Received: 24 November 2020 | Accepted: 30 November 2020

DOI: 10.1111/ina.12774

ORIGINAL ARTICLE

WILEY

House characteristics and condition as determinants of visible mold and musty odor: Results from three New Zealand House Condition Surveys in 2005, 2010, and 2015

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Funding information
Building Research Association of New Zealand; CRESA; Ministry for Business Innovation and Enterprise (MBIE); Energy Efficiency and Conservation Authority (EECA)

Abstract

This study assessed associations between house characteristics and mold and musty odor, using data from three consecutive (2005, 2010, and 2015) New Zealand House Condition Surveys, involving a total of 1616 timber-framed houses. Mold, musty odor, and house characteristics were assessed by independent building inspectors. We used multivariate logistic regression analyses mutually adjusted for other house characteristics for each survey separately. Positive and independent associations were found with tenure, ventilation, insulation, and envelope condition for both mold in living and bedrooms and musty odor. In particular, we found significant dose-response associations with envelope condition, ventilation, and insulation. Odds of mold increased 2.4–15.9 times (across surveys) in houses with the worst building envelope condition (BEC; $p < 0.05$–0.001 for trend); optimal ventilation reduced the risk of mold by 60% and the risk of musty odor by 70%–90% ($p < 0.01$ for trend). Other factors associated with mold and musty odor included: tenure, with an approximate doubling of odds of mold across surveys; and insulation with consistent dose-response patterns in all outcomes and surveys tested ($p < 0.05$ for trend in two surveys with mold and one survey for odor). In conclusion, this study showed the importance of BEC, ventilation, and insulation to avoiding harmful damp-related exposures.

KEYWORDS

house condition, insulation, ventilation, mold, musty odor, indoor environment

1 | INTRODUCTION

Consistent associations between indoor damp and respiratory symptoms have been demonstrated,[1,2] with indoor mold suggested to play a key role,[3] although the specific underlying mechanisms remain largely unclear.[4] In addition to visible mold, the presence of musty and moldy odor has also been associated with respiratory symptoms and rhinitis.[5–7] These dampness-related health effects present a major and avoidable cost to individuals' health and to the healthcare system, as demonstrated both in New Zealand[8] and internationally.[9]

Evidence suggests that even small improvements in housing quality may have significant health benefits,[10–12] but due to the complexity of the causes of indoor dampness, which are multi-factorial and frequently inter-related, it is unclear which specific improvements are most effective. Better understanding of the relative importance of the many contributing factors of indoor dampness is therefore needed, as this can guide more effective policies to reduce indoor dampness and mold, and resultant respiratory symptoms.

Significant positive associations with age of the house and visible mold[13–19] and moldy odor[7,18,20] have been demonstrated, but this in itself provides few clues about effective interventions. Other house characteristics associated with indoor dampness and mold include the number of occupants, heating, ventilation, insulation, window construction, roof type, foundation type, and house type.[14–16,19,21–23]

An aspect that has been less extensively studied is the association between the condition of the exterior and indoor dampness and mold. Studies that focused on these issues have found consistent positive associations between poor repair and increased indoor mold.[15,22,24] However, these studies assessed poor repair only as a single overall rating, and only one of these studies had the maintenance condition rated by a building professional,[24] with the other two studies[22,24] relying on self-reporting. None of these studies further defined or characterized this poor repair rating, hence significant knowledge gaps remain.

The current study, using data from three consecutive House Condition Surveys in New Zealand conducted in 2005, 2010, and 2015, examined associations between a wide range of housing characteristics including an overall condition rating (OCR), and inspector-reported indoor mold and musty odor (both strongly associated with indoor dampness). No associations with health were assessed.

Practical Implications

- This paper contributes a more detailed understanding of the drivers of indoor dampness and musty odor in a residential setting.
- Results may contribute to the development of more effective interventions to reduce indoor dampness and mold exposure.

2 | METHODS

2.1 | The New Zealand house condition survey

The New Zealand House Condition Survey is conducted by BRANZ, a national building research body, approximately every 5 years since 1994.[25] The study reported here, used data collected in the three most recent surveys, that is, 2005, 2010, and 2015. The sampling methodology is described in detail elsewhere.[25–28] Briefly, the three surveys were restricted to single family, timber-framed dwellings (no apartments were included), with each survey involving an entirely new sample, that is, no houses were included in more than one survey. While using almost identical assessment tools, there were some differences between the three surveys, which are summarized in Table 1. In particular, in 2005, the sample was limited to only owner-occupied houses in the three largest New Zealand cities and outlying regions: Auckland and Wellington in the North Island, and Christchurch in the South Island. Also, home inspectors (trained building professionals) worked within regions and no training specifically related to the survey was provided. In contrast, for the 2010 and 2015 surveys, rental houses and smaller rural towns were also included, and a sampling structure was developed to capture a representative sample of dwellings. This involved dividing the country into 13 strata, 11 of which corresponded to cities and the remaining two being the rest of the North Island, and the rest of the South Island. Cluster sampling was used within strata based on census mesh-blocks (smallest statistical area unit). Also, training for home inspectors was introduced, involving a day of theory, followed by supervised inspections. In 2010, inspectors travelled nationally, while in 2015, there were again regional survey teams.

TABLE 1 Differences between the three house condition surveys

	2005	2010	2015
Data collection differences			
Musty odor	–	Y	Y
Tenure	–	Y	Y
Floor area	Y	Y	–
Heating behavior	–	–	Y
Methodology differences			
Surveyor (*n*)	6	7	15
Surveyor area	Regional (3 regions)	National	Regional (13 regions)
Survey training	–	Y	Y

2.2 | House characteristics

The surveys included >1500 individual components, including presence of insulation, heaters and mechanical ventilation systems, site details such as location, slope of site, and exposure to noise, air pollution, and sun. Other information collected included land and house value, number of occupants, year of construction, and date of survey. Of these variables, 62 variables were selected as potentially associated to indoor dampness (see Table S1); apart from these 62 variables, no other variables were assessed. Inspection of wall cavities to assess the presence of insulation was conducted in the 2005 survey, but this was abandoned in later surveys due to practicality and health and safety concerns. In these cases, wall insulation was identified based on the house age and conversation with the occupants. Age of the house was identified and categorized as follows: pre-1930s/1930–1979/1980 and newer, with categories reflecting the broad shift toward increasing airtightness over time. Houses built prior to 1930 used almost exclusively strip floors, and often strip wall linings, and are the least airtight; from 1930, increasing use of plaster and sheet floor and wall materials increased airtightness; and 1979 marked the introduction of the first insulation regulations in new builds (roof-cavity only). Along with detailed records of material types for most of the building components, condition ratings on a 5-point scale (Excellent, Good, Moderate, Poor, Serious) were given for major components, that is, windows, doors, roof, gutters, subfloor ventilation, exterior paint condition, etc. These rating values were based on the inspectors' assessments of the urgency of any potential repair required. For the purpose of this analysis, rating variables were collapsed from a 5-point scale into a binary outcome: 0 = excellent/good and 1 = moderate/poor/serious.

2.3 | Mold and musty odor

Visible mold was reported for each room in the house separately using a 5-point scale of mold severity (none (1), specks (2), patches (3), large patches (4), extensive (5)). For the purpose of the analyses, due to relatively low numbers in each of those five categories, we treated the living or bedrooms as having mold if at least one bedroom or living room had any visible mold (ie, a single present (scores 2–5)/absent score (score 1). In addition to analyzing mold in living and bedrooms separately, we also assessed mold present/absent anywhere in the house. Musty odor was recorded for the whole house and not for individual rooms. Inspectors' training (2010 and 2015 only) to assess mold involved using photographs to standardize the interpretation of severity. For the purpose of this study, we consider mold and musty odors markers of indoor dampness; therefore, when discussing some results we use the term indoor dampness.

