

## **Experience on Commissioning of Heating/Cooling System and Thermal/Air Quality Environment**

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### **Summary**

This paper discusses how the commissioning process should be and the related problems, through a case study of a residential house. The items to be commissioned, measurement methods and the commissioning results are shown. Through the commissioning process, the problems pertaining to residential houses, such as the measurement problems, are clarified and the importance of commissioning established.

Development of a simple and appropriate measuring method, monitoring of energy consumption and the verification of that value based on a standard value, enhancement of the resident's interest in the indoor environment and energy consumption and attention to their life style require future study.

**Keywords:** residential building, ventilation, energy, cooling/heating

### **1. INTRODUCTION**

Not only in a non-residential but also in a residential building, the necessity of commissioning the performance of the building equipment and systems such as heating/cooling and ventilation systems is expected to increase, in addition to the thermal insulation and air-tightness. Since it is difficult to evaluate each item of equipment independently in the commissioning process, the equipment and the house should be evaluated as a total system.

This paper discusses how the commissioning process should be and the related problems, through a case study of a residential building. The house studied here has been investigated for five years after acceptance, in terms of its indoor thermal environment and energy consumption<sup>1)2)</sup>.

### **2. COMMISSIONING IN PROJECT AND PLANNING PHASE**

#### **2.1 Design Intent**

- 1) A healthy, comfortable and energy conserving residential house for an elderly lady was the objective. The goal is to design an environmental system that resolves the social and technical problems in a aging society, and can also optimize the indoor thermal/air quality environment throughout the year, in a highly insulated air-tight residential house in a relatively warm region in Japan.
- 2) concept of environmental design: Hybrid system of passive and active systems

is adopted to realize a residential building cool in summer and warm in winter.

## 2.2 Project and Planning Team

A professional who has long experience in designing equipment and systems led the design team as the key-person, and he (a son-in-law of the owner), also served as the commissioning authority (Cx.A). A group composed of the Cx.A, A&E of equipment and systems, and A&E from an industrialized house maker carried out the planning and designing.

## 2.3 Outline of Building

The residential house thus designed (**Fig. 1**) is a highly insulated and airtight steel frame house with an attic space<sup>3</sup>. The resident is an elderly lady, and she spent most of her time in the bedroom.

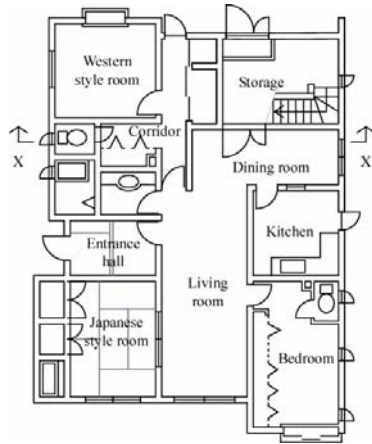


Figure 1 First floor plan

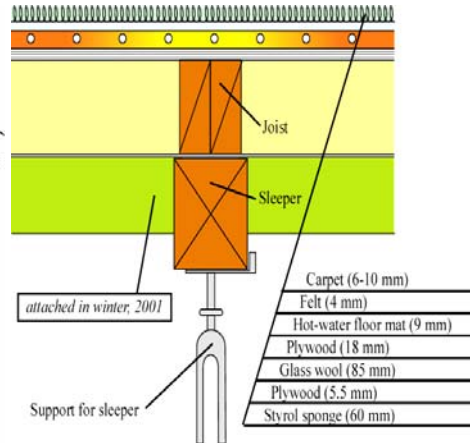


Figure 2 Floor section

## 2.4 Design Specification

1) thermal insulation: The insulation thickness of the external wall and the floor are 100 mm (GW 10 K) and 145 mm (85 mm GW and 60 mm styrol-sponge), respectively. **Figure 2** shows the structure of the floor. Low-E pair glasses, whose overall heat transfer coefficient is  $2.7 \text{ W/m}^2\text{K}$ , glaze all windows and the solar transmittance is 0.74. The outer windows on the south and west sides are installed with outside blinds.

2) air-tightness: The glazing is the second level of Japanese Industry Standard, JIS, ( $2 \text{ m}^3/\text{h}/\text{m}^2/\text{Aq}$ ). The Cx.A asked the constructors so that the intersections between the walls and the floor or ceiling should be carefully filled with insulation material.

