Issues on humidity environment and health problem

Hiroshi Yoshino*[1], and Kenichi Hasegawa[2]

1 Emeritus Professor, Tohoku University
Kasuga-machi Fine Bldg. 4F, Kasuga-machi, Aoba, Sendai,Japan
** yoshino@sabine.pln.archi.tohoku.ac.jp*

2 Akita Prefectural University
84-4 Ebinokuchi, Yurihonjo, AKita, Japan

ABSTRACT

Japan is characterized by high humidity in summer and low humidity in winter. Therefore, summer is in a climatic condition where mold is easy to grow, and in fact, mold damage is occurring. Due to improvement of the thermal insulation and airtightness of houses, the temperature in the room is maintained high even in winter, and mold damage occurs. We will introduce the research we have conducted regarding humidity environment and health problems, and discuss future subjects. The outline is as follows.

1. The results of long-term measurements on the temperature and humidity environment of houses in regions with different climatic conditions are shown, and it is stated that the humidity environment is significantly different in each region and house. In addition, the mold index was used to investigate the possibility of mold generation.
2. A survey was conducted on approximately 5,000 homes nationwide regarding the relationship between dampness and children's health. Condensation and mold often occur on the surfaces of the outer walls, window glass, and windows frames. It was found that the higher the dampness index based on condensation and mold occurrence, the more the prevalence of allergic diseases such as allergic rhinitis and atopic rhinitis.
3. A survey on relationship of low humidity with dryness and health effects in winter was conducted on approximately 4,000 houses nationwide. As a result, the rate of feeling dryness was about 60%, and the rate of responding that health was affected was 23% of the whole. However, there are occupants that feel dryness even in houses with high relative humidity, and it is found that the feeling of dryness is not always due to low humidity. It is also found that the effect of air pollution cannot be ignored.
4. From the above, it is necessary to improve the thermal insulation performance to solve the problem of dampness, and controls of humidity and air quality are important to prevent a sense of dryness. Also it is noted that the factors affecting the feeling dry need to be further studied.

KEYWORDS

Humidity, Dry, Indoor, Environment, Health

1 INTRODUCTION

The climatic conditions of Japan are characterized by high temperature and humidity in summer, but low temperature and humidity in winter. Therefore, summer has a situation where mold is easy to grow, and the issue of mold damage is commonly found in many houses. In addition, due to the influence of thermal insulation and airtightness in modern building design, the room temperature in winter is often maintained at a relatively high level, and this also causes the mold damage occurred even in winter. As a result, health problems caused by mold are a big concern throughout the year. On the other hand, the problem of being too dry in a well-insulated house has been pointed out.

In this paper, based on the research conducted by the current authors regarding humidity environment and health problems, the actual indoor environmental conditions, especially temperature and humidity, of houses in various parts of Japan are firstly described. The results of a large-scale questionnaire survey on the relationship between indoor humidity and children's allergic diseases will be given. In addition, the relationship between dryness and health/comfort will be presented, and finally the problems of humidity environment and health will be summarized as well as future research directions will be described.

2 INDOOR TEMPERATURE/HUMIDITY ENVIRONMENTS OF HOUSES IN JAPAN

2.1 Outline of the survey

The Research Committee established in the Architectural Institute of Japan had conducted a survey on the energy consumption and the indoor thermal environment of the houses from 2002 to 2004. The targets were 80 houses in 6 areas: Hokkaido, Tohoku, Hokuriku, Kansai, Kinki, and Kyushu. Indoor temperature and humidity were measured using a temperature and humidity logger. The measurement interval was 15 minutes, except for the case of Hokkaido where 10 minutes measuring interval were adopted. The authors had analyzed the temperature and humidity, which were measured throughout the year of 2003, of the living room in 51 detached houses and 21 apartments. Two journal papers have been published based on the results of this database. In this chapter, some of the important results will be outlined.

