Architectural Engineering Technology

Shiue, J Archit Eng Tech 2013, 2:2
http://dx.doi.org/10.4172/2168-9717.1000112

Research Article Open Access

Building Engineering Epidemiology: Northern Ireland House Condition Survey, 2009

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Abstract

Background: There have been several studies investigating the effects of housing characteristics on human health and biomarkers but how buildings could have become sick buildings was unknown. Therefore, we aimed to use a housing condition survey in a region-wide and building-based setting as an example to assess the architectural engineering correlates that could be related to "sick buildings" by adopting the epidemiological method commonly used in etiology and disease management research.

Methods: Data were analyzed in Northern Ireland House Condition Survey, 2009 (n=3,000). We hypothesized that the pathway is going from housing built year, on to indoor built environment fitness outcomes and The Decent Homes Standard, and then to long standing illnesses of the occupants. Statistical analysis included chi-square test and general or multi-level logistic regression modelling.

Results: Apparently, when the age of buildings went higher, the likelihood of having unacceptable indoor built environment fitness outcomes also increased, regardless of any fitness outcome. Similarly, the odds of having poor The Decent Homes Standard were higher for buildings that were built long time ago than those built in recent years. The greatest odds were seen among buildings that were built pre 1919.

Conclusion: To our knowledge, this is the first study investigating potential architectural engineering correlates for sick buildings by adopting an epidemiological method more than the usual surveying engineering method. Future research moving from etiology aspect to sick building management in a well-established surveillance for proper maintenance would be suggested in order to ensure the housing equality for all occupants/residents.

Keywords: Risk Assessment; Building Engineering Epidemiology; Public Health; Sick Building Syndrome; Housing Policy

Introduction

Housing inequalities have posed significant social and health problems in every society [1]. There have been several studies investigating the effects of housing characteristics on human health and biomarkers [2,3] and in children in particular [4-9]. There were also several studies that have examined the relationship of being homeless and human health, although mainly using mental health or quality of life as the study outcome. However, examination on the built environment itself and the correlates to be associated with rather than its effect on health and well-being is much scarce. Since these topics have getting attention nowadays, here we have proposed to rectify this type of research as an emerging area, namely "building engineering epidemiology". Following this context, we aimed to use a housing condition survey in a region-wide and building-based setting that was carried out in Northern Ireland as an example to introduce this emerging research, to describe what/how to assess, and to indicate near future research directions.

Epidemiology and building engineering epidemiology

According to *A Dictionary of Epidemiology* [10], epidemiology is the study of the patterns, causes, and effects of health and disease conditions in defined populations. It is the cornerstone of public health, and informs policy decisions and evidence-based medicine by identifying risk factors for disease and targets for preventive medicine. Epidemiologists have helped with study design, collection and statistical analysis of data, and interpretation and dissemination of results over the last decades and mainly specialize in methodology across disciplines. Engineering science in helping (environmental) exposure assessment is one of the areas that epidemiologists heavily rely on as well [11], in particular in identifying harmful environmental exposures, since they have been indicated to be linked with human health. Following these contexts, we may further define building engineering epidemiology as the study of the patterns and effects of buildings and occupants' conditions in defined geographic areas. It should be the cornerstone of housing studies and informs policy decisions and occupant-based welfare by identifying architectural engineering factors for (regular) maintenance or preservation and targets for occupant well-being. Sick building syndrome could be regarded as the origin of this type of research that has arisen since the 1980s [12,13] although previous researchers only investigated its adverse effect on human health but not its architecture engineering correlates. One classic example can be found in a recent systematic review from Cochrane Database, being known for evaluating existing evidence for medical research, which has shown moderate to very low-quality evidence on mould-damaged houses and offices and asthma-related symptoms and respiratory infections from previous studies [14]. This has indicated how "sick buildings" could impact on human respiratory health but how buildings could have become sick buildings was unknown.

