# NATIONAL SRVEY ON VENTILATION SYSTEM AND OCCUPANTS' HEALTH IN JAPAN

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## ABSTRACT

The indoor environment and occupants' health of approximately 5,000 residential buildings were investigated by a questionnaire covering entire Japan. The purpose of this survey is to clarify the association between indoor air pollution and adverse health effect, and to study effective ways of keeping indoor air clear with ventilation systems in house. Questionnaires were distributed to 7,812 occupants living in a house with a mechanical ventilation system across 47 Prefectures in Japan on February 2012 using internet survey web site. The questionnaires were completed and returned within 5 days by occupants. The contents of the 50-question survey addressed the indoor environment, installed equipment, the type of ventilation system, occupant behaviour, shelter performance of the building, occupant characteristics, health related QOL (SF8 Health Survey Japanese version provided by Institute for Health Outcomes & Process Evaluation Research) and health problems such as respiratory symptoms, allergic diseases and chemical sensitivities. As a result, the total number of respondents was 5,265 and the response ratio was 67.4%. Also the actual conditions of both the perception of thermal environment, dryness, wetness and air quality and house characteristics such as thermal performance on envelopes, heating system and ventilation system have been clarified, and several problems related to using ventilation systems have been grasped.

This paper described the outline of investigation and the results obtained from the questionnaire survey. In particular, the features of the home environment and occupants health conditions with health related QOL were shown and the association between indoor dampness such as mould growth and ventilation system were discussed through a multivariable regression analysis. This survey revealed the ratio of the type of an installed ventilation system and the pattern of using it in Japan and the possibility of the association between adverse health effect and indoor environmental factors such as inadequate ventilation.

## KEYWORDS

Ventilation system, Occupants' behaviour and health, Indoor Air Quality, Questionnaire survey in Japan, Health related QOL

## INTRODUCTION

It is important to maintain adequate air change rate in indoor for keeping the occupants healthy in dwellings. In Japan so called "sick house problem" has happened in 2000's, and the indoor concentration of chemical substance such as formaldehyde had been higher than the guideline in many newly built dwellings. After this affair, revision of the Building Standard Law was approved on July, 2002, and the installation of mechanical ventilation has been needed in any dwellings [1].

In order to clarify the actual conditions such as installation and occupants' operation of the ventilation system and to study effective ways of keeping indoor air clear with a ventilation system in a dwelling, a questionnaire about the ventilation system and indoor environment covering entire Japan were conducted to the approximately 5,000 dwellings. Questionnaires

were distributed to 7,812 occupants living in a house with a mechanical ventilation system across 47 Prefectures in Japan on February 2012 using internet survey web site. The questionnaires were completed and returned within 5 days by occupants. The contents of the 50-question survey addressed the indoor environment, installed equipment, the type of ventilation system, occupant behaviour, shelter performance of the building, occupant characteristics, health related QOL [2] and health problems such as respiratory symptoms, allergic diseases and chemical sensitivities.
This paper described the outline of a questionnaire survey and the results obtained from the survey. In particular, the features of the home environment and occupants health conditions with health related QOL were shown and the association between health problems and influencing factors were discussed through a multi-regression analysis. This survey revealed the ratio of the type of an installed ventilation system and the pattern of using it in Japan and the possibility of the association between adverse health effect and indoor environmental factors such as inadequate ventilation.

## METHOD

### Outline of survey

Questionnaires were distributed to 7,812 occupants using internet survey web site on February 2012. The investigated houses were detached house and apartment house which were completed after 2003 and were installed a mechanical ventilation system. The questionnaires were completed and returned within 5 days by occupants. In this paper, investigated areas were divided into six kinds of regions according to heating degree days as shown in Figure 1. Table 1 shows the investigated areas (Region I, II, III, IV, V+VI), the number of questionnaires sent and respondents. The total number of respondents was 5,265 and the response ratio was 67.4%.
The contents of the 50-question survey addressed the indoor environment, installed equipment, the type of ventilation system, occupant behaviour, shelter performance of the building, occupants' characteristics, health related QOL [2] and self-reported health problems such as respiratory symptoms, backache, stiff shoulder, mental symptoms and so on. The SF8 in Japanese version which was provided by Institute for Health Outcomes & Process Evaluation Research was used as a simple tool with which to evaluate the health related QOL using eight kinds of questions. The health rerated QOL was assessed from the viewpoints of physical function, body pain, general health perception, vitality, mental health and so on, and were calculated by a combination of scale answers to specific questions.

