Indoor Air Quality and Ventilation in Newly Built Homes

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In Summary

- Reducing heat loss in residential buildings is a necessary part of Ireland's Climate Action Plan: Informed residential retrofitting and design of new builds is key.
- Current regulations and energy rating tools overlook real-world indoor environmental performance. Building standards and Building Energy Rating (BER) assessments lack measured indoor air quality (IAQ) data, limiting their ability to ensure healthy, comfortable homes.
- Energy efficiency improvements can compromise indoor air quality without appropriate ventilation strategies. Natural ventilation, by its nature, is highly variable and is also influenced by the behaviour of residents, often resulting in year-round unhealthy IAQ, with higher concentration of pollutants in winter and overheating in summer.
- This policy brief draws from research conducted as part of the ALIVE Project in the University of Galway and University College Dublin to make recommendations for these integrated actions to relevant policymakers. The ALIVE project assessed how well natural ventilation can reduce energy use and prevent overheating in energy-efficient buildings, while still maintaining acceptable IAQ.
- The EPBD recast (May 2024), to be transposed by May 2026, requires EU Member States to set requirements for adequate Indoor Environmental Quality (IEQ) in both new and existing residential buildings, and to include IEQ-related recommendations in Energy Performance Certificates.

1 Ventilation and Health: Issue Overview

Ireland's strategy to reduce building-related carbon emissions has focused heavily on improving the energy performance of its housing stock through large-scale retrofitting and more stringent standards for new construction. These efforts are essential to meeting Irish national and EU climate targets. Key measures include increasing the thermal insulation of dwellings and improving airtightness, i.e., limiting the amount of uncontrolled air leakage through the building envelope. While these design changes reduce heating demand due to lower heat loss, they also limit the natural movement of air through the building. While this improves energy efficiency, these energy-efficiency measures introduce critical risks to indoor environmental quality (IEQ) specifically Indoor Air Quality (IAQ) and thermal comfort. The problem arises from a performance gap: buildings meet regulatory requirements on paper (e.g. air permeability thresholds, passive ventilation provisions), but often fail to provide adequate ventilation, effectively remove indoor pollutants, or mitigate overheating under real-world conditions.

Despite advances in energy-efficient building design, naturally ventilated (NV), energy efficient dwellings are experiencing a performance gap between intended energy saving and real-world IAQ. Specifically, low air exchange rates (AER), especially in winter, can result in poor dilution of indoor pollutants such as PM2.5, CO_2 and TVOCs. The current passive ventilation systems (wall vents and trickle vents) are insufficient to maintain adequate IAQ year-round, especially during winter when occupants reduce window use due to cold outdoor temperatures. This is compounded by increased pollutant exposure during common activities like cooking and limited occupant knowledge of ventilation best practices, ultimately undermining the intended benefits of airtight, energy-efficient homes. The Irish building regulations, as outlined in Technical Guidance Document F (Ventilation), specify that required ventilation rates in dwellings should primarily be met through a combination of background ventilators and natural infiltration. While features like windows are designed for intermittent 'purge' ventilation to quickly clear pollutants, the home's primary ventilation is meant to be provided by background ventilators (wall and trickle vents) designed for constant airflow.

Poor IAQ, particularly in energy-efficient homes that rely solely on natural ventilation, poses health risks with wide-reaching consequences. Elevated levels of PM2.5, CO_2 and TVOCs have been linked to a range of adverse health outcomes. PM2.5, which was found to exceed World Health Organization (WHO) 24-hour limits on 93% of winter days in monitored Irish kitchens, is associated with respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD), as well as increased risk of cardiovascular events including strokes and heart attacks. High indoor CO_2 levels exceeding 1000 ppm for for a longer period can impair cognitive function, including concentration, memory, next-day performance, and decision-making. TVOCs, often emitted from cleaning agents, personal care products and building materials, contribute to symptoms such as headaches, dizziness and skin or eye irritation, and can lead to long-term respiratory issues with repeated exposure. Vulnerable groups such as the elderly, young children and individuals with pre-existing health conditions are disproportionately affected, particularly in winter months when cold temperatures discourage window opening and limit ventilation. Economically, the health costs of indoor air pollution in Ireland is estimated at €0.15bn, or 0.06 percent of GDP per year. Poor indoor climate can lead to increased healthcare costs. With its impact on asthma and respiratory conditions, poor IAQ can cost European health services over €2.6 billion per year. These findings reinforce the urgent need for integrated policy solutions that address the intersection of energy performance, indoor air quality and public health.

