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SUMMER INDOOR CLIMATE AND RESIDENT'S BEHAVIOR IN HIGHLY INSULATED HOUSES IN JAPAN

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INTRODUCTION

The object that per capita CO_2 emission after 2000 shall be stabilized on 1990 level, has been set in Japanese action program to arrest global warming. In the program, the promotion of houses with high energy efficiency, such as highly insulated house or passive solar house, is included as one of the potential countermeasures to save unrenewable energy.

As the first step for the promotion, the notification relating to energy conservation for houses was revised in February 1992, in which the insulation standard of new houses is raised and the concept of airtight house is newly introduced in order to decrease heat loss by infiltration.

In this paper, summer indoor climate, annual energy consumption and other factors which were observed in early examples of the highly insulated and airtight houses in Japan will be discussed.

BACKGROUND OF RESEARCH

From the view point of some Canadian, indoor climate of Japanese houses especially in Winter might seem to have unacceptable low temperature. In fact, it is not difficult to observe temperature lower than "comfort zone", during occupancy. It can be said that the tendency to accept lower temperature in houses (except for northern area such as Hokkaido) is mainly due to Japanese climate more moderate than Canadian or Scandinavian climate, rather than due to lack of residents' consciousness to arrange living environment comfortable. Japanese traditionally find a pleasure in relationship with climate, and such cultural aspect might contribute to acceptance of rather cold or hot indoor climate.

However, if there is possibility to build more comfortable indoor climate with less or same amount of unrenewable energy and reasonable cost, new technology such as highy insulated airtight house with appropreate appliances, should be developped, tested and promoted.

The highly insulated airtight house with mechanical ventilation system (specific leakage area is less than $5cm^2/m^2$(floor area)) has become one alternative as energy conservative and high quality house in Hokkaido where Sapporo is located. Its winter indoor climate has obtained a good reputation and there is tendency that it becomes popular in the near future. In this study, its summer indoor environment, residents' responses and annual energy consumption was investigated.

SUBJECTS OF THIS STUDY

Five houses with specific air leakage area much smaller than $5cm^2/m^2$ (floor area) shown in Table 1 were investigated. All of them are built in Sapporo of which monthly average temperature is drawn in Figure 9. The climate of Sapporo belongs to the subarctic zone. They were built by popular and reliable builders. Mean floor area and air volume are $161.4m^2$ and $371.1m^3$, respectively. As examples, the plans of House-HY and House-ST are shown in Figure 1. The numbers of family member are from 2 to 4 persons, and the age of householders is 40s or 50s. All of them have central heating systems. The ventilation systems installed in them are categorized into type-A and type-B, whose schematic diagrams are in Figure 2. Type-A is balanced supply and exhaust system with a heat recovery ventilator, while type-B is exhaust only system.

RESULT OF QUESTIONNAIRE

Measurements and questionnaire were done in summer of 1991. Some results from questionnaire are shown in Figure 3(a), 3(b) and 3(c). About 80% windows are not always closed and are sometimes open mainly during the daytime (Figure 3(a)). The primary reason why residents open windows in summer is lowering temperature or ventilation cooling. While opening windows is necessary for thermal comfort, air-conditioner is needed only by one among five subjects, and electric fan is needed by two (Figure 3(b)). A certain survey shows that the percentage of households owning an air-conditioner in Sapporo is lower than 5%. In case of highly insulated airtight house, necessity for air-conditioner does not seem to become higher.

All of ventilation systems are operating at all times in summer (Figure 3(b)). Subjective assessment on air quality, quietness, brightness and condensation problem are shown in Figure 3(c). There was no negative assessment at all.

TEMPERATURE

The temperature and humidity measurement was made at 6 or 7 points for each house, with data collector units. The unit includes a resistance thermometer of ±3 ℃ accuracy, a relative humidity sensor of ±3% accuracy and memory which can store up to 2880 data. In this case, measurement interval was 10 minutes and measurement through up to 10 days was possible.

Figure 4 is an example of temperature observation. According to meteorological data of average year, the last eleven days of July is the hottest time of year in Sapporo, and the average of daily maximum and minimum temperature during the time of average year are 26.9 ℃ and 18.4 ℃, respectively. The measurement was carried out from July 24 to July 31 in 1991. The average of daily maximum and minimum temperature during our measurement were 25.5 ℃ and 19.2 ℃, of which deviations from average year were -1.4 ℃ and +0.8 ℃, respectively. Since the deviations are not large, the results of this measurement can be considered as typical data of the hottest season in Sapporo.

The relations between outdoor and indoor temperature are shown in Figure 5. Each point in Figure 5 is average temperature of every six hours from 0 a.m. The average indoor temperature above 29 ℃ is hardly observed (only 3 points of House-HY and 4 points of House-KH), and residents seem to live under thermally acceptable condition with openable windows and an electric fan when necessary.

HUMIDITY

Two examples of observed deviation of indoor humidity ratio from outdoor are shown in Figure 6(a) and 6(b). In either case, both deviations to plus and minus sides were observed, though the plus deviation was more frequent.

Figure 7 shows the relation between the deviation of temperature and humidity ratio. There is generally positive correlation, since both deviations of temperature and humidity ratio decrease in daytime and increase in nighttime. The deviation of humidity ratio was mostly in the range from -1g/kg(DA) to 2g/kg(DA).

