EXPERIMENTAL STUDY ON EFFECT OF LOW HUMIDITY PREVENTION STRATEGY IN WINTER IN HIGHLY INSULATED AND AIRTIGHT HOUSE

Tomonari Chiba 1†, Yoichi Sakurai 2, Zhang Huibo 3, Rie Takaki 3, Soung hun Yun 3, and Hiroshi Yoshino 3
1Tohoku Electric Power Co., Inc., Sendai, Japan
2Tohoku Development Consultant Co., Inc., Sendai, Japan
3Department of Architecture & Building Science, Tohoku University, Sendai, Japan

ABSTRACT
As highly insulated and airtight houses have build popularly, the problem which indoor air becomes low humidity in winter, is paid attention. The problem is caused by rise of heating level and increase of ventilation amount by mechanical ventilating equipments, etc.1) Then, to clarify the actual condition of indoor low humidity in winter, we monitored the actual humidity environment in 29 occupied houses in the Tohoku region and Niigata, Japan, from 2001 to 2006. As the result, it is found that the indoor low humidity in winter is a common problem regardless of the house condition. And low humidity prevention strategy is necessary for most of the houses in winter.2) Then, to estimate the quantitative effects of various low humidity prevention strategies, we performed experiments both in the laboratory scale house and the occupied houses. As the result, we quantitatively estimated the humidity rise due to each low humidity prevention strategies such as Total heat exchanger, Foliage plant, Drying laundry, Humidifier, Opening bathtub, and Humidity controlling material.

KEYWORDS
Experiment, low humidity prevention strategy, Highly Insulated and airtight house, Laboratory scale house, Occupied house

INTRODUCTION
Recently, as highly insulated and airtight houses have build, the problem which indoor air becomes low humidity in winter happens. The problem is caused by the rise of the heating level and the increase of ventilation amount by the mechanical ventilating method, etc.1) Then, to clarify the actual condition of indoor low humidity in winter, we monitored the actual humidity environment in 29 occupied houses in the Tohoku region and Niigata, Japan, from 2001 to 2006. As the result, it is found that the indoor low humidity in winter is a common problem regardless of the house condition. And low humidity prevention strategy is necessary for most of the houses in winter.2) Then, this study aims to clarify quantitative effects of various low humidity prevention strategies by the experiment both in laboratory scale house and occupied house.

THE EXPERIMENT IN THE LABORATORY SCALE HOUSE
Method of experiment
To clarify the quantitative effects of low humidity prevention strategies, we performed experiments at two laboratory scale houses (A house and B house) which is the same room size, located in the Research and Development Center of Tohoku Electric Power Co., Inc, Sendai city. The two laboratory houses are adjacent at intervals of 8m and the shades don’t influence each other. The temperature and number of air change for the experiment were set to 22°C by the air conditioner and 0.5 times/hr by the

† Corresponding Author: Tel: +81 22 799 6105, Fax: +81 22 227 5841
E-mail address: w050101@tohoku-epco.co.jp
mechanical ventilation (exhaust) in both A house and B house. Table 1 and Figure 1 show the outline and the plan of laboratory scale houses, and Table 2 shows the experimental conditions. The main measurement items are temperature, humidity, an amount of ventilation, and an amount of humidification (the weight change of humidifying source). We examined the effects of each experimental condition by comparing humidity of A house with that of B house.

Table 1  Laboratory room outline (A house and B house)

<table>
<thead>
<tr>
<th>Location</th>
<th>Built year</th>
<th>Total floor area [m²]</th>
<th>Ventilating system</th>
<th>Over all heat loss coefficient [W/(m²·K)]</th>
<th>Equivalent crack area [cm²/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sendai, Japan</td>
<td>2004</td>
<td>34.9</td>
<td>Mechanical ventilation (Exhaust)</td>
<td>2.12</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 2  Experimental conditions

<table>
<thead>
<tr>
<th>Experiment</th>
<th>A house Ventilating system</th>
<th>Humidifying source</th>
<th>Finish material</th>
<th>B house Ventilating system</th>
<th>Humidifying source</th>
<th>Finish material</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
<td>Natural ventilation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>②</td>
<td>Mechanical ventilation</td>
<td>Constant amount of humidification</td>
<td>Plaster board covered with vinyl cloth</td>
<td>Mechanical ventilation (Exhaust)</td>
<td>Humidifier</td>
<td>Humidity controlling material</td>
</tr>
<tr>
<td>③</td>
<td>Foliage plant</td>
<td>Drying laundry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>④</td>
<td>Drying laundry</td>
<td>Humidifier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>⑤</td>
<td>Opening bathtub with hot water</td>
<td>Humidity controlling material</td>
<td>Plaster board covered with vinyl cloth</td>
<td>Mechanical ventilation (Exhaust)</td>
<td>Humidifier</td>
<td>Humidity controlling material</td>
</tr>
</tbody>
</table>

Experiment ①
To clarify the influence of ventilation, mechanical ventilation in the living room of A house was stopped and it was assumed the natural ventilation. And it was executed under the constant amount of humidification by humidifier in the living room of both A house and B house. Moreover, to measure the amount of humidification, the weight of humidifier was measured by electronic weighing machine.

