Scoping Study of Condensation in Residential Buildings

Appendix 01: Terms of Reference

23 September 2016

Research funded by:
Australian Building Codes Board
Department of Industry Innovation and Science
Commonwealth of Australia

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Summary of Requirement

The Customer requires the Supplier to provide certain consultancy services to develop and deliver a scoping study to determine the nature and extent of the issue of condensation in new residential buildings and new building work (National Construction Code (NCC) Class 1 and 2 buildings) constructed over the last 10 years.

The scoping study should include an analysis of the results of the ABCB Condensation Survey conducted in December 2015-February 2016, and a literature review, to holistically explore the following:

a. the issue of condensation in residential buildings and what may be causing any increase in condensation;
b. the nature and extent of the problem(s) including climate specific considerations;
c. any requirements within the NCC which may influence the risk of condensation forming;
d. any evidence of a relationship between changes in NCC regulation and an increase in condensation forming in new residential buildings;
e. potential gaps in the requirements of the NCC, which may influence the risk of condensation forming;
f. the capacity of the Australian building industry, and building occupants to manage condensation risk;
g. regulatory and non-regulatory approaches being used nationally and internationally to manage condensation risk; and
h. learnings from work already undertaken by Tasmania and New Zealand (details to be provided to successful supplier).

The scoping study should also include recommendations for addressing and minimising condensation risk with respect to the role and objectives of the NCC. The recommendations must be realistic, achievable, and for each recommendation:

a. detail implementation options and effectiveness;
b. outline costs and benefits; and
c. explore potential unintended consequences.

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Appendix 02: Statistical Analysis of Nationwide Condensation Survey

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ABCB nationwide condensation survey and statistical analysis

Overview

For a number of years there has been a growing voice from building owners raising concern with builders, building surveyors, building designers and building regulators about mould and condensation in new and sometimes old buildings. The concerns generally focused on the visible consequences of condensation such as, moisture on internal walls; dripping soffit linings, dripping ceilings, wet roof spaces, excessive condensation within the house, wet subfloor zones, and mould in bathrooms, laundries, kitchens, bedrooms, living rooms, enclosed subfloors and roof spaces. The ABCB recognised that, despite the development of a range of non-mandatory resources, they and State and Territory building regulators had received anecdotal evidence that indicated an increase in the presence of condensation was occurring in new residential buildings (NCC Class 1 and Class 2). This dichotomy of building class type presents some key preliminary data, namely:

- Class 1 buildings are often constructed by non-commercial builders
- Class 2 buildings are often constructed by commercial builders
- Both Class 1 and Class 2 buildings range from unconditioned, intermittently conditioned to continuously conditioned. In many of these types of building, the heating and/or cooling system is often designed and installed post submission of regulatory design and construction documentation.
- Whereas close to 50% of Class 1 buildings owner occupied, approximately 80% Class 2 buildings are occupied by tenants. This data mix establishes that less than 35% of building occupants would contact the building regulator if they were concerned about the presence of mould and condensation within their new home.

However, at that early stage, it was not clear whether this potential increase in condensation concern was due to the way people were using buildings, or due to minimum building regulatory requirements. In response to these concerns in late 2015 to early 2016, the ABCB undertook a survey to gather evidence and feedback on the extent of condensation problems and the likely causes, as well as gain an understanding of industry's capacity to manage condensation risk in new residential buildings.

The nationwide Condensation Stakeholder Survey was designed "to gather evidence and feedback on the extent of condensation problems and the likely causes, as well as gain an understanding of industry's capacity to manage condensation risk in new residential buildings" (ABCB: Purpose of survey). The survey polled the building industry on the prevalence of condensation in Class 1 and Class 2 buildings constructed in different time periods, namely 2–5 and 10–15 years. The survey was designed to assess the extent of the condensation problem in the building stock generally, parts within buildings where condensation occurred, attribution of responsibility, effects, design factors, awareness and industry sector education. The survey received 2664 responses. The statistical analysis of the survey raw data included general summaries, cross-tabulation analysis, Bayesfactor modelling and text mining of the perceived prevalence of condensation, based on the broad national trends and, where applicable, notable effects when sub-categorised by state, climate zone or building profession.

Patterns of prevalence in Class 1 (houses) and Class 2 (apartments) were broadly similar. Likewise, responses about comparison with 10–15 years ago, and with 2–5 years ago, were broadly similar.

This may suggest a lack of effect from different versions of the Code, since both time periods had similar responses. The survey does not provide evidence that the code amendments are directly responsible for condensation. It should be mentioned that it is a lack of evidence either way, (i.e., that there is also no evidence that the code is not responsible for increasing the occurrence of condensation). An attempt to categorise the respondents by state did not yield a clear trend in terms of regulatory changes and perceived increased occurrence of condensation. Whilst there is no evidence that regulation has increased condensation risk, it is also true to say there is no evidence to the contrary. In the text analysis of open-ended question, "energy efficiency" comes out at a very high frequency. In reading the responses, other indicators of a relationship to regulation are the adoption of tighter building enclosures to meet BAL ratings and inconsistencies in the Australian Standards.

In summary, the overall magnitude of problems (as assessed by respondents) varies but does appear to be extensive enough to be of concern. The extent of problem was generally assessed as high. The detailed results from the statistical analysis follow later in the General Analysis. The detailed statistical analysis that follows provides details on the response rates, a report for each question surveyed with the statistical method used, and a discussion addressing each point presented in the Approach to Marketing (ATM) document.

Data analysis results

The element of self-selection in the data collection means that only indicative conclusions can be drawn (scientific inference is impossible). Thus, any statistical significance criterion (such as a p-value) will only be used as an indicator of the size of an effect. There are compensating advantages in self-selection, in that respondents with deep knowledge have been able to contribute. Triangulation of our analysis methodologies is achieved here with the aid of free-response commentaries asking for observations or explanations. Generally, one can only note the most commonly used relevant words amongst the responses, but this is enough to indicate a view of the issues regarded as most important, and in most cases this textual analysis supports the conclusions from the fixed-response questions. We also judged it likely that some knowledgeable respondents were to be found making the longer free responses, so these were read and considered in detail.

General

There were 2,662 usable responses submitted between December 2015 and February 2016, many with at least some questions unanswered. Most returns arrived early in this period, with later surges presumably associated with reminders. A small number of responses were unusable due to excess verbosity or overlap with existing web content. See Figure 1 and Figure 2.

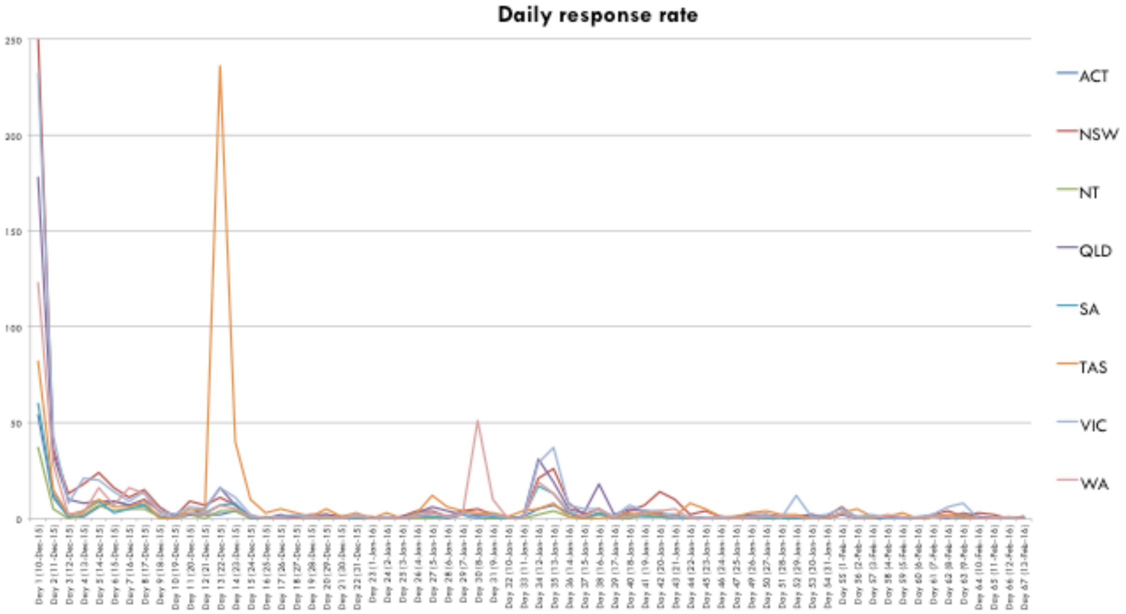

Figure 1. Daily tally of responses to the ABCB Condensation Survey, by states

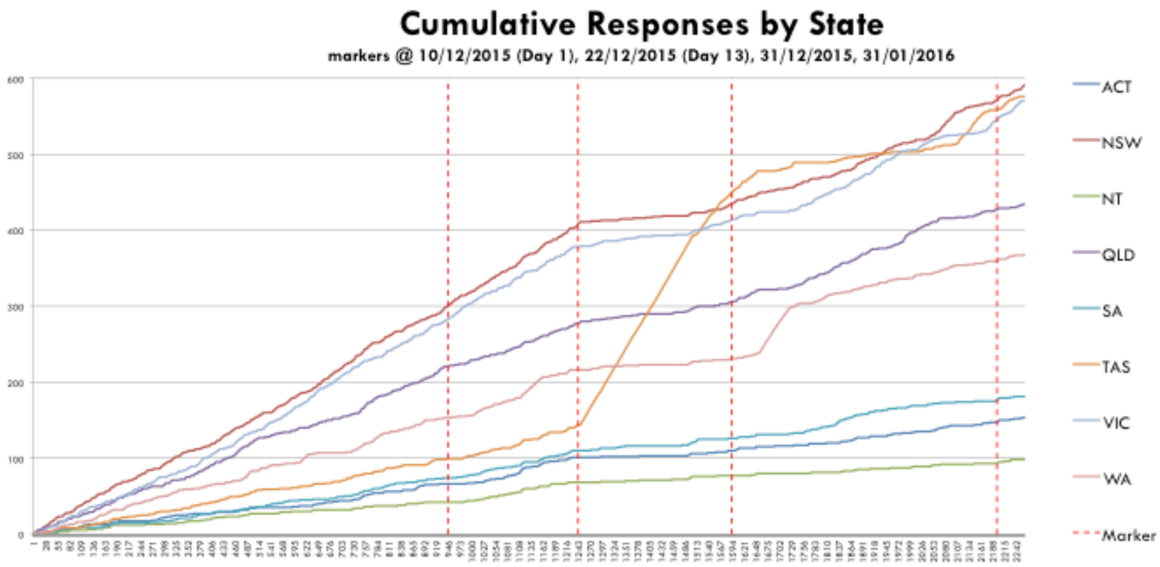

Figure 2. Cumulative responses to survey by states.

Major variable summaries (frequencies)

1 Demographics:

State or Territory of practice:

2,023 respondents reported a unique jurisdiction for their practice, 109 named two states or territories (not always adjacent), and 132 three or more. Of the 2,023 unique states (let's say states to mean states or territories) the distribution was:

State	Count
ACT	50
NSW	415
NT	29
QLD	279
SA	91
TAS	459
VIC	427
WA	273

Did these responses broadly reflect the differing scales of the building industry in the different states? Using a proxy of industry size, the number of dwelling starts in each state averaged over 2003–2012 (ABS, 8750.0 - Dwelling Unit Commencements, Australia, Preliminary, Jun 2012), we have the following comparison (sorted in decreasing order of response proportions) of relative sizes:

State	Proportion of industry	Proportion in sample
TAS	0.02	0.29
NSW	0.22	0.21
VIC	0.29	0.21
QLD	*0.23*	*0.14*
QA	0.14	0.14
SA	*0.07*	*0.04*
ACT	0.02	0.03
NT	0.01	0.01

It will be seen that Tasmanian respondents are spectacularly over-represented in the sample, while Queensland, South Australia and Victoria are relatively somewhat under-represented. A spike in Tasmanian responses was observed, due perhaps to a well-timed reminder message; hardly sufficient, one would think, to explain the magnitude of the effect noted here. One is tempted to speculate that condensation in dwellings is a much bigger issue in the southernmost state.

This suggests analysing the multi-state respondents as a bloc, even though they are quite heterogeneous, since the “sensible” combinations (QLD/NSW, ACT/NSW, NSW/VIC) have quite small numbers. The counts for respondents mentioning a unique state, with a separate category for respondents naming multiple states, were as follows:

State	Count
TAS	459
VIC	427
NSW	415
QLD	279
WA	273
MULTI	241
SA	91
ACT	50
NT	29
Total	2,264

This ordering is almost the same if we treat the question a little differently: if we consider any mention of a state, we have these counts:

State	Proportion	Count
NSW	0.26	592
TAS	0.25	576
VIC	0.25	570
QLD	0.19	434
WA	0.16	368
SA	0.08	181
ACT	0.07	154
NT	0.04	98
Total		2973

Note all mentioned total = 2,973.

Roles of respondents

As already reported in the Survey Monkey output, the make-up of roles is as shown below. Many respondents gave multiple roles, often with just one to four respondents for each unique combination. The "Other" category was also correspondingly diverse, including specialist professions, trades and suppliers. Further classification was scarcely possible. The overall impression is that a wide spectrum of roles has been covered.

Answer options	response percent	Response Count
Architect or Building Designer	0.21	483
Builder - residential	0.2	444
Building Certifier/Survey/Inspector (private or council)	0.17	381
Tradesperson (other than a builder)	0.1	230
Builder - commercial and residential	0.1	221
Engineer	0.09	209
State, Territory or Commonwealth Government	0.04	96
Energy Assessor	0.03	74
Builder - commercial	0.03	73
Council (other than Building Certifier)	0.03	59
Education Provider	0.02	56
Student	0.01	42
Health Professional	0.03	21
Other (please specify)	0.16	354

General analysis

Q1A	Do you think the instances of condensation occurring in new houses (Class 1) have increased over the last 10-15 years?
Q1AY	Please explain why you believe this to be the case:
Q1B	Do you think the instances of condensation occurring in new houses (Class 1) have increased over the last 2-5 years?

Q1BY	Please explain why you believe this to be the case:
Q1C	Do you think the instances of condensation occurring in new residential apartment buildings (Class 2) have increased over the last 10-15 years?
Q1CY	Please explain why you believe this to be the case:
Q1D	Do you think the instances of condensation occurring in new residential apartment buildings (Class 2) have increased over the last 2-5 years?
Q1DY	Please explain why you believe this to be the case:

The survey is broken down into states and zones. Where there is a statistically significant deviation from the predicted percentage (indicated by a high chi-square value, here taken at $\chi^2 > 5$), the results are noted below. A higher than average responding 'Yes' is presented together with a lower than average responding 'No' as an indicator that condensation in a particular state or climate zone is perceived as greater than the overall percentages would indicate, and vice versa.

		Overall response	Specific observations
Class 1	Q1A	53.9% Yes	More condensation problems perceived in TAS and practitioners in multiple climate zones. Less in QLD, WA and Zone 2.
	Q1B	46.2% Yes	Less condensation problems perceived in QLD and Zone 2.
Class 2	Q1C	36.6% Yes	More condensation problems perceived in ACT and practitioners in multiple states and climate zones. Less in QLD, TAS and Zone 2.
	Q1D	34.4% Yes	More condensation problems perceived in ACT and practitioners in multiple climate zones. Less in TAS, QLD and Zone 2.

There is a general consensus across the Australian building industry that condensation is a widespread observation, with more observations in Class 1 buildings than in Class 2, and more medium term observations (10–15 yrs) compared to short term (2–5 yrs).

Q1E What do you believe is the overall proportion of new residential buildings (both houses and apartments) affected by condensation?

Q1F What do you believe is the proportion of residential (houses and apartments) buildings (new or old) condensation affected, which have been renovated or altered (such as by installing bulk ceiling insulation or sarking)?

We extracted consistent and more precise information here. For this reason, we mainly focus on the conclusions from Q1E, but repeat that they are consonant with those from the earlier questions (Q1A–Q1D), in which a sizeable proportion of respondents thought the problem had increased.

Estimates of the prevalence of problems in new dwellings and in dwellings as renovated broadly agreed, with some variation. The responses agreed in 50% of cases, with the estimate for renovations higher in about 30% of cases, amongst responses where both were estimated. There were more usable estimates for new dwellings, probably partly due to the possible ambiguities in Q1F. For these reasons we shall analyse only Q1E.

Question	Relative response grade	Count
Q1E> Q1F	prevalence of condensation higher for new dwellings	155
Q1E= Q1F	responses with the same grade	415
Q1E< Q1F	prevalence of condensation higher for renovated buildings	262
Usable		832
Some null		1428

In both classes, the median prevalence estimate was in the range 11–25%, but near the top of that range. So, say 20% as a point estimate; or about 25% as the overall mean estimate (Figure 3). In this figure, each "violin" shows the distribution of state estimates, similarly to a smoothed histogram. The breadths are proportional to the subsample sizes; the central dot and bars show the estimated mean and its standard error. The horizontal line indicates the overall mean. Higher estimates are given by respondents practising in NT, TAS and in more than one state; the NT estimate is particularly variable due to the small subsample size. A small discrepancy between new and renovated estimates here is due to there being more usable estimates for new dwellings; the discrepancy between the median and mean estimates is mostly due to the different distributions, with the presence of some very high estimates.

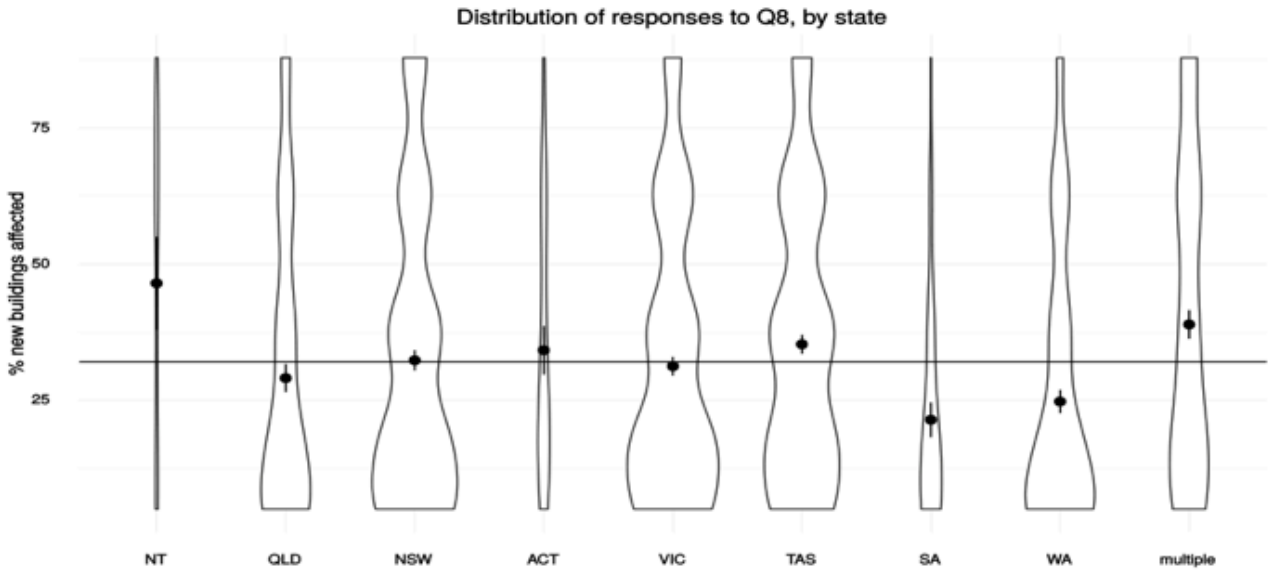

Figure 3. Violin plot, percent of new buildings affected, by State or Territory (Q1E, here called Q8).

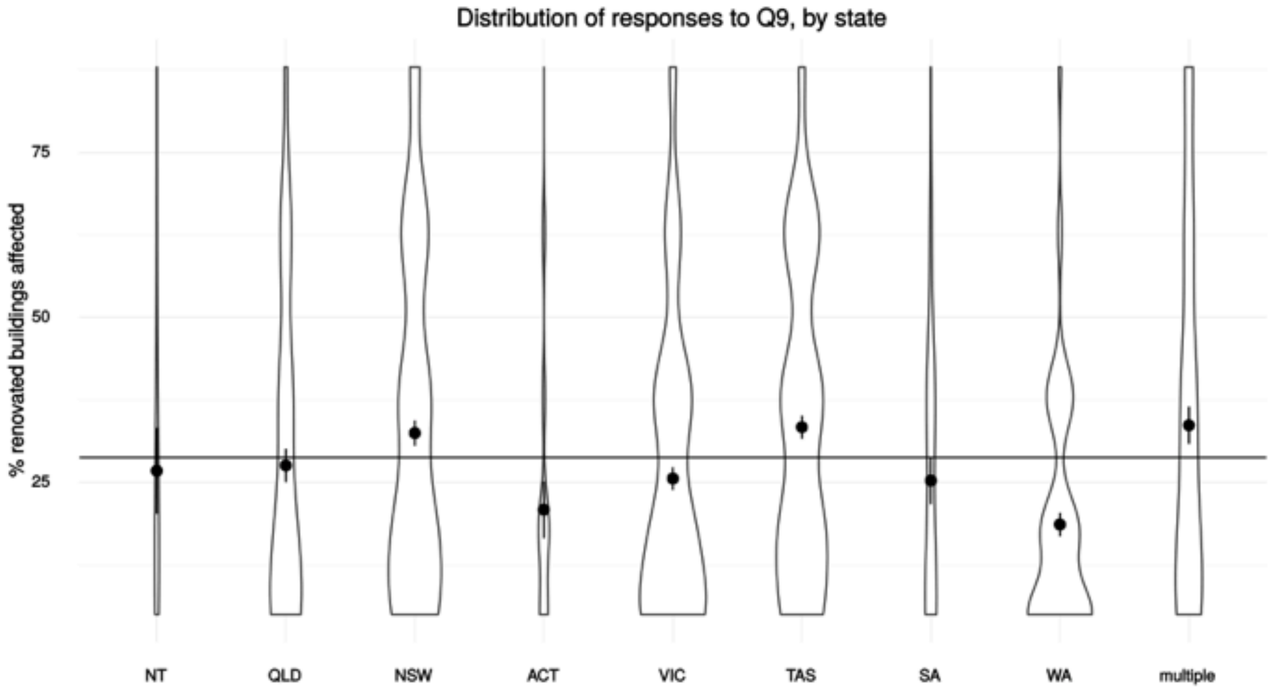

Figure 4. Violin plot, percent of renovated buildings affected, by State or Territory (Q1F here called Q9). Lower estimates in ACT, VIC, and WA; higher in NSW, TAS, and multistate practitioners.