2.4 | Temperature and rainfall data, seasons and climate zone

Twenty-four-hour rainfall and maximum temperature was obtained for each house for a 30-day period prior to the date of the survey. Data were sourced from the National Climate database[29] from the weather station closest to the house (generally <10 km). Data were expressed as 30-day total rainfall (mm) and mean 30 daily maximum temperature (°C). To assess the effects of season and climate on mold and musty odor we also classified houses by climate zone (North, approximate latitudes 30–36°S; Mid, approximate latitude 36–41°S; and South, approximate latitude 41–46°S), with each climate zone having different insulation requirements as recognized in the New Zealand building regulations, and by season that houses were inspected (spring, summer, autumn or winter). New Zealand has a temperate climate, where winter and spring are generally the coldest, and summer and early autumn the warmest and driest. Because of the strong impact of surrounding oceans, mean daily temperatures generally remain within a relatively narrow band of around 10°C throughout the year,[30] and this differs somewhat from the most northern parts of the country, with a hotter more humid climate and mean daily temperatures of 18°C in summer and 12°C in winter, to the southern-most climate zone, with a cooler, drier climate, and mean daily temperatures ranging from 15°C in summer to 10°C in winter.[30]

2.5 | Data analyses

Analyses were conducted using STATA 15 (StataCorp LP) for each survey separately. Associations between home characteristics and mold and musty odor were assessed using logistic regression. For visible mold, multivariate models mutually adjusting for other factors, were developed by including variables that fulfilled one of two requirements: (1) in unadjusted analyses, associations were consistent and (borderline) statistically significant ($p \leq 0.1$) for that variable in two or more of the surveys; (2) consistent associations with mold were observed across all three surveys, and statistically significant ($p \leq 0.05$) in at least one. For musty odor, which was available for only two surveys, variables were included if they were consistently associated with the outcome variable and were significant ($p \leq 0.05$) in one of the two surveys. All models were further adjusted for surveyor (except 2005, as surveyor was highly correlated with climate zone, thus resulting in multi-collinearity), average 30-day rain (mm) and 30-day average maximum temperature (°C).

In addition to considering individual factors, we conducted analyses involving aggregated variables by combining variables within the same domains. Prior to doing so, we checked for consistency of associations (negative or positive) for each individual variable. The aggregated variable for mechanical ventilation involved combining information on independently operated kitchen, bathroom, and clothes dryer extraction fans into one variable with each fan used to control a particular moisture point source. For this purpose, we used a score of "1" for the presence and "0" for the absence of each of these ventilation types and this was summed for each house and subsequently used in the analysis (the total sum variable ranged from zero to three). For the insulation domain, the presence of roof, underfloor and wall cavity insulation were summed, resulting in a score ranging from zero (no insulation) to three (all three areas insulated). The subfloor domain summed the presence of ponding or leaks, insufficient subfloor ventilation, and lack of ground moisture barrier, again resulting in a combined score ranging from zero to three. The building envelope condition (BEC) domain summed moderate to serious condition of roof cladding, wall cladding, exterior paint, windows, and spouting/guttering, with a combined score ranging from zero to five. These aggregate domains allowed dose-response relationships within each domain to be assessed. In the analysis, houses with a score of three were used as the reference category for the insulation domain, due to low numbers in the category with zero insulation. For all other aggregate variables, the houses with a combined score of zero were used as the reference category.

Finally, in addition to measuring associations using the BEC domain as described above, we also conducted analyses using the OCR provided by the assessors at the end of the survey as single summary condition for the house rated on a 3-point scale: well maintained, moderately maintained or poorly maintained. This was based on the assessors' judgment of all maintenance needed anywhere in the house to bring it to "as new" standard. Materials and fittings both inside and out were included in the assessment, and the presence of mold was considered a condition in need of maintenance. A flow diagram detailing all analyses is included in Figure S1.

Tests for trend were conducted by treating each categorical domain as a continuous variable in the identical model, and using the resultant *p*-value. Collinearity was tested for all models using variance inflation factors, and all scores were under 3. Correlations between two variables were assessed using Spearman correlation tests.

3 | RESULTS

3.1 | Sample characteristics

The age distribution of the houses in the three samples was similar with around half of the houses (52%–55%) built between 1930 and 1979, around a third (30%–36%) built after 1979, and 11%–15% built before 1930. Houses with three to four bedrooms and metal roof cladding were more common (Table 2). Houses in the 2010 and 2015 surveys, which included rental properties, were more likely to have fewer bedrooms and occupants compared to 2005, and there was a slightly higher proportion of rental houses in the 2015 survey, that is, 27% compared to 22% in 2010. The three surveys also differed in terms of climate zone with the 2005 survey including more houses in the northern (warmest; sub-tropical) climate zone. The 2010 survey was the only one of the three to conduct the bulk of surveys in the colder, wetter months of winter and spring (Table 2). These differences in season of inspection were reflected in the weather data, with significantly more houses in the highest rainfall category and the lowest temperature category in the 2010 survey (Table 2).

The proportion of houses with mold in living and bedrooms differed across the three surveys with 4% in 2005, 15% in 2010, and 18% in 2015. Musty odor was detected in 11% and 6% of houses in 2010 and 2015, respectively (Table 2).

3.2 | Associations with mold

Tenancy was associated with mold in living and bedrooms in both surveys that included rental properties, statistically significant in the 2010 survey (aOR 2.1; $p < 0.05$) and borderline statistically significant in the 2015 survey (aOR 1.7 $p < 0.1$). The presence of extract ventilation in the bathroom was associated with reduced living and bedroom mold, reaching statistical significance in the 2015 survey (aOR 0.6; $p < 0.05$) and borderline statistical significance in the 2010 survey (aOR 0.5, $p < 0.1$). Other home characteristics that were consistently associated with mold in the living and bedroom across the three surveys include the following: missing or leaking flashings on windows or doors (aORs 2.0–3.9, significant in 2010, $p < 0.05$), poor window condition (aORs 1.7–3.4, significant in 2005, $p < 0.05$) and number of occupants (≥5; aORs 1.1–5.1, significant in 2005 $p < 0.01$; Table 3).

When analyzing the summed aggregate variables, we found a dose-response association for insulation ($p < 0.05$ for trend, 2005 and 2015), with fewer types of insulation (roof, walls, and underfloor) associated with increased odds of visible mold (aORs 2.3–11.4, for homes with no insulation compared to those with all three types of insulation; Table 4). Similarly, for aggregate BEC defects, we found a clear positive dose-response association across all surveys ($p < 0.05$–0.01 for trend), with aORs for the largest number of defects ranging from 2.4–4.3 ($p < 0.05$) when compared to houses with the fewest defects. A consistent dose-response association ($p < 0.01$ for trend, all surveys) was also shown for ventilation (kitchen, bathroom, and clothes dryer ventilation), with the presence of more types of ventilation associated with a 60%–80% reduced likelihood of indoor mold (Table 4). Using the inspectors' OCR, we found similar, but more pronounced, dose-response associations compared to our BEC rating ($p < 0.01$–0.001 for trend), with poor condition ratings increasing the risk of mold 8–16 times ($p < 0.01$; Table 4).

