COMMISSIONING TOOLS FOR HEATING/COOLING SYSTEM IN RESIDENCE

-VERIFICATION OF FLOOR HEATING SYSTEM AND ROOM AIR CONDITIONING SYSTEM PERFORMANCE-

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Summary. Tools of evaluating the performance of floor heating and room air conditioner are examined as a commissioning tool. Simple method is needed to check these performance while in use by residents, because evaluation currently requires significant time and effort. Therefore, this paper proposes a) two methods of evaluating the floor heating efficiency from the room / crawl space temperature and the energy consumption and b) method of evaluating COP of the room air conditioner from the data measured at the external unit. Case studies in which these tools were applied to actual residences are presented to demonstrate their effectiveness.

Keywords: Cx. tool, Room air conditioner, Floor heating, Residence.

INTRODUCTION

Recently, in terms of global warming, energy saving is necessary. However, energy consumption in residential sector has been increasing in the last decade. Therefore, there is an urgent need to reduce the consumption.

Moreover, since the number of existing buildings is larger by far than that of the new constructed one, saving energy in the existing buildings is more important. Up to now, to reduce energy consumption, performances of residential equipment and the building envelope (e.g. insulation, air leakage) have been improved. Nevertheless, energy consumption has not been reduced effectively because of improper design, construction and operation (maintenance). Therefore, (1) checking whether designed according to the resident's intent, (2) checking whether constructed according to the blueprint and (3) checking whether maintained and used properly are important. And if required, the building and the equipment should be repaired, reformed and adjusted. One of the predominant ways to do these terms is the commissioning (Cx.) process.

On the one hand, Cx. for non-residential equipment is prevailing, differently from the residential one. Applying Cx. process to residential equipment may considered to be difficult because residents cannot pay the cost for Cx. process. Nevertheless, since total energy consumption in each house is large, Cx. for residential equipment will be increasingly important and it should be implemented by means of a policy like mandatory energy-efficiency standards.

In this paper, the performance estimation tools for residential equipment to fulfill steps (2) and (3) described above are represented. Moreover, case studies in which this tool was applied to actual residences are presented to demonstrate its effectiveness.

OUTLINE OF THE ESTIMATION TOOLS

Outline of the estimation tools. The real performance of the equipment may be lower than that assumed in the design process by several reasons such as an inadequate installation, improper maintenance, system malfunction etc. Therefore, the performance estimation tools are needed to judge whether they are constructed according to the blueprint and whether they are maintained and used properly. Whether performance recover measures are needed is judged on these tools.

Convenient means. The detailed measurements for evaluation of the performance needs a great deal of time and effort. Therefore, it is necessary to perform a simple test under real conditions because it attempts to be used periodically in many houses. This paper reports some methods.

INVESTIGATED EQUIPMENTS

Table 1 shows the residential equipments of which we should check the performance. Among them, checking the performance of the heating / cooling equipment is most important to save energy because they have been used extensively in many countries. Therefore, in this paper, the performance estimation tools for floor heating and room air conditioner are presented.

Table 1. Residential equipments of which we should check the performance.

Items	Equipments
Heating/Cooling System	Floor heating system (Hot water & Electric type) Room air conditioner
Ventilation System	Natural Mechanical (Central, Heat exchanger…)
Envelope	Thermal insulation Air-tightness
Hot water supply System	Storage electrical water heater Fuel cell Co-generation system

PERFORMANCE ESTIMATION OF FLOOR HEATING

Performance degradation. The efficiency of the floor heating system decreases due to the heat loss from the hot water piping and heat loss from the heating panel. These heat loss increase due to the improper construction of the insulation around the piping and below the heating panel. Moreover, the system efficiency decreases due to decline in the boiler efficiency.

Outline of the performance estimation tools. To evaluate thermal performance, heat losses should be measured. Therefore, the information mentioned below is needed.

- Upward and downward heat flow from the panel
- Energy consumption (electricity, gas, kerosene)
- Inlet and outlet water temperature of the panel (hot-water heating system)
- Inlet and outlet water temperature of the boiler / heat pump (hot-water heating system)

To evaluate the performance with simple measurement, a Cx. process consisting of the following three steps is proposed and step 1 & step 2 are represented in this paper. Steps 1, 2 and 3 need increasingly detailed data in that order. First, step 1 is carried out. If the result is judged inadequate, the Cx. continues to step 2 and then step 3.

I. The first step aims to detect floor heating systems with low efficiency based only on the energy consumption and the room temperature, which can be easily measured.
II. At the second step, heat loss to the crawl space from the floor and the piping (hot-water floor heating system) is evaluated by comparing the crawl space temperatures with the floor heating system on and off.
III. The third step, based on detailed data, aims at clarifying the heat flow from the floor panel by calculation, using a thermal model.

