

AMOUNT OF MOISTURE PRODUCTION AND FIELD MEASUREMENT IN DRESSING ROOM

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ABSTRACT

In recent years, occupants conduct various behaviors in the appurtenant dressing room, so it is important to know the amount of modern moisture production in the appurtenant dressing room. Investigation data showed amount of moisture production caused by the behaviors in the dressing room did not differ between males and females, and amount of moisture production caused by washing clothes and drying clothes did differ depending on the equipment. During winter the thermal environment in the dressing rooms were measured and field measurement data showed the type of ventilation system of the dressing room and the duration of ventilating time were important to maintain a desirable environment.

KEYWORDS

Moisture production, dressing room, ventilation, basic unit, field measurement

INTRODUCTION

The amount of moisture production by bathing was provided as previously reported¹⁾. Yet, there are several other sources of moisture production around the bathroom besides bathing. But the publicized data^{2) 3) 4)} of the basic unit of the amount of moisture production is several decades old and provides very little data which includes detailed information on measurement methods. Therefore, in order to investigate the amount of moisture production with recent human behaviors around the bathroom, this paper reports on results regarding the amount of moisture production due to human behavior mainly within the appurtenant dressing room.

EXPERIMENT SUMMARY

Moisture sources and experiment conditions for measuring moisture production are shown in Table 1. The categories; "shampooing", "drying hair" and "dressing" as human behaviors related moisture production and also "washing clothes", "drying clothes" for moisture production which does not involve human behavior were chosen for measurements. The ventilation was also adjusted to prevent any condensation that may occur on the surface of the walls in the bathroom as an experimental chamber and when the ventilation was turned off, the vent on the bathroom door and the surrounding of the door were covered. The external temperature and humidity around the bathroom were kept to 20°C and 50% respectively.

Shampooing, Drying Hair and Dressing

Five healthy males and females, all in their 20s, were chosen as a total of 10 subjects. These subjects acted as they usually did. Photos of measurement and equipments are shown in Photo 1. A simple wash stand was placed in the bathroom for shampooing and dressing, considering that shampooing

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and dressing would take place at the dresser/wash stand in the appurtenant dressing room. The water temperature was adjusted to 40°C and the water was supplied from the shower in the bathroom. The water from the simple wash stand flowed directly into the drain in the bathroom and not remained into the bathroom. Since the length of the hair of the subjects was also expected to influence the amount of moisture production, the length of hair between the whirl on the top of the head to the neck was previously measured to find a representative value. Males that participated varied between 20-25cm (average 22.6cm) and as for females 27-48cm. There was no significant difference between the males subjects. The female average was 16cm greater than that of the male and even differed as much as 19cm among individuals.

1) Shampooing; A shampoo was used and the duration was determined by the subjects as they usually did so. The time of beginning of shampooing and the end, in which the subject wiped their hair with a towel, was announced through an intercom located in the bathroom.

2) Drying hair; The subjects placed a shower cap on their head after shampooing to prevent any moisture from evaporating. The experiment started as shower cap was taken off and the subject used the hair dryer, and measurements were performed till the subjects decided that their hair was dry. A hair dryer with the 2 modes, 1200w and 600w, was used. The duration and method of drying was determined by the subjects.

3) Dressing; The following series of activities; rinsing to fix hair, drying hair, washing the face, brushing the teeth, shaving (male), makeup (female), were performed in consideration of typical behaviors within the appurtenant dressing room in the morning. The duration and sequence of the activities were determined by the subject and reported by intercom.

Table 1 Moisture sources and experiment conditions for measuring moisture production

Moisture source	Factor	Condition
Shampooing	Time	Depending on subjects
	Shampoo	Using
	Temp. of hot water	40°C
	Water consumption	Depending on subjects (weight of exhaust water measured)
Drying hair	Time	Depending on subjects
	Electric consumption	1200 or 600 W
	Temp. of hot water	40°C
Dressing	Action(male)	Combing, setting hair by dryer, washing face, teething, shaving
	Action(female)	Combing, setting hair by dryer, washing face, teething, make-up
	Time/procedure	Depending on subjects
	Water consumption	Depending on subjects (weight of exhaust water measured)
Washing clothes	Supply water temperature	15°C, 22°C, 30°C
	Volume of washed clothes	Clothes for 2 people
	Water consumption	Measuring weight of exhaust water
Drying clothes	Volume of dried clothes	Clothes for 1 people
	Drying duration	90 min.
	Volume of exhaust water	Measuring weight of exhaust water