In addition to considering mold in the living and bedroom, we also assessed associations with reported mold anywhere in the house. Age of the house was associated with mold in the whole house (aORs 0.3–0.8 for houses built in 1980 or later; Table 5), although this was significant only in 2015 ($p < 0.01$). The apparent protective effect of bathroom fans was more pronounced compared to the relationship with living and bedroom mold (aORs 0.8–0.4, significant in 2010 and 2015, $p < 0.05$–0.001), while the reduction in odds of mold related to presence of a range hood (extraction fan over cooker) (aORs 0.9–0.7, $p < 0.1$ in 2015) was less pronounced. The individual factors making up the BEC domain (window, wall cladding, exterior paint, roof, and spouting condition) were also associated with mold in the whole house, with each of these factors associated with statistically significant increased odds of mold in at least one of the three surveys, except roof condition (Table 5). Analysis of aggregated domains showed a significant dose-response trend for climate zone, which was not observed for the other outcomes, with aORs for houses in the southern (colder) zone ranging from 0.2–0.5 ($p < 0.05$ for 2010 and 2015, $p = 0.08$ in 2005 for trend; Table 6). Other associations were similar, or in some cases more pronounced, to those described for mold in living and bedrooms. In particular, across all three surveys a significant positive dose-response trend was observed, with the number of occupants, with aORs ranging from 2.4–4.5 for five or more occupants compared to 1–2 occupants (Table 6).

3.3 | Musty odor

Tenancy and the presence of an open fireplace both increased the odds of musty odor in the 2010 survey (aOR 3.1, $p < 0.05$ and aOR 7.6, $p < 0.001$, respectively) but this was not shown in the 2015

TABLE 2 Sample and home characteristics of the three house condition surveys

	2005 (565 houses) *n* (%)	2010 (491 houses) *n* (%)	2015 (560 houses) *n* (%)
Visible mold (living and bedroom)			
None	543 (96)	419 (85)	458 (82)
Specks	12 (2)	31 (6)	42 (8)
Patches	6 (1)	24 (5)	38 (7)
Large patches	1 (0.5)	13 (3)	16 (3)
Extensive	3 (0.5)	4 (1)	6 (1)
Musty odor			
No	—	439 (89)	524 (94)
Yes		52 (11)	36 (6)
Survey season			
Summer (December–February)	540 (96)	50 (10)	172 (31)
Autumn (March–May)	10 (2)	—	149 (27)
Winter (June–August)	—	56 (12)	1 (0)
Spring (September–November)	15 (3)	383 (78)	238 (43)
30-day rain			
0–50 mm	302 (53)	206 (42)	308 (56)
51–100 mm	212 (38)	104 (21)	199 (36)
101–150 mm	44 (8)	70 (14)	41(7)
151 mm or more	7 (1)	107 (22)	6 (1)
30-day temp (average)			
<15°C	0	177 (36)	48 (9)
15.1–20°C	183 (32)	260 (53)	233 (42)
20.1–25°C	315 (56)	49 (10)	229 (41)
>25°C	67 (12)	1 (0.2)	47 (8)
Climate zone			
North	304 (54)	161 (33)	183 (33)
Mid	111 (20)	227 (46)	159 (28)
South	150 (26)	101 (21)	218 (39)
Age category			
Pre-1930	87 (15)	58 (13)	62 (11)
1930–1979	307 (55)	242 (52)	294 (53)
1980 and older	167 (30)	163 (35)	204 (36)
Overall condition rating (OCR)			
Well maintained	280 (50)	125 (25)	243 (44)
Reasonably maintained	195 (35)	127 (26)	220 (39)
Poorly maintained	85 (15)	112 (23)	96 (17)
Missing	5 (1)	127 (26)	
Tenure			
Rented	—	108 (22)	149 (27)
Owner-occupied	565 (100)	383 (78)	411 (73)
Occupants			
1–2	273 (48)	277 (56)	336 (60)
3–4	213 (38)	167 (34)	175 (31)
5 or more	63 (11)	47 (10)	49 (9)
Missing	16 (3)		
Bedrooms			
1–2	35 (6)	74 (15)	104 (19)
3–4	489 (87)	392 (80)	422 (75)
5 or more	41 (7)	23 (5)	32 (5.5)
Missing			2 (0.5)
Foundation type			
Piles	321 (57)	314 (64)	339 (60)
Concrete slab	148 (26)	137 (28)	207 (37)
Mixed foundations	96 (17)	40 (8)	14 (3)
Cladding type			
Timber weatherboard	186 (33)	97 (20)	128 (23)
Fiber cement	55 (10)	43 (9)	66 (12)
Brick	86 (15)	61 (12)	110 (20)
Mixed/other	238 (42)	290 (59)	256 (46)
Roof type			
Metal roof	372 (66)	287 (58)	409 (73)
Concrete/clay tiles	183 (32)	201 (41)	121 (22)
Other	10 (2)	3 (1)	30 (5)

(Continues)

survey (Table 3). Fiber cement cladding type was consistently associated across both surveys, with a greater risk of musty odor (aOR 4.7 and 6.1, respectively; $p < 0.05$), and a similar association was found for brick cladding, but this was observed only in the 2015 survey (aOR 14.3, $p < 0.01$). However, confidence limits were wide as these cladding types were not common (Table 3). Of interest, presence of a kitchen range hood was associated with reduced odds of musty odor, but this was statistically significant only for the 2015 survey.

Associations with aggregate domain variables were generally similar to those observed for visible mold, with insulation, ventilation, and envelope defects (BEC) showing significant dose-response trends (Table 4). Dose-response associations ($p < 0.01$–0.001 for trend) were particularly consistent for building envelope defects (BEC) with aORs ranging from 4.3 to 15.9, $p < 0.05$. Also, similar to findings for visible mold, strong and consistent associations were observed with inspectors' OCR (Table 4).

4 | DISCUSSION

This study showed that a wide range of house characteristics were independently associated with indoor visible mold and musty odor, including tenure, occupancy, climate, ventilation, insulation, and

TABLE 3 Multivariate analysis of visible mold in living and bedrooms and musty odor in three house condition surveys