2.2 Annual frequency distribution of indoor relative humidity

Figure 1 shows the frequency distribution of annual relative humidity of the living room in six houses, which have typical characteristics. The relative humidity of detached houses Tohoku D01 and Hokuriku D06 are distributed in a wide range with almost constant frequency. For the Hokuriku apartment (i.e. Hokuriku D03), two peaks are found at 40-45% and 65-70%, indicating that summer is humid and winter is dry. In cases of Hokkaido A03and Kanto D07; although the width of distribution is different, the range shows a bell-shaped trend. In Hokkaido A03, the distribution is rather narrow with 50-70%, because the unvented space heater is used in winter and hence the absolute humidity is high. In the case of Kansai D04, the relative humidity is found over 60%, because the room temperature in winter is low with less than 15 °C, consequently the relative humidity is also high even in winter.

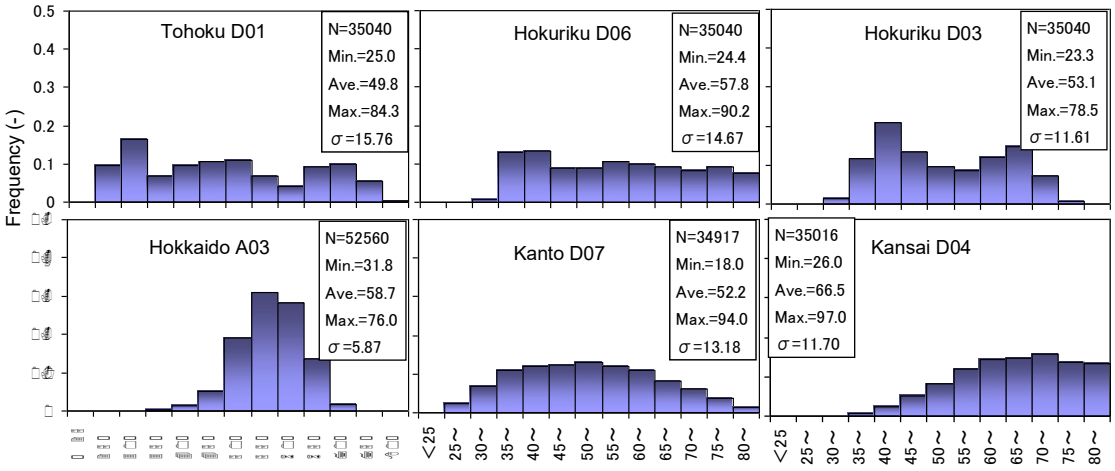

Figure 1: Frequency distribution of the annual relative humidity of 6 houses

2.3 Characteristics of relative humidity in winter

(1) Time variations of temperature and humidity

Figure 2 shows the time variations of temperature and humidity over 5 consecutive days in winter, with 2 houses of low relative humidity (Tohoku D01 and Kanto D07) and 2 houses of high relative humidity (Kanto A02 and Kansai D04). The temperature of Tohoku D01 is constantly around 24 °C by continuous operation of space heating. Reflecting the continuous heating, the relative humidity is almost below 30%. The temperature of houses in Hokkaido, which is not shown in the figures, is almost constant due to continuous heating operation. With the exception of the houses in Hokkaido and Tohoku D01, space heating is commonly adopted and operated intermittently, therefore the temperature varies significantly. In particular, when heating is not operated at night, the room temperature deceases and then the relative humidity increases. Although the temperature changes due to intermittent heating operation in Kanto D07, the absolute humidity is very low and the room air is dry. The relative humidity is high in both the Kansai D04 and the Kanto A02, in which the temperature of the former case is observed low and the absolute humidity of the latter case is found high.