### Statistical analysis

We analyzed the data using the Statistical Package for the Social Sciences (SPSS). Associations between indoor dampness such as mould growth and condensation on the surface of windows and the factors related to ventilation system were estimated using logistic regression models. Odds ratios were estimated including the 95% confidence interval (CI). Indoor environment factors selected from the results of the single regression analysis were estimated in multiple logistic regression models with a P value <0.2 as representing significance.

Table 1. Investigated area, number of questionnaires distributed and response.

| Region | Distributed Questionnaires | No. of Respondents | Response[%] |
|---|---|---|---|
| Region I | 787 | 526 | 67.4 |
| Region II | 641 | 417 | |
| Region III | 1,279 | 990 | |
| Region IV | 4,816 | 3,235 | |
| Region V, VI | 289 | 97 | |
| Total | 7,812 | 5,265 | |

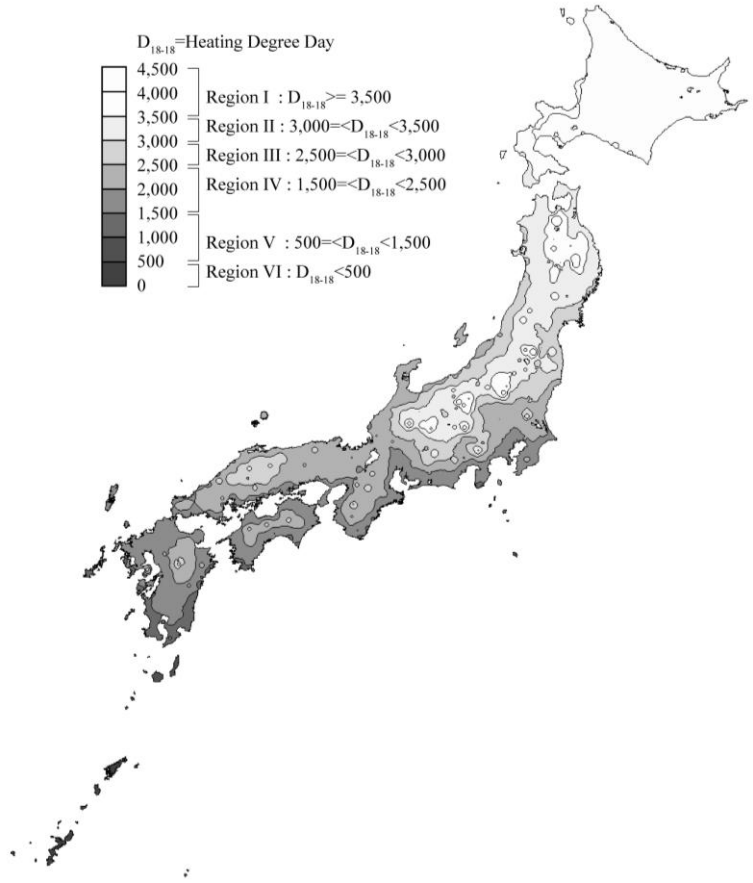



Figure 1. Heating degree days ($D_{18\text{-}18}$) and areas of investigated houses.

## RESULTS AND DISCUSSION

Table 2 shows characteristics and indoor environment of investigated houses in each regions determined from the questionnaire.

### Building characteristics

Most of the respondents were from 30s to 40s, and about 50% of respondents were male and female. Thermal performance of dwellings in accordance with the equivalent of 1992's standard dwellings was around 50% of all. The dwellings to fulfil newly standard was around 20% in each area.