There was little in the distribution of roles in the different states to suggest that any different make-up was contributing to the differences between states. This should be qualified by the remark that cutting up the sample in this way reduces the number of cases in each combination to often quite small numbers, from which it may not be possible to draw reliable conclusions. Likewise, although the association between states and their applicable climate zones is evident, there is nothing to suggest that climate zone is a better predictor of difference in responses than is state. Thus we have to look for such explanation, if at all, in the different applications or concerns in the code implementation in each state, either through regulation or local training in requirements, etc.

Q1G1 In your experience, when condensation forms, where is it usually located? (Select all that apply)

Question	Count
Internal window/glass surfaces	1175
Internal wall or floor surfaces	586
The roof space in general	581
In the roof space above a bathroom	499
Interstitially (inside the building fabric)	402
Sub-floor space under the building	322
In the roof space above a laundry	309
In the roof space above a kitchen	223
Other	114

“Internal window/glass” was most often noted amongst those who responded, but all the suggested sites were mentioned to significant degrees. The order of prevalence was much in the order listed, except that “interstitial” was ranked higher, and “sub-floor” lower, than in the listed order. We see that condensation is more commonly observed in the visible areas. The following sub-categories tended to observe this more frequently: NT, QLD, Zone 1, Zone 2, Education Providers and Energy Assessors.

Q1H1	Have you seen particular materials, construction methods, design features or occupant behaviour which has contributed to an increased amount of condensation forming? (Select all that apply)

Cause of condensation	Count
Yes - occupant unaware that their behaviour contributes to condensation	991
Yes - increased air-tightness due to improved sealing of windows and doors	895
Yes - occupant reluctance to open windows/doors due to energy costs	812
Yes - the venting of bathrooms, kitchens or laundries into the ceiling space	670
Yes - the venting of bathrooms, kitchens or laundries has not been considered	649
Yes - ceiling spaces designed to be unventilated	637
Yes - use of vapour barriers (sarking)	417
Yes - increased use of bulk insulation materials	376
Yes - building orientation is poor or not adequately considered	371
Yes - lack of adequate sub-floor drainage	350
No	86
Not applicable	23

Respondents were willing to attribute a contribution to condensation problems to many factors, human factors being high on the list, as also improved sealing, (mis)use of vapour barriers, and factors related to ventilation. Occupant behaviour and energy efficiency are perceived to be the primary features responsible for condensation. This sentiment is generally widespread.

Q1I1 Have you seen any of the longer term effects of condensation? (Select all that apply)

Many respondents claimed to have seen other effects. The leading effects are:

Question	Count
Yes - mould	1,264
Yes - damage to building materials and finishes such as paint and plasterboard	1,074
Yes - mildew	891
Yes - health conditions	471
Yes - damage to structural building elements such as roof trusses	342
No - I have not seen any long term effects of condensation	132
Yes - dust mites	125
Not applicable	30

Mould or mildew or both were noted in 1,321 responses, but should be considered synonyms of microscopic fungi.

	Q1I2		
Q1I1	(empty)	Yes-mildew	Total
(empty)	943	56	999
Yes (mould)	429	836	1265
Total result	1372	892	2264

Mould and water damage to finishes feature highly in these responses, with practitioners in multiple states and multiple climate zones responding more strongly than average. Respondents generally have not made a connection with health (allergy and immunology) and structural degradation (like the reduction in bearing capacity of nail plates, or wet and dry rot of timber structure). This knowledge gap will present a significant area of education. It should further be added that effects of condensation relate to the mission of ABCB to "oversee issues relating to health, safety, amenity and sustainability in building" (ABCB Annual Business Pan 2015-16).

Q2A	DESIGN: What proportion of building projects do you believe consider condensation risk at the design stage?
Q2C	CONSTRUCTION: What proportion of building projects do you believe consider condensation risk during the construction phase?

Two questions asked for estimates of the proportion of building projects in which condensation risk was considered at the design and construction phase, respectively. About 1,200 respondents gave estimates, with a very similar pattern to the two questions. Estimates were spread across the scale, but the median estimate (by those who responded) was slightly under 10% in each case. This points to a pretty widespread view that this consideration does not happen in a large proportion of projects.

Estimate	Q2A	Q2C
(empty)	904	906
10% or less	664	675
11%-25%	230	223
26%-50%	170	177
51%-75%	103	107
76%-100%	112	83
Not applicable	82	93
Total results	2,265	2,264

Q2E1	GENERAL: Whose responsibility is it to consider and manage condensation risk? (Select all that apply)

Some 1,380 respondents expressed a view about the responsibility for considering and managing condensation risk, mostly naming multiple agents:

Responsible professional	Count
Designer or architect	1,244
Builder	959
Building Occupant/Owner	778
Building Certifier/Surveyor/Inspector	723
Building Product Manufacturers	443
Building Product Suppliers	365

Amongst those who responded to this section, there was almost unanimous agreement that responsibility for condensation management resides with the designers (a group including building designers and architects), followed by builders. As vapour management is a complicated phenomenon requiring systems thinking, legislation and regulation at the design stage would likely receive the broadest support from industry. This would be followed up by inspecting to ensure that construction conforms to the design. Whilst overall product manufacturers and suppliers rank last, practitioners in Climate Zone 8 nominate these higher by two standard deviations, showing a recognition by them of the importance of working with manufacturers in the alpine climate.

Q2F1	Are you aware of climate responsive housing designs, techniques or materials to better manage condensation risk? (Select all that apply)

The 1,365 respondents to this question on the awareness of techniques again selected multiple options, with ventilation issues foremost:

Technique	Count
Yes - venting bathrooms, kitchens or laundries to the outside	1,067
Yes - venting ceiling spaces	935
Yes - mechanical ventilation	895
Yes - use and location of vapour control (permeable) materials as appropriate	830
Yes - venting masonry cavities	766
Yes - use and location of bulk insulation materials as appropriate	719
Yes - ensuring building orientation is appropriate	606
Yes - hygrothermal (condensation) analysis at design phase	326
No	147

The responses for condensation management favour various use of ventilation, with only a third being aware of design being informed by hygrothermal analysis. Taken with the previous question, it appears that whilst designers are recognised as being primarily responsible for this problem, the methods by which it can be solved by design are not yet common knowledge.

Q2H1 In your opinion what are suitable solutions to reduce the risk of condensation forming? (Select all that apply)

Likewise, solutions were probed, and again (with 1,365 responding) ventilation was a popular choice amongst multiple suggestions:

Solution	**Count**
Venting bathrooms, kitchens or laundries to the outside	1117
Venting ceiling spaces	980
Opening windows and doors	889
Use and location of vapour control (permeable) materials as appropriate	868
Mechanical ventilation	859
Venting masonry cavities	774
Use and location of bulk insulation materials as appropriate	746
Ensuring building orientation is appropriate	617
Hygrothermal (condensation) analysis at design phase	511
Don't know	48

Once again the general approach to reducing condensation is perceived to be ventilation, or bulk air movement. It should be noted that the average Australian house suffers major infiltration. CSIRO's testing of 20 houses in Melbourne (4 stars and above) found an average 19.7 ACH @ 50 Pa (Ambrose et. al., 2013, *The Evaluation of the 5-Star Energy Efficiency Standard for Residential Buildings*). In our industry communication, we have been advised that mechanical ventilation only needs to be considered at 5 ACH @ 50 Pa and below. Thus in the current situation, ventilation should not be the first option. There also appears to be little knowledge around other moisture management techniques like vapour diffusion and hygric buffering.

Q2I	Do you think that the average building occupant is aware of the role they play in managing condensation risk?

Overall response	Specific notes
29.4% Yes	Common perception across Australia with no appreciable difference in state and climate zone.

Occupant awareness rates low for this question. Taken together with Q1H1, where there was very strong agreement that the “occupant [is] unaware that their behaviour contributes to condensation”, it would seem the industry perceives the occupant to be primarily responsible, yet uninformed. This would suggest a need to use robust systems which are primarily passive or automated to manage condensation, accompanied by a larger educational drive to the general public.

Q3A1	Do you use Industry, Building Authority or ABCB educational and resource materials on condensation, and which ones do you use? (Select all that apply)

Source of material	**Count**
Yes - Industry Association publications	555
Yes - Product Manufacturer publications	532
Yes - ABCB Information Handbooks	526
Yes - NCC Explanatory Information	440
Yes - Building Authority publications	430
No - as I am unaware of any educational materials	305
Yes - ABCB YouTube Clips	126
Not applicable	91
No - as I do not need to understand condensation risk and management	61

1,348 stakeholders replied positively to the question on educational materials, with substantial numbers citing one or more of the authoritative publications listed, although there is also an apparent lack of awareness (305 responses), particularly in QLD and WA, which may require deeper investigation.

Model testing

Four questions had responses along a linear scale: Q1E, Q1F, Q2A and Q2C.

Q1E	What do you believe is the overall proportion of new residential buildings (both houses and apartments) affected by condensation?
Q1F	What do you believe is the proportion of residential (houses and apartments) buildings (new or old) condensation affected, which have been renovated or altered (such as by installing bulk ceiling insulation or sarking)?
Q2A	DESIGN What proportion of building projects do you believe consider condensation risk at the design stage?
Q2C	CONSTRUCTION What proportion of building projects do you believe consider condensation risk during the construction phase?

This allowed us to test for any effects of role, state and climate zone on these responses.

Our data consisted of the response variable (the proportion given in response to the question, coded as the midpoint of each range) and three factors (role, state and climate zone). We used Bayesian linear models to test whether there is evidence for any of these factors (including interactions between them) having an effect on the response.

For Q1E, the preferred model is that with state as the only predictor, for which there is strong evidence, with a Bayes factor of 97 against the null model.

Similarly, for Q1F, the model with state as the only predictor is again preferred, in this case with very strong evidence, with a Bayes factor of 3,644 against the null model.

For Q2A, the null model is preferred (with a Bayes factor of 4.4 against the next best model), and for Q2C there is weak evidence (Bayes factor 1.1 against the null model) for an effect of role.

These effects for Q1E and Q1F can be seen if we plot the distributions of the responses, divided up by state (see Figures 3 and 4 above). For new buildings (Q1E), respondents practising in NT, TAS or more than one state give higher estimates of the prevalence of condensation than the overall average, and those in SA and WA give lower estimates. For renovated buildings (Q1F), we see higher estimates for TAS, NSW and multiple states, and lower estimates for WA, ACT and VIC.

Text mining

Several groups of the free-response questions address closely related topics, and we were thus able to carry out textual analysis on combined data from these. For example, Q1A–D all concern the perceived causes of increased condensation, albeit over different time periods and in different classes of buildings.

Q1A	Do you think the instances of condensation occurring in new houses (Class 1) have increased over the last 10–15 years?
Q1AY	Please explain why you believe this to be the case:
Q1B	Do you think the instances of condensation occurring in new houses (Class 1) have increased over the last 2–5 years?
Q1BY	Please explain why you believe this to be the case:
Q1C	Do you think the instances of condensation occurring in new residential apartment buildings (Class 2) have increased over the last 10–15 years?
Q1CY	Please explain why you believe this to be the case:
Q1D	Do you think the instances of condensation occurring in new residential apartment buildings (Class 2) have increased over the last 2–5 years?
Q1DY	Please explain why you believe this to be the case:

We therefore present a word cloud in Figure 5 showing terms commonly used in answers to these four questions by respondents who think the incidence of condensation has increased. Note that 'condensation' and 'building' have been excluded from all textual analysis. Also, some sets of synonyms have been standardised into single terms, e.g. 'membrane' covers all mentions of 'wall wrap', 'house wrap', 'building wrap', 'frame wrap', 'sarking', 'sisalation', 'hardiewrap', 'tyvek', 'ametalin', or 'breather'.

It is clear that 'ventilation', 'seal' and 'window' are among the most common terms, with 'insulation', 'energy' and 'air-conditioning' (and variants such as 'A/C', coded as 'aircon') also mentioned frequently. To identify issues that may be identified more frequently by respondents with particular roles, or in particular states or climate zones, we can plot the frequencies of the most commonly mentioned words, split according to these factors, as seen in Figure 6. This allows us to see, for example, that 'air-conditioning' is the most common term used by respondents practising in QLD and NT, but is rarely mentioned by those in VIC and TAS. Conversely, 'energy' and 'seal' are mentioned often by those in VIC and TAS but less frequently further north, and we see a similar pattern when the data are split by climate zone. We can thus gain some insight into differences in the factors that are perceived to cause condensation in different regions.

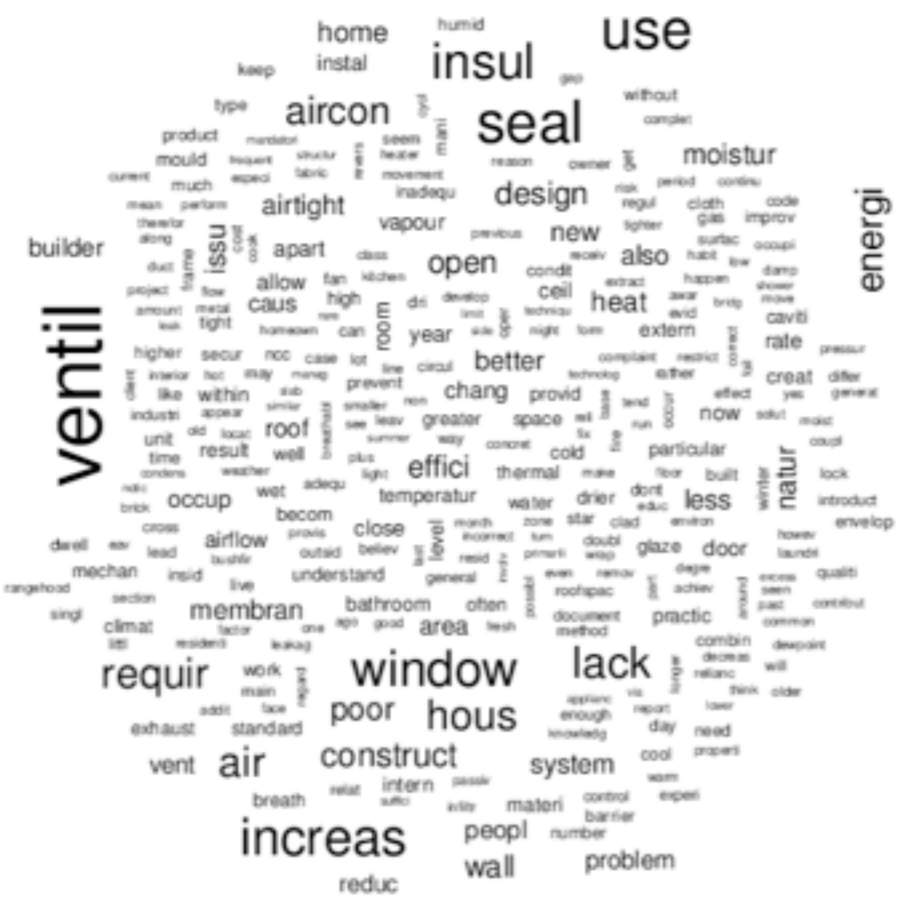

Figure 5. Word cloud to the open-ended response for Q1A-Q1D.

Because these four questions cover two time periods (10–15 years and 2–5 years), we can look at differences in word use between responses for the two periods to identify changes in perceived causes. In Figure 7 we see that for the earlier period, 'lack', 'insulation' and 'window' are mentioned more frequently, while for more recent buildings 'require', 'increase', 'energy' and 'efficiency' are more common. This could suggest that an increase in energy efficiency requirements is widely perceived as a cause of increased condensation in recent years, and indeed this is borne out by a reading of the full responses.

In most instances, there was a large amount of repetition to the potion “Please explain why you believe this to be the case” for the four questions (Q1A to Q1D), or many respondents simply stating “as above” for the following three questions. For text mining purposes the above text was replicated, but this manner of response does indicate that for the majority, there was no clear distinction between the reasons for condensation happening over the two time periods, or between the two Building Classes.

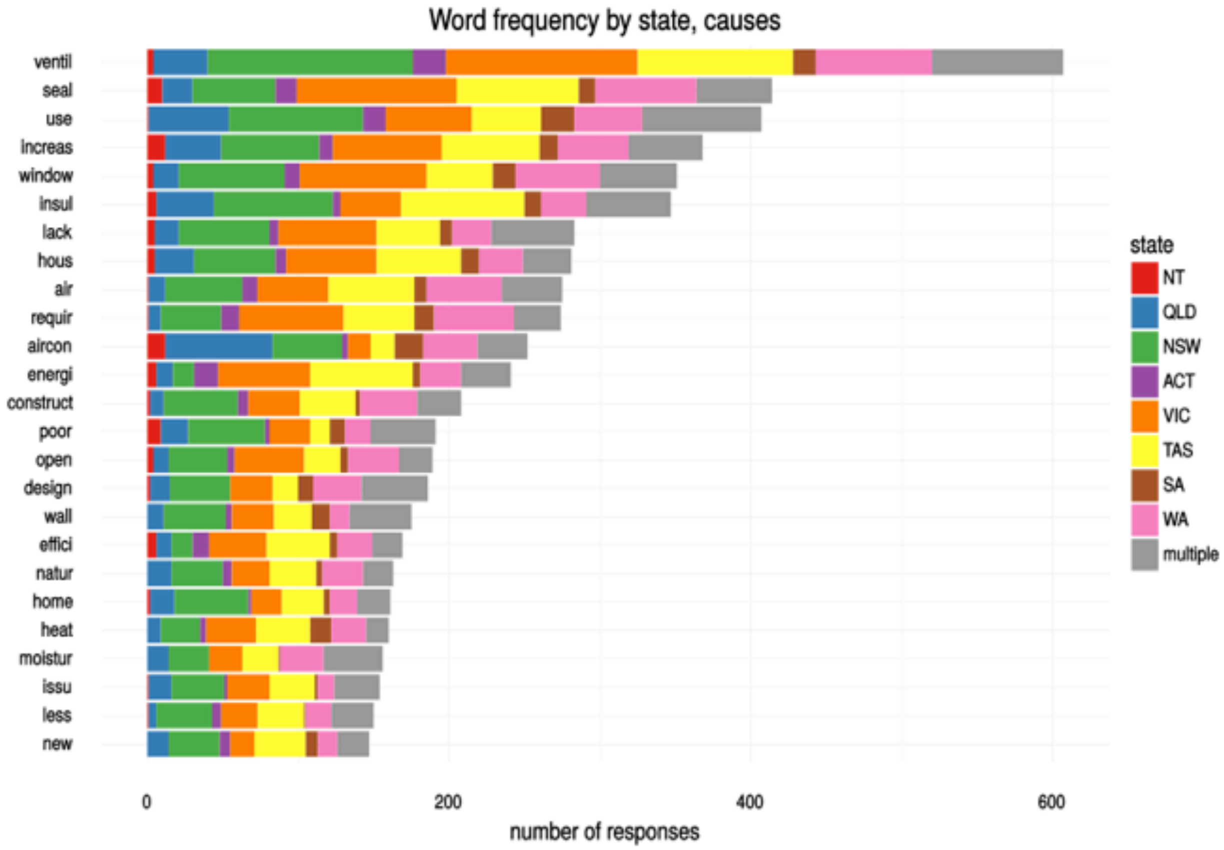

Figure 6. Frequencies of the 25 most frequently used terms in responses to questions addressing the perceived causes of condensation, coloured by State or Territory.

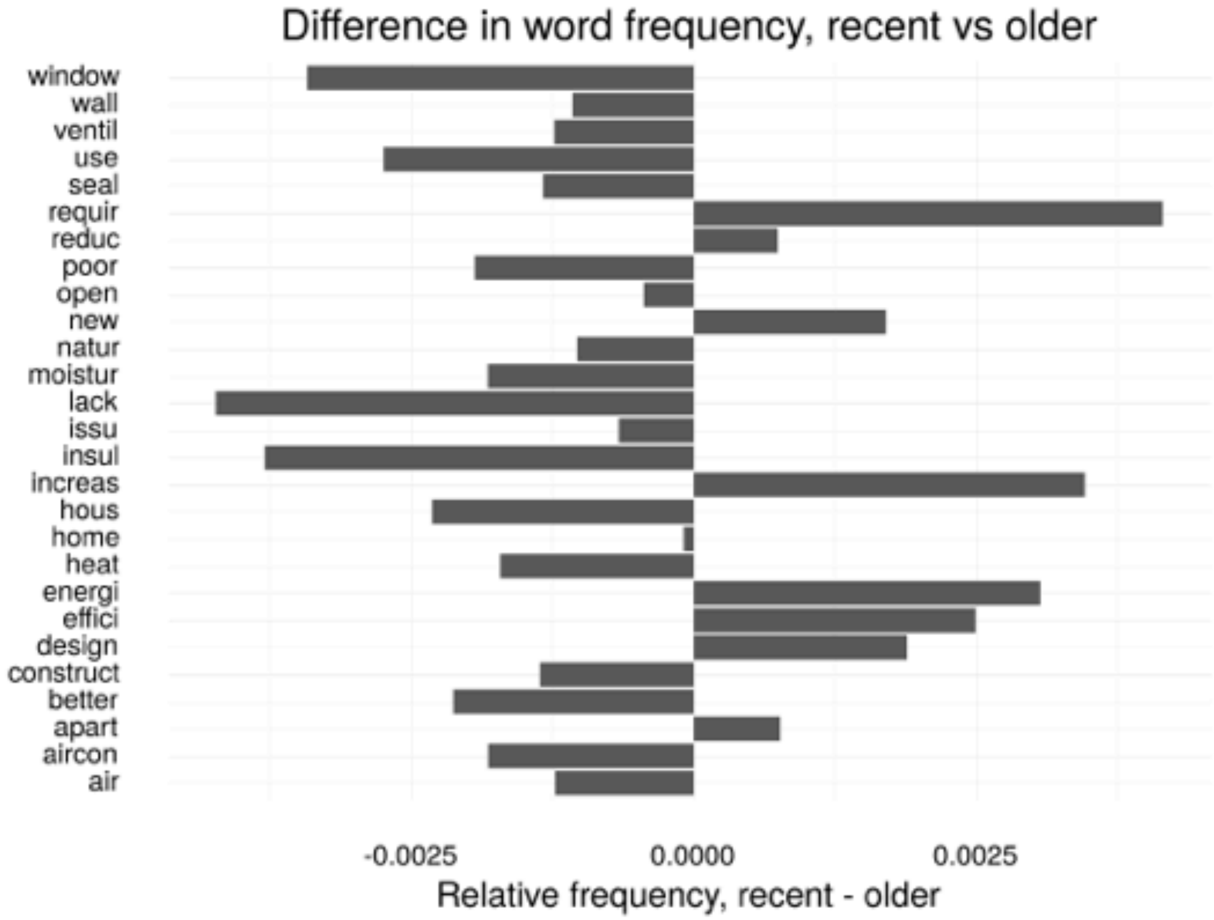

Figure 7. Relative frequencies of terms used in responses to questions regarding the perceived causes of condensation, for the periods 2–5 years and 10–15 years. Words used more frequently in responses regarding the more recent period have positive values (to the right of the y-axis), those used more frequently for the earlier period are negative.

