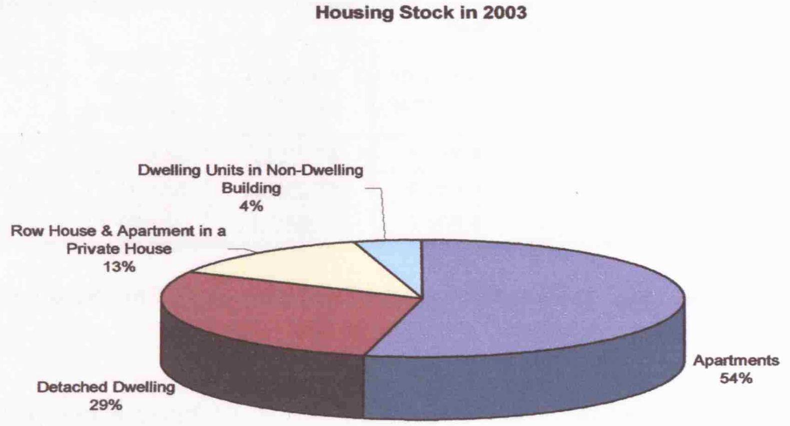
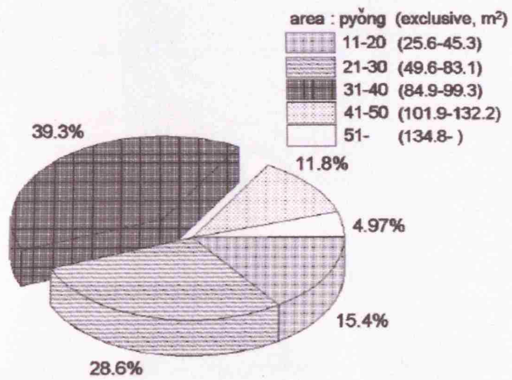
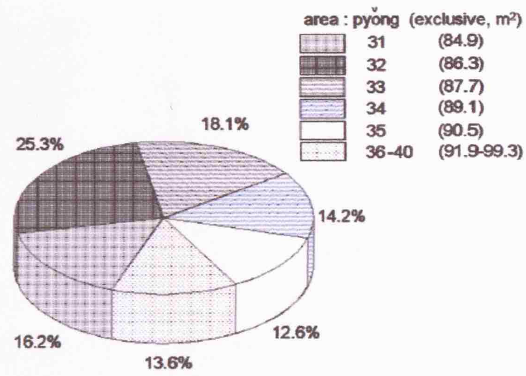


Figure 14. Housing Stock in 2003 Korea

There are studies [7][8] that have surveyed the energy consumption according to different heating methods, which are district heating, unit heating and central heating, of apartments. The results are in table 3. In these studies, they selected the household with nominal floor area of 84(31py) to 86 m² (32py) which is the most representative among Korean apartments (figure 15).



(a) The total number of households: 406,376



(b) The number of households between 31 and 40 py: 159,485

*Source: Analysis of Heating Energy in a Korean-Style Apartment Building 2: The Difference according to Heating Type

Figure 15. Distribution Chart for the number of apartments households in Gangnam-gu

Base on these studies carried out in Seoul, the energy amount used in heating can be compared according to the heating type: 7,227.78kWh/year for unit heating, 7,802.78kWh/year for the central heating and 11,280.56kWh/year for the district heating system.

	Supplied energy [kWh/year]	Used Energy				Energy loss including public usage [kWh/year]
		Heating [kWh/year]	Hot water [kWh/year]	Total [kWh/year]	CO2 Emission [Kg/year]	
Unit heating	12,230.56	**7,227.78**	3,169.4	10,397.18	150	2,827.78
Central heating	15,180.56	**7,802.78**	3,169.4	10,972.18	158	4,208.3
District heating	15,480.56	**11,280.56**	3,169.4	14,449.96	209	1,030.56

Table 3. Comparison of Energy Consumption for Heating and Hot Water According to Heating Type

Cooling energy consumption in Korean apartments is hard to find. However, one of the government departments, named KPX (Korean Power Exchange), has done for domestic building's electric consumption. In this study, it does not only survey on electricity consumption for air conditioning systems, and electric fan, but also on the extra heating device's electricity consumption. Figure 16 shows the number of days each electric heating and cooling equipments is used in each month in 2004.

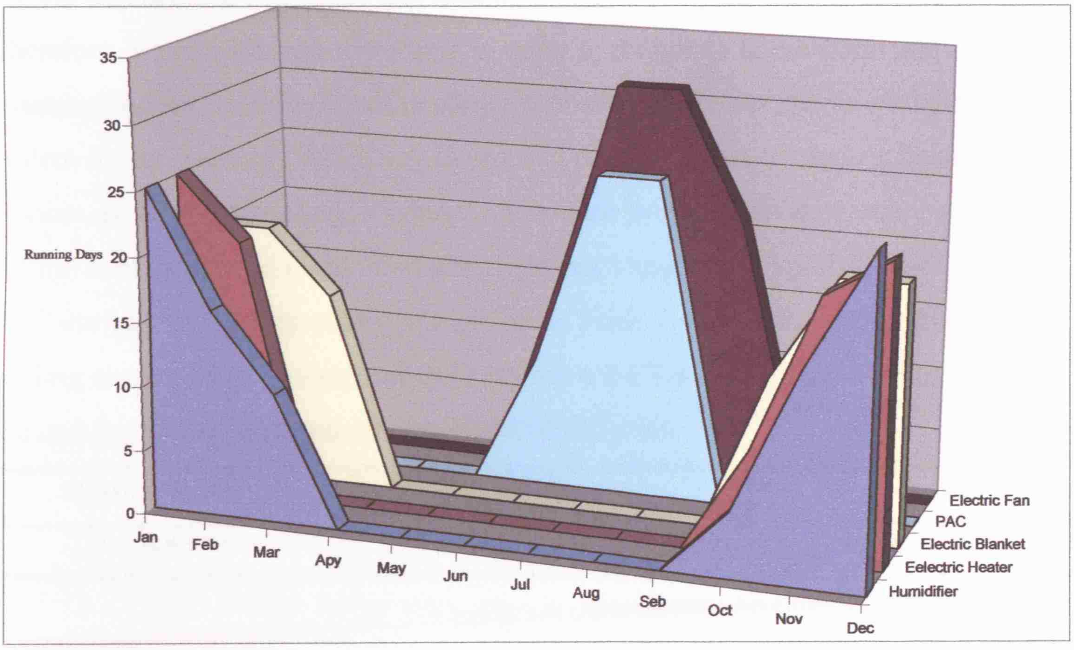


Figure 16. Monthly data for heating and cooling electric equipments

Table 4 represents how much electricity is consumed and how much CO2 released by different electric equipments.

According to KPX survey, PAC and Electric Heater consume most electricity in summer and winter respectively; however, PAC's CO2 emission and energy consumption is much higher than any other electric equipment.

	Humidifier	Electric Heater	Electric Blanket	PAC	Electric Fan
Running Hours	437	235	552	255	608
Electricity Consumption	50,255	211,735	102,672	437,835	35,872
CO2 Emission	1.6	6.5	3.2	13.5	1.1

*Unit: hr, Wh, and kgCO2/year

Table 4. Electricity consumption and CO2 emission by equipments

In Korean apartment's CO2 emissions from heating is 1.3kgCO2/m^2 and from cooling is 0.16kgCO2/m^2. Table 3 shows that both district heating and central heating supplied energy is almost the same, however, the difference between these two heating types is heating energy and energy loss by ducting, piping and public usage. So, the unit heating consumes less heating energy due to less piping and ducting. Therefore, we can suggest something in order to reduce CO2 emission and energy consumption for heating. Korea needs to improve the Korean apartment heating system for more energy efficiency in order to reduce the use of electric heating devices. In terms of cooling, it needs to introduce passive cooling system, such as, natural ventilation and night ventilation systems (Appendix 1) to decrease the use of PAC during summer especially of night time. Table 5 shows the total heating and cooling energy consumption and CO2 emission for Korean apartment houses which use unit heating system and all the electric equipments.

Heating Energy	Cooling Energy	CO2 emission
7,596.5kWh/year	473.7kWh/year	180KgCO2/year

Table 5. Energy consumption in typical Korean Apartments

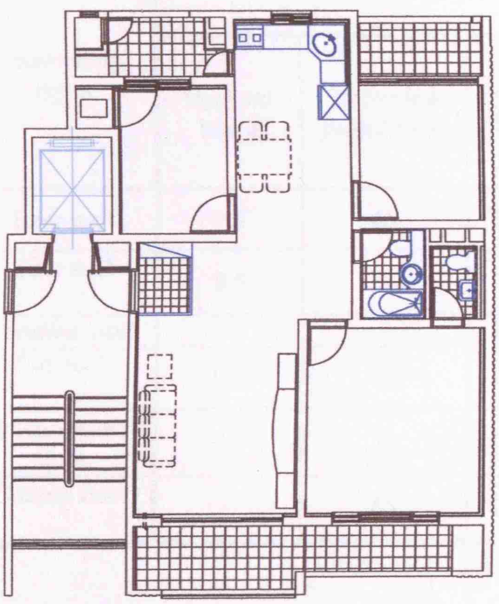
5. ENVIRONMENTAL SIMULATION

5.1 REFURBISHED BALCONY HEATING LOAD

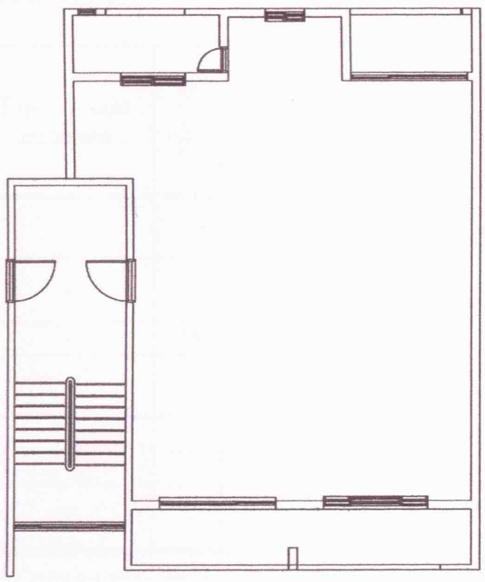
This part of simulation looks into the effects of various factors on the energy consumption of Korean apartments. Based on some assumptions, an actual apartment in simplified into a model that is used for thermal load calculations. The factors considered here include type of remodelling which are original balcony, refurbished balcony and remodelled apartments, and window types and check the various insulation levels which are old insulation level, current level and super insulation levels and one more simulation will be carried out for heating load which is change indoor target temperature from 24°C to 20°C during heating season in Korea.

5.2 STUDY MODEL

The study model will use one of the typical Korean apartments plan (figure 17(a)), which is named 32pyoung apartments plan. One pyoung is around 2.6m² and 32 pyoung is around 84 to 86m². It has 3 balconies one is in front of the apartment and the other two are next to the kitchen. The apartment has a living space, a dining room with kitchen and three bed rooms. Between two apartments, it has stair and lift space. Figure 17 compares the actual and the modelled apartments. Both have a total volume of 325m³, and a floor to ceiling high of 2.3m.



(a) The plan of an actual apartment house



(b) A simplified model corresponding to (a)

Figure 17. 32 Pyoung Korean Style Apartment plan

Table 6[9] and 7 [8] are describes the thermal properties of wall materials and detail of the each construction types. In 2001, Korean building regulation has changed to improve the insulation level depending on the building location. The regulation on insulation materials used for apartment building in central Korea is 0.034W/m.K according to the new regulation. But, the old building regulation did not specify any minimum thermal conductivity.

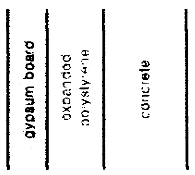
Material	Thermal conductivity (W/mK)	Specific heat (KJ/kgK)	Density (kg/m³)
Gypsum board	**0.21**	**1.13**	**910**
Expanded polystyrene	**0.0035**	**1.25**	**28**
Concrete	**1.62**	**0.79**	**2400**
Lightweight concrete	**0.17**	**1.09**	**600**
Mortar	**1.51**	**0.79**	**2000**
Levelling mortar	**0.37**	**0.79**	**2000**

Table 6. Thermo physical Properties of Wall Materials

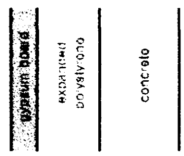
Table 7 represents current building regulation's insulation level, materials thickness and U-Value for each construction. The figure shows how compose the materials to make construction types.

Construction types	Materials thickness (mm)						U-Value (W/m²K)
	Gypsum board	Expanded polystyrene	Concrete	Lightweight concrete	Mortar	Levelling mortar	
Rear wall	9.5	65	180	-	-	-	0.473
Side wall	9.5	90	180	-	-	-	0.348
Partition wall	-	-	108	-	24	-	9.045
Flat roof	9.5	110	180	-	-	-	0.287
Intermediate floor	9.5	30	150	50	-	40	0.776
Ground floor		65	180	50	-	40	0.431

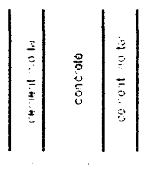
Table 7. Detail of Each Composition Wall



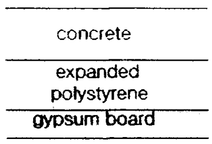
(a) Real wall



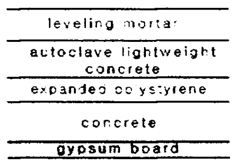
(b) Side wall



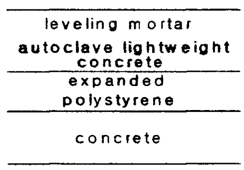
(c)Partition wall



(d) Floot roof



(e) Intermediate floor



(f) Ground floor

5.3 TAS MODELS

In this chapter describes what simulation tools are used and how the models are designed and what input data were used for simulations. In this simulation part one simulation tool were used; TAS Building Designer^{TM}

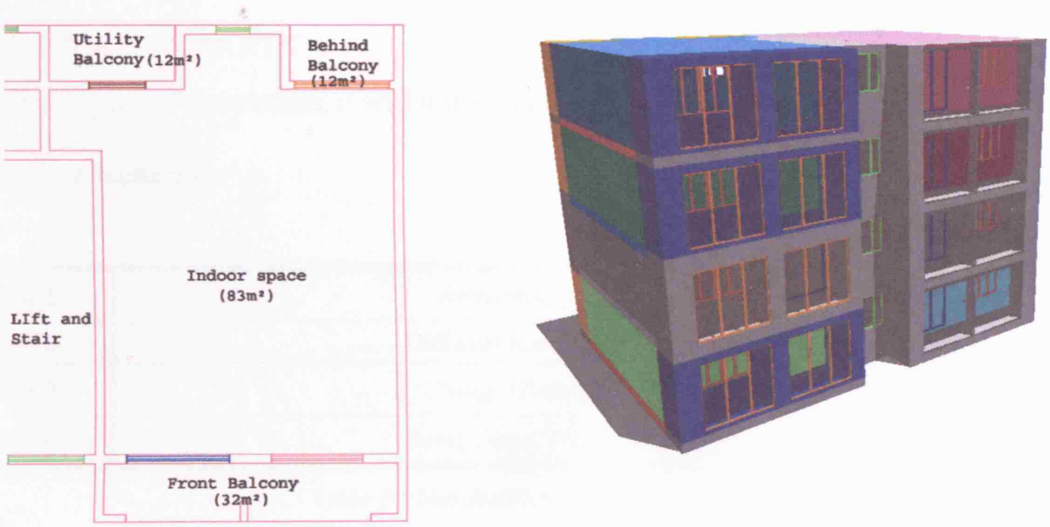
TAS Building Designer^{TM} has 3 different parts which is 3D Modeller, Building Simulator and Results Viewer section. The 3D Modeller is used to draw, zone and view the model. When a 3D model has been created and zoned, the data can be exported to Tas Building Simulator. During this stage, it performs shadow calculation for any period of the year. After creating 3D model, it will show the Building Simulation sector which can be set about construction materials, zone names and occupation patterns for building. Once the model contains sufficient information it will run a dynamic simulation. It can do temperatures, humidity, loads and energy consumption through the natural ventilation airflow rates and compensation analysis. Data is available in graphical and tabular format and the result can be exported directly into Excel.