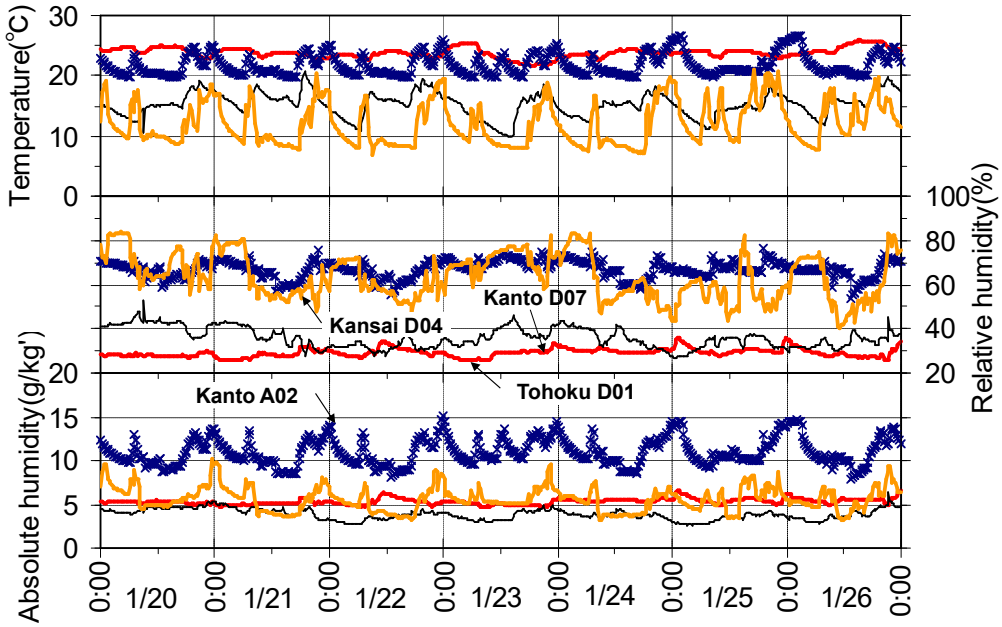

Figure 2: Time variations of indoor environment of four houses in winter

(2) Characteristics of overall relative humidity in January and February

The average relative humidity is less than 40% and the room air is dry, in 50% of the investigated houses in Hokkaido, and nearly 40% of the investigated houses in Tohoku and Hokuriku. Elsewhere, the average values of most of the houses are over 40% and some of them are more than 60%. In houses of Hokkaido, the fluctuation range of relative humidity is small because of the continuous heating operation. In the houses of other areas, the rooms are in general intermittently heated and the range of fluctuation is large. Therefore, there are hours when the relative humidity exceeded 80%.

2.4 Characteristics of relative humidity in winter

(1) Time variations of temperature and humidity

Figure 3 illustrates the time variations of temperature and humidity over a 5-day period in summer, with 2 houses of low relative humidity (Kansai A01 and Kansai D02) and 2 houses of high relative humidity (Kyushu D05 and Hokuriku D06). In each of the house, the room temperature rises during the daytime, and there are some cases where the room temperature exceeds 30 °C. In the cases of Kansai A01 and Kansai D02, the absolute humidity drops sharply during nighttime because these houses are air-conditioned at those hours. The absolute humidity is high and the temperature is low in Hokuriku D06 and Kyushu D05, among which some houses have high relative humidity exceeded 80%.