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Received October 21, 2013; **Accepted** November 20, 2013; **Published** November 25, 2013

Citation: Shiue I (2013) Building Engineering Epidemiology: Northern Ireland House Condition Survey, 2009. J Archit Eng Tech 2: 112. doi:10.4172/2168-9717.1000112

Sick building syndrome has been known for describing situations in which building occupants experience health and comfort effects. However, the pattern and effects were not inclusive. By adopting epidemiology science theory, we could further frame the building engineering epidemiology as shown in the Figure 1. As illustrated, in the first step, researchers try to establish a surveillance that will monitor the functioning of buildings and to ascertain the diagnosis for the buildings that would need care. In the second step, researchers try to find out the factors and/or triggers that could acutely or chronically affect the proper functioning of buildings and then to establish prevention strategies since these would influence the health and/or well-being of occupants once buildings have become sick buildings. After a complete diagnosis, researchers put the "sick buildings" into "admission and/or hospitalization" phases depending on its severity. To be specific, buildings could be classified into "fine until next examination", "need repair as usual management", and "need renovation as radical treatment" groups according to their "symptoms". During this phase, there might be "complications" that would occur, such as "recurrent damage", "incomplete construction works", "occupant life change", "lack of finance", and etc. These complications could greatly impact on the functioning of buildings leading to sick building syndrome an even worsened state, if not properly managed "in hospital". After discharge when approved by (civil and/or architectural) engineering professionals, researchers set up follow-ups on a regular basis including actively surveying by professionals and/or passively reporting from occupants. The targets in the follow-up phase would include examination of both buildings and occupants to ensure that the sustainability is still prioritized and prolonged and an understanding in the knowledge, attitude, and perception of relationship of buildings and humans among occupants. Meanwhile, guidelines on how to screen, prevent, manage, and treat sick buildings in a standard way should be properly established and monitored while revisiting guidelines regularly could take place when necessary.

Study Aim

In the next section, we used Northern Ireland House Condition Survey as an example to assess the factors that could be related to "sick buildings" by adopting the epidemiological method used in etiology and disease management research [15].

Materials and Methods

Study sample

Data were retrieved from Northern Ireland House Condition Survey, 2009 (details via: http://www.nihe.gov.uk/index/corporate/housing_research/house_condition_survey.htm). In this survey, the total number of dwellings selected for participation was 3,000. This included 220 properties in each of Northern Ireland's 10 new council areas outside Belfast with 800 selected for the Belfast area (200 in North, East, South and West Belfast). The sample is in two

