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Research

Innovation Voucher Report IV:20210423 Lennon Lines and Products Ltd

Lennon Lines
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Report of energy, health and environmental impacts associated with Passive Indoor Drying (PID) and mechanical convection (tumble) drying regimes. Presented in the context of energy & health attributes afforded by the Lennon Line outdoor drying system.

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1.0 Context and Research methodology

By its very nature, the practice of outdoor laundry drying in the Northern hemisphere is becoming increasingly unfeasible due to a variety of factors, e.g. inadequate and lack of secure, spacious and convenient drying facilities, people having to work away from the home during daylight hours as well as dealing with inclement and unreliable weather patterns. For this reason a greater dependency has been placed on the use of passive indoor drying practices (PID) and tumble dryers that can lead to raised moisture levels in the home, increased energy costs and potential exposure of occupants to a variety of illness as a result of poor indoor air quality otherwise known as sick building syndrome (SBS).

Currently, Irish building standards do not provide a specific set of guidelines as to how indoor drying can be adequately accommodated other than a remit for the provision of ventilation in buildings in order to reduce the content of moisture in indoor air. With the advent of low energy and sustainable buildings (nZeb), and the practice of building airtight envelopes, the ability for moisture to become trapped has been manifested with only those who have installed mechanical ventilation & heat recovery (MVHR) systems able to control moisture levels. This is of particular concern for dwellings that have been built pre-2006 and indeed much older dwellings that must encounter significant expenditure to reach amenable moisture (and energy) levels in accordance with the national Building Energy Rating (BER) mandate and retrofit programmes.

This report will seek to research, appraise and present the case for the Lennon line range of clothes drying products as a viable, energy efficient, sustainable alternative to traditional energy intensive machine drying and passive indoor drying (PID) practices. The report will also draw on insights from relative research studies with particular reference to the environmental , health (air quality) and sustainable (energy and Co2 savings) that can be reciprocated.

Addressing the widespread problems associated with passive indoor drying (PID) should be done so in tandem with a number of viable options such as improved efficiency of appliances, solar technology, capture and reuse of extracted heat etc….however all such options can be expensive. As a comparison, Lennon lines seek to present their outdoor clothes drying products as a viable and cost effective means of drying clothes unencumbered with issues of energy use , air quality and space restrictions.

2.0 Project Overview

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Objective: To audit and report primary energy, carbon, health and environmental impacts associated with both passive indoor drying (PID) and mechanical convection(tumble) drying systems. This to include a review of energy cost savings and health benefits that can be attributed over the lifetime of using an outdoor drying solution from the Lennon lines ltd product range of outdoor clothes drying solutions.

3.0 Mechanical tumble dryer working dynamics

The components and construction of dryers haven't changed that much in 30 years. Practically all tumble dryers operate on the same general principle. An electric motor rotates the drum filled with wet clothes, simultaneously driving the fan which circulates hot air through the drum. A heater heats the air, and a thermostat maintains the correct temperature. Water in the clothing evaporates due to **circulating hot air**. And what happens with this steam depends on the type of tumble dryer.

Size (European): The standard size of tumble dryers is similar to the size of washing machines. **Their width is usually 60 cm, depth ranges 60 - 65 cm and height 85 cm.** Similar to washing machines, the capacity of tumble dryers is also measured in kilograms. Most tumble dryers can dry **7 to 9 kg** of laundry, but other capacities are also available. However, bigger is not necessarily better. A larger drum for smaller quantities of clothes is not an optimal choice because the drying results will suffer somewhat, and the costs will be higher. In principle, **a tumble dryer with 7 kg capacity is enough for two people**, while a **four-member family needs a dryer with around 9 kg capacity**. In washer dryers, the capacities of washing and drying are different. If, for example, the capacity of washing is 9 kg, the capacity of drying is around 6 kg. This also means that one full washing load has to be dried in two parts, which takes more time.

Size (US): A standard-sized dryer in the US would be considered (>4.4 cubic feet) The motor turning the drum and fan of a dryer typical to this size is approximately 200 to 300 watts. The heater draws about 5 kW of electrical power or 20,000 to 25,000 BTU/hr of gas. This heats 100 to 150 cfm of air to a temperature of 93 °C – 150 °C, (200°F to 300°F). The air cools to approximately 32 °C – 75°C., (90°F to 170°F) as it evaporates water from the clothes and is then vented outdoors.

A typical drying cycle has two main stages, a bulk drying stage and a high-heat stage.

During the bulk drying stage, the exhaust air is usually 32°C-48°C. (90 to 120°F) and 60 to 80% relative humidity. These conditions are relatively constant for the bulk-drying stage, which lasts 15 to 40 minutes (depending on the amount of water in the clothes) as most of the water is evaporated. The heater may stay on continuously through the bulk drying stage or it may cycle on and off. About 2/3 of the heat energy evaporates water and about 1/3 is heating the air that is drawn through.

4.0 Tumble Dryer types.

For the basis of this study, the primary distinction between tumble dryer types is the technology used in their manufacture, operational use and resulting energy consumption (output). Heating technologies are an important consideration as they have a strong influence on the dryers energy efficiency.

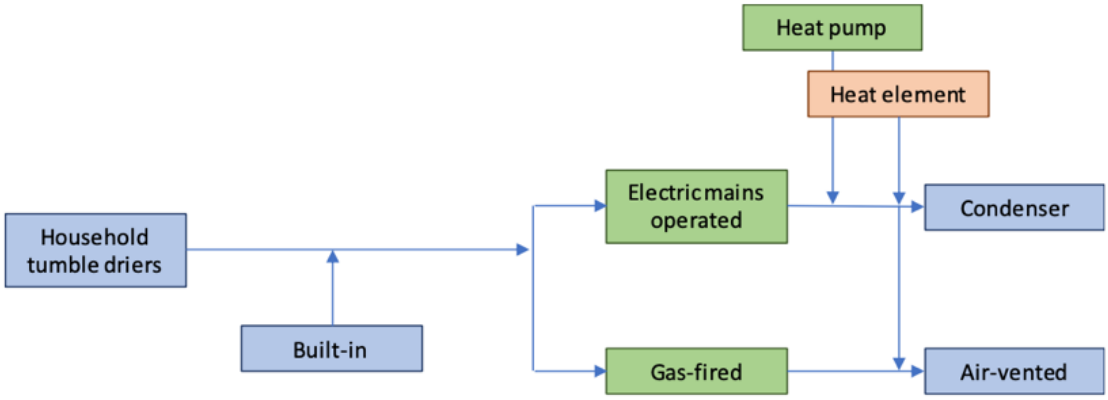


Figure 1: Overview of tumble dryer classification.