Glossary of Terms

Airtightness: The extent to which unintended air leakage is prevented in a building, usually measured in $m^3/h{\cdot}m^2$ at 50 Pa pressure differential. High airtightness improves energy efficiency but can limit natural airflow.

AER (Air Exchange Rate): A measure of how many times the air within a space is replaced per hour. Typically expressed in h^{-1}.

Natural Ventilation: Natural Ventilation relies on natural forces (wind and buoyancy) and passive devices like wall vents or trickle vents, without continuous operating mechanical fans in wet rooms.

Trickle Vent: A small opening in a window frame that allows a constant but limited amount of air to flow indoors for ventilation purposes.

Purge Ventilation: The act of temporarily opening windows or doors to rapidly dilute indoor pollutants. It is often controlled by occupants.

Glossary of Terms

BER (Building Energy Rating): An Irish energy efficiency label for buildings, with ratings from A (most efficient) to G (least efficient). A1, A2 and A3 represent high-performance energy-efficient homes which this study is focused on.

IEQ (Indoor Environmental Quality): IEQ refers to the overall quality of the indoor environment within a building, encompassing various factors like indoor air quality, thermal comfort, visual comfort and acoustic conditions.

IAQ (Indoor Air Quality): The quality of the air inside buildings, influenced by pollutants like PM2.5, CO_2, VOCs and NO_2, is crucial for occupant health and comfort.

CO_2 (Carbon Dioxide): A common indoor pollutant and a proxy indicator for ventilation adequacy. High concentrations (above 1000 ppm) indicate insufficient ventilation.

PM2.5: Fine particulate matter with diameter less than 2.5 micrometres. Often emitted during cooking and linked to respiratory issues. WHO 24-hour guideline: 15 $\mu g/m^3$.

TVOC (Total Volatile Organic Compounds): A catch-all measurement of gaseous chemicals emitted from products like paints, cleaning agents and personal care items. They can affect health and perceived air freshness.

2 ALIVE Project Research Findings

The findings of the ALIVE project highlight the challenges associated with the delivery of adequate ventilation by passive systems, and identifies the combined impact of occupant behaviour and ventilation system design issues. The ALIVE project used sensors to collect data in buildings and created computer models to understand the impact of natural ventilation on health and energy efficiency [1, 2, 3]. The ALIVE project and its associated studies provide robust empirical, longitudinal and simulation-based insights into these issues:

Indoor Air Quality (IAQ) Deficiencies in naturally ventilated energy efficient homes

- CO_2 exceeded 1000 ppm during 94% of winter sleeping hours in nine dwellings breaching WHO and EN16798 recommendations and thresholds.
- Fine particulate matter (PM2.5) concentrations exceeded the WHO 24-hour guideline in 92% of kitchen measurements during winter and 51% in summer (n=9) even with the monitored homes using electric cooking, suggesting that gas cooking could further exacerbate the problem.
- TVOCs frequently exceeded 430 ppb, particularly in bedrooms, and were linked to the use of personal care and cleaning products. Peak values reached 1200–4600 ppb which can lead to health impacts.
- Ventilation rates (AERs) were consistently below recommended levels with mean values of winter mean: 0.21 hr^{-1}; summer mean: 0.33 hr^{-1}; annual mean: 0.28 hr^{-1}.

Thermal Performance and Overheating

- During summer, seven out of nine monitored rooms failed CIBSE TM59 Criterion A for overheating. Temperatures exceeded 24°C for an average of 54% of time across bedrooms and average of 44% in kitchens during summer [4].
- Adaptive comfort models indicated that natural ventilation alone was often insufficient to fulfil the potential of passive cooling and maintain indoor temperatures within recommended IEQ categories, even during shoulder seasons (spring and autumn).