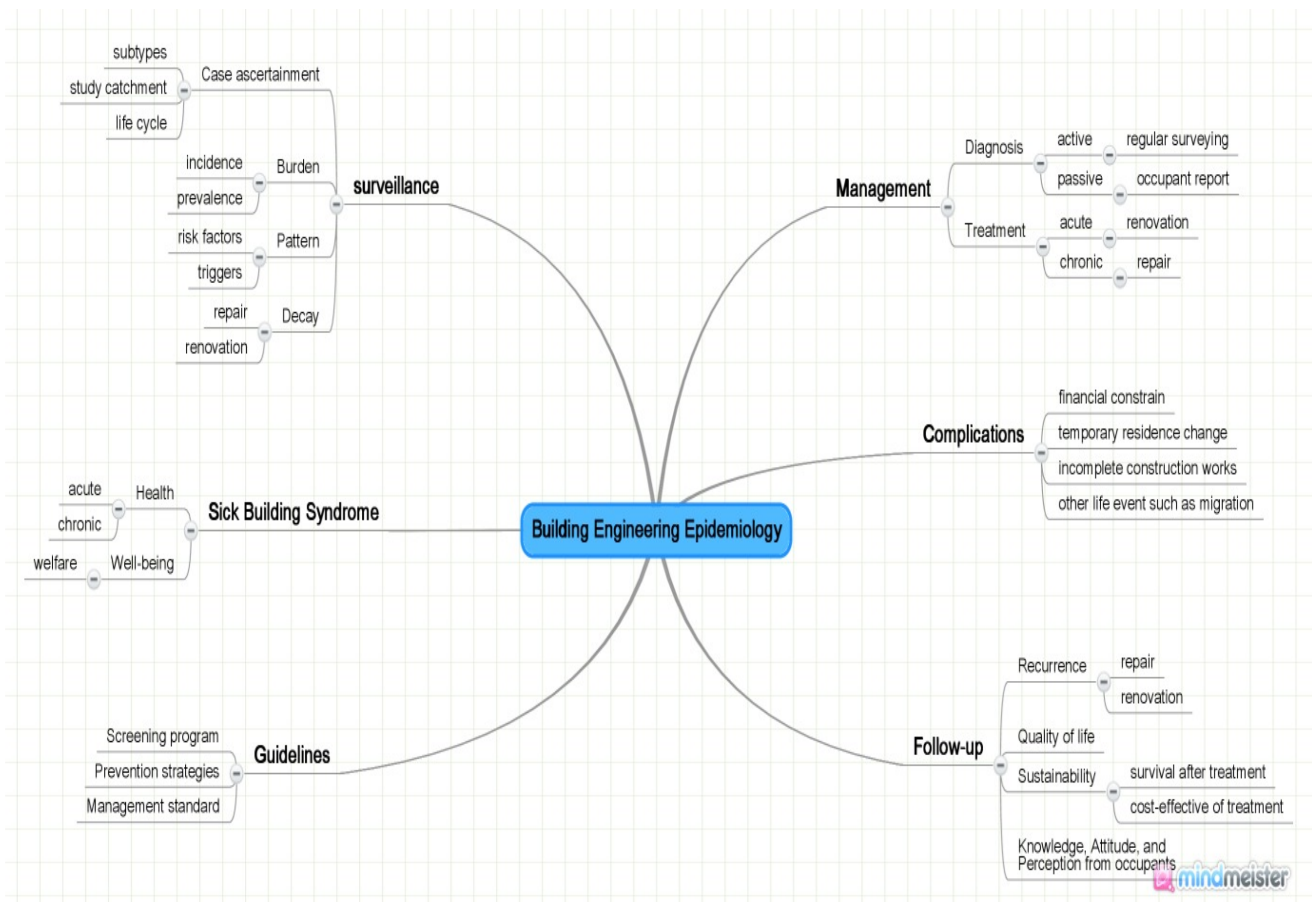

Figure 1: Structure of building engineering epidemiology.

parts. A fresh sample which consists of a stratified random sample of properties from throughout Northern Ireland. Dwellings were stratified by council area and Capital Value band to reflect the fact that properties in poor condition tend to be concentrated in lower Capital Value bands. A detailed technical survey form was filled out for each property where the surveyor gained access. The surveyor completed an inspection of the interior and exterior of the house. The surveyor also inspected the front and back plot of the survey dwelling and makes an assessment of the local neighborhood. Key information was gathered in the physical section which allowed measurement of repairs costs, the Fitness Standard, The Decent Homes Standard, Fuel Poverty, SAP and the Housing Health and Safety Rating System. A total of 18 surveyors were employed to work on the Survey. The surveyors employed are either Environmental Health Officers or chartered surveyors. Four supervisors have been appointed and are responsible for quality assuring the work of the surveyors. Letters and leaflets are sent to all households selected a few weeks before the surveyor calls.

Statistical analysis

We hypothesized that the pathway is going from housing built year, on to indoor built environment fitness outcomes and The Decent Homes Standard, and then to long standing illnesses of the occupants. Therefore, in the first attempt, in addition to showing the characteristics of buildings in Northern Ireland in Table 1, we examined the effect of built year on indoor built environment fitness outcomes (including structure, disrepair, lighting, heating, ventilation, dampness, water facility, food safety, WC, bath, drainage) and The Decent Homes Standard separately and we showed the results in Table 2 and Table 3, respectively. We then examined the effects of indoor built environment fitness outcomes and The Decent Homes Standard on self-reported long standing illness of the occupants separately and we also showed the results in Table 4 and Table 5, respectively. Study effects were reported in odds ratios (OR) from general logistic regression models or relative risk ratios (RRR) from multi-level logistic regression models depending on the study outcomes being binary or ordinal together with 95% confidence intervals (CI), with $P<0.05$ considered statistically significant. Statistical software STATA version 13.0 (STATA, College Station, Texas, USA) was used to perform all the statistical analyses. Since this study is only a secondary data analysis by extracting data from the UK Data Archive website, no further ethics approval is required.

	N (%) or Mean (SD)
Dwelling age	
Post 1980	489 (22.5%)
1965-1980	537 (24.7%)
1945-1964	366 (16.8%)
1919-1944	260 (12.0%)
Pre 1919	522 (22.5%)
Settlement type	
Urban	887 (40.8%)
Urban-district town	558 (25.7%)
Small rural settlement	284 (13.1%)
Isolated rural area	445 (20.5%)
Tenure	
Owner occupied	1,081 (49.7%)
Private rented and others	335 (15.4%)
Social housing	485 (22.3%)
Vacant	273 (12.6%)
Age of household reference person	
18-24	75 (3.5%)
25-39	458 (21.2%)
40-59	640 (29.4%)
60-74	425 (19.6%)
75 and above	291 (13.4%)
Sex of household reference person	
Male	1,112 (51.2%)
Female	777 (35.7%)

Table 1: Characteristics of buildings (n=2,174).