4.1 Air-vented tumble dryer

Air-vented tumble driers are the traditional type of drier, which draws in air from its surrounding room and then heats it and blow it through the clothes to remove moisture from it. The humid air is then exhausted through a ventilation duct in the wall to the outdoors. Hence the vented driers have to be fitted with a hose connected to a wall or window through which the humid air from the drum can be exhausted.

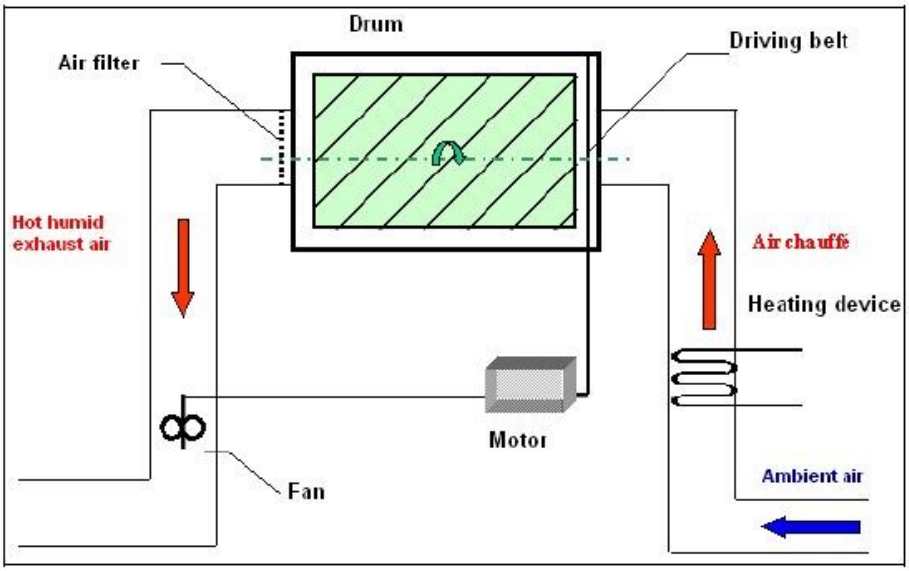


Figure 2: Air-vented tumble dryer functional profile.

4.2 Condenser tumble dryer: These dryers work by condensing the steam inside the machine with the help of outside air and turning it into water. This is collected in a removable container or tank, which is installed at the top or bottom of the dryer. The tank is easily removed and can be emptied into the sink when full.

4.3 Condenser tumble dryer with a heat pump. These dryers operate on a closed loop system whereby the air is heated by a heat pump and dry on lower temperatures to ensure gentle care of clothes . The heat pump allows for a fast exchange of temperature. Condensed steam extracted from the laundry evaporates into a tank while the cooled air used during the drying process is recycled and reused for a new drying cycle. This means that as much as four times less energy is consumed, and heat losses are minimised. it is also important to note that a malfunctioning heat pump tumble dryer constitutes hazardous waste because the heat pump contains gas for transferring heat energy that is generally harmful to the environment, thus it is important that such dryers are correctly and carefully maintained and operated.

4.4 Washer dryer: The combination of a washing machine and tumble dryer in one appliance is a compromise for an all-in-one laundry solution if space is an issue. Drying works on the same hot air circulation principle as with all the dryers, only that the washing and drying happens in the same drum and can be performed directly following the other upon selection of the relevant programme.

5.0 Tumble dryer penetration rate

There are a number of key legislative directives currently in place within the EU tumble dryer market that have influenced an uptake in the use of more energy efficient appliances in recent years. Such legislation has resulted in the energy class distribution of tumble driers evolving since 2013 with heat pump condenser driers presenting the largest shift and the most efficient driers. Since 2018 penetration rate of household tumble driers in the EU has been calculated at **24.7%,** counting on a total number of households in the EU of approximately **217 million**. This penetration rate is expected to increase to **28.3% by 2030**. (1)

A summary of the percentage share of each type of dryer in the EU market is expressed below indicating a rise in energy efficient models adopting heat pump technology and thus better energy efficiency capabilities attributable to energy efficiency regulatory standards put in place.

Stock, million units		2000	2005	2010	2015	2020	2025	2030
Condenser	Heat pump	0.00	0.00	0.44	7.27	21.18	34.89	44.61
	Heat element	24.82	29.38	31.26	29.09	25.17	21.45	18.73
Air-vented	Heat element	17.31	20.71	19.61	15.16	10.67	7.63	4.70
	Gas-fired	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Total		**42.15**	**50.10**	**51.32**	**51.53**	**57.03**	**63.98**	**68.18**
Penetration rate		**NA**	**NA**	**25.0%**	**24.2%**	**25.8%**	**27.7%**	**28.3%**

Figure 3:EU stock of tumble dryers 2000 to 2030: Ref: EU report: Review study of household tumble driers: 2019. Note: Data for gas fired dryers did not form part of this study.

Data shows that heat pump technology has become prevalent in the EU with a market share increase from 31% in 2013 to 51% in 2016. This has been at the expense of the electric heat element tumble driers, both the condenser and the air-vented type. In 2016 the market share of heat element condenser driers was 34%, down from 49% in 2013, whereas the air-vented market share decreased from 20% to 14% in that same period. The gas tumble drier market share is in the range of 0. 1-0. 2% per year, corresponding to less than a thousand units per year.