Occupancy-Ventilation Interaction

- Occupant behaviour, including reduced winter window use, variable cooking habits and limited purge ventilation (manual opening of windows), exacerbated seasonal IAQ issues. This interaction is not accounted for in current Dwelling Energy Assessment Procedure (DEAP) or BER assessments. A newly created optimisation framework demonstrated that occupancy, window operation duration and heating setpoints critically affect heating consumption, CO_2 levels and discomfort hours.

3 Policy Recommendations

The general findings of the ALIVE project indicate that while airtightness improves energy performance, natural ventilation alone is insufficient to maintain healthy indoor conditions year-round, without significant occupant engagement; examples of excellent practice exist within the dataset. To address this, the following interventions are proposed:

1. Develop a Framework for Post-Occupancy Performance Verification: To close the gap between design and real-world performance, building regulations should evolve to include post-occupancy performance. As a first step, we recommend piloting a program for seasonal IAQ and overheating testing in a representative sample of new homes. This data would inform the development of a cost-effective verification method, such as sensor audits or validated CO_2 decay tests, that could be integrated into future regulations.

2. Introduce Risk-Based Auditing of Indoor Environmental Quality: Rather than mandating universal testing, regulations should require developers to demonstrate compliance through risk-based auditing. A statistically significant percentage of homes from new developments would undergo seasonal post-occupancy testing for IAQ and overheating. If a development's sample fails to meet performance standards (e.g., CIBSE TM59 or EN 16798-1), it would trigger wider testing and require remedial action, thus incentivise developers to build for real-world performance from the outset.

3. Promote Hybrid or Mechanical Ventilation Integration: Challenges have been observed in the underperformance of passive natural ventilation in new homes, underscoring the need for careful consideration during the design phase. Where natural ventilation is likely to be insufficient to achieve desired indoor conditions, hybrid or mechanical ventilation strategies should be explored. Kitchen extraction systems should not only comply with the minimum airflow rate requirements (e.g., ≤ 30 L/s as outlined in the TGD Part F), but also be subject to routine performance checks over time to ensure ongoing pollutant removal efficiency during cooking, highlighted in the ALIVE study as a key source of indoor air pollution. These interventions would ensure that ventilation is not left to occupant discretion and reduce IAQ degradation.

4. Educate Occupants and professionals on energy and health: Occupant behaviour plays a decisive role in the performance of naturally ventilated homes. National awareness campaigns should be launched to educate residents on the effective use of trickle vents, purge ventilation and recognition of poor air quality indicators such as condensation, odours, or headaches. Simultaneously, industry professionals (including BER assessors, retrofit contractors and ventilation system installers) should receive updated training that includes ventilation commissioning, sensor-based verification and best-practice IAQ strategies. Integrating these modules into professional development pathways ensures a competent workforce that understands both energy and health outcomes.

5. Integrate IEQ into Energy Rating and Retrofit Assessment Tools: To ensure occupant health and comfort are not side-lined in the pursuit of energy efficiency, the national DEAP and NEAP frameworks should be expanded beyond static inputs to explicitly include IEQ performance indicators. While ventilation type and heating system efficiency are considered, these frameworks do not currently assess time-based or occupant-facing outcomes such as air quality or overheating risk. Metrics such as the number of hours CO_2 exceeds 1000 ppm, the percentage of occupied hours above 26°C, and ventilation performance (e.g., air exchange rates or purge capability) would provide a more complete picture of real-world performance. Linking SEAI grant eligibility to these combined energy and IEQ indicators would incentivise more holistic design decisions that balance energy use, indoor air quality, and thermal comfort. This is particularly important as retrofit activity scales up, with a risk of unintended consequences like poor ventilation or overheating in highly airtight homes. Pilot programmes using in-situ monitoring (CO_2, PM2.5, temperature, humidity) in A-rated homes can help verify the alignment between predicted and actual indoor conditions. These data can create a feedback loop to refine performance-based thresholds, support improved DEAP/NEAP methodologies, and inform future iterations of building regulations that prioritise occupant well-being alongside decarbonisation targets.

4 Implementation by Stakeholders

These policy recommendations will require a coordinated implementation approach across a range of sectoral stakeholders (Table 1).