	Mold									Musty odor					
	2005 $N/n = 545/22$ $p = 0.0001$ $R^2 = 0.26$			2010 $N/n = 486/72$ $p = 0.0000$ $R^2 = 0.25$			2015 $N/n = 526/101$ $p = 0.0000$ $R^2 = 0.26$			2010 $N/n = 487/52$ $p = 0.0000$ $R^2 = 0.35$			2015 $N/n = 520/34$ $p = 0.0000$ $R^2 = 0.43$		
	N	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR
Age of house															
Pre-1930	*84*	*5*	*Ref*	*56*	*7*	*Ref*	*61*	*13*	*Ref*	*57*	*11*	*Ref*	*59*	*4*	*Ref*
1930–1979	*300*	*16*	1.0 (0.3, 3.5)	*242*	*42*	1.8 (0.6, 5.2)	*278*	*58*	0.8 (0.4, 1.9)	*242*	*34*	0.5 (0.2, 1.5)	*277*	*28*	1.0 (0.2, 5.6)
Post-1980	*161*	*1*	*0.1 (0.01, 1.6)*^	*160*	*17*	2.5 (0.7, 9.4)	*187*	*30*	1.2 (0.5, 3.2)	*160*	*4*	0.3 (0.1, 2.1)	*184*	*2*	0.2 (0.0, 2.1)
Missing/mixed				*28*	*2*	0.6 (0.1, 3.8)				*28*	*3*	0.4 (0.1, 2.4)			
Climate zone															
North			(not included in model)	*159*	*23*	*Ref*	*170*	*40*	*Ref*						
Mid				*226*	*32*	**0.4 (0.1, 0.9)***	*147*	*40*	1.5 (0.2, 11.8)			–			
South			[a]	*101*	*17*	0.7 (0.2, 2.0)	*209*	*21*	0.4 (0.1, 2.3)						
Occupants															
1–2	*272*	*8*	*Ref*	*272*	*35*	*Ref*	*314*	*69*	*Ref*						
3–4	*210*	*6*	0.8 (0.3, 2.6)	*167*	*29*	1.0 (0.5, 1.8)	*164*	*31*	0.9 (0.5, 1.7)			–			–
5 or more	*63*	*8*	**5.1 (1.6, 16.1)****	*47*	*8*	1.2 (0.4, 3.2)	*48*	*11*	1.1 (0.4, 2.8)						
Tenure															
Owner occupier	*545*	*22*		*378*	*46*	*Ref*	*384*	*62*	*Ref*	*379*	*33*	*Ref*	*379*	*22*	*Ref*
Tenant	*0*	*0*	*NA*	*108*	*26*	**2.1 (1.0, 4.4)***	*142*	*39*	*1.7 (1.0, 3.1)*^	*108*	*19*	**3.1 (1.2, 7.8)***	*141*	*12*	0.8 (0.3, 2.5)
Open fireplace															
No										*444*	*37*	*Ref*	*492*	*30*	*Ref*
Yes			–			–			–	*43*	*15*	**7.6 (2.7, 21.8)*****	*28*	*4*	3.0 (0.5, 17.6)
Range hood															
No	*329*	*18*	*Ref*	*194*	*42*	*Ref*	*195*	*53*	*Ref*	*195*	*33*	*Ref*	*194*	*29*	*Ref*
Yes	*216*	*4*	0.4 (0.1, 1.4)	*292*	*30*	0.6 (0.3, 1.1)	*331*	*48*	0.7 (0.4, 1.2)	*292*	*19*	0.5 (0.2, 1.3)	*326*	*5*	**0.1 (0.0, 0.3)*****
Bathroom ventilation															
None	*387*	*19*	*Ref*	*292*	*52*	*Ref*	*242*	*66*	*Ref*	*292*	*40*	*Ref*	*241*	*22*	*Ref*
Vented to outside	*158*	*3*	0.6 (0.2, 2.5)	*194*	*20*	*0.5 (0.3, 1.1)*^	*257*	*34*	**0.6 (0.3, 1.0)***	*195*	*20*	0.7 (0.3, 1.6)	*253*	*10*	0.7 (0.2, 2.2)
Missing							*27*	*1*	0.2 (0.0, 2.0)				*26*	*2*	0.9 (0.1, 9.9)

(Continues)

TABLE 3 (Continued)

	Mold									Musty odor					
	2005 *N/n* = 545/22 *p* = 0.0001 R^2 = 0.26			**2010** *N/n* = 486/72 *p* = 0.0000 R^2 = 0.25			**2015** *N/n* = 526/101 *p* = 0.0000 R^2 = 0.26			**2010** *N/n* = 487/52 *p* = 0.0000 R^2 = 0.35			**2015** *N/n* = 520/34 *p* = 0.0000 R^2 = 0.43		
	N	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR
Sufficient subfloor ventilation															
Yes	156	12	*Ref*	74	9	*Ref*	94	29	*Ref*	75	7	*Ref*	93	9	*Ref*
No	259	8	**0.3 (0.1, 0.9)***	242	44	1.5 (0.6, 4.0)	219	41	**0.4 (0.2, 0.7)*****	242	38	1.1 (0.3, 3.7)	218	20	1.0 (0.3, 3.4)
Slab foundation	130	2	0.7 (0.1, 4.1)	170	19	1.1 (0.4, 3.4)	213	31	**0.4 (0.2, 0.9)***	170	7	0.9 (0.2, 3.8)	209	5	0.3 (0.1, 1.8)
Roof condition rating															
Excellent/good	400	16	*Ref*	287	30	*Ref*	297	41	*Ref*	288	18	*Ref*	293	12	*Ref*
Moderate/poor	145	6	0.4 (0.1, 1.5)	171	37	*1.9 (1.0, 3.7)*$^{\wedge}$	229	60	0.7 (0.3, 1.4)	171	30	1.5 (0.7, 3.5)	227	22	1.4 (0.3, 5.5)
Missing				28	5	2.6 (0.7, 9.9)				28	4	*4.4 (0.9, 21.6)*$^{\wedge}$			
Missing/leaking flashings															
No	508	19	*Ref*	467	62	*Ref*	502	92	*Ref*	467	49	*Ref*	496	31	*Ref*
Yes	37	3	2.7 (0.6, 12.3)	19	10	**3.9 (1.3, 12.2)***	24	9	2.0 (0.7, 5.8)	20	3	1.5 (0.3, 7.3)	24	3	0.5 (0.1, 3.2)
Window condition															
Excellent/good	368	16	*Ref*	249	22	*Ref*	292	27	*Ref*	249	11	*Ref*	288	9	*Ref*
Moderate/poor	177	6	**3.4 (1.1, 11.2)***	223	47	1.8 (0.8, 3.7)	230	73	1.7 (0.8, 3.7)	224	40	*2.2 (0.9, 5.8)*$^{\wedge}$	228	24	1.0 (0.2, 4.2)
Missing				14	3	2.3 (0.5, 11)	4	1	4.2 (0.2, 78.2)	14	1	0.2 (0.0, 3.3)	4	1	*52.4 (0.9, 2998.3)*
Wall cladding paint deterioration															
No	273	8	*Ref*	366	46	*Ref*	367	56	*Ref*	367	37	*Ref*	363	12	*Ref*
Yes	272	14	1.2 (0.5, 3.4)	120	26	0.9 (0.4, 1.8)	159	45	1.4 (0.7, 2.6)	120	15	1.1 (0.4, 2.7)	157	22	2.3 (0.7, 8.3)
Wall cladding condition															
Excellent/good	397	12	*Ref*	128	5	*Ref*	306	38	*Ref*	128	8	*Ref*	302	7	*Ref*
Moderate/poor	148	10	1.0 (0.4, 3.2)	339	64	**4.1 (1.4, 11.9)****	220	63	1.3 (0.6, 2.7)	340	42	1.0 (0.3, 3.1)	218	27	**5.7 (1.3, 25.2)***
Missing				19	3	*4.6 (0.8, 27.3)*$^{\wedge}$				19	2	1.9 (0.2, 16.9)			
Cladding type															
Timber weatherboards										95	16	*Ref*	119	8	*Ref*

(Continues)

TABLE 3 (Continued)