Experiment ②
To clarify the effect of latent heat recovery, total heat exchanging type ventilating was set up in the living room of A house. And it was executed under the constant amount of humidification by humidifier in the living room of both A house and B house. Moreover, to measure the amount of humidification, the weight of humidifier was measured by electronic weighing machine.

Experiment ③
To clarify the effect of foliage plant, two kapoks (a: Height 1,100mm, Width 600mm, Gross area of leaves 1.3〜1.4m², b: Height 1,100mm, Width 600mm, Gross area of leaves 0.8〜0.9m²), which have the large amount of transpiration3) and common plant in Japan, were set in the living room of A house. And enough water was given for them at nine o’clock every morning. Moreover, to measure the amount of transpiration from two foliage plants, the weight of them was measured by electronic weighing machine.

Experiment ④
To clarify the effect of drying laundry in the room, the laundry was washed and dehydrated with the washing machine, and it was dried in the living room of A house. Moreover, to measure the amount of evaporation from laundry, the weight of laundry was measured by electronic weighing machine. In addition, dry weight of the laundry was about 2kg, and weight after wash and spin-dry was about 3.5kg.
It was assumed the amount of laundry of two persons in accordance with the laboratory house size\(^4\).

**Experiment ④**
To clarify the effect of humidifier, heaterless fan type humidifier (Humidifying capacity 0.67kg/h) was set in the living room of A house and it was driven as the preset relative humidity 55%. Moreover, to measure the amount of humidification, the weight of humidifier was measured by electronic weighing machine.

**Experiment ⑤**
To clarify the effect of opening bathtub with warm water, warm water (43°C) was poured into the bathtub in the bathroom of A house, and the lid of bathtub and the partition doors of each room were opened. Moreover, to assume the amount of evaporation from bathtub with warm water, the container (Surface area 0.60m\(^2\)), which is as high as the bathtub (Surface area 0.60m\(^2\)) and made from styroform, was set in the bathroom of A house. And warm water (43°C) was poured into the container, the weight and the surface temperature of warm water was measured.

**Experiment ⑥**
To clarify the effect of humidity controlling material, zeolite panels were put to the partition wall of the north side in the living room of A house. And the living rooms in both A house and B house were humidified for 12 hours as preset relative humidity 55%.

**Results analysis and discussion**
Table 3 and Figure 2～4 show the mean values of measurement results on experiment ①～⑦ and the change of temperature and relative humidity on the experiment ④～⑥ as representation.

**Table 3  Mean values of measurement results on experiment ①～⑦**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Temperature [℃]</th>
<th>Relative humidity [%]</th>
<th>Absolute humidity [kg/kg']</th>
<th>Amount of ventilation [m³/h]</th>
<th>Amount of humidification [kg/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural ventilation</td>
<td>A house</td>
<td>25.9</td>
<td>68.7</td>
<td>0.014</td>
<td>22.5</td>
</tr>
<tr>
<td></td>
<td>B house Out</td>
<td>22.1</td>
<td>46.6</td>
<td>0.008</td>
<td>19.5</td>
</tr>
<tr>
<td>Total heat exchanger</td>
<td>B house Out</td>
<td>22.9</td>
<td>41.9</td>
<td>0.007</td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>A house</td>
<td>22.9</td>
<td>35.7</td>
<td>0.008</td>
<td>19.3</td>
</tr>
<tr>
<td>Foliage plant</td>
<td>B house Out</td>
<td>22.8</td>
<td>36.5</td>
<td>0.008</td>
<td>22.3</td>
</tr>
<tr>
<td></td>
<td>A house</td>
<td>22.8</td>
<td>36.5</td>
<td>0.008</td>
<td>22.3</td>
</tr>
<tr>
<td>Drying laundry</td>
<td>B house Out</td>
<td>24.2</td>
<td>29.3</td>
<td>0.005</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td>A house</td>
<td>24.2</td>
<td>29.3</td>
<td>0.005</td>
<td>22.0</td>
</tr>
<tr>
<td>Humidifier</td>
<td>B house Out</td>
<td>23.3</td>
<td>27.8</td>
<td>0.008</td>
<td>22.3</td>
</tr>
<tr>
<td></td>
<td>A house</td>
<td>23.3</td>
<td>27.8</td>
<td>0.008</td>
<td>22.3</td>
</tr>
<tr>
<td>Opening bathtub</td>
<td>B house Out</td>
<td>22.6</td>
<td>38.3</td>
<td>0.008</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>A house</td>
<td>22.6</td>
<td>38.3</td>
<td>0.008</td>
<td>22.6</td>
</tr>
<tr>
<td>Humidity controlling material</td>
<td>A house Out</td>
<td>23.5</td>
<td>34.4</td>
<td>0.007</td>
<td>22.5</td>
</tr>
<tr>
<td></td>
<td>B house</td>
<td>23.5</td>
<td>34.4</td>
<td>0.007</td>
<td>22.5</td>
</tr>
</tbody>
</table>