Similarly, we can compare responses regarding houses with those regarding apartments. This time the results are less informative, but we do see more mention of 'insulation', 'energy' and 'seal' where houses are concerned.

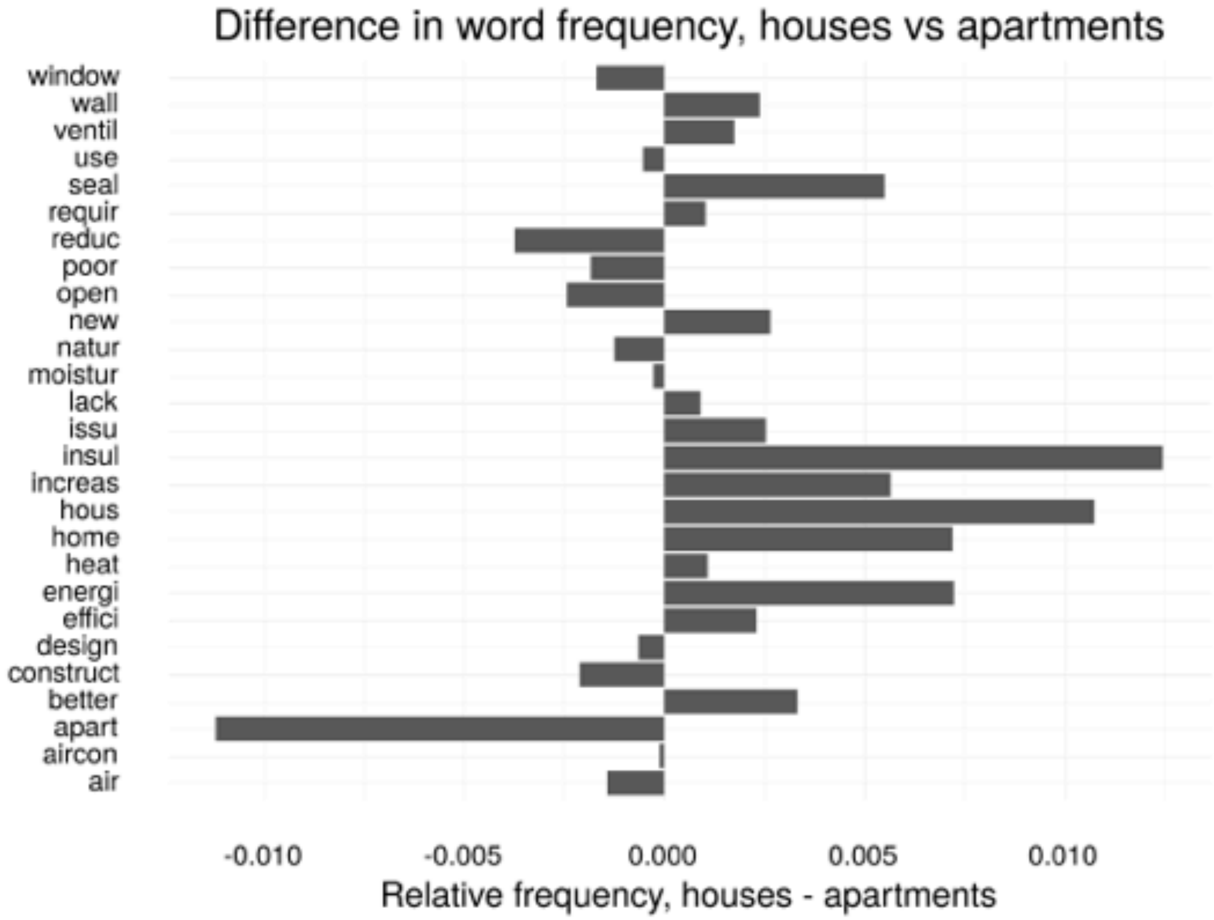

Figure 8. Relative frequencies of terms used in responses to questions regarding the perceived causes of condensation, for houses and apartments. Words used more frequently in responses regarding houses have positive values (to the right of the y-axis), those used more frequently for apartments are negative.

Q2B	DESIGN: How is condensation risk considered and managed during the design phase?
Q2D	CONSTRUCTION: How is condensation risk considered and managed during the construction phase?
Q2G	What steps do you personally take to reduce condensation risk?

Questions Q2B, Q2D and Q2G all concern solutions to the problem of condensation, and can also be pooled to produce a single word cloud in Figure 9. Again, 'ventilation' immediately stands out as the most commonly used term. Breaking the word frequencies down by state, we see that respondents practising in NT are more likely to mention 'vapour' and 'barrier', while those in TAS are more likely to mention 'vent' and 'roof' (see Figure 10).

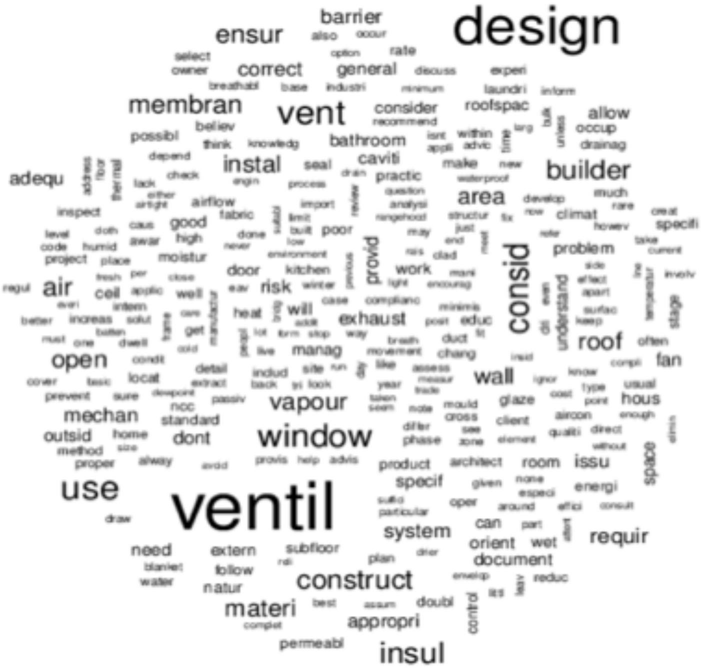

Figure 9. Word cloud for responses to the open ended sections of Q2B, Q2D and Q2G.

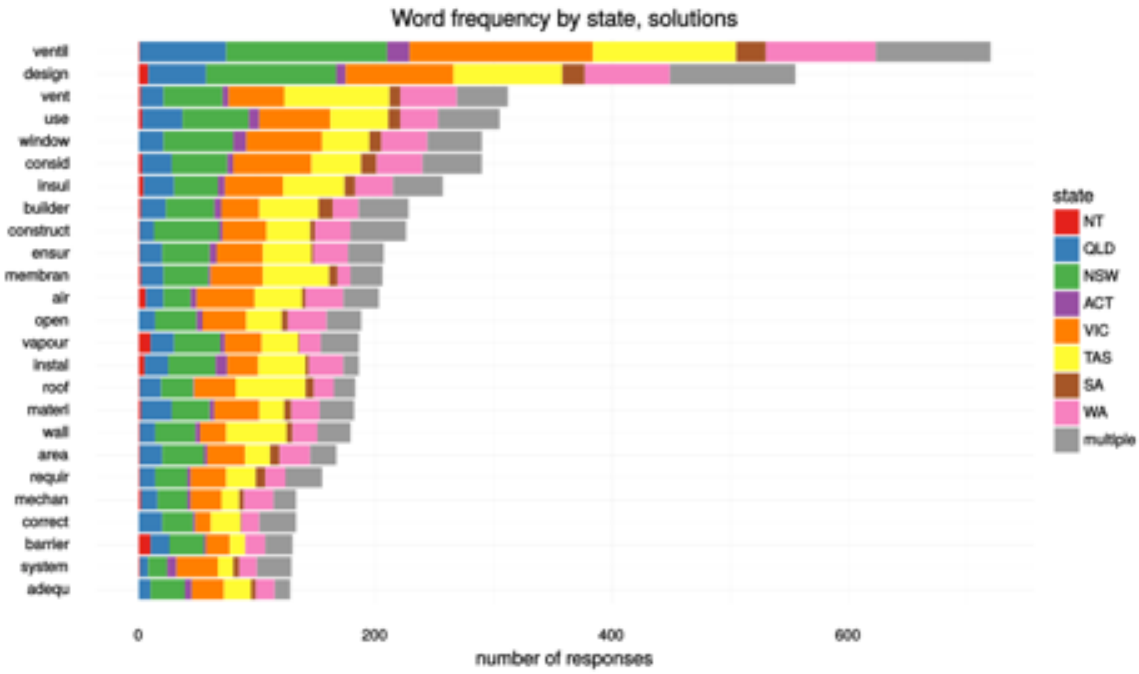

Figure 10. Frequencies of the 25 most frequently used terms in responses to questions addressing ways in which condensation is or could be managed, coloured by State or Territory.

Q1J	Please provide any supporting evidence which may assist the ABCB in understanding the nature and extent of condensation issues further, noting that all information provided will be kept confidential.

Q1J asks respondents to provide any supporting evidence which may assist the ABCB in understanding the nature and extent of condensation issues further. 'Ventilation' is again the commonest term by a wide margin, and 'mould' is also high on the list.

Q3B1	Do you think more needs to be done to assist industry and the community in responding to condensation related issues?

Q3B asks how the industry and community could be assisted in responding to condensation related issues. Here 'design' and 'education' top the list, with 'information' also high in the rankings.

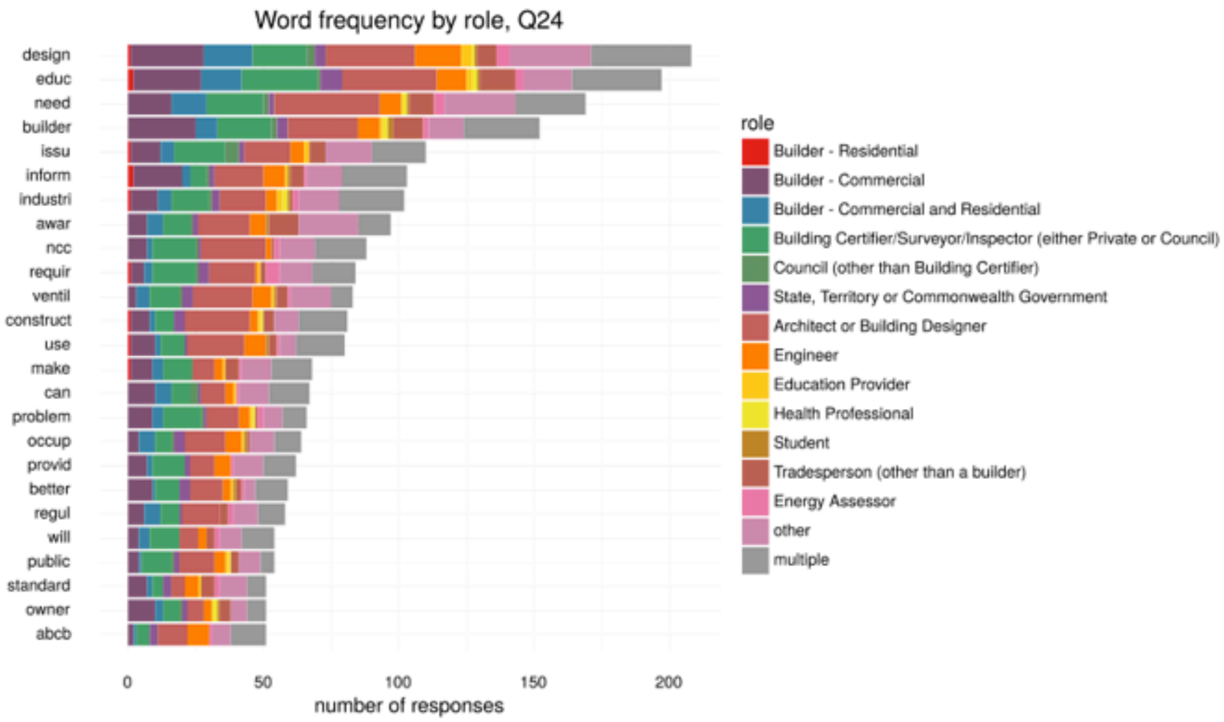

Figure 11. Frequencies of the 25 most frequently used terms in responses to Q3B, coloured by role.

Discussion: Nationwide survey

As part of the methodology, the survey was to be analysed to address specific queries in the Approach to Marketing (Appendix 1)

a. [The scoping study should include an analysis of the survey results… to holistically explore:] The issue of condensation in residential buildings and what may be causing any increase in condensation

Patterns of prevalence in Class 1 (houses) and Class 2 (apartments) were broadly similar. Likewise, response about comparison with 10–15 years ago, and with 2–5 years ago, were broadly similar.

This suggests a lack of effect of different versions of the Code, since both time periods had similar responses. The survey does not provide evidence that the code amendments are directly responsible for condensation. It should be mentioned that it is a lack of evidence either way, i.e. that there is also no evidence that the code is not responsible for increasing the occurrence of condensation. In fact, the open-ended responses, taken together with the literature review and discussions with industry, indicate that increasing energy efficiency, bushfire legislation and occupant comfort expectations are commonly believed to be the causes for an increase in condensation.

The survey reveals a widespread perception that occupants are responsible for the management of condensation but are often not doing enough in this regard. More details are worth collecting in a follow-up survey, to understand what roles the industry expects occupants to play in condensation management. It is worth highlighting that the Canadian regulations stipulate that the occupant plays no role in controlling condensation—it is the role of the built fabric.

b. The nature and extent of the problem(s) including climate specific considerations

The occurrence of condensation seems generally widespread. The overall magnitude of problems (as assessed by respondents) varies but does appear to be extensive enough to be of concern. The extent of problems was generally assessed as high.

Between the sub-categories of climate zones and states, it appears that state is a stronger predictor of how one would respond in the survey. This would be consistent with the state-based adoption of the Code and how practitioners see themselves identifying more with a particular state than a particular climate zone.

c. Requirements within the NCC which may influence the risk of condensation forming,

Whilst this has not been particularly covered in the survey as a poll, the open-ended questions indicate that energy efficiency and occupant comfort expectations have been the primary drivers for greater air-tightness. This increased tightness, when advanced without an accompanying vapour management plan, is the widely perceived problem behind increased condensation.

d. Any evidence of a relationship between changes in NCC regulation and an increase in condensation forming in new residential buildings,

An attempt to categorise the respondents by state did not yield a clear trend in terms of regulatory changes and perceived increased occurrence of condensation. Whilst there is no evidence that regulation has increased condensation risk, it is also true to say there is no evidence to the contrary.

In the text analysis of open-ended question, “energy efficiency” comes out at a very high frequency. In reading the responses, other indicators of a relationship to regulation are the adoption of tighter building enclosures to meet BAL ratings and inconsistencies in the Australian Standards.

e. Potential gaps in the requirements of the NCC, which may influence the risk of condensation forming,

This will be covered in greater depth in the literature review. The following response indicates that there are people in the industry who wish to see the NCC further developed.

“My opinion is based on anecdotal evidence as well as an understanding of the NCC and inconsistencies that I see in it. The NCC lags behind the rest of the world in the detail and specificity of its building code relating to energy efficiency. Some of the underlying building science informing the code is outdated. Materials and methods allowed and in some cases required by the building code have the potential to create surfaces within wall and roof assemblies that can lead to condensation.”

Respondent 4395240564

f. The capacity of the Australian building industry, and building occupants to manage condensation risk,

The industry leans towards design being the primary approach to managing condensation, followed by construction and building occupants (Q2E). Of these the average occupants are mostly seen to be unaware of their role in managing condensation risk (Q2I). In the open-ended responses, there is a clear call for more education and information that is both easily understood and accessible.

Summary

1. In summary, the overall magnitude of problems (as assessed by respondents) varies but does appear to be extensive enough to be of concern. The extent of problems was generally assessed as high.

2. Patterns of prevalence in Class 1 (houses) and Class 2 (apartments) were broadly similar. Likewise, responses about the last 10–15 years, and the last 2–5 years, were broadly similar.

3. This suggests a lack of effect of different versions of the Code, since the time periods had similar responses. The survey does not provide evidence that the code amendments are directly responsible for condensation. It should be mentioned that this differs markedly from views found in the literature review and discussions with industry where increasing energy efficiency, bush fire legislation and occupant comfort expectations have been commonly cited as causes of increased incidence of condensation.

Some further recommendations

After being alerted to the issues, a well-designed and tested follow-up evaluation/survey may be advantageous in three to six years. Something that might be considered in the interim is a smaller stratified sample from the same frame (as an update) to spare all respondents from a follow-up request.

Scoping Study of Condensation in Residential Buildings

Appendix 03: Industry Consultation

23 September 2016

Research funded by:
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Industry Consultation – Response to Draft Recommendations and Discussion of Nationwide Condensation Survey

The Project Team consulted numerous industry stakeholders to better understand industry's capability to manage condensation risk and also receive their input regarding the recommendations of this study. Below is a summary of industry consultation by stakeholder in response to the first draft of the recommendations, as shown in Table 1; the industry stakeholders included: architects, building surveyors, manufacturers and quantity surveyors.

Stage 1 2019

1. To mandate the use of vapour permeable building wrap systems when specified for wall, ceiling and subfloor wrap systems
2. To ensure that supply ventilation is documented and constructed for all unconditioned roof spaces (Cathedral & Attic)
3. To ensure that exhaust ventilation is documented and provided for all unconditioned roof spaces (Cathedral & Attic)
4. Supply ventilation is considered of any room with a mechanical exhaust system - range–hood, tastic, etc
5. No items puncture the ceiling air barrier system (compliance issue)
6. Sarking systems are installed as per the manufacturers specification – Under battens. (compliance issue)
7. Cavity construction for all external wall systems – weatherboard, ply, cement sheet, sheet-metal
8. Inspection of building wrap systems (lapping, taping, fixing)
9. Requirements of drawings – like Tas Directors list (revision of AS1100)
10. Clothes dryers to be externally vented
11. Steady state dew point analysis for external walls in climates 6, 7 & 8
12. Have different rules for roof systems subject to pitch and climate – sarking systems and ventilation needs.
13. Split Roof space R values into ceiling and roofing (Insulate conditioned zone)
14. NCC to specify an ACH for subfloors, house envelope and roof spaces with view to testing in 2022

Table 1. Draft recommendations for industry response.

Architects and Building Designers

R1

- Consider correct application of the wrap will require inspection by architect, project manager or building surveyor.
- Request a simple table-based classification system for membranes to be created, outlining membrane requirements by climate type. This should be straightforward to use and have standardised labelling.
- Manufacturers need to supply the relevant information. Most likely requiring standardisation and regulation of labelling for membrane classification including size and location.
- Ask that any changes should simplify documentation and specification rather than complicate it.
- Believe public awareness of condensation must be increased.
- Believe mechanical engineers have a better understand of condensation issues than structural engineers
- Consider building surveyors lack knowledge regarding air barriers and vapour control (according to architects). The feeling is that this will increase the occurrence of non-compliant designs being certified.
- A simple onsite review process to follow.
- Asked for a revised approach to review and compliance process is required as an initial step towards increasing regulation in 2019.

R2 / R3

- Suggest creation of ventilation table that simplifies the specification roof space ventilation. Similar to the calculation of sub floor vents.
- Ask for a performance solution so designers can retain control of ventilation placement, design and specification.
- This table could operate by either volumetric (m3) measure requiring a set ventilation rate in litres per hour or an area (m2) measure which requires a set number of vents or a given mm or vent per m2 of roof space.
- Think ventilation should be drawn on documentation and considered rather than simply specified in the ncc.
- Want both clear deem to satisfy (DTS) provision but the freedom of alternative solutions.
- Believe professionals and building occupants require educating that airflow is a positive rather than a negative.
- Are reluctant to see the design process complicated, for example ventilation rates requiring consultant input.

R5

- Agreed the current use of downlights should be outlawed.
- Agree with the recommendation

- A compliance issue with as 3000 electrical installation

R6

- Consider this a compliance issue at a manufacturer level. Note: some manufacturers do not provide a warranty for sarking when it is used at an angle of less than 15° in a roof space.

R7

- Agree with the recommendation
- Ask for cavity construction for all external wall systems should be implemented where a 13 – 25mm cavity is required.
- Recommend the NCC must show envelope systems as cavity construction not hard fixed.

R8

- Consider inspection of building wrap systems – wrap, frame, structure and insulation
- It becomes difficult to check the structure and bracing if the wrap is already on this would require a second inspection which would raise the cost of compliance. But would save guard correct construction.
- Bracing in other countries such as the US and UK uses OSB sheet or plywood as a bracing element this is possibly how

R9

- Completely agreed with the recommendation that a definitive list of drawing requirements should exist such as the Tasmanian directors list at a national level.
- Agree that AS1100.3 part 3: architectural drawings requires updating and should be used to regulate documentation.
- State AS1100 requires attention regardless of condensation issues, to take into account modern computer package such as BIM.
- Ask that the standard show relevant examples of notional construction systems that consider condensation risk and bushfire compliance, such as those in the BSOL guide in Tasmania.
- Suggest educational material need to show professionals how to solve technical problems with simple solutions
- Mobile application that can be used on site as a checklist approach that might have examples of correct application of building materials and construction techniques.

R10

- Suggest the creation of a steady state due point analysis program or calculator such as the window or lighting calculators is a good idea.

General Comments

- Education forms a significant section of this issue

- Trades on site generally do not know or understand the requirements or how to comply with the regulations or standards.
- Trades often have little regard to the consequences of incorrect application or selection of building products.
- Agreed that the standardisation of terminology and drawn examples should occur across the NCC and Australian Standards.
- Contractual concerns were raised as to who is responsible for what and the issues of self-certification; which international examples show is being phased out.
- The average building occupant also needs to be able to understand the issue.
- Trades level of understanding they do not understand the ramifications their decisions.
- Other countries require minimum energy usage or average u-values for compliance
- There is concern with the level and range of interpretation that occurs in the certification of construction at the hands of building surveyors.
- Want to be shown examples of condensation problems in buildings and accepted construction methods to avoid them.
- Numerous industry representatives have acknowledged the booklet put out by building standards and occupational licensing (Department of Justice in Tasmania) called Condensation in Buildings: Tasmanian designers guide as a great resource.
- If a revised industry standard is to be implemented to improve building fabric design in this context it should be focussed and resolved around Australian conditions reflective of location and micro-climate. It should not be solely based on whole of country standardised prescriptive solution. Rather it should be based on performance design goals and solutions which do not exclude naturally ventilated breathable buildings.