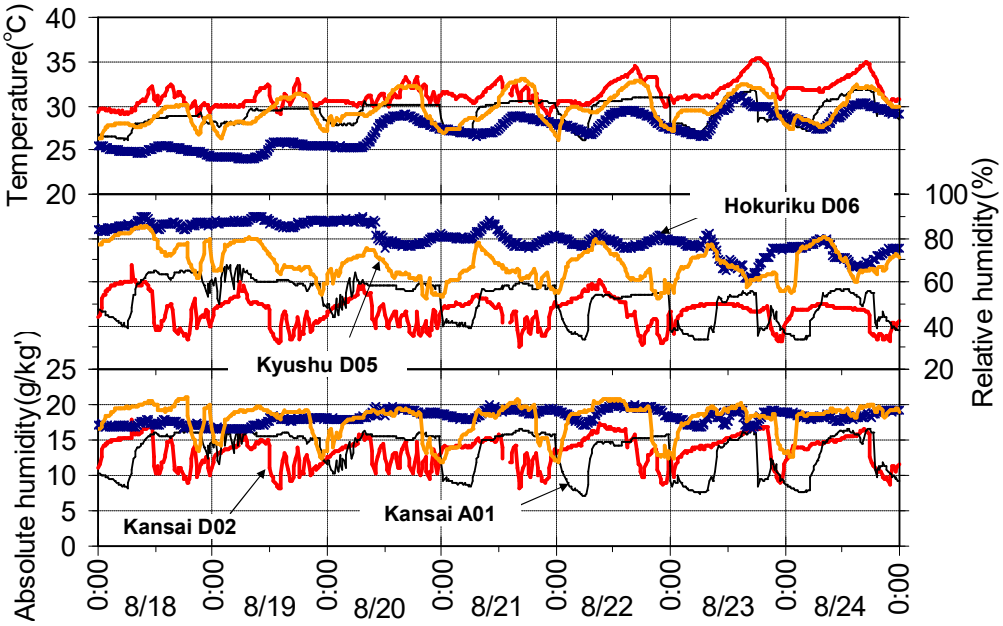

Figure 3: Time variations of indoor environment of four houses in summer

(2) Characteristics of relative humidity in July and August

Except in Hokkaido where the outside air humidity is low, the average relative humidity in most of the houses is distributed between 60-80%, and the room is humid. About 25% of the total houses, except Hokkaido, space cooling is often used and there are cases where the absolute humidity of the room is lower than that of the outside air.

2.5 Prediction of indoor mold contamination

The mold index was used to assess the possibility of mold contamination. The mold index is an index quantitatively representing the degree of growth of mold mycelium per week at a certain temperature and relative humidity, and if it is 3.0 ru/week or more, the possibility of mold contamination becomes high.

Figure 4 shows the number of hours when the mold index is found 3.0 ru/week or more. The bar charts are arranged from the one where summer relative humidity is high, and the number of days with missing data is indicated in parentheses. The houses in Hokkaido have a maximum of 328 hours, while some others houses, especially half of houses in Kansai and Kyushu, have more than 1000 hours. Questionnaire survey was conducted for the houses in the Tohoku region, where the number of hours with the mold index is more than 3.0 ru/week. As a result, it was confirmed that molds were visible in the living rooms of D06, A01 and A03, but mold

was not visible in the living room of D08 (with many houseplants), and in D01 and D03 the mold was visible in the rooms other than the living room.

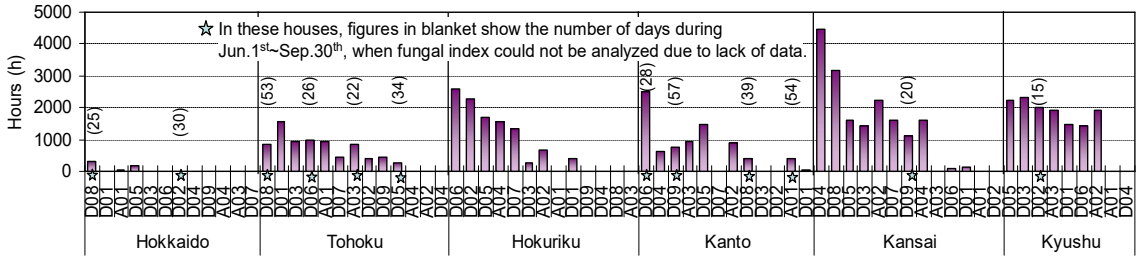

Figure 4: Cumulative hours when fungal index exceeded 3ru/week in each house

2.6 Summary

With regard to the indoor humidity environment in Japanese homes, the relative humidity is generally 60% or more in summer, which creates an environment prone to mold. However, in houses where cooling is frequently operated, the relative humidity is rather low with less than 50%.

On the other hand, in winter, the humidity environment varies between houses greatly and depends on the type of space heating equipment, the way of heating operation, the setting temperature, etc. In the houses of Hokkaido where the temperature is maintained high by space heating in all rooms, the humidity is as low as 30% or less. Hence, in the houses of other areas, the relative humidity is over 60% when the room temperature is low due to the intermittent heating operation. Especially, when the room is not heated at night, the relative humidity exceeds 80%,

Although we did not mention the situation in the rooms other than the living room, it is clear, from the database, that in most of the houses, except Hokkaido, the bedrooms are not heated enough and the relative humidity is high because the temperature is low.