Vented kerosene burners and central heating system were used as the source of winter heat in Region I and II, which are cold climatic regions in winter. On the other hand, in Region III to VI, unvented kerosene heaters were still being used in around 20% of dwellings. About 50% of dwellings in Region IV to VI used air conditioning during winter. A ventilation system of a mechanical exhaust and supply with and without a heat recovery was installed in about 30% of all dwellings. Type of a mechanical exhaust was used more than a mechanical exhaust and supply.

Around 40% of dwellings operated a mechanical ventilation system all the time during winter, while around 50% operated it intermittently. There were dwellings which didn't operate a mechanical ventilation system. Table 3 shows reasons for not operating a mechanical ventilation system. In Region I to IV about 40% of dwellings felt cold when operating a ventilation system. 30 to 40% of dwellings didn't operate a ventilation system for economizing on electric power. A few occupants thought that outdoor air pollutants such as

pollen and airborne dust entered into indoor rooms with operating a mechanical ventilation system. Around 40% of dwellings were cleaning a ventilation system regularly.

Table 2. Characteristics and indoor environment of investigated housing

| Items \ Region | Region I [n(%)] (N=526) | Region II [n(%)] (N=417) | Region III [n(%)] (N=990) | Region IV [n(%)] (N=3,235) | Region V, VI [n(%)] (N=97) |
|---|---|---|---|---|---|
| Age groupe | | | | | |
| 20-29 | 23 (4.4) | 24 (5.8) | 46 (4.6) | 150 (4.6) | 4 (4.1) |
| 30-39 | 224 (42.6) | 169 (40.5) | 431 (43.5) | 1,383 (42.8) | 36 (37.1) |
| 40-49 | 185 (35.2) | 155 (37.2) | 336 (33.9) | 1,093 (33.8) | 34 (35.1) |
| 50-59 | 66 (12.5) | 49 (11.8) | 111 (11.2) | 401 (12.4) | 16 (16.5) |
| 60- | 28 (5.3) | 20 (4.8) | 66 (6.7) | 208 (6.4) | 7 (7.2) |
| Gender | | | | | |
| Male | 262 (49.8) | 182 (43.6) | 480 (48.5) | 1,586 (49.0) | 52 (53.6) |
| Female | 264 (50.2) | 235 (56.4) | 510 (51.5) | 1,649 (51.0) | 45 (46.4) |
| Housing type | | | | | |
| Detached | 265 (50.4) | 305 (73.1) | 540 (54.5) | 1,707 (52.8) | 61 (62.9) |
| Apartment | 261 (49.6) | 112 (26.9) | 450 (45.5) | 1,528 (47.2) | 36 (37.1) |
| Thermal insulation level | | | | | |
| Equivalent of 1980's standard | 148 (28.1) | 105 (25.2) | 301 (30.4) | 946 (29.2) | 26 (26.8) |
| Equivalent of 1992's standard | 265 (50.4) | 200 (48.0) | 457 (46.2) | 1,536 (47.5) | 49 (50.5) |
| Equivalent of 1999's standard | 80 (15.2) | 84 (20.1) | 165 (16.7) | 532 (16.4) | 18 (18.6) |
| No data | 33 (6.3) | 28 (6.7) | 67 (6.8) | 221 (6.8) | 4 (4.1) |
| Main heating equipment in a living room | | | | | |
| Vented kerosene or gas heater | 116 (22.1) | 124 (29.7) | 58 (5.9) | 40 (1.2) | 1 (1.0) |
| Unvented kerosene or gas heater | 56 (10.6) | 79 (18.9) | 334 (33.7) | 917 (28.3) | 21 (21.6) |