Building Surveyors

- Considers compliance is a large issue, agreed with the need to reduce non-compliant construction.
- Cavity construction is the right direction the building industry should be heading.
- Standardisation of terminology should be a priority
- Suggests that educational material can be delivered through institute of building surveyors
- Suggests builders will require simplified educational materials
- States building membranes are not understood in general by the industry.
- Suggested more required documentation such as standards referenced in the NCC should be freely available.
- Construction must control and consider vapour load of large bodies of water such as indoor pools. Indoor pools can add extreme vapour loads on the building fabric.
- Building act (legislation) at a state level would have to be amended in order for the additional inspection to be mandated as per recommendation no. 8 “inspection of the wrap system’

- Once blower door testing is required inspection of the vapour layer will not be necessary as the pressure test is a more accurate measure of compliant air barrier installation.
- Agrees with the idea of a calculator approach to dew point analysis as it is simple.
- Agrees with creation of a dynamic analysis plugin for accurate.
- Ventilation of concrete floors is not required.
- Concerned about the effects of ventilated vs.unventilated skylights and the implications for condensation.

Quantity Surveyor

- Agrees cavity construction is a priority.
- Considers the building wrap is best placed in relation to the cavity (framing side or cladding side).
- Mentioned that younger people in the industry tend to include (or lean towards the creation of) a cavity in a wall. He guessed this could possibly be due to their fresh education they are not stuck with an outdated mindset.

Building Scientists

R1

- Agree on this recommendation, the use of foils and other vapour barrier can limit drying potential.
- Care needs to be taken depending on climate zone and building use, as in some cases a non-permeable wrap is a better option where there is a high vapour pressure difference across the wall.

R2 / R3

- Does this point relate to installing mechanical ventilation in a roof-space to actively ventilate it, or is this passive?

R4

- Worried about the terminology used in this recommendation.
- “I’m taking it means to ensure makeup vents are provided? If this is the case i would be specific, stressing that the origin of makeup air needs to be considered, and that ventilation openings need to be provided for this”

R5

- Good point. Roof-space moisture issue is in general due to air migration across the ceiling diaphragm (particularly in skillion roofs).

R7

- Definitely cuts down on weather-tightness issues, there is the option of a risk-matrix style of specifying this, where the risk is low, direct fix should be ok.

R8

- Important, it forms a critical weather-tightness function, and should be checked before cladding (also ensure it is lapped in the correct order)

R10

- Very good move, major contributor to internal moisture.

R11

- Steady state is fairly crude, and would probably end up too conservative. Options like wufi etc exist and are now quite mature (dynamic analysis).
- This big unknown is the internal climate (however this also applies for the steady state case) and failure criteria.

R14

- It might be nice to know the ACH of a roof-space or subfloor, but testing en-masse will be very difficult to realise (especially the roof).
- Subfloors can be detailed to limit evaporation, and if enough ventilation is provided problems should be minimal (in tropical climates there is the chance of issues with air-conditioning of the space above cooling the floor that are worth investigating).
- Before specifying the ACH of the dwelling, a thorough cost-benefit would need to be undertaken.
- It needs to be stressed that the number produced from a blower door test is around 20 times the actual in-service leakage rate, and care must be taken not to overstate the energy losses

General Comments

- It is worth stressing that some clear failure criteria must be specified regarding hygrothermal analysis, and that all model inputs are provided for assessment.
- Hygrothermal models are complicated, and there is a risk of uneducated users or assessors not picking up on issues.
- If number 2 (the dynamic models above) is done correctly, there is no need for this point.
- Understanding what is the likelihood of condensation accumulation is important, and can the drying potential of the wall cope with small amounts if/when it does happen.
- Building tighter without considering ventilation could lead to increased indoor moisture issues.
- Wary of calling the building wrap/wall underlay a “vapour management barrier”. The primary role is to provide a means to keep liquid water from reaching insulation, having a degree of vapour permeance is desirable to make sure the assembly is able to dry in both directions (conditions permitting).

- Also lining and air barrier can be one in the same depending on the building, airtight drywall is reasonably easy to accomplish, and physical damage to the layer is not hidden.
- Standardisation is good, though even in this document there are multiple terms for the same thing membrane/building wrap/underlay/vapour management barrier.
- Another issue is the use of ACH, it should be made clear whether we are talking ACH-50, n50 etc from a blower door, or actual ACH in service, as these are quite different numbers.
- Regarding education, the building physics at play here are complicated, I think there is a fair amount of education work to be undertaken. There is confusion at all levels.
- For dynamic simulation, the failure criteria are my biggest concern here, plus the education of surveyors/inspectors will be very important.

Manufacturer Perspective

- Amendments required to AS4200.2 in relation to definitions
- Worried about market response for 2019 recommendations specifically regarding the industry capability to implement vapour permeable building wraps. It was suggested that this could potentially put some smaller manufacturers of foil based products out of business.
- Comment below DTS provisions should suggest dynamic simulation and blower door testing for houses that want to achieve above the minimum energy efficiency requirements.
- AS1668.2 ventilation, Table B1 shows required ventilation rates in litres per hour. Discussion as to whether ceiling ventilation would be written into this standard referenced by a provision in the NCC.
- Dedicated circuit for clothes dryer with automatically switches a fan as current is drawn.
- Suggested interlinking standards such as AS3999, AS1668.2, AS4200 and AS4859 each standard calls upon the other standards for compliance.
- 2019 dampcourse connect to subfloor can cause condensation…. No stack effect for drying the subfloor.
- Concern that suburban density reduces air flow for passive ventilation the building fabric. This means housing that meets the regulatory requirements may still have moisture related problems.
- AS4859 should assume that cavity cannot be considered in thermal calculations. A cavities function is to drain and dry as moisture control measure… cavities should be removed from the mathematical model for simulation of thermal performance and calculation of R-values.
- Concern with plumber's taking the cheap option to meet AS3959 bushfire standard. Where sarking in the roof is vertically run from ridge cap to the gutter with a 150mm overlap and then insulation is used to seal gaps. This can lead to condensation problems as insulation is absorbing water from the underside of the roofing iron. Problems because of this detail are being seen in country areas.

- Agree the roof space should be split. Insulation at ceiling level and roof space ventilated and unconditioned. Same issue regarding AS4859 and calculation of thermal resistance.
- Standard truss fabrication limits the application of insulation at the ceiling level. This is only a problem where trusses are not specified by the builder or designed to allow clearance.
- AS3999 shows in diagrams that are likely to cause condensation issues also lapping practices that could lead to water ingress due to a minimum requirement for 50mm.
- All the services in a roof space such as ducting sitting on the batt is wrong…
- There are no provisions currently that specify lifted and supported services such as ducting in the roof space meaning that current installation practices can lead to insulation being compacted.
- Recommend insulated rigid ducting commercial ducting systems with dedicated air handling unit and exchangers by 2022.
- Ventilation requirements can be passive delivered through the building fabric as a DTS provision with specified flow rates or as with performance requirements for mechanical ventilation rates eg 10 ACH-50
- 4 ACH in the roof space international standards condensation should not be a problem if other detailing is adequate.
- NCC contains a poorly worded requirement regarding exhaust ventilation contaminated air into a cavity. For example venting a 'tastic' fan/heater/light combination into the roof space is therefore a compliance issue. The code is quite open to interpretation in this case…
- Pushing for blower door testing now as of 2019. But industry not currently capable of implementing this for 2019.
- Large residential housing should have a blower door test to prove compliance with star ratings as of 2019. This is a strategy to mobilise the market to increase demand of thermally efficient thus airtight housing. Once air tightness is controlled vapour permeability will have to be used to passively control vapour levels.
- Blower door as performance solution for housing above 6 stars….
- Issues of thermal performance in residential construction regarding framing factors. Issue of thermal bridging and thus potential for moisture related problems (condensation).
- Need to push alignment between NCC and AS4200.2 and a condensation analysis tool (static or dynamic) with the classification of membranes. Eg. Class 1, 2, 3 of vapour permeance, specified by climate type rather than permeance this is simpler for the industry to understand.
- Education is a major issue at all levels.
- Industry has had a positive reaction to the BSOL pamphlet (condensation in buildings: tasmanian designers guide as a great resource, 2014). Details meet BAL ratings which were designed with input from the AS3959 committee as well as consider condensation.
- The BSOL pamphlet was said to better than ABCB document in regards to the details provided due to AS3959 compliance.

- Concern about getting buildings to comply with current presumed air change rates which are around 10 ACH-50
- Currently some buildings are being accidentally sealed to well. Which when the building wrap is vapour impermeable in a cool climate will increase the likelihood of condensation.
- Generally, buildings are being built and specified without understanding of the implications of air tightness, it is assumed to be good due to increased energy efficiency which it is but has to be considered in relation to moisture control. Currently water can get in but cannot get back out.
- Average 8 ACH-50 by accident across Australia.
- 'vapour control membrane' was suggested at the terminology that the definition should use in the NCC and relevant Australian Standards (wording rather than vapour permeable).
- We need more building science research by climate zone relating to air tightness and permeability which can be used to create climate specific regulation for a class 1, 2, or 3 vapour control membrane for example.
- Lifestyle in hot humid people generally accept and acclimatise to the humidity.
- International example in Florida is to have different classifications of habitable space so that active and passive systems can be used in the same house; conditioned (esky space), tempered or unconditioned (outdoor).
- The building industry cannot instantly start making (considered) tight buildings without further education.
- Currently mix of membranes on the market could lead to confusion, this requires careful definition so certain manufacturers can still use their products.
- Give the market time to adjust to the changes regarding recommendation no. 1.
- Qld apply less insulation to their buildings predominantly using lightweight direct fixed cladding systems. However, qld is using a high level of building wrapping predominantly foil based as builders believe this gives them their insulative properties.
- NSW is using more insulation but less wrapping than QLD.
- Recommendation no. 1 requires a serious research program to scope the industry capabilities to implement these changes. Need more time to understand international experiences. Use the international experience to leap frog so we do not have the same issues or time frame (eg 20 years) to implement the required changes.
- Ventilation rates l/ps (litres per second) fans capability required based on volume of house. Continuous background ventilation at a given flow rate.
- Ncc and or as1668.2 should specify flow rates for spaces with high vapour loads such as bathrooms, laundries and kitchens not just a l/ps requirement.
- As4200.2 best practice is for sarking to be installed under battens as this is the safest option. Currently both over and under battens are shown. Again lapping was discussed as an issue.
- A continuous gap is required between the roof material and the sarking

- Buildings are not built the way the simulation assumes (quality and compliance issues) this makes blower door testing important as built quality with have to increase to comply.
- Industry is concerned about commercial building types not just classes 1 and 2 residential constructions. Any building that has a heating and cooling load has the potential for condensation, particularly intermittently conditioned spaces.
- Volume building, the commercial realities of the building market. Undercutting the market for builders who want to do the right thing.
- Building materials shouldn’t need to be treated if design is right. For example, anti-fungal plasterboard or paint, these are a cure rather than prevention.
- Immediate costings done for 2019 detailed costing of all other proposed changes must be made. For example, alternate solution to sheath building in oriented strand board (OSB) as a vapour control layer or membrane but also acts as the bracing element. This was discussed as a way to simplify compliance with both vapour control and bracing.

Occupant Perspective

Awareness

Building occupants have a significant impact on two of the major factors relating to condensation. Firstly, on the internal vapour load; through normal operation 10 – 50 litres of moisture is released inside a house every day, occupants generally are unaware of this (CMHC, 2015). See Table 2 for a breakdown of vapour produced through typical operation of a house.

Task Description	Vapour produced L/h (litres per hour)
Adult (breathing)	0.1
Hot bath	1.5
Washing machine	3
Clothes drying	5
Hot shower	10

Table 2. Typical quantities of water vapour produced in the home (CSIRO, 2001).

Issues also arise from the type of heating used as many domestic heaters that use gas, oil or kerosene as the primary fuel source produce large quantities of water as a by-product of combustion when.

Furthermore, storing firewood inside a building can add up to 270 litres of vapour to the internal vapour load (CMHC, 2015). Secondly, vapour can be allowed to build up if windows and doors remain closed and there is no adequate mechanical ventilation provided to control humidity levels.

Operating the building without adequate ventilation drastically increasing the likelihood of condensation occurring. Not understanding these factors and the building occupant's role in managing vapour loads can result in condensation occurring, consequently this impacts the indoor air quality (IAQ) which can lead to health problems and building sickness (ref US document).

The general consensus of all respondents from the ABCB scoping survey is that there is a low level of occupant awareness around the issues of condensation and management thereof. Subsequently occupants are increasing the likelihood of condensation occurring, which has a detrimental impact on the indoor environment quality of their homes.

It has been found during a typical 6 month heating season in Canada, between 2,000 to 10,000 litres of moisture is released and if not ventilated becomes trapped inside the building envelope (CMHC, 2015). This moisture can quickly lead to condensation issues that are not necessarily evident to the building occupants. The following data from the survey results reinforce this hypothesis, of all survey respondents:

- The highest number of respondents nominated that the average building occupant is unaware of the role they play in managing condensation risk, thus increasing condensation, with 991 counts, compared to 895 who believe increasing air-tightness is the cause of increased condensation (Q1H)
- Of this, 81.9% perceive occupants as reluctant to open windows and doors due to energy costs.
- Compared to the number of responses nominating for designers being responsible (the largest count for Q2E), 62.5% as many claim that it is the responsibility of the building occupants to manage condensation risk (77.1% for builders).

Contrary to this popular notion, the Canadian construction code explains that building occupants cannot be held responsible for condensation accumulation. This is because the Canadian code considers moisture control is the role of the building fabric and continuous mechanical ventilation. Mechanical ventilation becomes necessary as the airtightness of the building envelope is increased for energy efficiency. It also simplifies the role of the building occupant if the building can self-regulate.

Once the building fabric is built occupants only have control over active systems. The common example and expectation is for windows and door to be the primary source of ventilation other than in bathrooms and kitchens. However, management strategies such as these require physical input, require the occupants to be at home to manage, compromise energy efficiency and security, allow noise transmission and reduce privacy.

Designers and builders cannot rely on occupant controlled ventilation, which is the current practice, as the survey results suggest 81.9% of respondents say that occupants are reluctant to open windows and door. However, 79.6% of respondents believe an acceptable solution to reduce the risk of condensation is to ventilate by opening windows and doors. It must be noted the question was suitably vague in regards to whether these are acceptable solutions to reduce the risk in existing housing stock or if opening windows and door is an acceptable solution to rely upon for new housing. The sensible answer in this case would be, no, given the current reluctance to ventilate with this method.

Education

Through reviewing the survey responses, it becomes clear the primary issue regarding the condensation issue and moisture control at both an industry and occupant level is education.

Education becomes a large part of the immediate strategy to reduce the rates of condensation occurring and reducing the rate of non-compliant construction from occurring.

- 55% of all respondents were unaware of any educational materials that exist pertaining to condensation management and prevention, this includes professionals and homeowners.
- 90% of respondents think more needs to be done to assist industry and the community to respond to issues relating to condensation.

A preliminary review of education material aimed at educating building occupants regarding the risks of condensation has found little material exists with this purpose. The majority of education material is aimed at industry education containing detailed and technical descriptions. What exists that is intended for building occupants is generally information regarding the control of mould issues rather than the control of vapour. While these documents often do discuss ventilation as a means to reduce a mould issue then do not specifically make people aware of the true cause. A number of guide and factsheets exist at a state government level these primarily discuss the mould issue resulting from excess vapour inside the building. While a handful of these guide specifically target condensation and management strategies, in general most do not. Material exists at a national level with the ABCB guide, at a state level primarily housing departments and occasionally at a local government level. The following are typical examples of the advice provided as solutions to condensation management:

- Remove or reduce indoor moisture sources,
- Use of dehumidifiers,
- Keeping surfaces warm,
- Providing adequate ventilation, mechanical or passive.
- It is not acceptable to ask people to resort to active systems such as opening windows.

Typical home user guides provide occupant's general education on the prevention and management of moisture related issues particularly condensation. Solutions provided are generally provided for operation of existing homes but these documents can be used to increase the market demand for condensation conscious buildings. Comprehensive operational manuals and guide aimed at building occupants are commonplace in the US, Canada, UK and NZ. The information provided on 'yourhome' the government website which is a primary source of educational material provides basic explanation of condensation and dew point. This website also suggests building occupants and homeowners, 'Ask [their] designer and builder for an owner's manual… If you sell your home make sure the new owners have a copy.'

There is no official standardised educational material suitable for circulation to homeowners and building occupants that simply identify risks and management solutions for existing condensation issues. Education of both the industry and building occupants may lead to clearer contractual obligations being established so clear liability can be determined. In this sense contractually all parties will better understand their obligations regarding condensation management. The general public must be educated prior to building construction so that there is a level of awareness and expectation that can drive the market for new building products, increased energy efficiency and moisture control. This might require a number of different approaches and forms of media to deliver information. For example:

- Ad campaigns,
- Updates to hard and soft information such as yourhome.gov

- Guides
- Seminars
- Trade shows
- Manufacturers information

Homeowners would like to see more validation undertaken at the design phase before construction starts. The following comments were taken from respondents reporting to be homeowners in the survey. 'More needs to be done at the energy efficiency assessment stage' another respondent states, 'supply the buildings with condensation ratings and reports' as a compliance measure. These comments are supported by those of the building surveyors which suggest blower door testing and dynamic simulation will increase compliance. At the design phase, validation of the building design through static or dynamic simulation would allow clients to have a measure to gauge their expectations. This gives homeowners a level understanding regarding where their building sits within a given scale, in this case the star ratings. This education and level of expectation will start to drives market demand for quality design solutions. Specifically, those that apply effective specification and construction detailing to reduce the risks of condensation while retaining energy efficiency.

Other occupant related recommendations include:

- Self-managing ventilation systems and other solutions that simplify dehumidification and cross flow of supply and exhaust air minimising occupant input.
- Simple maintenance processes regarding operation of any passive or active systems.
- Operational guides, manuals, handbooks or the like upon project completion outlining:
    - Operation of all ventilation systems, requirements and frequency of maintenance.
    - Warranties of all heating, cooling and ventilation systems
    - Educational material distributed through different forms
    - Television
    - Radio
    - Internet (comprehensive update to yourhome.gov.au / NatHERS)
    - Leaflets / Pamphlets
    - Exposure at seminars, trade and owner builder shows

Scoping Study of Condensation in Residential Buildings

Appendix 04: Residential Building Codes – An International Perspective

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Residential Building Codes – An International Perspective

Introduction

This section provides an in-depth analysis of the management of condensation risk in the residential building codes from the United States, United Kingdom, Canada, Europe and New Zealand. The review focused on these countries and region because of the facility to source, not just the regulations, but a range of supporting technical and specialised documentation.

Like Australia, a number of the regulations examined were national model codes. These are then implemented in whole, or with regional variants by state and local jurisdictions (USA, England, Canada, and Europe). The focus of the review was the model codes. In each case elements of the codes that provide regulatory requirement, performance or guidance have been extracted for discussion and comparison.

However, in the case of the USA the regulatory mechanisms of the states of California and Florida were compared to the national model code, to ascertain any difference occurred at a state level, as a result of responding to specific climatic conditions.

The review of European Regulations focused on European Union regulation. Some examples are then given on how individual member states have implemented these regulations. This provides a snapshot into the variety of approaches taken to manage condensation and the level of sophistication reached in considering issues around internal environmental conditions.

The regulatory systems examined represent a diverse range of climatic conditions and building practices. Additionally, the analysis focussed on climate typologies, similar to those experienced in Australia, namely:

- Cool - a dominate Internal heating load;
- Temperate - a mix of Internal heating and cooling loads; and
- Warm - a dominate internal cooling load;

Each Regulatory system analysed represented building practices that are historically and geographically unique to that country or region. The analysis did not aim to compare specific building typologies and practises. Rather, under the analysis heading of 'Structure" building typologies were examined at their fundamental level. That is, floor, wall and roof systems are described in terms of their ability to manage condensation, vapour control, thermal control and air movement.

To build a deeper picture of how some countries are managing condensation in buildings, the analysis also reviewed key parts of each regulation system that responded to issues of condensation internal moisture, humidity control, internal environmental control, air movement, and condensation related human health. This analysis was conducted using a matrix developed out of the review of literature into condensation risk and mitigation. Specifically, each country's regulatory system was examined under the following criteria:

- **Definition** – was condensation defined in the regulations. If so how?
- **Structure** – how is condensation managed within the building fabric or envelope. This was divided into the sub-groups of Floor, wall and roof

- **Internal Environment** – this relates to minimum and maximum internal temperature and air quality requirements. A number of countries responded to issues associated with condensation under the broad heading of Internal Air Quality (IAQ).
- **Air Movement** – the management of condensation risk through both minimum ventilation rates and air-tightness controls
- **Implementation** – A number of Regulations examined were prescriptive, focusing on *what* was to be achieved. They often referenced other documents to provide the what, when and how to achieve the regulatory requirements. A review of these explanatory guides and reference was completed to assist in understanding how condensation risk has been mitigated.
- **Compliance Testing** – Regulations set minimum standard. The mechanisms used to ensure compliance and certification around condensation management were examined.
- **Social Drivers** – this is a broad heading. Its aim is to capture the wider context and motivations behind amendments to building regulations. Many changes to regulations, around condensation, did not occur because of an identified long-term failure in building systems but rather, because of changes in social expectations around the internal built environment and energy efficiency.

Each country's regulations sit within a well-defined and long established technical and experimental research framework. This research is conducted by government, industry and non-for–profit organisations. It was not difficult to find in each jurisdiction substantial bodies of research on condensation in residential buildings. Its focus included health impacts, building physics, material capabilities and building systems analysis.

The research was also highly targeted to specific climate zones and a range of building typologies. Due to the volume and often highly specific nature of each nation's research, this report has included the literature review undertaken for the Tasmanian condensation report. It is noted that this was heavily focused on cool temperate Australian climate zones. Therefore, this research has also included literature from tropical zones, like Florida U.S.

The review of international literature also included a separate review which focused on condensation, cause, effect and mitigation. The findings of this review assisted in gaining a deeper understanding of the drivers behind the historical changes within the international residential codes from each country. For each country, the review regulations was conducted in two parts, namely:

1. Historical changes to the residential building code. This was to identify any significant patterns or trends in regulatory change that was aimed at condensation mitigation. Consideration was given to changes in terminology, standardisation of terms, definitions and solutions.
2. Any change in Regulation was then traced through the supporting implementation documents to ascertain how they manifested in changes to standard building practice. Direct discussions were also held with BRANZ on the current regulatory environment in New Zealand, and upcoming amendments to the N.Z. residential code in response to condensation issues.

United States of America

Only in relatively recent times has the United States had an overarching, national building code. Prior to this three independent regionally based model building codes operated. In 2000 these three model codes and a range of other codes regarding, for example fire management, were unified into the 'International Codes'. The International Codes cover a range of construction typologies (i.e., non-residential and residential) and regulatory issues such as amenity and universal access. The documents of interest were:

- International Residential Code (IRC) covering all 1-2 family homes under 3 stories, and
- International Energy Conservation Code (IECC) covering minimum design and construction requirements for energy efficiency

The use of the word 'International' could be seen as confusing but it refers to an 'inter-national' model and not a set of trans-national agreement or regulation that extends outside the regulatory jurisdiction of the United States. The IRC and IECC are model codes. Each state, jurisdiction and municipality within the United States determines if it is to adopt the IRC and IECC in full or in part. Furthermore, Federal departments, such as Defence or Housing can adopt the IRC and IECC as a regulatory framework. This is very similar to the regulatory framework in Australia.