Sales, %		2005	2010	2015	2020	2025	2030
Condenser	Heat pump	0%	9%	47%	57%	65%	80%
	Heat element	59%	64%	37%	32%	28%	20%
Air-vented	Heat element	41%	28%	16%	11%	7%	0%
	Gas-fired	0%	0%	0%	0%	0%	0%
Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Figure 4: Heat pump market share trajectory 2005 - 2030

These are figures that are being replicated throughout the EU including Ireland, as households become more energy conscious and seek to change their dryer to a more energy efficient appliance once their current solution has reached end of life. Figures released by the Energy Saving Trust (UK) home appliance site (TopTenUK.org) show that picking the top-rated A+++ dryer models can potentially save the consumer more than £750 in running costs over the lifetime of the appliance based on a 160 cycles per year making a class B or C dryer economically unviable by comparison.

Consumers need to factor in the overall cost of ownership (operational & maintenance) of a tumble dryer appliance over its lifetime. For example, the Energy Trust outlines an example by stressing that although a B rated appliance such as the Aquarius TCM580BP condenser seems like a bargain at upfront costs of £240, its lifetime costs in reality stack up to £1,413. When this is compared with a A+++ appliance such as the Grundig GTN38267GCW heat pump dryer which has a prohibitive purchase price of £650, but a lifetime running cost of £981 (70% less energy consumption compared to C rated appliances), then the myth of buying low (cost) to saving money over the lifetime of the appliance is questionable. More and more households are now beginning to realise that buying lower rated appliances does not prove more economical than buying a A+++ rated appliance, hence the explanation for the year-on-year increase in sales of energy rated heat pump dryers.

In terms of the demographic of tumble dryer ownership that exists in context to household gross income, a survey conducted (UK) in 2020 concluded that 36% of surveyed households in the lowest ten percent income bracket owned a dryer and 73% reported owning a dryer in the highest ten percent income group with a national average of approximately **56-60%** reported.

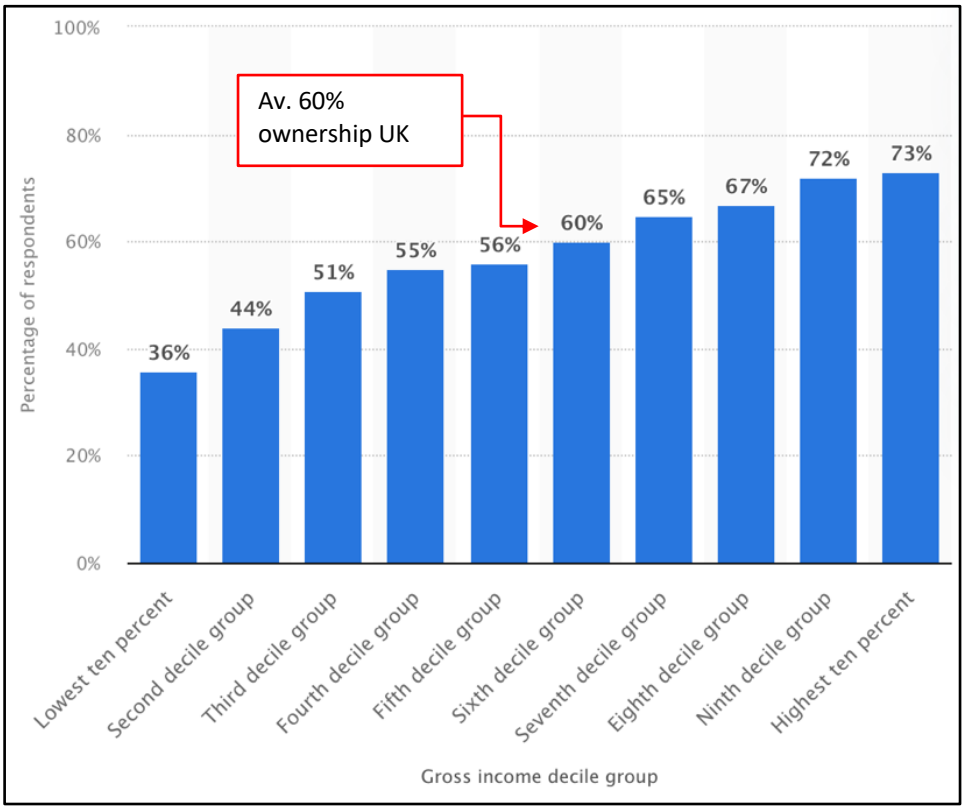


Figure 5: Percentage household dryer ownership UK: 2020

By contrast, in Ireland the national average of households that use a tumble dryer has been presented in Central Statistics Office (CSO) yearly reports as being in the 60% bracket. It must be

noted that the most recent report outlined a 2015- 2016 dryer usage estimate of 64.8% (slightly down from 2009-2010 estimates of 66.2%)

	2004-2005	2009-2010	2015-2016
			%
Household appliances			
Vacuum cleaner	95.5	94.5	94.9
Tumble dryer	61.7	66.2	64.8
Washing machine	95.3	96.3	97.5
Dishwasher	50.1	63.2	64.7
Refrigerator	43.4	26.1	25.6
Refrigerator with freezer	63.4	79.4	81.6
Separate deep freeze	35.4	35.3	36.1
Microwave oven	86.0	91.0	91.7
Television set	99.2	97.2	96.5
One TV set only	50.5	32.4	41.0
Two or more TV sets	48.7	64.8	54.5
Home computer	56.2	77.3	80.8
One home computer only	*	*	29.9
Two or more home computers	*	*	50.9
Games console	29.2	38.9	38.1

Figure 6:: Irish Central Statistics Office (CSO) yearbook 2017 report: Percentage of households using select household appliances, 2004-2005, 2009-2010, 2015-2016.