| Electric heater | 87 (16.5) | 86 (20.6) | 143 (14.4) | 219 (6.8) | 5 (5.2) |
| Central heating system | 225 (42.8) | 74 (17.7) | 66 (6.7) | 33 (1.0) | 0 (0.0) |
| Floor heating | 30 (5.7) | 20 (4.8) | 81 (8.2) | 412 (12.7) | 4 (4.1) |
| Air conditioning | 4 (0.8) | 32 (7.7) | 292 (29.5) | 1,506 (46.6) | 51 (52.6) |
| Others | 8 (1.5) | 2 (0.5) | 16 (1.6) | 108 (3.3) | 15 (15.5) |
| Ventilation system in rooms | | | | | |
| Mechanical exhaust and supply | 75 (14.3) | 82 (19.7) | 192 (19.4) | 669 (20.7) | 24 (24.7) |
| Mechanical ventilation with heat recovery | 56 (10.6) | 62 (14.9) | 111 (11.2) | 286 (8.8) | 6 (6.2) |
| Mechanical exhaust using fans on walls | 264 (50.2) | 216 (51.8) | 415 (41.9) | 1,286 (39.8) | 45 (46.4) |
| Mechanical exhaust using ductwork system | 131 (24.9) | 57 (13.7) | 272 (27.5) | 994 (30.7) | 22 (22.7) |
| Pattern of operating the ventilation system during winter | | | | | |
| Using all the time | 222 (42.2) | 180 (43.2) | 356 (36.0) | 980 (30.3) | 36 (37.1) |
| Intermittently | 239 (45.4) | 198 (47.5) | 514 (51.9) | 1,780 (55.0) | 50 (51.5) |
| Not using | 38 (7.2) | 31 (7.4) | 91 (9.2) | 339 (4.2) | 8 (8.2) |
| Others | 27 (5.1) | 8 (1.9) | 29 (2.9) | 136 (4.2) | 3 (3.1) |
| Cleaning of ventilation system regularly | | | | | |
| Yes | 191 (36.7) | 168 (40.5) | 385 (39.4) | 1,369 (43.0) | 54 (57.4) |
| No | 330 (63.3) | 247 (59.5) | 529 (60.6) | 1,818 (57.0) | 40 (42.6) |
| Vapor condensation on the glass surface in a living room during winter | | | | | |
| Observed, clouded | 36 (6.8) | 37 (8.9) | 77 (7.8) | 342 (10.6) | 10 (10.3) |
| Observed, drop of water attaching | 131 (24.9) | 113 (27.1) | 287 (29.0) | 936 (28.9) | 24 (24.7) |
| Observed, drop of water flowing | 54 (10.3) | 53 (12.7) | 149 (15.1) | 434 (13.4) | 8 (8.2) |
| Not observed | 305 (58.0) | 214 (51.3) | 477 (48.2) | 1,523 (47.1) | 55 (56.7) |
| Visible mould during winter | | | | | |
| Observed, in a living room and/or bed room | 63 (12.0) | 82 (19.7) | 141 (14.2) | 364 (11.3) | 14 (14.4) |
| Observed, in a bathroom | 112 (21.3) | 151 (36.2) | 328 (33.1) | 1,018 (31.5) | 37 (38.1) |
| Observed, in a kitchen | 20 (3.8) | 24 (5.8) | 52 (5.3) | 141 (4.4) | 7 (7.2) |
| Observerd, other rooms | 43 (8.2) | 50 (12.0) | 100 (10.1) | 278 (8.6) | 14 (14.4) |
| Not observed | 360 (68.4) | 218 (52.3) | 584 (59.0) | 1,985 (61.4) | 51 (52.6) |
| Percept of odor in indoor | | | | | |
| Mold | 18 (3.4) | 28 (6.7) | 44 (4.4) | 161 (5.0) | 8 (8.2) |
| Garbage | 28 (5.3) | 33 (7.9) | 46 (4.6) | 166 (5.1) | 2 (2.1) |
| Tobacco smoke | 26 (4.9) | 25 (6.0) | 38 (3.8) | 142 (4.4) | 2 (2.1) |
| Chemical material from furniture etc. | 5 (1.0) | 11 (2.6) | 23 (2.3) | 72 (2.2) | 3 (3.1) |
| Pet | 43 (8.2) | 28 (6.7) | 55 (5.6) | 205 (6.3) | 4 (4.1) |
| Not perceived | 225 (42.8) | 161 (38.6) | 440 (44.4) | 1,455 (45.0) | 43 (44.3) |