The IRC and IECC have been adopted in a complex and inconsistent way across the United States. Some states have adopted them in full, some reference part of the codes and some retain their own codes. Within this context, this analysis has focused on the IRC as a model code and its adoption in two states (Florida and California). These two States were selected due to their diverse range of climatic zones; from hot tropical, to coastal marine, hot & dry, temperate and alpine. There are subtle differences in climate classification between the United States and Australia however, in broad terms the climates of these two states are quite comparable to Australian climates.

The International Residential Code 2015 (IRC)

The IRC is a 'cookbook' style regulatory framework for construction of typical domestic dwellings. It stated aim is to be a prescriptive-oriented (specification) code with some examples of performance code (IRC 2015 Preface). For example, it simply specifies how a timber stud wall is to be assembled, which includes basic minimum performance standards]. However, any technical specifications or compliance testing are generally referenced and contained in other documents.

Key Components of condensation control and mitigation

Between, the development of the initial IRC 2000 and the current IRC 2015, there has been significant refinement in how the issue of condensation is addressed and managed, as shown in Table 1. This includes the standardisation of specific terms and descriptions across the IRC.

Provided below is a summary of the key sections of the IRC which either seek to explicitly mitigate and control condensation, or, as in IRC-Chapter 11 changes to the building construction regulation in response to the driver of improved energy efficiency and building thermal performance.

IRC Chapter 4 – Foundations

This Section addresses moisture control under floor spaces. The Key sections are: R408-1 Ventilation in which:

> *The minimum net area of ventilation openings shall not be less than 1 square foot for each 150 square feet (0.67 m² for each 100 m²) of under–floor space area. One such ventilating opening shall be within 3 feet (914 mm) of each corner of said building.*

Unvented Crawl Spaces are permitted if there is: *Continuously operated mechanical exhaust and supply ventilation*.

Florida and California have fully adopted this section of the IRC. California also requires for unvented crawl spaces, perimeter wall will be insulated in accordance with the California Energy Code (page)

IRC Chapter 7 – Wall Coverings

From 2000 to 2006 there was no specific mention of Vapour Retardants in the IRC. In IRC 2009 it was added within Chapter 6 – Wall Construction. However this chapter focuses on construction issues, such as timber sizing, bracing and fixings. As a result, in the IRC 2012 edition '*vapor retarders'* were separated out into their own *Section*: *R702.7 Vapor retarders*. This entry requires:

> *Class I or II vapor retarders are required on the interior side of frame walls in Zones 5, 6, 7, 8 and Marine 4*

The Climate Zones specified are those with a predominant heating requirement. Class I is a very low permeability vapour retarders, rated at 0.1 perms or less, (i.e., unperforated aluminium foil). Class II is low permeability vapour retarders, rated at greater than 0.1 perms and less than or equal to 1.0 perms, (i.e., Kraft paper). Class III Vapor retarders are permitted but in very specific circumstances, generally, over a vented cladding system or a continuous insulation layer.

Section 703.1 – Exterior Wall Coverings initially stated in IRC 2000 that:

> *Exterior walls shall provide the building with a weather–resistant exterior wall envelope. The exterior wall envelope shall include flashing as described in Section R703.8. The exterior wall envelope shall be designed and constructed in such a manner as to* ***prevent the accumulation of water within the wall assembly by providing a water–resistive barrier behind the exterior veneer*** *as required by Section R703.2.*

This section was amended in IRC 2006 with the inclusion of:

> ***Protection against condensation in the exterior wall assembly shall be provided . .***

In IRC 2012 the Exterior wall description was separated into external and internal sides of the wall. The General description of Section 703.1, dealing with external moisture control and flashings remained. Moisture on the internal side of the external wall was addressed with the addition of a new *Section R703.1.1 Water Resistance*. It states:

> *The exterior wall envelope shall be designed and constructed in a manner that prevents the accumulation of water within the wall assembly by providing a water-resistant barrier behind the exterior veneer as required by Section R703.2 and a means of draining to the exterior water that enters the assembly.* ***Protection against***

> ***condensation** in the exterior wall assembly shall be provided in accordance with Section R702.7 of this code.*

R702.7 As noted above deals with vapour retardant classes. Therefore in climates zones with internal heating requirements, a vapour retardant needs to be used on the internal side of a wall assembly.

However, in IRC 2009, three exemptions were given to when vapour retardants needed to be used:

> 1. In detached accessory buildings.
>
> 2. Under exterior wall finish materials as permitted in Table R703.4.
>
> 3. Under paper-backed stucco lath when the paper backing is an approved water-resistive barrier.

These exemption were reduced in the IRC 2012 to only allow exemption 1. However, Florida and California have both retained the IRC 2009 exemptions.

Section 7 also provides standard construction details. These are entitled “Expectations”, and provide generic detailing for certain standard construction types. In the IRC 2000 the waterproofing layer within the wall assembly is described as *Water Repellent*. From IRC 2009 to the Current IRC 2015 this barrier is called the Water Resistive Barrier. This reflects a recognition that in climate zones with predominant internal heating the wall assembly needs to be water impermeable, but vapour permeable to some degree to allow internal vapour loads to exit the wall assembly.

In Section 7 there is no explicit detail on making vapour barriers air-tight. However, this is addressed in Section 11, discussed below.

Chapter 8 – Roof – Ceiling Construction

In the IRC 2000 *Section R806.1 - Ventilation* required:

> *Enclosed attics and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof rafters shall have cross ventilation for each separate space by ventilating openings protected against the entrance of rain or snow. Ventilating openings shall be provided with corrosion-resistant wire mesh, with 1/8 inch (3.2 mm) minimum to ¼ inch (6.35 mm) maximum openings.*

Over time there has been minimal changes to the opening sizes (mainly standardising them to the metric system). The *IRC 2012, Section R806.1* was expanded so that:

> *. . . required ventilation openings shall open directly to the outside air.*

In *IRC 2000 Section R806.2 - Minimum area*, the Minimum ventilation area of a roof space was 1/150. This could be reduced to 1-300 if 50% of ventilation was located in the upper portion of the roof space, or a vapour barrier used on the worm side of the ceiling.

This was amended in IRC 2006 and IRC 2009 to give more clarity to the definition of a vapour barrier. In *IRC 2012,* this was further defined as . . . *In Climate Zones 6, 7 and 8, a Class I or II vapor retarder is installed on the warm-in-winter side of the ceiling*. . . An example of how terminology and systems have been standardised across the IRC.

Furthermore, significant detail is given in IRC 2015 on the location of vents, so that:

> *Upper ventilators shall be located no more than 3 feet (914 mm) below the ridge or highest point of the space, measured vertically, with the balance of the required*

ventilation provided by eave or cornice vents. Where the location of wall or roof framing members conflicts with the installation of upper ventilators, installation more than 3 feet (914 mm) below the ridge or highest point of the space shall be permitted.

Florida and California have adopted *Section R806.1* in full.

R806.5 - Unvented attic assemblies

This was not part of the original *IRC 2000*. In *IRC 2006* unvented attic spaces were permitted under certain conditions. These were:

No interior vapor retarders are installed on the ceiling side (attic floor) of the unvented attic assembly.

An air-impermeable insulation is applied in direct contact to the underside/interior of the structural roof deck

In Zones 3 through 8, sufficient insulation is installed to maintain the monthly average temperature of the condensing surface above 45°F (7°C).

Since *IRC 2006* the definition of an unvented attic assemblies has been refined and more detail added. Also the requirements have been increased and become more defined.

The most significant in *IRC 2015* are:

The unvented attic space is completely contained within the building thermal envelope.

No interior Class I vapor retarders are installed on the ceiling side (attic floor) of the unvented attic assembly or on the ceiling side of the unvented enclosed rafter assembly.

In Climate Zones 5, 6, 7 and 8, any air-impermeable insulation shall be a Class II vapor retarder, or shall have a Class III vapor retarder coating or covering in direct contact with the underside of the insulation

Air-impermeable insulation only. Insulation shall be applied in direct contact with the underside of the structural roof sheathing

air-permeable insulation installed directly below the structural sheathing, rigid board or sheet insulation shall be installed directly above the structural roof sheathing as specified in Table R806.5 for condensation control.

insulation shall be installed directly above the structural roof sheathing to maintain the monthly average temperature of the underside of the structural roof sheathing above 45 der F (7deg C). For calculation purposes, an interior air temperature of 68deg F (20deg C) is assumed and the exterior air temperature is assumed to be a monthly average outside air temperature of the three coldest months.

It should be noted that the Florida IRC does not contain this last point. The Californian IRC does. Additionally, some new advisory notes have stipulated that ALL roof spaces are to be ventilated

Chapter 11 – Energy Efficiency

The Key evolution in this Chapter of the IRC was the introduction of a Statement of Intent in IRC 2012. It states:

This code shall regulate the design and construction of buildings for the effective use and conservation of energy over the useful life of each building. This code is intended *to provide flexibility to permit the use of innovative approaches and techniques to achieve this objective. This code is not intended to abridge safety, health or environmental requirements contained in other applicable codes or ordinances.*

The last two sentence re-iterate the intention of the IRC generally to provide prescriptive standards that can then be achieved in a flexible and efficient way.

Also in IRC 2012 section *N1101.9 (R302.1) - Interior Design Conditions* was included. It mandates the interior temperature of residential buildings so that:

The interior design temperatures used for heating and cooling load calculations shall be a maximum of 72°F (22°C) for heating and minimum of 75°F (24°C) for cooling.

This applies across all climate zones and has been adopted by both Florida and California.

N1102.1 - Thermal Performance

The minimum performance requirements for different building systems is summarised in Table *N1102.1 - Insulation and Fenestration Requirements by Component*. It states the minimum R-values for all Building components such as floors, wall and roof of various construction type as well as Fenestration. Detail is then provided on the application of insulation in these space and any specific requirements and exemptions. In IRC 2000 thermal insulation requirements were divided into 17 zones based on number of Number of Heating days. Minimum R-values were required for glazing, ceiling, floor and walls, basements, slabs and crawl spaces. (Table N1102.1). Over time the climate zones within the table were reduced from a complex matrix of 17 to a broad set of 8 zones. These are broadly in line with the current Australian Climate Zones.

Changes in the IRC from 2000 to 2015, have generally required higher amounts of insulation for all building element. This may not be surprising for cool and cold climate zones (zones 6-8). However, in Zones 1-2, which are considered tropical and humid, the insulation requirements have also increased, for example, Zone 1 has increased from R13 to R30 for ceilings. (IRC 2000 Table N1102.1 and IRC 2015 Table N1102.1.2). During the same period, cool and cold climate zones increased from R20 in walls to R25. But interestingly this was mandated as R20 cavity insulation and R5 continues insulations, (or over cladding).

Chapter 11 - Minimum Requirements

Both changes in R-Values for warm and cool climates has an impact on the management of condensation and how a building fabric functions over time. Therefore the thermal performance requirements are followed in the IRC by a set of minimum requirements.

N1102.2.3 -Eave baffle

In IRC 2012 the use of Eave baffle became mandatory in both Cool and Hot climate zones.

These are described as:

For air permeable insulations in vented attics, a baffle shall be installed adjacent to soffit and eave vents. Baffles shall maintain an opening equal or greater than the size of the vent. The baffle shall extend over the top of the attic insulation. The baffle shall be permitted to be any solid material.

N1102.1.10 - Air Leakage*:*

This was originally referenced in IRC 2000. However, this was a general statement that:

All joints, seams, penetrations . . and other sources of air leakage . . shall be . . sealed to limit uncontrolled air movement.

In IRC 2006 Air leakage was incorporated into a new section *N1102.4.1 Building thermal envelope*. However, the definition remained fundamentally the same.

In IRC 2012 this section was expanded and refined. For example the new Definition became:

> *The building thermal envelope shall be constructed to limit air leakage in accordance with the requirements of Sections N1102.4.1 through N1102.4.4.*

Specific requirements for walls, ceilings, floors, crawl spaces, basements, recessed lighting, crawl space etc were now detailed in *Table N1102.4.1.1 (R402.4.1.1) Air Barrier and Insulation Installation.* This provides a comprehensive set of minimum requirements for thermal control and air leakage control within the build fabric. The reason for this approach is in response to International and U.S. research which identified leaking building fabric as a key location of condensation risk.

Compliance & Testing

Air leakage testing was introduced in IRC 2009 and expanded in IRC 2012 so that:

> The building or dwelling unit shall be tested and verified as having an air leakage rate of not exceeding **5 air changes per hour in Zones 1 and 2, and 3 air changes per hour in Zones 3 through 8**.

It is now mandatory for a new residential building to be pressure tested before it can receive a energy rating certification under the IECC (discussed in more detail below).

Other Chapters of the IRC

Mechanical Ventilation and Climate control Systems

A significant proportion of the IRC is dedicated to mechanical ventilation, heating and cooling. In fact Sections 12 to 19, a third of the Code has this as its key focus. Furthermore, both the *Florida Building Code - Energy Conservation* and the *California Energy Code* include a significant proportion on mechanical systems within the home. This is due to the substantial energy efficiency gains that can be made through the proper use of such systems. But it is also recognised that an inappropriate and/or poorly installed mechanical system can lead to moisture leakage and condensation. For example, in *Subsection 7 Part M* of the *Californian Energy Code*, the installation of air ducts in roof spaces for both hot and cool climates is prescribed in detail. The insulation of ducts in cavities and roof spaces is prescribed to limit temperature differentials in these spaces that may lead to condensation. A detailed analysis of how and what building methods and mechanical systems, prescribed in the IRC, contribute to alleviating condensation risk is discussed further below. This is in the context of the considerable amount of research undertaken into very specific aspects of these issues.

Technical Specifications:

As noted above the IRC is a prescriptive document. The benefit of this approach is that it simplifies the IRC as a minimum guide to construction. The negative, is the complexity of references to Technical Codes and Specifications. The IRC is not bound to a set of Specifications. On the issue of condensation, the IRC references Standards from:

- The American National Standards Institute
- International Organization for Standardization
- British Standards
- Canadian Standards

As a result, standards prescribed in the IRC may change but not be updated automatically in the IRC. This complexity is compounded by the fact that the IRC is a voluntary code. As mentioned above, States may adopt it in full or in part. Likewise, Jurisdictions are free to reference other standards or codes (national or international). This diversity is again further complicated by the differences in definition of climate zone between standards and descriptions of what constitutes a 'common' construction systems.

Social Drivers - International Energy Conservation Code (IECC)

Like the IRC the IECC is a model code for minimum design and construction requirements for energy efficiency. It was first introduced in 1998. The IECC 2012 sets out minimum requirements to achieve a certified level of Energy efficiency. The IECC addresses energy conservation requirements for all aspects of energy uses in both commercial and residential construction, including heating and ventilating, lighting, water heating, and power usage for appliances and building systems. The IECC sets minimum requirements for construction like; exterior envelope insulation, window and door U-values and SHGC ratings. The objective is to give consumers a simple overall guide to the level of energy efficiency achieved by any particular home. The IECC does not specifically address condensation rather, when prescribing minimum performance levels, it references back to the IRC. For example, when prescribing minimum R-values for roof spaces, it must be done in compliance with IRC – Chapter 8: Roof.

Rating System

The IECC 2012 establishes a theoretical 'Model Home'. If the model home was built it would comply fully with the IECC 2012. This model home is then give a score of 100. Any new home is certified against this model home and is given a *Home Energy Score*. For example:

- A score of 70 would mean the home is 30% more efficient than required by the IECC 2012
- A score of 100 meets the requirements of the IECC
- A score over 100 would mean the home is less energy efficient than the IECC requires.
- If the score was 0, the house is zero-CO2 and zero net energy.

The U.S.A Environmental Protection Agency has developed the *Energy Star Rating*. This is an independently certified rating system assessing a package of energy efficiency measures adopted in the design and construction of a home. Verification usually includes a house pressurisation test. The U.S.A Department of Energy has used the Star Rating system and the Home Energy Score to drive its national goal to:

> *reduce by 2025, the energy use for space conditioning and water heating in single-family homes by 40% from 2010 levels.*

This would mean a home built in 2025 would use 40% less energy than an IECC model home in 2010. Therefore, the IECC is not prescribing regulations to mitigate condensation, but rather, the IRC has been amended so that the performance requirements set out in the IECC can be achieved in a way that mitigates condensation risk.

Use of IECC

As mentioned previously, the IECC is a voluntary code. Although most States have adopted the IECC is some form, there are significant differences between States. Therefore any assessment of the IECC at a national level is difficult. Of the two states examined in this report:

- California's *2013 Building Energy Efficiency Standards* meets or exceeds the stringency of the IECC 2012.
- Florida's *2014 Florida Building Code, Energy Conservation* is based on the IECC 2012 but Florida also provides a "deemed-to-comply" option.

Therefore, although there are national drivers of energy efficiency, the complexity of regulation of both the IRC and the IECC at a jurisdictional level makes any assessment of national implementation and national response to condensation issues difficult. There are no overarching reference documents such as the United Kingdom's: *BS5250 2011 – Code of Practice for the Control of Condensation in Buildings* (discussed in detail below). However, the drive towards more energy efficient housing has prompted a response to the issue of condensation within the construction requirements specified in the IRC. This response is expressed in regular amendments to the IRC and IECC. However, the Codes do not provide substantial detail as to 'how' the minimum requirements should be translated into design and building practice. This is left to the skill set of the design and construction industries.

Implementation

Best Practice Guidelines

What is prevalent in the United States is clear and detailed best practice guides which focus on climate specific issues and needs at a local level. Best practice guides can be categorised as information, handbook and manuals which show the 'how to' of the IRC and IECC for designers and builders. The most comprehensive set of best practice guides and compliance documents for the control and mitigate condensation, have been developed by:

- Environmental Protections Agency (EPA) focusing on issues of Indoor Air Quality (IAQ); and
- *Building America*, a Division of the *Department of Energy* and *Department of Housing and Urban Development*

The Environmental Protections Agency provides considerable information and guidance on improving Indoor Air Quality. An aspect of this is a focus on moisture and mould in homes[1]. The EPA makes the link between poor IAQ, resulting from internal moisture and mould, and respiratory issues such as asthma[2,3]. The EPA also provides a number of guides to designers, builders, health professionals and homeowners on IAQ[4,5,6]. Contained within these guides are specific recommendations on reducing the risk of internal moisture, humidity and the eradication of mould. These guides also make clear that, improving a building's energy efficiency via improved insulation and air-tightness, can risk the quality of the indoor environment. As a result there are recognised changes in design and construction practice to mitigate condensation and mould risk. The Recommendations made are based on building type, construction system and climate zone.

Building America is a network of research and industry partners who seek to:

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[1] https://www.epa.gov/indoor-air-quality-iaq

[2] https://www.epa.gov/mold/ten-things-you-should-know-about-mold

[3] https://www.epa.gov/mold/mold-and-health

[4] https://www.epa.gov/mold/publications-about-mold

[5] https://www.epa.gov/mold/resources-health-professionals

[6] https://www.epa.gov/mold/resources-health-professionals#Clinician_Guide

develop innovative, cost-effective energy saving solutions—better products, better new homes, better ways to improve older homes, and better buildings in which we work, shop, and lead our everyday lives.

Building America's information on condensation can be divided into three streams, namely:

- Research - into specific climate and building typologies,
- Building Guides – identifying and resolving technical construction details, and
- Public Information – targeting home owners with user friendly guides and advice.

The first stream research, tests ideas and provides findings and recommendations on key issues of condensation. These recommendations are based on publicly available research on a range of floor, wall and roof assemblies and mechanical systems in different climate zones. Building America partners with the Building Science Corporation to undertake a substantial amount of its primary research. Building America makes clear the link between improving energy efficiency, by increasing the air tightness of construction and the subsequent risk of interstitial condensation. Building America also explicitly links condensation to building fabric decay and a negative impacts on human health from mould and fungal growth resulting from prolonged build-up of moisture. A summary of Building America's key research examining the link between condensation and health listed below.

Building America provides a set of best practice guides for the construction of energy efficient homes in different climatic conditions that comply with the IRC and IECC. The guides are based on the findings stemming from their theoretical and practical research. Building America also recognises that innovation and technology will always see change and improvement in best practice, and so notes the guides it develops are always subject to improvement and change. Guides are divided into two types; namely whole of house guides and best practice construction details.

The 'whole of house' guides are usually climate specific guides aimed at demonstrating overall energy efficient design. They often reference a specific house that has been constructed and outline the range of design solutions used to improve energy efficiency. Moisture control is included within documentation, in particular vapour control is explicitly explained as a requirement to mitigate condensation. The whole of house approach focuses not only building assembly, but also, ducting, air conditioning, piping, fixture and ventilation systems.

The 'best practice construction details' provide a number of climate specific documents covering a range of building assembly types. These guides provide clear climate zone specific responses to condensation, vapour control, and mould. Despite the complexity of building and construction methods used across the United States, there are clear variations in how the best practice construction details mitigate condensation in cold, temperate, hot dry and hot humid climates.

Summary - U.S.

How the IRC have been adopted to minimize the occurrence of condensation in dwellings

Definitions

No definition of condensation

Structure

Foundations: - Minimum rates for sub-floor ventilation. Size and position of vents are also prescribed.

Walls – the Class of Vapour Barrier and use is standardised and defined. Air and vapour control are location (internal or external side of wall system) and is prescribed by climate zone.

Roofs – Minimum ventilation size, location and area of a roof space is prescribed. The class of permeability of vapour barrier to be used is standardised and defined (note: only vapour permeable sarking to be used). Also air-impermeable insulation is only used as insulation in direct contact with the underside of the structural roof sheathing.

Internal Environment

The interior design temperatures used for heating and cooling prescribed as maximum of 22°C for heating and minimum of 24°C for cooling.

Air Movement

Air-tightness – Minimum requirement for air leakage. (5 to 3 ACR depending on climate zone)

Ventilation rates prescribed.

Implementation

Significant climate zone specific construction guides and research

Significant regulation and sophisticated level of technical guidance on the use of mechanical ventilation systems

Compliance Testing

Building pressurisation tests compliance testing required for all new residential buildings (blower door).

Social Drivers

Energy Efficacy targets affecting both the regulations and the research undertaken to identify and resolve issues of condensation in thermally efficient housing models.

Recognition that condensation and its potential consequence has an impact on human health, with IAQ driving a broader change to building systems and regulation.

Canada - National Building Code

Like the United States, the Canadian National Building Code (NBC) is a 'Model Code' that is then adopted by individual provinces and some municipalities. The NBC establishes minimum standards. The NBC sets out basic prescriptive and performance requirements for building elements. It also covers basic building envelope and interior and exterior finishes and how they are to be constructed. The code establishes requirements to address the following five objectives; Safety, Health, Accessibility for Persons with Disabilities, Fire and Structural Protection of Buildings, and Environment.

The NBC comprises three divisions, namely:

- Division A, which defines the scope of the Code and contains the objectives, the functional statements and the conditions necessary to achieve compliance.