If the ventilation system did not perform well, vapor emitted from hot water, human body, food and so on would accumulate indoors and make humidity ratio much higher. Except for the only data in bathroom which was obtained in House-HY, no considerable accumulation of vapor was observed. Unfortunately, we did not make measurement in bathroom of other four houses. House-HY has type-A ventilation system (balanced supply and exhaust system with a heat recovery ventilator), and it is reported that measured exhausted air volume from the bathroom is $25m^3/h$ (ΔP=-0.47 mmAq), when the normal operation of the ventilation system with all doors and windows closed[1)]. It can be seen in Figure 8 that after vapor emission ceasing relative humidity drops immediately due to ventilation system. Though relative humidity in the bathroom during occupancy increases up to 98%, average relative humidity through six day measurement is 76%, which seems to be satisfactory in order to keep the bathroom dry.

AIR QUALITY

In order to examine ventilation performance, CO_2 concentration in each living room and bed room was measured by another researcher[1]. The measurement was done at 10-minutes intervals during the same period as the temperature and humidity measurement mentioned above, with infrared CO_2 analysers and automatic data-collectors. As for living rooms, no CO_2 concentration over 1000ppm was observed, and the maximum was 980ppm in House-NE. It is because living rooms of five houses have large air volume and windows of these rooms were frequently left open during occupancy.

On the other hand, as for bed rooms, CO_2 concentration up to 1780ppm was observed in House-KH, although daily average CO_2 concetration in all bed rooms measured were below 1090ppm. The CO_2 concetration in bed rooms has a tendency to increase gradually since the beginning of occupancy, to reach an equilibrium after about four hours, and to decrease immediately after occupants' rising. The average CO2 concentration during the nighttime (6p.m.-6a.m.) was found to be from 390ppm to 1170ppm. Therefore, it seems that the ventilation systems of five houses operated appropriately and that contaminants represented by CO_2 were exhausted from bed rooms without any serious problem.

ENERGY CONSUMPTION

In the questinnaire, residents were asked to fill out energy audit. In Figure 9, monthly energy consumption (in case of oil, purchased volume base) and average outdoor temperature in Sapporo are shown. To calculate secondary energy consumption, coefficients of 8900kcal/liter (37.3MJ/liter) and 860kcal/kwh (3.60MJ/kwh) are used.

In Figure 10, annual energy consumption of each house is shown with reference data on the right side to be compared. Among investigaed 5 houses, House-KH and YM need relatively fewer energy, while House-NE needs almost twice as much energy as mean of other four houses.

Comparing to reference data A (twenty-nine houses with specific leakage area smaller than $5cm^2/m^2$, of which average floor area is $119m^2$), House-NE seems to have worse insulation, less efficient heater or higher temperature setting as handicaps to energy saving. In addition, another report[1] says that it has the following problem with ventilation, which can have some contribution to energy loss.

According to the report, type-B ventilation system of House-NE does not work well, that is, total exhaust air volume is measured $200m^3/h$ in winter which is much more than total replace air through fresh air inlets ($28m^3/h$). Though specific leakage area of House-NE is $2.6cm^2/m^2$(floor area) and rather small comparing usual houses, it seems that the airtightness is insufficient for appropriate operation of type-B ventilation system. The rest of the replace air is supposed to come inside through cracks and holes and to cause drafts to some extent. In the rooms where the drafts exist, occupants might require higher room temperature to compensate uncomfortableness due to the drafts. In this case, the air change by ventilation and infiltration in winter, which is estimated to be $0.52h^{-1}$, can not account for so much increment of oil consumption.

The total floor area of House-YM is 30% larger than the average of 29 samples (REF.A), while energy consumption of the former is 34% fewer than the latter. It means that House-YM needs only half energy per unit floor area comparing to REF.A. The houses of REF.A have central heating system and ventilation system with specific leakage area smaller than $5cm^2/m^2$. We had better analyse further the characteristics of House-YM as the most energy conservative model. Especially the contribution of airtightness should be examined.

Though fewer family members live and the total floor area is a little smaller than other four houses, House-KH has still higher energy efficiency.

REF.B[2] in Figure 10 is the data of seventy-one randomly sampled detached houses in Sapporo. Only 29% of them have central heating system and the rest have independent heaters for each space. Comparing five subjects and REF.B, it can be said that the increment of electricity consumption mainly due to ventilation system is sufficiently compensated by the decrease of oil consumption in House-YM and House-KH. The result of these two houses proves undoubted potential of the highly insulated and airtight house for energy saving.

SUMMARY

The highly insulated airtight houses, which are built in Sapporo (northern part of Japan belonging to the subarctic zone), were investigated as for their summer indoor climate and annual energy consumption. It is proved that there are thermally comfortable room temperature without air-conditioners. The residents are normally using cross ventilation through open windows in order to reduce room temperature.

The average deviation of indoor humidity ratio from outdoor one was found to be mostly in the range from -1g/kg(DA) to 2g/kg(DA), except for a bathroom. In the bathroom, though humidity ratio deviation above 5g/kg(DA) was observed, emitted vapor is exhausted by ventilation system and there seems no problem with humidity control.