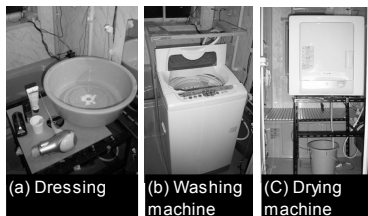


Photo 1 Equipments for measuring

Washing Clothes and Drying Clothes

The washing machine and drying machine were placed in the bathroom. The standard models for laundry are shown in Table 2, Photo 2.

1) Washing Clothes; Clothes, assumed to amount for 2 people, were washed. The average washing capacity of the washing machine was 4.2kg, which is a fully automatic and washes with a whirling process. The conditions for the standard was, 'standard mode' (wash, rinse twice, spin-dry) with 43 liters of tap water at 22°C. Other conditions include the use of remaining water in the bath tub (30°C) and changing the level of water to 37 liters, which resulted a total of 6 measurements. Furthermore, to examine the reliability of the reproduction of the experiment and the difference in moisture production by washing machine, a machine with an average washing load of 5.0kg was operated on standard mode with 49 liters of water for 4 times and another machine with 48 liters of water on standard mode for 3 times. Measurements were performed on 3 kinds of machines and 13 different conditions. Measurements were taken for laundry that was hand washed in a wash tub to compare with former research⁶⁾. Washed under the following two condition, with tap water (15°C) and warm water (30°C), measurements were taken place with laundry amounting for two people, till the laundry was squeezed with the hands for drying.

2) Drying Clothes; Clothes assumed to amount for one person was placed in the dryer for drying. A dryer with a drying capacity of 3.0kg and 4.0kg was used for a period of 90 minutes, provided by preliminary test results. The test started after the clothes were spin-dried in the washer. The weight difference of the clothes and water which drained from the dryer was also measured. As with the washing machine, to examine the difference in moisture production between different dryers, measurements were performed in 9 different conditions using 3 different dryers.

Table 2 Standard model for washed clothes

Kind of clothes	Number for	
	1 people	2 people
Y-shirt	1	2
T-shirt	1	2
Thick pajamas	1 set	2 sets
Thin pajamas	-	1 set
Sox	1 pair	2 pairs
Under wear	1	2
Bath towel	1	1
Towel	-	1
Pillow cover	1	2



Photo 2 Standard model for laundry (for 2 people)

Calculation for Moisture Production from the Human Body

Moisture production from the body is calculated by the 'volume of total loss by evaporation'. 'Volume of total loss by evaporation' is found by the sum of the volume of evaporation by heat loss of the skin and

the volume of evaporation caused by respiration⁶⁾. The SET⁺ calculation program of Gagge et al⁷⁾ was used to calculate the volume of evaporation by heat loss of the skin and the volume of evaporation caused by respiration.

Conditions for calculation of volume of total loss by evaporation are shown in Table 3. Air temperature is 20°C, 22°C, 25°C, 26°C and 27°C, five conditions. Relative humidity was set at 50%, in which the radiating temperature was equal to air temperature. The air current was considered to be calm and thus set at 0.1m/s. Metabolic volume was calculated in consideration that shampooing, drying hair and dressing to be similar as standing calmly and walking as researched in the past study^{8) 9)} to be 1.4 met. For the amount of surface of clothes worn, the value for SET⁺ was set as neutral (23.9°C) when the temperature was 25°C and when the other input from the categories were under the same conditions. The area of body surface was calculated by utilizing the Du Bois formula¹⁰⁾ with the average height and weight in the database¹¹⁾ for human body measurements performed in 1992 on 505 youths. No external work was performed.

By calculating total evaporation by heat loss with the SET⁺ calculation program, evaporation was calculated to be 674 W·h/kg¹²⁾. With this value, the basic unit of the amount of moisture production (g/h) was calculated. The calculation results of moisture production from the human body are shown in Table 4.