Table 3. Reasons for not operating a mechanical ventilation system

| Items \ Region | Region I [n(%)] (N=276) | Region II [n(%)] (N=228) | Region III [n(%)] (N=601) | Region IV [n(%)] (N=2,113) | Region V, VI [n(%)] (N=58) |
|---|---|---|---|---|---|
| Reason for not operating the ventilation system | | | | | |
| Heat loss with operating it | 76 (27.5) | 64 (28.1) | 153 (25.5) | 512 (24.2) | 9 (15.5) |
| Feeling cold with operating it | 129 (46.7) | 99 (36.9) | 222 (36.9) | 800 (37.9) | 17 (29.3) |
| Entering pollen or dust from outdoor air | 13 (4.7) | 16 (7.0) | 63 (10.5) | 217 (10.3) | 2 (3.4) |
| Economizing on electric power | 77 (27.9) | 75 (32.9) | 209 (34.8) | 839 (39.7) | 25 (43.1) |
| Feeling noise when operating it | 35 (12.7) | 39 (17.1) | 91 (15.1) | 374 (17.7) | 10 (17.2) |
| Not necessary to use it | 87 (31.5) | 79 (34.6) | 215 (35.8) | 781 (37.0) | 27 (46.6) |

## Indoor air quality and health conditions

Vapour condensation on the glass surface in a living room was "Not observed" around 50% of all dwellings, 8.2 to 15.1% of them observed vapour condensation with drop of water flowing. Mould was visible on the surface of building envelopes in living room and bed room in 11.3 to 19.7% of all dwellings. About 40% of dwellings observed mould growth on the surface in rooms. Occupants perceived odour in indoor such as mould, garage, tobacco smoke, chemical material, pet and so on.