Outline of the measurement. These steps were applied to two houses (A&B). House A has an electric floor heating system, while House B is heated by a hot-water floor heating system. The operating mode of floor heating systems was selected freely by the residents.

Evaluation based on energy consumption for heating. Given that the heat supplied to the room from the panel is measured, the efficiency of the floor heating can be evaluated. However, it is difficult to measure the supplied heat. Therefore, even a crude evaluation of the supplied heat by measuring only the room temperature is highly desirable. We will propose a new method and use it to make estimation. If the proposed method is applicable, the efficiency of floor heating can be estimated by statistical means after accumulating sufficient data in residences.

Usually, a floor heating system controls the heat input to the panel so that the surface temperature is kept at a set point. Given that the floor surface temperature (T_{surf}) is maintained at the set point and the heat transfer coefficient (h) is assumed to be constant, the supplied heat can be calculated by only measuring the room temperature. Figure 1 shows the supplied heat with solid lines and an example of the energy consumption with circles.

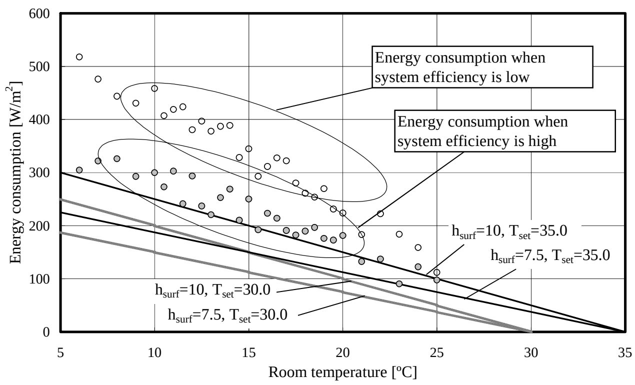
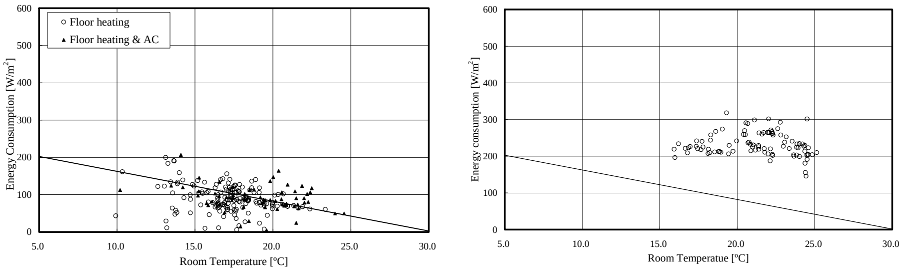


Figure 1. Estimated heat supply and energy consumption.

Heat supply and examples of measured energy consumption are represented with solid lines and circles, respectively. h_{surf} is the heat transfer coefficient and T_{set} is the set point temperature.

If the efficiency of the gas boiler is 100% and there is no heat loss, the supplied heat should be identical to the energy consumption. In real situations, however, there are heat losses and the efficiency of the gas boiler is 90% at the maximum, making the energy consumption larger than the supplied heat. The efficiency of the floor heating system can be evaluated from the difference between the energy consumption and the supplied heat. In order to apply this method, the room temperature and gas / electric consumption were measured in the residences.

Figure 2 shows the correlation between room temperature and energy consumption when the floor heating is operated. In House A, the energy consumption is nearly identical to the estimated supplied heat, which means the floor heating system was operated at high efficiency. In House B, the energy consumption is double the estimated supplied heat. It seems that the efficiency of the heating system in this house is low, and a great deal of heat is lost to the crawl space or/and in the boiler.

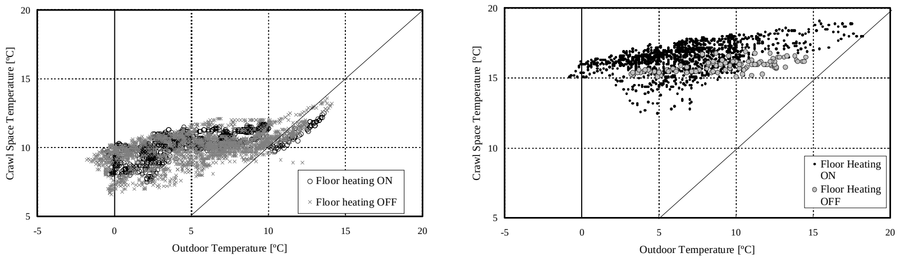


a) House A (Elec. floor heating) b) House B (Hot-water floor heating).