The first simulation will test the heating load of Korean apartments under various conditions during the winter time. To make TAS simulation model, it will need some of the assumption in table 8 which will be the base case (figure 18) to compare against other refurbished models. [10]

Item	Reference Condition		
Internal Temperature	Winter	24°C	
Period and Pattern of Conditioning	Winter	From October to March continuous for all day long	
Ventilation	Winter	1.5 ACH	
Insulation Level	Old Level of Insulation		
Internal Space	Conditioned	Indoor	
	Unconditioned	Front, Utility and Behind Balconies and Lift & Stair Space	
Internal Gain	4 People	Sensible	70.1 W/person
		Latent	45 W/person
	Lighting	20 W/m²	
	Equipment	Sensible	16 W/m²
Construction Year	Before 2001		

Table 8. Reference Condition for Heating Load Calculation

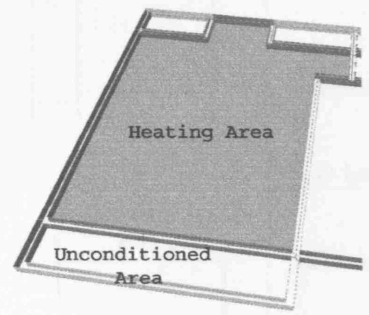
All the construction material is based on table 6 and 7. However, the insulation level of this TAS simulation model is based on old insulation level according to the construction year. Figure 18 shows how looks like the TAS model's plan and 3D model.



(a) TAS model plan (b) TAS 3D model

Figure 18. TAS Simulation models

To make Korean apartment simulation model in TAS, it will need to simulate the Korean heating system, which is under floor heating system. Unfortunately, TAS does not have this heating option. In this paper, this type of heating system is simulated by a small chamber with a floor surface temperature of 25 to 38.8°C (mean value of around 28 to 31°C and the room temperature ranges between 21.1 and 23.5°C). [11] Table 9 shows assumption of the floor heating system and image.



Internal temperature	35°C	
Ceiling	Surface temperature	30°C
	Material	Mortar 40mm
Floor	Material	Intermediate floor (table 7)
Internal gain	-	
Geometry	Heating Area	83m^2 x 0.3m
	Unconditioned Area	56m^2 x 0.3m

(a) TAS model plan (b) Reference Condition

Table 9. Reference Condition for Floor Heating Panel

5.4 SIMULATION PART I

Within this part of simulation, it will test several different conditions and table 10 shows four scenarios.

Test 1	Remodelling Cases
Test 2	Different Insulation Level
Test 3	Change Glazing Types
Test 4	Reset Target Temperature

Table 10. Simulation part I

Test 1 will calculate heating load for original apartment, refurbished balcony apartment and remodelled apartment. Before simulation, it is expected that the RB case might be the best cases and the RA might be the worst case for heating energy consumption. The detail of the test 1 is shown in table 11.

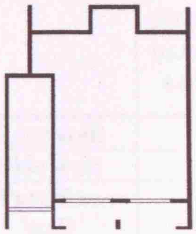
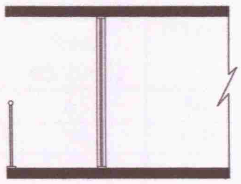
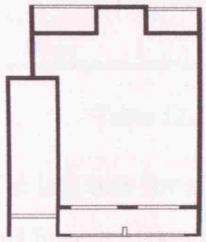
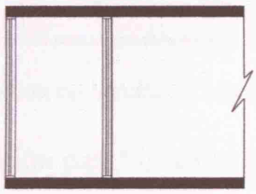
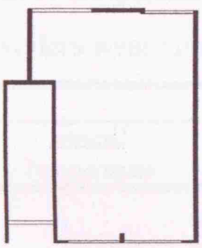
Plan	Section	Comment	Heating Area
 OA	 Original Apartment	Only interior window present (Balconies are open to outdoor)	83m²
 RB	 Refurbished Balcony	Interior and exterior window present (balconies are unconditioned, but closed)	83m²
 RA	 Remodelled Apartment	Only exterior window present (balconies belong to indoor)	139m²

Table 11. Remodelling Case Under Consideration Condition

The refurbished balcony is based on the current balcony system in Korea and when people want to use more indoor space the internal windows which are placed between living room and front balcony are removed. Test 2 and 3 are all about to improve thermal conductivity for construction materials and window types. (Table 12) Especially, window changes will be installed only for balcony sash.

Insulation level (unit: mm)				Glazing type			
	OI	NI	SI		RB	RB&D	RB&TA
	Old (from 06/1992 to 04/2001)	Now (Effective from 05/2001)	Super		Current	Double	Trifle with Argon
Rear wall	50	65	80	Composition (mm)	10	4/10 (air)/4	4/12(argon)/ 4/12(argon)/4
Side wall	70	90	110				
Partition wall	-	-	-	Thermal conductivity (W/m^2K)	100	5.96	2.5
Flat roof	80	110	150				
Intermediate floor	-	30	50				
Ground floor	50	65	80				

Table 12. Regulation on Insulation Materials used for Apartment and Glazing Types

The last test for simulation part I is about to reset indoor temperature from 24 to 20˚C and how it effect the heating load. The Korean Building regulation suggests indoor temperature for dwelling at 20˚C, however, user and construction companies set the indoor temperature at 24˚C [12]. Which is maintained during the winter while dwellers wear summer clothes in apartments.

	Current apartment (RB24)	Reset temperature Apartment (RB20)
Internal Temperature	24˚C	20˚C

Table 13 Reset the Internal Temperature

5.5 RESULT AND DISCUSSION

This simulation is based on heating period time in Korea which is October to March.

5.5.1 INTERNAL CONDITION IN THE COLDEST DAY

Figure 19 shows that the thermal performance of refurbished balcony apartment is better than any other apartments. The below graph represents the apartment internal condition during coldest day in winter (day 29) without any heating system except heat gains from internal gain (table 8). The best thermal performance is RB followed by OA, the worst one is RA. RB and OA show same of temperature pattern, but, shifted by 3˚C temperature difference. The temperature difference between RB and OA is caused by the refurbished balcony functioning as a conservatory. This result shows the potential effect of refurbished balcony on heating energy consumption which will be analyzed in the following section.

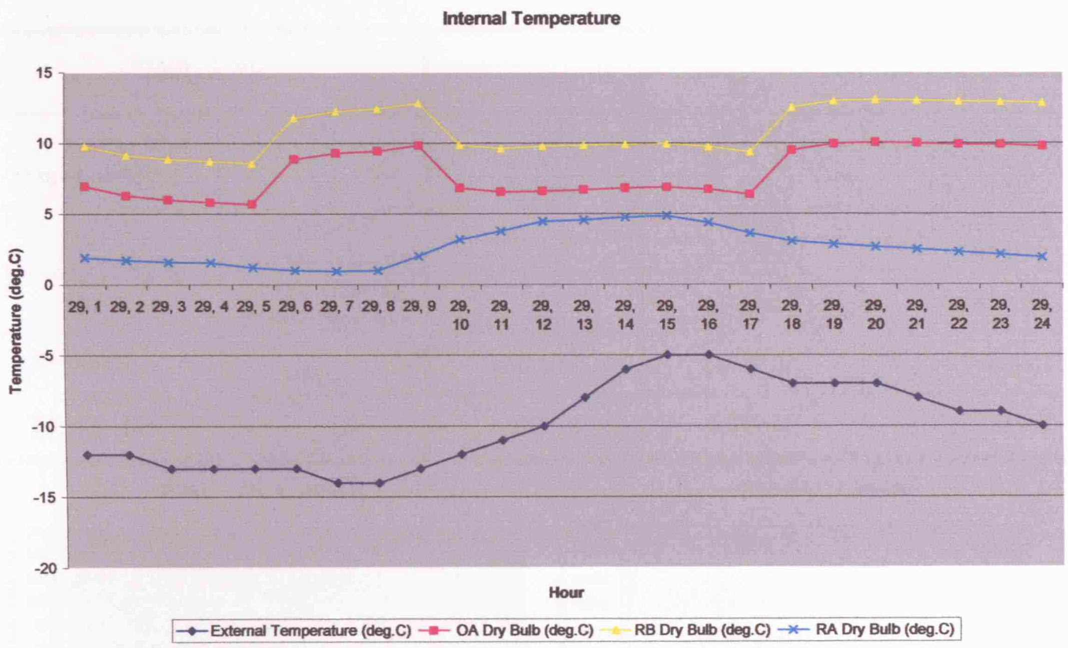
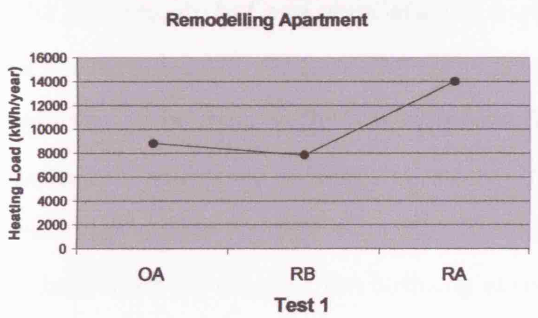


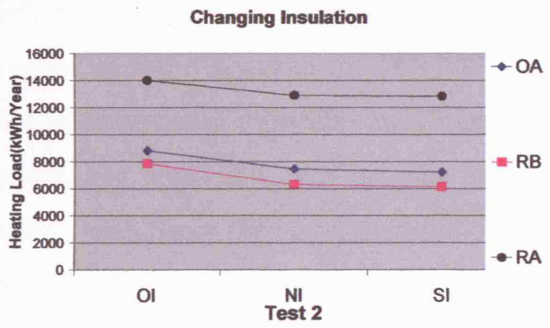
Figure 19. Internal Temperature for OA, RB and RA in Coldest Day

5.5.2 EFFECT OF VARIOUS FACTORS ON THE HEATING ENERGY CONSUMPTION

This simulation is aimed at estimating the effect of various factors on heating energy consumption of a Korean apartment using TAS Building Designer^{TM} . Test one is based on apartment remodelling, test two on changing insulation level according to Korean building regulation, test three on window type and the last one internal temperature setting . The base case is OA with OI. In test two, the insulation level is changed, but for other tests, the base model insulation level is kept to the old condition. The results of these simulations are presented in table 14. From test 1 results, the difference between actual heating load (7,596.5 kWh) and simulation result, which is RB (current apartment), is 0.3%. As said by the test 1's results, the best reduction of heating energy consumption is RB. The most significant change in second test is OA case with NI, which shows a decrease by 15% compared with OA with OI case. The reason is due to introducing insulation to the intermediate floor at current insulation standard which shows quite big reduction of heating load. So that a cost-effectiveness analysis may be needed when amending the building regulation concerned.

*Unit : kWh		Test 1 OA	Test 1 RB	Test 1 RA
Test 2 Insulation level	OI	8,809.34	7,840.81	14,008.64
	NI	7460	6301.42	12,891.64
	SI	7213.89	6132.04	12,821.21
Test 3 Balcony Glazing Types	Current	-	7,840.81	14,008.64
	Double Glazing	-	6292.65	11,086.07
	Triple Glazing with Argon gas	-	5,811.68	10,561.83
Test 4 Internal Temperature	24°C	8809.34	7,840.81	14,008.64
	20°C	6,072.78	5,742.69	9,969.89





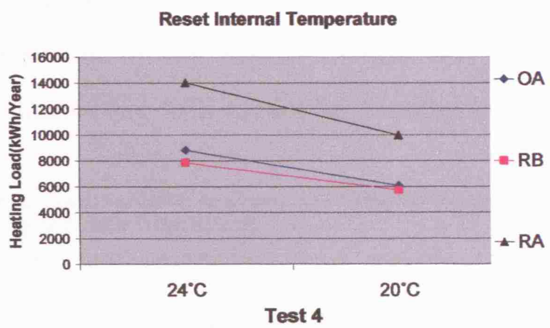


Table 14. Results of Simulation Part I

Result in test 3, RA with double glazing shows a significant decrease in heating load by 20% compared with RA, but the best result in test 3 is RB with triple glazing window according to test 3 simulation. As shown in test 4, when internal target temperature is reduced from 24°C to 20°C the reduction in heating load is 35% and the annual CO_2 emissions from heating is also a decreases from 150kgCO_2 (OA case) to 83kgCO_2 (RB 20).

6. NATURAL VENTILATION STRATEGEIES

6.1 METHODOLOGY

The second part of the simulation is all about natural ventilation. This simulation is about comfort ventilation and night time ventilation for cooling during summer night time. The comfort ventilation which is air passing over the skin creates a physiological cooling effect by evaporating moisture from the surface of the skin and this was air motion across the skin to promote thermal comfort. The term comfort ventilation is useful in hot and humid climates, where it is typical for air temperatures to be moderately hot and ventilation is required to control indoor humidity. [13] In all but the most humid climates, the night air is cooler than the day time air. This cool night air can be used to flush out the heat from building mass; especially in Korean apartments which are of heavy concrete structure. The precooled mass can then act as a heat sink during the following day by absorbing heat. Since the ventilation removes the heat from the mass of the building at night, this time-tested passive technique is called night-flush cooling. This part of simulations is base on refurbished balcony system and this current balcony system will be improved to get more efficient result. The TAS model is almost same as the fist simulation model without the floor heating panel and table 15 gives some assumption to make base TAS model for simulating natural ventilation strategies.