3) ventilation plan and centralized HVAC system: A centralized air conditioning system, which supplies and exhausts the minimum necessary air volume ( $200 \text{ m}^3/\text{h}$  in total) through a total heat-exchanger, is adopted so that increase in energy consumption can be minimized whilst preventing degradation of the air quality due

to lack of fresh air (**Fig.3**). All rooms are supplied with fresh air, and the supplied air is exhausted through the washroom and corridor. The doors between the bedroom and living room, living room and corridor have undercuts.

During heating and cooling seasons, the hot/chilled water produced by an electric chiller is supplied to the fan-coil units. The heating and cooling pipes run through the crawl space, go up the corner of the Japanese-style room, and are connected to the fan-coil units in the duct room on the second floor.

4) floor heating: All rooms except for the Japanese-style room are installed with the hot water floor heating system including a bathroom. **Figure 4** schematically shows the heating panels and piping network for floor heating. Hot water is produced by a gas-boiler and flows to the header located in the crawl space beneath

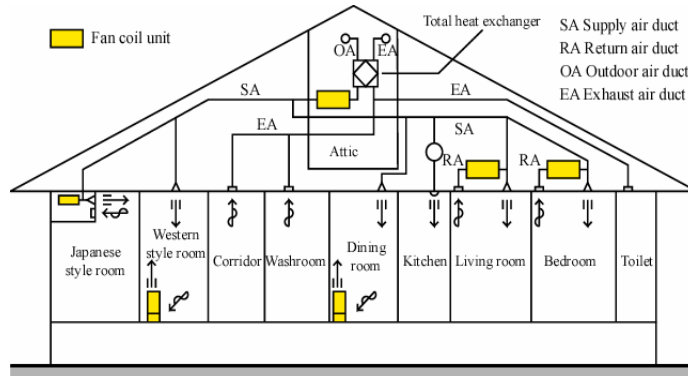


Figure 3 Duct system

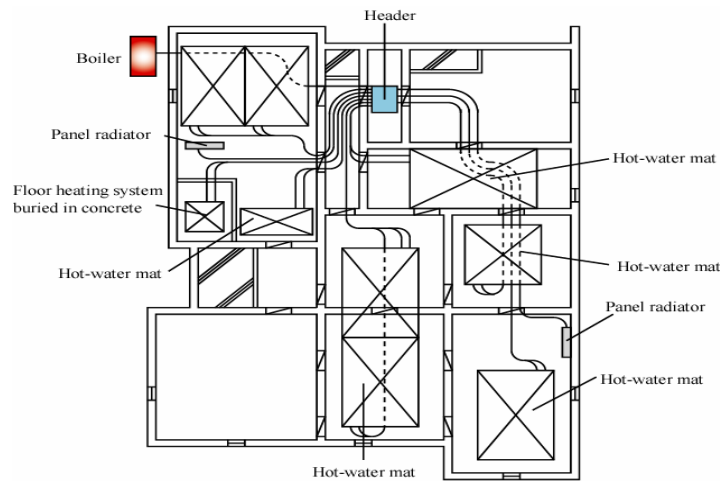


Figure 4 Heating panel and piping network for hot water floor heating

the closet-corridor. The header controls the water flow rate.

5) IAQ plan: The necessary fresh air is supplied by the central ventilation system. The walls and the ceiling are finished with non-formaldehyde finishing materials.

During heating and cooling seasons, the minimum volume of outdoor air is introduced, and the windows are planned to be closed in principle. However, either natural ventilation by opening the window or forced ventilation can be chosen in the bathroom while the window of the toilet can be opened if necessary.

### **2.5 Problems in Commissioning Process**

The main project planner was well aware of the owner's (resident) wishes and considered these in the design. He also served as a Cx.A. Although the situation seemed the best for commissioning, several issues should be addressed.

Since this house was designed as highly insulated and airtight, not common in the warm area at that time, the engineers of the house maker lacked sufficient experience in designing and constructing this kind of house and, central HVAC system. Also, since the house was built under a critical situation just after the Kansai earthquake, communication was not easy between the A&E and constructors. This might be one of the reasons why the careless mistakes occurred, which are described later. The floor heating system was designed and constructed by a gas supplier, however, they lacked care in the insulation and did not fully understand that the house and the floor heating system should be treated as a total system. The concept of commissioning should be prevailed widely in order to resolve these problems.