Results

In Table 1, we have shown characteristics of buildings that were included in the region-wide survey in Northern Ireland. Among all, only 489 (22.5%) were built after 1980 and 60-70% were located in the so-called urban regions. The prevalence of sick buildings across Northern Ireland in 2009, which were linked with self-reported long standing illness of occupants, was 29.7% (645/2,174). About half of the buildings were occupied by the owners.

Effect of built year on indoor built environment fitness outcomes and the decent homes standard

In Table 2, we have presented the associations of building built year and several indoor built environment fitness outcomes. Apparently, when the age of buildings went higher, the likelihood of having unacceptable indoor built environment fitness outcomes also increased, regardless of any fitness outcome. Similarly, in Table 3, the odds of having poor The Decent Homes Standard were higher for buildings that were built long time ago than those built in recent years. The greatest odds were seen among buildings that were built pre 1919.

Effects of indoor built environment fitness outcomes and the decent homes standard on long standing illnesses

Furthermore, associations of indoor built environment fitness outcomes and self-reported long standing illnesses of the occupants were statistically significant (Table 4). In particular, unfit disrepair (OR 1.70, 95%CI 1.14 to 2.55, P=0.010) and food safety (OR 1.75, 95%CI 1.10 to 2.79, P=0.018) were linked with long standing illness of the occupants. Other unfit outcomes could be linked with long standing illnesses of the occupants as well, although the associations were not statistically significant due to the small sample size in each cell. In Table 5, we have shown that poor The Decent Homes Standard had a great impact on long standing illness of the occupants, from overall unfit (OR 1.37, 95%CI 1.05-1.80, P=0.022) to disrepair (OR 1.93, 95%CI 1.15-3.22, P=0.012) and faults on interior (OR 1.45, 95%CI 1.14-1.85, P=0.002). Interestingly, fails on home modernization could be related to long standing illnesses of occupants as well (OR, 1.55, 95%CI 1.01-2.37, P=0.045).

Discussion

Main findings

In the current study, we have firstly observed possible architectural engineering correlates for "sick buildings" in a region-wide and building-based setting, in addition to the prevalence (close to 30%) of sick buildings. The research hypothesis for the pathway from building to human health was that older households (ageing of buildings) could impact on poor human health via poor maintenance of the households over years. Specifically, we firstly documented the evidence on the link between housing built year and indoor built environment fitness outcomes and The Decent Homes Standard. Secondly, we documented the evidence on the link between indoor built environment fitness

Structural stability	Post 1980	1965-1980	1945-1964	1919-1944	Pre 1919
Acceptable	reference	2.02 (0.70-5.86)	3.01 (1.04-8.74)	18.86 (7.35-48.40)	20.35 (8.16-50.76)
Defective or unfit	reference	N/a	2.74 (0.25-30.29)	20.70 (2.61-164.38)	87.57 (12.11-633.52)
Disrepair					
Acceptable	reference	1.94 (1.42-2.65)	2.45 (1.76-3.43)	4.45 (3.09-6.40)	5.62 (4.01-7.87)
Defective or unfit	reference	3.37 (1.57-7.23)	4.60 (2.10-10.07)	18.19 (8.66-38.21)	75.03 (37.52-150.03)
Lighting					
Acceptable	reference	3.67 (0.77-17.38)	5.45 (1.15-25.84)	25.93 (6.07-110.66)	33.89 (8.22-139.68)
Defective or unfit	reference	0.61 (0.10-3.68)	1.36 (0.27-6.79)	8.64 (2.42-30.93)	22.99 (7.15-73.92)
Heating					
Acceptable	reference	1.97 (0.84-4.60)	2.24 (0.92-5.48)	5.77 (2.53-13.15)	9.44 (4.45-20.02)
Defective or unfit	reference	1.24 (0.28-5.55)	3.22 (0.83-12.55)	6.99 (1.90-25.64)	42.11 (13.24-133.93)
Ventilation					
Acceptable	reference	2.16 (0.82-5.67)	2.74 (1.02-7.36)	7.35 (3.19-19.78)	10.82 (4.62-25.30)
Defective or unfit	reference	N/a	N/a	N/a	N/a
Dampness					
Acceptable	reference	2.66 (1.04-6.79)	6.00 (2.44-14.79)	22.32 (9.40-53.02)	24.78 (10.59-57.96)
Defective or unfit	reference	3.28 (0.68-15.87)	5.04 (1.04-24.41)	47.83 (11.38-200.93)	255.80 (63.02-1038-30)
Water facility					
Acceptable	reference	2.44 (0.64-9.26)	2.24 (0.53-9.42)	13.10 (3.83-44.72)	16.26 (5.01-52.78)
Defective or unfit	reference	0.69 (0.15-3.09)	0.67 (0.12-3.69)	4.14 (1.23-13.88)	15.31 (5.50-42.63)
Food safety					
Acceptable	reference	1.90 (1.01-3.57)	4.29 (2.34-7.87)	4.50 (2.36-8.58)	5.24 (2.90-9.47)
Defective or unfit	reference	1.53 (0.76-3.10)	2.71 (1.35-5.43)	5.91 (3.05-11.47)	19.18 (10.71-34.36)
WC					
Acceptable	reference	2.19 (0.95-5.95)	3.77 (1.66-8.58)	6.14 (2.71-13.95)	7.68 (3.60-16.43)
Defective or unfit	reference	0.71 (0.31-1.63)	0.32 (0.09-1.12)	2.96 (1.42-6.15)	9.65 (5.33-17.47)
Bath					
Acceptable	reference	3.13 (1.47-6.65)	3.58 (1.64-7.84)	5.01 (2.26-11.12)	5.87 (2.82-12.24)
Defective or unfit	reference	0.63 (0.25-1.54)	1.05 (0.44-2.52)	3.76 (1.82-7.77)	12.68 (6.89-23.32)
Drainage					
Acceptable	reference	2.75 (0.74-10.21)	3.62 (0.95-13.74)	11.67 (3.39-40.23)	25.63 (7.99-8.22)
Defective or unfit	reference	0.46 (0.08-2.51)	1.02 (0.23-4.58)	4.63 (1.41-15.21)	19.52 (7.05-54.08)