The measurement of CO_2 concentration in living rooms and bed rooms shows no serious problem with indoor air quality.

Among five subjects of this research, two highly insulated airtight houses show considerably high energy efficiency. Their annual total energy consumption are 13.2Gcal/a(55.3GJ/a) and 15.0Gcal/a(62.9GJ/a), while the average annual total energy consumption for the reference group of randomly sampled datached houses in the same city is 22.4Gcal/a(93.9GJ/a). Though a few subjects of this research need the same or more energy than reference groups, it is proved that highly insulated airtight house with central heating and ventilation system has a considerable potential for raising thermal environment quality and reducing energy consumption. More sophisticated design and construction system of houses is needed in order to avoid malfunction of ventilation system. In addition, especially in Japan, further research including computer simulation and experiment is necessary in order to examine the potential in more mild climatic condition under which air-conditioning is necessary in Summer.

ACKNOWLEDGEMENT

The investigation was performed as an activity of the special committee for the new standard of indoor environment, which was organized in Institute of Building Energy Conservation. The secretariat of IBEC is acknowledged for their help. The authors express their gratitude to Dr. Komine, the author of reference 1), who gave them some important information of subjects.

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1)H. Komine: Field measurement on ventilation performance of highly insulated airtight houses, Report on the development of new energy conserving technology for raising housing quality, Vol.2, IBEC, Chapter 12,(1991)

2)Hokkaido Electric Power Company: Suvey on the trend of household energy consumption and lifestyle in Hokkaido, (1991)

TABLE 1 LIST OF INVESTIGATED HOUSES IN SAPPORO

HOUSE	DWELLING PERIOD	FLOOR AREA(M^2)	AIR VOLUME(M^3)	FAMILY MEMBER	VENTILATION SYSTEM	SPECIFIC LEAKAGE AREA (CM^2/M^2)
NE	OCT 1990 -	168.0	386.3	3	TYPE-B	3
HY	AUG 1989 -	216.3	497.6	4	TYPE-A	2
YM	SEP 1990 -	155.3	357.1	3	TYPE-A	<5
KH	DEC 1987 -	115.5	265.7	2	TYPE-A	<5
ST	AUG 1990 -	151.9	349.9	3	TYPE-B	1
	MEAN	161.4	371.1			