Table 3 Conditions for calculation of moisture production from human

Air temperature	20°C, 22°C, 25°C, 26°C, 27°C
Radiation temp.	Equivalent to air temp.
Relative hum.	50 % rh
Air velocity	0.1 m/s
Metabolic ratio	1.4 met
Clo	Value that make SET* in case of 25°C neutral(23.9°C)
Weight	63.3 kg(male), 52.6 kg(female)
Surface area of human	1.74 m ² (male), 1.52 m ² (female)
External work	0 W/m ²

Table 4 Basic unit of moisture production from human, g/h

Air temperature	20°C	22°C	25°C	26°C	27°C
Male	42	43	72	83	95
Female	37	38	63	73	83

MEASUREMENT RESULTS

Measurement Results for Shampooing, Drying Hair and Dressing

Shampooing, drying hair and dressing results are shown in Table 5. Table 5 (1) represents results of the amount of moisture production in the bathroom including moisture production from the human body and (2) represents calculated results without moisture production from the human body with Table 4 and the measured average of temperature and humidity.

1) Shampooing; The amount of moisture production by shampooing, including moisture production from the human body, was 34-74g for males (50g average) and 34-89g for females (58g average). Average duration of shampooing was 7 minutes for males and 9 minutes for females. Since the females had longer hair than males, the duration of shampooing for females was 2 minutes longer. The basic unit of the amount of moisture production, including moisture production from the human body, was 256-489g/h (400g/h average). Although the difference was insignificant between males and females, it was suspected that the amount of hot water used and the manner of shampooing had a significant

influence on the results.

2) Drying Hair; The values of moisture production for drying hair, including moisture production from the human body, are 13-17g (15g average) for males and 25-59g (44g average) for females. Moisture production was 3 times greater for females than males, showing a significant difference between the two. Average duration of drying hair was 2 minutes for males and 6 minutes for females. The female average was 3 times greater than that of males, reflecting the fact that the time required to dry hair varied by hair length, which also influenced moisture production. The basic unit of the amount of moisture production, including moisture production from the human body, was 308-557g/h (414g/h average). The difference between males and females was insignificant.

According to the research performed by Muro et al³⁾, the average time required for drying hair for females was 9 minutes and 6 minutes for males, which was slightly longer than the findings in this experiment. Furthermore, the amount of moisture production by drying hair was 28.3g, which was less than the findings in this experiment. Like the research of Muro et al, the data provided for drying hair in the 'Kenchiku Shiryō shūsei'²⁾(176.4g/h) was less than the findings in this experiment.

3) Dressing; Duration for males was 9-15 minutes (average of 12 minutes) and 13-29 minutes (average of 22 minutes) for females. Thus, females required more time than males for dressing. The difference in water usage was insignificant since males used an average of 12 liters of water and females used an average of 11 liters. The moisture production including moisture production from the body for females was 34g greater on average than males, as the amount for males were 30-79g (53g average) and 45-132g (87g average) for females. Since females spent more time for dressing, the moisture production was expected to be greater. As with shampooing and drying hair, the difference in the basic unit of the amount of moisture production, which was 178-331g/h (248g/h average), did not differ much between the male subjects and the female subjects. It was evident that the basic unit of the amount of moisture production was greater for subjects that used the much water, rather than the difference between male and female.

Table 5 Results of moisture production for shampooing, drying hair, dressing

		Consumed water volume, L		Operated time, min		Amount of moisture production, g (1)		Amount of moisture production, g (2)		Basic unit of moisture production, g/h (1)		Basic unit of moisture production, g/h (2)	
		Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Shampooing	Male	25	18~33	7	5~11	50	34~74	44	30~65	400	256~489	356	218~452
	Female	20	15~27	9	7~12	58	34~89	52	30~82				
Drying hair	Male	-		2	2~3	15	13~17	12	11~14	414	308~557	347	253~494
	Female	-		6	5~8	44	25~59	38	20~52				
Dressing	Male	12	4~21	12	9~15	53	30~79	42	22~64	248	178~331	195	126~228
	Female	11	8~15	22	13~29	87	22~64	69	36~107				

(1): including moisture production from human, (2): without moisture production from human

Measurement Results for Washing Clothes and Drying Clothes

Measurement results for washing clothes and drying clothes are shown in Table 6.