At a pan-European level, heat pump dryers that exist in the <200, 220 – 225, and 225 – 250 kWh/year energy consumption bracket have all made an overall increase in market size share while more inefficient dryers in the >250 kWh/year interval have steadily decreased. Overall the market share of the three lowest intervals ***<200, 220 – 225, and 225 – 250 kWh/year increased from 44% to 73%*** (2013-2016) and has been consistently high year-on-year to the present date due to public awareness of cost savings attributed to dryers in the 200 – 250 kWh/year thresholds.

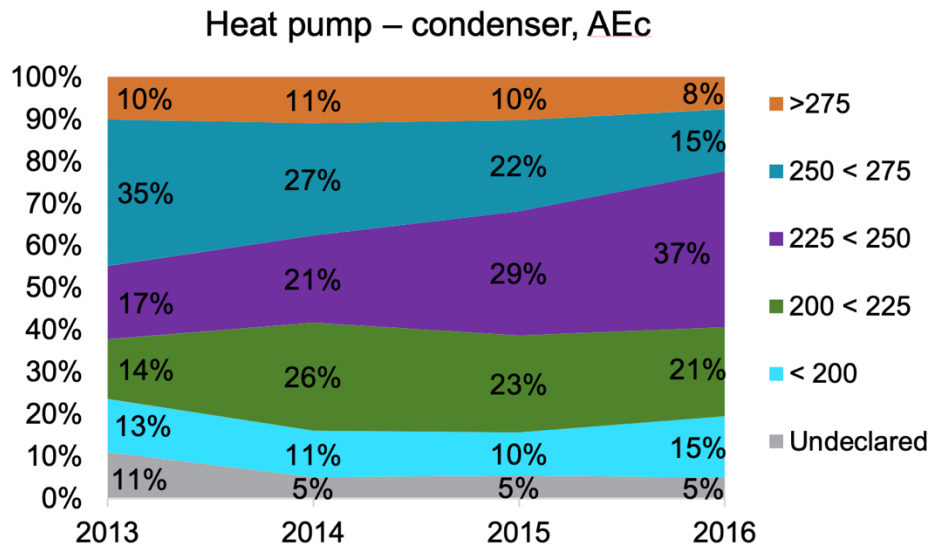


*Figure 7: Distribution of annual energy consumption for heat pump dryers (2013 – 2016) outlining a gradual increase in market share for the 200 - <275 kWh/year energy consumption threshold: Ref: **Review study of household tumble dryers report**: EU Directorate-General for Energy Report, June 2019.*

6.0 Overview of relevant legislation influencing tumble dryer efficiency

6.1 EU Directive 2009/125/EC. – Eco-design for energy-related products.

The Eco-design Directive provides consistent EU-wide rules for improving the environmental performance of energy-related products placed on the EU market. The directive's main objective was to provide a framework for reducing the environmental impacts of products throughout their entire life cycle. It also sought to influence improvements in environmental performance through mandating changes at the product design stage.

6.2 Commission Regulation (EU) No 932/2012 – Eco-design requirements for household tumble driers.

This regulation establishes energy efficiency requirements for electric mains-operated and gas-fired household tumble driers and built-in household tumble driers, including those sold for non-household use. The Regulation does not apply to household combined washer-driers and household spin-extractors. The requirements in the Regulation have been introduced in two tiers which are:

From 1 November 2013:

o The energy efficiency index (EEI) shall be < 85 for all household tumble driers

o The weighted condensation efficiency shall be ≥ 60% for condenser

household tumble driers

• From 1 November 2015, for condenser household tumble driers:

o The energy efficiency index (EEI) shall be < 76

o The weighted condensation efficiency shall be ≥ 70%

Besides these specific requirements, the Regulation sets out some generic requirements. These are requirements regarding the use of standard programme for the different calculations as well as information requirements.

- The basis for calculating the energy consumption and other parameters, are set to a cycle that dries cotton laundry with an initial moisture content of 60%, down to a moisture content of 0%
- This cycle shall be clearly identifiable on the programme selecting device as the "Standard cotton programme".

- This cycle shall be set as the default cycle for tumble driers with automatic programme selection functions.

o If the program is selected automatically with switching on the drier, then the standard cotton cycle shall be preselected at switch on automatically.

6.3 EU Regulation 2017/1369 :Framework for energy labelling and replacing Directive 2010/30/EU

Energy label showing their energy efficiency rating, with different labels for electric air-vented, gas air-vented and electric condenser appliances. As of May 2013, the most efficient tumble driers carry an A+++ label. In 2017, the EU agreed clearer energy efficiency labelling rules, by moving from the current A+++ to G scale to an A – G energy scale in order to simplify the criteria for consumers.

7.0 Parameters that influence the energy consumption

The performance of a dryer in the context of this report will be primarily based on two key parameters:

- The annual energy consumption (AEc)
- The condensation efficiency (C).

Both these parameters are defined in the EU Commission Regulation No. 932/2012 and Commission delegated regulation No. 392/2012 and reflects consumer behaviour related to the use of the tumble dryer.

7.1 Consumption

All household appliances bear energy labels. Similar to other household appliances, tumble dryers are rated into seven classes, from A to G, depending on their energy efficiency. **Class A is the most energy efficient**, while class G is the least efficient. Appliances that receive a letter grade from A to C are considered energy-efficient, whereas appliances that consume considerable amounts of energy are labelled with classes from D to G. Heat pump tumble dryers can also carry **labels A +++,** which means that they are that much more efficient compared to the regular A energy class because they dry laundry at substantially lower temperatures compared to other dryers. Letter grades can also be followed by **plus signs**. **Each plus means 10% lower consumption** compared to the A class.
The annual energy consumption of a dryer is based on measurements of energy consumption and the cycle time specific to that dryer. These measurements are conducted with the standard cotton program reducing the moisture content of a test fabric from 60% to 0%. The measurements are

made with both full load and partial load and includes the assumption that for every 7 drying cycles, the machine is full loaded 3 times and part loaded 4 times.

