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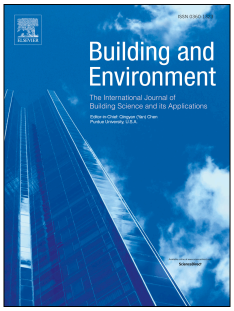

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The influence of tenure status on housing satisfaction and indoor environmental quality in Finnish apartment buildings

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Abstract

Based on a previous national scale housing and health questionnaire survey, we observed significant differences in many housing quality attributes by dwelling types and tenure status. Respondents living in apartment buildings and rental houses reported being less satisfied with their housing conditions than respondents living in owner-occupied apartments or houses in Finland. In this subsequent work, we aim to study the associations between tenure status and housing satisfaction among respondents living in apartment buildings (N=397). Further on, we used measurement data collected from 28 apartments in six buildings to determine if the differences in housing satisfaction could be related to objectively measured indoor environmental quality indicators: indoor temperature, relative humidity, and carbon dioxide concentrations. Based on the results, the respondents from rental flats were significantly more unlikely to be satisfied with their dwelling, and to report their dwellings suitable warm in winter than the respondents from owner-occupied flats. Based on the measurement data, small differences were observed in thermal conditions by tenure status, however, a large portion of all apartments appeared to be overheated, and only one apartment experienced room temperatures below 18^{o}C during winter. In conclusion, there were large differences between occupant self-reported satisfaction and thermal comfort by tenure status, but differences in measured parameters were relatively small. The results indicate that occupant characteristics are likely to explain majority of differences by tenure status, which should be taken into account when assessing the overall relationships between housing and health.

Keywords: indoor air quality, questionnaire, residential, thermal conditions, ventilation

1 Introduction

Housing is an important area of research because people spend most of their time in residential environment [1], which can affect health [2]. Satisfaction with dwelling is associated with physical and mental health, and health satisfaction [3]. Many housing and indoor environmental factors have been associated with occupant health. For example, too high room temperature can increase chemical emissions from interior materials and cause symptoms such as fatigue, and decreased ability to concentrate [4, 5]. Dampness and mould are well-known risk factors for asthma symptoms and other respiratory symptoms [6]. There exists evidence about noise exposure inflicting cardiovascular diseases and symptoms [7-9]. Environmental tobacco smoke causes many harmful effects including cardiac diseases and lung cancer for adults and respiratory tract infections and asthma for children [10]. Occupant density, behaviour of occupants, and season can affect indoor environmental quality (IEQ), for example opening windows is more effective way to dilute high carbon dioxide (CO_2) concentrations and indoor air pollutants than infiltration of fresh air [11], but may also results in decreased indoor temperature.

According to our previous study utilizing the same questionnaire data, occupant reported inadequate size of the residence, moisture or mould damage on interior wall, floor or ceiling surfaces, dissatisfaction with indoor air quality (IAQ), and neighbour noise disturbance were associated with self-reported general symptoms [12]. In addition, dissatisfaction with IAQ, as well as moisture or mould damage on interior surfaces were associated with upper and lower respiratory track symptoms and respiratory tract infections. Moisture or mould damage was also associated with eye and skin symptoms, and daily neighbour noise disturbance with sleep disturbance [13].

In addition to occupant reporting, information about IEQ can be collected by objective measurements. With respect to IEQ measurements, temperature (T) and relative humidity (RH) are commonly used as indicators of thermal comfort, and CO_2 is used as an indicator of occupancy (crowding), ventilation, and IAQ.

Socioeconomic and –demographic inequalities have been found to be strong determinants of environmental risks for example through exposure to environmental hazards [14]. These inequalities can be expressed in relation to factors such as income, education, employment, age, gender, race/ethnicity, and specific locations or settings. Tenure status has been used as an indicator of socioeconomic position, and associated with housing conditions, self-reported morbidity, and higher mortality rates [15-18].

In 2010, some 30 % of Finnish households lived in rental flats [19]. Household-dwelling units in rental flats are mainly (85 %) one or two person households. Especially young population lives in rental flats [20]. Average income level is lower in rental households than owner-occupied households. Differences in incomes between these two groups have been increasing: in 1989 the disposable income of rental households was 79 % of disposable income of owner-occupied household, whereas in 2010 it was about 60 % [19].

The aim of this study was to examine the associations between tenure status and housing satisfaction and IEQ related factors in Finnish apartments. The null-hypothesis is that housing satisfaction and IEQ are independent of tenure status.

2 Materials and methods

Material consisted of a national scale housing, health, and safety questionnaire data based on a random sample (N=3000) of Finnish households collected in 2007 [21], and a separate sample of six apartment buildings with both measurement and questionnaire data (N=65) collected in 2010-2012.

The national survey was conducted by sending invitation letters and paper questionnaires by mail. The respondents (one 18–75 year old respondent per household) could complete and return the paper questionnaire by regular mail or complete the same questionnaire via the internet. Response rate was 44 % (N=1308), and responses comprised of a representative sample of households in Finland. Tenure status was originally categorized to 1) owner-occupied flat, 2) rental flat in a housing associating building, and 3) rental flat in tenement building. This study focuses on rental and owner-occupied flats in apartment buildings (N=397).

First, questionnaire responses were cross tabulated by tenure status, including selected socio-demographic variables (e.g. gender, age, marital status) and housing quality attributes, such as satisfaction with dwelling, dwelling perceived large enough, satisfaction with IAQ, ventilation, trickle vents in bedroom(s), satisfaction with temperature conditions of the dwelling, airing by hood and opening windows, unpleasant odour in the dwelling (general stuffiness), and moisture or mould damage on interior surfaces. Chi-square test was used to test differences for categorical variables, and Kruskal-Wallis test was used for continuous variables (e.g. age of the responders).