*Results were presented with RRRs and 95%CIs

Table 2: Associations of built year and indoor built environment fitness outcomes (n=2,174).

	Post 1980	1965-1980	1945-1964	1919-1944	Pre 1919
Faults on across interior elements	reference	2.02 (1.48-2.76)	2.34 (1.68-3.27)	4.73 (3.35-6.69)	9.89 (7.30-13.40)
Faults on across exterior elements	reference	2.32 (1.78-3.02)	2.88 (2.16-3.84)	5.77 (4.15-8.01)	13.87 (10.22-18.81)
Any Fabric Disrepair	reference	2.37 (1.84-3.05)	2.68 (2.03-3.54)	5.61 (4.01-7.84)	13.44 (9.77-18.49)
Any urgent across 11 elements front & back	reference	2.42 (1.68-3.48)	3.22 (2.21-4.70)	6.32 (4.29-9.31)	18.22 (12.85-25.82)
Fails on decent homes overall	reference	3.24 (2.09-5.01)	4.80 (3.07-7.50)	9.44 (6.01-14.83)	21.60 (14.29-32.67)
Fails on decent homes thermal comfort	reference	4.43 (2.45-8.02)	5.87 (3.21-10.75)	10.40 (5.69-19.03)	25.70 (14.70-44.95)
Fails on decent homes on disrepair	reference	4.62 (1.01-21.19)	14.82 (3.45-63.63)	37.88 (9.03-158.86)	99.11 (24.40-402-53)
Fails on decent homes-unfit	reference	1.05 (0.50-2.23)	1.24 (0.56-2.75)	6.08 (3.17-11.66)	21.48 (12.04-38.32)
Fails on decent homes modernization	reference	7.58 (2.27-25.33)	8.87 (2.60-30.21)	30.33 (9.29-99.00)	59.37 (18.77-187.78)

*Results were presented with ORs and 95%CIs

Table 3: Associations of built year and The Decent Homes Standard (n=2,174).

outcomes and The Decent Homes Standard and self-reported long standing illnesses of occupants.

Strengths and limitations

The strengths of this study lie in its region-wide and building-based setting in Northern Ireland and complete surveying diagnosis with several standard indicators for each included household in recent years. The included buildings were representative of the whole region by using the random sampling method based on administrative clusters. Details of the sampling method were already stated in the Method section previously. However, a limitation is that data obtained from this survey were collected by several different surveyors which could involve certain measurement errors, from an epidemiology perspective. Although they were all qualified surveyors which would provide the promising reliability of the data gathered in the survey, there still could be minor difference in (subjective) views among the surveyors. Future research might need to consider to employ multiple surveyors to replicate surveying for the same buildings in order to minimize the potential difference of surveying results among surveyors. Moreover, in the present study architectural engineering correlates for sick buildings were only derived from current available standard surveying questionnaire, from an engineering perspective. Methodologically speaking, there is still room for improvement on novel investigation (i.e. modifying standard engineering surveying questionnaire into