## **3. COMMISSIONING IN CONSTRUCTION PHASE**

### **3.1 Working team and Commissioning**

The people from the house maker, the building equipment company and the gas supplier carried out their jobs, almost independently. The commitment of the owner and Cx.A was not so great in this phase. The house maker only did an in-company inspection. The commissioning of the equipment installation performed in situ, was done according to the standard testing method specified by the equipment maker.

### **3.2 Unresolved Issues Regarding Commissioning in Construction Phase**

In the present housing construction system, the following procedures are taken after construction; a) ordering the building materials from the sales branch to the factory, b) dispatching the building materials from the factory to the site, c) installing in situ. Checking stage a) is difficult. Good information transfer by well-experienced staff is needed, especially in order to reflect special requests such as in the present case from the owner to the constructor, and ordering the building materials from the factory exactly. Whether the equipment is accepted as merchandise for the house maker is determined following JIS or other similar performance testing methods. The commissioning in situ of the equipment

installation is based on the standard test specified by the equipment maker. It is best to check the floor heating, water flow rate, water leakage and the hot water temperature at the exit of the boiler. In the case of the air-conditioner, Freon pressure, operation of the fan (not air volume) and air temperature (only hot or cool) are usually checked by electric equipment engineers.

For these reasons commissioning was far from ideal at this stage.

#### 4. COMMISSIONING IN ACCEPTANCE PHASE

As the commissioning item, only the IAQ measurement was performed in this house<sup>4)</sup>, because the completion of the building was in spring.

The concentration of chemicals and other environmental factors were measured, and the effect of a non-formalin building materials, the relationship between the indoor concentration and ventilation rate, and the relationship between indoor concentration and materials were investigated. Although no other measurement was performed in this house, the commissioning in this phase is quite important. The problems clarified in the following sections could be avoided if the commissioning in acceptance phase was done thoroughly.

#### 5. COMMISSIONING IN OPERATION PHASE

##### 5.1 Thermal Insulation

1) commissioned items: a) whether the insulation is installed as specified according to the design intent, whether there is an insulation deficit, b) whether there are any metal frame/fittings that act as a heat bridge, were checked.

2) measured items: The building materials that can be seen relatively easily, such as insulation in the attic space, were checked visually. The other parts such as the inside of the walls were checked by the surface temperature measurement using a thermo-camera.

3) results: A part of the roof insulation was separated and pending. Out of the floor insulation, visual inspection through the floor trapdoor in the kitchen revealed that a 60 mm thick styrol-sponge was not attached as specified by the design document. As a result of the surface temperature measurement by a thermo-camera (**Fig.5**), the separation of the insulation from the ceiling panel was found, which resulted from the air gap between the ceiling and the insulation due to the braces.

**Figure 6** shows the measured temperature distribution in the duct space of the attic. The temperature of the upper part of the column and the metal hangers are higher than 40°C.

4) unresolved issues: Regarding the hidden areas such as the inside of the walls or the areas difficult to see such as crawl space, it is quite difficult to judge whether the building elements are insulated exactly following the design documents. In that sense, an infrared thermo-camera is very effective. Even though, other methods should be developed for the location such as crawl space, and also simple measuring method of the overall heat transfer coefficient<sup>5)</sup> is highly required.



Figure 5 insulation defect at ceiling of living room

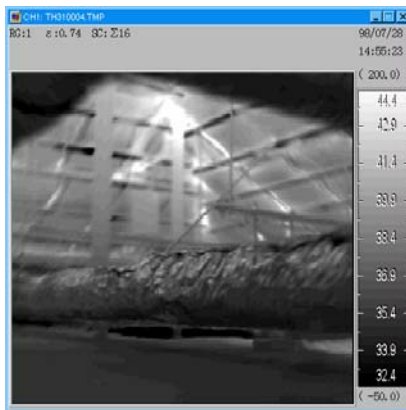


Figure 6 Heat bridge in duct room

## 5.2 Ventilation

1) commissioned items: a) whether the air flow routes are realized according to design, b) whether the room temperature distribution is uniform during heating/cooling period, were checked.