Where significant differences were observed by tenure status, multiple logistic regression analyses were performed. These analyses were performed for satisfaction with dwelling,

dwelling perceived large enough, suitable warm dwelling in winter, and too cold dwelling in winter. Independent variables were chosen to the models stepwise. First, tenure status was included in the models by method “enter”. Second step employed three socio-demographic variables (i.e. gender, age, marital status) by method “enter”. In addition, third step included additional variables that could be associated with socioeconomic status and/or the dependent variables: proportion of gross income used for living costs, education, and occupation, by method forward conditional. For level of statistical significance we chose $p < 0.05$. Missing data were excluded from the analyses. These analyses were performed with PASW Statistics 18.0 Release 18.0.0 –program.

In addition of national survey data, a separate sample of six apartment buildings located in Eastern Finland was studied more thoroughly. Measurement data were collected from a total of 28 apartments who volunteered to participate: nine apartments in three buildings were owner-occupied and 19 apartments in the other three buildings were rental. Heating season with more stable indoor thermal conditions was targeted in order to minimize the impact from other factors (e.g., opening windows). One building was studied in 2010, four buildings in 2011, and one in 2012.

Measurements included two months continuous monitoring of T, RH, and CO_2 recorded in two locations from each apartment (i.e., bedroom, kitchen or living room) every ten seconds using a wireless building monitoring system developed by research group of Environmental Informatics at the University of Eastern Finland [22]. The monitoring system has been previously utilized in several studies [23-26]. Sensors were installed approximately 1.4-1.8 meters above the floor level, and far from ventilation ducts, windows and doorways. The reliability of the measurements was tested in a few randomly selected dwellings with TSI’s

IAQ-CalcTM Indoor Air Quality Meter 7525. No significant difference was observed between the TSI and installed sensors, and the reliability was within the manufacturer's specifications [27]. Contemporary outdoor T and RH data from local monitoring stations were obtained from Finnish Meteorological Institute for comparative purposes.

The 10-second resolution data during 2-month monitoring was averaged to 1-hour resolution. Descriptive statistics such as frequencies, means, and variances were calculated and compared for quality assurance checks. Normality assumptions of continuous variables were examined and outliers identified. Correlation coefficients were calculated for continuous variables. Further on, we used multilevel modelling (SAS-program's proc mixed procedure) for indoor T, RH, and CO_2 levels, where interaction of month and year was used as a random effect, and outdoor T, RH, and the tenure status were used as fixed effects. The main goal of the modelling was to evaluate possible differences between owner-occupied and rental buildings. Temperature data from five apartments were omitted from analysis: three apartments were unoccupied during the measurement period, and two apartments had an error in the equipment settings. Three rental apartments had missing data due to equipment error. The final sample with valid measurements included nine apartments from owner-occupied buildings and 16 apartments from rental buildings (Table S1).

The occupants of these six buildings were also asked to fulfil the questionnaires, but due to small sample size and low response rate only group level descriptive analysis was conducted by cross tabulating selected housing quality attributes (i.e. satisfaction with dwelling, dwelling perceived large enough, satisfaction with IAQ and temperature conditions of the dwelling, and unpleasant odour caused by general stuffiness) by tenure status.

3 Results and discussion

3.1 Bivariate analyses of questionnaire data

Table 1 shows socio-demographic variables by tenure status based on national survey data. Respondents living in owner-occupied flats were older and more frequently (43 %) married than respondents living in rental flats both in the housing association buildings (12 %), and in the tenement buildings (21 %). Almost half (47 %) of respondents living in owner-occupied flats had a college degree, whereas the corresponding percentage was 28 % for respondents living in rental flats in housing association buildings, and 22 % for respondents living in rental flats in tenement buildings. The largest differences regarding to occupational group were that only 3 % of owner-occupied dwellers were students, compared to that over 21 % of rental-dwellers were students. Also, 10 % of the respondents living in owner-occupied flats were executive/superior official, whereas the corresponding percentage was 3 % among the respondents from rental flats. In addition, owner-occupied dwellers used lower proportion of their gross income for living costs. For example, only 4% of them used over 65% of their cross income for living costs, whereas the percentage was 12 % among respondents living in rental flats in housing association building.

Table 2 shows results from cross tabulation of selected housing quality attributes by tenure status. Statistically significantly larger proportion of respondents from owner-occupied flats (44 %) were satisfied with their dwelling than from rental flats (24 %), and perceived their dwelling large enough more frequently. They were also more satisfied with temperature conditions of their dwellings than respondents from rental flats, and the differences in winter thermal conditions were statistically significant (82 % vs. 65 % reported their dwelling suitable warm).

Owner-occupied dwellers were more commonly satisfied with IAQ and reported less frequently moisture condensation on the windows than tenants, but the differences were not statistically significant. Other non-significant differences included owner-occupied dwellers reporting unpleasant odour caused by general stuffiness, and moisture or mould damage on interior surfaces less frequently than tenants.

Respondents living in rental flats reported significantly more frequently that they did not know the type of the ventilation system in their dwelling. This could be related to that on the average they had lived a shorter period of time in their current dwelling (data not shown), or it could indicate that they are less interested in the building characteristics than the owner-occupied respondents. In addition, respondents living in owner-occupied flats reported more frequently airing by hood. However, airing by opening windows was reported in a similar fashion by all groups of respondents.

3.2 Logistic regression analyses of questionnaire data

Table 3 shows odds ratios between different housing and health variables and tenure status. Crude models only include tenure status and adjusted modes also include gender, age and marital status. None of the additional variables in step 3 (the proportion of gross income used for living costs, education, and occupation) were included in the final models, since they did not improve the models significantly, and their effects on the associations between housing and health variables and tenure status were negligible.