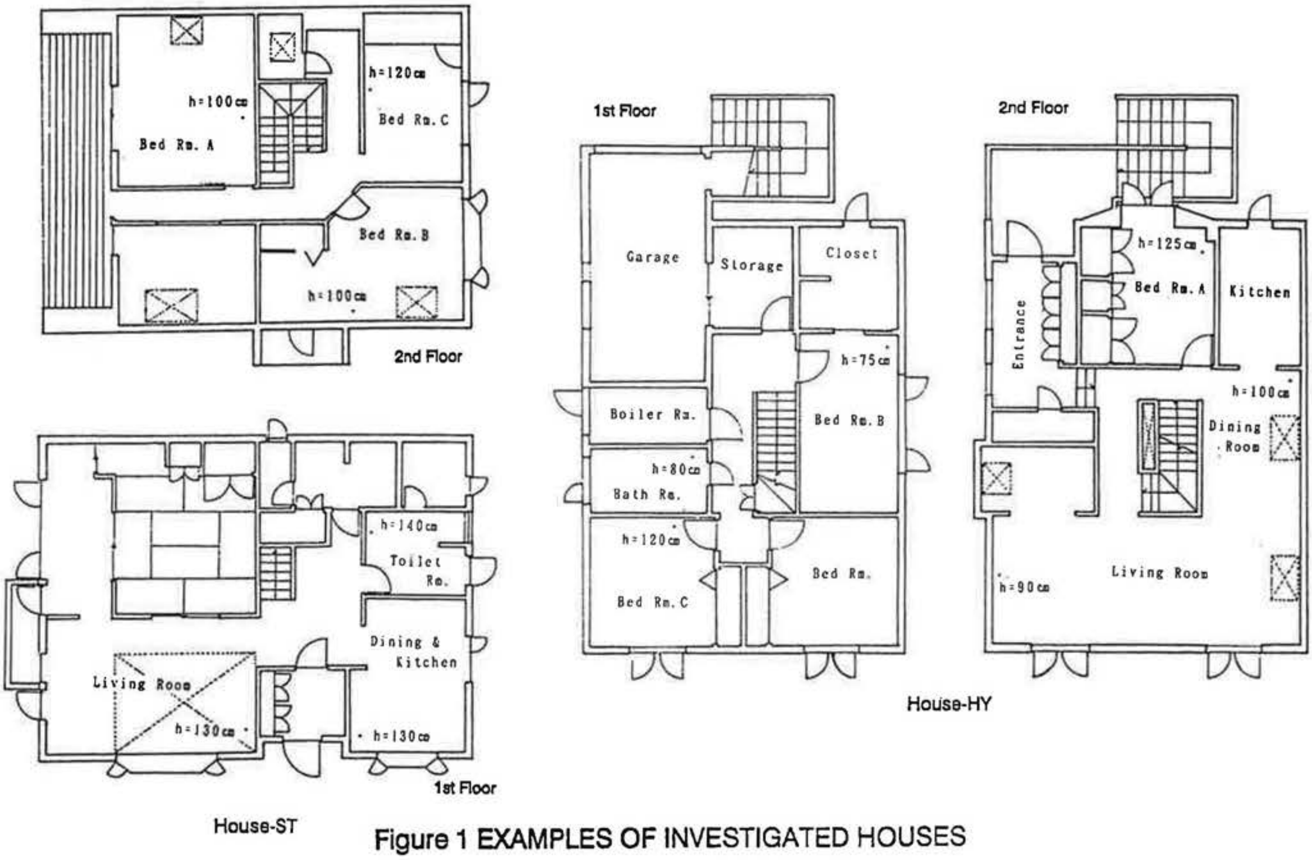

Figure 1 EXAMPLES OF INVESTIGATED HOUSES

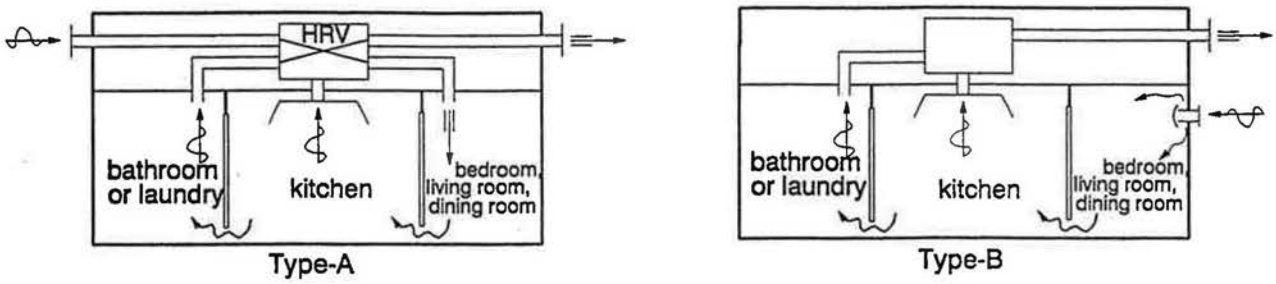

Figure 2 SCHEMATIC DIAGRAM OF VENTILATION SYSTEMS

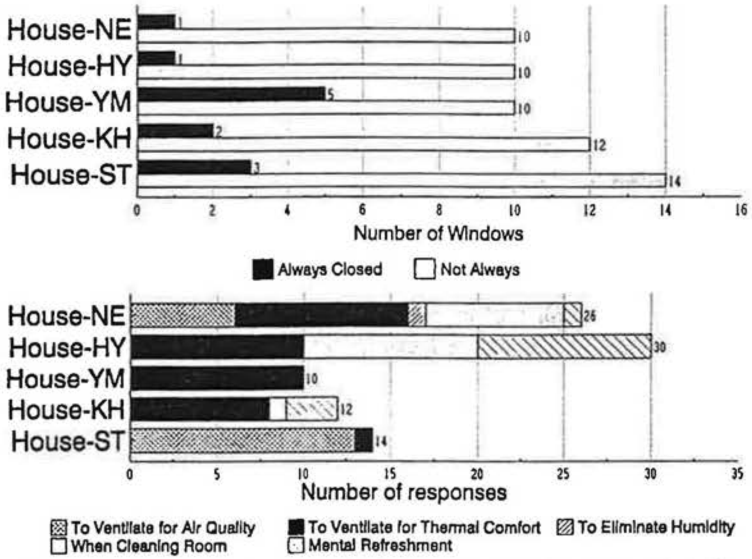

Figure 3(a) WINDOW OPENING BEHAVIOR AND REASONS