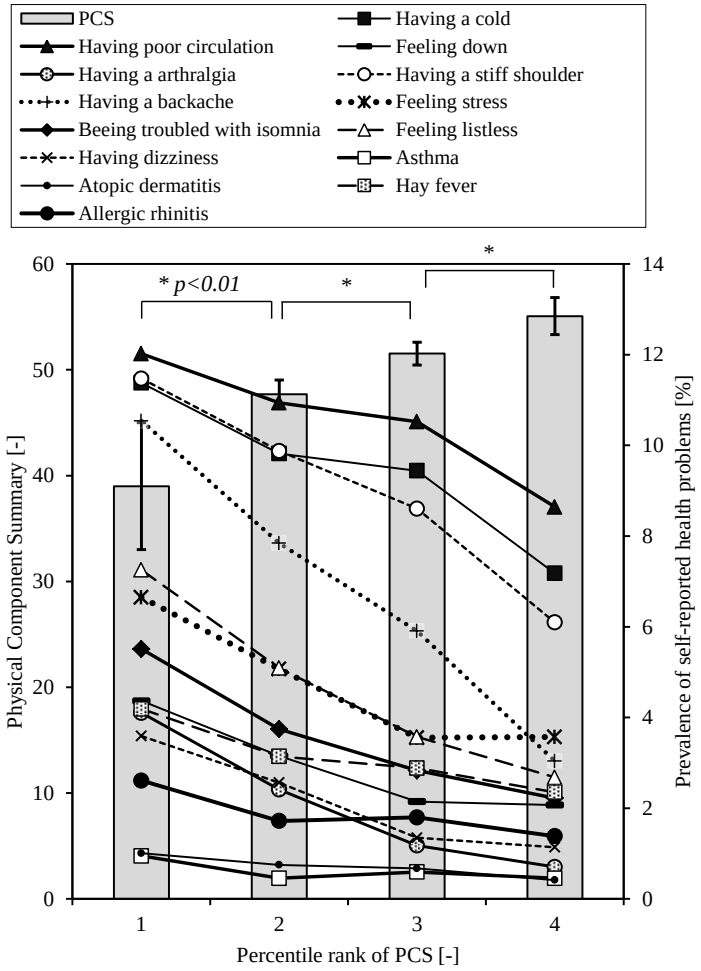
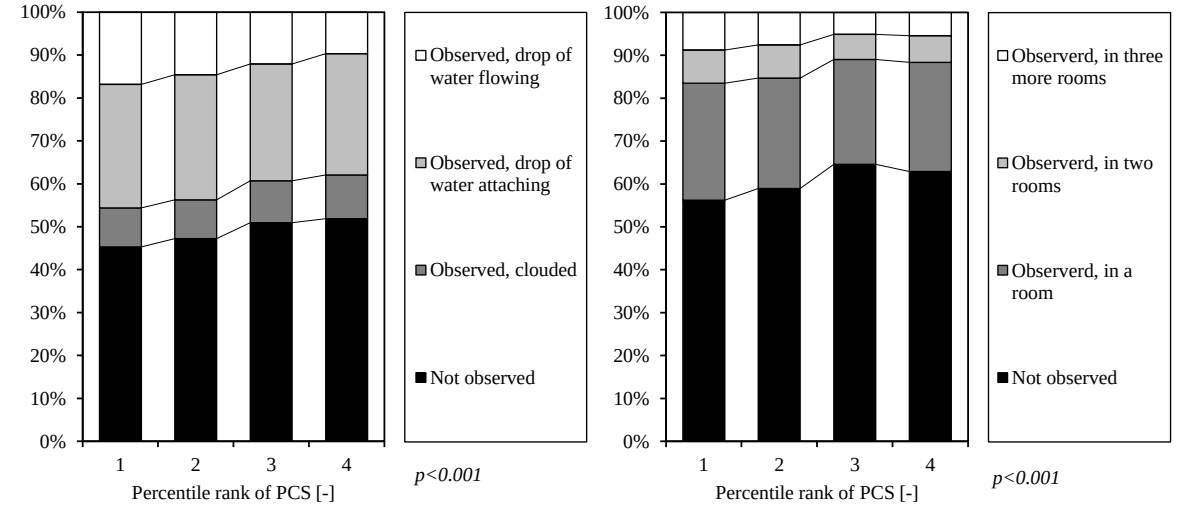



Figure 2. The prevalence of self-reported health problems and its association with health related QOL

Figure 2 shows prevalence of disease and its association with health related QOL. The health rerated QOL was assessed by Physical component summary (PCS) from the eight kinds of scales such as physical function, body pain and so on. PCS of each occupant was calculated using self-reported score to eight kinds of scales. The PCS score had an average score of 50.0 and the level of health related QOL was rising according as the PCS score was increasing

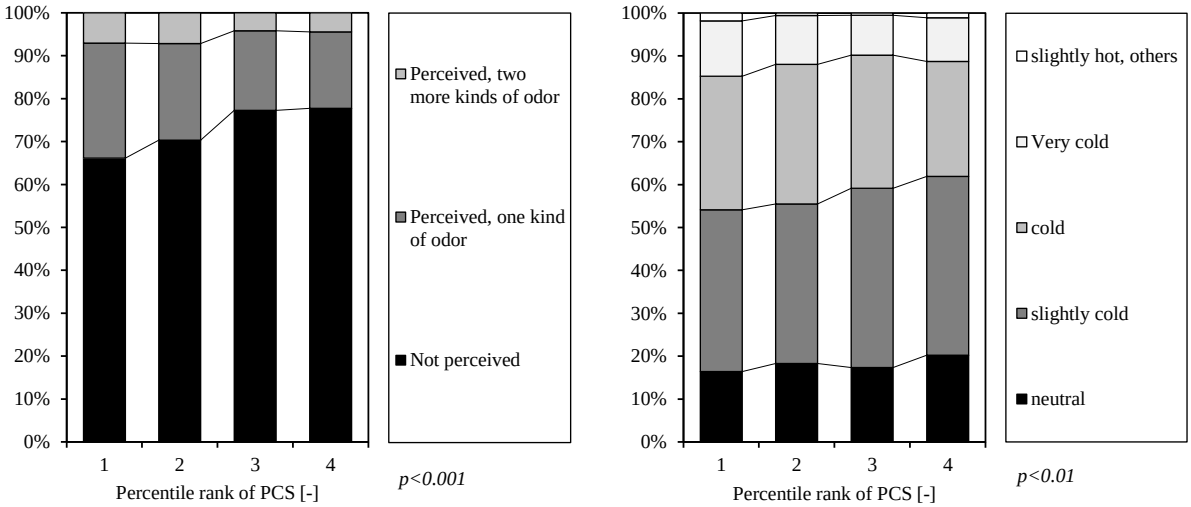
more than 50.0. In this paper all data were distributed among 25% percentile rank of the PCS score. Rank 1 included lower score than 25 % percentile rank. Rank 2 was between 25% and 50% percentile rank and Rank 3 was between 50 and 75%. Rank 4 included occupants accessed as higher score than 75% percentile rank. Each 'Percentile rank of PCS' in Figure 2 shows averaged score in the range each rank. The averaged PCS score was significantly increasing when 'Percentile rank of PCS' was high.