After adjusting for selected socio-demographic variables, there were no significant differences between respondents in rental and owner-occupied flats regarding dwelling perceived large enough, and too cold in winter. However, based on the adjusted models, respondents from rental flats both in tenement (OR=0.42) and housing association buildings (OR=0.32) were statistically significantly more unlikely to be satisfied with their dwelling, and respondents from rental flats in tenement buildings (OR=0.48) were also significantly more unlikely to perceive their dwellings suitably warm in winter than respondents from owner-occupied flats.

It should be noted that the results based on questionnaire responses are prone to reporting bias. Some bias could be related to tenants' lack of possibilities to influence their housing conditions [28] and/or being generally more dissatisfied with their living conditions than owner-occupied dwellers. Questionnaire responses regarding thermal conditions in winter could be affected by the long recall period, as data were collected during the summer season of 2007. However, compared to similar questionnaire data from 2011, there were no significant differences in occupant reporting of indoor thermal conditions during winter [29]. Regardless of limitations related to use of questionnaires, it is important to collect information about housing and health directly from the occupants. In addition, a better understanding could be obtained by complementing questionnaire based data with objective measurements.

3.3 Analyses of IEQ measurement data

First, we checked questionnaire responses related to thermal conditions and IAQ by tenure status from the sample of apartment buildings selected for measurements. All occupants from these buildings were asked to respond and a total of 67 responses were collected (33 were owner-occupiers). In these data, larger proportion of the respondents from owner occupied flats were satisfied with their dwelling (41 %) than from rental flats (29 %), perceived their dwelling large enough (81 % vs. 73 %), and were more frequently satisfied with IAQ (27 % vs. 19 %) and thermal conditions both during summer and winter. They also reported less general stuffiness (9 % vs. 15 %) than the respondents from rental flats. On the other hand, the respondents from rental flats reported moisture condensation on the windows in winter less frequently (10 %) than the respondents from owner occupied flats (17 %). Whereas statistical testing or modelling was not conducted due to small sample size, the crude results concurred with the national survey data in terms of that tenants reported being less satisfied with their housing conditions than owner-occupiers.

Table 4 shows the measured levels of T, RH, and CO_2 in bedroom, kitchen and/or living room. All owner-occupied flats were monitored in both one bedroom and the living room, and the results from different locations were highly correlated with each other (r=0.86. 0.85, 0.98 for T, RH and CO_2, Table S2). The rental buildings were monitored in one bedroom and the kitchen, with one building in the living room only. The correlations of T and CO_2 between bedroom and kitchen were also high (r=0.83 and 0.98), but it was only moderate for RH (r=0.40). In general, the measured parameters from different locations in owner-occupied flats showed less variation, especially for indoor T, indicating more stable indoor conditions.

Due to high correlation, average T, RH and CO_2 from different locations were calculated and used as “indoor levels”, and the correlation coefficients with outdoor values are given in Table 5. Correlation between indoor and outdoor T in rental buildings was slightly higher than in own-occupied buildings, and indoor RH was highly correlated with outdoor T (r=0.80), indicating temporal effects related to outdoor conditions (e.g., due to occupants’ behaviour such as window opening). The owner-occupied apartments had higher correlations of indoor T and both RH and CO_2, which might again suggest more stable indoor conditions.

Figure 1 shows the percentage of T, RH and CO_2 over time in owner-occupied and rental flats. Based on Finnish housing and health guidelines [30], recommended room temperature is 21 ºC (acceptable temperature is 18 ºC), and it should not exceed 23-24 ºC during the heating season, whereas recommended range for RH is 20 – 60 %. Temperature in the measured apartments appeared to meet the guidelines (18-23 ºC) better in owner-occupied (33 %) than rental flats (22 %), but rental flats exceeded the guidelines (>23oC) more frequently. One owner-occupied apartment had a period of 66 hours when the temperature (average 16.5 ± 0.9 ^{o}C) was below the acceptable level (18 ºC). However, there were no statistically significant differences in T or RH levels by tenure status based on the multilevel models.

Some 79% of the rental flats exceeded 23 ^{o}C, all apartments had T above the acceptable level, and 5% had RH values below 20%; whereas 65% of owner-occupied flats exceeded 23^{o}C, and 17% had RH values below 20%. The total amount of time with low RH (16.9 ±2.9 % for owner-occupied and 18.4 ± 1.4 % for rental flats) was about a month regardless of the tenure status. The results with respect to T and RH data concur with another sample of 94 Finnish apartments in 16 buildings from several regions in terms of that a large proportion of Finnish apartments appears to be overheated: in this sample (majority owner-occupied) indoor temperature exceeded 23 ^{o}C in 36%, and RH was below recommended in 29% of the apartments [31].

Some 36% of the owner-occupied flats had CO_2 levels higher than 1000 ppm, whereas majority of rental flats had moderate CO_2 levels (95% lower than 1000 ppm). The multilevel model showed a statistically significant difference in average CO_2 levels between owner-occupied and rental flats. The main reason was detected to be due to high levels in three owner-occupied apartments, ranging from 1196 ± 216 ppm to 1975±417ppm (Table S1). If the three apartments were excluded, the CO_2 levels would be comparable (722 ± 273 ppm in owner-occupied and 702± 196 ppm in rental flats). One owner-occupied apartment had relatively low T (18.49 ± 0.51 ºC in the bedroom and 18.93 ± 0.49 ºC in the living room,

Table S1), and CO_2 levels were also low (567 ± 18 ppm and 480 ± 20 ppm, respectively). This could be related to low occupancy in the spacious dwelling (Table 2).

