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The Causes of Surface Condensation and Mould, and the Responsibility of Relevant Parties to Alleviate Them

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Introduction
Condensation and mould growth on the internal surface of a room are caused by a combination of factors due to specific conditions. In severe cases, one of these factors may lead to surface condensation and/or mould growth, but in general, surface condensation and/or mould growth occurs when two or three of these occur together. A selection of these basic factors includes: inadequate rapid ventilation, inadequate levels of extract ventilation where the moisture is generated, high moisture generation rates, cold surfaces (due to a lack of insulation or very low external temperatures), and partial insulation renovations that leave some surfaces warmer than others.
As insulation renovations generally allow higher room temperatures to be maintained for longer, they also ensure that more vapour can be held in the air. The use of a psychrometric chart will show that double jeopardy arises where moisture levels are higher than before, but poorly specified, poorly implemented, or partial insulation renovation result in surfaces that in winter are as cold – or even cooler – than before the works were undertaken. Confounding the expectation of owner and occupant, more condensation (and therefore more mould) may form at these locations than before.
Even though multiple causes and shared responsibility may disappoint or confuse, the building physics of surface condensation is actually well understood and unambiguous. It becomes clear that reducing the risk of surface condensation to acceptable levels requires agreement, cooperation and action by owners and occupants.

Change in technical guidance for ventilation
There are many studies from Ireland, the UK and France which indicate that non-compliance of installed ventilation systems is common (e.g. Coggins, M. et al. (2010), Mawditt, I. et al. (2015), Guyot et al. (2015)). Indeed, the extent to which residential ventilation systems in dwellings are under-performing may rightly be considered a crisis, given their impact on indoor air quality, occupant health, surface condensation and mould growth.
It should be noted that until 2009 the only ventilation system for dwellings that was referred to in technical guidance of the Irish Building Regulations was so-called 'natural' ventilation. This system relies on wall or window vents, an intermittent extract fan in wet rooms and kitchen extract hood (typically only used when cooking). The system is cheap to install. Guidance on how it can be installed to ensure a high-quality result has generally been inadequate and until 2019 independent commissioning of mechanical elements of any ventilation system was not required. Without doubt most of the dwellings in Ireland with problematic indoor air quality feature 'natural' ventilation, whether installed well or badly, However, there is increasing research from abroad to show that many installations of mechanical systems can also fail if poorly designed, installed or commissioned.
In 2009 mechanical ventilation with heat recovery (MVHR) was finally introduced and cross-ventilation guidance was improved. In 2019 constant mechanical extract ventilation (MEV) was finally introduced, and background ventilation rates for natural ventilation were increased. Natural ventilation was also removed as an option for very airtight dwellings (i.e. $<3\ m^3/m^2.hr$)

in an acknowledgement of its inability to maintain indoor air quality (IAQ) in such dwellings. Independent commissioning (based on IS EN 14134:2004) was introduced for the mechanical elements of all residential ventilation systems in all new dwellings and in existing dwellings undergoing 'major renovation'. However, there is no such requirement for new systems installed in existing dwellings otherwise.
It is tempting to consider how much better conditions in Irish dwellings would now be if the current increasingly robust technical guidance and commissioning system were introduced decades ago.

Assessing conditions for condensation, damp and mould
The table below gives a very brief synopsis of factors, conditions and remediation of surface condensation and mould. A responsible body, or bodies, is proposed in each case.

A number of key documents are quoted:

- TGD L:2019: Technical Guidance Document L - Conservation of Fuel and Energy - Dwellings
- TGD F:2019: Technical Guidance Document L - Ventilation
- SR 54:2014: Code of practice for the energy efficient renovation of dwellings
- BS 5250:2016: Code of practice for control of condensation in buildings

Factor	**Condition & responsibility**
Surface temperature of the thermal envelope	A low surface temperature can lead to surface condensation forming. Section 2.1.3.1 of TGD L:2019 states: '*To avoid excessive heat losses and local condensation problems, reasonable care should be taken to ensure continuity of insulation and to limit local thermal bridging'.* The Temperature Factor (f_{Rsi}), described in Sections D.2 of both TGD L (2019) and BS 5250 2016), is a ratio that relates the temperature on a room surface to the internal and external ambient temperatures. Section D.2 of TDG L:2019, states '*for dwellings, the value of f_{Rsi} should be greater than or equal to 0.75, so as to avoid the risk of mould growth and surface condensation.* The ratio is simply calculated using temperatures: those values can be established through measurement or calculation using thermal modelling. As an example, if the outside ambient temperature were 0 ^{0}C and the inside 20 ^{0}C, the room surface would need to be 15 ^{0}C or above to comply with the 0.75 f_{Rsi} threshold value. As the f_{Rsi} increases to 0.85 and beyond surface condensation is less and less likely to happen, *even* with high relative humidity due to elevated levels of moisture generation. Similarly, where the f_{Rsi} drops to 0.60 and lower the ambient relative humidity would need to be increasingly low for surface condensation not to occur.
Responsibility:	**Owner, developer, builder or specifier** It is clear therefore that an unacceptable Temperature Factor has nothing to do with the occupant. It is created by the construction process, or the deficiency or omission of a high-quality energy efficient renovation. Note a Temperature Factor below 0.75 indicates a high risk of surface condensation occurring.