Structural stability	No illness	Illness	OR (95%CI)	P value
Satisfactory	1173 (94.3%)	593 (91.9%)	reference	N/a
Acceptable	63 (5.1%)	43 (6.7%)	1.68 (1.06-2.67)	0.029
Defective or unfit	8 (0.6%)	9 (1.4%)	0.89 (0.32-2.52)	0.832
Disrepair				
Satisfactory	822 (66.1%)	386 (59.8%)	reference	N/a
Acceptable	338 (27.2%)	185 (28.7%)	1.35 (1.05-1.74)	0.019
Defective or unfit	84 (6.8%)	74 (1.5%)	1.70 (1.14-2.55)	0.010
Lighting				
Satisfactory	1203 (96.7%)	617 (95.7%)	reference	N/a
Acceptable	37 (3.0%)	25 (3.9%)	1.36 (0.74-2.49)	0.320
Defective or unfit	4 (0.3%)	3 (0.5%)	0.82 (0.17-4.02)	0.807
Heating				
Satisfactory	1191 (95.7%)	605 (93.9%)	reference	N/a
Acceptable	44 (3.5%)	31 (4.8%)	0.98 (0.58-1.65)	0.930
Defective or unfit	9 (0.7%)	9 (1.4%)	1.49 (0.53-4.19)	0.452
Ventilation				
Satisfactory	1194 (96.0%)	612 (94.9%)	reference	N/a
Acceptable	43 (3.5%))	29 (4.5%)	1.23 (0.70-2.14)	0.476
Defective or unfit	7 (0.6%)	4 (0.6%)	0.65 (0.17-2.52)	0.533
Dampness				
Satisfactory	1074 (86.3%)	541 (83.9%)	reference	N/a
Acceptable	98 (7.9%)	48 (7.4%)	1.09 (0.71-1.66)	0.707
Defective or unfit	72 (5.8%)	56 (8.7%)	1.25 (0.80-1.95)	0.331
Water facility				
Satisfactory	1217 (97.8%)	623 (96.6%)	reference	N/a
Acceptable	26 (2.1%)	18 (2.8%)	1.57 (0.78-3.18)	0.210
Defective or unfit	1 (0.1%)	4 (0.6%)	3.65 (0.40-33.36)	0.251
Food safety				
Satisfactory	1122 (90.2%)	528 (81.9%)	reference	N/a
Acceptable	77 (6.2%)	65 (10.1%)	1.60 (1.08-2.39)	0.020
Defective or unfit	45 (3.6%)	52 (8.1%)	1.75 (1.10-2.79)	0.018
WC				
Satisfactory	1181 (94.9%)	512 (91.8%)	reference	N/a
Acceptable	47 (3.8%)	37 (5.7%)	1.54 (0.93-2.56)	0.095
Defective or unfit	16 (1.3%)	16 (2.5%)	0.96 (0.45-2.02)	0.909
Bath				
Satisfactory	1167 (93.8%)	592 (91.8%)	reference	N/a
Acceptable	59 (4.7%)	31 (4.8%)	1.00 (0.60-1.65)	0.989
Defective or unfit	18 (1.5%)	22 (3.4%)	1.27 (0.64-2.52)	0.486
Drainage				
Satisfactory	1206 (97.0%)	614 (95.2%)	reference	N/a
Acceptable	30 (2.4%)	24 (3.7%)	1.41 (0.76-2.62)	0.275
Defective or unfit	8 (0.6%)	7 (1.1%)	1.50 (0.47-4.75)	0.493

*Adjusting for age, sex, ethnicity, and built year

Table 4: Associations of indoor built environment fitness outcomes and long standing illness (n=1,889).

standard engineering and epidemiological surveying questionnaire) in terms of indoor environment in each household in future studies.