In summary, energy labelling regulations require that the energy consumption of today's tumble dryers are defined by the following parameters:

- Energy consumption pr. cycle at full and half load
- Time duration pr. cycle at full and half load
- Energy consumption in off-mode
- Energy consumption in left-on mode
- Time the drier takes to switch automatically to off-mode after being in left-on mode, once a drying program is finished (when drier counts with a power management function)
- The standard energy consumption of the drier used as reference value, which is calculated from the drier's rating capacity; this includes a penalization factor for air- vented driers

7.2 Condensation efficiency

The condensation efficiency is stated on the energy label of every new tumble dryer. The better the condensation efficiency of the dryer, the less moisture it expels into the surrounding area which is important to mitigate the impacts of excessive moisture such as mould growth. The condensation efficiency is only relevant for condensing driers (incl. heat pump dryers), and not for air-vented appliances (including gas dryers). Condensation efficiency is labelled with letter grades from A to G. In summary, the condensation efficiency of tumble driers in eco-design and energy labelling regulations is defined by the following parameters:

- Percentage of water collected pr. cycle at full and half loads
- Sample weight of water in clothes before and after the drying process
- Number of test runs

Furthermore, the assumption concerning the distribution between full and half load also plays an important role on the calculation of the energy efficiency: For every 7 drying cycles, the machine is full loaded 3 times and half loaded 4 times.

7.3 Sensor Technology

Automatic sensor technology has become a feature of the majority of tumble dryers that are being manufactured today enabling sensors to detect when the laundry load is dry and thus stopping the machine accordingly. This has the dual benefit of avoiding clothes from being over-dried and also of preventing the appliance from continuing to run unnecessarily and wasting energy. A tumble dryers

sensory system will need some regular maintenance and cleaning to ensure that it performs to its optimal level to successfully detect how wet the clothes are and therefore how much drying time is needed.

8.0 Where is the energy used during tumble drying cycle.

During a typical tumble drying cycle the following 'energy' specific processes take place.

- Energy to heat the air, provided by electricity and/or gas (natural or propane) in order to:
    1. Evaporate water from the clothes
    2. Heat the clothes
    3. Heat the metal (and plastic) components of the dryer.
    4. Heat the air that is exhausted from the dryer.

- Energy to rotate the drum and to circulate the air within the dryer.
- Energy to power & operate dryer controls and any standby mode energy when not in use.
- Energy to condition the room air that is used and vented by the dryer, or equivalently, energy to condition the outside air sucked into the room to replace air vented by the dryer.

The tumble drier unit consists of multiple components which can be of different types and qualities. The following components and their configurations have a major influence on the energy consumption of the dryer:

- The motor type and setup
- The presence of variable speed drives for fans and drum motors.
- The controller, including humidity sensor components.
- The drum design and sealing method.
- The cleaning of lint filters and heat exchangers.

Loading of the dryer by the consumer can also influence the specific energy consumption of the appliance in terms of the energy used per kg of dried laundry.

According to input from industry, a fixed energy is required to heat up the drier itself, regardless of the amount of loaded laundry. This increases the specific energy consumption at partial loads (partial meaning not loaded at 100% nominal capacity). Furthermore, as the drum volume is less full at lower loads, the drying air comes into less laundry surface area, which reduces the effectiveness of the drying and hence increases the energy consumption.

Some manufacturers use the same drum volume independently of the nominal capacity. The change in capacity is thus based on motor sizes and heating capabilities instead.

9.0 Dynamics of energy conversion (liquid to vapour state) during drying cycle.

Ultimately in laundering procedures, energy is used for the removal of water from the clothes. To understand the amount of energy used, it is necessary to understand the conversion process that is involved. In liquid water, hydrogen bonds are constantly being formed and broken as water molecules slide past each other.

The breaking of these bonds is caused by the energy of motion (kinetic energy) of the water molecules due to the heat contained in the system. When heat is applied in a dryer, the higher kinetic energy of the water molecules causes the hydrogen bonds to break completely and allows water molecules to escape into the air as water vapour or steam.

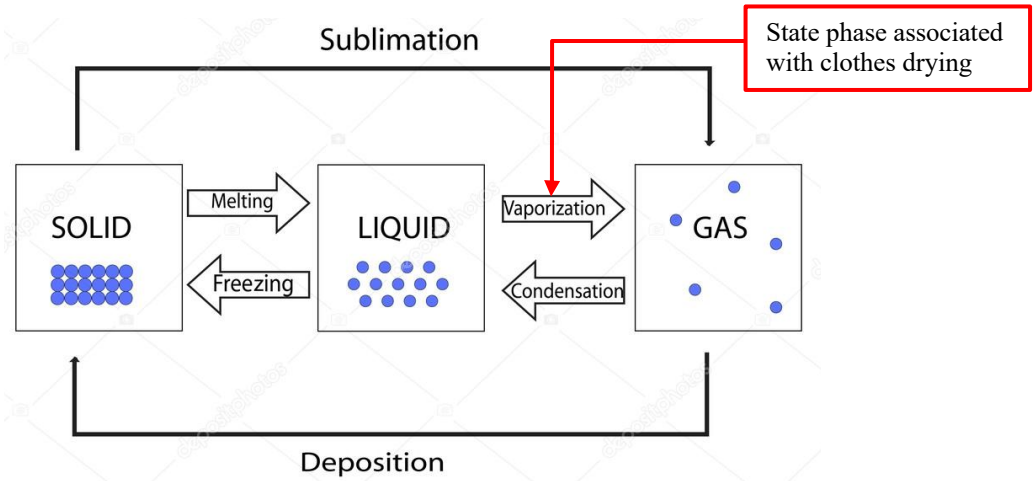


Figure 8: Schematic diagram of water vaporization during the drying process.