3 SURVEY ON THE RELATIONSHIP BETWEEN DAMPNESS AND CHILDREN'S HEALTH

3.1 Outline of the survey

The authors conducted a questionnaire survey for elementary school students in the fourth and fifth grades from 2007 to 2010, with the aim of clarifying the relationship between dampness and children's health problems, especially on allergic diseases. The survey was divided into two stages; the first stage was to investigate the presence and type of allergic diseases. Questions for allergic diseases were answered by parents based on the doctor's diagnosis. For the method of survey, we asked prefectural educational authorities throughout the country to randomly select elementary schools situated in the urban areas and the suburbs where the prefectural office was located. The number of distributions was 30,332, the number of responses was 8,336, which means the recovery rate was about 27.5%. As the second step, the present authors examined the relationship between allergic symptoms and the living environment for the houses selected from the first survey in which occupants agreed to cooperate detailed investigation. The number of distributions was 2,865 and the number of responses was 1846, that means the recovery rate was 64.4%. The results of this survey were summarized and reported in a journal paper. This chapter abstracts and introduces the key findings from the journal paper.

3.2 Actual situation about allergic diseases of children in the first stage of the survey

Allergic diseases are classified into asthma, allergic conjunctivitis, allergic rhinitis, allergic dermatitis, digestive tract allergy and others, in this research. The ratio of the children with any allergies accounted for 49.9% overall, with little difference between regions. In addition, the prevalence rate of boys is higher than that of girls in any area, with 55.3% boys and 44.8% girls overall.

It was revealed that, among the abovementioned allergic diseases, the prevalence of allergic rhinitis was the highest in all regions, following with asthma and allergic dermatitis. The prevalence of allergic rhinitis was found as high as 37.2% in Tokai, around 30% in other regions, and 33.3% overall. There were no regional differences in other diseases.

The causes of allergic diseases are generally attributed to pollen, mites and house dust. The results indicated that pollen was a cause for 25.1% of children in all regions, and it was observed high with 36.4% in Tokai. In terms of regional characteristics, the proportion of house dust, ticks and molds which were listed as the causes, was about 3% to 10% higher in the eastern part of Japan than in the western portion of Japan. Due to the differences in housing performance and thermal environment, the adverse effects of microbes on children's health had become serious in the northern regions where the houses were well insulation.

Figure 5 presents the relationship between the different allergic diseases and their causes. Ticks and house dust were found in high rate as the cause of asthma. And pollen (followed with house dust) was mostly responsible for the cause of allergic rhinitis and allergic conjunctivitis, as high as 60% or more. House dust was indicated as the main cause for atopic dermatitis, in more than 50%.

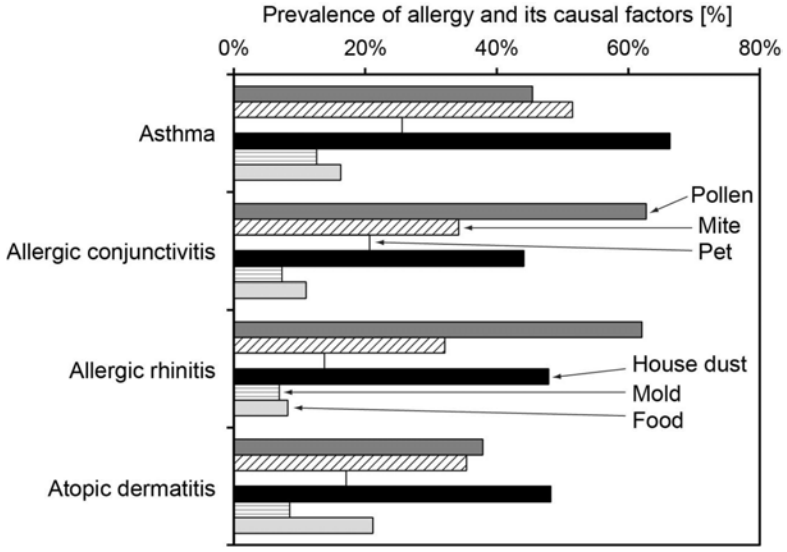

Figure 5: Causes of various allergic symptoms

3.3 Relationship between residential environment and allergic symptoms in the second stage of the survey

According to the results obtained from the second stage of the questionnaire survey, the percentage of children with allergic symptoms was 61.2%. The ratio of pollen symptom was over 49.0% in Hokkaido and over 50% in all the investigated regions. Especially in Kanto, the ratio showed high with 62.2%. The prevalence ratios of wheezing, airways hyperresponsiveness, asthma-like symptoms (severe) and asthma-like symptoms (not severe) were 5.5%, 12.5%, 5.4% and 11.9%, respectively.