In summary, while these data did not support the results from the questionnaire data indicating less acceptable thermal comfort and IAQ in the rental flats, a bigger sample size is needed for drawing more definite conclusions. In addition to sample size, the study has limitations with respect to information on occupant activities that could affect thermal conditions and CO_2 levels, e.g., cooking, and opening of windows and doors. The influence of outdoor conditions was taken into account in the multi-level modelling, but the general results regarding indoor T, RH, and CO_2 are reported as absolute values, without considering the temporal variation by tenure status. Such variation could affect the results, as the measurements were not conducted simultaneously in all buildings.

4 Conclusions

Based on the analyses of comprehensive and nationally representative survey data from Finland, respondents from owner-occupied apartments were significantly more satisfied with their dwelling and perceived their dwellings as suitably warm in winter. Based on continuous measurement data in a separate sample of 28 apartments, indoor temperature during heating season fulfilled the national guidelines in most of the apartments, and a large proportion of the apartments appeared to be overheated during the majority of the 2-month measurement period regardless of the tenure type. In addition to confirming these findings, possible differences in both perceived and measured IAQ should be studied with a large sample size.

5 Acknowledgments

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6 Declaration of competing interests

The Authors declare that there is no conflict of interests.

7 References

1. Jantunen MJ, Hänninen O, Katsouyanni K, Knöppel H, Künzli N, Lebret E, Maroni M, Saarela K, Srám R, Zmirou D. Air pollution exposure in European cities: The "EXPOLIS" study. Journal of Exposure Analysis and Environmental Epidemiology 2008, 8:495-518.
2. Dales JR, Liu L, Wheeler AJ, Gilbert, NL. Quality of indoor residential air and health. Canadian Medical Association Journal 2008, 179:147-152.
3. Dunn JR, Hayes MV. Social inequality, population health, and housing: A study of two Vancouver neighborhoods. Social Science and Medicine 2000, 51:563-587.
4. STM (Finnish Ministry of Social Affairs and Health) 2003. Asumisterveysohje. (Housing and health guidelines, In Finnish) Edita Prima Oy, Helsinki. ISSN 1236-116X, ISBN 952-00-1301-6, 93 p.

5. STM (Finnish Ministry of Social Affairs and Health) 2009. Asumisterveysopas (Housing and health guidebook, In Finnish) 3rd edition. Ympäristö ja Terveys -lehti, Pori. ISBN 978-952-9637-38-6, 200 p.
6. WHO 2009. WHO guidelines for indoor air quality: dampness and mould. Ed. by Heseltine E, and Rosen J. Printed in German by Druckpartner Moser. 131 s + appendix 95 s ISBN 978 92 890 4163 3.
7. van Kempen EEMM, Kruize H, Boshuizen HC, Ameilng CB, Staatsen BAM, and de Hollander AEM. The Association between noise exposure and blood pressure and ischemic heart disease: A meta-analysis. Environmental Health Perspectives 2002, 110 (3), 307–317.
8. Passchier-Vermeer W and Passchier WF. Noise exposure and public health. Environmental Health Perspectives 2000, 108 (Suppl. 1), 123–131.
9. Willich SN, Wegscheider K, Stallmann M, and Keil T. Noise burden and the risk of myocardial infraction. European Heart Journal 2006, 27 (3), 276–282.
10. U.S. Department of Health and Human Services 2006. The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Coordinating Center for Health Promotion, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health.
11. Haoru L, Xiaofeng L, Meiwei Q. Field testing of natural ventilation in college student dormitories (Beijing, China). Building and Environment 2014; 78: 36-43
12. Iso-Markku K, 2013. Housing health factors in the viewpoint of symptoms. MSc Thesis. General Toxicology and Environmental Health Risk Assessment. University of Eastern Finland. Department of Environmental Science.

13. Turunen M, Iso-Markku K, Pekkonen M, Haverinen-Shaughnessy U. Unpublished data.

14. WHO-Europe office 2012. Environmental health inequalities in Europe. Assessment report.

15. Sundquist J and Johansson S-E. Indicators of socio-economic position and their relation to mortality in Sweden. Social Science and Medicine 1997; 45(12): 1757–1766.

16. Macuintyre S, Ellaway A, Der G, Ford G, Hunt K. Do housing tenure and car access predict health because they are simply markers of income or self esteem? A Scottish study. Journal of Epidemiology and Community Health 1998, 52, 657–664.

17. Galobardes B, Shaw M, Lawlor DA, Lynch JW and Smith GD. Indicators of socioeconomic position (part 1). Journal of Epidemiology and Community Health 2006; 60: 7–12.

18. Macintyre S, Elleway A, Hiscock R, Kearns A, Der, G, McKay L. What features of the home and the area might help to explain observed relationships between housing tenure and health? Evidence from west of Scotland. Health and Place 2003, 9 (3) 207–218.

19. Official Statistics of Finland (OFS) 2010: Tulonjakotilasto [e-publication]. ISSN=1795-8121. 4 Kotitalouksien asuminen, tulot ja asumismenorasite (in Finnish). Helsinki: Tilastokeskus [referred: 7.1.2013]. Access method: http://www.tilastokeskus.fi/til/tjt/2010/tjt_2010_2012-05-23_kat_004_fi.html.

20. Official Statistics of Finland (OFS) 2011: Dwellings and housing conditions [e-publication]. ISSN=1798-6761. Helsinki: Statistics Finland [referred: 7.1.2013]. Access method: http://www.tilastokeskus.fi/til/asas/2011/01/asas_2011_01_2012-10-24_kat_002_en.html.