Relative humidity of the surface of the thermal envelope, and moisture buffering capacity of room surfaces and furnishings	Mould can germinate on, or within the surface of, hygroscopic materials at a relative humidity (%RH) above 80 %RH. This is a lower threshold of risk than for surface condensate, which forms on any surface at 100 %RH. (Source: Section A.5 Mould, BS 5250:2016.) Common hygroscopic room surfaces include emulsion-painted, wet-plastered walls or plasterboard, traditional wall paper, timber panelling or fibreboard lining the back of most storage units, as well as exposed brick or concrete. Other common hygroscopic materials found in dwellings are, of course, natural carpets, soft furnishings with natural upholstery (such as leather), and clothing made of natural fabrics. One of the great *advantages* of hygroscopic materials *is* their ability to contribute positively to IAQ *without* risk of mould growth (as long as relative humidity levels drop some time afterwards). They do this by absorbing water vapour from the air (binding it as a liquid to pore surfaces) and later desorbing, thereby reducing peaks in ambient relative humidity levels that may fluctuate through the day and year. Hygroscopic materials can 'buffer' moisture in this manner for many years without a problem, where healthy/low levels of moisture are present. In such a situation, mould will only manifest (for the first time) on surfaces with a low Temperature Factor during extended periods of very cold weather. In recent memory this occurred in the Dublin area in January and February 2011. In the warmer weather that followed that extended cold spell, mould bloomed on room finishes in many dwellings for the first time. If relative humidity levels in a room remain high for long periods of time with little drying, the ability of hygroscopic room finishes to buffer moisture and thus contribute to a positive IAQ declines. It is possible that mould will begin to form first within the material, out of sight, before becoming visible on its surface. Therefore, attempts to remove mould by surface washing and re-painting will often leave the source mould in place, ready for the next unsuspecting occupant. Mould can re-occur at lower levels of relative humidity once established, much to the distress of occupants who may feel they are behaving in an exemplary manner. Many occupants respond to the sight of mould on hygroscopic room surfaces by installing increasing amounts of non-hygroscopic, 'mould-proof ' materials like fully-vitrified wall and floor tiles, acrylic paints, melamine coated panels, 'mould-blocking' wall paper, synthetic upholstered furnishings etc. Inadvertently they lose the moisture buffering value of the original hygroscopic room finishes and as a result are likely to experience higher levels of relative humidity and again poor IAQ. If moisture levels remain high, room surfaces that are still hygroscopic, and may now be out of sight, may be burdened with greater mould growth. In extreme cases increasing amounts of surface condensation on the new, non-hygroscopic surfaces can lead to mould forming on them too. A common response is to raise the air temperature, which perversely increases the capacity of the air to hold *more* moisture as a vapour and may lead to a *further* decline in IAQ. In these dwellings it is not uncommon to find mould spores forming quickly on bed sheets, on bags or soft toys thrown in a corner, or clothes hung in a wardrobe, especially in a north-facing room with a poorly insulated wall. It is not surprising