- Division B, which contains acceptable solutions (commonly referred to as "technical requirements") deemed to satisfy the objectives and functional statements listed in Division A, and

- Division C, which contains administrative provisions.

Therefore, any consideration of condensation issues is separated out into 'what' is expected (Division A) and then 'how' this is achieved is detailed in Division B. However, Division B is separated between Acceptable Solutions (non-residential buildings) and Acceptable Solutions: Housing and Small Buildings (Part 9) (residential buildings). The focus in this report will be on condensation mitigation in Part 9 of the NBC. In regards to the management of internal moisture the NBC prescribes the following objective:

Division A: Section 2 Part 2.2.1.1. Health OH1 Indoor Conditions

> *An objective of this Code is to limit the probability that, as a result of the design or construction of the building, a person in the building will be exposed to an unacceptable risk of illness due to indoor conditions. The risks of illness due to indoor conditions addressed in this Code are those caused by—*
>
> *OH1.1 –inadequate indoor air quality*
>
> *OH1.2 –inadequate thermal comfort*
>
> *OH1.3 –contact with moisture*

This is further refined in the Devision A: Part 3 Functional Statements, Section 3.2.1.1:

> *The building or its elements to perform the following functions . . Function 63 - To limit moisture condensation*

Of note in the NBC is the standardisation of terminology. For example the risks to illness listed above, which include indoor air quality, thermal comfort, contact with moisture and condensation, are used throughout Division A. As an example, when prescribing air barrier system requirements, notation is given on how critical a functioning air barrier is in achieving air quality, thermal comfort and condensation control. This same approach is repeated throughout the NBC, including ventilation, and vapour control.

Structure

Floors

All sub floors (crawl space) are required to be ventilated under Division B - 9.18.3.1 Ventilation. In which:

> *1) Unheated crawl spaces shall be ventilated by natural or mechanical means.*
>
> *2) Where an unheated crawl space is ventilated by natural means, ventilation shall be provided to the outside air by not less than **0.1 m2 of unobstructed vent area for every 50 m2 of floor area**.*
>
> *3) Vents shall be a) uniformly distributed on opposite sides of the building, and b) designed to prevent the entry of snow, rain and insects*

Section 9.18.6.1 Ground Cover, reqires all unheated crawl spaces to have ground cover.

Walls

As Part of *NBC Section 9.27 - Cladding,* a number of cladding systems are described and regulated. A standard principle applies that:

> *Exterior walls exposed to precipitation shall be protected against precipitation ingress by an exterior cladding assembly consisting of a first plane of protection a capillary break of 10 mm Min and a second plane of protection.*

Historically a climates vapour membrane was used as the second plain of protection for insulated walls. However, provisions in the NBC 1995 relaxed restrictions on the use of materials with low water-vapour permeability as rain screens. These changes to the Code were made in order to reduce the potential for condensation of moisture on the interior face of vapour impermeable barriers. The NBC now recognises that there is an increased risk of condensation when low vapour permeable or vapour retardant materials are installed as second plain protection of insulated stud walls in buildings, with internal heat loads and where relative humidity is high.

To address this issue *NBC Part 9.27.3.2 - Sheathing Membrane Material Standard*, requires an additional sheithing layer to be placed on the internal side of the rain screen. A range of sheathing options are prescribed, including membranes, rigid insulation, OSB and wood board. Each has details on compliance with relevant standards, size, thickness and fixing (Parts 927.3.2 - 5).

Additionally, steady state modelling establishes prescriptive requirements of minimum 'Ratio of Outboard to Inboard Thermal Resistance' for buildings to maintain the temperature and the relative humidity of the internal side of the rain screen above dew point.

Roofs

In the NBC the requirements for roofs are divided between *Part 9.19 - Roof Spaces*, and part *9.26 - Roofing*, focusing on structural issues such as fixings and load bearing. This separation provides a clear distinction between the different functions of the roof. In Part 9.19, all roof spaces are to be ventilated, unless an engineered solution is provided. There is no distinction made between roof types or cathedral ceilings.

9.19.1.1 - Required Venting

> *Except where it can be shown to be unnecessary, where insulation is installed between a ceiling and the underside of the roof sheathing, **a space shall be provided between***

the insulation and the sheathing, and vents shall be installed to permit the transfer of moisture from the space to the exterior*.*

9.19.1.2. - Roof Space Vent Requirements

- Roofs with greater than 1:6 pitch should have a total net unobstructed vented area of 1/300 of ceiling.
- Roofs with less than 1:6 pitch should have a total net unobstructed vented area of 1/150 of ceiling.
- Venting should combine both continues ridge cap vents and soffit vents uniformly on opposite sides of the building with no more than 25% at the top or bottom of space.
- Except where each joist space is separately vented, roof joist spaces shall be interconnected by installing purlins not less than 38 mm by 38 mm on the top of the roof joists.

Where insulation is exposed to the weather and subject to mechanical damage, it shall be protected (9.25.2.3 (6). The NBC provides a number of acceptable materials. These essentially describes baffles to prevent wicking and weather driven degradation of ceiling insulation.

Air Movement

Section 9.25. Heat Transfer, Air Leakage and Condensation Control

The Scope of this section is:

This Section is concerned with heat, air and water vapour transfer and measures to control condensation. All walls, ceilings and floors separating conditioned space from unconditioned space, the exterior air or the ground shall be provided with

- *thermal insulation,*
- *an air barrier and*
- *a vapour barrier*

The scope makes the clear link between heat, air and water vapour and condensation control. A change in the management of one requires the consideration of the other factors. Furthermore, the building fabric (Floor, walls and ceiling) will clearly separate 'conditioned' and 'unconditioned' spaces with the key elements of air-barrier, thermal envelope and vapour control layer. This section also reiterates the importance of condensation mitigation in the NBC by requiring in Section 9.25.2.1:

All walls, ceilings and floors separating heated space from unheated space, the exterior air or the exterior soil shall be provided with sufficient thermal insulation to ***prevent moisture condensation on their room side during the winter*** *and to ensure comfortable conditions for the occupants.*

Condensation is given equal consideration to thermal comfort.

Thermal Performance

Section 9.25.2.1 sets out the minimum requirements for insulation for the building:

> *All walls, ceilings and floors separating heated space from unheated space, the exterior air or the exterior soil shall be provided with sufficient thermal insulation to prevent moisture condensation on their room side during the winter and to ensure comfortable conditions for the occupants*.

Part 9.36.2.9 Air-tightness, prescribes that leakage of air into and out of conditioned spaces shall be controlled by a continues Air Barrier. The building assembly will have an air leakage rate not greater than 0.20 L/(s·m2) when tested at either 75Pa or 65Pa, depending on wind classification.

The NBC prescribes in, *Part 9.36.5.4* the Calculation Method for determining the energy efficiency of residential buildings. This sets out climate data, expected internal temperatures, assembly orientation, proportion of fenestration, etc. *Part 9.36.5.10(9) - Modeling Building Envelope of Proposed House*, assumes an **Air Change Rate (ACR) of 3.2 ACR50 to 2.5 ACR50,** depending on the air-barrier system used. In accordance with *CAN/CGSB-149.10-M, Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method*

Air Barriers

This is a substantial and detailed section of the NBC. Section 9.25.3.1 - Required Barrier to Air Leakage

> Wall, ceiling and floor assemblies separating conditioned space from unconditioned space or from the ground shall be constructed so as to include an air barrier system that will provide a continuous barrier to air leakage
>
> a) from the interior of the building into wall, floor,attic or roof spaces, sufficient to prevent excessive moisture condensation in such spaces during the winter, and
>
> b) from the exterior or the ground inward sufficient to
>
> i) prevent moisture condensation on the room side during winter
>
> ii) ensure comfortable conditions for the occupants, and
>
> iii) minimize the ingress of soil gas

The NBC does not prescribe any particular material properties to make up the air barrier. However, Part 9.25.3.3 sets out in segnificant detail the requierments to ensure continuity of the air barrier, which includes:

- For rigid materials - All joint to be sealed
- For flexible materials - Sealed, lapped (100mm) and supported
- Penetrations (doors, windows, electrical wiring, electrical boxes, piping or ductwork) shall be sealed to maintain the integrity of the air barrier system over the entire surface.

Vapour Control

The NBC prescribes the use of a Vapour Control Layer (VCL) that is continuous and manages vapour diffusion through the built fabric and interstitial spaces. Additionally, the VCL shall protect the warm side of wall, ceiling and floor assemblies. Specifically, Part 9.25.4.1 states:

> *Thermally insulated wall, ceiling and floor assemblies shall be constructed with a vapour barrier so as to provide a barrier to diffusion of water vapour from the interior into wall spaces, floor spaces or attic or roof spaces.*

It should be noted that in many of these regulations, a vapour barrier is not necessarily vapour impermeable but has a permeability rating. The NBC in part 9.25.4.2 perscribes that a **VCL will have a permeance not greater than 60 ng/(Pa·s·m2)**. This Part also describes the materials that can be used as a vapour control layer and the relevant standards that products must comply with to be considered a VCL. For example, where a coating is applied to gypsum board to function as the vapour barrier, the permeance of the coating shall be determined in accordance with CAN/CGSB-1.501-M - *Method for Permeance of Coated Wallboard*.

Steady State Application of VCL

The NBC allows materials to be used in assemblies if they have minimum properties of:

- an air leakage characteristic less than 0.1 L/(s·m2) at 75 Pa
- a water vapour permeance less than 60 ng/(Pa·s·m2)

Materials that meet this requirement can then be used in a steady state assessment of condensation risk. They must be placed:

> *at a location where the ratio between the total thermal resistance of all materials outboard of its innermost impermeable surface and the total thermal resistance of all materials inboard of that surface is not less than that required by Table 9.25.5.2., and outboard of an air space that is vented to the outdoors. (Part 9.25.5.2)*

Table 9.25.5.2 - Ratio of Outboard to Inboard Thermal Resistance perscribes the number of Heating Degree days and the Ratio of Total Thermal Resistance Outboard of Material's Inner Surface to Total Thermal Resistance Inboard of Material's Inner Surface.

The objective is to provide a simple means of determining the differential in thermal resistance between the internal and external side of an assembly depending on climate zone. Warm climates zones need to maintain a higher differential. This is to prevent dew point being reached within the wall assembly.

Ventilation (Section 9.32)

The NCC separates out ventilation into:

- Non-heating natural ventilation
- Non-heating mechanical ventilation
- Heating Season Mechanical Ventilation

The Non-heating natural ventilation rate requires an unobstructed openable ventilation area to the outdoors of 0.09m2 total floor area for bathrooms and 0.28m2 total floor area for all other occupied spaces (living rooms, bedrooms). Non-heating mechanical ventilation relates to mechanical cooling. It must have the capacity to exhaust air from inside the room or space, or to introduce outdoor air into that room or space, at a rate of 10L/s in master bedrooms and kitchens, and 5L/s for all other occupied rooms.

The NBC provides a number of minimum requirements for heating mechanical systems, but specific detail is referenced to CAN/CSA-F326-M, "Residential Mechanical Ventilation Systems, and ASHRAE and HRAI handbooks and Standards. The System must be able to provide ventilation of outdoor air and also have an exhaust capacity, that is, capable of between 18-25L/s and 30-45L/s depending on the number of bedrooms. (9.32.3.3).

Venting of Laundry-Drying Equipment - Exhaust ducts or vents connected to laundry-drying equipment shall discharge directly to the outdoors (9.32.1.3).

Like other codes with significant cool climate zone conditions, Section 9.32 provides significant prescriptive detail on a range of different mechanical heating system requirements, including: forced air heating system flow rate (9.32.3.4), exhaust only venting (9.32.3.6), protection against depressurization (9.32.3.8), and ducts (9.32.3.11)

Section 9.33 - Heating and Air Conditioning of the NBC refers to heating systems that are to be used on a continuous basis throughout winter months.

Part *9.33.3.1. Indoor Design Temperatures* require heating facilities to be capable of maintaining an indoor air temperature of not less than

- 22°C in all living spaces
- 18°C in unfinished basements, common service rooms and ancillary spaces
- 15°C in heated crawl spaces

In a similar nature to the U.S. IBC, significant detail is provided in the NBC on the installation and maintenance of air conditioning systems. Including protection against contaminants, ducts, dampers, outlets, inlets, and noise levels.

Compliance

NBC Part 9.36.5.10(10) allows for the 'design' air tightness calculations to be assigned for use in the energy model calculations until the actual air tightness has been measured. On completion of a building, a pressurisation test at 50Pa is performed, in accordance with *CAN/CGSB-149.10-M, Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method.* The results of this test are used to adjust the buildings energy efficiency calculations. It is this final calculation that determines the buildings 'as-built' energy performance rating.

Implementation

Because the NBC is only model guide, to be adopted by provinces, at a national level the focus of most documentation is on best practice minimum requirement. The application of this is then integrated into best Practice Guides developed by each province. These focus on the particular climatic conditions of the province and regionally appropriate building systems. As a result there is no single set of best practice 'deem to satisfy' construction details for the control of condensation. However, there are a number of very good regional guides.

The *Canadian Wood-Framed House Construction Guide* developed by Canada's national housing agency, Canada Mortgage and Housing Corporation, is considered to be a concise reference for compliance with the NBC for timber framed construction. The Guide reflects 'typical' construction techniques compliant with the NBC. Additionally, some aspects of the guide exceed then NBC's minimum standards. The guide details how to detail construction of floor wall and roof systems to comply with the NBC. This includes details of where air barriers should be in a roof assembly, how air diffusion is minimised and air leakage reduced. Construction details are also provided. Due to the diversity of Canadian climate zones, usually three construction options are given. Examples of details that are relevant to the report are:

- Brick veneer cladding with insulation in the framing space and outboard (page 54)
- Eave details to avoid blocking ventilation (page 52)

Similarly, the Canadian Home Builders' Association '*Builders' Manual'* provides a comprehensive guide to building residential homes that comply with and exceed the requirements of the NBC. The Manual provides advice on compliance and standard details on: Indoor Air Quality, Air, Weather, Moisture, Thermal, Vapour Management, Termite

Barriers, Air Barrier System Construction, Ventilation Systems and Mechanical Systems. The Manual which has been published since 1941, is so well regarded it is referenced on a number of government and industry websites as the referenced guide for meeting and exceeding detailing and construction systems compliance.

Social Drivers

The EnerGuide Rating System is a national initiative through which builders work with energy advisors to choose energy efficiency upgrades to their house plans before the house is built. The system enables builders and new home buyers to compare and evaluate upgrades that they may wish to include in their new homes. As part of the EnerGuide Rating Service, the building pressurisation test is performed after the house has been built, so that the 'as-built' results of the test are incorporated into the house performance rating.

The rating system is implemented under the *EnerGuide for New Houses: Administrative and Technical Procedures*[7]. The procedures do not specifically reference condensation issues or mitigation. However, required built fabric ventilation is referenced in the context of achieving the broader objective of IAQ. However, EnerGuide references the moisture and vapour management procedures within the Canadian Home Builders' Association *Builders' Manual.*

Summary - Canada

Definition

The Objectives and the Functional Statements in the NBC make a clear link between prevention of illness of occupants and the management of indoor conditions, including vapour, moisture and mould. The regulation stresses that the built fabric elements must perform the function of limiting moisture and condensation.

Structure

Floors

Minimum sub-floor ventilation requirements and lining sub-floor surfaces

Walls

Defines two plans of weather protection, each have prescribed functions. Requirements for a sheathing layer on the second plane. Insulation needs to be installed to maintain the temperature and the relative humidity of the internal side of the second plane above dew point. Steady State Modeling used.

Roof

Separated between 'structure' and 'roof space'. ALL roof spaces are to be ventilated. The Ratio of vents to roof area is prescribed based on roof pitch (between 1/150 to 1/300). Roof Baffles are to be used to protect edge of insulation and guarantee roof space supply ventilation.

Internal Environment

Depending on zone function, maintaining an indoor air temperature of not less than 15°C or 22°C.

Air Movement

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[7] Natural Resources Canada. Office of Energy Efficiency. (2005). *EnerGuide for New Houses: Administrative and Technical Procedures*. Canada: Natural Resources Canada.

Significant requirements on *measures to control condensation.* Achieved by clearly defining conditioned and un-conditioned spaces. The role and function of thermal insulation, air barriers and vapour control.

Based on prescribed performance characteristics of materials and climate, Steady State Modeling is used to ensure condensation does not occur on the warm side of any building assembly.

Ventilation is comprehensively addressed and significant detail given on the installation of mechanical systems.

Natural ventilation rates are prescribed by ratio to floor area of room, between 0.09m2 and 0.28m2 .

Mechanical ventilation must provide between 10L/s and 5L/s and an exhaust capacity of 18-25L/s and 30-45L/s

Implementation

NBC is a model code and there is significant difference in building practice across regions and climate zones. Two key guides to builders are: Canadian Wood-Framed House Construction Guide and Canadian Home Builders' Association Builders' Manual

Compliance Testing

Mandatory Blower Door Test on completion of build. In accordance with CAN/CGSB-149.10-M, Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method

Social Drivers

The EnerGuide Rating System

England - Building Regulations 2010

Construction of any building in the United Kingdom is controlled by the Building Act 1984. The Act invokes the Building Regulations 2010, which apply to residential buildings. These are national regulations with sub-variants for Scotland, Wales and Ireland.

This report focusses on the Building Regulations as they relate to England. These are periodically updated, rewritten and consolidated. The latest and most current version being the Building Regulations 2010 (the Regulations).

The Regulations are divided into 14 sections. The Regulations contain definitions, procedures, and what is expected in terms of the technical performance of building work. Each Section sets out the 'requirements' with which the individual aspects of building design and construction must comply in the interests of the health and safety of building users, of energy conservation, and of access to and use of buildings.

The broad issues associated with condensation are addressed in three parts of Schedule 1 of the Regulations, namely:

- Part C - Site preparations and resistance to contaminants and moisture.
- Part F1 - Means of Ventilation
- Part L1A 2013 – Conservation of fuel and power in new dwellings

Table 2, below provides a summary of these regulations regarding condensation and amendments over time.

Structure

All three Parts set out prescriptive measures and minimum requirements for compliance. Sitting under each Part of the Schedule is an 'Approved Document". These are intended to provide guidance for some of the more common building situations. However, it is recognised that there may be alternative ways of achieving compliance. To allow for a performance based approach other methods can be used, as long as the solution meets the requirements contained within a 'Part' or the Regulations. The Approved Documents reference a comprehensive range of British Standards and guide documents. It is within these documents that the mechanism for achieving compliance is detailed. Of relevance here are documents such as:

- *BS 5250:2002 Code of Practice for the Control of Condensation in Building*s
- *BS EN ISO 13788:2002 Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation. Calculation methods*
- *BRE Report BR 262 Thermal insulation: avoiding risks, 2002*

Minimize the Occurrence of Condensation in Dwellings

Part C: Site Preparations and Resistance to Contaminants and Moisture

Part C of Schedule 1 of the Regulations addresses the issue of condensation specifically in section C2 – Resistance to Moisture:

The walls, floors and roof of the building shall adequately protect the building and people who use the building from harmful effects caused by–

(a) ground moisture;

> *(b) precipitation including wind-driven spray;*
>
> *(c) **interstitial and surface condensation**; and*
>
> *(d) spillage of water from or associated with sanitary fittings or fixed appliances.*

This definition was first used in the 2004 revision of the Regulations. It is a significant progression from the original in the 2000 Regulations which simply stated:

> *The walls, floors and roof of the building shall adequately resist the passage of moisture to the inside of the building.*

Approved Document for Part C - Site Preparations and Resistance to Contaminants and Moisture

In the introduction of the Approved Document it is noted that:

> *Regulations do not require anything to be done except for the purpose of securing reasonable standards of health and safety for persons in or about buildings; and*
>
> *The requirements in Part C address health and safety, and do not seek to protect the building fabric for its own sake.*

Therefore the primary function of Part C is protect human health from condensation, protection of the built fabric is of a lower order concern.

The Approved Document provides guidance and details on the following since 2004:

- Floors exposed from below (resistance to damage from interstitial condensation)
- Floors (resistance to surface condensation and mould growth)
- External walls (resistance to damage from interstitial condensation)
- External walls (resistance to surface condensation and mould growth)
- Roofs (resistance to damage from interstitial condensation)
- Roofs (resistance to surface condensation and mould growth)

For each of the points above, The Approved Document, provides minimum standard and basic information on how to achieve the standard. As an example and with regard to resistance to surface condensation and mould growth for Floors, Walls and Roofs, they need to be:

> *designed and constructed so that the thermal transmittance (U-value) does not exceed 0.7W/m2K at any point.*

To resistance damage from interstitial condensation in floors, the Approved Document provides some examples of construction details, but these are primarily focused on ground moisture control. However, the approved document guides designers and builders to the referenced British Standards, such that:

> *A Floor will meet the requirement if it is designed and constructed in accordance with Clause 8.5 and Appendix D of BS 5250:200296, BS EN ISO 13788:200297 and BR 262.* The *BS5250 2011 – Code of Practice for the Control of Condensation in Buildings* (Code of Practise)

For walls the Approved Document provides some construction detail for walls. However, these are generic in nature with no substantial information provided other that listing the basic elements, (i.e., brick veneer wall construction). Rather, like the floor example above guidance is provided to use the appropriate British Standards, Part C 5.34 states that:

> *A wall will meet the requirement if it is designed and constructed in accordance with Clause 8.3 of BS 5250:2002129, and BS EN ISO 13788:2002, the junctions between elements and details of openings, such as doors and windows, are designed to Accredited Construction Details 99, or follow the guidance of BRE IP17/01132)*

For roof, no general detailing diagrams are provided for roof construction. However, once again, under Section 6.10 guidance is provided the use the appropriate British Standards:

> *A roof will meet the requirement if it is designed and constructed in accordance with Clause 8.4 of BS 5250:2011 and BS EN ISO 13788:2002142. Further guidance is given in the BRE Report BR 2621*

Under Section 6.11 the requirement can be met by the ventilation of cold deck roofs, (i.e., those roofs where the moisture from the building can permeate the insulation). However, no specification is given to the type of ventilation required.

Part 6.12 states:

> *To avoid excessive transfer to roof voids gaps and penetrations for pipes and electrical wiring should be filled and sealed, this is particularly important in areas of high humidity, e.g. bathrooms and kitchens*.

Reference is also made to BRE Guide *262 Thermal insulation: avoiding risks (2002)*. The Guide provides recommendations from BRE on good design and construction practice associated with thermal standards, the technical risks associated with meeting the requirements of the building regulations for thermal insulation, this includes condensation and ventilation.

Part F - Ventilation

Part F2, in the Building Regulations 2000 condensation was explicitly addressed through the requirement that:

> *Adequate provision shall be made to prevent excessive condensation—*
>
> *(a) in a roof; or*
>
> *(b) in a roof void above an insulated ceiling.*

However in the Building Regulations 2010 this was substantially re-written. All reference to condensation was removed and the focus of Part F2 was on mechanical systems of ventilation, as shown in **Error! Reference source not found.**.