Item	Reference Condition		
Internal Temperature	summer	28°C (50%)	
Period and Pattern of Conditioning	Natural Ventilation	From 9am to 20pm	
	PAC	From July to August intermittent cooling for all day long	
Ventilation	Natural Ventilation	27 ACH[14] (from 9am to 20pm)	
	PAC	0.5 ACH	
Insulation Level	Old Level of Insulation		
Internal Space	Conditioned	Indoor	
	Unconditioned	Front, Utility and Behind Balconies and Lift & Stair Space	
Internal Gain	4 People	Sensible	70.1 W/person
		Latent	45 W/person
	Lighting	20 W/m²	
	Equipment	Sensible	16 W/m²
Construction Year	Before 2001		

Table 15. Reference Condition for Cooling TAS Model

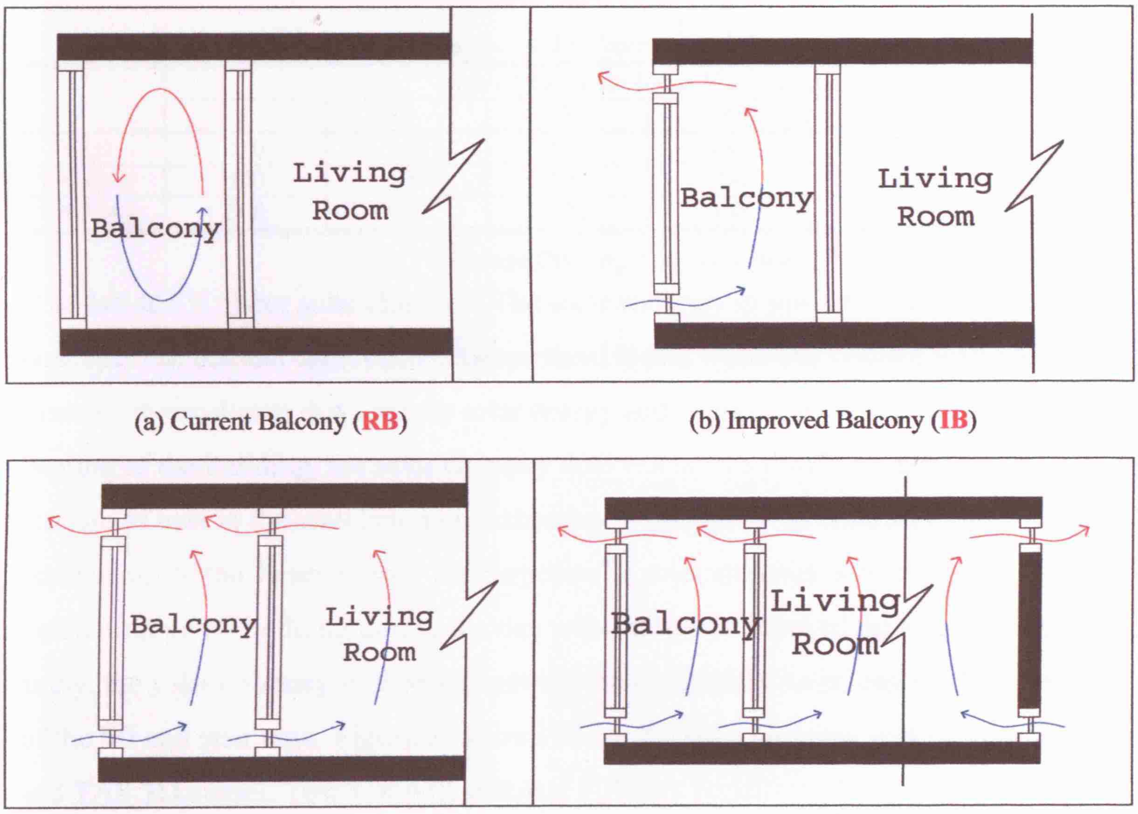
6.2 SIMULATION PART II

In this part of simulation, it will test various night ventilation strategies which are explained as follows. Within these tests, it will naturally ventilate during day time and then at night all the windows will be closed except ventilated dampers. This part of simulation will only concern night time thermal comfort (from 9 pm to next day morning) and especially a hot still day 211 according to TAS weather data.

Test 1	Improved Balcony (comfort ventilation)
Test 2	Ventilated Apartment (comfort ventilation with night –flush cooling)
Test 3	Solar chimney

Table 16. Simulation Part II

The test 1, it will simulate RB (figure 20 (a)), improved balcony (figure 20(b)), ventilated apartment I (figure 20(c)), and ventilated apartment II (figure 20(d)) to compare how the internal temperature will be affected during summer night.



(a) Current Balcony (**RB**) (b) Improved Balcony (**IB**)

(c) Ventilated Apartment I (**VA I**) (d) Ventilated Apartment II (**VA II**)

Figure 20. The Air Flow in the Different Balcony systems

Based on the results of test 1 for the four conditions, the night ventilation simulation of test 2 will be carried out on the test 1 condition with the best thermal performance. In the second test, it will customize opening window size for maximum air speed and cool indoor temperature to achieve the recommended comfort zone for Korean summer, which will be explained in later chapter. Furthermore, this test will simulate the possibility of cooling the structure's temperature and its effectiveness on a heat sink the next day in controlling the internal condition. Below figure 21 and table 17 show where the opening windows are and their condition used in test 2.

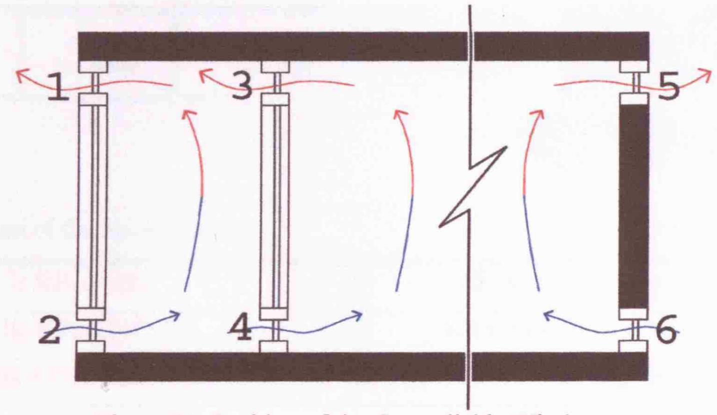
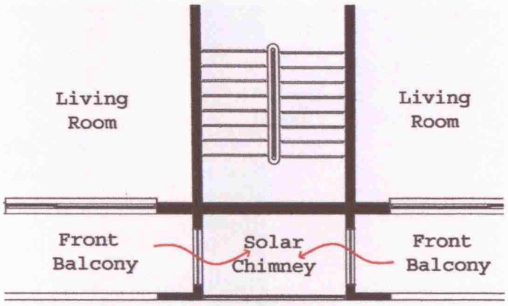


Figure 21. Position of the Controllable Windows

	High of the Controllable Window (mm)					
	1	2	3	4	5	6
VAII	150	150	150	150	150	150
VAII300	300	300	300	300	300	300
VAII500	500	300	300	300	500	300

Table 17. Change Opening Area for Test 2

The last test is about solar chimney. The solar chimney is similar to the Trombe wall concept. The distinct difference between them is that while the Trombe wall has a massive thermal wall that absorbs solar energy and recirculates warm air for passive heating of the building, the solar chimney does not have a massive wall. Rather, storage of heat in the wall behind the absorber is undesired. In contrast to the application of the Trombe wall, the purpose of a solar chimney is to provide ventilation to the building during the day without recirculation of the room air. In this study, the solar chimney will be set between two apartment units, especially in front of the lift and stair case. Figure 22 shows where the solar chimney will be installed and TAS 3D model. Test 3, it will simulate different condition of the solar chimney, i) RB with low solar chimney, ii) RB with high solar chimney iii) VAII with high solar chimney and iv) VAII500 with high solar chimney. It will be observed how the internal temperature is different and how the air flows from indoor to solar chimney during summer night. It will suggest the way to increase air movement from indoor to balcony and decrease internal temperature to remain near the recommended thermal comfort zone in summer.



(a) Position of the Solar chimney

(b)TAS 3D model

i) RB&SHL	RB with low solar chimney (16m)
ii) RB&SHH	RB with high solar chimney (36.5m)
iii) AVII&SHH	AVII with high solar chimney
iv) AVII500&SHH	AVII500 with high solar chimney

Figure 22. Solar Chimney and Test Details

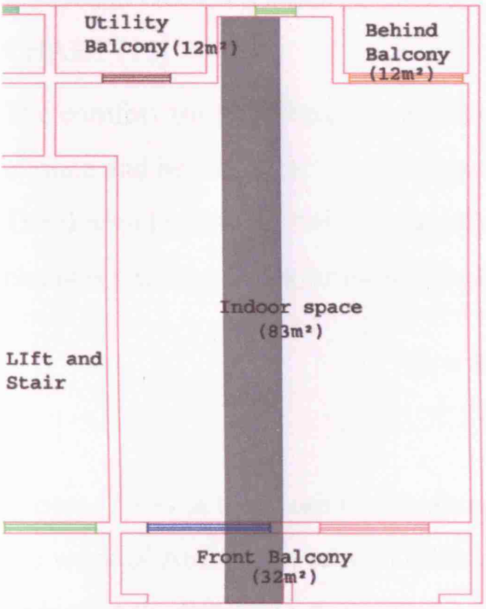
6.3 TAS AMBIENS

The TAS Ambience is used for micro climate CFD simulation of special variations in internal comfort which allows user to generate a view of the micro climate across a 2D section (a drawing created in Ambiens represents a 1metre deep vertical cross-section through a building) of an internal space. It can create graphical displays for special variations in radiant, air and resultant temperatures. Plots of air velocity, humidity and PPD comfort level are also included.

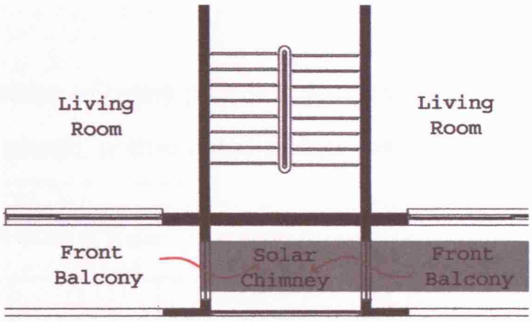
This CFD simulation relates to all the natural ventilation simulations, and it will suggest what we need to change to get better result. From that result it will use to analyse how the internal condition response when it is changed.

For the TAS Ambiens model, some input data from TAS Building Designer is required. Table 18 shows the input data from TAS Building Designer and the location of the 1m wide Ambiens model (grey colour).

The purpose of the Ambiens model is to analysis the environment strategies of passive cooling within Korean apartment unit and it will give some feed back to improve the design as well.



(a) Indoor with Balcony



(b) Balcony with Solar Chimney

Required input data	Surface Temperatures
	Internal Gains (from table 14)
	Inlet air speed, temperature of air and RH
	Outlet air speed

Table 18. Plan of the TAS Ambiens and Required Input Data

6.4 QuickSTREAM

QuickSTREAM has very simply graphic user interface, base on icon and dialog boxes, for quick modelling and 3D simulation with bitmap gradients. Plots of air velocity, pressure, temperature, contamination and unsteady energy contour plot are also displayed in 2D section and 3D model. It can do X-Y and Y-Z, Z-X each plane plot. In this simulation, it will give more dynamic 3D result with visual graphical result based on all the same input data used for TAS Ambiens modelling. TAS Ambiens can only simulate 1m deep vertical cross section; in this case it can not look at the whole unit's air movement. Therefore, QuickSTREAM is used to model more accurate air movement and internal conditions. The following chapter will compare TAS Ambiens result with QuickSTREAM result.

6.5 CONSTRUCTION OF COMFORT ZONE ON THE PSYCHROMETRIC CHART [15]

The comfort zone can be plotted on the Psychrometric chart that will vary with the climate and be different for each month.

The thermal neutrality temperature (the median of many peoples' vote), which changes with the mean temperature of the month, is calculated as follows

$$T_n = 17.6 + 0.31 \times T_{o.av} \quad (1)$$

Where, To.av is the mean temperature of the month (these coefficients are based on the work of Auliciems: several other research workers found correlation coefficients only slightly different). For both the warmest and coldest month, the limits of upper and lower comfort can be calculated as from

$$T_{L1} = T_n - 2.5°C$$
$$T_{U1} = T_n + 2.5°C \quad (2)$$

Where, T_{L1} is the limit of comfort low temperature and T_{U1} is the limit of upper temperature. Then mark these on the 50% RH curve.

The corresponding sloping SET lines is constructed by determining the X-axis intercept TL and TU from

$$TL = T_{L1} + 0.023 \times (T_L - 14) \times AH50\,T_{L1}$$
$$TU = T_{U1} + 0.023 \times (T_U - 14) \times AH50\,T_{U1} \quad (3)$$

Where SET is standard effective temperature scale and $AH50T_{L1}$ is the absolute humidity (g/kg) at the RH50% level at the T_{L1} temperature and $AH50T_{U1}$ is the absolute humidity (g/kg) at the RH50% level at the T_{U1} temperature. These TL and TU will be the side boundaries for comfort zone.

The humidity limits (top and bottom) will be 12 and 4 g/kg respectively.

6.5.1 SUMMER THERMAL COMFORT ZONE OF KOREA

	Cooling Time in Korea	
	July	August
Mean Temperature	**22.8°C**	**23.4°C**

Establish the mean temperature of the warmest month:

August, mean temperature is 23.4°C

Find the neutrality temperature for both, from equation (1)

$T_n = 17.6 + 0.31 \times 23.4 = 24.8°C$
And the limits of comfort by equation (2)

Lower: $T_{L1} = 24.8 - 2.5 = 22.3°C$
Upper: $T_{U1} = 24.8 + 2.5 = 27.3°C$
Mark these on the 50% RH curve in the Psychrometric chart.

For the side boundaries take the AH for T_{L1} and T_{U1}, which are $AH50T_{L1}$ and $AH50T_{U1}$: 8.5 and 11.5 g/kg

Construct the corresponding sloping SET line by determining the X-axis intercept TL and TU from equation (3)

For $TL = 22.3 + 0.023 \times (22.3 - 14) \times 8.5 \approx 24°C$
For $TU = 27.3 + 0.023 \times (27.3 - 14) \times 11.5 \approx 31°C$
These TL and TU will be the side boundaries for comfort zone.

Draw the side boundaries.

Top and bottom boundaries are at the 12 and 4g/kg level in absolute humidity.