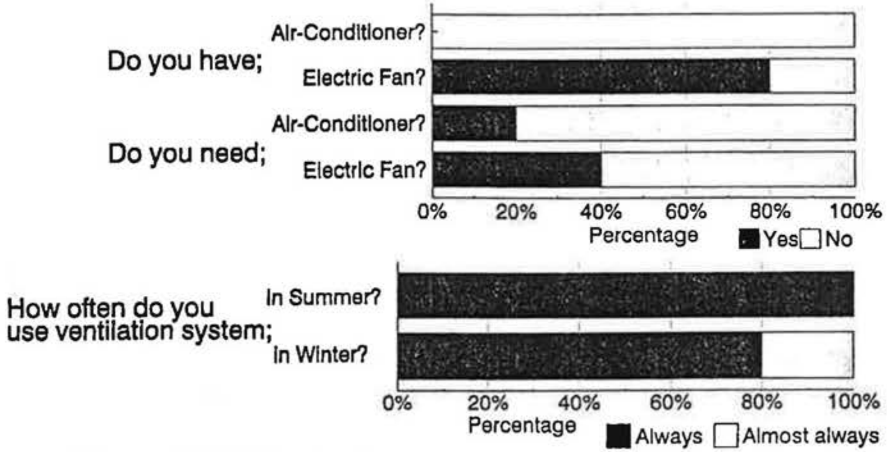

Figure 3(b) USAGE OF AIR-CONDITIONER, ELECTRIC FAN AND VENTILATION SYSTEM

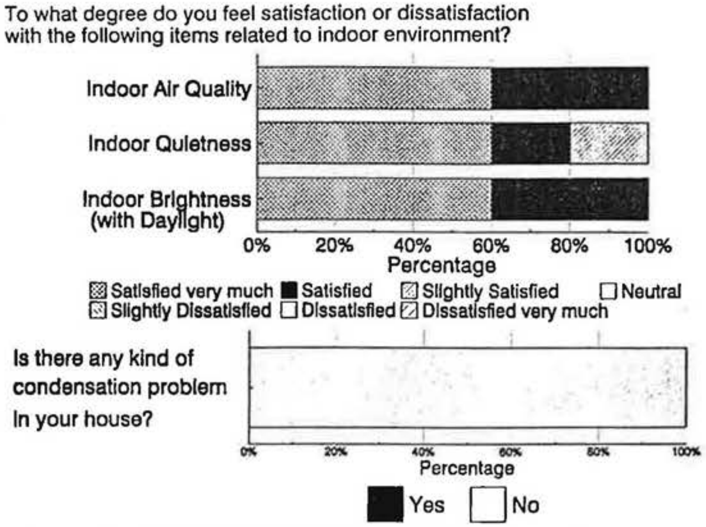

Figure 3(c) SUBJECTIVE EVALUATION BY RESIDENTS

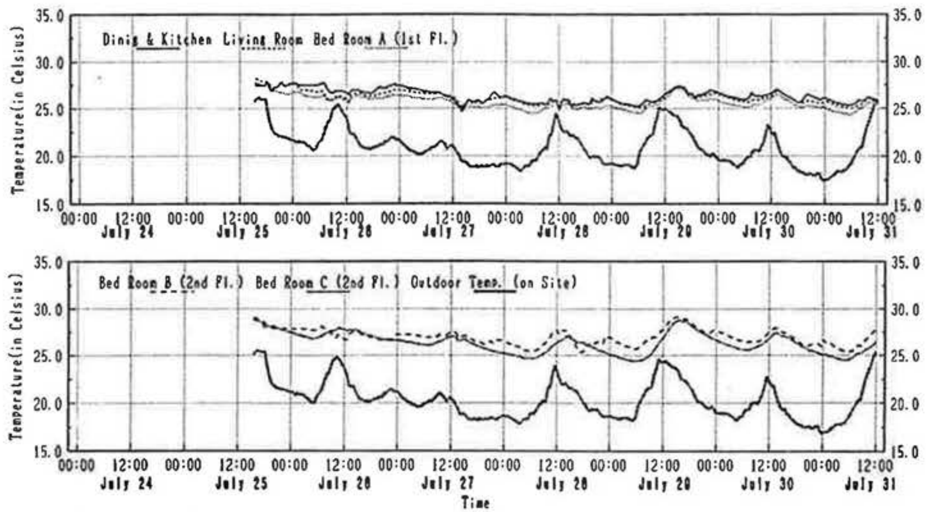

Figure 4 EXAMPLE OF TEPERATURE OBSERVATION (House-YM)