It was recognized that prevalence of self-reported health problems was associated with 'Percentile rank of PCS'. The lower the prevalence of health problems was, the higher 'Percentile rank of PCS' became. Therefore health related QOL could represent the inclusive health condition on the basis of occupants' self-reported answers.




(a) Vapour condensation on the glass surface in a living room during winter.

(b) Visible mould during winter.




(c) Perception of odour in indoor.

(d) Feel thermally comfortable in the morning

Figure 3. Association between percentage rank of PCS and indoor environment

## Occupants' health and indoor environment

Proportion of respondents regarding indoor environmental quality due to health related QOL are shown in Figure 3. Vapour condensation on the glass surface and visible mould growth in rooms significantly decreased when 'Percentile rank of PCS' was rising. Also perception of odour in indoor and feeling thermally uncomfortable in the morning gradually reduced according as 'Percentile rank of PCS' was rising. These results indicated indoor dampness

related to the indoor environmental quality was significantly associated with occupants' health conditions.

**Ventilation system and Indoor environmental factors related health**

Associations between ventilation system and indoor dampness related to occupants' health are shown in Table 4. Adjusted ORs were calculated using a multivariable regression models adjusted for area (Region I-VI) of housing location. We selected several variable factors related to ventilation system such as the type of ventilation system, pattern of operating a ventilation system, cleaning of a ventilation system and feeling thermally comfortable.

The adjusted ORs for mechanical ventilation with heat recovery (OR=0.7, 95% CI=0.51-0.96) was statistically significant for not visible mould in rooms. This result indicates that this type of ventilation system was operating more effectively due to prevent dampness in rooms than the other types. The adjusted ORs for operating intermittently a ventilation system (OR =2.10, 95% CI=1.84-2.38) and not using it (OR=2.21, 95% CI=1.76-2.78) were statistically significant for visible vapour condensation on the surface openings. With less frequency in use of a ventilation system, the adjusted ORs for vapour condensation, visible mould and mouldy odour were larger. The risks of vapour condensation and visible mould in rooms increased with pattern of operating a ventilation system ($p<0.001$). The adjusted ORs for not cleaning of a ventilation system (OR=1.21, 95% CI=1.08-1.38) was statistically significant for occurring vapour condensation. Feeling thermally comfortable in the morning increased the risks of vapour condensation, visible mould and mouldy odour in rooms with the adjusted ORs of 0.16-0.65 ($p<0.001$). Indoor thermal environment in the morning was affected by thermally insulation levels of building envelopes. It indicated that dwellings of occupants' feeling cold in rooms in the morning didn't have enough thermally performance of building envelopes. Therefore vapour condensation and visible mould in rooms could occur easily.