1) Washing Clothes; The average for the amount of consumed water and duration of washing clothes was 136 liters and 50 minutes respectively. The amount of moisture production of a model with the capacity of 4.2kg with water was 33g on average and the average for warm water was 36g. The average was 24g for a model with the capacity of 5.0kg. The basic unit of the amount of moisture production for each condition was 37g/h, 44g/h and 30g/h respectively. The average of all conditions for the amount of moisture production was 28g for washing. Also, since the model with a capacity of 4.2kg produced as much as 10.6g more moisture production than the one with a capacity of 5.0kg, it was concluded that the amount of moisture production for washing clothes was influenced by the

performance of the machine rather than water temperature and the volume of water or laundry. Reproduction rate was 95-99%. The ratio of the amount of consumed water measured by flow meter to the sum of the amount of water drained from washing clothes, amount of water from clothes and amount of moisture production was 92-100%, so the measurements were considered reasonable. The amount of moisture production by hand washing clothes, not including moisture production from the body, was 64g/h for cold water and 124g/h for warm water. The basic unit of the amount of moisture production for cold water was 79g/h and 158g/h for warm water, which was practically the same as Muro's finding of 150g/h.

2) Drying Clothes; When drying clothes, the average amount of moisture production of a model with the capacity of 3.0kg was 405g and the basic unit of the amount of moisture production was 270g/h. For a model with a capacity of 4.0kg the results were 389g and 260g/h respectively. In comparison of the total amount of moisture production, the maximum difference by model was 50g which proved to be insignificant. The measurements were considered reasonable with reproduction between 97-99%, a figure of 94-103% was confirmed by balancing the input and output of the sum of; the weight difference of the laundry, amount of water drained by drying and amount of moisture production. Also there was a significant difference with Muroga⁵⁾ finding of 2,680g/h. It was guessed that drying machine at that time was an old type, and had a little ability to drain.

Amount of Moisture Production in the Appurtenant Dressing Room

The basic unit of the amount of moisture production was about 400g for shampooing and drying hair, about 250g for dressing and drying clothes and about 35g for washing clothes. Investigation data showed that the amount of moisture production for drying clothes, 405g, exceptionally was large as one behavior in the appurtenant dressing room.

Table 6 Results of moisture production for washing clothes, drying clothes

	Consumed water volume, L		Operated time, min.		Amount of moisture production, g		Basic unit of moisture production, g/h	
	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Washing clothes	138	112~174	50	43~60	28	22~39	34	24~45
Drying clothes	-			90	405	370~445	270	247~297

FIELD MEASUREMENT OF THE ACTUAL ENVIRONMENT AROUND THE BATHROOM DURING WINTER

It is clear by the previous heading that a great deal of moisture is produced in the appurtenant dressing room. Therefore, the investigation of the actual thermal environment and humidity around the appurtenant dressing room in actual households was performed.

Measurement Summary

The field measurement was taken place voluntarily from December 9, 2005 to January 4, 2006. A total of 11 households were chosen for investigation in which 4 of the subjects were single about the age of college students which lived in the suburbs of Tokyo and 7 subjects which lived with their family. This paper focused on the difference in ventilation systems between households, thus the data in the ventilation system of 4 out of the 11 households was described on. The investigation period and lifestyle of 4 subjects are shown in Table 7. The usage and configuration of the subjects' bathroom and appurtenant dressing room were also investigated. All subjects reported up on the dimensions of the bathroom and appurtenant dressing room, the dimension and type of door, whether or not a ventilation system was present, if there was a window or not and whether a washing machine and/or dryer is used in the appurtenant dressing room.