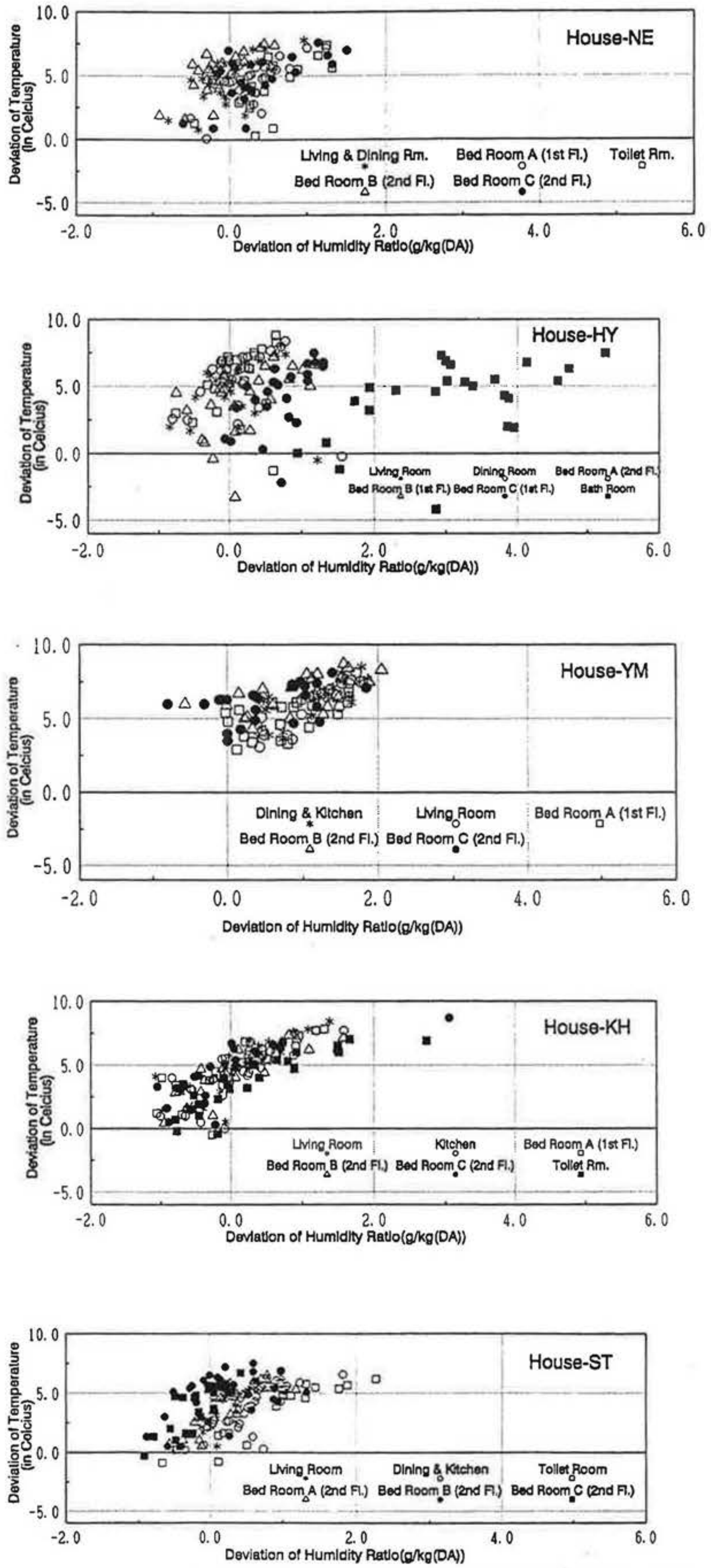

Figure 7 DEVIATIONS OF ROOM TEMPERATURE AND HUMIDITY RATIO FROM OUTDOOR

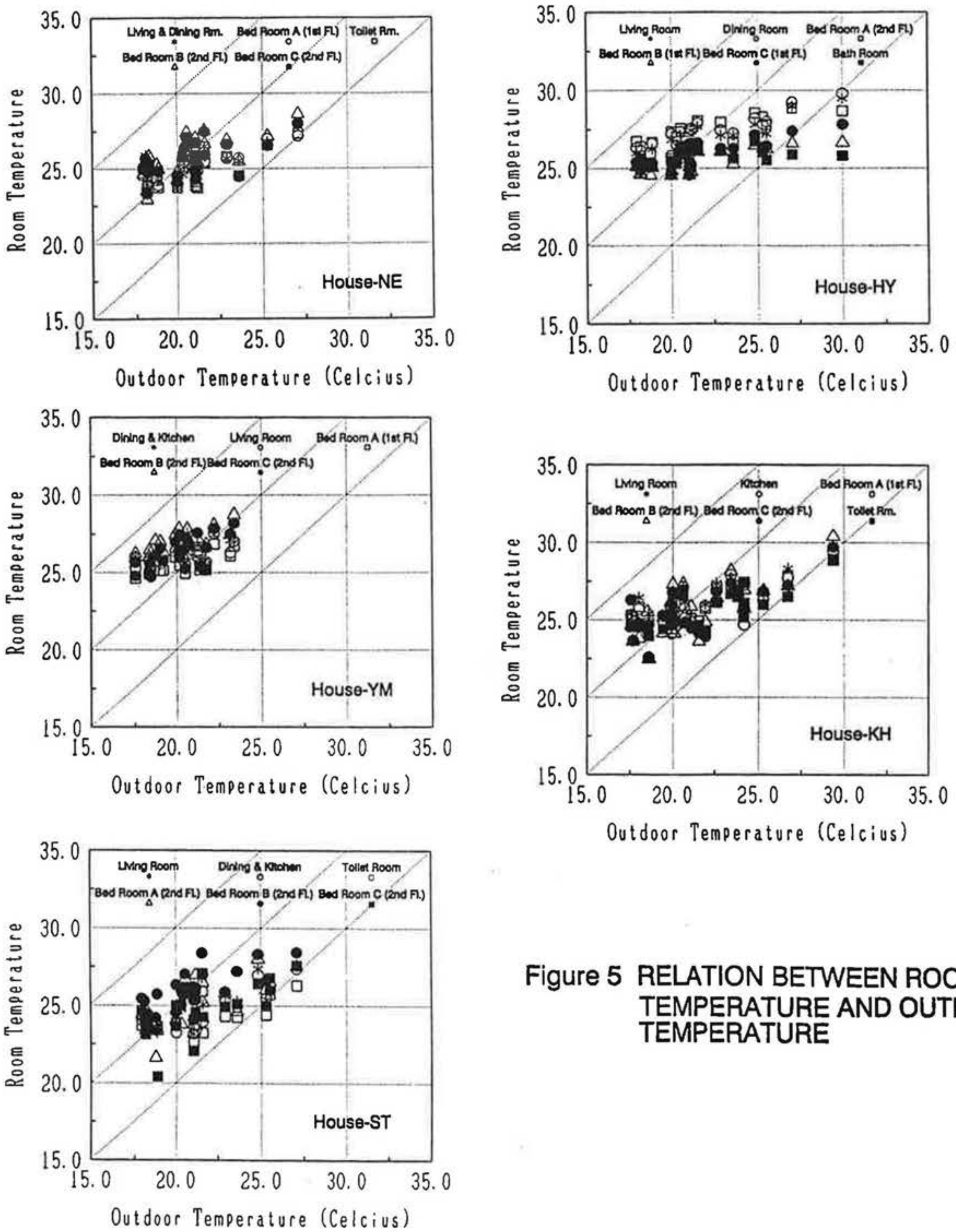

Figure 5 RELATION BETWEEN ROOM TEMPERATURE AND OUTDOOR TEMPERATURE

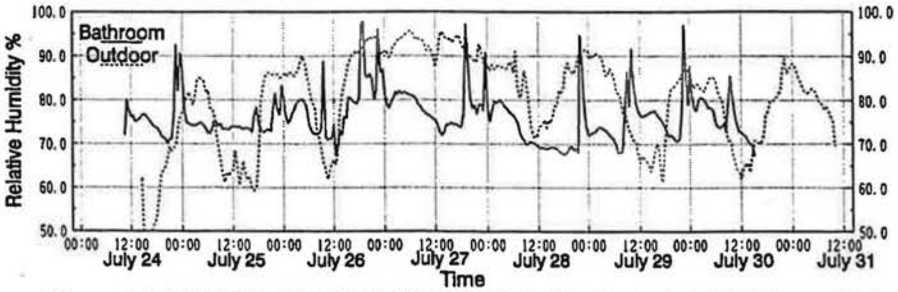