Figure 2. Energy Consumption vs. Room Temperature

Evaluation based on crawl space temperature. The temperature of the crawl space is affected by the outdoor, room and ground temperatures, and the heat released from the floor heating system. If the heat loss from the heating panel and hot-water pipe is large, the crawl space temperature during operation must be higher than it is when the heating system is off. Therefore, heat loss to the crawl space was evaluated by comparing the crawl space temperatures with the system on and off.

Figure 3 shows the result. In House A, the difference in crawl space temperature is quite small between system-on and off states. Therefore, the heat loss is judged too small to increase the crawl space temperature. In House B, the crawl space temperature when using floor heating is higher than when it is off. The heat loss to the crawl space seems to have affected the crawl space temperature. Additional measurements to discover the causes of the heat loss have shown that the surface temperature of the piping was significant, resulting in heat loss from the piping to the crawl space[1]. Therefore, it can be concluded that the proposed Cx. tool, that is, a comparison of the crawl space temperatures, can predict undesirable heat losses.



a) House A b) House B

Figure 3. Outdoor temperature vs. Crawl space temperature

PERFORMANCE ESTIMATION OF ROOM AIR CONDITIONER

Performance degradation. The factors, which decrease the performance of air conditioner, have been well researched[3]. Regarding residential room air conditioner, the factors are summarized as follows:

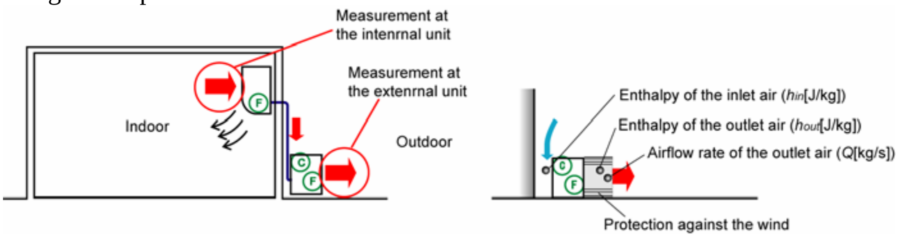
- Setting of an external unit of air conditioner may be inadequate.
- In case that the filters of the internal and external unit are not clean and the surface of the condenser and evaporator is dirty, efficiency of heat exchange becomes lower.
- Decrease of the equipment performance (e.g. compressor malfunction, fan malfunction, gas leakage).

Therefore, the internal and external units of the air conditioner should be set properly and maintenance should be carried out in order to keep the optimal performance. For the Cx. of the settings and maintenance, the performance in real situation should be measured. The checking period and items are the following;

- When the air conditioner is installed, whether the external/internal units and piping are set properly is checked.
- Periodically, change of the performance is checked. If the performance deteriorates, the performance intended is restored.

Outline of the performance estimation tools. To measure COP, power input data and heating/cooling load data are required. Heating/cooling load is calculated from the outlet airflow rate and the difference between the inlet and outlet air temperatures. These parameters are usually measured at the internal unit. However, in this study, they were measured at the external unit (Fig. 4) because the measurement at the internal unit may bother the residents.

Figure 4 shows the measured parameters to calculate the cooling load. The measuring points are temperature/humidity at the inlet / outlet air and air velocity. We attached a protection against the wind in the external unit in order to reduce the effect the wind has on the outlet air velocity. Aside from this, during the measurement period, distribution of the outlet air velocity was measured in detail. The outlet air velocity was measured continuously but the outlet airflow rate was not measured at all. Therefore, the outlet airflow rate was calculated from the air velocity distribution. The relation between the outlet air velocity and the outlet airflow rate was investigated, and then the outlet air velocity was converted into the outlet airflow rate by applying this relation. The power input was also measured using a cramp meter.



(a) (b)

Figure 4. (a) Measurement was carried out at the external unit as opposed to the internal unit. (b) Measurement points.

In order to calculate the cooling load, we should subtract heat radiation of the external/internal fan and compressor, from the measured heat radiation at the external unit (Eq. 1). In this equation, total heat radiation from the fans and compressor is assumed to be equal to the power input.

$$L = Q\left(h_{in} - h_{out}\right) - \left(H_{comp} + H_{fan,in} + H_{fan,ex}\right) \quad (1)$$

L	Cooling load, W
Q	Air velocity, kg/s
h_{in}	Enthalpy of the inlet air, J/kg
h_{out}	Enthalpy of the outlet air, J/kg
H_{comp}	Heat radiation of the compressor, W
$H_{fan,in}$	Heat radiation of the internal fan, W
$H_{fan,ex}$	Heat radiation of the external fan, W

Outline of the measurements. The measurement was carried out at an experimental house in Osaka, Japan on the afternoon of August 25th, 2003. Table 2 shows the rated performance. The cooling load was approximately constant and the operating mode chosen was the automatic operative mode.