2) measured items: Airflow rates at the inlets and outlets were measured by the air flow meter or anemometer with precision of several cm/s. The ventilation rates between rooms were calculated by multiplying the measured air velocity through the small openings and their area. At the same time, ventilation calculation was carried out by using the measured airflow rate through the inlets and small openings.

3) results: Measured supply and exhaust air flow rates, airflow between the rooms during winter are shown in **Fig.7**. All the doors and windows were closed during the measurement. The cold air enters from the storage room to the dining room and from the porch to the living room. **Figure 8** shows the temperature distribution around the lower part of the door between the storage and dining rooms, seen from the dining room. Low temperature air can be seen entering the dining room. During winter, the airflow rate from the porch to the living room, the airflow rate entering the living room, which comes through the small openings between storage and dining rooms and flows through the curtain, are quite large (**Fig. 7**). The incoming air flows towards the exhausted outlets in the washroom and the corridor, through the undercuts of the doors between the living room and washroom and between the living room and corridor. In such a case, the heat exchange efficiency of the total heat exchanger decreases, since the exhaust air from the living room with low temperature cannot exchange heat with the outdoor air. Furthermore, the indoor air cannot be exchanged with fresh outdoor air. Airflow rate, the location of the inlet and outlet and the width of the small openings should be examined.

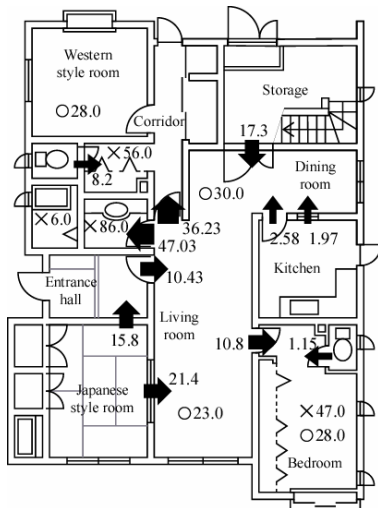


Figure 7 Airflow from inlet and outlet, between rooms



Figure 8 Door between storage and dining rooms (seen from dining room)

4) problems: Measurement of airflow rates through the small openings such as door undercut is quite difficult. Appropriate and simple measuring method and the method of data analysis are required. On the other hand, since cold outdoor air inflow and indoor air temperature distribution can easily be identified by a thermo-camera, an evaluation method of ventilation efficiency could be developed by making use of the thermo-camera.

### 5.3 Floor Heating

1) commissioned items: a) whether the boiler works as specified by the design document, b) whether the hot water pipe is sufficiently insulated c) if the upward and downward heat fluxes from the panel are appropriate, were checked.

2) measured items: In order to check the boiler efficiency, gas consumption (read by gas-meter), the temperature (thermocouples) and flow rate of the hot water (electro-magnetic flow meter) were measured. The insulation was inspected visually and by touching the pipe. The hot water temperatures at the inlet and exit of the panel, water flow rate, the temperatures at the upper and lower surfaces of the floor, and the air temperature both over and under the floor (handy-type thermo-hygrometer), were measured to determine the upward and downward heat flux.

3) results: The monthly energy consumption in 1997<sup>3)</sup>, peaks during winter, especially December and January. Heat loss from the heating systems to the crawl space is the apparent reason. Thus, the temperatures in the crawl space were measured by handy-type thermo-hygrometers. As a result, it was found that the

temperatures of the header and hot water pipes were high and the insulation to the pipes for floor heating was insufficient. Also, a part of the floor insulation (styrol-sponge 60 mm) was not attached as specified in the design document. Therefore, the heat loss through the floor and the downward heat flux from the floor heating panel were estimated to be much larger than expected.

**Figure 9** shows the efficiency of the boiler, heat loss through the piping and the calculated heat flux emitted upward and downward (partly estimated). The heat loss from the piping is significant.

4) problems: A simpler method should be developed for measuring hot water temperature and upward and downward heat flow rate, since the measurements are difficult and time consuming. Also, the performance of the floor heating system might be specified as a catalogue value. The floor heating was measured in detail because there was not good agreement between the measured and calculated heat balance of the whole house. Even a very simple calculation of heat balance provides a lot of information. This can be used effectively for commissioning.