## CONCLUSION

In order to clarify the actual conditions of installed ventilation system and to study effective ways of keeping indoor air clear with a ventilation system in a house, a questionnaire survey were conducted to the approximately 5,000 dwellings in Japan. Vapour condensation on the glass surface and visible mould growth in rooms significantly decreased when health related QOL was rising. These results indicated indoor dampness was significantly associated with occupants' health conditions. Through a multivariable regression analysis, it was revealed that the mechanical ventilation with heat recovery was operating more effectively due to prevent dampness in rooms than the other types. In addition, the risks of occurring vapour condensation and visible mould growth increased with pattern of operating a ventilation system.

## ACKNOWLEDGEMENTS

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Table 4. Association between vapour condensation, visible mould, perception of mouldy odour, and factors related indoor ventilation.

| Variable factor | Vapor condensation | | Mould in rooms | | Perception of mouldy odor | |
|---|---|---|---|---|---|---|
| | visible/not visible (N=5,062) | Adjusted OR (95% CI) | visible/not visible (N=5,062) | Adjusted OR (95% CI) | perceptible/not perceptible (N=5,062) | Adjusted OR (95% CI) |
| Type of ventilation system | | | | | | |
| Mechanical exhaust | 2,253 / 1,344 | 1.00 (Ref.) | 468 / 3,129 | 1.00 (Ref.) | 27 / 476 | 1.00 (Ref.) |
| Mechanical ventilation with heat recovery | 290 / 213 | 0.82 (0.67-1.00) | 80 / 453 | 0.70 (0.51-0.96)* | 41 / 921 | 1.07 (0.70-1.63) |
| Mechanical exhaust and supply | 640 / 322 | 0.99 (0.85-1.16) | 128 / 834 | 0.86 (0.69-1.07) | 179 / 3,418 | 0.72 (0.51-1.03) |
| Pattern of operating a ventilation system | | | | | | |
| Using all the time | 880 / 894 | 1.00 (Ref.) | 153 / 1,621 | 1.00 (Ref.) | 55 / 1,719 | 1.00 (Ref.) |
| Intermittently | 1,937 / 844 | 2.10 (1.84-2.38)*** | 406 / 2,375 | 1.74 (1.43-2.14)*** | 162 / 2,619 | 1.82 (1.32-2.50)*** |
| Not using | 366 / 141 | 2.21 (1.76-2.78)*** | 87 / 420 | 2.01 (1.49-2.71)*** | 30 / 477 | 1.85 (1.15-2.97)* |
| Cleaning of a ventilation system regularly | | | | | | |
| Yes | 1,752 / 1,212 | 1.00 (Ref.) | 326 / 2,638 | 1.00 (Ref.) | 136 / 2,828 | 1.00 (Ref.) |
| No | 1,431 / 667 | 1.21 (1.08-1.38)** | 320 / 1,778 | 1.23 (1.03-1.46)* | 111 / 1,987 | 0.96 (0.74-1.26) |
| Feel thermally comfortable in the morning | | | | | | |
| Very cold | 437 / 115 | 1.00 (Ref.) | 137 / 415 | 1.00 (Ref.) | 60 / 492 | 1.00 (Ref.) |
| cold | 1,096 / 441 | 0.65 (0.52-0.83)*** | 221 / 1,316 | 0.52 (0.41-0.67)*** | 90 / 1,447 | 0.50 (0.35-0.71)*** |
| slightly cold | 1,227 / 781 | 0.44 (0.35-0.56)*** | 211 / 1,797 | 0.38 (0.29-0.48)*** | 78 / 1,930 | 0.33 (0.23-0.47)*** |
| neutral | 407 / 507 | 0.25 (0.19-0.32)*** | 67 / 847 | 0.24 (0.17-0.33)*** | 17 / 897 | 0.16 (0.09-0.27)*** |
| slightly hot, others | 16 / 35 | 0.16 (0.08-0.30)*** | 10 / 41 | 0.73 (0.35-1.53) | 2 /49 | 0.34 (0.08-1.45) |

Note: ***p<0.001, ** p<0.01, * p<0.05, + p<0.1 ; Adjusted for Area( Region I - VI). Ref.=referent.