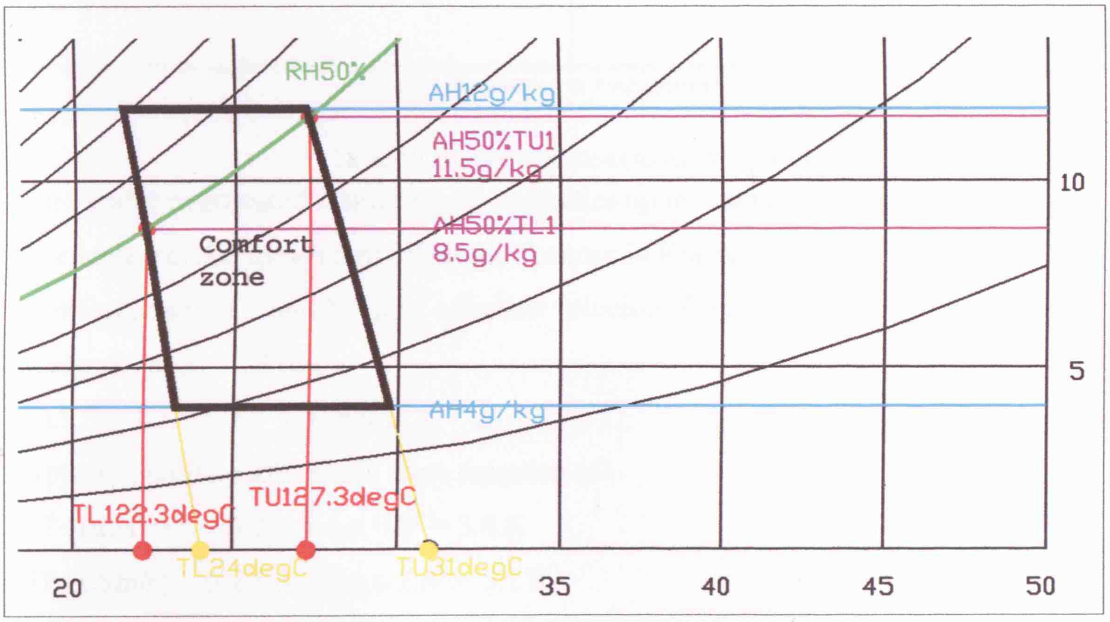


Figure 23. Summer Comfort Zone for Seoul

6.5.2 AIR MOVEMENT EFFECT ON THERMAL COMFORT ZONE [16]

Air movement accelerates convection, but it also changes the skin and clothing surface heat transfer coefficients (reduces surface resistance), as well as increase evaporation from skin, thus producing a physiological cooling, the apparent cooling effect of air movement (dT) can be estimated as

$$dT = 6 \times Ve - 1.6 \times Ve^2 \quad (4)$$

Where the effective air velocity is $Ve = V - 0.2$ and V is air velocity (m/s) at the body surface and the expression is valid up to 2m/s. Subjective reaction to air movement are represented in table 19.

Air velocity (m/s)	**Subjective reaction**
<0.1	Stuffy
0.1 to 0.2	Unnoticed
0.2 to 0.5	Pleasant
0.5 to 1	Awareness
1 to 1.5	Draughty
>1.5	Annoying

* Source: Introduction to Architectural Science

Table 19. Subject Reactions to Air Movement

But, under overheated conditions air velocities up to 2m/s may be welcome.

For instance. Air movement effect for summer in Korea, in relation to the August comfort zone for 1 and 1.5 m/s, effective velocities from

$Ve1 = 1 - 0.2 = 0.8$ m/s

$Ve1.5 = 1.5 - 0.2 = 1.3$ m/s

Apparent cooling affects dT from equation (4)

$dT\ (1m/s) = 6 \times 0.8 - 1.6 \times 0.8^2 = 3.8$ K

$dT\ (1.5m/s) = 6 \times 1.3 - 1.6 \times 1.3^2 = 5.1$ K

Limiting temperatures: $T_{Ul} + dT$

$Lt\ 1m/s = 27.3 + 3.8 = 31.1$

Lt 1.5m/s = 27.3 + 5.1 = 32.4

mark these on the 50% RH curve find the X-axis intercept TU1m/s and TU1.5m/s

from equation (3) : AH50%1m/s = 14.2g/kg and AH50%1.5m/s = 15.6 g/kg

For TU1m/s = 31.1 + 0.023 x (31.1 – 14) x 14.2 ≈37 ˚C

For TU1.5m/s = 32.4 + 0.023 x (32.4 – 14) x 15.6 ≈ 39˚C

and draw the boundary from the this intercept upwards from the 50% RH curve only for the lower half take half of this intercept the top limit is the 95% RH curve

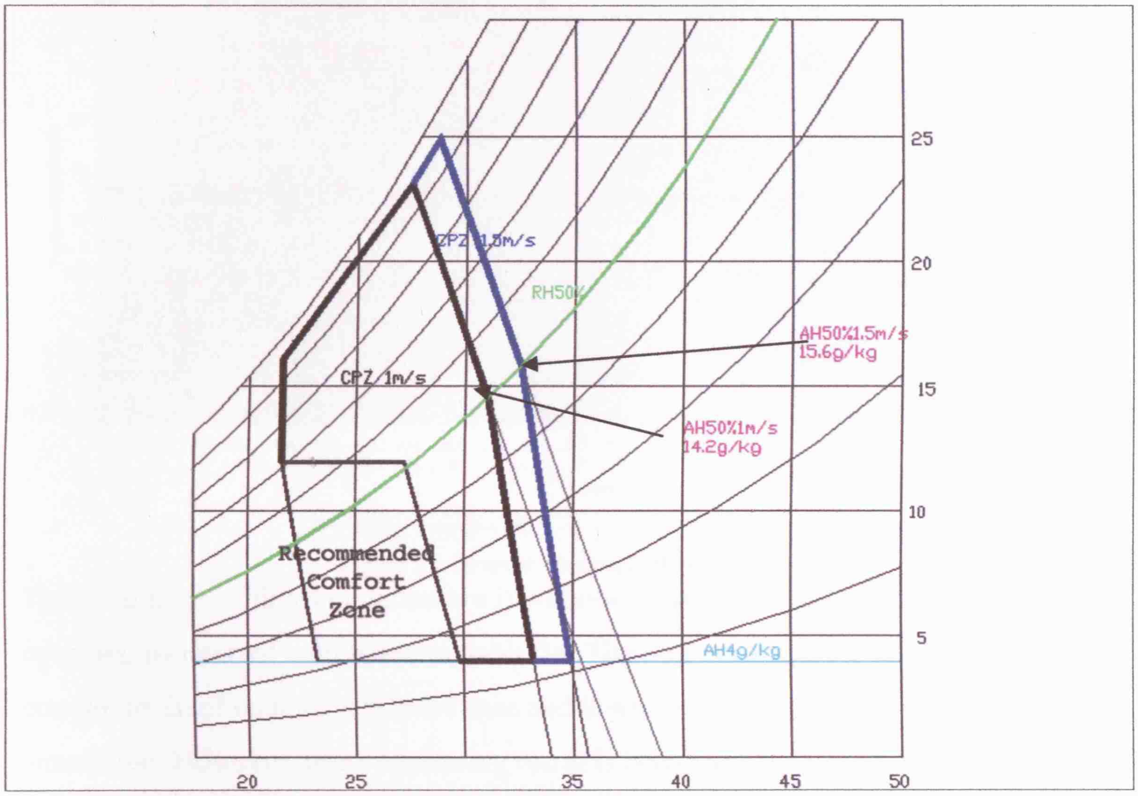


Figure 24. Air Movement Effect for summer August Comfort Zone for 1 & 1.5m/s

The figure 24 is the result of the air movement effect on recommended comfort zone. From this Psychrometric chart, when the air moved by 1m/s the boundary of the recommended comfort zone can be bold black line and the 1.5 m/s air movement effect shows bold blue line. These two bold lines are all about the physiological cooling.

6.6 RESULT AND DISCUSSION

6.6.1 INTERNAL CONDITION OF EXISTING BALCONY ON HOT STILL DAY

Figure 25 presents the internal condition of current Korean apartment balcony system compared with OA in a hot still day (day 211).

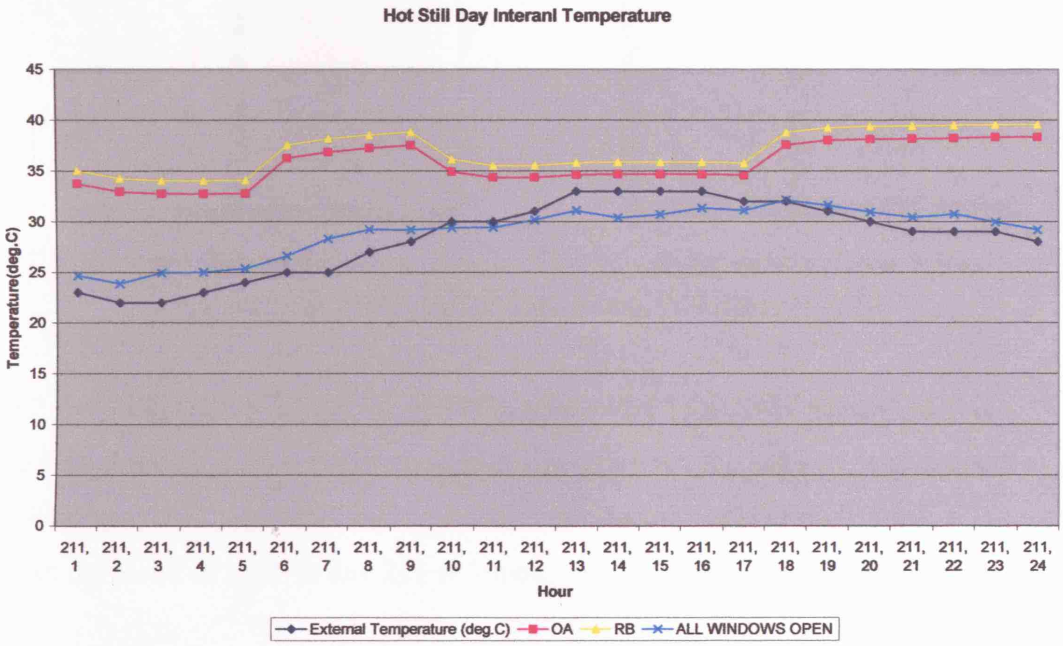
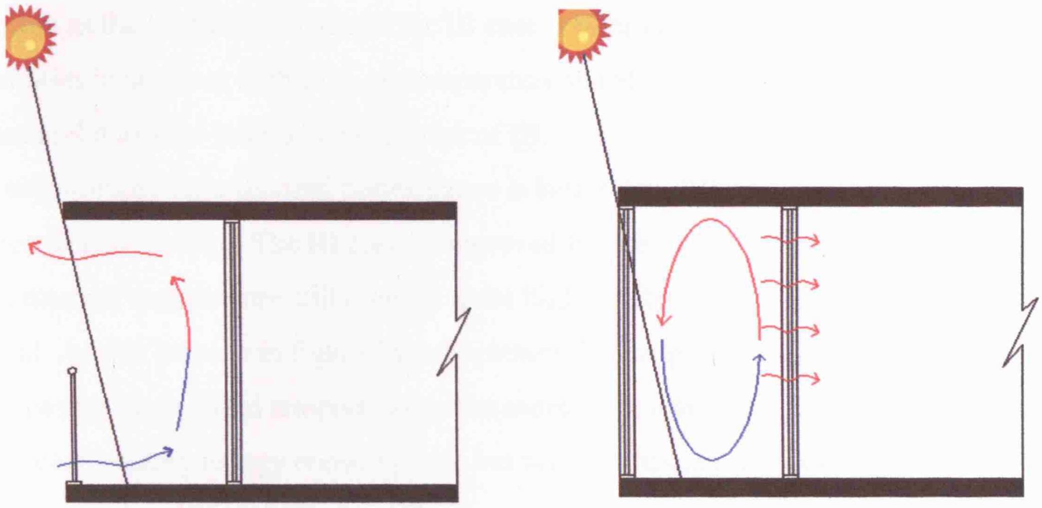


Figure 25. Internal condition of hot still day

The conditions of this simulation are i) without ventilation system except all window open and ii) internal gain based on table 14. The best performance under these conditions is, of course, ventilated case and it will be the bench mark of the rest of simulation. However, most interesting result is between RB and OA. In winter (figure 19), the temperature difference between RA and OA is almost 3°C; but, in a hot still day (day 211), the temperature difference is only about 1.2°C. Because as figure 26(b) explains as the air inside the balcony is heated by solar radiation, the heated air is not exhausted from the refurbished balcony, but remains stagnant. This heated air risen the air temperature of adjacent spaces such as living room and master bedroom in the current balcony, which is RB. According to the refurbished balcony heating load and internal condition results, refurbished balcony is very good at heating load reduction during heating time, but figure 25 RB case has an effect on internal temperature and raises the internal temperature and cooling load in summer time.



(a) the summer solstice in OA (b) the summer solstice in RB

Figure 26. OA and RB thermal performance of the summer solstice

6.6.2 INTRODUCE NATURAL VENTILATION IN KOREAN APARTMENTS

The first simulation is all about thermal characteristic of the balcony with natural ventilation system and ventilated apartment unit during summer night time. Figure 27 shows the result of test1 in day 211 at 10pm.

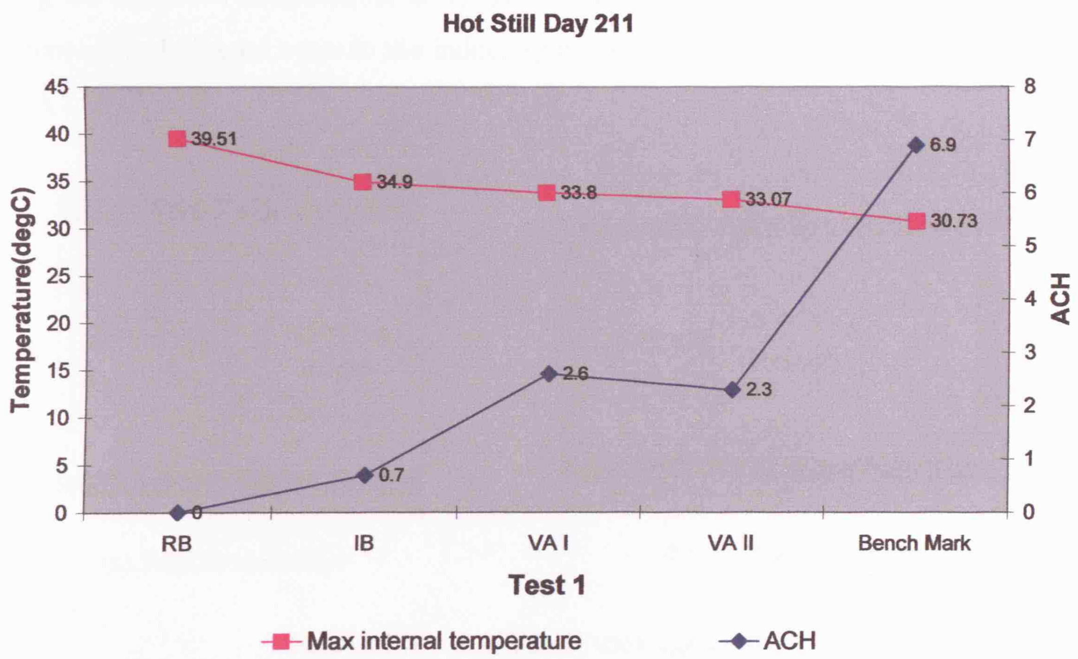
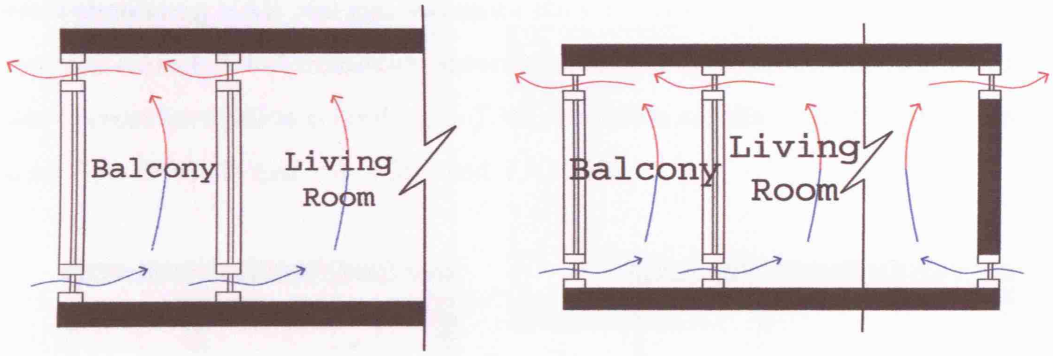


Figure 27. Part II results in Test 1

Figure 27 shows the temperature difference in various conditions of balconies and refurbished apartments. IB and RB case can not derive cooled outdoor air into indoor. Thus, both of the indoor ACH is 0 at night. But the internal temperature difference occurs as the heated air inside of the IB case is exhausted through natural ventilator facilities in summer night; the air temperature in balcony has fallen compare to RB case and it affects internal temperature of IB.