	Mold									Musty odor					
	2005 $N/n = 545/22$ $p = 0.0001$ $R^2 = 0.26$			**2010** $N/n = 486/72$ $p = 0.0000$ $R^2 = 0.25$			**2015** $N/n = 526/101$ $p = 0.0000$ $R^2 = 0.26$			**2010** $N/n = 487/52$ $p = 0.0000$ $R^2 = 0.35$			**2015** $N/n = 520/34$ $p = 0.0000$ $R^2 = 0.43$		
	N	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR
Fiber cement			–			–			–	*43*	*5*	**4.7 (1.0, 22.4)**[*]	*59*	*7*	**6.1 (1.1, 33.0)**[*]
Brick										*59*	*8*	0.8 (0.2, 3.4)	*104*	*5*	**14.3 (1.8, 111.6)**[**]
Mixed/other										*290*	*23*	1.0 (0.4, 2.5)	*238*	*14*	2.6 (0.7, 9.8)
Spouting condition															
Excellent/good	*435*	*13*	*Ref*	*307*	*40*	*Ref*	*329*	*40*	*Ref*	*308*	*20*	*Ref*	*325*	*12*	*Ref*
Moderate/poor	*110*	*9*	*2.7 (0.9, 7.9)*[^]	*143*	*29*	0.7 (0.4, 1.4)	*197*	*61*	*2.1 (0.9, 4.6)*[^]	*143*	*28*	1.9 (0.8, 4.5)	*195*	*22*	2.5 (0.6, 10.2)
Missing				*36*	*3*	0.5 (0.1, 2.4)				*36*	*4*	1.0 (0.2, 4.4)			

Note: *N*, number of houses in subgroup; *n*, number of houses in subgroup affected with mold/musty odor. NA, data not available; –, not associated in univariate analysis. All models adjusted for surveyor (except 2005 because of collinearity with zone), 30 day rain (mm), 30 day mean high temperature (°C) & wall insulation. Musty odor only, also adjusted for leaking plumbing indoors, ponding and leaks under house, dryer ventilation & window material. Bold has been used for statistically significant results (p less than or equal to 0.05). Italics have been used for "borderline statistically significant" results (p less than or equal to 0.1).

[a]Perfectly explains failure.

^$p \le 0.10$.

*$p \le 0.05$.

**$p \le 0.01$.

***$p \le 0.001$.

TABLE 4 Analysis of aggregated variables and visible mold in living and bedrooms and musty odor in three house condition surveys

	Mold									Musty odor					
	2005 N/n = 549/22 p = 0.0002 R^2 = 0.20			2010 N/n = 486/72 p = 0.0000 R^2 = 0.18			2015 N/n = 527/101 p = 0.0000 R^2 = 0.26			2010 N/n = 486/52 p = 0.0000 R^2 = 0.25			2015 N/n = 494/34 p = 0.0000 R^2 = 0.31		
	N	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR
Climate zone															
North	304	18	(not included in model)	159	23	Ref	171	40	Ref	159	16	Ref	157	10	Ref
Mid	111	4		226	32	0.5 (0.2, 1.2)	147	40	1.0 (0.2, 6.3)	226	26	0.5 (0.2, 1.3)	142	16	1.1 (0.0, 64.9)
South	150	0	[a]	101	17	0.6 (0.2, 1.6)	209	21	0.7 (0.1, 3.1)	101	10	0.4 (0.1, 1.2)	195	8	0.8 (0.0, 33.3)
Trend			NA			NS			NS			NS			NS
Occupants															
1–2	273	13	Ref	272	35	Ref	315	59	Ref	272	27	Ref	295	18	Ref
3–4	213	15	0.9 (0.3, 2.8)	167	29	1.1 (0.6, 2.0)	164	31	1.0 (0.6, 1.9)	167	22	1.2 (0.6, 2.5)	152	12	2.0 (0.8, 5.1)
5 or more	63	11	**4.7 (1.6, 14.5)**[**]	47	8	1.3 (0.5, 3.4)	48	11	1.3 (0.5, 3.2)	47	3	0.5 (0.1, 1.9)	47	4	1.2 (0.3, 4.8)
Trend			$p < 0.05$			NS			NS			NS			NS
Tenure															
Owner occupier	549	22		378	46	Ref	385	62	Ref	378	33	Ref	357	22	Ref
Tenant	0	0	–	108	26	1.8 (0.9, 3.6)[^]	142	39	**2.1 (1.2, 3.9)**[*]	108	19	2.0 (0.9, 4.2)[^]	137	12	1.5 (0.6, 4.0)
Ventilation/3 (kitchen/bathroom/clothes dryer)															
0	239	13	(not included in model)	142	35	Ref	132	40	Ref	142	26	Ref	132	19	Ref
1	188	9		168	20	**0.4 (0.2, 0.8)**[**]	172	36	0.8 (0.4, 1.4)	168	18	0.5 (0.2, 1.1)[^]	172	13	0.6 (0.2, 1.5)
2	113	0	[a]	142	14	**0.4 (0.2, 0.8)**[**]	190	23	**0.4 (0.2, 0.8)**[**]	142	7	**0.3 (0.1, 0.9)**[**]	190	2	**0.1 (0.0, 0.6)**[**]
3	25	0	[a]	34	3	**0.2 (0.0, 0.8)**[*]	33	2	0.3 (0.1, 1.5)	34	1	0.1 (0.0, 1.2)[^]			[a]
Trend			NA			$p < 0.01$			$p < 0.01$			$p < 0.01$			$p < 0.01$
Insulation/3 (ceiling/underfloor/wall cavity)															
3	206	5	Ref	144	13	Ref	118	9	Ref	144	5	Ref	105	3	Ref
2	149	11	**6.1 (1.2, 31.6)**[*]	185	32	1.4 (0.6, 3.1)	311	65	2.0 (0.8, 5.0)	185	18	2.3 (0.7, 7.3)	298	21	1.0 (0.2, 4.7)
1	167	17	**7.3 (1.2, 44.4)**[*]	151	26	1.5 (0.6, 3.6)	90	24	**3.2 (1.1, 9.8)**[*]	151	28	**4.5 (1.4, 14.8)**[**]	83	7	0.5 (0.1, 3.0)
No insulation	27	6	**11.4 (1.4, 96.4)**[*]	6	1	2.3 (0.2, 25.8)	8	3	3.5 (0.5, 25.5)	6	1	**15.7 (1.3, 195.6)**[*]	8	3	5.0 (0.5, 48.3)

(Continues)

TABLE 4 (Continued)