**Experiment ①**
Relative humidity of B house (Mechanical ventilation) was 13.1% lower than that of A house (Natural ventilation) on the average in Table 3. Therefore, it is evidence that ventilation is one of the causes of low humidity. In addition, the amount of ventilation of B house was 22.5 m³/h, and the amount of humidification in A house and B house was 0.15 kg/h on the average.

**Figure 2  Change of temperature and relative humidity (Experiment ④ Drying laundry)**
Experiment ②
Relative humidity of A house (Total heat exchanger) was 5.6% higher than that of B house (Mechanical ventilation) on the average in Table 3, because of the effect of latent heat recovery. In addition, the amount of humidification of A house and B house was 0.15 kg/h. And sensible heat exchange coefficient, latent exchange coefficient and total exchange coefficient were about 75%, 22%, and 59% on the average.

Experiment ③
Relative humidity of A house (Foliage plant) was 5.2% higher than that of B house (Nothing) on the average in Table 3. In addition, the amount of transpiration from foliage plant in A house was 0.01 kg/h on the average.

Experiment ④
Relative humidity of A house (Drying laundry) is 26.4% or less higher than that of B house (Nothing) in Figure 2. Thereby relative humidity was kept within the comfortable range (40~60%) for about 10 hours. In addition, the amount of evaporation from laundry in A house was 0.07 kg/h on the average.

Experiment ⑤
Relative humidity of A house (Humidifier) reached preset relative humidity 55% in about 2 hours, and it was always kept within the comfortable range in Figure 3. In addition, the amount of humidification from humidifier in A house was 0.18 kg/h on the average.

Experiment ⑥
Relative humidity of A house (Opening bathtub with warm water) was 27.6% or less higher than that of B house (Nothing) in Figure 4. Thereby relative humidity was kept within the comfortable range for about 24 hours. In addition, the amount of evaporation from bathtub in A house bathroom was 0.12 kg/h on the average.

Experiment ⑦
Relative humidity of A house (Humidity controlling material on the north partition wall of the living room) was 2.7% higher than that of B house (Plaster board covered with vinyl cloth) on the average after stopping humidifying in Table 3. In addition, the amount of transpiration from foliage plant in A house was 0.01 kg/h on the average. As the main factor of small effect, it is enumerated that the area of the humidity controlling material was only about 14% of all surface areas in living room.

Comparison of effects of each experiment
It is found that the low humidity prevention strategy with the largest effect was humidifier (31.6% rise), and next, opening bathtub (18.8% rise), drying laundry (11.5% rise), total heat exchanger (5.6% rise), foliage plant (5.2% rise), and humidity controlling material (2.7% rise) in table 3. In addition, the influence of ventilation that causes low humidity was 13.1%.

THE EXPERIMENT IN THE OCCUPIED HOUSE

Method of experiment
To verify the effects of low humidity prevention strategies, we performed experiments at the occupied house in Iwanuma, Miyagi. All of the partition doors were always opened, and all of the rooms were heated by a thermal storage heater in the living room. The inhabitants are a man of office worker, a
housewife, a little child and a baby. Table 4 and Figure 5 show the outline and the plan of the house, and Table 5 shows the experimental conditions. The main measurement items are temperature, humidity, and an amount of ventilation. We examined the effects of each experimental condition by comparing humidity of experiment $\text{ⅱ~ⅴ}$ with that of experiment $\text{ⅰ}$.