Table 5. The rated performances

Cooling capacity, kW	2.8 (0.3-3.9)	Compressor output, W		750
Rated power, W	510 (55-990)	Fan output, W	Internal	40
Rated COP	5.49		External	50

Results. Figure 5 shows the cooling load, the power input and COP, which were calculated by the inlet / outlet temperature and airflow rate. Cooling load and power input were stable with COP being constant at about 8.0 – 10.0 except under the dehumidifying mode when COP fell to 2.0-3.0. However, after 6 a.m. when the outdoor temperature lowered, the COP changed little from the value 7.0-8.0 (before 6 a.m.) to the value 9.0-10.0 (after 6 a.m.). The COP is much higher than the rated value because the outdoor temperature is lower than that defined in JIS[2)].

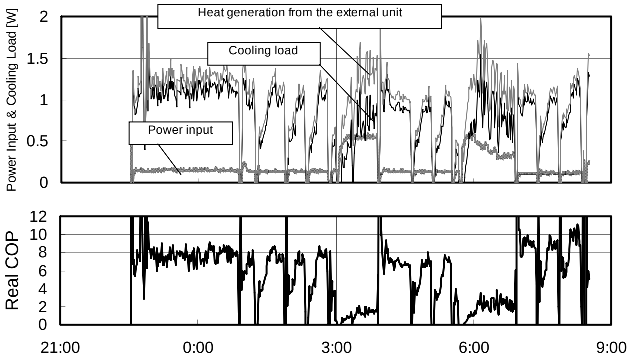


Figure 5. Cooling load, power input and COP

Discussion. Real COP depends on the outdoor temperature. To compare the performance between real condition and rated condition, and to evaluate the degradation of the performance in different periods, a method to compare the performance on similar condition is required. Therefore, referring the indoor / external temperature and humidity, measured COP is modified to the value by which we can compare. First, the ideal COP by using Carnot cycle is calculated (The condenser temperature is assumed to be 7 ^{o}C lower than the indoor temperature dew point and the evaporator temperature is assumed to be 7 ^{o}C higher than the outdoor temperature. The real COP is lower than the value calculated with Carnot cycle, which is the ideal cycle. However, the tendency of the COP changes is assumed to be similar to the real case and thus, we converted the measured value in order to compare under equal conditions as in equation 2.

$$COP_{equalcond} = COP_{ex} \times \frac{COP_{Carnot,rated}}{COP_{Carnot,ex}} \qquad (2)$$

$COP_{equalcond}$ Modified value to compare COP in equal conditions
COP_{ex} Measured COP
$COP_{Carnot,rated}$ COP calculated with Carnot cycle (rated condition)
$COP_{Carnot,ex}$ COP calculated with Carnot cycle (experimental condition)

Figure 6 shows the measured real COP and modified one, which was calculated with $COP_{Carnot,rated}$ of 8.27, $COP_{Carnot,ex}$ of 10.08 (when outdoor temperature is 25 ^{o}C) and of 12.83 (when outdoor temperature is 30 ^{o}C). Modified COP keeps constant before and after 6 a.m. when the outdoor temperature changed. Average COP modified is about 6.0, which corresponds to the rated value 5.49.

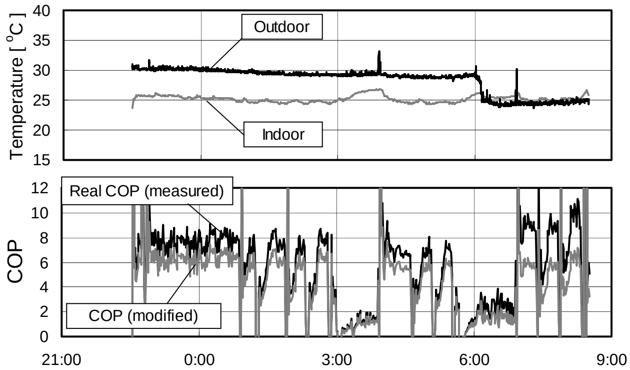


Figure 6 Real COP and the COP modified in rated condition

CONCLUSION

This paper proposes a) two methods of evaluating the floor heating efficiency from the room / crawl space temperature and the energy consumption and b) a method of evaluating COP of the room air conditioner from the data measured at external unit. Case studies in which these tools were applied to actual residences are presented to demonstrate their effectiveness.

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