Vaporization is defined as the amount of heat needed to turn 1g of a liquid into a vapour, without a rise in the temperature of the liquid.

Heat is a measure of energy transfer. Specific heat capacity is defined as the amount of heat (in calories) required to raise the temperature of 1 gram of water by 1 degree Celsius. Water has a specific heat capacity of 4182 J/kg°C. Any energy put toward heating water is split between breaking bonds and heating the water which makes it possess a higher heat capacity (and thus uses more energy) compared to other substances.

10.0 Understanding the labelling on tumble dryers

Energy labels carry the following information:

- Brand name
- Suppliers model number
- Energy efficiency class

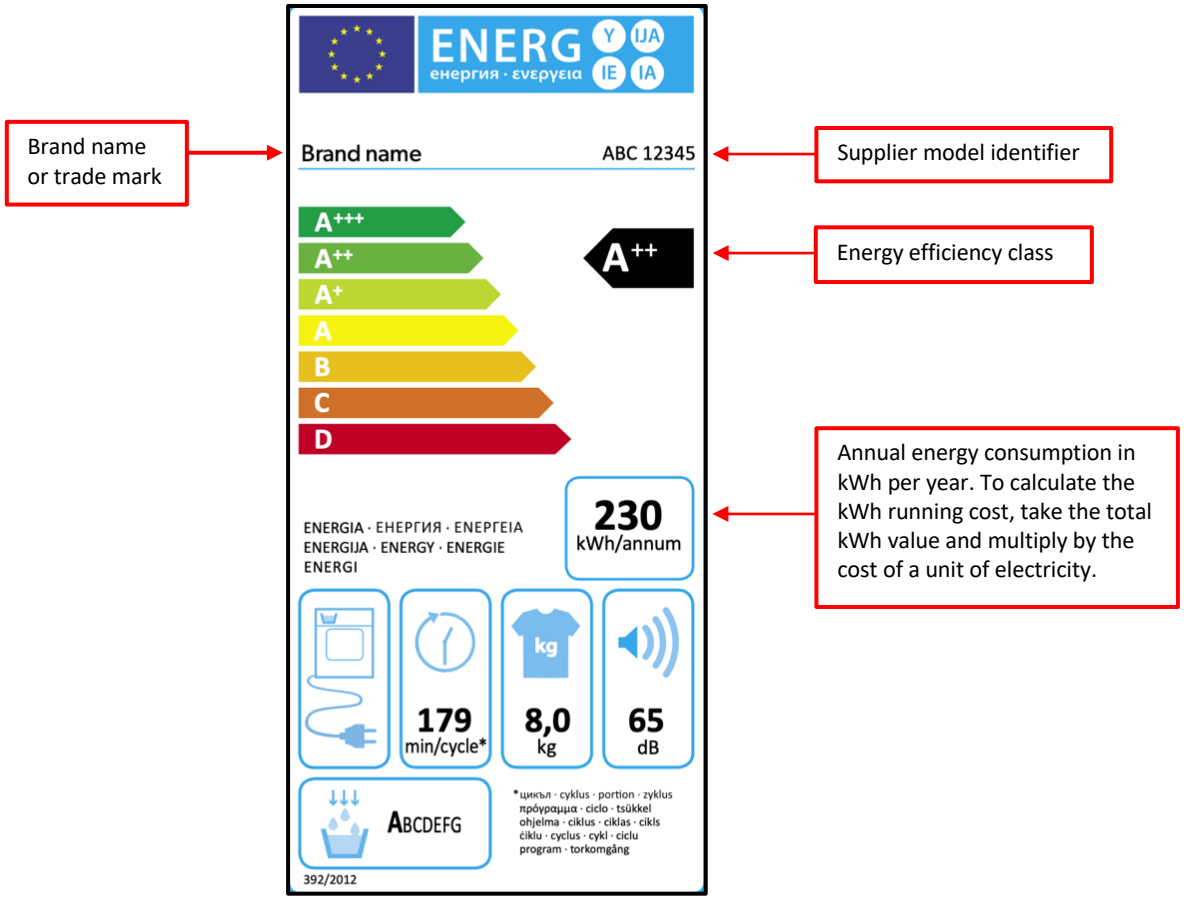


Figure 9: Energy label sample tumble dryer

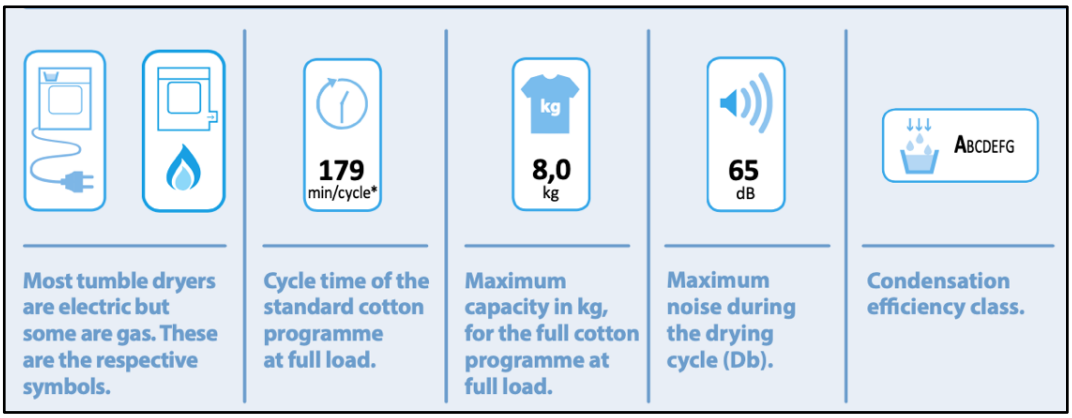
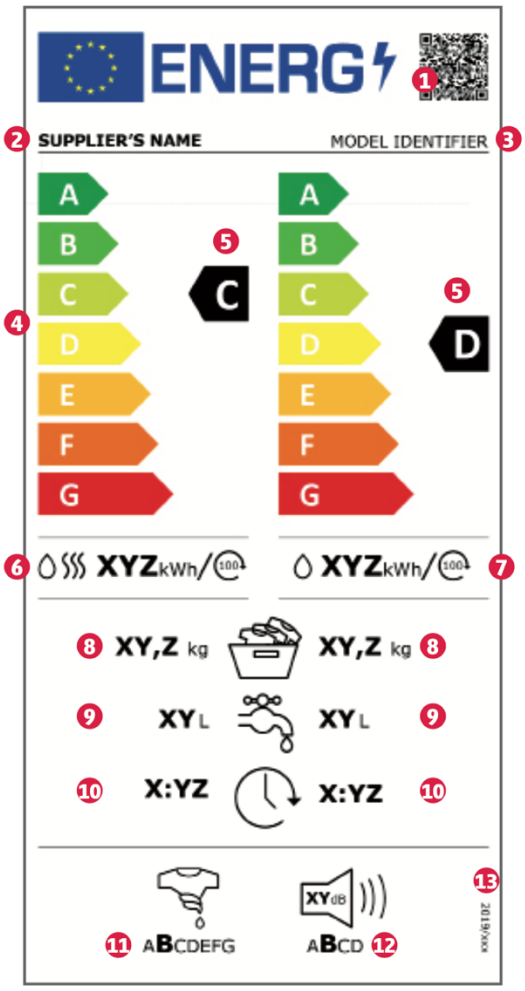