Table 7 Specific of field measurement

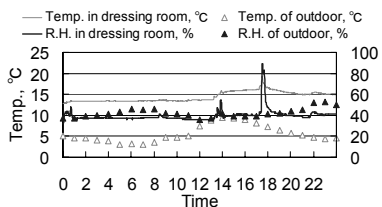
House	Measurement period	Number of living people	House Build in years ago	Ventilation Equipment	
				In dressing room	In bathroom
A	12/9~13	1	12	not equipped	equipped
B	12/16~20	3	13	not equipped	equipped
C	12/23~27	2	24	not equipped	equipped
D	12/31~1/4	3	7	equipped	equipped

Measurement Method

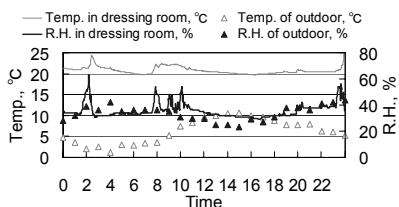
The Thermo Recorder was handed to the subjects to place at a height of 1100mm in the appurtenant dressing room of their house to measure the temperature and humidity. The measurement period differed by subject, but each of the measurements was performed during 5 continuous days. Sampling intervals were set for each 1 minute. For the subjects that lived alone and did not have an appurtenant dressing room, measurements were taken place where subjects changed their clothes before and after bathing.

Temperature and Humidity Measurement Results

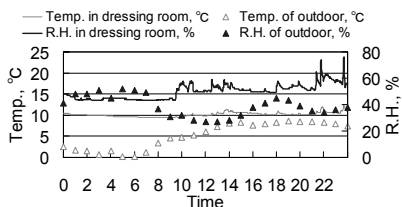
The temperature and the relative humidity of the appurtenant dressing room, along with the exterior temperature and relative humidity in residences A, B, C and D are shown in Figure 1.



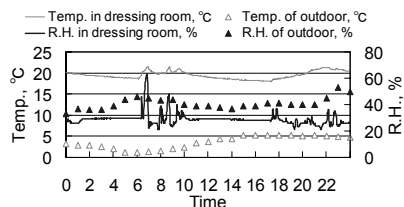
(a) House A (bathroom ventilation operated during 24h)



(b) House B (bathroom ventilation operated after bathing)



(c) House C (naturally ventilated in bathroom after bathing)



(d) House D (bathroom and dressing room ventilation operated)

Figure 1. Results of temperature and relative humidity in actual residential houses

The data shown in Figure 1 is a representative day among the 5 days, since the measurements of the temperature and humidity in the appurtenant dressing room or each of the residents did not vary much from day to day. The hourly data¹³⁾ for exterior temperature and humidity of Tokyo was collected from the Meteorological Agency.

It was confirmed that moisture was produced in the appurtenant dressing room several times a day in

all houses. It was considered that the influence of changes in exterior temperature and humidity on the temperature and humidity of the appurtenant dressing room was slight.

Although, there was no ventilation system in the appurtenant dressing room of residence A, the 24 hour ventilation system in the bathroom removed the moisture produced in the appurtenant dressing room in a short period of time. Since there was no ventilation system in residence B and the ventilation in the bathroom was only turned on after bathing, the humidity remained higher for an extended period of time than residence A. As for residence C, there was no ventilation system in the appurtenant dressing room and the window was left open in the bathroom after bathing for ventilation, thus the humidity remained high in the appurtenant dressing room for an extended period of time. There was a ventilation system in residence D, therefore the moisture produced was removed immediately.

It was concluded that in an actual house, moisture produced in the appurtenant dressing room did not remain for an extended period of time if the ventilation in the bathroom was operated for 24 hours or ventilation in the appurtenant dressing room was used. For those houses without a ventilation system in the appurtenant dressing room or those which used the ventilation after bathing only, the humidity by moisture produced in the appurtenant dressing room remained high for an extended period of time.

CONCLUSIONS

- (1)The basic unit of the amount of moisture production, including moisture production from the human body for washing hair was 256-489g/h (average of 400g/h), for drying hair; 308-557g/h (average of 414g/h), for dressing; 178-331 g/h (average of 248g/h).
- (2)The basic unit of the amount of moisture production for washing clothes was 24-45g/h (average of 34g/h), drying clothes; 247-297g/h (average of 270g/h), which differed by the model of the machine.
- (3)The moisture produced in an actual house did not remain for an extended period of time when the ventilation in the bathroom was operated on for 24 hours or the ventilation in the appurtenant dressing room was turned on.

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