Regarding the indoor environment related to humidity, about 10% and 20% of respondents stated that condensation did not occur in Hokkaido and other areas, respectively. This implied that condensation occurred in many houses, and it was found especially on windows and sashes. The ratio of houses with mold was more than 50%, and mold also appeared often on windows and sashes.

According to the analysis of the relationship between the indoor environment related to moisture and the allergic symptoms, there revealed a significant association between prevalence of all symptoms and the occurrence of mold on the internal surfaces other than window sash in the living room and bedroom. In particular, for airway hyperresponsiveness and asthma-like symptoms Adjusted Odds Ratio (AOR) were 3.05 ($p < 0.01$) and 3.76 ($p < 0.01$), respectively, in comparison to the case without mold. As for the relationship between each symptom and the Dampness Index, which indicates the degree of dampness (zero when there is no condensation, no mold, and no water stains; three when there are three phenomena), AOR is significantly greater than 1.0 when the Dampness Index is 3 for all symptoms except wheezing.

In order to find out which factors have strong influence on the occurrence of allergic symptoms to children, a further analysis was necessary. Thus, a multivariate model was constructed using the living environmental factors including the Dampness Index as explanatory variables. From the analysis of factors related to airway hyperresponsiveness and asthma-like symptoms, the findings are as follows; 1) In terms of surrounding environment, industrial areas increase the risk of symptoms, 2) The use of humidifiers and/or aquariums affects allergic symptoms, 3) The installation of a television and/or personal computer affects the symptoms, 4) The risk of occurrence increases when the Dampness Index is at 3 ru/week.

3.4 Summary

The prevalence of children allergic diseases in children in Japan reaches about 50%. Considering the bias that respondents are parents of children with allergic disease, it is a large figure. Allergic diseases include conjunctivitis, rhinitis and dermatitis, which are caused by pollen, mite, house dust and so on. According to the correlation analysis between the Dampness Index and the allergic disease, the relationship between the Dampness Index and the prevalence rate of allergic diseases, except wheezing, was clearly indicated.

In addition, according to the multivariate analysis including various environmental factors (without considering the Dampness Index), living in an industrial area, use of a humidifier and/or a aquariums, installation of a television and/or a personal computer are the influencing factors that enhance symptoms. In terms of indoor environment, it can be concluded that measures to prevent high humidity and measures against condensation are important.

The present authors conducted a similar nationwide questionnaire survey on January 2015 in the other opportunity, and analyzed the relationship between dampness and allergic symptoms based on 3,262 reliable responses. Dampness index was rated from 0 to 24 based on condensation, mold growth and mold odor in the living room, bedroom, bathroom, washroom and kitchen in this study. Figure 6 shows the distribution of the dampness and the rate of reported allergic symptoms. From this figure, it is clearly indicated that the larger the dampness index is, the greater the proportion of reported symptoms.