#### 5.4 Central Air-Conditioning System

1) commissioned items: With respect to the central HVAC, a) whether the supplied and exhaust air volume are the design values, b) Whether the air flow rate is appropriately distributed to each room, c) whether the performance of the total heat exchanger satisfies the design requirement, were the main items to be checked. With respect to the fan-coil unit, d) whether the specified performance was realized at the heat-pump, e) whether the pipes for fan-coil units are suitably insulated.

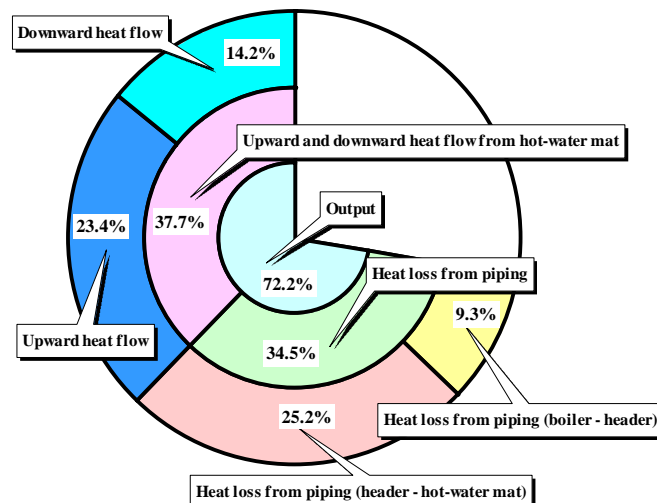


Figure 9 Efficiencies of floor heating system and heat source



2) measured items: The airflow, supply and exhaust air rates were measured by the air flow meter and anemometer. The air temperature and relative humidity were measured at the inlet and outlet of the total heat exchanger by handy-type thermo-hygrometers. With respect to the fan-coil units, the inlet and outlet temperatures and flow rate, and the electricity consumption for the operation of the chiller were also investigated.

3) results: The total of the airflow rate of the supply air was around 200 [m<sup>3</sup>/h], design value. However, total supplied airflow rate is larger than total exhaust air. This might be caused by the clogging of the filters.

During summer, the maker of the chiller checked the performance of the chiller. The overall COP including the pump was between 1.62 and 1.89. Since the input to the pump is 0.3 kW, the COP without pump input ranged 2.09 to 2.37, slightly lower than the rated value. Energy consumption for pumps and fans cannot be neglected even in a residential house.

4) unresolved issues: Although the air temperature and humidity at the inlets and outlets of the total heat exchanger can be easily measured through the openings for check, the measurement of the air flow rates at other inlets and outlets by an anemometer are quite tedious. With respect to the chiller also, the measurement of the water temperature is easy while water flow rate is difficult.

### 5.5 Usage of Resident

1) design intent and commissioned items: solar shading is controlled by suitably operating the electrically driven blind installed on the outside, which also serves as a shutter. During heating and cooling seasons, the minimum volume of outdoor air is introduced, and the windows are designed to be closed in principle.

2) results: The operation panel for the central HVAC systems is not simple to operate, operability should be improved, particularly in the case of elderly residents as in this house. Although the solar shade during summer is quite important in a highly insulated and airtight house, for example, the electrically driven blind was not used in accordance with the design intent. During the air conditioning period, the windows, particularly those at the toilet and bathroom were kept open.

3) Problems: The way the resident actually uses the building may not be included in the commissioning at the operation phase. Contrary to a regular office building where professional operators manage the equipment, residents without professional knowledge usually have to operate the heating and cooling equipment by themselves in a residential house. It is important for the residents to understand the design intent and to know how to operate the equipment to some extent. At the same time, building equipment with good operability and design are required to realize the design intent.

## 6. CONCLUSION

This report presents an example of commissioning a residential house. The

items to be commissioned, measurement methods and the commissioning results are shown. Through the commissioning process, the problems pertaining to residential houses, such as the measurement problems, are clarified and the importance of commissioning established.

Development of a simple and appropriate measuring method, monitoring of energy consumption and the verification of that value based on a standard value, enhancement of the resident's interest in the indoor environment and energy consumption and attention to their life style require future study.

#### **Acknowledgement**

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