	Mold									Musty odor					
	2005 $N/n = 549/22$ $p = 0.0002$ $R^2 = 0.20$			2010 $N/n = 486/72$ $p = 0.0000$ $R^2 = 0.18$			2015 $N/n = 527/101$ $p = 0.0000$ $R^2 = 0.26$			2010 $N/n = 486/52$ $p = 0.0000$ $R^2 = 0.25$			2015 $N/n = 494/34$ $p = 0.0000$ $R^2 = 0.31$		
	N	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR	*N*	*n*	aOR
Trend			$p < 0.05$			NS			$p < 0.05$			$p < 0.01$			NS
Subfloor/3 (ponding or leaks/absence of ground cover/insufficient ventilation)															
0	*182*	*8*	*Ref*	*27*	*3*	*Ref*	*210*	*32*	*Ref*	*27*	*1*	*Ref*	*195*	*5*	*Ref*
1	*189*	*19*	0.6 (0.2, 2.0)	*388*	*48*	1.4 (0.4, 5.5)	*140*	*32*	1.0 (0.5, 2.0)	*388*	*37*	3.0 (0.4, 26.1)	*135*	*11*	2.2 (0.6, 8.0)
2	*156*	*10*	0.2 (0.1, 1.1)[^]	*71*	*21*	2.2 (0.5, 9.7)	*154*	*30*	0.7 (0.3, 1.4)	*71*	*14*	3.5 (0.4, 33.6)	*142*	*13*	2.1 (0.6, 7.4)
3	*22*	*2*	0.2 (0.0, 2.9)				*23*	*7*	0.5 (0.1, 1.9)				*22*	*5*	**6.1 (1.0, 37.0)**[*]
Trend			$p = 0.05$			NS			NS			NS			NS
BEC/5 (Poorer condition of; roof cladding/wall cladding/windows/exterior paint/spouting and guttering)															
0–1	*319*	*8*	*Ref*	*156*	*13*	*Ref*	*236*	*25*	*Ref*	*156*	*5*	*Ref*	*221*	*3*	*Ref*
2–3	*170*	*16*	**3.0 (1.0, 8.8)**[*]	*161*	*26*	1.5 (0.7, 3.3)	*137*	*24*	1.5 (0.7, 3.1)	*161*	*21*	**3.3 (1.1, 9.8)**[*]	*124*	*11*	**9.1 (1.9, 44.1)**[**]
4–5	*60*	*15*	**4.9 (1.3, 19.0)**[*]	*85*	*22*	**2.4 (1.0, 6.1)**[*]	*154*	*52*	**2.6 (1.1, 5.9)**[*]	*85*	*15*	**4.3 (1.3, 14.2)**[*]	*149*	*20*	**15.9 (3.5, 71.5)**[***]
Missing				*84*	*11*	1.6 (0.6, 4.1)				*84*	*11*	**3.7 (1.1, 12.5)**[*]			
Trend			$p = 0.01$			$p < 0.05$			$p < 0.05$			$p < 0.01$			$p < 0.001$
Overall condition rating (OCR)															
Excellent	*274*	*3*	*Ref*	*123*	*2*	*Ref*	*237*	*17*	*Ref*	*156*	*3*	*Ref*	*215*	*1*	*Ref*
Moderate	*186*	*9*	**4.0 (1.0, 15.6)**[*]	*127*	*14*	**4.7 (1.0, 22.2)**[*]	*218*	*44*	**2.8 (1.3, 5.9)**[**]	*161*	*8*	2.4 (0.6, 10.4)	*206*	*11*	**16.7 (1.8, 153.1)**[**]
Poor	*89*	*10*	**8.0 (1.9, 33.3)**[**]	*111*	*38*	**15.6 (3.3, 72.8)**[***]	*95*	*40*	**8.0 (3.2, 19.8)**[***]	*85*	*40*	**23.8 (5.7, 98.1)**[***]	*95*	*22*	**67.9 (7.0, 657.6)**[***]
Missing				*125*	*8*	**8.4 (1.7, 40.8)**[**]				*84*	*1*	0.4 (0.0, 4.4)			
Trend			$p < 0.01$			$p = 0.001$			$p < 0.001$			$p < 0.001$			$p < 0.001$

Note: N, number of houses in subgroup; *n*, number of houses in subgroup affected with mold/musty odor. NS, non-significant; —, data not available. All models adjusted for surveyor (except 2005), 30 day rain (mm) and 30 day mean high temperature (°C). Bold has been used for statistically significant results (p less than or equal to 0.05). Italics have been used for "borderline statistically significant" results (p less than or equal to 0.1).

[a]Perfectly explains failure.

[^]$p \le 0.10$.

*$p \le 0.05$.

**$p \le 0.01$.

***$p \le 0.001$.

TABLE 5 Multivariate analysis of mold in the whole house in three House Condition Surveys

	2005 $N = 536$ $p = 0.0000$ $R^2 = 0.34$		2010 $N = 486$ $p = 0.0000$ $R^2 = 0.25$		2015 $N = 542$ $p = 0.0000$ $R^2 = 0.27$	
	N	aOR	N	aOR	N	aOR
Age of house						
Pre-1930	82	*Ref*	56	*Ref*	61	*Ref*
1930–1979	297	2.3 (0.5, 8.4)	242	*0.9 (0.4, 2.0)*	285	0.6 (0.3, 1.2)
Post-1980	157	0.3 (0.0, 3.4)	160	0.8 (0.3, 2.1)	196	**0.4 (0.2, 1.0)****
Missing/mixed			28	1.5 (0.4, 4.9)		
Climate zone						
North	291	*Ref*	159	*Ref*	177	*Ref*
Mid	104	**0.2 (0.0, 0.7)***	226	1.3 (0.7, 2.5)	153	0.4 (0.1, 2.3)
South	141	**0.2 (0.1, 0.9)***	101	0.6 (0.3, 1.3)	212	**0.2 (0.0, 0.7)****
Occupants						
1–2	267	*Ref*	272	*Ref*	326	*Ref*
3–4	208	1.1 (0.4, 2.9)	167	**1.7 (1.0, 2.7)***	167	**1.9 (1.2, 3.2)****
5 or more	61	**4.0 (1.3, 11.7)****	47	**2.3 (1.1, 5.0)***	49	*2.2 (1.0, 5.1)*^
Tenure						
Owner occupier	536		378	*ref*	399	*Ref*
Tenant	0	*NA*	108	1.2 (0.7, 2.2)	143	0.9 (0.6, 1.6)
Range hood						
No	324	*Ref*	194	*Ref*	202	*Ref*
Yes	212	0.9 (0.4, 2.2)	292	0.9 (0.6, 1.5)	340	*0.7 (0.4, 1.1)*^
Bathroom ventilation						
None	381	*Ref*	249	*Ref*	249	*Ref*
Vented to outside	155	0.8 (0.3, 2.7)	194	**0.4 (0.3, 0.7)*****	266	**0.6 (0.4, 1.0)***
Missing			43	0.8 (0.4, 1.8)	27	0.5 (0.2, 1.6)
Sufficient subfloor ventilation						
Yes	154	*Ref*	74	*Ref*	97	*Ref*
No	254	0.5 (0.2, 1.2)	242	1.6 (0.8, 3.4)	224	0.9 (0.5, 1.7)
Slab foundation	128	0.5 (0.1, 2.5)	170	1.4 (0.6, 3.0)	145	0.7 (0.3, 1.3)
Roof condition rating						
Excellent/good	396	*Ref*	287	*Ref*	294	*Ref*
Moderate/poor	140	0.5 (0.2, 1.5)	171	1.4 (0.8, 2.3)	230	1.5 (0.9, 2.7)
Missing			28	1.2 (0.5, 3.2)	18	1.2 (0.3, 4.2)
Window condition						
Excellent/good	361	*Ref*	249	*Ref*	303	*Ref*
Moderate/poor	175	**6.4 (2.2, 18.2)*****	223	1.2 (0.7, 2.0)	239	1.6 (0.9, 2.9)
Missing			14	**0.2 (0.1, 1.0)***		
Wall cladding paint deterioration						
No	266	*Ref*	366	*Ref*	379	*Ref*
Yes	270	1.2 (0.5, 3.2)	120	1.0 (0.6, 1.8)	163	**2.3 (1.3, 3.9)*****
Wall cladding condition						
Excellent/good	390	*Ref*	128	*Ref*	315	*Ref*
Moderate/poor	146	*2.5 (1.0, 6.6)*^	339	**2.3 (1.3, 4.2)****	227	1.1 (0.6, 2.0)

(Continues)

TABLE 5 (Continued)