This changed occurred because ventilation, as it relates to condensation mitigation has now been substantially addressed within *BS5250 2011 – Code of Practice for the Control of Condensation in Buildings*.

Approved Document for Part F - Ventilation

The Approved Document F (ADF) notes that one of the functions of ventilation is:

> *. . .control of excess humidity (arising from water vapour in the indoor air.*

The ADF makes a distinction between a*ir-infiltration*, being and uncontrollable air exchange between the inside and outside and *Ventilation* being a controllable air exchange between the inside and outside (Page 6). The ADF recommends methods of achieving sufficient purpose-provided ventilation, allowing for a reasonably high level of air tightness. In fact, the document assumes an air permeability down to around 3–4m3/h per square metre (page 7). The ADF identifies three forms of ventilation:

- Extract ventilation
- Whole building ventilation
- Purge ventilation

All three are recommended for the effective removal of internal water vapour. The ADF does not recommend natural or mechanical solutions. Rather that the ventilation be controllable

> . .*so that it can maintain reasonable indoor air quality and avoid waste of energy* (page 7)

Furthermore, the ADF recommends:

> *humidity controlled devices to regulate the humidity of the indoor air and, hence, minimise the risk of condensation and mould growth. These are best installed as part of an extract ventilator in moisture-generating rooms (e.g. kitchen or bathroom).*

The AFD prescribes minimum ventilation rates. However, these are dependent on the ventilation system used, the type of room and its use. With regard to internal vapour control the two key ventilation rate, from table 1.1a and 1.1b of the ADF, are:

> Extract ventilation rates – which for example in a bathroom is 15 l/s; and
>
> Whole building ventilation rates – which for a standard 3 bedroom house would be 21 l/s

Implementation

BS5250 2011 – Code of Practice for the Control of Condensation in Buildings

This British Standard, as a Code of Practice provides a comprehensive guide to the control of condensation. It provides information on:

> the risks associated with excessive humidity in buildings, notably mould growth and condensation, which can endanger the health and well-being of building occupants and the integrity of the building fabric.

The standard describes the principal sources of water vapour, its transportation and deposition. It provides guidance on how to manage those risks during the design, construction and operation of buildings. Additionally, the standard does not provide guidance on how to avoid penetration of the building envelope by water, such as rain, as this is contained in other British Standards. This purposeful separation makes a clear distinction between moisture types affecting buildings with the focus in this standard being condensation.

The Code of Practice is not a regulatory document in itself. But, it provides a set of construction details that address condensation in a more detailed way than the *Accredited Construction Details*. As a result, a construction will meet the requirements of the *Building Code* if designed and constructed in accordance with the Code of Practice.

The Standard notes:

- That mould growth and condensation affect about 15% of homes in England to some degree.
- The requirement for more efficient use of energy in the operation and use of buildings has led to increased levels of thermal insulation and airtightness in both new and refurbished buildings; this has led to an increased risk of damage from condensation.
- The occurrence of condensation is governed by complex interrelationships of factors
- Designers and builders need to integrate a range of principles to resolve condensation risk
- Buildings are often not used as intended by occupants and so a designers and builders need to err on the side of caution and adopt robust fail-safe built fabric solutions.

The Standard also notes; elements of building construction should meet their functional requirements, which include the avoidance of damaging surface and interstitial condensation (Page 8). The Code of Practice then provides an overview of the key issues to consider in the design and construction process, namely:

- Arrangement of materials – materials with the highest vapour resistance should be place on the warm side, and those with low vapour resistance on the cool side of thermal insulation.
- Minimising thermal bridging
- Air tightness layer on the warm side of the envelope
- The physical characteristics of any insulations used be carefully assessed to avoid interstitial condensation
- Care and caution should be given to the use and placement of low emissivity materials
- Air and Vapour Control layers (AVCL) – the plan on which they will most effectively operate must be determined. The AVCL should be continuous.

In Annex F - *Application of Design Principles*, of the Standard provides a comprehensive set of construction details for a number of construction systems.

Annex K - *Occupied Space Ventilation,* of the Standard mirrors many of the statements in the ADF. For example, buildings are being constructed to be more airtight to limit heat loss. But this will require more consideration be given to the ventilation system to ensure that any build-up of condensation is reduced to a minimum. A balance needs to be established between minimising heat loss and health risks from adequate ventilation.

Additionally, the Standard does not recommend a particular ventilation solution, nor does it recommend passive or mechanical ventilations systems unilaterally. Rather, the ventilation system should respond to the specific needs and requirements of the building and users and the whole life cost of the ventilations system. The Standard then provides an overview of the basic ventilation options, their negative and positive attributes, and principles on how they can be applied in design and construction to minimise condensation risk. Methods suggested include:

- Background ventilation
- Natural Ventilation
- Mechanical ventilation

- Heat pumps

Part L – Conservation of Fuel and Power (energy efficiency)

In the UK there has been a national aim to improve the energy efficiency in homes for more than ten years. **Error! Reference source not found.** below, shows the significant changes in Part L since 2000. The language has become more sophisticated in its description, recognising, for example, heat gain and loss during summer and winter months. Additionally, the language has become broader in its definitions. These simplifications were not the result of a watering down, but rather an attempt to encapsulate a wider range of functions and activities under Part L of the Regulations. For example, part L1 (a) (ii) *have effective controls*, this covers control of all devices in the home, like lighting, ventilation, heating and cooling.

Approved Document L1a - Conservation of fuel and power in new dwellings ADL1a, notes that:

> *. . . many condensation problems arise because the majority of buildings are not used 24 hours a day for every day of the year and so are not heated continually. . . . the duration and amount of heating should be regulated to maintain the surface temperature above dewpoint. . . ignoring the comfort of occupants, the aim should be to maintain an air temperature above 10deg C in all parts of the building that are heated.*

This statement is mirrored in BS5250.

Approved Document L1a in Criterion 1 established the requirement to achieve the regulatory TER and TFEE in new dwellings. These requirements are defined as:

- Target CO2 Emission Rate (TER), - the mass of CO2 emitted in kilograms per square metre of floor area per year, and
- Target Fabric Energy Efficiency (TFEE) rate - the amount of energy demand in units of kilowatt-hours per square metre of floor area per year

There is a considerable compliance regime around archiving these two performance requirements both before, during the design stage, and after construction. Compliance testing is undertaken to demonstrate that the building, as constructed, meets the TER and TFEE rate as required. However, compliance with these two criteria must be met hand-in-hand with the vapour pressure management, moisture, condensation and mould mitigation requirements of Parts C, F & L. As a result, to achieve the TER and TFEE a building may need to have higher performance element within its floor, wall and roof assembly. If this does occur, this must be a considered impact risk on the condensation profile of that building's design and construction.

Section 5 of Approved Document ADL1a provides a summary table of the minimum performance criteria for building elements such as walls and floor, fenestration and airtightness. These are called the '*concurrent notional building specification'.* It is noted that the concurrent notional building specifications are not prescriptive and may not be the most economic specification in every case. Therefore, Designers are free to explore the most economic specification, provided that this specification meets all other provisions within this approved document.

Air Permeability and Pressure Testing and Vapour Control Layer (VCL)

Page 20 of ADL1a describes matters pertaining to air permeability and the Vapour Control layer (VCL). An air permeability of 10m3/hm2 at 50 Pa id prescribed for a domestic dwelling. Best practice is also recommended as 5m3/m2h at 50 Pa. Section L1 requires the performance of the building fabric and services to be verified through appropriate site inspection procedures, testing and commissioning. ADL1a does not provide any construction details or information as to how this air permeability is to be achieved. Rather ADL1a refers to the:

- *Accredited Construction Details*, and
- *BS5250 2011 Code of Practice*

The *Accredited Construction Details*, cited by ADL1a are a set of standard details, similar in nature to Deemed To Satisfy construction guidelines, which if followed avoid the need for costly compliance testing. The *Accredited Construction Details* focus on building air tightness and thermal bridging. They prescribe a level of air tightness to the building fabric. However, it is recognised in this document that details that improve the airtightness of a building will impact on the management of internal moisture and condensation. The *Accredited Construction Details* focus on thermal performance, show but do not provided extensive detail on issues of condensation. Rather, like the Part C above, they refer to *BS 5250 2011 Code of Practice for the control of condensation*. Additionally, the evolution of this Standard shows a deeper understanding of thermal bridging, its capacity to support moisture and mould, and measure taken to reduce thermal bridging in floors, walls and roof spaces.

BS5250 provides considerable detail on where and how a VCL should be used in a variety of standard construction systems (pages 38 to 77). Each provides information on how and the proposed design detail mitigates the risk of condensation. The most significant change in the Standard from 2002 to the current 2011 version, is the detailed description given to the Vapour Control Layer (VCL). The 2002 the Standard did not prescribe what material the VCL should be made of or specify a perm rating. It only noted that the VLC should, as an approximation, have a vapour resistance of at least five times the sum of the vapour control layer on the cool external side of the wall assemble (Page 15). This demonstrates a significant learning process that has been applied within the updated Standard. Additionally, Annex E of the 2011 version of the Standard defines properties of materials, namely:

- The vapour resistance of standard building material
- The vapour resistance of thin membranes and foils (page 34)
- Thermal resistance of cavities
- Vapour properties of cavities
- Factors for the conversion of vapour permeability and vapour permeance (page 37)

This last dot point is key, as it provides a clear definition of *vapour resistance* and *vapour permeability* and the difference between both. This is significant because it is this standardisation of terminology that is then used both in construction details (including the Accredited Construction Details) and the terminology within Parts c, F and L of the Building Regulations and all Approved Documents.

Social Drivers

The Home Quality Mark (HQM) is the latest home energy rating system developed by the BRE Group, an independent research-based advisory, testing and training organisation, who are also the developers of the BREEAM measure of sustainability of buildings. HQM is a national standard for new homes, which uses a 5-star rating to provide information from on a new home's design, construction quality and running costs. The criteria for rating a new residential home are broad. They consider all aspects of energy and running cost, but also access to transport, water use, access to outdoor amenities, and ethical sourcing of construction materials. Additionally, the HQM rating of the buildings also focuses on the occupant's health and wellbeing, namely:

> *as buildings become more airtight, respiratory conditions rise . . . if air quality is not managed appropriately this can impact your health*

In the HQM Technical Manual *Part 14 – Ventilation* (Page 81) the Aim is:

> *To encourage specification of adequate and appropriate ventilation systems, and provision of any associated operational support to reduce the risk of pollutant and moisture build up indoors that can negatively impact occupant health*

The HQM requires ventilation to be: *sufficient to avoid issues of poor air quality, stuffiness and high pollutant levels including VOCs and mould spores.* This is an example of a how the issue of condensation and mould has moved out of the regulatory environment. It is no longer just a minimum standard, but now included in a broader understanding around issues of air quality and human health in the built environment. The expectation that a building's internal environment is managed to provide human comfort has been expanded in the HQM to encompass a broader range of Quality of life, environmental and cost of living criteria. Internal Air Quality and the required management of internal moisture issues are now taken as a given in the design and construction of a good home.

Successes and failures in the U.K. model

Parts C, F and L have been periodically amended since 2000. For Example in 2010 Part F simplified the definition of ventilation. But this broader definition in the regulations represented a migration of the specifics and details out ***of*** the Building Regulations and into Approved Document F.

Part C places human health over protection of building fabric. Additionally Part C has addressed issues of condensation affecting floors, walls and roofs in 2004, twelve years ago.

The Approved Documents are not binding, they simply specify an approved method of compliance. Therefore there is a significant scope for innovation and the use of methods that may achieve, or even exceed the regulations in a cost effective or more sustainable way.

New Zealand - New Zealand Building Code (NZBC)

All building work in New Zealand is mandated under *The Building Act 2004*. A key purpose of the Act is: *to ensure that people can use buildings safely without endangering their health*. This principle is further described in the Act as:

> *harmful effects on human health resulting from the use of building methods, products, design or building work need to be prevented or minimised*.

Under the Act sits the *Building Regulations 1992* which also address issues such as earthquakes, building fees, levies and authorities. Schedule 1 of the Building Regulation contains the *New Zealand Building Code* (NZBC). This contains the compulsory rules for building work.

The NZBC provides three methods for compliance:

Objective

This is divided into the Acceptable Solutions and Verification Methods. The Acceptable Solutions are simple step-by-step instructions that show one way to comply with the Building Code. Whilst the Verification Methods are tests or calculation methods that prescribe one way to comply with the Building Code. These methods provide details for construction that, if followed, result in compliance with the Building Code. There is at least one Acceptable Solution or Verification Method for compliance with each of the Building Code clauses.

Functional Requirements

Functional Requirements allow works to comply if it can be demonstrated that a product or system meets the nominated Performance Requirements of the Building Code, or it complies with a prescribed legislation or National Standards, or is resolved via the determination method. Each of these paths are deemed to meet the performance requirements of the Building Code that they cover.

Alternative Solutions

Alternative Solutions are building solutions that differ, in part or wholly, from the solutions offered by the descriptive solutions mentioned above. These built fabric solutions achieve compliance with the performance requirements of the Building Code to the satisfaction of the building consent authority.

Similar to Australia, the NZBC sets functional and performance based requirements and provides both an 'Acceptable Solutions' and 'Verification Method' as means of achieving the requirements of the code.

The NZBC is divided into 8 Clauses, A through to H. Each clause addresses a specific aspect of the Building Regulations, such as Stability, Access, Safety and Energy Efficiency. Each Clause of the NZBC is supported by Technical Guides that outline in detail the Acceptable Solutions and Verification Methods. It is in these Technical Guides that the detail on *how* to achieve the performance requirements of the NZBC are outlined in detail. The Technical Guides reference National Standards, Best Practice Guides and other Clauses within the NZBC. In the context of this research, the relevant clause is Clause E. Clause E addresses the issue of moisture. It is divided into three sub clauses:

- E1 – Surface moisture
- E2 – External Moisture
- E3 – Internal Moisture

The Objective of Clause E3 Internal Moisture is to:

> *(a) Safeguard people against illness, injury, or loss of amenity that could result from accumulation of internal moisture; and*
>
> *(b) Protect household units and other property from damage caused by free water from another household unit in the same building.*

As a result, under Section E3.2 all buildings must be constructed to avoid the likelihood of—

> *(a) Fungal growth or the accumulation of contaminants on linings and other building elements; and*
>
> *(b) Free water overflow penetrating to an adjoining household unit; and*
>
> *(c) Damage to building elements caused by the presence of moisture.*

The Performance Requirement (3.3.1) States that:

> *An adequate combination of thermal resistance, ventilation, and space temperature must be provided to all habitable spaces, bathrooms, laundries, and other spaces where moisture may be generated or may accumulate.*

Technical Guide: *Acceptable Solutions and Verification Methods for E3 – Internal Moisture*

The Technical Guide for Clause E3 establishes the minimum requirements for building construction to comply with NZBC. The very first statement to be made in the Acceptable Solution E3 1.0.1 is:

> Fungal growth (mildew) is avoided by minimising internal condensation. Condensation is avoided or reduced by maintaining the correct balance between interior temperature and ventilation. Insulation assists in maintaining interior temperatures at a suitable level (Page 13)

The New Zealand Building Code does not specify minimum heating requirements for residential buildings. However, the Technical Guide notes:

> *it is necessary and sufficient, for condensation control in winter, to keep interior temperatures 5°C to 7°C above exterior temperatures in a ventilated space. (Page 13)*

The Technical Guide specifies minimum R-values for the thermal resistance to prevent significant temperature differentials between room temperature and wall cavity temperature. For example:

> 1.1.1 a - For light timber frame wall or other framed wall constructions with cavities, 1.5 (R-value). (Page 13)

BRANZ who provide quite a lot of depth and breadth in building science knowledge in New Zealand have many publications to assist designers and builders. The BRANZ House Insulation Guide provides examples of acceptable wall, roof and ceiling constructions to satisfy the heating requirements specified above.

Other Minimum requirements within the Technical Guide are:

- *Building paper shall extend from the upper side of the top plate to the underside of the bearers or wall plates supporting the ground floor joists.*

- *There shall be no perimeter gaps between the insulating material and the framing members.*
- *Where steel studs are used, a thermal break shall be provided for each steel member.*
- *If foil insulation is used it must be placed on the lining side of studs, not the cladding side.*

It is noted that, frame construction with 10 mm plaster board linings and a single layer of foil has an R-value of approximately 0.9 and does not satisfy the requirements of part 1.1.1. The Technical Guide also notes that *Insulation satisfying the energy efficiency requirements of NZBC H1 cannot automatically be assumed to meet the R-values for internal moisture requirements* (page 13).

This is because, Insulation for energy efficiency relates to the building as a whole. It is possible, for example, to obtain sufficient energy efficiency in a building by heavily insulating the floor and ceiling with no insulation in the walls. This would not satisfy the requirement for this acceptable solution because there would not be sufficient thermal resistance in the walls to minimise condensation.

Other changes that have occurred within the NZBC include terminology. Building Paper, referred to above, has been superseded by the new term *Wall Underlay*. Wall Underlay is defined in the *New Zealand Building Code Handbook* (page 148g) and is used to describe the range of materials that can be used to provide an air barrier and a vapour control layer. The Wall Underlay must have a vapour resistance of 7 MN s/g or less. This is a 'Low' vapour barrier under AS/NZS 4200.1. or more commonly referred to as a breathable membrane. However, the use of terminology from AS/NZS starts to create confusion. The material is expected to be an Air barrier and be Vapour Control Layer with a rated vapour permeance. This is not Breathable.

Part 1.2- Ventilation - notes that: *Ventilation shall be provided naturally or mechanically*, but it refers to the acceptable solutions for Ventilation in Clause G.

Condensation is further referenced in Part 1.3 of the Technical Guide. However, in this section the focus is on the construction of aluminium windows, requiring them to have condensation disposal via collections channels. It is noted that condensation can be reduced by 'good ventilation', but this refers to the use of passive perimeter vents in the window system.

A note of caution is that the majority of the Technical Guide for Internal Moisture addresses issues of internal liquid moisture resulting from water over flow and water splash (parts 2.0 and 3.0). This is not vapour control and condensation mitigation. However, it is recognised in the Acceptable Solutions documents for E2, that the type of roof construction system used will impact on moisture control on the internal side of the assembly, (condensation on the inside face of roof sarking).

Section E3 makes no distinction between floors, walls and roofs, indicating that the provisions apply equally to all three built fabric systems.

No specific reference to condensation is made in the *Acceptable Solutions documents* for E2. However, the New Zealand Government encouraged industry groups to develop compliance guides for their own industry. These are not part of the *Acceptable Solutions* documents that sit under the NZBC but they do provide construction detailing that, if followed complies with the provisions of the NZBC.

The *New Zealand Metal Roof and Wall Cladding Code of Practice* is a code developed by the New Zealand Metal Roofing Manufacturers INC. It provides detailing for best practice design and workmanship for roofs, over and above that required to be deemed to comply with the NZBC. The *Metal Roof and Wall Cladding Code of Practice* provides:

equal prominence to the importance of condensation and the interaction of underlays, insulation and ventilation as to that of the external weathering of metal roof and wall cladding.

It further notes that although the primary purpose of a roof cladding is to act as a rain screen, it is equally important to ensure that the building is kept dry from within (p104). The Code of Practice of Metal roofs and wall Claddings stipulates the following:

- Cool roofs with metal cladding must have a 20mm air gap between the cladding and the control layer (vapour barrier)
- Vapour barrier must have a vapour transmission resistivness of at least 500MNs/g
- Permeable underlays must have a permeability of 36g/m2/day or vapour resistance of no more than 7MNs/g
- To prevent vapour condensing on its surface, the vapour barrier must be installed on the warm or inner side of the framing.

Additionally unconditioned roof spaces are required to have minimum ventilation rates, and are specified as:

- Roof spaces must have an 0.5 Air Change Rate per hour
- 1m2 net free ventilated area per 150m2 of ceiling area (ratio of 0.6%)
- Additional vents must be provided if roof pitch is less than 15deg
- Roofs of less than 10deg should increase this ratio

The Code makes the clear distinction between vapour barrier is an impermeable membrane that will prevent the passage of water vapour and should not be confused with permeable underlays described above. A vapour barrier that is not sealed is more correctly named a 'vapour check', The Code recommends that:

if positive measures are not made for the provision of ventilation (in a roof space), to minimise the passage of water vapour into the roof space in cold or humid climates, a vapour barrier should be placed immediately above the ceiling lining in areas that generate water vapour and beneath any insulating material incorporated in the roof space. (Page 117)

It is also noted that, the application of a gloss sealing paint to a sheet ceiling lining can only form an effective vapour check not vapour barrier.

The Code specifies the use of *Underlays* as the secondary rain screen protection under the roof sheeting. However, here Underlays, are prescribed to be a breathable or permeable membrane. A breathable membrane is further described as permitting:

….*vapour to flow from one side to the other which, enables the equalisation of vapour pressure across the underlay but resists the passage of water.*

The Code provides a number of standard details to illustrate the construction systems that meet the requirements of the NZBC.

Additionally, the Compliance Document 'Simple House' provides acceptable solutions for single storey, stand-alone household units that meet the definition for a 'simple house'. There are significant caveats on what constitutes a 'simple house', but in most cases, a standard family home could be constructed in accordance with the document, and it would comply with the NZBC and Clause E3. The Simple House provides extensive guidance and construction details for standard construction methods. However, it is difficult to determine where in the in the guide Clause E3 is specifically addressed.

European Union (EU)

The EU is made up of 28 member states and contains a significant range of climatic conditions and residential building practices. The EU does not have a single unified building code that addresses all aspect of building construction. Each member state Implements its own Building Code. There is significant diversity between each country's codes, reflecting different historical, social and climatic conditions. Codes can be National (Denmark), Model Codes (Germany) or integrate aspects of neighbouring countries codes (Belgium unifies aspects of its code with both France and Germany).

Eurocodes

The EU has established the *Eurocodes*. The Eurocodes include 10 standards, these being EN 1990 to EN 1999. They cover various subjects related to construction and apply to the design of buildings and other civil engineering works. For example, *Eurocode 5 - EN 1995* covers the use of all timber products. The Eurocodes are intended to provide uniform levels of safety in construction and are mandatory for all member states. However, the Eurocodes also included some 'model codes' that are not mandated.

Drivers of change in EU States Building Codes

The most significant issue driving change, in relation to the issue of condensation, in EU building codes, is the aim to reduce energy consumption of buildings. This is driven by two documents, namely:

- The *2010 Energy Performance of Buildings Directive* (2010 Directive), and
- The *2012 Energy Efficiency Directive* (2012 Directive)

The *2010 Energy Performance of Buildings Directive requires that* all new buildings must be nearly zero energy buildings by 2020; and EU countries must set minimum energy performance requirements for new buildings. Additionally, the 2010 Directive clearly states that minimum energy performance requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation.

Whilst the 2012 Energy Efficiency Directive requires member countries to develop and maintain National Energy Efficiency Action Plans (NEEAPs) that set out energy efficiency measures and the improvements individual EU countries expect to achieve.