Figure 8 EXAMPLE OF RELATIVE HUMIDITY IN BATHROOM(House-HY)

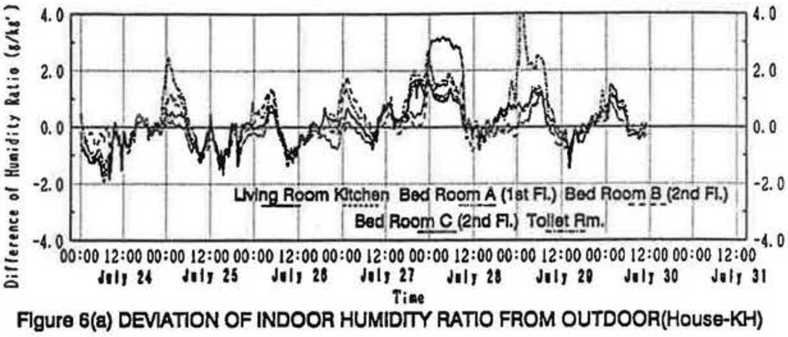

Figure 6(a) DEVIATION OF INDOOR HUMIDITY RATIO FROM OUTDOOR(House-KH)

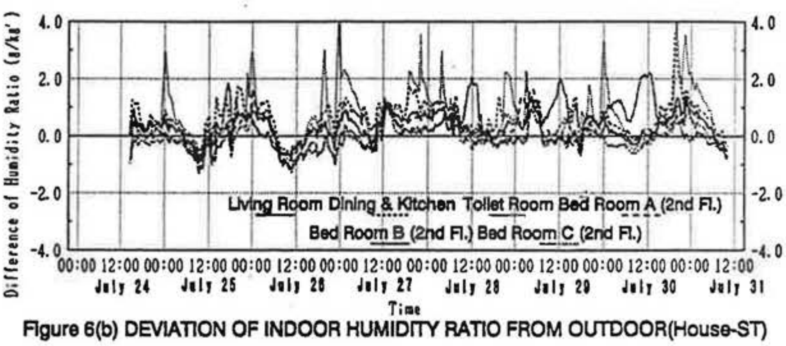

Figure 6(b) DEVIATION OF INDOOR HUMIDITY RATIO FROM OUTDOOR(House-ST)