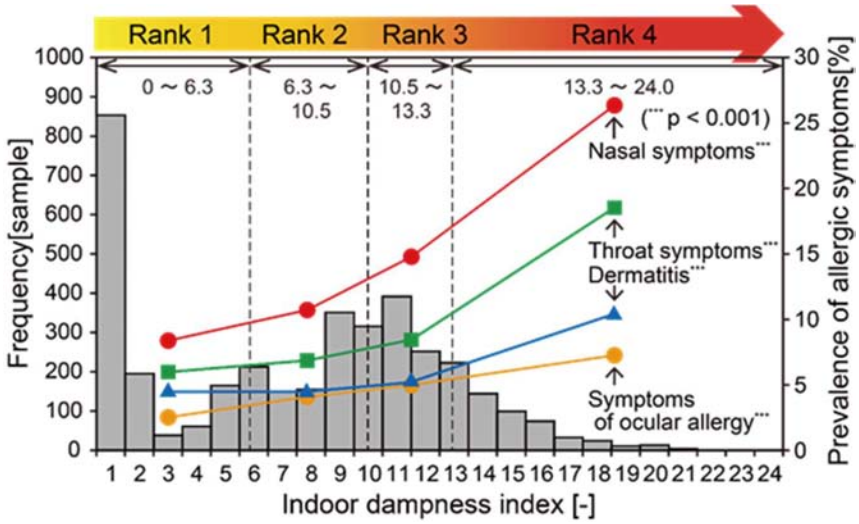

Figure 6: Distribution of dampness index and prevalence of allergic symptoms

4 SURVEY ON THE SENSE OF DRYNESS AND THE HEALTH EFFECTS OF DRYNESS

4.1 Outline of the survey

We conducted a nationwide questionnaire survey and measurement survey, looking into the actual condition of dryness in the houses and the health effect by dryness. The questionnaire survey was conducted via Internet in January 2011 for households living within 10 years. The number of valid responses was 3,879 and the response rate was 83.3%. The contents of the survey include residents' characteristics and types, as well as their operation style of the heating equipment, with/without the presence or absence of ventilation equipment and its way of operation, indoor environmental problems in winter, and so on. The measurement of indoor temperature and humidity was conducted to the households who suffered from health problems due to dryness and damage to buildings. The number of houses for the measurement was 102. The survey period was from February to March 2011. The results were reported in a journal paper. In this chapter, the main conclusions will be summarized.

4.2 Results of questionnaire survey

According to the questionnaire survey, the percentage of the households who felt dryness was over 50% in all regions of Japan, and it was over 70% in Hokkaido and South Kanto. Overall, the percentage was found higher in the northern territory. In addition, the percentage of households who felt dryness and pointed out a health problem was 30.2% in Hokkaido, and 25-27% in Tohoku, South Kanto and Shikoku. Percentage of households feeling dryness as well as having problems with comfort or damage to buildings ranged from 9% to 19% depending on location.

Figure 7 shows the analysed results of whether occupants felt dryness or whether they felt health problems, and other specific health effects. The percentage of occupants who actually felt dryness was 61.1%, and 37.1% of occupants thought that the dryness was a problem. Furthermore, the percentage of occupants suffering from health problem was 22.8% of the total. Health problems included: easy to catch cold (12.3%), sore throat (9.0%), allergy worsened (2.4%). The percentages of dry skin (16.6%) and dry throat (15.8%) were relatively high. On

the other hand, the percentages of occupants citing the loss of comfort as a problem and the damage to buildings were 17.4% and 2.4% of the total, respectively.
The analysis of the relationship between the feeling dryness and the residential environment factors indicated that the longer the operation time of space heating and ventilation, the higher the rate of reporting feeling dryness and health problems.
Furthermore, according to the results of detailed statistical analysis, the case that occupants have a health problem and feel dry only at the upper airway, is associated with a long heating time. The effect on the upper airway is likely to be related to low humidity, because a longer heating time creates a dry environment. On the other hand, it was found that occupants had odor perception when they felt dry on all parts of the upper respiratory tract, eyes and skin; these are the symptoms affecting health problems.