21. Turunen M, Paanala A, Villman J, Nevalainen A and Haverinen-Shaughnessy U. 2010. Evaluating housing quality, health and safety using an Internet-based data collection and response system: a cross-sectional study. Environmental Health 2010, 9 article number 69.
22. Skön, J-P, Johansson, M, Kauhanen, O, Raatikainen, M, Leiviskä, K and Kolehmainen, M. Wireless Building Monitoring and Control System. World Academy of Science, Engineering and Technology 2012, 65, 706-711.
23. Skön J-P, Johansson M, Raatikainen M, Haverinen-Shaughnessy U, Pasanen P, Leiviskä K and Kolehmainen M (2012) Analysing Events and Anomalies in Indoor Air Quality Using Self-Organizing Maps. International Journal of Artificial Intelligence 9(A12): 79–89.
24. Raatikainen M, Skön J-P, Turunen M, Leiviskä K and Kolehmainen M. Evaluating Effects of Indoor Air Quality in School Buildings and Students' Health: A Study in ten Schools of Kuopio, Finland. International Proceedings of Chemical, Biological & Environmental Engineering 2013, 80-86.
25. Skön J-P, Johansson M, Raatikainen M, Leiviskä K & Kolehmainen M. Modelling Indoor Air Carbon Dioxide (CO2) Concentration Using Neural Network. World Academy of Science, Engineering and Technology 2012, 61: 879–883.
26. Raatikainen M, Skön J-P, Johansson M, Leiviskä K, Kolehmainen M. Effects of Energy Consumption on Indoor Air Quality. World Academy of Science, Engineering and Technology 2012, 65: 804:809.
27. Skön J-P, Raatikainen M, Johansson M, Leiviskä K & Kolehmainen M. Assessing Indoor Air Quality Measurement Correlations and Variations in School Buildings. International Proceedings of Chemical, Biological & Environmental Engineering 2013, 51: 16–22.

28. Frontczak, M, and Wargocki, P. Literature survey on how different factors influence human comfort in indoor environments.

29. Anttila, M, Pekkonen, M, and Haverinen-Shaughnessy, U. Quality, health and safety of residential environments in Finland in 2007–2011. Results of the ALTTI 2011 survey [Asuinympäristön laatu, terveys ja turvallisuus Suomessa 2007–2011. ALTTI 2011 -tutkimuksen tuloksia.]. National Institute for Health and Welfare (THL). Discussionpaper 29/2013. ISBN 978-952-245-975-6 (printed); ISBN 978-952-245-976-3(online publication) Kuopio, Finland 2013 (in Finnish, abstract in English).

30. Ministry of social affairs and health, "Finnish Housing Health Guide" (Sosiaali- ja terveysministeriö, "Asumisterveyohje", Oppaita 2003:1). ISBN 952-00-1301-6, ISSN 1236-116X. Helsinki 2003 (In Finnish).

31. Du L, Prasauskas T, Leivo V, Turunen M, Aaltonen A, Kiviste M, Martuzevicius M, Haverinen-Shaughnessy U. Assessment of Indoor Environmental Quality and Health in Existing Multi-family Buildings in North-East Europe. Provisionally accepted for publication.

Table 1. Socio-demographic variables and dwelling costs by tenure status.

Gender			
	Owner-occupied flat % (95%CI)	**Rental flat in a housing associating building % (95%CI)**	**Rental flat in tenement building % (95%CI)**
Female	61.9 (55.5–68.4)	64.6 (54.0–76.2)	65.8 (57.1–74.5)
Male	38.1 (31.7–44.6)	35.4 (23.8–47.0)	34.2 (25.5–43.9)
Age***1			
Mean	52.8 (50.8–54.8)	34.8 (31.0–38.6)	42.2 (39.0–45.4)
Marital group***			
Single	25.0 (19.2–30.8)	40.0 (28.1–51.9)	34.2(25.5–42.9)
Common-law marriage	11.6 (7.3–15.9)	33.8 (22.3–45.3)	18.4(11.3–25.5)
Marriage	43.1 (36.5–49.7)	12.3 (4.3–20.3)	21.1(13.6–28.6)
Divorced	14.4 (9.7–19.1)	10.8 (3.3–18.4)	21.9(14.3–29.5)
Widowed	6.0 (2.8–9.2)	3.1 (-1.1–7.3)	4.4(0.6–8.2)
Education level***			
Academic degree	24.8 (19.1–30.5)	18.5 (9.1–27.9)	12.3 (6.3–18.3)
College degree	22.0 (16.5–27.5)	9.2 (2.2–16.2)	9.6 (4.2–15.0)
Professional degree	25.7 (19.9–31.5)	26.2 (15.5–36.9)	30.7 (22.2–39.2)
High school graduate	2.3 (0.3–4.3)	26.2 (15.5–36.9)	16.7 (9.9–23.6)
Middle school	7.3 (3.9–10.8)	12.3 (4.3–20.3)	15.8 (9.1–22.5)
Elementary school	17.9 (12.8–23.0)	7.7 (1.2–14.2)	14.9 (8.4–21.4)
Occupational group***			
Executive / superior official	10.2 (6.2–14.2)	3.2 (-1.2–7.6)	2.7 (-0.3–5.7)
Official / Employer	48.1 (41.4–54.8)	39.7 (27.6–51.8)	43.4 (34.3–52.5)

Self-employed person	4.2 (1.5–6.9)	3.2 (-1.2–7.6)	3.5 (0.1–6.9)
Student	3.2 (0.9–5.6)	30.2 (18.9–41.5)	21.2 (13.7–28.7)
Retired/unemployed	34.3 (28.0–40.6)	23.8 (13.3–34.3)	29.2 (20.8–37.6)
Proportion of gross income used for living costs*			
Under than 15 %	28.5 (22.4–34.7)	8.2 (1.3–15.1)	7.3 (2.4–12.1)
16–25 %	32.4 (26.0–38.8)	29.5 (18.1–40.9)	27.3 (19.0–35.6)
26–35 %	18.8 (13.5–24.1)	19.7 (9.7–29.7)	18.2 (11.0–25.4)
36–50 %	14.5 (9.7–19.3)	26.2 (15.2–37.2)	30.0 (21.4–38.6)
51–65 %	4.8 (1.9–7.7)	4.9 (-0.5–10.3)	13.6 (7.2–20.0)
More than 65 %	1.0 (-0.4–2.4)	11.5 (3.5–19.5)	3.6 (0.1–7.1)

