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# A measurement of water vapor generation rate for various activities in a multi-residential building in Korea

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**Abstract**

Recently condensation and mold problems have been reported frequently in modern residential buildings with air-tightened and insulated compared to the traditional housing in Korea. The condensation in residential buildings can be solved by controlling the humidity level or surface temperature. The purpose of this study is to develop the ventilation system to prevent condensation in residential building. In this study, the water vapor generation rates were measured by field measurement considering the life style and building conditions of Korean households. Field measurements were conducted in 148.5m$^2$ of the residential building. Relative humidity and temperature were recorded to analyze the water vapor generation rate by various household activities. Shower, bathing, cooking, drying laundry were specified as moisture generating activities in Korean households. Indoor moisture generation rates were calculated from the measured relative humidity data. The moisture generation rate was 358.1g/h, 153.2g/h, respectively in case of the shower and bath. The moisture generation rate was about 567.8g/h in cooking, and about 173.6g/h in laundry drying. The moisture generation rates suggested in this study were somewhat lower than those of the previous studies. However this results reflects the Korean life-style and residential building characteristics.

.***Keywords - Condensation, Field measurement, Multi-residential building, Water vapor generation rate***

## 1. Introduction

Thermal insulation and air tightness of building envelopes were strengthened to improve thermal comfort, energy efficiency and indoor air quality (IAQ). Energy recovery ventilator (ERV) is required in residential building in Korea in terms of IAQ and energy saving [1]. However new problems are reported in Korean modernized residential buildings in winter such as condensation. Condensation is caused by the low insulation level of the building envelope and excessive generation of indoor water vapor. Even though the insulation level is good, condensation can be occurred due to the high humidity level in room. Because of the condensation is related to surface temperature and indoor humidity. Korean government has established the standard to prohibit the condensation in multi-residential buildings [2]. The insulation performance has strengthened to raise the surface temperature of envelope as a countermeasure of the condensation in Korea. But, the condensation problems are still reported in residential buildings in winter. Therefore, indoor moisture generation is an important factor to control the condensation problems in residential buildings.

Some researchers and institute suggested the moisture generation rates according to the various indoor activities [3]. The results were suggested by various measurement conditions such as measurement methods, measurement periods, test houses, family member etc. The values for the same activity have wide ranges. Moisture generation rates for shower are 110~800g/person · day, 27.5~600g/person · day for bathe, 529~3000g/day for cooking and 1750~11970g/day for laundry drying. This is because the indoor water vapor generation rates and its behavior could be varied depending on the culture and residential styles of each country.

The purpose of this study was to develop the ventilation system capable of preventing the condensation by controlling the indoor humidity level. To make a control algorithm of the ventilation system, it was required to investigate the moisture generation rates by various activities in Korean households because it is difficult to apply the indoor moisture generation rates suggested by conventional studies. Some Korean researchers examined the amount of water vapor in actual apartment building where people were living [4]. However the reason why the moisture level was formed and the generation rates didn't suggest yet.

In this paper, the moisture generation rates according to the various household activities in a multi residential building in Korea were measured and analyzed.

## 2. Method

The field measurements were accomplished during two months, January to February, 2015. The analyzed house is located at Songdo, Korea. The analyzed house was built on the basis of Korean Building Energy Conservation Design Standards, total floor area is 149$m^2$. Fig. 1 shows the floor plan and sensor installation location in the analyzed house. Portable data-logger (Testo175H1) capable of simultaneously recording the temperature and relative humidity was used. The measurement interval was one minute, and the data-logger was installed at three points as shown in Fig 1.

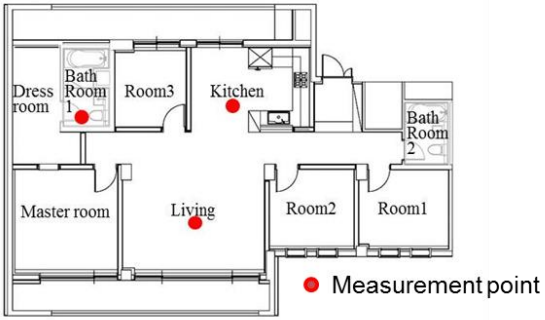


Fig. 1 Plan of the analyzed house and measurement points

Measurement cases are shown in Table 1. Measurements of the moisture generation rates were conducted for four activities; shower, bath, cooking, clothes drying, these are main activities that release the moisture indoors in Korean residential buildings. Shower and bath were accomplished for about 20 minutes based on the Lifestyle Survey Report in Korea [5]. The experiments for shower and bath were conducted 5 times, respectively and the measurements were continued until the humidity level in the bathroom dropped to a constant level. In case of cooking, kimchi and soybean-paste stew are popular in Korean. About 1L of water is used for stew cooking. The experiment for cooking, about 1L of the cold water in the pot was boiled for 30 minutes to reproduce the stew cooking. The weight of pot before and after cooking was measured to determine the moisture generation in cooking. The experiment for cooking was conducted twice. In case of drying laundry, about 3kg of laundry was dried. The check to see that the laundries are dry throughout was based on the feel of fluffy. Also the weight of laundry was measured before and after drying, and this experiment were conducted twice. All doors were closed and exhaust fans in bath room were not operated because the purpose of these experiments was to investigate the water vapor generation rate in a various activities.