	2005 *N* = 536 *p* = 0.0000 R^2 = 0.34		2010 *N* = 486 *p* = 0.0000 R^2 = 0.25		2015 *N* = 542 *p* = 0.0000 R^2 = 0.27	
	N	aOR	*N*	aOR	*N*	aOR
Missing			*19*	*3.2 (0.9, 10.8)*^		
Cladding type						
Timber weatherboards	*178*	*Ref*	*94*	*Ref*	*123*	*Ref*
Fiber cement	*52*	1.5 (0.3, 7.9)	*43*	1.5 (0.6, 4.0)	*72*	1.7 (0.7, 4.0)
Brick	*82*	2.5 (0.6, 11.3)	*59*	1.2 (0.5, 3.0)	*107*	1.6 (0.7, 3.7)
Mixed/other	*224*	1.3 (0.5, 3.8)	*290*	0.7 (0.3, 1.3)	*240*	*1.9 (1.0, 3.5)*^
Spouting condition						
Excellent/good	*428*	*Ref*	*307*	*Ref*	*339*	*Ref*
Moderate/poor	*108*	**3.3 (1.2, 8.8)***	*143*	*1.7 (1.0, 2.9)*^	*201*	1.3 (0.7, 2.5)
Missing			*36*	1.0 (0.4, 2.6)	*2*	0.4 (0.0, 17.3)

Note: NA, data not available. All models adjusted for surveyor (except 2005 because of collinearity with zone), 30 day rain (mm), 30 day mean high temperature (°C), age of house, shade, close to a busy road, gas heaters, wall insulation, ceiling insulation, roof material, window material, double glazing, ponding or leaks under house & missing or leaky flashings. Bold has been used for statistically significant results (p less than or equal to 0.05). Italics have been used for "borderline statistically significant" results (p less than or equal to 0.1).

^$p \leq 0.10$.

*$p \leq 0.05$.

**$p \leq 0.01$.

***$p \leq 0.001$.

BEC, with evidence of dose-response associations across multiple surveys.

4.1 | Visible mold

Compared to 2005, reporting of visible mold increased substantially in the 2010 and 2015 surveys, from 4% to 15% and 18% of surveyed homes. This may be due to methodological differences, with the two later surveys including rental homes and introducing assessor training. In addition, the vast majority of assessments for the 2005 survey were conducted in summer (the driest months in New Zealand), whereas assessments conducted for the 2010 and 2015 surveys were also conducted in the colder and wetter seasons, that is, winter and spring.

Poor condition of the building envelope was strongly associated, in a dose-dependent fashion, with increased visible mold, both when using the BEC index created for this analysis, and the building inspectors' OCR. The OCR was consistently more strongly associated with both visible mold and musty odor than our BEC. However, since visible mold was one of the condition factors contributing to the OCR this is to be expected. The few other studies that have assessed associations between poorer building condition either assessed by self-report[15,22] or by building assessor[24] found a similar relationship. Unlike previous studies, our study assessed specific condition defects that may underpin this association, demonstrating that roof and wall claddings as well as windows, spouting and exterior paint all contribute to the buildings' waterproofing.

Extract ventilation (particularly bathroom ventilation) was associated with reduced living and bedroom mold, with clear dose-response associations observed when ventilation data were aggregated, with more types of ventilation (kitchen, bathroom and clothes dryer) associated with reduced likelihood of visible mold. One other study also showed reduced self-reported visible mold in homes that used kitchen range hoods,[14] whereas another study reported the opposite, with kitchen and bathroom extract ventilation associated with an increase in mold.[17]

Although individual insulation factors were not significantly associated with mold in the initial multivariate analysis, when aggregated, there was evidence of a dose-response association. This is consistent with an earlier phone survey conducted in New Zealand, that found that a lack of any insulation was associated with increased visible mold,[15] and a study from the UK that found that houses with <250 mm loft insulation had an increased risk of indoor mold.[17] Two studies assessing the results of insulation interventions also found reduced visible mold.[12,19] The heating behavior of the occupants is likely to impact these associations, but in the one survey where this information was available (2015), it was not found to significantly change these findings (data not shown). Also, type of heating present (electric/gas-flued/gas-unflued/enclosed fire/open fire/central heating) was analyzed for all three surveys, but none of these types

TABLE 6 Aggregated multivariate analysis of mold in the whole house in three House Condition Surveys

	2005 **$N = 526$** **$p = 0.0000$** **$R^2 = 0.26$**		**2010** **$N = 480$** **$p = 0.0000$** **$R^2 = 0.21$**		**2015** **$N = 527$** **$p = 0.0000$** **$R^2 = 23$**	
	N	**aOR**	**N**	**aOR**	**N**	**aOR**
Climate zone						
North	286	Ref	158	Ref	171	Ref
Mid	97	**0.2 (0.1, 0.8)**[*]	222	0.9 (0.5, 1.7)	147	0.6 (0.1, 3.4)
South	143	0.5 (0.2, 1.4)	100	**0.4 (0.2, 0.9)**[*]	209	**0.2 (0.1, 0.8)**[*]
Trend		$p = 0.08$		$p < 0.05$		$p < 0.05$
Occupants						
1–2	266	Ref	271	Ref	315	Ref
3–4	201	1.3 (0.6, 3.1)	162	**1.8 (1.1, 2.9)**[*]	164	**2.0 (1.2, 3.1)**[**]
5 or more	59	**4.5 (1.6, 12.4)**[***]	47	**3.0 (1.4, 6.5)**[**]	48	**2.4 (1.1, 5.0)**[*]
Trend		$p < 0.01$		$p < 0.01$		$p < 0.01$
Tenure						
Owner occupier	529		372	Ref	385	Ref
Tenant	0	—	108	1.2 (0.7, 2.1)	142	1.2 (0.8, 2.0)
Ventilation/3 (kitchen/bathroom/clothes dryer)						
0	234	Ref	142	Ref	132	Ref
1	181	1.5 (0.6, 3.4)	166	**0.5 (0.3, 0.8)**[**]	172	0.9 (0.5, 1.6)
2	111	0.5 (0.1, 1.9)	139	**0.3 (0.2, 0.6)**[***]	190	**0.4 (0.2, 0.7)**[***]
3		[a]	33	**0.1 (0.0, 0.3)**[***]	33	**0.3 (0.1, 0.7)**[**]
Trend		NS		$p < 0.001$		$p < 0.001$
Insulation/3 (ceiling/underfloor/wall cavity)						
3	199	Ref	144	Ref	118	Ref
2	143	2.3 (0.7, 7.4)	185	1.0 (0.6, 1.7)	311	1.5 (0.8, 2.7)
1	157	**4.4 (1.3, 14.9)**[*]	151	1.2 (0.6, 2.1)	90	**3.8 (1.7, 8.6)**[***]
No insulation	27	**5.8 (1.1, 30.4)**[*]			8	*5.9 (0.8, 42.5)*[^]
Trend		$p = 0.01$		NS		$p < 0.001$
Subfloor/3 (ponding or leaks/absence of ground cover/insufficient ventilation)						
0	176	Ref	27	Ref	210	Ref
1	179	0.7 (0.3, 2.1)	382	*2.2 (0.9, 5.6)*[^]	140	1.1 (0.6, 1.9)
2	151	0.4 (0.1, 1.3)	71	**4.1 (1.3, 12.5)**[**]	154	1.5 (0.9, 2.6)
3	20	0.4 (0.1, 3.0)			23	1.2 (0.4, 3.8)
Trend		NS		$p = 0.01$		NS
BEC/5 (Moderate to serious condition of; roof cladding/wall cladding/windows/exterior paint/spouting and guttering)						
0–1	303	Ref	155	Ref	236	Ref
2–3	165	**3.7 (1.4, 9.4)**[**]	159	*1.6 (0.9, 2.8)*[^]	137	**2.1 (1.2, 3.7)**[**]
4–5	58	**15.2 (5.2, 44.7)**[***]	82	**5.8 (2.7, 12.5)**[***]	154	**3.0 (1.6, 5.8)**[***]
Missing			84	1.2 (0.6, 2.2)		
Trend		$p < 0.001$		$p < 0.001$		$p < 0.001$
Overall condition rating (OCR)						
Excellent	254	Ref	123	Ref	237	Ref
Moderate	184	**5.0 (1.3, 19.1)**[*]	125	**2.5 (1.4, 4.7)**[**]	218	**3.6 (2.2, 6.0)**[***]
Poor	88	**26.8 (7.0, 102.3)**[***]	108	**9.3 (4.3, 20.2)**[***]	95	**11.1 (5.2, 23.5)**[***]