***p < 0.001; **p < 0.01; *p < 0.05

[1] Based on Kruskal-Wallis –test

Table 2. Housing conditions by tenure status

Variables[1]	**Owner-occupied flat % (95%CI)**	**Rental flat / housing associating building % (95%CI)**	**Rental flat / tenement building % (95%CI)**
Satisfied with dwelling[*]			
Satisfied	44.4 (37.8–51.0)	23.4 (13.0–33.8)	24.1 (16.2–32.0)
Fairly satisfied	49.1 (42.4–55.8)	59.4 (47.4–71.4)	56.3(47.1-65.5)
Rather unsatisfied	6.5 (3.2–9.8)	12.5 (4.4–20.6)	13.4(7.1-19.7)
Unsatisfied	0.0 (0.0–0.0)	4.7 (-0.5–9.9)	6.3(1.8-10.8)
Residence perceived large enough[*]			
Yes	83.4 (78.5–88.4)	73.8 (63.1–84.5)	70.2 (61.8–78.6)
Satisfied with indoor air quality			
Satisfied	35.8 (29.4– 42.3)	24.6 (13.8–35.4)	26.8(18.6-3)
Fairly Satisfied	54.7 (48.0–61.4)	55.7 (43.2–68.2)	58(48.9-67.1)
Rather Unsatisfied	8.0 (4.4–11.7)	16.4 (7.1–25.7)	8.9(3.6-14.2)
Unsatisfied	1.4 (-0.2–3.0)	3.3 (-1.2–7.8)	6.3(1.8-10.8)
Ventilation[***]			
Mechanical support and exhaust	25.9(20-31.8)	15.9(6.9-24.9)	26.3(18.2-34.4)
Mechanical exhaust	39.6(33.0-46.2)	12.7(4.5-20.9)	28.1(19.9-36.4)
Natural ventilation	17.0(11.9-22.1)	15.9(6.9-24.9)	7.0(2.3-11.7)
No ventilation	5.2(2.2-8.2)	15.9(6.9-24.9)	5.3(1.2-9.4)
Not known	12.3(9.1-15.5)	39.7(34.9-44.5)	33.3(28.7-37.9)
Trickle vents in bedroom(s)[*]			
Yes	53.6(46.9-60.3)	42.6(30.2-55.0)	61.9(53.0-70.9)

Moisture condensation present on the windows of dwelling, in winter			
At least weekly	5.1(2.0-8.2)	11.1(3.3-18.9)	12(5.9-18.1)
Less frequently	31.0(24.5-37.5)	39.7(27.6-51.8)	33.3(24.4-42.2)
Never	64.0(57.3-70.7)	49.2(36.9-61.6)	54.6(45.2-64.0)
Airing by hood			
Daily/almost daily	47.1(39.3-55.0)	27.5(15.3-39.8)	42.3(31.3-53.3)
Less frequently	4.5(1.3-7.8)	3.9(-1.4-9.2)	2.6(-0.9-6.1)
If need (for example when cooking)	29(21.9-36.1)	37.3(24.0-50.6)	21.8(12.6-31.0)
Never/not possible	19.4(13.2-25.6)	31.4(18.7-44.1)	33.3(22.8-43.8)
Airing by opening windows^{NS}			
Daily/almost daily	84.0(79.1-88.9)	82.5(73.1-91.9)	87.5(81.4-93.6)
Less frequently	5.7(2.6-8.8)	4.8(-0.5-10.1)	4.5(0.7-8.3)
If need (for example when cooking)	9.4(5.5-13.3)	12.7(4.5-20.9)	8.0(3.0-13.0)
Never/not possible	0.9(-0.4-2.2)	0(0-0)	0(0-0)
Unpleasant odour in the dwelling, general stuffiness			
Yes	5.0(2.1-7.9)	12.3(4.3-20.3)	8.8(3.6-14.0)
Temperature conditions in summer			
Suitably warm	63.3 (56.9–69.7)	49.2 (37.1–61.4)	53.5 (44.3–62.7)
Too warm	38.5(32.0–45.0)	46.2 (34.1–58.3)	41.2 (31.2–50.2)
Temperature conditions in winter			
Suitably warm***	81.7 (76.6–86.8)	64.6 (53.0–76.2)	64.0 (55.2–72.8)
Too cold*	8.7 (5.0–12.4)	10.8 (3.3–18.4)	18.4 (11.3–25.5)
Moisture or mould damage indoor surfaces			
	4.6 (1.8–7.4)	6.2 (0.3–12.1)	7.9 (3.0–12.9)

***p < 0.001; **p < 0.01; *p < 0.05

[1]"No opinion / cannot tell" was excluded from analyses

Table 3. Odds rations between different housing and health variables and tenure status. Crude models include only tenure status and adjusted models include also gender, age, and marital status.

Dependent variable	Tenure Status					
	Owner-occupied flat		Rental flat in a housing associating building		Rental flat in tenement building	
	Crude	Adjusted	Crude	Adjusted	Crude	Adjusted
Satisfied with dwelling	1	1	0.37 (0.19–0.72)**	0.32 (0.15–0.68)**	0.43 (0.25–0.72)**	0.42 (0.24–0.74)**
Residence perceived large enough	1	1	0.57 (0.29–1.12)	0.96 (0.45–2.06)	0.52 (0.30–0.90)*	0.74 (0.41–1.35)
Suitable warm in winter	1	1	0.47 (0.25–0.91)*	0.65 (0.31–1.34)	0.39 (0.23–0.67)**	0.48 (0.27–0.84)*
Too cold in winter	1	1	1.16 (0.44–3.06)	0.78 (0.27–2.24)	2.35 (1.18–4.67)*	1.85 (0.89–3.87)

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Table 4. Temperature (T), relative humidity (RH), and carbon dioxide (CO_2) in bedroom, kitchen and living room.