Table 1. Measurement cases

| Case | Activity | Fan | Door | Measurement items |
|---|---|---|---|---|
| 1 | Shower | Off | Close | Absolute humidity, temperature, water vapor generation rate |
| 2 | Bath | | | |
| 3 | Cooking | | | |
| 4 | Laundry Drying | | | Absolute humidity, temperature, water vapor generation rate, weight |

## 3. Results and discussion

Moisture generation rate for shower and bath are summarized in Table 2. The amount of moisture generated from shower was about 125.3g/once (358.1g/h), while the moisture generation rate from bath was about 51.1g/once (153.2g/h).

Figure 2 illustrates the characteristic of moisture generation rate in the shower. During the first 5minutes, the moisture generation rates were increased rapidly, while there was no more increase for the rest 15minutes. Figure 3 shows the relative humidity changes in the shower in bathroom. As shown in Fig. 3, the relative humidity of the bathroom was rapidly increased for the first 5 minutes and then the relative humidity level remained relatively constant for the latter 15 minutes. This is because the inside of the bathroom was already reached at the moisture saturation condition in 5minutes and the generated water vapor after saturation was turn into the condensation liquid watery.

The characteristic of the water vapor generation during bath is shown in Fig. 4. The moisture generation behavior in the bath has different appearance from the shower. Water molecules are diffused in the air as a fine flow in case of the shower, while the water is filled in the tub and evaporates and diffuses from water surface in case of the bath. As result, the water vapor slowly diffuses and the humidity does not reach to the saturation condition. However, the moisture generated steadily in case of the bath as show in Fig. 5.

The moisture generation rates for shower and bath suggested by previous studies were 110~800g/person·day, 27.5~600g/person·day, respectively, and the range was very wide. The moisture generation rates suggested by this study were to a somewhat less degree compared to the results suggested by prior studies. Indoor moisture content could be different values according to the temperature of water, shower habit, bathroom envelope material, time for shower and bath, presence of towel, etc.

Table 2. Moisture generation rate for shower

| | 1st | 2nd | 3rd | 4th | 5th | Avg. |
|---|---|---|---|---|---|---|
| g/once (20 min.) | 132.0 | 135.7 | 140.0 | 116.1 | 102.5 | 125.3 |
| g/h | 378.1 | 387.8 | 399.9 | 331.6 | 293.0 | 358.1 |

Table 3. Moisture generation rate for bath

| | 1st | 2nd | 3rd | 4th | 5th | Avg. |
|---|---|---|---|---|---|---|
| g/once (20 min.) | 51.3 | 34.1 | 74.2 | 52.6 | 43.1 | 51.1 |
| g/h | 153.8 | 102.4 | 222.5 | 157.7 | 129.4 | 153.2 |