(Continues)

TABLE 6 (Continued)

	2005 N = 526 p = 0.0000 R^2 = 0.26		2010 N = 480 p = 0.0000 R^2 = 0.21		2015 N = 527 p = 0.0000 R^2 = 23	
	N	aOR	N	aOR	N	aOR
Missing			*124*	1.5 (0.8, 3.0)		
Trend		$p < 0.001$		$p < 0.05$		$p < 0.001$

Note: All models adjusted for surveyor (except 2005 because of collinearity with zone), 30 day rain (mm), 30 day mean high temperature (°C). —, data not available; NS, not significant. Bold has been used for statistically significant results (p less than or equal to 0.05). Italics have been used for "borderline statistically significant" results (p less than or equal to 0.1).

[a]Perfectly explains failure.

^$p \le 0.10$.

*$p \le 0.05$.

**$p \le 0.01$.

***$p \le 0.001$.

of heaters met the criteria for inclusion in the multivariate models presented here (ie, they were not significantly associated across at least two surveys in univariate analysis—see Section 2), except presence of an open fireplace. In contrast to our findings, some studies have shown that energy-efficiency interventions (including insulation retro-fits) may enhance the presence of some indoor fungi.[31] This is likely due to reduced air-exchange[32,33] in houses that are already reasonably airtight, unlike most houses in New Zealand which are generally fairly draughty.

Consistent with other studies,[15,17,19,34] rental tenure and, number of occupants, were associated with indoor mold. Associations with rental tenure cannot be explained by BEC, insulation and ventilation as analyses were controlled for these factors. However, as shown previously using the same survey data,[25,27] rental homes are more likely to have higher occupant density, which may contribute to the higher risk of indoor mold as demonstrated in other studies for both visible mold[17] and airborne fungi.[35] Information for floor area was available for 2005 and 2010, and a ratio of occupants to floor area was calculated for these two surveys. This ratio was significantly associated with mold in the whole house, and to a lesser degree mold in living and bedrooms, but not musty odor (data not shown). However, the explained variance of this variable ($R^2 = 0.001$) was not greater than that of the number of occupants only, and therefore, for consistency, we instead used the number of occupants in all multivariate models.

4.2 | Musty odor

No association between number of occupants and musty odor was found, but musty odor was associated with rental tenure. To our knowledge, no other studies have reported associations with occupancy and tenancy and musty odor, although studies assessing the health impact of moldy odors frequently adjust for occupant density, as it is considered a confounding factor for asthma and allergy.[6,36]

While there were several similarities between associations with mold and musty odor, there were also some differences, and the correlation between both variables was relatively poor ($r = 0.14$, $p < 0.01$ in 2010 and $r = 0.23$, $p < 0.001$ in 2015). The similarities were more apparent when variables were aggregated; for example, similar effects and trends were demonstrated for tenure, aggregated ventilation, insulation, and BEC. However, there were important differences between characteristics predicting visible mold and musty odor in the analysis of individual characteristics. For example, the presence of an open fire was associated with musty odor and not mold. The reason is not clear, but open fires may indicate an older house that has not been renovated, as open fires have not been commonly installed in new houses built after circa 1940. Also, open chimneys (a common feature of open fires) may result in musty odor either due to ingress of moisture, an uncontrolled open vent, or increased draughtiness. Another characteristic associated with musty odor, but not visible mold, was cladding type. Fiber cement wall cladding was associated with musty odor in both surveys for which data was available, while brick cladding was associated with musty odor in 2015 only. Fiber cement cladding may have characteristics that increase risk of moisture ingress[37] but associations with musty odor (or mold) have not previously been reported, so results should be interpreted with caution, particularly since analyses were based on a relatively small number of houses with this cladding type. Brick cladding is often considered low maintenance, but periodic repointing is required, but often not done, which may result in excess moisture entering the wall cavity.

4.3 | Strengths and weaknesses

A strength of the study is the level of detail of the data collected on physical aspects of the houses involved, along with measures of mold that do not rely on home occupants' self-reports, which may be biased. On the other hand, musty odor assessed by inspectors may be less accurate than self-reported odor, as it may be transient and therefore a single assessment by an inspector may increase rather than decrease exposure measurement error. Another weakness is that musty odor assessment is subjective and not easily standardized across inspectors. As our samples did not include any apartments and the vast majority involved timber-framed houses, it is unclear whether results are generalizable to non-timber-framed houses, although several findings (eg, for insulation, extraction fans and "poor repair") were comparable with previous studies that included non-timber-framed buildings.[14,17–19,24]

The explained variance (R^2) of the regression models described in Tables 3–6 was relatively low (18%–43%), indicating a large proportion of unexplained variance. The lack of data included in these surveys on human behavior, in particular, the use of heating and ventilation, is an important weakness, which if included, would likely explain more of the variance in indoor mold and musty odor. Other important considerations for such surveys are to include both number of occupants and floor area, so accurate ratios of persons to area can be determined. Information on age-ranges and household habitual behaviors, for example, proportion of time spent at home, may also improve the ability of future studies to explain visible mold and musty odor. The relatively low proportion of houses in each of the three samples with mold and musty odors (4%–18%) has resulted in reduced power to identify associations, particularly for house characteristics and conditions that are relatively rare. Although this was partially mitigated by analyzing and comparing results across three surveys, future surveys likely require larger sample sizes to ensure sufficient power for all potential associations to be validly assessed. Also, avoiding sampling during summer (the driest months in New Zealand) may increase the proportion of homes where mold and musty odor are detected.

5 | CONCLUSIONS

In conclusion, this study showed the importance of BEC in avoiding harmful damp-related exposures. It also identified several other modifiable risk factors that may contribute to the development of effective interventions to reduce indoor dampness and mold. In particular, mechanical extract ventilation in kitchens and bathrooms, along with regular maintenance of the building envelope, with attention to spouting, wall and window condition may be important in protecting homes from indoor mold and musty odors.

ACKNOWLEDGMENTS

We would like to thank the researchers, inspectors, and participant households who were involved in the three BRANZ House Condition Surveys. Their participation allowed this research to be possible. We are also grateful to the Centre for Research, Evaluation and Social Assessment (CRESA) and the National Institute of Water and Atmospheric Research (NIWA), for provision of additional data. The house condition surveys and a PhD scholarship were funded from the Building Research Levy. House Condition Surveys were further supported by funding from CRESA, the Ministry for Business Innovation and Enterprise (MBIE), and the Energy Efficiency and Conservation Authority (EECA).

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/ina.12774.

DATA AVAILABILITY STATEMENT

Data is available by request from BRANZ limited, for research purposes. Requests will be considered on a case by case basis.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Taptiklis P, Phipps R, Jones M, Douwes J. House characteristics and condition as determinants of visible mold and musty odor: Results from three New Zealand House Condition Surveys in 2005, 2010, and 2015. *Indoor Air*. 2021;31:832–847. https://doi.org/10.1111/ina.12774