It is confirmed IB's thermal performance is better than RB by 4.6°C difference in internal temperature. The IB case is improved front balcony's thermal condition, but, the internal temperature still remains quite high, which is about 35°C during summer night. As can be seen in figure from 25, internal gains play very important role in increasing the internal temperature in the morning and at night. It is very helpful for reducing heating energy consumption; but very detrimental in cooling period.

Figure 27 shows that the best result in temperature decrease is VA II as expected. Although Even the VA II result is the best one, the internal temperature is still high at around 33°C in summer night. The most interesting result in test 2 is air change rate of VA I and VA II and internal temperature. Figure 27 shows that VA II's ACH is less than VA I by contrast with internal temperature. The temperature difference occurs as heated air inside of the VA I case is exhausted through one ventilator facilities which is facing outside and cooled outside air is delivered through one dampers. Although VA II's ACH is less than VA I, the VA II has one more inlet and outlet, which are facing the outside. The heated air in VA II is exhausted more to outside and cooled outdoor air is delivered more to the indoor space. Figure 28 shows the air movement in VA I and VA II.



(a) VA I air movement

(b) VA II air movement

Figure 28. Air Movement in VA I and VA II

6.6.3 CHANGE SIZE OF DAMPER

The test 2 improved on the VA II case by changing the size of the inlet and outlet. The changing size of the ventilated damper affects the internal temperature by changing air change rate. The result is presented in figure 29. The test 2 shows that the best case is VA II500. The internal temperature of VA II500 is more or less same as target temperature during summer night time. The size of the ventilated dampers is increased as the effect of internal gain is decreased.

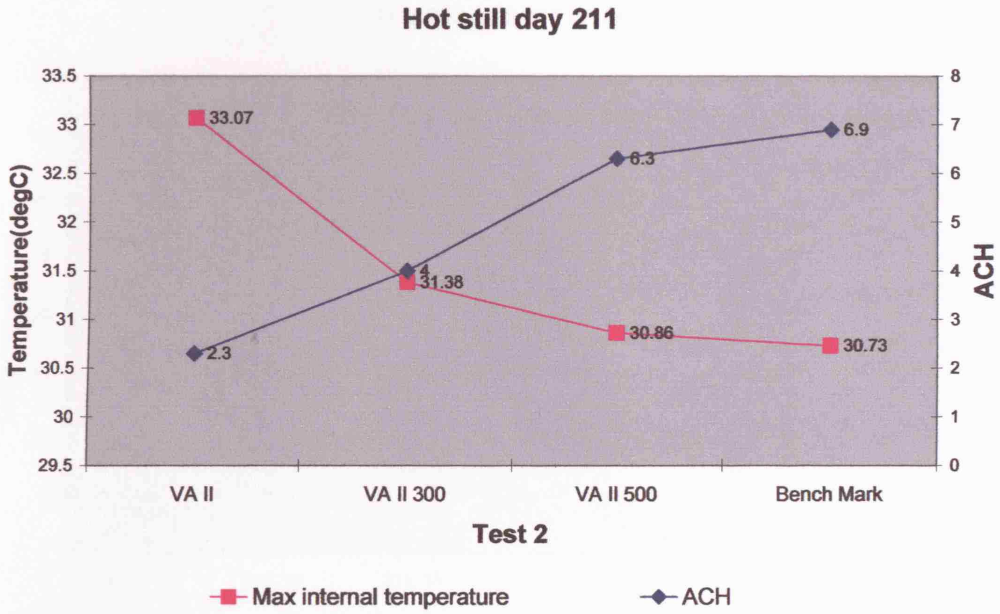
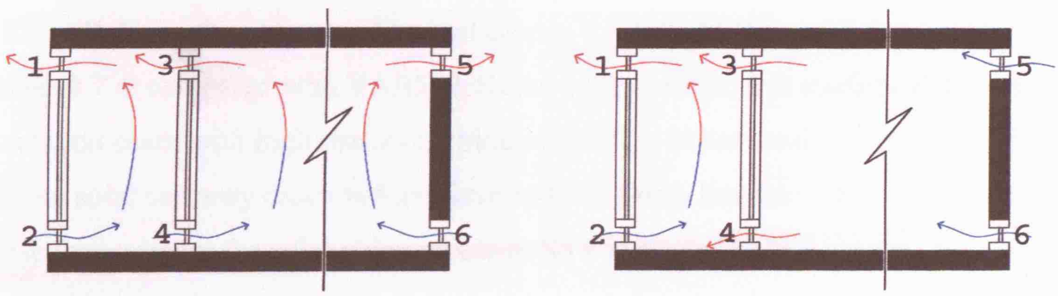


Figure 29. Part II results in Test 2

Before simulating VAII 300 and 500 cases stack effect in front balcony and indoor space was expected, but simulation shows stack effect in front balcony and the indoor space is cross ventilation according to TAS simulation results. Figure 30 represents the air flow in VA II and VA II 300 and VA II 500.



(a)VA II air movement (b) VA II 300&500 air movement

Figure 30. Actual air flow in VAII and VA II 300&500

Figure 31 shows the effect of night flush cooling on the internal temperature. It is observed for one week based on the hottest week in the TAS weather file. The base case for this simulation is RB case (not open windows all day long) and the comparing case is VA II 500 (opens all the dampers from 21pm to next day 08 am). From this result, it shows very clear evidences for night flush cooling is very efficient for control the internal condition for the apartment unit. From figure 31, the floor surface temperature difference between RB and night flush cooling unit is about 7.5°C.

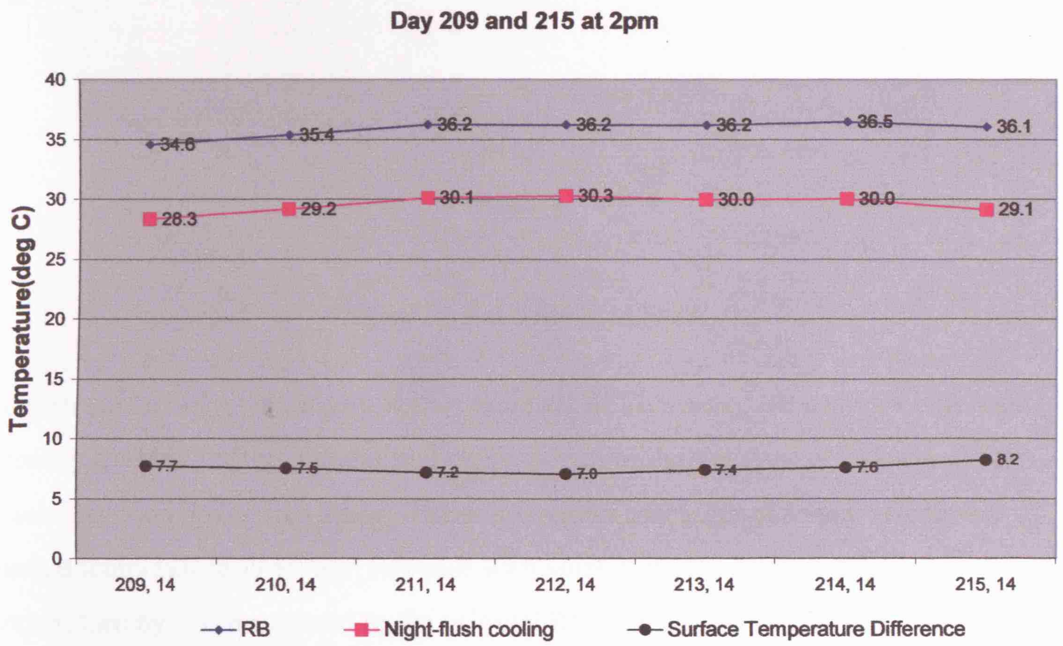


Figure 31. Night Flush Cooling Effect on Internal Condition

6.6.4 SOLAR CHIMNEY WITH VENTILATED APARTMENTS

Figure 32 shows how the solar chimney works under various conditions (from figure 21) and its effect on internal condition. Compared the mean temperature difference between RB and RB&SHH is more than 2°C in a hot still day at night. The worst case is RB with low solar chimney. The best case is VAII500&SHH and it decreased further 0.7°C compared with VAII500. Based on the results, it is confirmed that any simulation cases with high rise solar chimney produce better result comparing with without solar chimney cases and any invested cases with low rise solar chimney is worse than without the solar chimney cases. So it is needed to find out the optimum standard height of solar chimney in high rise apartments and furthermore, to study the effect of wall materials, volume of the solar chimney and the size of inlet and outlet ratio.

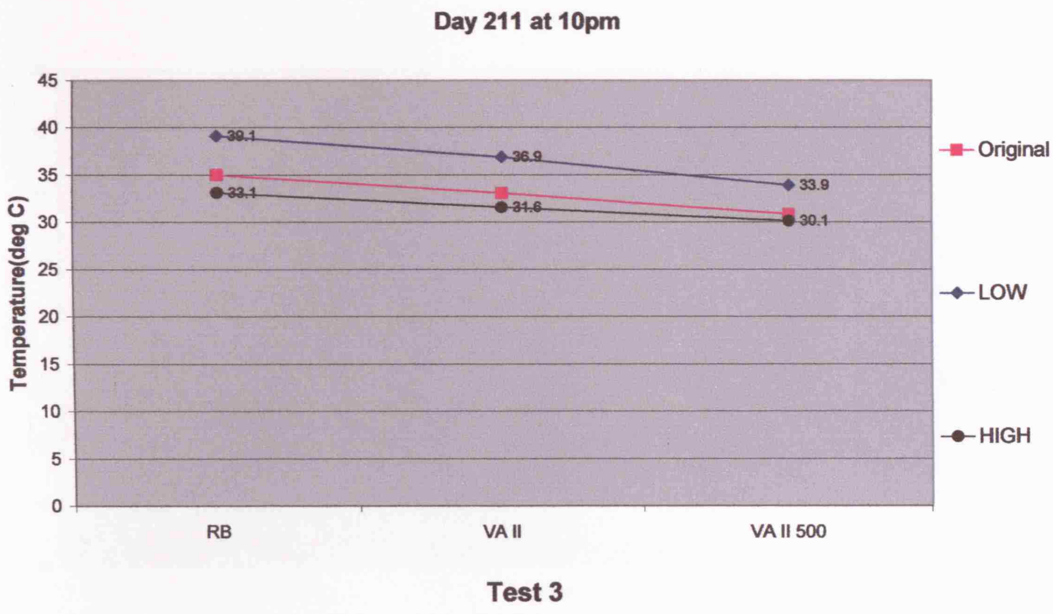


Figure 32. Part II results in Test 3

The extra simulation carried on within this part II. This simulation shows that solar chimney is able to affect the thermal performance under the current balcony system which is named RB in this study. The result shows that solar chimney affects the internal temperature in winter. RB case with solar chimney increases indoor temperature by 2°C compared to the original RB case. One of the Korean researchers studied about ventilated balcony's thermal performance [17] and in that paper it was found that during the day time, front balcony's temperature is higher than indoor temperature and therefore, it is possible to invite heated air from the balcony into the indoor, and thereby reduce heating load during the heating period. So, this simulation found simulation condition. Table 20 shows the operation of the ventilated dampers and the simulation result. Base case is RB without heating system and heat gains from internal gains.

		Windows operation					
		1	2	3	4	5	6
Base Case	RB	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Case 1	VAII500	CLOSE	CLOSE	**OPEN**	CLOSE	CLOSE	CLOSE
Case 2	VAII500	CLOSE	CLOSE	CLOSE	**OPEN**	CLOSE	CLOSE
Case 3	VAII500&SHH	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE

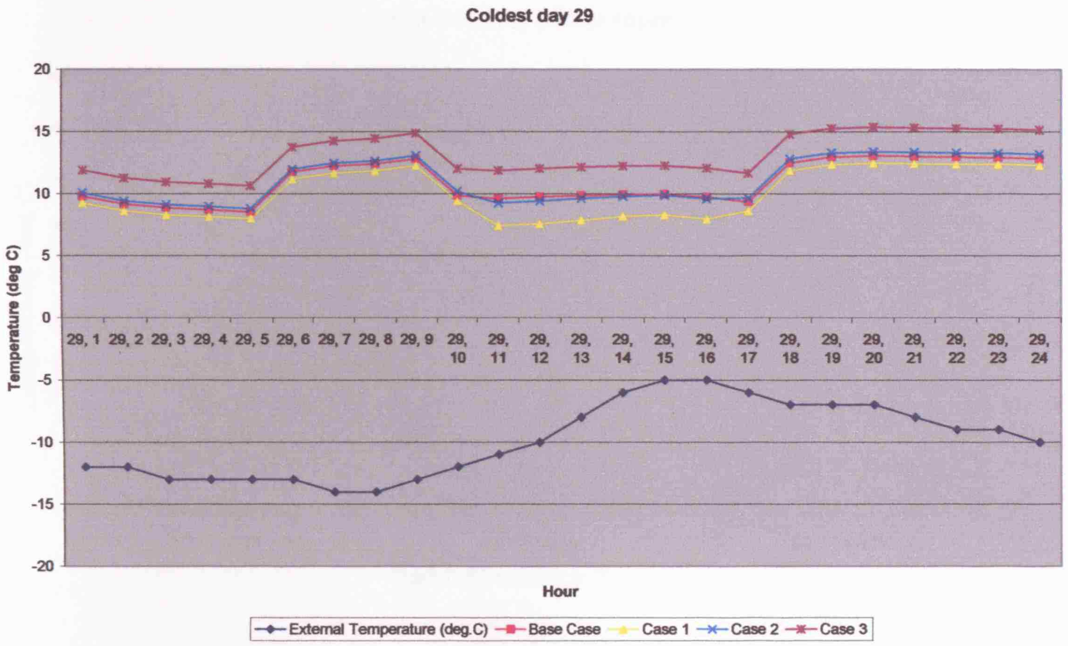


Table 20. Study of operating dampers and internal conditions

From the result, it checked that theory does not work and the suggestion case is the worst one which is case 1. Case 2 is a better than the base case during the night time rather than day time. The best is case 3 as expected. Table 20 shows that case 3 internal temperature increases by 2 °C due to the front balcony temperature rise by 2°C. Current Korean apartments are no insulation in balcony wall. Without solar chimney, the front balcony loses heat by side balcony wall conduction. On the other hand, internal temperature of the solar chimney reaches up to 60°C and then the side balcony wall is heated by hot air in solar chimney then the balcony air is heated by side balcony wall. The heated air in the front balcony affects indoor temperature by conduction and convection.