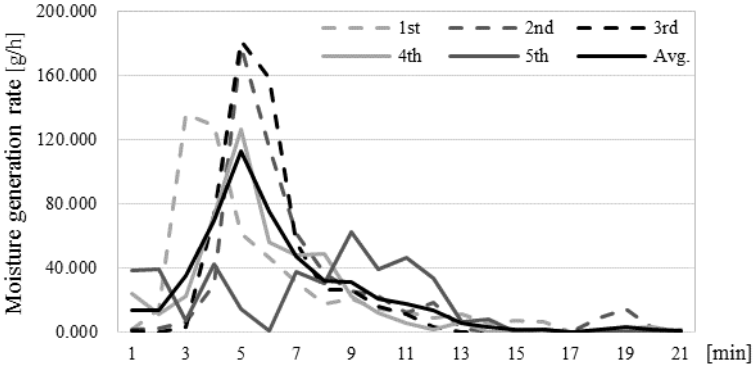


Fig. 2. Water vapor generation characteristic during the shower

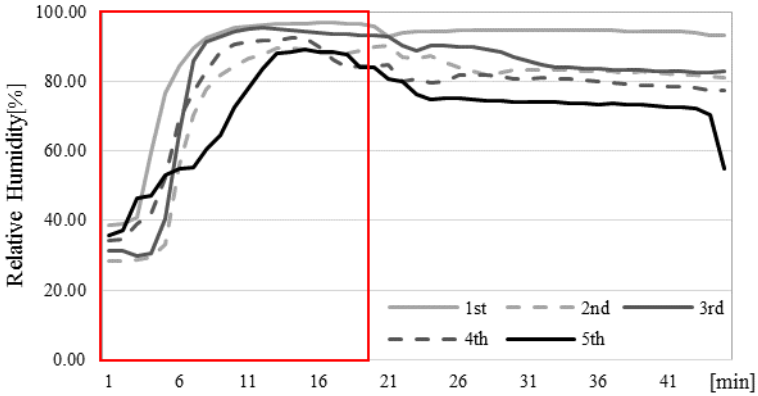


Fig. 3. Relative humidity changes in the bathroom during the shower

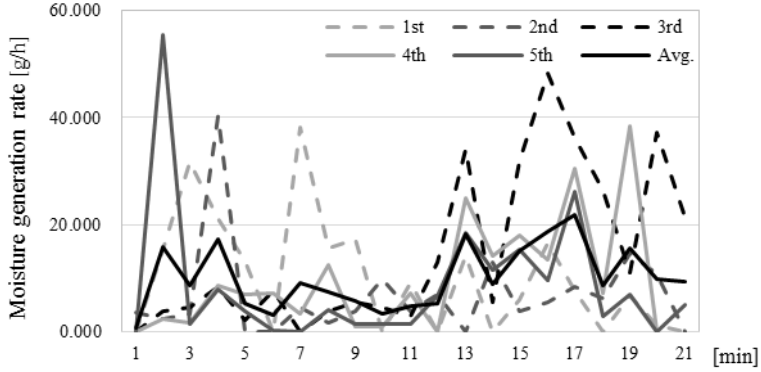


Fig. 4. Water vapor generation characteristic during bath

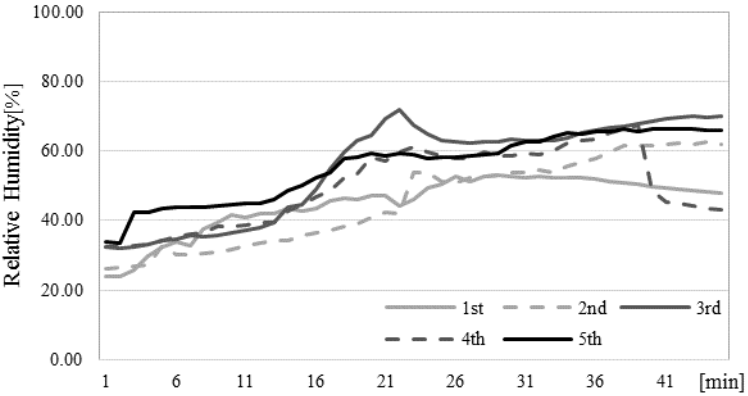


Fig. 5. Relative humidity changes in the bathroom during bath

Table 4. Moisture generation rate for cooking

| | Before | After | g/once | g/h |
|---|---|---|---|---|
| 1st | 1,152 | 885.9 | 275.6 | 532.2 |
| 2nd | 1,205 | 903.3 | 305.4 | 603.4 |
| Avg. | - | - | 290.5 | 567.8 |

Table 5. Moisture generation rate for laundry drying

| | Before | After | g/once | g/h |
|---|---|---|---|---|
| 1st | 5,620 | 3,996.5 | 1,623.5 | 162.4 |
| 2nd | 5,604 | 3,940.4 | 1,663.6 | 184.8 |
| Avg. | - | - | 1,643.6 | 173.6 |

To measure the moisture generation rate during cooking, the differences between the initial and final weights of the pot were measured when the moisture rate was zero, about 1 hour after cooking. The loss of the weight after cooking was 290.5g/once and it can be converted as 567.8g/h in average. The moisture generation rates caused by cooking suggested by prior researches are 529~3000g/day and it also has the wide range of values. The generation rate deduced from this measurement is within this range but to a less degree. However most of the foreign results were resulted from a meal for a family four, so the values could be higher than the values from this study.

Generally, laundry drying can be ignored from the contribution of indoor moisture content in western countries because the laundry is rarely dried inside and most of the households have a separated drying room. However, in case of Korean housing, indoor moisture generation rate by clothes drying could be crucial because most of Korean households dry laundries in the living room especially in winter due to the cold weather. Moisture generation rate comes from laundry drying is shown in Table 8. For measuring the moisture generation rates for laundry drying, the difference between the initial and final weights of laundries was measured. The moisture generation rate was 1643.6g/drying (173.6g/h) on the average.

Existing results of moisture generation rate for laundry drying are 1,750~11,970g/day which has a wide range of values, and its results also vary depending on lifestyle e.g. load of the laundry, mode of spin and fabric of clothes. The results suggested by this study were somewhat less degree but the generation rate between the prior studies and this study for laundry drying are a very close result.

## 4. Conclusin

In this study, the water vapor generation rates were measured by field measurement considering the life style and building conditions of the Korean households. Field measurements were conducted in a residential building, and shower, bathing, cooking, drying laundry were specified as moisture generating activities in Korean households. The results deduced from this study as follows;

The moisture generation rates for the shower and bath were 358.1g/h, 153.2g/h, respectively. Also, the moisture generation rate was about 567.8g/h in cooking and 73.6g/h in laundry drying. The moisture generation rates suggested in this study were somewhat lower than those of the previous studies. However, these results were reflected the life-style and residential building characteristics in Korea. The results can be used in comparison with the other countries. Also, the results deduced from this study will be used as boundary conditions for simulation to investigate the indoor moisture generation and its diffusion characteristics.


## Acknowledgment

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