Statistics		Bedroom			Kitchen			Living room			Total		
		T (°C)	RH (%)	CO_2 (ppm)	T (°C)	RH (%)	CO_2 (ppm)	T (°C)	RH (%)	CO_2 (ppm)	T (°C)	RH (%)	CO_2 (ppm)
Owner-occupied	N	2089	2506	3721	-	-	-	2483	3571	3027	3048	4424	4680
	Mean	24.00	32.89	1148	-	-	-	24.71	33.68	1041	24.24	33.12	1032
	SD	3.40	13.59	631	-	-	-	3.28	12.75	587	3.23	11.30	568
	Median	23.76	24.80	908	-	-	-	26.28	35.61	828	26.01	35.84	849
Rental	N	3792	6718	6286	4224	6718	6285	7887	9350	9343	12111	16500	16060
	Mean	22.57	25.37	714	23.25	26.39	720	24.22	33.03	698	23.80	29.95	702
	SD	1.56	4.09	191	1.44	4.18	176	0.98	8.67	203	1.30	7.85	196
	Median	22.95	23.90	755	23.15	25.54	761	24.09	33.81	652	23.85	26.74	693
Total	N	5881	9224	10007	4224	6718	6285	10370	12921	12370	15159	20924	20740
	Mean	23.08	27.41	875	23.25	26.39	720	24.34	33.21	781	23.89	30.62	777
	SD	2.48	8.58	464	1.44	4.18	176	1.83	9.97	370	1.86	8.79	349
	Median	23.13	23.97	788	23.15	25.54	761	24.26	34.20	684	23.91	27.96	724

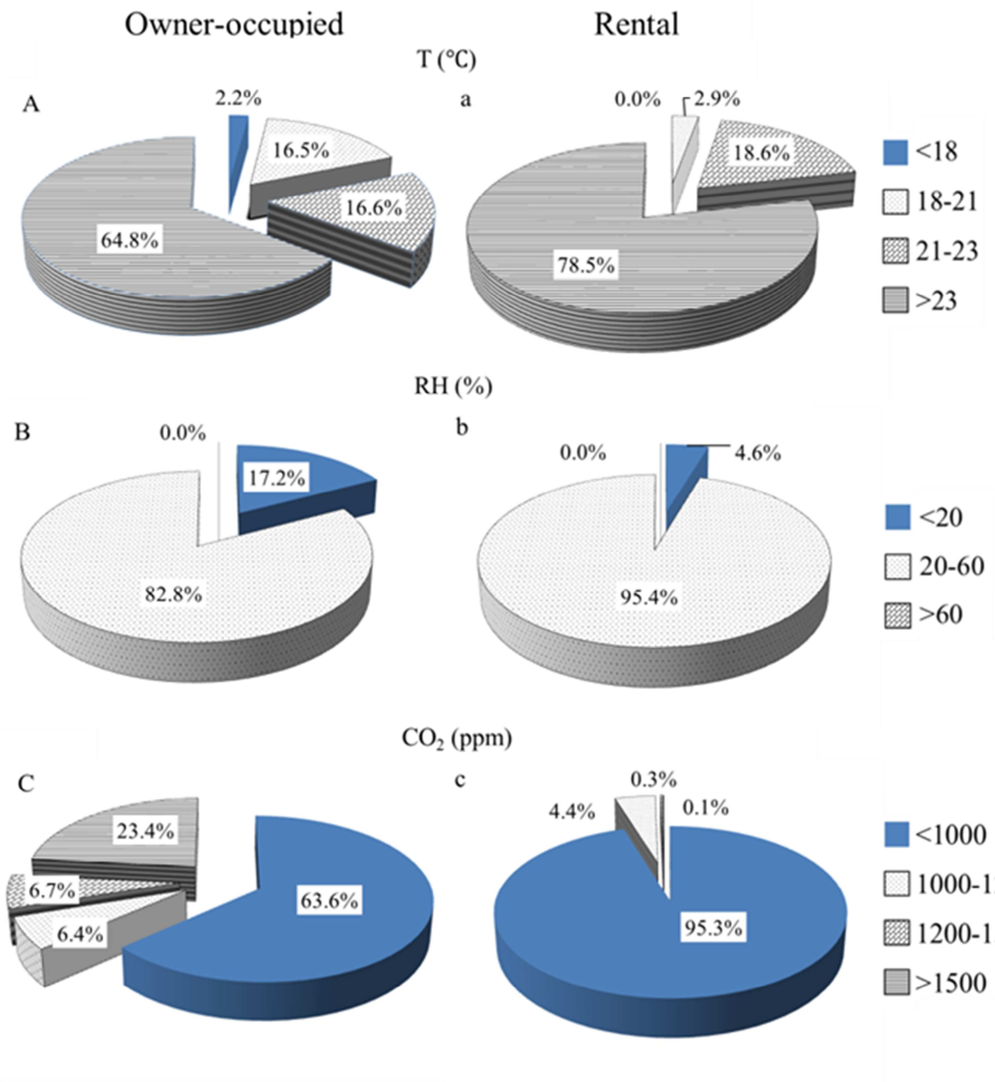
Table 5. Spearman correlation coefficients between indoor (I-) and outdoor (O-) for temperature (T), relative humidity (RH) and CO_2: own-occupied apartments (A), and rental apartments (B).