Neither the 2010 Directive nor the 2012 Directive indicated *how* indoor climate conditions are to be taken into account, when reducing energy consumption. As a result, the issue of *indoor climate conditions* has been included in responses to the broader issue of IAQ. It has been recognised by member states and the EU collectively that the implementation of the 2010 and 2012 Directives would significantly alter the current building systems in use through member countries. These changes will have a potentially negative impact on IAQ.

As a result, particular responses to thermal performance, airtightness and ventilation would need to be made to mitigate the impacts of energy efficiency driven changes from the Directives. It is noted that these changes could be seen as an opportunity to improve the IAQ of EU residential building stock. (BPIE Report 2015).

The 2010 Directive allows each European country to develop its own methodology to determine a building's energy efficiency. For example, the DOCET method in Germany and the CALENER method in Italy. These methodologies apply certain metrics, such as primary energy consumption, final energy consumption, or CO2 emissions, with variations accounting for the type of building, climatic variables, passive solutions and minimum thermal requirements. This has resulted in all European countries having some form of minimum requirements for thermal comfort. These are most often expressed as a minimum and maximum indoor air temperatures.

However, there is no standard approach. A number of EU states have also introduce 'limits of overheating'. For example, Belgium mandates an indoor temperature no greater than 25deg C for a maximum of 5% of the year (BPIE Report 2015 Page 44). The EU recommends, but does not mandate a minimum and maximum indoor air temperature of 20deg C 26deg C respectively (EN15251).

Ventilation within buildings is addressed through EU member State regulations and standards. Ventilation at its simplest form is, the exchange of external 'fresh air' into a relevant internal space. However, ventilation rates and how they are measured differ across EU states. EN 15251 Annex B2, provides a default values to use, if no national regulation is available. A minimum ventilation rate per floor area between 0.05 to 0.1 l/(s·m2). EU States such as Germany require:

> *all new buildings are to be built airtight . . . in a manner that ensures appropriate air exchange for a healthy and warm indoor environment.*

German Standard *DIN 1946-6* divides ventilation into four types. Each requires a minimum air exchange for different kind of uses. The four levels are:

- Ventilation for protection against humidity: A basic ventilation level that should guarantee minimal ventilation depending on energy performance/ insulation levels. This avoids damages caused by wet air. This level has to be ensured at all times, independently of the user.
- Reduced ventilation: for minimal hygienic requirements, mostly independently of the user
- Nominal ventilation: active ventilation via window
- Intensive ventilation: For intensive uses, cooking, washing etc (German Standard DIN 1946-6)

Level 1 - *Ventilation for protection against humidity* defines a minimum requirement based on floor area. Additional ventilation systems (including mechanical) may be needed, if air exchange via leakages is not enough. This definition of ventilation was first introduced in 2009. It was a response to the move towards highly efficient and airtight buildings. German Standard *DIN 1946-6* goes on to state:

> *mould can be avoided if a humidity of 80% on surface is not exceeded*.

The Standard also takes into account the influence of thermal bridges on surface temperature and humidity. The German Standard does not mandate but does recommend the use of mechanical ventilation as a response to the very low infiltration rates it mandates. It is argued that, the appropriate mechanical ventilation, when operating in conjunction with passive systems, provides more consistent ventilation, leading to a more consistent IAQ in high performance, highly airtight buildings (BPIE Report 2015 Page 22)

Airtightness, is a building envelopes ability to the resistance inward or outward air leakage. This inward and outward consideration is a critical aspect when reviewing the performance properties of air barrier systems. Airtightness is a crucial aspect of energy performance of buildings. European Standard EN 13829 describes the measurement method of air permeability of buildings through fan pressurisation at an infiltration airflow rate at 50 Pa. There is no consistency within the EU regarding infiltration rates and pressurisation rates, as well as the mandatory/voluntary requirement for blower door testing. Therefore, full comparison between EU states is not possible. (BPIE Report 2015 Page 26)

In Denmark, air leakage must not exceed 1.5 l/(s·m²) of the heated floor area. (DS/EN 1382961). However, for low energy buildings (class 2015), air changes must not exceed 1.0 l/(s·m²). For building class 2020 (nearly zero energy buildings) air changes must not exceed 0.5 l/(s·m²).

This compares to Germany which requires a maximum of 3 ACR/h for natural ventilated houses, 1.5 ACR/h for mechanically ventilated house and the *Passivhaus* standard limits air leakage to 0.6 ACR/h.

A number of countries have produced reports and guides on condensation issues in residential buildings. Since the 1970s the EU has been working to address issues of Air Quality (both internal and External)[8]. The EU carried out a comprehensive review of the EU air quality policy framework between 2011 and 2013. The EU prescribes a strict regulatory framework around IAQ under Directive 2008/50/EC[9]. The contaminants considered to be pollutants or damaging to human health are restricted and proscribed. These include, Lead, Radon, Solpha and fine particulates[10].

At Present 'Microbial' pollutant are not contained in the directive. Supporting information does identify that damp buildings can lead to mould and fungal growth and these have an impact on human health and can contribute to the development of asthma and allergies. But it is noted that the correlation is difficult to quantify and it is still not known precisely how dampness intervenes in the appearance of these symptoms and which are the main substances responsible[11].

As a result, Mould has not been included in the EU IAQ directives. However, as part of the Directives review process in 2013 the Environment and Human Health Joint EEA-JRC report argued that:

> *measures in the environment and health area have typically been based on dose-effect studies of individual polluting substances and stressors, this new report makes the case for a more integrated take on health issues, acknowledging the complex inter-linkages between resource-use patterns, environmental pressures, multiple exposures and disease burden, as well as the key role that social inequalities play.*

The Report goes on to recommend a more holistic approach to IAQ. It expands IAQ to include, not just chemicals, but also water, noise, electromagnetic fields, ultraviolet radiation, nanoparticles, and climate change. The report argues that IAQ is critical in the achievement of broader environmental and social health objectives.

This is an example of a move from seeing condensation as merely a building science issue to one that is, not just bound up in a discussion on IAQ, but now the broader context of the internal built environment and the regulation of residential buildings role and responsibilities in providing good social health outcomes. The Report does not provide specific

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[8] http://ec.europa.eu/environment/index_en.htm

[9] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0050

[10] http://ec.europa.eu/environment/air/quality/standards.htm

[11] http://ec.europa.eu/health/scientific_committees/opinions_layman/en/indoor-air-pollution/l-2/8-building-dampness.htm#0

recommendations but rather goes on to identify strategies that have been developed in a collaboration between the EU and the World Health Organisation.

Since 2004, the EU has been collaborating with the *World Health Organisation – Europe (WHO)* on the general issue of Air Quality and human health. Collaboration between the EU and WHO resulted in the publication of the *WHO - Guidelines for Indoor Air Quality: Dampness and Mould* (WHO Guide).

The WHO Guide Identified that condensation, mould and poor IAQ were prevalent throughout Europe across all climate zones, and all building types. It references a number of European studies that indicated between 25 and 38 percent of homes showed signs of moisture damage and microbial presence in 65% of buildings (page 34). Part 4, within the WHO Guide addresses Health effects associated with dampness and mould provides a review and a synthesis of the epidemiological, clinical and toxicological evidence on the health effects of dampness and mould (page 63).

The WHO Guide concludes that:

> *Sufficient epidemiological evidence is available from studies conducted in different countries and under different climatic conditions to show that the occupants of damp or mouldy buildings, both houses and public buildings, are at increased risk of respiratory symptoms, respiratory infections and exacerbation of asthma.*

The WHO Guide notes, energy conservation measures that are not properly implemented (tightened building envelopes, ventilation deficits, and improper insulation) contribute to the conditions associated with increased exposure to dampness and mould and the risks of adverse health effects due to biological contaminants of indoor air.

The WHO Guide argues that, at present, building standards and regulations with regard to comfort and health do not sufficiently emphasize requirements for preventing and controlling excess moisture and dampness. Management of moisture generally focuses on entry during occasional events, such as water leaks, heavy rain and flooding. There is not sufficient focus on moisture which enter a building via incoming air, including that infiltrating through the building envelope or that resulting from the occupants' activities. On the basis of this review, three guidelines were formulated, namely:

- Persistent dampness and microbial growth on interior surfaces and in building structures should be avoided or minimized, as they may lead to adverse health effects.
- Well-designed, well-constructed, well-maintained building envelopes are critical to the prevention and control of excess moisture and microbial growth, as they prevent thermal bridges and the entry of liquid or vapour-phase water.
- Management of moisture requires proper control of temperatures and ventilation to avoid excess humidity, condensation on surfaces and excess moisture in materials. Ventilation should be distributed effectively throughout spaces, and stagnant air zones should be avoided.

The recommendation of the WHO Guide have been reinforced by the BPIE Report 2015. It concludes that:

- IAQ health and comfort aspects should be considered to a greater extent in European building codes than is current practice
- Any amendment to Building codes to improve energy efficiency , should also effects on and improvements to IAQ

- Any increase in insulation and airtightness should be completed by appropriate minimum requirements for indoor air exchange and ventilation
- IAQ should be included in any Energy Performance Certification
- The co-benefits of a healthy indoor environment should be taken into account when assessing the macroeconomic impact of energy improvement measures.

An assessment of the success and/or failure, and further enhancements to regulations that may have occurred.

Sympathetically, the German Standard DIN 1946-6 references the need to have basic ventilation level that should guarantee minimal ventilation depending on energy performance/ insulation levels. This avoids damages caused by wet air. The Standard defines that mould can be avoided if a humidity of 80% on surface is not exceeded.

Scoping Study of Condensation in Residential Buildings

Appendix 05: International literature review – health impacts from condensation in buildings

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International literature review – health impacts from condensation in buildings

Introduction

There have been a number of studies into the impacts of condensation on buildings. There are also a number of population based studies examining the economic impact of repertory disease such as asthma. The specific focus of this review was to examine research that attempted to extrapolate the economic impact from disease directly correlated to 'wet buildings'. Provided here is the references list used in the literature review.

Chapman, R., Howden-Chapman, P., Viggers, H., O'Dea, D., & Kennedy, M. (2009). *Retrofitting houses with insulation: A cost-benefit analysis of a randomised community trial*. Journal of Epidemiology and Community Health, 63(4), 271-277

Chestnut, L. Thayer, M, Lazo, J. Van Den Eeden, S, (2006) *The Economic Value of Respiratory and Cardiovascular Hospitalizations* Journal of Contemporary Economic Policy

Collins, K. J. (1986). *Low indoor temperatures and morbidity in the elderly. Age and Ageing*, 15(4), 212-220.

Fisk, W. J. (2000). *Health and productivity gains from better indoor environments and their relationship with building energy efficiency*. Annual Review of Energy and the Environment, 25, 537-566.

Fisk, W. J. (2002). *How IEQ affects health, productivity*. ASHRAE Journal, 44(5), 56+58-60.

Fisk, W. J. (2015). *Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures*. Building and Environment, 86, 70-80.

Fisk, W. J., & Black, D. (2010). *Benefits of improved IEQ: Better health and improved work performance*. Paper presented at the IAQVEC 2010: 7th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings.

Mudarri, D. H. (2014). *National expenditures, jobs, and economic growth associated with indoor air quality in the United States*. Journal of Environmental Health, 76(9), 26-31

Mudarri, D. H. (2016). *Valuing the economic costs of allergic rhinitis, acute bronchitis, and asthma from exposure to indoor dampness and mold in the US*. Journal of Environmental and Public Health

Mudarri, D., & Fisk, W. J. (2007). *Erratum: Public health and economic impact of dampness and mold*. Indoor Air, 17(4), 334.

Mudarri, D., & Fisk, W. J. (2007). *Public health and economic impact of dampness and mold*. Indoor Air, 17(3), 226-235.

Sahakian, N., Park, J., & Cox-Ganser, J. (2009). *Respiratory morbidity and medical visits associated with dampness and air-conditioning in offices and homes*. Indoor Air, 19(1), 58-67.

Scoping Study of Condensation in Residential Buildings

Appendix 06: Australian Standards Referenced by the NCC

23 September 2016

Research funded by:

Australian Building Codes Board

Department of Industry Innovation and Science

Commonwealth of Australia

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Australian Standards referenced by the NCC

The following is a list of Australian Standards referenced within the NCC that require further review in relation to the Scoping Paper's proposed recommendations and industry consultation.

Standard No.	Date	Title	Revision description
AS 1562.1	1992	**Design and installation of sheet roof and wall cladding Part 1: Metal**	Include consideration of condensation during the design and construction of metal cladding systems. (currently includes an explanatory note as an appendix, discussing the topic of roof ventilation, water vapour and condensation, informative only, this is note is outdated and not in keep the current international understanding of condensation)
AS 1668.2	2012	**The use of ventilation and air conditioning in buildings Part 2:**	Applicable to residential commercial (class 2) building practices. Construction diagrams should consider condensation issues, particularly in relation to thermal bridging and ventilation. section 1.1: scope and general outlines that this standard specifically does not include requirements 'for the elimination of condensation.'
AS 1684	2010	**Residential timber-framed construction Part 2 - 4**	Definitions need clarification, for example the term moisture. Language about weatherproofing should be more explicit and include prescriptions regarding vapour control. Diagrams should consider condensation.
AS 1720.1	2010	**Timber structures Part 1: Design methods**	Should include or refer to definitions for vapour control and condensation.
AS 1720.5	2015	**Timber structures Part 5: Nailplated timber roof trusses**	Mentions in-service moisture control though it is not mandated this section refers readers to Appendix b4 moisture control in roof spaces has information of water infiltration and refers readers to further information on nail plate trusses and specifically to the condensation handbook by ABCB
AS 2047	2014	**Windows and external glazed doors in buildings**	Mention of condensation risk included in the appendix b Environmental considerations
AS 3500.5	2012	**Plumbing and drainage Part 5: Housing installations**	Does not outline the risks of damaging the building wrap or compromising the insulative layer during plumbing. NCC should reference this with new requirement regarding recommendation no. 5 2019, no items puncture the air barrier system.
AS 3660.1	2014	**Termite management Part 1: New building work**	Diagrams showing typical construction systems
AS 3740	2010	**Waterproofing of domestic wet areas**	Diagrams showing typical construction systems
AS 3959	2009	**Construction of buildings in bushfire prone areas**	Diagrams showing typical construction systems should be updated Should specify the risks of sealing unconditioned spaces such as attics and sub floors
AS 4200	1994	**Pliable building membranes and underlays (parts 1 and 2)**	Definitions of air barrier and vapour permeability. Table based classification of membranes by climate type. Permeability changes based on climate.
AS 4654	2012	**Waterproofing membranes for external above-ground**	Diagrams showing typical construction systems

		use Part 1: Materials Part 2: Design and Installation	
AS 4773	2015	**Masonry in small buildings (parts 1 and 2)**	Diagrams showing typical construction systems
AS 4859	2002	**Materials for the thermal insulation of buildings**	Diagrams showing typical construction systems. Cavities and roof spaces should not be considered in thermal calculations. This has implications for condensation management.

Below are standards that are not referenced in the NCC, but the Project team believe should be reference in the NCC and considered in relation to condensation risk.

Standard No.	Date	Title	Description
AS 1100	1992	**Technical drawing**	Industry comment require updating for CAD drawing and BIM Required drawing list Typical plans and sections show bushfire compliant and condensation conscious examples
AS 3000	2007	**Electrical installations**	Should be referenced as per recommendation no. 5 to consolidate trade requirements and education. Address compliance regarding puncturing the air barrier system.
AS 3999	2015	**Bulk thermal insulation—Installation**	See comments for AS 4859.

Scoping Study of Condensation in Residential Buildings

Appendix 07: Comparison Table of NCC Volume Two, from 2003 to 2016

23 September 2016

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Scoping Study of Condensation in Residential Buildings

Appendix 08: Model house costings

23 September 2016

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Model homes – full costings

To establish likely costs for homeowners, draft recommended changes were provided to a quantity surveyor. The quantity surveyor was provided with three volume builder style house plans, namely:

- An average sized single storey house (247m^2),
- An average sized two storey house (276m^2),
- A larger single storey house (357m^2), and
- A double storey Class 2 unit.
-

The costs shown below**Error! Reference source not found.** were developed based on nationally standard volume builder pricing for Australian houses, in 2016.

Single Storey House

House Size	Single Story Average Size (Area 247m²)				
Alteration\Cladding Type	Typical	Brick	Weatherboard	FC Sheeting	Sheet Metal (Colorbond)
Building Wrap	$280	$280	$280	$280	$280
Vent Eaves Ex Attic Roof	$1840	$1840	$1840	$1840	$1840
Vent Eaves Non-Ex Cathedral Roof	$3600	$3600	$3600	$3600	$3600
Building and service systems with no punctures to ceiling air barrier system (e.g. Vented Down lights to Sealed Down lights) All new downlights already sealed. Allow to supply and install draft stoppa kit to each bathroom	$125	$125	$125	$125	$125
Sarking as per manufacturers specification					
Cavity construction for all external wall systems. (e.g. weatherboard, ply, fibre cement sheeting, sheet metal…)	$3095	$0	$3095	$0	$3095
Inspection of building wrap and insulation systems as part of the structural inspection	$500	$500	$500	$500	$500
Blower door test as part of structural inspection	$500	$500	$500	$500	$500
Cloth dryer to be externally vented	$195	$195	$195	$195	$195
Steady state dew point analysis to be added to documentation in climates 6,7 & 8	$250	$250	$250	$250	$250
80mm-100mm Foil blanket system for roofs less than 5 degree pitch in climate 7 & 8	$3300	$3300	$3300	$3300	$3300
Trusses to have upstands such as bobtail truss or similar to ensure ceiling fully insulated (ramifications include a higher truss and approximately two extra courses of brick)	-	$4600	$3000	$3000	$2550
Cardboard baffle to protect ceiling insulation	$1000	$1000	$1000	$1000	$1000
Anti ponding boards to be added to roofs	$1500	$1500	$1500	$1500	$1500

Two Storey House

House Size	Two Story Average Size (Area 276m²)				
Alteration\Cladding Type	Typical	Brick	Weatherboard	FC Sheeting	Sheet Metal (Colorbond)
Building Wrap	$480	$480	$480	$480	$480
Vent Eaves Ex Attic Roof	$3055	$3055	$3055	$3055	$3055
Vent Eaves Non-Ex Cathedral Roof	$4815	$4815	$4815	$4815	$4815
Building and service systems with no punctures to ceiling air barrier system (e.g. Vented Down lights to Sealed Down lights) All new downlights already sealed. Allow to supply and install draft stoppa kit to each bathroom	$125	$125	$125	$125	$125
Sarking as per manufacturers specification					
Cavity construction for all external wall systems. (e.g. weatherboard, ply, fibre cement sheeting, sheet metal…)	$5175	$0	$5175	$0	$5175
Inspection of building wrap and insulation systems as part of the structural inspection	$800	$800	$800	$800	$800
Blower door test as part of structural inspection	$800	$800	$800	$800	$800
Cloth dryer to be externally vented	$195	$195	$195	$195	$195
Steady state dew point analysis to be added to documentation in climates 6,7 & 8	$250	$250	$250	$250	$250
80mm-100mm Foil blanket system for roofs less than 5 degree pitch in climate 7 & 8	$2700	$2700	$2700	$2700	$2700
Trusses to have upstands such as bobtail truss or similar to ensure ceiling fully insulated (ramifications include a higher truss and approximately two extra courses of brick)		$4200	$3000	$3000	$2500
Cardboard baffle to protect ceiling insulation	$1550	$1550	$1550	$1550	$1550
Anti ponding boards to be added to roofs	$2300	$2300	$2300	$2300	$2300

Two Storey Large House

House Size	Two Story Large Size (Area 357m²)				
Alteration\Cladding Type	Typical	Brick	Weatherboard	FC Sheeting	Sheet Metal (Colorbond)
Building Wrap	$510	$510	$510	$510	$510
Vent Eaves Ex Attic Roof	$3250	$3250	$3250	$3250	$3250
Vent Eaves Non-Ex Cathedral Roof	$5209	$5209	$5209	$5209	$5209
Building and service systems with no punctures to ceiling air barrier system (e.g. Vented Down lights to Sealed Down lights) All new downlights already sealed. Allow to supply and install draft stoppa kit to each bathroom	$125	$125	$125	$125	$125
Sarking as per manufacturers specification					
Cavity construction for all external wall systems. (e.g. weatherboard, ply, fibre cement sheeting, sheet metal…)	$5530	$0	$5530	$0	$5530
Inspection of building wrap and insulation systems as part of the structural inspection	$800	$800	$800	$800	$800
Blower door test as part of structural inspection	$800	$800	$800	$800	$800
Cloth dryer to be externally vented	$195	$195	$195	$195	$195
Steady state dew point analysis to be added to documentation in climates 6,7 & 8	$250	$250	$250	$250	$250
80mm-100mm Foil blanket system for roofs less than 5 degree pitch in climate 7 & 8	$2700	$2700	$2700	$2700	$2700
Trusses to have upstands such as bobtail truss or similar to ensure ceiling fully insulated (ramifications include a higher truss and approximately two extra courses of brick)		$4500	$3200	$3200	$2700
Cardboard baffle to protect ceiling insulation	$1400	$1400	$1400	$1400	$1400
Anti ponding boards to be added to roofs	$2140	$2140	$2140	$2140	$2140

Class 2 Double Storey Unit

House Size	Class Two Double Storey Unit (Floor area 110m²)				
Alteration\Cladding Type	Typical	Brick	Weatherboard	FC Sheeting	Sheet Metal (Colour bond)
Building Wrap	$150	$150	$150	$150	$150
Vent Eaves Ex Attic Roof	$450	$450	$450	$450	$450
Vent Eaves Non-Ex Cathedral Roof	$1,100	$1,100	$1,100	$1,100	$1,100
Building and service systems with no punctures to ceiling air barrier system (e.g. Vented Down lights to Sealed Down lights) All new downlights already sealed. Allow to supply and install draft stoppa kit to each bathroom	$125	$125	$125	$125	$125
Sarking as per manufacturers specification					
Cavity construction for all external wall systems. (e.g. weatherboard, ply, fibre cement sheeting, sheet metal…)	$850	$0.00	$850	$0	$850
Inspection of building wrap and insulation systems as part of the structural inspection	$500	$500	$500	$500	$500
Blower door test as part of structural inspection	$500	$500	$500	$500	$500
Cloth dryer to be externally vented	$195	$195	$195	$195	$195
Steady state dew point analysis to be added to documentation in climates 6,7 & 8	$250	$250	$250	$250	$250
80mm-100mm Foil blanket system for roofs less than 5 degree pitch in climate 7 & 8	$650	$650	$650	$650	$650
Trusses to have upstands such as bobtail truss or similar to ensure ceiling fully insulated (ramifications include a higher truss and approximately to extra courses of brick)		$980	$980	$980	$980
Cardboard baffle to protect ceiling insulation	$250	$250	$250	$250	$250
Anti ponding boards to be added to roofs	$420	$420	$420	$420	$420