Sick buildings by urbanization levels

In addition to finding out possible architectural engineering correlates for sick buildings using an epidemiological assessment method, we further explored the variance across urbanization levels as to have an overview of the overall regional building situation that might provide local policy implications. Specifically, we presented the associations of housing built year and urbanization levels for buildings in Northern Ireland and have observed that, as expected, very old dwellings (1944-1919 and pre 1919) tended to be located in the rural areas while younger dwellings were located in urban areas, and in the city in particular (Table 6). Furthermore, we have shown in Table 7 that indoor built environment fitness outcomes were poorer mostly in isolated rural areas than in city urban areas even after adjusting for building built year. In Table 8, we have found that The Decent Homes Standard was less satisfying in the rural areas after adjusting for building built year, particularly in isolated rural areas, than in urban areas. Apparently, building maintenance was poorly managed and/or controlled in rural areas, which could mostly be deprived areas, due to shortage of finance, awareness of maintaing the housing and living standard, and/or any other individual, family, or neighborhood/community reasons resulting in more long standing illness among occupants. In this context, family member migration would also need to be considered in future research as either a protective factor (emigrating from old households) or added population burden (re-immigrating after a period of urban residence).

Conclusion

In summary, the prevalence of sick buildings seemed to be 30% in Northern Ireland in 2009 and we have provided recent evidence on the link between housing built year and indoor built environment fitness outcomes and The Decent Homes Standard, and then the link between indoor built environment fitness outcomes and The Decent Homes Standard and self-reported long standing illnesses of occupants

	No illness	Illness	OR (95%CI)	P value
Faults on across interior elements	352 (61.8%)	218 (38.3%)	1.45 (1.14-1.85)	0.002
None	892 (67.6%)	427 (32.4%)	reference	N/a
Faults on across exterior elements	595 (64.3%)	331 (35.8%)	1.22 (0.97-1.53)	0.088
None	649 (67.4%)	314 (32.6%)	reference	N/a
Any Fabric Disrepair	686 (63.7%)	391 (36.3%)	1.44 (1.15-1.82)	0.002
None	558 (68.7%)	254 (31.3%)	reference	N/a
Any urgent across 11 elements front & back	296 (59.3%)	203 (40.7%)	1.47 (1.14-1.90)	0.003
None	948 (68.2%)	442 (31.8%)	reference	N/a
Fails on decent homes overall	222 (55.9%)	175 (44.1%)	1.37 (1.05-1.80)	0.022
None	1022 (68.5%)	470 (31.5%)	reference	N/a
Fails on decent homes thermal comfort	158 (59.4%)	108 (40.6%)	1.08 (0.79-1.47)	0.644
None	1086 (66.9%)	537 (33.1%)	reference	N/a
Fails on decent homes on disrepair	40 (40.1%)	45 (52.9%)	1.93 (1.15-3.22)	0.012
None	1204 (66.7%)	600 (33.3%)	reference	N/a
Fails on decent homes -unfit	45 (50.0%)	45 (50.0%)	1.22 (0.75-1.98)	0.420
None	1199 (66.7%)	600 (33.4%)	reference	N/a
Fails on decent homes modernization	57 (47.5%)	63 (52.5%)	1.55 (1.01-2.37)	0.045
None	1187 (67.1%)	582 (32.9%)	reference	N/a

*Adjusting for age, sex, ethnicity, and built year

Table 5: Associations of long standing illness and The Decent Homes Standard (n=1,889).

	City urban	Urban-district town	Small rural area	Isolated rural area
Post 1980	217 (44.4%)	122 (25.0%)	64 (13.1%)	86 (17.6%)
1965-1980	203 (37.8%)	226 (42.1%)	87 (16.2%)	21 (3.9%)
1945-1964	210 (57.4%)	89 (24.3%)	41 (11.2%)	26 (7.1%)
1919-1944	150 (57.7%)	49 (18.9%)	22 (8.5%)	39 (15.0%)
Pre 1919	107 (20.5%)	72 (13.8%)	70 (13.4%)	273 (52.3%)

Table 6: Building built year across urbanization levels.