Table 4 Outline of occupied house

<table>
<thead>
<tr>
<th>Location</th>
<th>Built year</th>
<th>Total floor area $[m^2]$</th>
<th>Ventilating System</th>
<th>Over all heat loss coefficient $[W/(m^2 \cdot K)]$</th>
<th>Equivalent crack area $[cm^2/m^2]$</th>
<th>Number of persons in family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iwanuma, Miyagi</td>
<td>2005</td>
<td>135.4</td>
<td>Mechanical ventilation (Intake and exhaust, Total heat exchanger)</td>
<td>1.06</td>
<td>0.33</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 5 Experimental conditions

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Condition</th>
<th>Position of humidifying source</th>
</tr>
</thead>
<tbody>
<tr>
<td>ⅰ</td>
<td>Present state</td>
<td>—</td>
</tr>
<tr>
<td>ⅱ</td>
<td>Humidifier, Humidifying capacity 0.67kg/h</td>
<td>1F Living room</td>
</tr>
<tr>
<td>ⅲ</td>
<td>Foliage plant Kapok, Height 1,100mm, Width 400mm</td>
<td>1F Living room</td>
</tr>
<tr>
<td>ⅳ</td>
<td>Drying Laundry Dry weight 7kg, Weight after wash and spin-dry 11kg</td>
<td>1F Living room</td>
</tr>
<tr>
<td>ⅴ</td>
<td>Opening bathtub Surface area 0.58 m², Preset temperature 41℃</td>
<td>1F Bathroom</td>
</tr>
</tbody>
</table>

Experiment Ⅰ
The experiment was present state and no low humidity prevention strategy.

Experiment Ⅱ
To verify the effect of humidifier, heaterless fan type humidifier (Humidifying capacity 0.67kg/h) was set in the living room of A house and it was driven as the preset relative humidity 55%.

Experiment Ⅲ
To verify the effect of foliage plant, two kapoks (a: Height 1,100mm, Width 400mm, Gross area of leaves 0.8m², b: Height 1,100mm, Width 400mm, Gross area of leaves 0.8m²) were set in the living room. And enough water was given for them every morning.

Experiment Ⅳ
To verify the effect of drying laundry in the room, the laundry was washed and dehydrated with the washing machine, and it was dried in the living room. In addition, dry weight of the laundry was about 7kg, and weight after wash and spin-dry was about 11kg.

Experiment Ⅴ
To verify the effect of opening bathtub with warm water, the lid of bathtub and the partition doors of each room were opened after all of the family bathed. In addition, preset temperature of warm water was 41℃ before all of the family bathed.
Results analysis and discussion

Figure 6 shows temperature, relative humidity, absolute humidity, and absolute humidity difference (room - out) (the minimum, maximum, mean, standard deviation values) on experiment i ~ v. And Figure 8 ~ 10 show the change of temperature and relative humidity on the experiment ii, iv, v as representation.

Experiment i
Relative humidity of 1F living room and 2F hall is lower than the comfortable range, and it is low humidity on the average in Figure 6.

Experiment ii
Relative humidity of both 1F living room and 2F hall was always kept within the comfortable range because of using humidifier in Figure 6~7. Therefore it is found that the effect of humidifier at 1F living room influence 2F hall.

Experiment iii
The effect of the foliage plant couldn’t be confirmed clearly in Figure 6.

Experiment iv
Relative humidity of 1F living room and 2F hall was kept within the comfortable range from 9 to 13 after drying laundry in Figure 8.

Experiment v
Relative humidity of 1F living room and 2F hall was kept within the comfortable range from 18 to 6 by opening bathtub after all of the families had taken a bath in Figure 9.

Comparison of effects of each experiment
It is found that the strategy with the largest effect was humidifiers, and secondly, opening bathtub, drying laundry, and foliage plant in Figure 6. It is accordance with the experiment results in the laboratory scale house. In addition, the amount of ventilation in the house was 136.3m³/h (0.35 times/h).

CONCLUSION
The influence of ventilation that causes low humidity and the humidity rise effects of each low humidity prevention strategies
such as Total heat exchanger, Foliage plant, Drying laundry, Humidifier, Opening bathtub, and Humidity controlling material, were quantitatively clarified by the experiments in the laboratory scale house and the occupied house.

REFERENCES

NOTES
1. The amount of evaporation was assumed from equation (1)~(3).
   (1) \( E = \alpha W \cdot (X_s - X_a) \cdot A \)
   (2) \( E' = \alpha W \cdot (X_s' - X_a) \cdot A' \)
   (3) \( E' = E \cdot A' \cdot (X_s' - X_a) / (A \cdot (X_s - X_a)) \)

\( E \) : The amount of evaporation from water surface in the container [g/h], \( \alpha W \) : Humidity transfer coefficient [g/㎡·h·mmHg], \( X_s \) : Saturation absolute humidity to temperature of water surface in the container [g/kg], \( X_s' \) : Saturation absolute humidity to temperature of water surface in the bathtub [g/kg], \( A \) : Water surface area of container [㎡], \( A' \) : Water surface area of bathtub [㎡]