Figure 33 shows sums up all of nature ventilation simulation including the results of current apartment and the best one.

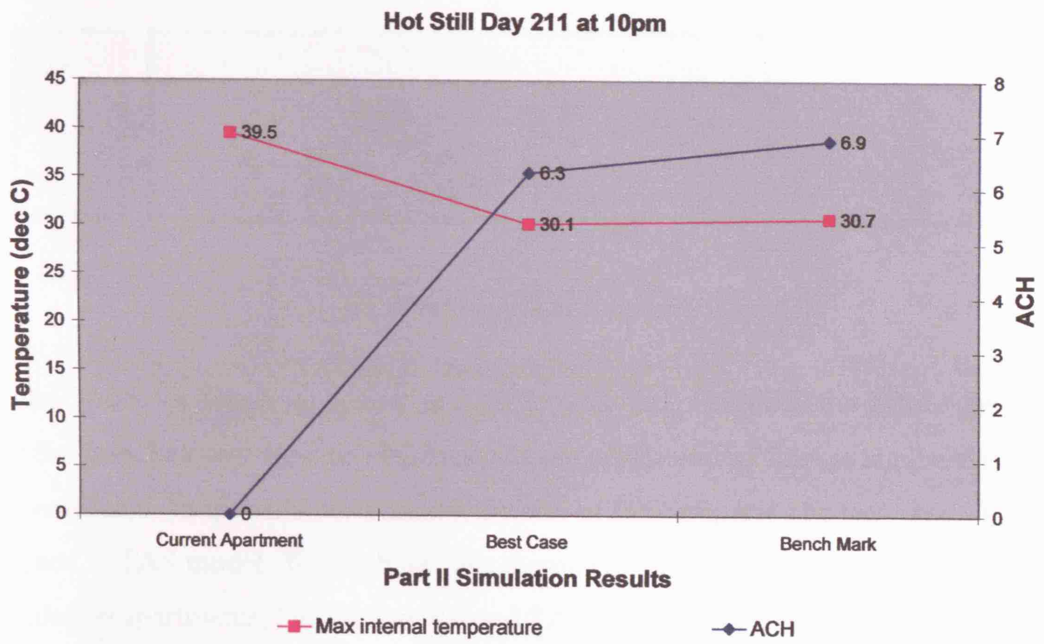


Figure 33. the result of the part II simulation

According to figure 33, it shows very clear result of current apartment and ventilated balcony's internal condition in day 211 at 10pm. The best case (VAII500&SHH) exceeds the bench mark temperature which is based on all windows being open all day. It also gives very strong evidence for using natural ventilation strategies in apartments during summer night time in order to reduce cooling load and electricity consumption.

6.6.5 TAS AMBIENS

Requires the input data for TAS Ambiens is derived from TAS model results and it is presented in table 21 and all the internal heat gains are from table 8. TAS Ambiens simulation was used to study the internal condition of day 211 at 10pm, which is the worst scenario of the natural ventilation simulation. TAS Ambiens was used to simulate two different part of the apartment which are the front balcony and the indoor space.

	Surfaces						
Temperature(deg C)	S1	S2	S3	S4	S5	S6	S7
	31	29	30	31	30	28	29.5
	Inlet					Outlet		
Dampers	2	3	4	5	6	1	3	4
Speed (m/s)	0.06	0.03	0.05	0.17	0.12	0.15	0.03	0.05
Temperature(deg C)	29	32	31	29	29	-	-	-
RH (%)	68	60	62	63	63	-	-	-

front balcony and internal space

Table 21. Input data from TAS model

Figure 34 shows the air movement and the internal temperature in the indoor space and the front balcony. Several simulations were performed by improving the design of the ventilated damper and customizing the size of the dampers. The best case was adapted in TAS model. To reach the best thermal performance of the natural ventilation apartments, the TAS model and TAS Ambiens interacted.

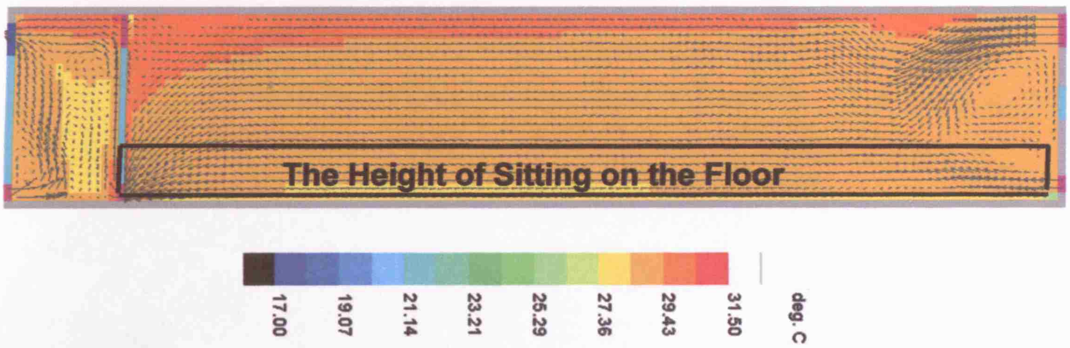
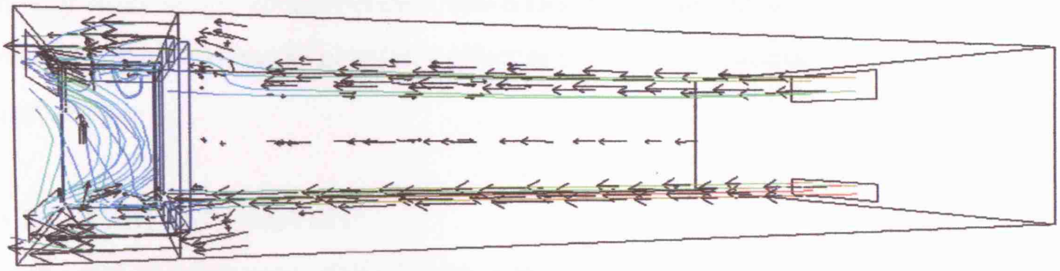


Figure 34. TAS Ambiens simulation result for front balcony with indoor

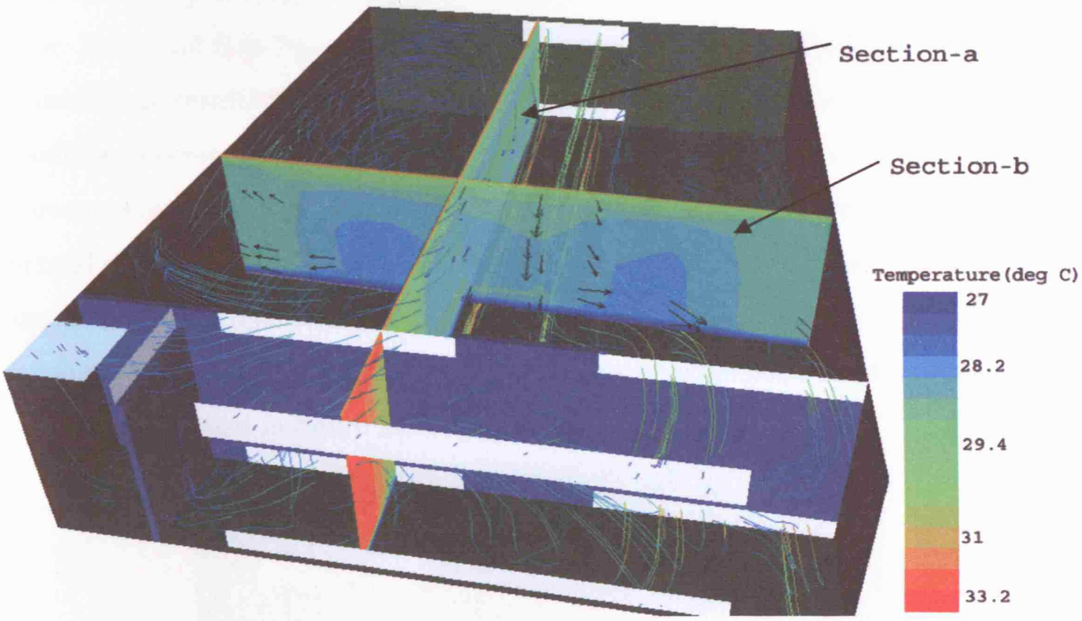
TAS Ambiens result shows that the internal temperature difference floor to ceiling is approximately 2˚C which is significant for Korean life style characterized by sitting and sleeping on the floor and which can indicate high difference in thermal comfort from sitting on the chair. The sitting height level from floor is marked on figure 34. Occupants sit on the floor where the ambient temperature is around 28˚C which is exact operating temperature of air conditioning system in Korean apartment. When only internal temperature is considered, it might be said the VHII500 and VAII500&SHH are enough to make internal condition to remain recommended Korean comfort zone. However, TAS Ambiens has limitation for simulation. It cannot simulate more than 1m deep cross section and divide one zone into two zones and figure 34 graphically combines the separate results of front balcony with indoor condition.

6.6.6 QuickSTREAM

To cover TAS Ambiens limitations used other CFD simulation tool, QuickSTREAM is used. All the input data for the QuickSTREAM is the same as the data used in TAS Ambiens. Figure 34 is presented result from QuickSTREAM.



(a) Section : air flow in Korean apartment



(b) 3D : air flow in Korean apartment

Figure 35. The result of QuickSTREAM

The result of 3D CFD (a) shows that most air comes from north façade inlets and flow toward south façade outlets. The front balcony has lots of air movement due to the effect of 5 inlets and 2 outlets. The air movements in indoor place, the centre of indoor space has very strong air flow toward front balcony by cross ventilation. Figure 35 shows internal air movement and temperature difference form floor to ceiling. In the indoor space, the air is circulating equally in the rest of spaces and with good mixing. The internal temperatures (section-a) are almost the same as TAS Ambiens result which is around 28°C. Section-b presents the internal temperature of sitting position which is in the middle of the living room and the master bed room.

But the results disagree with TAS Ambiens result which is in front balcony's internal temperature. According to the TAS Ambiens result, the balcony's temperature reached around 31°C, but the QuickSTREAM result shows internal temperature reached up to 33°C. It might be said the reasons of difference is that TAS Ambiens can only study single zone whereas QuickSTREAM simulates all the internal spaces. Thus TAS Ambiens hardly simulates effect of next zone's internal conditions by adjusted zone.

6.6.7 THERMAL COMFORT

The thermal comfort zone of the Korean summer was plotted in section 6.5.1. From TAS simulation results, the internal condition of the Korean apartment during summer night time (July to August) is plotted on the Korean summer recommended comfort zone. The result is in figure 36. The green points show the result of AVII500&SHH which is best result of this paper and the other points are current apartment's internal conditions during summer night. Before looking at the air movement effect on the Korean recommended comport zone, the results of best case are almost out of the thermal comfort zone. However, the best results are closer to comfort zone than current apartment results. It is expected that when air movement is introduced in summer, the best case's results will be within the recommended comfort zone. The result is represented in figure 36.

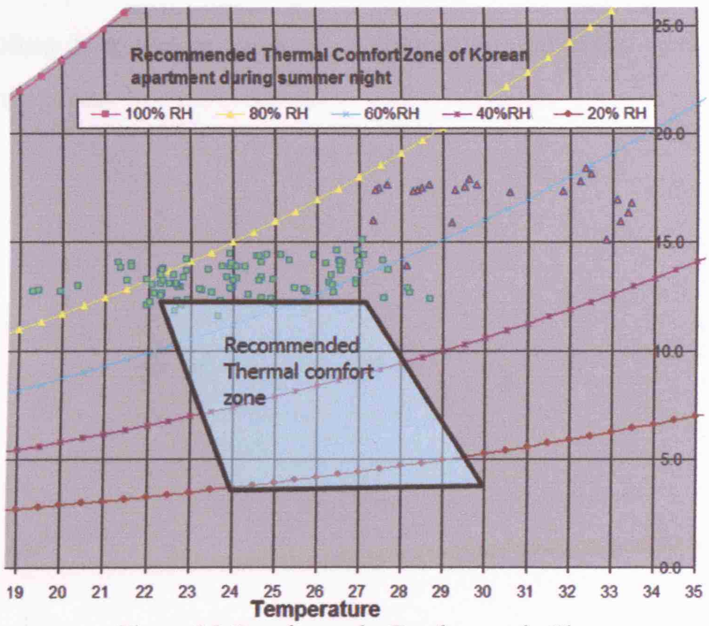
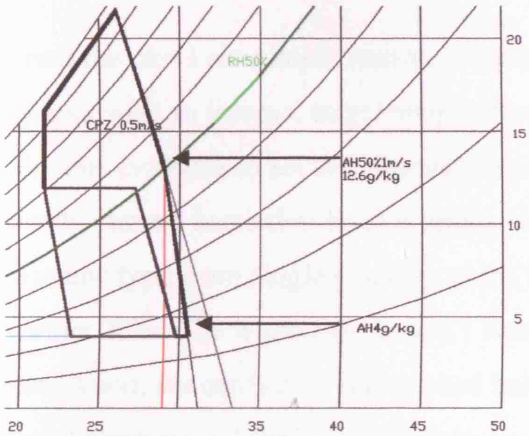
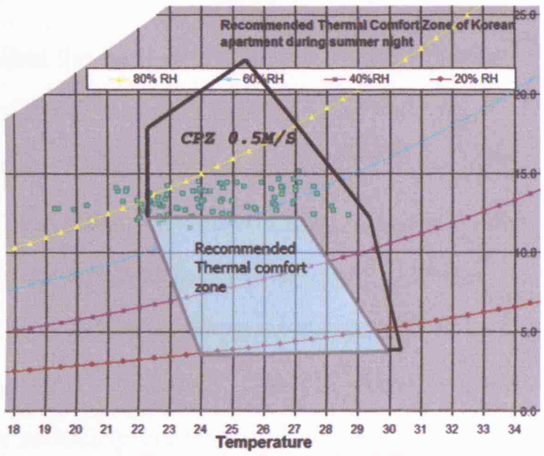


Figure 36. Results on the Psychrometric Chart

The mean air velocity of summer night time in VAII500&SHH case is about 0.5m/s. Section 6.5.2 table 19 shows air velocity from 0.2m/s to 0.5m/s to be pleasant. Based on the 0.5m/s air movement, most of the best case's results are placed on 0.5m/s CPZ (Control Potential Zone), but some of the results, which is in early morning, fall outside the 0.5m/s CPZ (temperature from19 to 22.5°C and RH from 50 to 85%). To solve these cases, the apartment will be needed to close the ventilated dampers or to heat the indoor air.