Figure 10:Ref SEAI public information document: 'Understanding the labels on tumble dryer'/.

11.0 Understanding the labelling for washer dryers.

From 1 March 2021 washer dryers were distributed differently among the energy classifications. The new label is split into two columns. The right-hand column shows the values for the washing cycle only. The left-hand column shows the values for the complete operating cycle 'washing & drying'.



1. QR code
2. supplier's name or trade mark
3. supplier's model identifier
4. scales of energy efficiency classes from A to G for the complete cycle (on the left side) and for the washing cycle (on the right side)
5. energy efficiency class for the complete cycle (on the left side) and for the washing cycle (on the right side))
6. weighted energy consumption per 100 cycles in kWh, for the complete cycle (on the left side))
7. weighted energy consumption per 100 cycles in kWh, for the washing cycle (on the right side)
8. rated capacity for the complete cycle (on the left side) and for the washing cycle (on the right side)
9. weighted water consumption per cycle in litre, for the complete cycle (on the left side) and for the washing cycle (on the right side);
10. cycle duration at rated capacity for the complete cycle (on the left side) and for the washing cycle (on the right side);
11. spin-drying efficiency class,
12. airborne acoustic noise emission class of the spinning phase of the eco 40-60 programme and value in dB(A) re 1 pW and
13. number of this Regulation

Washer-dryers are subject to new eco-design regulations. For the complete operating cycle (washing and drying), the new energy consumption requirements mean that as of 1st March 2024, all G-class and some F-class washer-dryers may no longer be placed on the market.

Energy Efficiency Class	Energy Efficiency Index (EEI_{WD})
A	$EEI_{WD} \leq 37$
B	$37 < EEI_{WD} \leq 45$
C	$45 < EEI_{WD} \leq 55$
D	$55 < EEI_{WD} \leq 67$
E	$67 < EEI_{WD} \leq 82$
F	$82 < EEI_{WD} \leq 100$
G	$EEI_{WD} > 100$

Figure 11: Energy efficiency classes of the complete cycle of a household washer-dryer.

12.0 Factors influencing tumble dryer energy costs.

A widespread perception had existed for a long time that all dryers are similar in energy usage, with no great value in urging consumers to purchase one model over another. Our research has found that this perception is not true. Consumer understanding and awareness has changed considerably in recent years on the back of appliance efficiency mandates such as the 2010/30/EU directive for energy labelling of household appliances. The energy labelling regulation has been more influential than the eco-design regulation, because the energy label has created the market pull necessary for the observed market transformation from conventional heating elements driers to heat pump driers. The visual reference of an energy label is now of significant relevant to the public when purchasing tumble dryers, with 33% of the consumer market anticipating that the label will be a crucial consideration next time they purchase a tumble dryer, while 49% anticipate that the label will be a priority in their decision.

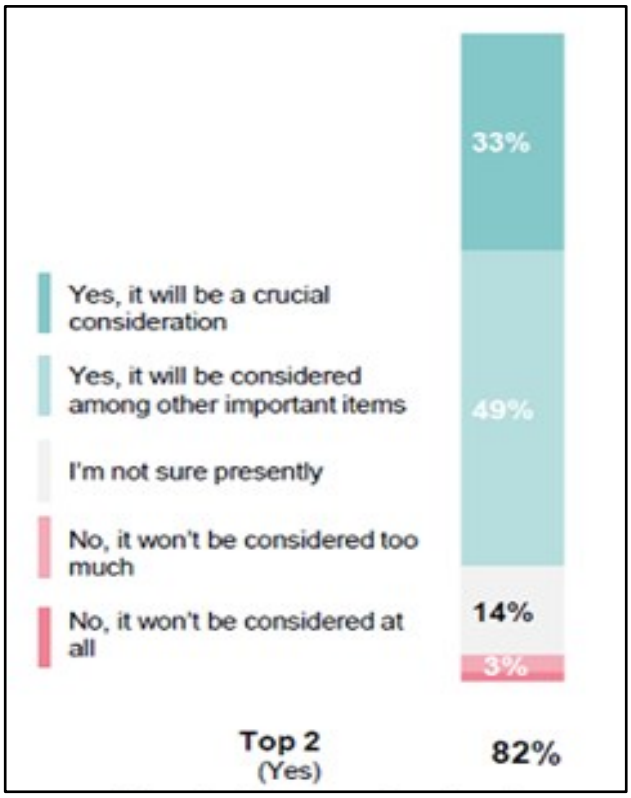


Figure 12: Tumble dryer usage and attitude: A survey in 12 European countries: APPLiA: Home appliance Europe, March 2018.