Structural stability	City urban	Urban-district town	Small rural area	Isolated rural area
Acceptable	reference	0.30 (0.16-0.54)	0.38 (0.20-0.72)	0.60 (0.39-0.93)
Defective or unfit	Reference	2.34 (0.65-8.45)	3.65 (1.04-12.87)	12.31 (4.29-35.31)
Disrepair				
Acceptable	reference	0.65 (0.51-0.84)	0.56 (0.40-0.79)	0.91 (0.67-1.24)
Defective or unfit	reference	1.02 (0.66-1.58)	1.82 (1.15-2.86)	4.68 (3.21-6.81)
Lighting				
Acceptable	reference	0.23 (0.11-0.50)	0.21 (0.08-0.55)	0.54 (0.33-0.89)
Defective or unfit	reference	0.40 (0.08-1.89)	2.80 (1.05-7.42)	7.93 (3.59-17.50)
Heating				
Acceptable	reference	0.70 (0.40-1.20)	0.95 (0.52-1.71)	1.01 (0.62-1.66)
Defective or unfit	reference	0.53 (0.19-1.47)	1.45 (0.62-3.39)	6.35 (3.54-11.40)
Ventilation				
Acceptable	reference	0.18 (0.09-0.38)	0.20 (0.09-0.48)	0.41 (0.25-0.67)
Defective or unfit	reference	0.57 (0.15-2.20)	0.50 (0.10-2.42)	1.50 (0.60-3.77)
Dampness				
Acceptable	reference	0.31 (0.18-0.53)	0.38 (0.21-0.71)	0.62 (0.39-0.98)
Defective or unfit	reference	2.38 (1.37-4.16)	3.44 (1.93-6.15)	9.03 (5.59-14.61)
Water facility				
Acceptable	reference	0.30 (0.13-0.68)	0.19 (0.06-0.63)	0.79 (0.46-1.37)
Defective or unfit	reference	0.95 (0.28-3.28)	2.58 (0.89-7.52)	8.74 (3.78-20.20)
Food safety				
Acceptable	reference	0.32 (0.20-0.52)	0.39 (0.22-0.70)	0.59 (0.38-0.93)
Defective or unfit	reference	1.11 (0.68-1.81)	1.68 (1.00-2.81)	5.58 (3.77-8.35)
WC				
Acceptable	reference	0.36 (0.20-0.64)	0.25 (0.11-0.58)	0.76 (0.47-1.21)
Defective or unfit	reference	1.11 (0.54-2.29)	2.27 (1.14-4.53)	7.21 (4.22-12.33)
Bath				
Acceptable	reference	0.28 (0.16-0.52)	0.49 (0.26-0.93)	0.71 (0.43-1.15)
Defective or unfit	reference	0.67 (0.34-1.30)	1.46 (0.78-2.72)	4.48 (2.85-7.04)
Drainage				
Acceptable	reference	0.49 (0.25-0.98)	0.33 (0.13-0.87)	1.44 (0.88-2.36)
Defective or unfit	reference	0.42 (0.05-3.78)	5.32 (1.58-17.97)	22.98 (8.10-65.17)

*Results were presented with RRRs and 95%CIs after adjusting for built year

Table 7: Indoor built environment fitness outcomes across urbanization levels (n=2,174).

	City urban	Urban-district town	Small rural area	Isolated rural area
Faults on across interior elements	reference	0.85 (0.66-1.08)	0.86 (0.63-1.16)	1.59 (1.23-2.05)
Faults on across exterior elements	reference	0.97 (0.77-1.22)	0.94 (0.70-1.25)	1.98 (1.50-2.61)
Any Fabric Disrepair	reference	0.88 (0.70-1.10)	0.76 (0.57-1.01)	1.59 (1.19-2.12)
Any urgent across 11 elements front & back	reference	1.89 (1.45-2.46)	2.00 (1.45-2.76)	3.76 (2.86-4.94)
Fails on decent homes overall	reference	1.19 (0.90-1.58)	1.64 (1.18-2.28)	2.79 (2.13-3.66)
Fails on decent homes thermal comfort	reference	1.20 (0.86-1.67)	1.69 (1.16-2.47)	2.98 (2.22-4.00)
Fails on decent homes on disrepair	reference	1.01 (0.61-1.68)	1.83 (1.10-3.06)	3.16 (2.16-4.62)
Fails on decent homes-unfit	reference	1.49 (0.87-2.55)	3.66 (2.18-6.13)	10.04 (6.63-15.18)
Fails on decent homes modernization	reference	1.24 (0.79-1.95)	2.12 (1.32-3.39)	2.43 (1.67-3.53)

*Results were presented with RRRs and 95%CIs after adjusting for built year

Table 8: The Decent Homes Standard across urbanization levels (n=2,174).

in a region-wide representative survey. To our knowledge, this is the first study investigating potential architectural engineering correlates for sick buildings by adopting an epidemiological method more than the usual surveying engineering method. Future research moving from etiology aspect to sick building management in a well-established surveillance for proper maintenance would be highly suggested in order to ensure the housing equality for all occupants/residents. In practice, a policy implication is that regular checks on housing situation for proper maintenance and preservation might be necessary since it would continuously need community resources, awareness, advocacy, and health professionals to help optimize the health and well-being of residents, particularly if facing housing transitions, difficulties, or insecurities [16].

Acknowledgements

IS was supported by the Global Platform Research Leader scheme.

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