	that many occupants can begin to think that the dwelling is 'fighting ' them.
Responsibility:	**Owner, occupant and weather** The owner has responsibility for the thermal performance of the building fabric, the heating system and also for the moisture extraction system fitted. The occupant has responsibility for the use of the heating and moisture extraction systems, the moisture generated and potentially, due to redecoration, may have some responsibility for a reduction in the moisture buffering capacity of room surfaces. The weather introduces an 'act of god' that can exacerbate conditions. In the author's experience occupants of dwellings in the worst conditions may have a strong focus on cleanliness and hygiene and are deeply embarrassed and upset by the conditions they are experiencing despite taking what they consider to be corrective actions.
Maintenance issues, water ingress and inter-stital condensation	Surface condensation can occur due to inadequate maintenance. For instance, a deep narrow crack can provide a route for driving rain to reach the room surface (manifesting perhaps as a localised or linear stain), or a leaking box gutter behind a parapet or missing tile at a roof eaves could deliver litres of water onto the top of a wall during each rainfall event. From there, water could spread through a large area of building fabric by capillary action, moving towards whichever surfaces would allow evaporation to occur. Evaporation to the external surfaces might not be evident, but significant staining and even mould growth could be visible on the room surface. Another subtler cause is interstitial condensation. This can occur when an inappropriate assembly of materials results in an accrual of moisture within the assembly of the thermal envelope. This phenomenon may have arisen at the time of an inappropriate energy efficient renovation. As the moisture content grows the vapour pressure differential can drive moisture back to the room surface.
Responsibility:	**Owner** While the builder/developer/specifier may have created the inappropriate assembly, the responsibility for maintenance clearly lies with the owner.
Moisture generation due to occupancy levels	Table D.6 of BS 5250:2016 lists specific average moisture generation rates. It records that a person could perspire and exhale 40 g of water vapour per hour when sleeping, 70 g/h when seated and 90 g/h when standing or doing housework. Theoretically, if the occupants didn't leave the dwelling, slept for seven hours, sat for ten hours and stood or did housework for seven hours, each could generate 1.6 Kg of moisture purely due to metabolic moisture generation. Therefore, three occupants could produce 4.8 kg and six occupants (potentially in the same size of dwelling) could produce 9.6 kg, regardless of whatever appliances they use, how often they shower or where they dry their clothes. It is clear, the level of occupancy and the duration to which occupants are present each day can be key drivers of moisture content

<u>Responsibility:</u>	**Owner and occupant** Complex social factors may drive high occupancies and the percentage of time spent in the dwelling each day. The owner has a responsibility to either accept the implications of high or continuous occupancy or provide alternate accommodation. Either way, they are obliged to ensure the moisture extraction systems are adequate to meet the demand. This should include moving from natural ventilation to a properly-designed and commissioned MEV or MVHR system. *'Any action to control condensation should take account of the intended use of the building and involve comprehensive consideration of heating, ventilation and thermal insulation'.* Quote from Section 6.1 - Action to control condensation, BS 5250:2016.
<u>Moisture generation due to activities</u>	Table D.6 of BS 5250 2011 lists the weight of water vapour (i.e., moisture) released by various domestic activities: • Cooking with gas cooker: 3,000 g/day • Cooking with electricity: 2 000 g/day • Dishwashing: 400 g/day • Washing clothes: 500 g/day • Drying clothes indoors: 1,500 g/day • 15-minute shower: 600 g (Note: Doubtless, modern power showers push more steam into the air) Typically, landlords declare that the act of drying clothes indoors is the main source of the condensate that forms on surfaces of the external envelope and is therefore the responsibility of the tenant. Looking at the list above however, it can be seen that cooking with gas or, say, three occupants showering each day will generate more moisture. There are dwellings in which clothes have regularly been air-dried which have never experienced surface condensation and equally dwellings (many social housing units) where clothes have never been left out to dry which experience chronic surface condensation and mould problems.
<u>Responsibility:</u>	**Shared** Tenants have a right to carry on normal domestic activities within a dwelling without fear of suffering surface condensation. The facilities provided – including moisture extraction and control of surface temperatures – should allay this concern. Of course, occupants must take responsibility for unusual levels of moisture generation, but drying clothes indoors of itself should not be singled out as causing an unacceptable level of moisture generation. It should be said that there is a large difference between drying clothes indoors on (a) a clothes horse and (b) on or in front of a source of heat. In case (a) only the moisture that the body of air around the clothes can absorb will evaporate from the clothes. The lower the ambient relative humidity, the greater the drying capacity. As long as the room temperature doesn't change and further sources of moisture are then added, this activity should *not* stress conditions nor result in surface condensation. In case (b), heat is being used locally to cause vigorous evaporation which may be far beyond the capacity of the room air to retain as vapour. Surface condensation on a cold surface is likely to follow. This difference is not sufficiently promoted.