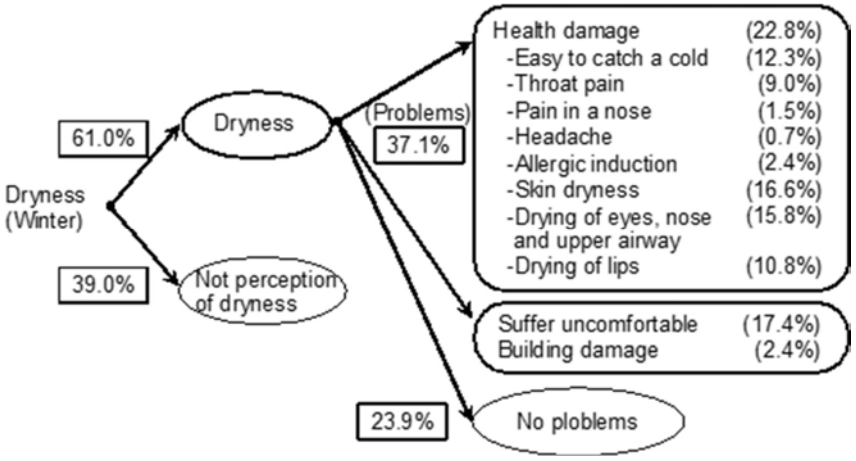

Figure 7: Ratio of dryness perception and claims of health problems

4.3 Analysis of dryness and related factors based on actual measurements

It was found that there was not clear correlation between the declaration of dryness and environmental conditions such as temperature, relative humidity, and absolute humidity. For example, in houses where occupants replied "slightly dry" or “dry” or "very dry", the relative humidity was largely distributed in a range below 50%, and the absolute humidity was also distributed in a range less than 7 g/kg. No relationship was found with the concentration of chemical substances.

4.4 Summary

The proportion of occupants who felt dryness was 61.1%, and the proportion that felt dryness was a problem was 37.1%. In addition, the proportion of occupants who had health problems due to dryness was 22.8% of the total, with susceptible to colds (12.3%), dry skin (16.6%), and dry throat (15.8%) reported at a relatively high rate. According to the measurement survey, the relationship between the feeling of dryness and the relative humidity is not clear, and even in a house with high relative humidity, occupants also feel dryness. Moreover, the relationship between the feeling of dryness and the concentration of chemical substance was also not clear. This is also concluded by Wolkoff (2018) that the cause of dryness is not yet elucidated.

5 CONCLUSIONS AND FUTURE DIRECTIONS

Generally, the climatic conditions of Japan are hot with high temperature and humidity in summer, low temperature and dryness in winter. But the conditions are quite different from the north to the south because it is a long island country. Especially in Hokkaido, the winter is severe and summer is relatively low humidity. Looking at the heating conditions alone, while all rooms are heated all day long in Hokkaido, many houses in other regions are intermittently heated and operated mainly in the living room. Therefore, the characteristics of the indoor temperature and humidity vary greatly depending on the heating and cooling conditions, and also depending on the location.

In addition, there is a large variation in dampness among houses. In houses where dampness is evaluated as a problem, it is found that dampness may be related to allergic diseases to children, especially airway hyperresponsiveness and asthma-like symptoms.

Therefore, it is necessary to keep an environment away from high relative humidity. In order to do so, the following measures can be considered;

1) To prevent the decrease in surface temperature of inside wall by installing thermal insulation
2) To equalize spatial and temporal distribution of indoor temperature during the operation of heating
3) Appropriate use of humidity control materials (further research is needed on how to install them)
4) Proper installation of the dehumidifier (further research is needed on how to install it) On the other hand, 61% of occupants feel about dryness in the winter, and 25-30% of the occupants describe that dryness is a health problem. A clear relationship between dryness and relative humidity has not been obtained, and the cause of dryness must be studied further.

6 REFERENCES

Zhang, H., Yoshino, H., Murakami, S., Bogaki, K., Tanaka, T., Hayama, H., Akabayashi, S., Inoue, T., Iio, A., Hokoi, S., Ozaki, A., Abe, K. (2007). Investigation of Actual Humidity Conditions in Houses and Evaluation of Indoor Environment by Fungal Index, Proceedings of IAQVEC 2007.

Zhang, H., Yoshino, H., Murakami, S., Bogaki, K., Tanaka., Akabayashi, Abe, K. (2009). Analysis of Indoor Humidity Environment in Nationally Residential Houses of Japan, AIJ Journal of Technology and Design, Vol.15 (30), 453-257.

Hasegawa, K., Yoshino, H., Mitamura, T. (2019). Investigation of Feeling Dryness and Its Adverse Health Effect in Residential Buildings of Japan, Journal of Environmental Engineering, Vol.84 (760), 587-596.

Wolkoff, P. (2018). The mystery of dry indoor air – An overview, Environmental International, 121, 1058-1065.