(a) o.5m/s air movement effect CPZ



(b) result of 0.5m/s CPZ

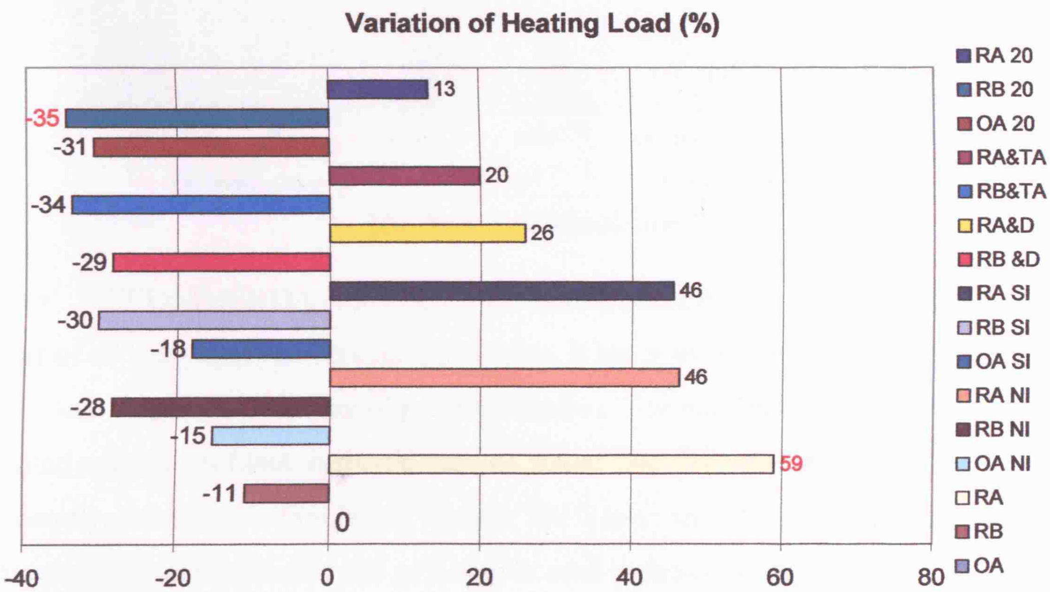
Figure 37. 0.5m/s CPZ in Korean apartment

Although some of the results fall outside of the 0.5m/s CPZ, it does not mean that natural ventilation strategies can not be adapted in Korean apartments. The ventilation strategy gives very positive and strong evidence that Korean apartments should use it for passive cooling strategies such as night ventilation and night flush cooling according to this paper.

7. CONCLUSION

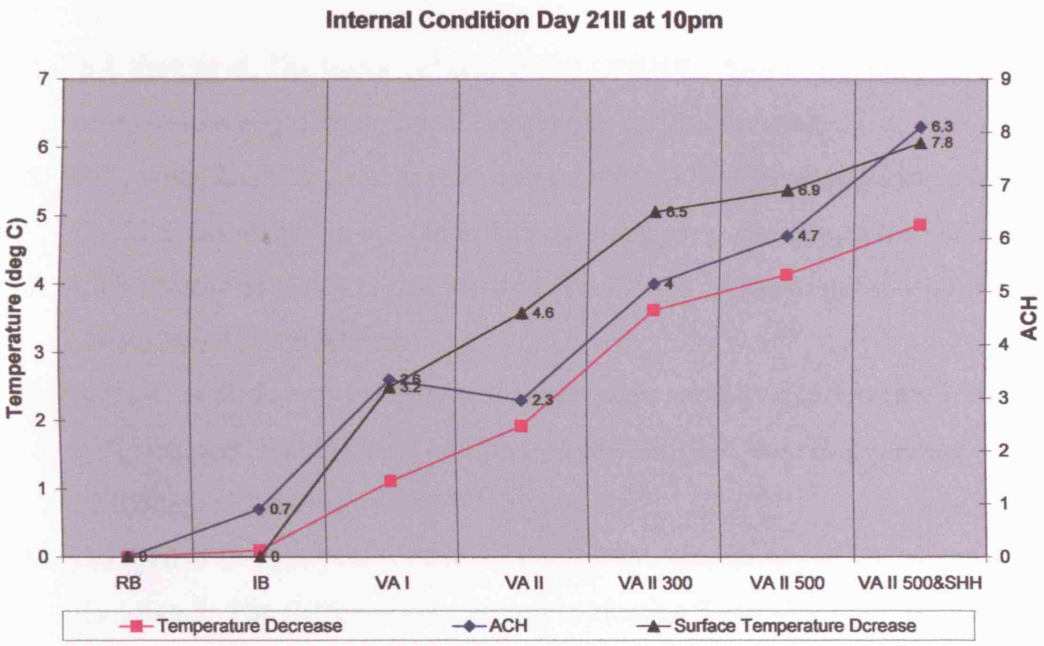
This paper has investigated two main topics. The first one is about current balcony system's thermal characteristic and how it affects the heating load and the energy consumption of Korean apartment. Secondly, how current balcony system performs during summer with design changes to improve natural ventilation at night and its impact on air conditioning.

From the part I simulation results, it shows that the best result is refurbished balcony system with an internal target temperature of 20˚C which is named RB20 giving obvious evidence to set the internal temperature at 20˚C rather than 24˚C. Base on the result, current insulation level is appropriate for reducing heating load. Changing the window type from single glazing, which is in balcony sash, to double will reduce further 20%. The worst case in part I simulation is RA. To sum up the part I simulation, we confirmed refurbished balcony has a benefit in reducing heating load and the easiest and the most efficient way of reducing heating load in current apartment (RB) is to set the internal temperature at 20˚C. RA case must be avoided in view of energy conservation as well as structural problem.



The Result of Simulation I

In the second part of the simulation, it was shown that, in a Korean apartment unit, it is possible to use natural ventilation strategies during the summer night time to reduce PAC's operating hours. In this simulation the best result is ventilated apartment with 500mm upper damper with high rise solar chimney, which is named VAII500&SHH in this paper. The best case exceeds the bench mark temperature which is based on all windows being open all day. The CFD result shows that during the night time Korean apartment unit can be within 28°C around the sitting height level from the floor. The psychometric chart shows that the introduction of air movement can bring almost all results from AV II500&SHH within the recommended comfort zone of Korean summer.



The Result of Simulation II

- RECOMMENDATION FOR FURTHER RESEARCH

First of all this paper has no actual field data, it has some of the Korean apartment data, but it comes from some of previous studies. For the further studies which are related with this subject, it should base on actual data from real apartments unit. Secondly, this study's simulation weather file is base on 1984 data. It is recommended that a more current weather file of Korea is used in future study.

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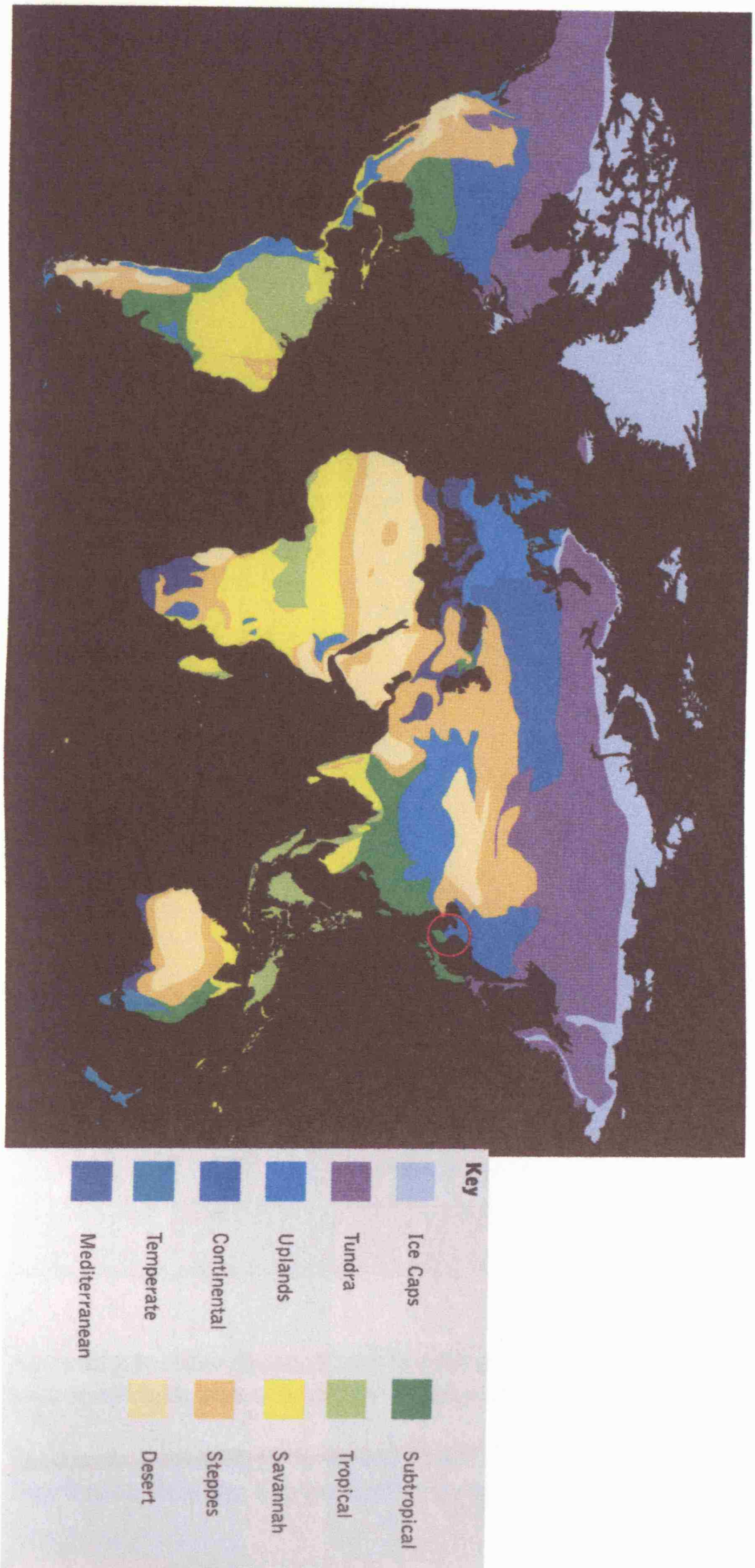
2. KPA : Korea Petroleum Association, http://www.oil.or.kr
3. KMA : Korea Meteorological Administration, http://www.kma.go.kr
4. KPX : Korea Power Exchange, http://www.kpx,or,kr
5. QuickSTREAM : http://www.quickstream.jp

APPENDIX 1-1


Key
Ice Caps
Tundra
Uplands
Continental
Temperate
Mediterranean
Subtropical
Tropical
Savannah
Steppes
Desert

APPENDIX 1-2

ENERGY-SAVING MEASURES BY GLOBAL REGIONS

Importance is rated from 0 to 7 or from pale blue to scarlet.

CLIMATIC ZONES

PASSIVE COMFORT MEASURES	ACTIVE COMFORT MEASURES	Ice Caps	Tundra	Uplands	Continental	Temperate	Mediterranean	Subtropical	Tropical	Savannah	Steppes	Desert
Natural Ventilation		0	0	1	4	6	6	7	7	7	7	7
	Mechanical Ventilation	5	5	3	3	3	4	5	6	6	6	6
Night Ventilation		0	1	2	3	5	6	7	7	7	7	7
	Artificial Cooling	0	0	0	1	1	3	5	5	5	5	6
Evaporative Cooling		0	0	0	1	2	3	2	2	5	6	7
	Free Cooling	0	0	0	4	3	5	6	6	7	7	7
Heavy Construction		3	4	4	6	5	6	2	2	3	5	6
Lightweight Construction		3	3	2	2	3	3	5	5	6	4	4
	Artificial Heating	7	7	7	7	6	4	0	0	2	4	1
Solar Heating		2	3	6	6	7	6	0	0	2	3	0
	Free Heating	7	7	7	6	6	5	0	0	0	3	0
Incidental Heat		6	6	6	5	5	4	0	0	1	2	0
Insulation/Permeability		7	7	7	7	6	5	0	0	1	3	4
Solar Control/Shading		0	1	3	4	5	6	6	6	6	7	7
	Artificial Lighting During Daytime	6	6	4	4	4	3	3	3	2	2	2
Daylight		6	6	6	6	6	6	5	5	5	4	4

Key

0 No Importance — 7 Very Important

ENERGY-EFFICIENT MEASURES WHICH ARE CONSTANT WHEREVER THE BUILDING IS LOCATED

Embodied, Grey and Induced Energy — **Comfort Management** — **Energy Generation**

Appendix / Architecture and the Environment

According to these figure, Korea is subtropical region. The appendix 1-2 recommends subtropical area uses natural ventilation and night ventilation.

Reference: David Lloyd Jones and Tadao Ando. Architecture and the Environment Bioclimatie Building Design, 1998, Appendix 244-247.

APPENDIX 2
CARBON DIOXIDE CONSUMPTION

Some energy calculations were based on actual data and were estimated using TAS by running the building for Korean heating time.