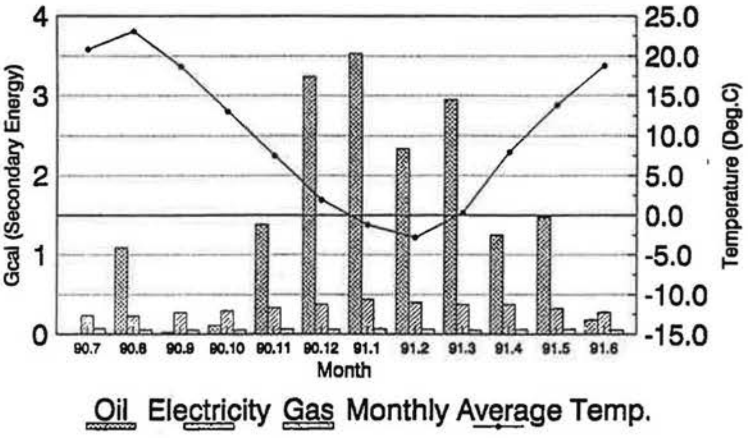

Figure 9 MONTHLY AVERAGE ENERGY CONSUMPTION

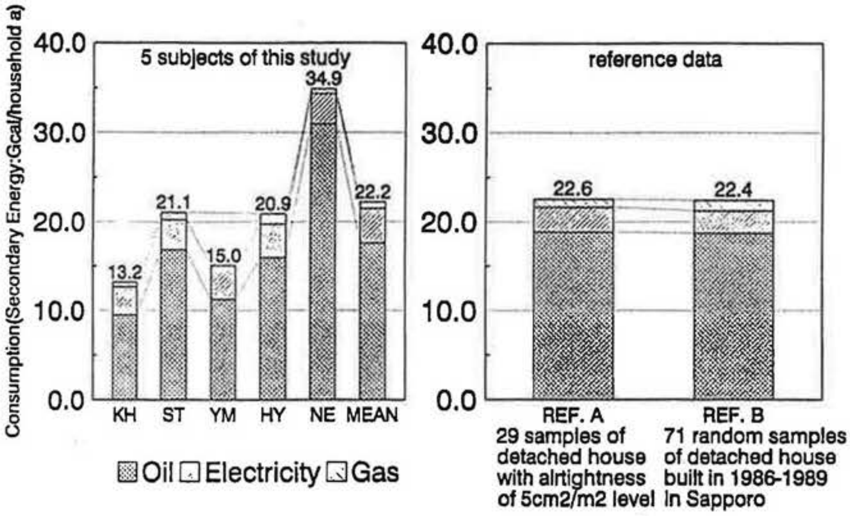

Figure 10 ANNUAL TOTAL ENERGY CONSUMPTION

APPLICATION OF COOLING SYSTEMS WITH RADIANT COLD PANELS : AIR QUALITY AND ACOUSTIC ENVIRONMENT

E.A DECAMPS, A. t'KINT de ROODENBEKE, M. QUENEUDEC, P. TOUBON et G. ROYER
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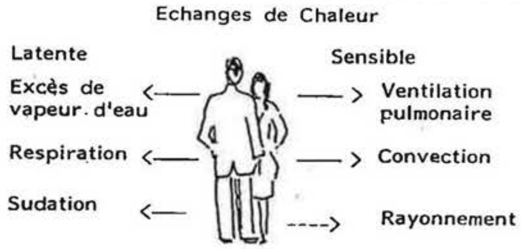


Bilan thermique	
Pertes par convection........	Ec
Pertes par rayonnement	Er
Pertes respiratoires :	
a) sensibles.....................	Cres
b) latentes	Eres
Pertes latentes par diffusion et évaporation....................	El
Métabolisme thermique fonction de l'activité..........	Mact

Pertes = Eres + Cres + Ec + Er + Edif en W
Métabolisme = 105W pour individu assis
Mth = 58,15 Mact. Adu (1-r)
avec Adu surface de la peau , r rendement
B = Mth - pertes
si B < O | - augmenter pertes convectives
| - réduire apports radiatifs
| - sudation

Mur en B.T.S expérimental Béton de Terre stabilisé avec circulation de fluide (vue intérieure)

NOTION GLOBALE DE CONFORT : PARAMETRE d'AMBIANCE intégrant thermique, acoustique, humidité, qualité de l'air...

CLIMATISATION CLASSIQUE joue essentiellement sur les pertes convectives

Avantages | Pas d'inertie | ΔT important
Inconvénients | Pas d'inertie - Bruit - Qualité de l'air négative
Δ T important - Fréon - Choc thermique

Améliorations : climatiseurs au gaz naturel (HD 2000)

CLIMATISATION PAR PAROI FROIDE : SOL + PAROIS

Jouer sur le terme Er fonction de la surface : circulation d'un fluide "froid" (16 à 18°C)
Préconise par le laboratoire dès 1981 (20th colloque COMPLES, Rabat)
Autre notion du confort thermique non liée directement à la température ambiante

Avantages : inertie - qualité de l'air - pas de bruit - répartition des températures
Inconvénients : inertie - faible ΔT - condensation

Parallèlement : - jouer sur T vitrages : occultation - circulation de fluide
- récupération du fluide en sortie de mur pour abaisser le renouvellement d'
- utiliser les parois internes

Réalisations récentes : MULTIBETON, M. SIMONESSA (SATEL), HD 2000 (Rennes)

Travaux commandités par le Directeur des Etudes et Techniques Nouvelles de gaz de France à HD 2000 Espace de Recherche et de Communication pour promouvoir l'Innovation dans l'habitat.

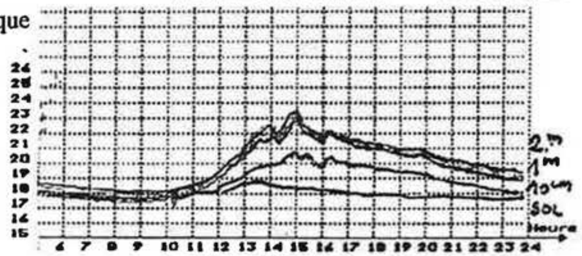
QUALITE DE L'AIR
- Pas de mouvement d'air
- peu de poussières
- diminution du taux des bactéries
- pas de fréon

REPARTITION DES TEMPERATURES
- La température n'est plus le critère fondamental du confort
- l'émission des murs recevant le soleil est atténuée
- répartition spatiale de la température interne modifiée
- pas de choc thermique en sortant de l'habitat

ACOUSTIQUE
Aucune émergence spécifique

COÛT
inférieur

TEMPERATURE : 9sep1992.ser



Exemple de gradiants de température (appartement T5 de HD 2000)

CENTRE D'INTERET DU LABORATOIRE : OPTIMISATION DU COÛT FINANCIER en améliorant l'adaptation de la technique à l'usage en fonction de la zone climatique dans le cadre de la **DOMOTIQUE**.

EN ZONE TEMPEREE CHAUDE : HABITAT INDIVIDUEL - HOPITAUX - ECOLES - BUREAUX.