A: r	I-T	I-RH	I-CO2	O-T	O-RH
I-T	1	0.690*	0.613*	0.542*	0.160*
I-RH	-	1	0.299*	0.005	-0.253*
I-CO2	-	-	1	0.157*	0.170*
O-T	-	-	-	1	0.286*
O-RH	-	-	-	-	1

B: r	I-T	I-RH	I-CO2	O-T	O-RH
I-T	1	0.483*	0.398*	0.599*	-0.093*
I-RH	-	1	0.123*	0.800*	-0.010
I-CO2	-	-	1	-0.084*	0.100*
O-T	-	-	-	1	-0.169*
O-RH	-	-	-	-	1

* significantly correlated at α=0.01.

Figure 1. Percentages of temperature (T), relative humidity (RH), and CO_2 levels over time in owner-occupied (A/B/C) and rental apartments (a/b/c)



Highlights

- Nationally representative housing questionnaire data were analysed by tenure status
- A sample of six apartment buildings included questionnaire and measurement data
- Thermal conditions were more satisfactory in owner-occupied than rental flats
- There were no large differences in measured T, RH, or CO_2 concentrations by tenure
- A large proportion of the apartments were overheated regardless of the tenure type.

Table S1. Averaged T, RH, and CO_2 in bedroom, kitchen and living room for each apartment.

		Bedroom			Kitchen			Living room		
		T (SD) [°C]	RH (SD) [%]	CO_2 (SD) [ppm]	T (SD) [°C]	RH (SD) [%]	CO_2 (SD) [ppm]	T (SD) [°C]	RH (SD) [%]	CO_2 (SD) [ppm]
Owner-occupied	B1A1	-	45.58 (1.77)	669 (397)	-	-	-	-	-	-
	B1A2	-	49.54 (0.95)	832 (146)	-	-	-	-	49.15 (1.02)	-
	B1A3	-	23.65 (0.66)	927 (237)	-	-	-	-	48.96 (1.00)	924 (257)
	B2A1	27.29 (0.31)	-	1975 (417)	-	-	-	27.12 (0.38)	37.35 (2.97)	1783 (365)
	B2A2	-	-	-	-	-	-	24.83 (2.96)	22.66 (3.48)	703 (214)
	B3A1	23.23 (0.26)	13.85 (3.41)	497 (146)	-	-	-	22.79 (0.44)	13.74 (3.46)	444 (120)
	B3A2	21.39 (0.67)	35.87 (3.61)	1410 (474)	-	-	-	-	-	-
	B3A3	18.49 (0.51)	19.48 (1.85)	567 (18)	-	-	-	18.93 (0.49)	18.29 (2.08)	480 (20)
	B3A4	23.32 (0.91)	21.72 (2.92)	1196 (216)	-	-	-	-	-	-
Rental	B1A1	23.55 (0.46)	24.56 (3.87)	-	25.90 (0.57)	-	651 (127)	-	-	-
	B1A2	24.73 (1.08)	28.23 (4.85)	521 (208)	23.13 (0.55)	26.14 (3.63)	-	-	-	-
	B1A3	-	-	-	24.64 (0.69)	28.65 (5.34)	-	-	-	-
	B2A1	-	-	-	-	-	-	23.41 (0.83)	21.13 (2.74)	509 (11)
	B2A2	20.93 (0.78)	25.41 (3.61)	488 (39)	21.92 (0.73)	22.88 (3.46)	499 (37)	-	-	-
	B2A3	23.29 (0.67)	28.30 (5.82)	774 (209)	23.42 (0.82)	28.01 (5.38)	730 (203)	-	-	-
	B2A4	-	23.17 (0.42)	774 (48)	-	29.13 (0.55)	783 (44)	-	-	-
	B2A5	-	-	-	-	-	-	-	24.30 (2.68)	977 (22)
	B2A6	-	24.00 (0.66)	878 (32)	-	24.95 (0.65)	890 (35)	-	-	-
	B3A1	-	-	-	-	-	-	23.69 (0.56)	41.24 (6.38)	760 (137)
	B3A2	-	-	-	-	-	-	25.55 (0.55)	34.02 (5.45)	592 (126)
	B3A3	-	-	-	-	-	-	24.37 (0.63)	38.66 (5.95)	735 (264)
	B3A4	-	-	-	-	-	-	25.11 (0.81)	36.94 (4.57)	758 (158)
	B3A5	-	-	-	-	-	-	24.41 (0.77)	37.51 (4.10)	686 (225)
	B3A6	-	-	-	-	-	-	24.13 (0.65)	36.30 (4.84)	623 (119)
	B3A7	-	-	-	-	-	-	23.58 (0.27)	39.43 (6.41)	584 (74)

Table S2. Spearman correlation coefficients for T, RH, and CO_2 in bedroom (BR) and living room (LR) in owner-occupied apartments (A), and bedroom (BR) and kitchen (KI) in rental apartments (B).

A: r	T-BR	RH-BR	CO_2-BR	T-LR	RH-LR	CO_2-LR
T-BR	1	-0.052	0.750*	0.864*	0.761*	0.786*
RH-BR	-	1	0.176*	-0.441*	0.854*	0.836*
CO_2-BR	-	-	1	0.767*	0.163*	0.976*
T-LR	-	-	-	1	0.779*	0.828*
RH-LR	-	-	-	-	1	0.710*
CO_2-LR	-	-	-	-	-	1

B: r	T-BR	RH-BR	CO_2-BR	T-KI	RH-KI	CO_2-KI
T-BR	1	0.458*	0.488*	0.834*	0.630*	0.756*
RH-BR	-	1	0.169*	0.421*	0.404*	0.148*
CO_2-BR	-	-	1	0.629*	0.466*	0.981*
T-KI	-	-	-	1	0.696*	0.661*
RH-KI	-	-	-	-	1	0.478*
CO_2-KI	-	-	-	-	-	1

* $p<0.05$