Delivered fuel	**Carbon emission factor (kgC/kWh)**
Natural gas	0.053
LPG	0.068
Biogas	0
Oil	0.074
Coal	0.086
Biomass	0
Electricity*	0.113
Waste heat	0
* This is estimated average figure for grid-supplied electricity for the period 2000- 2005. ** Source : Part L2 2002, Table 6, P.18	

Heating energy

Energy used for heating

- Unit heating 7,227.78 kWh
- Central heating 7,802.78 kWh
- District heating 11,280.56 kWh

Carbon Consumption

Assumed Natural Gas is the form of fuel

Figure above taken from Part L2 2002

Natural Gas = 0.053 kgC/kWh

- Unit heating 7227.78 kWh x 0.053 = 383.1 kgC
- Central heating 7802.78 kWh x 0.053 = 403.6 kgC
- District heating 11280.56 kWh x 0.053 = 597.9 kgC

Carbon dioxide consumption

Total CO_2 consumption from gas

- Unit heating 383.1kgC x 12/44 = 150 $kgCO_2$
- Central heating 403.6kgC x 12/44 = 158 $kgCO_2$
- District heating 597.9kgC x 12/44 = 209 $kgCO_2$

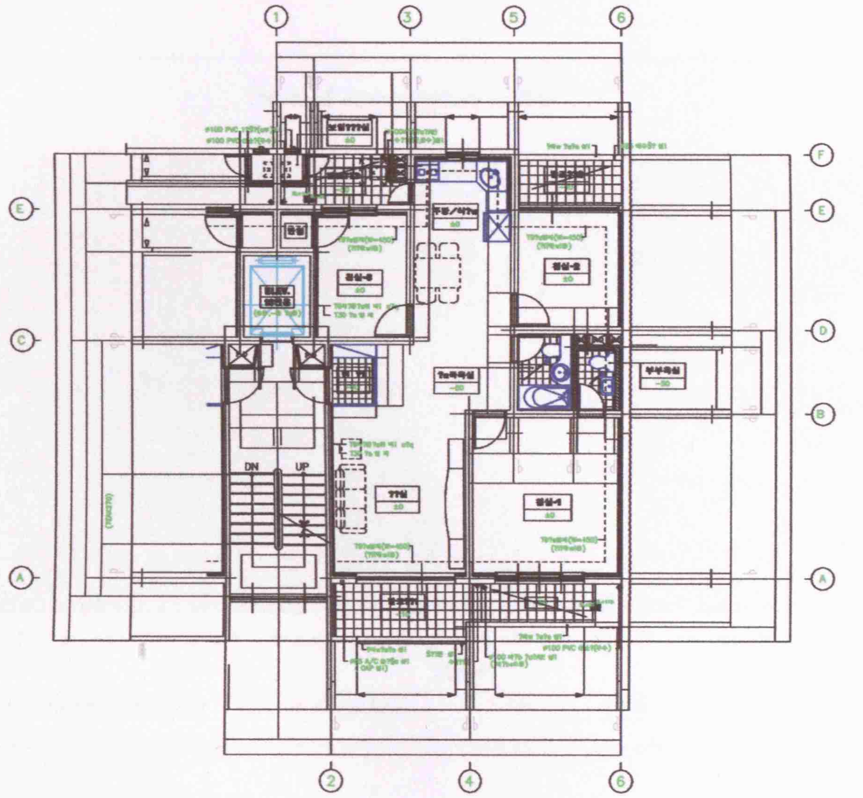
Total CO_2 consumption from electricity

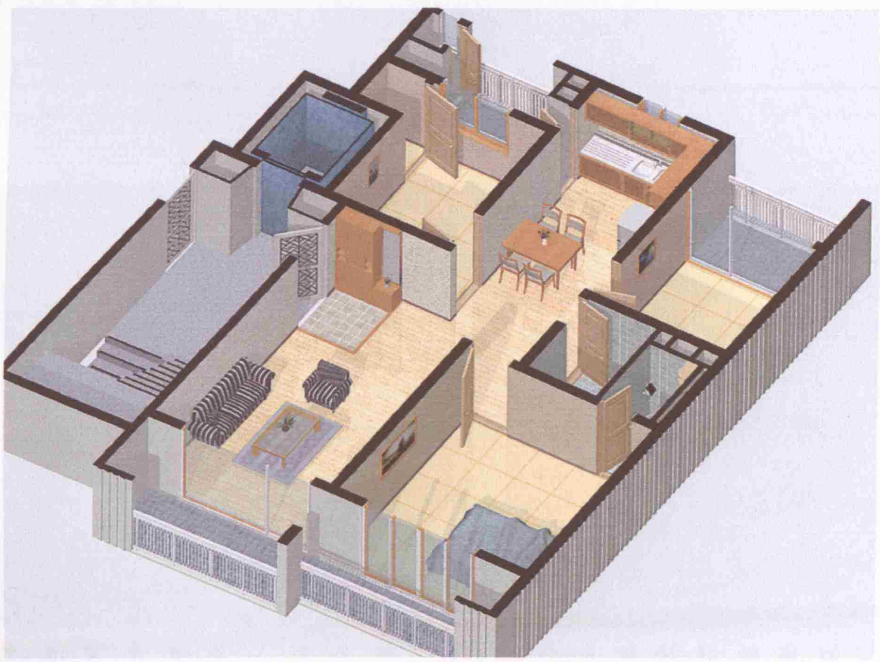
	Humidifier	Electric Heater	Electric Blanket	PAC	Electric Fan
Electricity Consumption	50,255	211,735	102,672	437,835	35,872
CO_2 Emission	1.6	6.5	3.2	13.5	1.1

*Unit: hr, Wh, and $kgCO_2$/year

APPENDIX 3

Actual Korean apartment plan and 3D Image

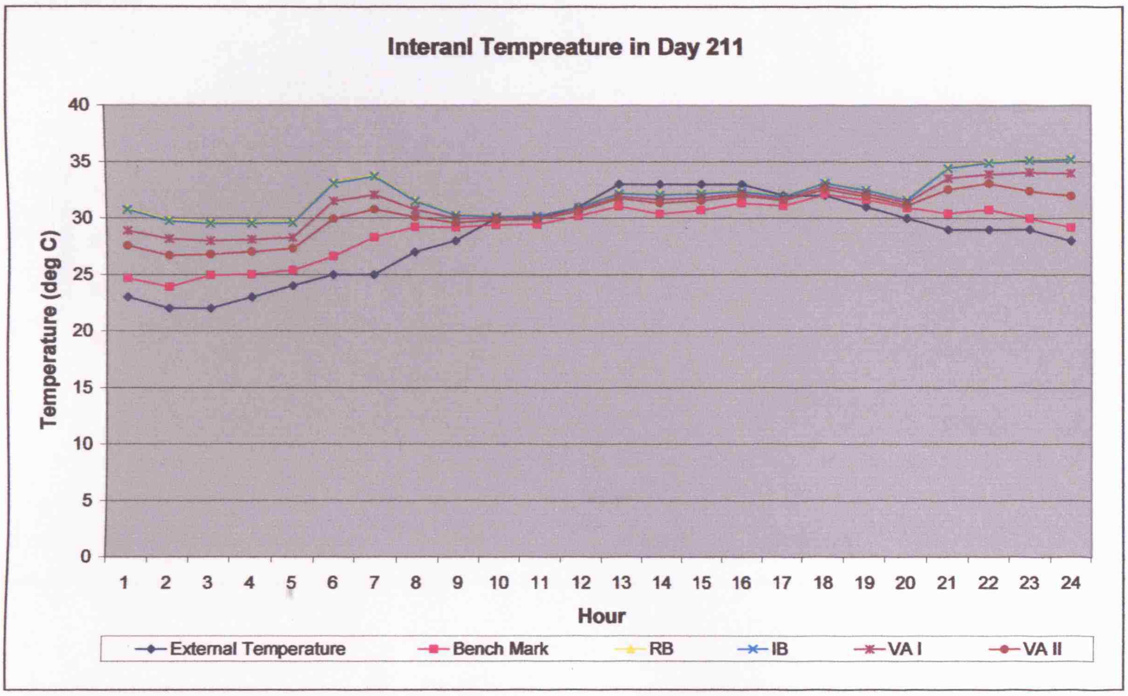




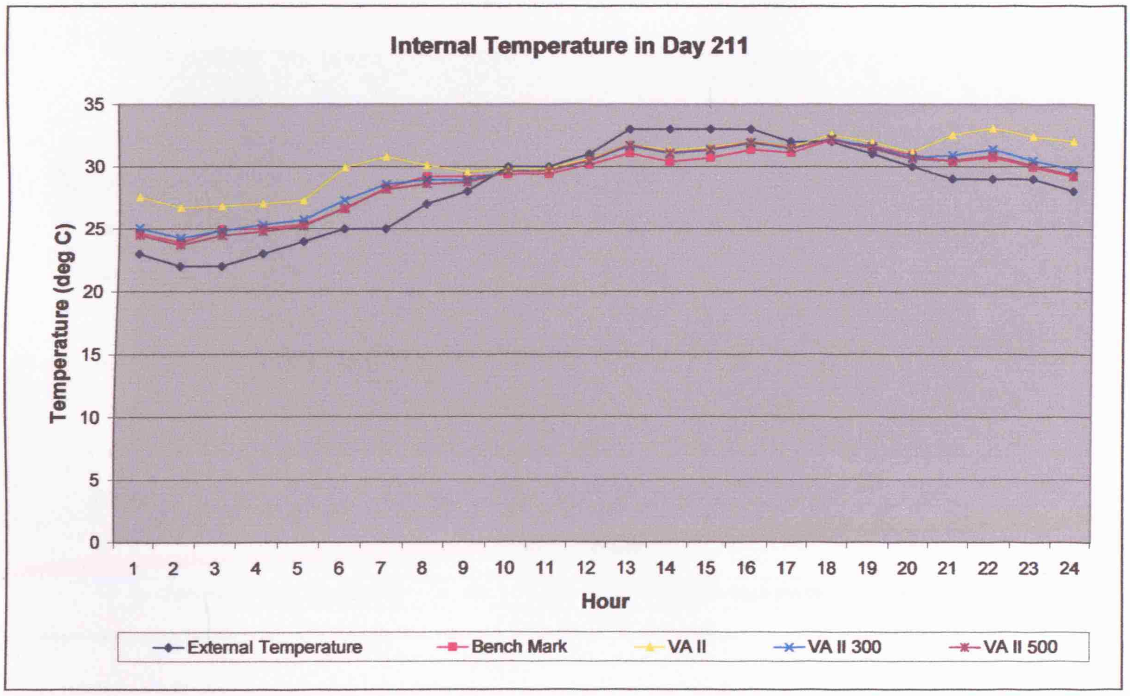
This image shows original apartment unit in Korea. Before refurbished balcony, the front and behind balcony does not install any sash.

APPENDIX 4

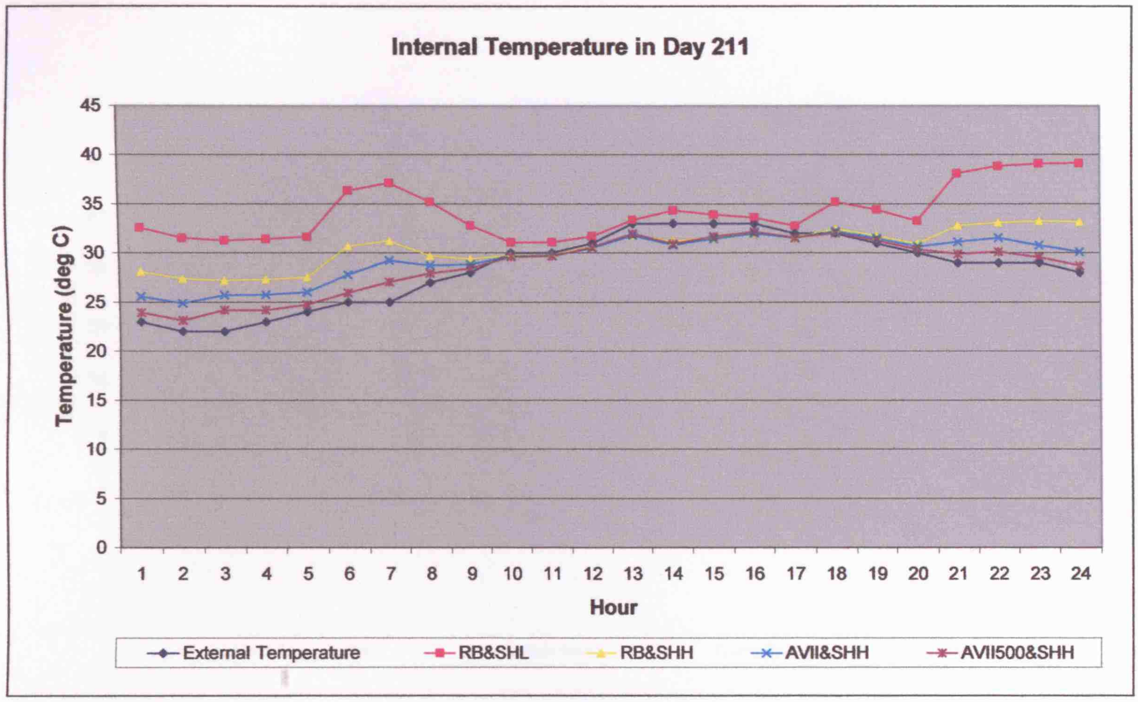
- **PART II TEST I RESULT**



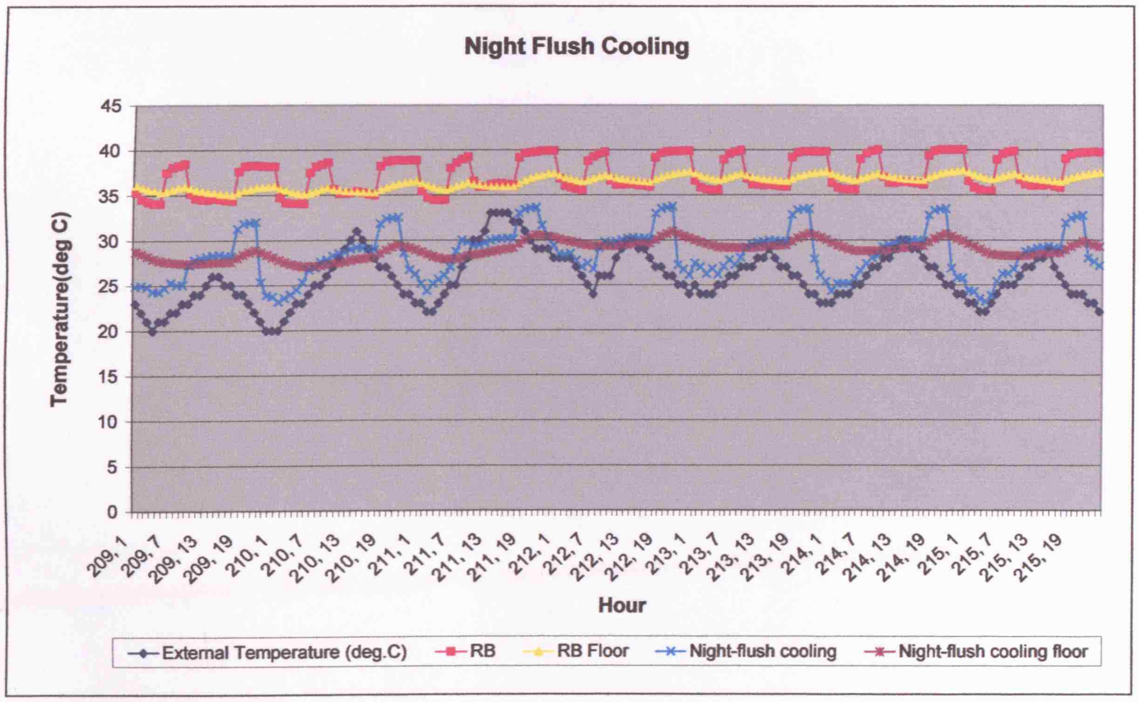
- **PART II TEST II RESULT**



- **PART II TEST III RESULT**



- **NIGHT FLUSH COOLING RESULT**



- **VENTILATION STRATEGY RESULT**