General ventilation	It is useful for the purpose of this study to separate out the function and provision of supply and extract ventilation, even if some technologies (such as window sashes) may have a role in both spheres. The purpose of supply ventilation is to provide oxygen-rich air with fewer contaminants than that present in the dwelling. Extract ventilation is arguably more important in that its function is to remove contaminants (including moisture, carbon dioxide, volatile organic compounds, etc.). However, air can only leave if it is supplied somewhere else. Ideally, a ventilation cycle occurs without discomfort to the occupant and with minimal loss in room temperature. Where vents have been purposefully blocked, it is clear the occupants have experienced sufficient discomfort to act. In many dwellings, the level of air supply is acceptable, but experience shows that the type and use of extract ventilation to move the supplied air in the right direction is not.
Supply ventilation	Supply ventilation is composed of design ventilation and infiltration. The former is broken down into rapid ventilation (i.e. opening window sashes) and background ventilation (wall vents or trickle vents). The latter is the unintended air supplied through gaps and cracks. As landlords have responded to requests to improve occupant thermal comfort and the drive to improve energy efficiency by installing tight fitting windows, the percentage of air supplied to renovated dwellings has fallen significantly. In 2019 technical guidance reflected this change for the first time. Many occupants in private and social housing will open window sashes less in winter due to a reluctance to lose heat and suffer decreased thermal comfort and increased fuel bills. Trickle or wall vents are often left shut because commonly available, low-cost models can result in draughts and noise pollution from the street outside on busy thoroughfares.
Responsibility:	**Government, owner, occupant** The author contends that the Department of Housing should revise TGD F:2019 to further limit where natural ventilation to instances that its desired functionality can be successfully achieved. All new residential ventilation systems should be commissioned, not just those installed as part of a new building or a 'Major Renovation'. In France mechanical extract ventilation (MEV, whether constant or oscillating) with humidity-triggered supply ventilation has become the minimum residential ventilation standard allowed. Ireland should follow suit. Background ventilators that have acoustic and air path baffles should be used in all cases as they are less likely to irritate occupants. Occupants need to accept their role in the provision of sufficient air quality to the dwelling through use of rapid and background ventilation paths.

Extract ventilation	Extract ventilation is also composed of design ventilation and infiltration. In this case the former includes cross ventilation (i.e., opening window sashes on opposite sides of the building) and natural or mechanical extract ventilation which includes unintended air supplied through gaps and cracks and the building's chimney stack. Modern apartments (many of which are rented) are far less likely to have windows on opposing sides of the dwelling than a house. This means the ability to cross ventilate (through opening of sashes on opposite side of the building) is unavailable. TGD F:2009 was the first edition of the ventilation technical guidance to recognise this limitation and respond accordingly. In existing single-sided apartments, window sashes may need to be open for a long time before the contaminants deep in the plan (i.e., in the kitchen, bathroom and utility room that produce most moisture) have been removed. The length of time required is likely be sufficient to result in a marked loss of heat engendering a far less positive situation than occurs with cross ventilation. While TGD F:2019 refers to passive stack ventilation as an option, most extract ventilation systems are small fans fitted in shower or bathrooms. The humidity-triggered variety are rarely-fitted in social housing and apartments: most builders and owners prefer to fit small, cheap units that are triggered by flicking a light switch and remain in use for a variable period of time after the light is turned off. (TGD F:2019 guides 15 minutes as the minimum period.) While it is common to also fit these devices in the kitchens of apartments in the UK, it has been rarely done in Ireland. This is because TGD F appears to allow installers of 'natural' ventilation systems to treat the cooker hood extract as the general extract ventilation for the kitchen. As most people only turn on the cooker hood when a significant amount of steam is being produced (and for the shortest duration possible), this means that at all other times the only mechanical extraction is the intermittent fan in the bathroom. Remember, even the metabolic moisture generation of a number of occupants may require extraction long before any appliance is turned on. Because the fans are often surface-mounted, they are generally loud and thus unpopular. Because they are small, they are likely to extract less moist air and have shorter lifespans. Also, as they are often located deep in the plan, the ducting to transfer the extracted vitiated air to the outside is often long and its narrow proportions sub-optimal. It is often questionable how much of the moisture reaches the outside still in the vapour state. The remainder condenses within the duct to evaporate in either direction later. Finally, because the fan is on for a short period, it can never remove all the moisture generated during a shower. Moisture levels in apartment shower rooms, have been shown to be elevated for as much as 20 hours after the shower. Only larger, acoustically-isolated, humidity-triggered extract fans are suitable for performing this task over many years, but they should be able to remove moisture from all moisture-generating areas of the dwelling on a constant basis. In this context, it is not surprising that some occupants (whether tenants or owners) misguidedly switch-off intermittent fans. Conversely, other occupants will contend they always leave the shower room's intermittent fan running for longer than 15 minutes and leave the door

	open thereafter, yet are horrified by mould covering the shower or bathroom's tile joints and corners and contaminating the air. The most effective form of extract ventilation in the majority of traditional dwellings is, however unintended, the chimney stack. Differences in temperature and buoyancy draw the air up the stack and the wind speed above roof level (higher than at ground level) can give additional draw. Stacks remove air regardless of how much extract ventilation is actually required. The level of over-ventilation and heat loss can be significant, however manually-operated dampers or chimney balloons can prevent over-ventilation allowing the occupants to avail of an open fire when required. Besides fitting airtight windows, landlords tend to block chimney stacks in social housing without (a) appreciating the resultant loss in moisture extraction and (b) installing a fit-for-purpose mechanical extract system.
Responsibility:	**Government, builder/developer, owner, occupant**