5 Conclusion

Ireland's climate action ambitions require improvements to the energy related performance of Ireland's building stock. Recommended measures include retrofitting of poorly rated dwellings and the design and construction of new builds to reduce heat losses over time. However, such improvements should not come at the cost of occupant health and indoor environmental quality. The findings of the ALIVE project underscore a important gap between regulatory compliance and real-world performance, particularly in energy efficient homes relying on natural ventilation. To bridge this gap, policy must evolve beyond energy consumption metrics to embrace a more holistic framework that integrates measured IAQ, occupant behaviour, and seasonal performance. This requires updating building regulations, embedding ventilation standards in retrofit grant schemes, educating both residents and industry professionals and expanding BER assessments to reflect real-world indoor conditions.

By implementing the recommendations outlined in this paper, which are grounded in empirical evidence and aligned with best international practice, policymakers can ensure that Ireland's building stock is not only energy efficient but also healthy, and comfortable for residents. The latest recast of the Energy Performance of Buildings Directive (EPBD), published on 8 May 2024 and entering into force on 28 May 2024, formally introduces IEQ at the European level and embeds it across the building life cycle. Member States, including Ireland, are required to transpose the directive into national law by 29 May 2026. This means that optimal IEQ must be integrated into energy performance requirements for new buildings and major renovations, key IEQ parameters such as temperature, humidity, carbon dioxide, and particulate matter must be monitored through smart building systems, and energy performance certificates must reflect IEQ. This integrated, evidence-based approach is essential not only for delivering robust climate action, but also for protecting the planet and improving the quality of indoor environments where people live and work.

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Table 1: Implementation Actions for Stakeholders

Stakeholder	**Action(s)**
Department of Housing, Local Government and Heritage (DHLGH)	Update **TGD Parts F (Ventilation)** and **L (Energy)** to incorporate IAQ and overheating performance metrics.
Department of the Environment, Climate and Communications (DECC)	Support **policies** ensuring newly built homes **do not compromise health**.
SEAI (Sustainable Energy Authority of Ireland)	Modify **BER/DEAP methodologies** to account for pollutant concentration risk and dynamic thermal performance. Require pre- and post-retrofit ventilation assessments for grant recipients.
NSAI (National Standards Authority of Ireland)	Develop national performance standards for ventilation equipment, passive vent design and in-use compliance testing. Incorporate occupancy-linked ventilation modelling in **S.R. 54** and related guidance documents.
Local Authorities	Include overheating and IAQ risk assessment as conditions for planning permission in new builds and major retrofits. Enforce compliance with updated regulations via site inspections and occupancy-phase validation.
Construction Industry	Adopt standardised testing protocols for air exchange rates (AER) and pollutant levels. Develop products and services that meet new IAQ and adaptive thermal comfort standards.
Research Institutions	Refine data-driven and physics-based methods for optimising building performance. Translate findings into policy guidance for retrofit strategies and climate-resilient building stock development.

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References

[1] Ibrahim Alhindawi, James A. McGrath, Divyanshu Sood, James O'Donnell, and Miriam A. Byrne. A seasonal assessment of indoor air quality and thermal performance in naturally ventilated airtight energy-efficient dwellings. *Building and Environment*, 276:112862, 2025.

[2] Divyanshu Sood, Ibrahim Alhindawi, Usman Ali, Donal Finn, James A. McGrath, Miriam A. Byrne, and James O'Donnell. Machine learning based multi-objective optimisation of energy consumption, thermal comfort and CO2 concentration in energy-efficient naturally ventilated residential dwellings. *Building and Environment*, 267:112255, 2025. Publisher: Elsevier.

[3] Divyanshu Sood. *Evaluating the effects of occupancy on energy use and indoor environmental quality in residential building archetypes over spatial and temporal scales.* PhD thesis, University College Dublin. School of Mechanical and Materials Engineering and UCD Energy Institute, 2025.

[4] Ibrahim Alhindawi, Jorge M. Fernandes, James A. McGrath, Divyanshu Sood, James

O'Donnell, and Miriam A. Byrne. Temporal assessment of overheating risk and thermal environment in naturally ventilated energy-efficient airtight dwellings. *Journal of Building Engineering*, 113:114027, November 2025.