As outlined earlier in this report, the market share of energy efficient appliances has increased significantly in recent years. An understanding of 'actual' percentage share of appliances in the <200, 220 – 225, and 225 – 250 kWh/year appliances in Ireland remains unknown. If we are to assume that the Irish households dryer use remains at 65% in line with the CSO statistics (dated 2015-2016), then

we would need to differentiate as to what portion of this amount exist for the various efficiency ranges. Such information would necessitate a national survey to be conducted encompassing all user demographics including business, residential, hospitality etc…

On a pan -European level however, that picture is much clearer with evidence of increased sales witnessed year-on-year for condenser (Heat pump) units since 2010 and a decline in heat element and gas-fired units as outlined in the following table outlining derived tumble dryer sales from 1990 to 2030.(1)

Sales million units		1990	1995	2000	2005	2010	2015	2020	2025	2030	
Condenser	Heat pump	-	-	-	-	0.34	2.22	3.05	3.60	4.46	**Increase**
	Heat element	3.55	3.55	3.44	2.38	2.54	1.78	1.68	1.55	1.11	Decrease
Air vented	Heat element	0.14	0.14	1.06	1.66	1.11	0.75	0.59	0.39	-	Decrease
	Gas-fired	0.001	0.001	0.001	0.001	0.001	0.000	0.001	-	-	Decrease
Total		**3.70**	**3.70**	**4.50**	**4.04**	**3.99**	**4.74**	**5.32**	**5.53**	**5.57**	

Figure 13:European tumble dryer sales 1990-2030: Ref: Review study of household tumble dryers report: EU Director - General for Energy Report June 2019.

12.1 Dryer annual energy consumption expectancies (kWh/year)

Comparative energy costs can be made based on the reported and advertised energy rating of a particular appliance and the highlighted energy consumption rate in kWh per year as stipulated by the appliance manufacturer in accordance with the A+++ to G energy labelling scale.

Example: The A++ rated 8kg heat pump dryer will use 230 kWh/year based on the official rating standard, this is less than 2kWh per load (1.43 kWh). In the EU, the estimated energy consumption is based on '***160 cycles of a combination of full and partial loads on a standard cotton programme'.*** That's equates to approximately 3 dryings per week (160 No. Cycles / 52 weeks = 3.077). To estimate the annual energy cost for that dryer it is a matter of multiplying the annual energy consumption (230kWh) with the national average cost of electricity per kWh.

As outlined previously, dryer type (gas – vented – electric-vented and condenser) also play a major influence in determining energy efficiency and overall annual energy consumption.

Cycle times for a full cotton load (min) are lower on vented dryers as they go up to higher degrees than condenser models and dryer capacity is usually determined by how much a tumble dryer can handle on a standard cotton drying cycle and can change depending on the programme selected.

Therefore, in order to gain a true understanding of the energy efficiency of any given dryer model, there are quite a number of variables that need to be taken into consideration. As well as this the life expectancy of the dryer appliance will directly influence its economic viability and justification over a Lennon line outdoor drying product. Again, many variables are at play here including the quality of the dryer manufacture, the regularity of operation and maintenance applied, what preventive measures are taken to avoid dryer exhaust 'lint build-up', as well as how well sealed the door remains during its lifetime to name just a few…

12.2 Tumble dryer lifetime expectancy

The UK Whitegoods Trade Association (https://www.whitegoodstradeassociation.org/) have acknowledged that 'white' goods in the home are no longer manufactured to be as durable as in previous generations. The reality is that for many the "they don't build them like they used to" adage applies to new appliances including tumble dryers with many believing that as prices for white goods have fallen, so too has quality of manufacture.

The Whitegoods trade Association go on to say that over the previous two decades ,electrical appliance prices have, in real terms, dropped largely due to consumer and retailer demand for lower-cost appliances. The reduction in prices has had several effects on the appliances themselves and a massive effect on the industry in general. In general terms most appliances including dryers are usually designed with what is known as a '***Mean Time Till Failure (MTTF)***' ranking, which means exactly what the saying implies, i.e the average duration (years) that the machine will operate for in terms of hours running and the drying cycles run before something breaks and the product reaches the '***end of useful life'*** status. Depending on the quality of the dryer, the amount of use it is given and how it is used will influence at what point it is liable to fail.

In the context of this report to draw parallels to the Lennon line range of outdoor drying products, we need to assume an industry recognised "lifetime span" for electrical tumble dryers. Our research has highlighted that from within an EU context, such a figure has been discussed at length and was determined that the lifetime of tumble dryers was ***13 years on average, with a deviation of 1.78.*** (2). This balances with other reports https://www.hrblock.com/tax-center/lifestyle/how-long-do-appliances-last/ which suggest a MTTF of between 10-13 years.

13.0 Electricity threshold index – Ireland

The most recent electricity usage figures for Ireland, produced by the commission for Regulation of Utilities (CRU), outline that ***4,200kWh*** is now the "official" average annual electricity usage for households in Ireland representing a typical 3-4 bed semi. (3).

Property Type	Annual Usage Kwh	Annual Bill	Monthly Bill	Bi-Monthly Bill
1 / 2 Bed Apartment	2100	€1020	€85	€170
1/ 2 Bed Apartment (All Electric)	5000	€1924	€160	€321
2 Bed Semi	3000	€1300	€108	€217
3/4 Bed Semi	4200	**€1674**	€139	**€279**
3/4 Bed Detached	6000	€2238	€186	€373
5/6 Bed Detached	8000	€2861	€238	€476

Figure 14: Anticipated average Irish household electricity expenditure from August 2020

To estimate the 'average' cost of a household bill for electricity we have applied rates from ***'Electric Ireland'*** which currently charges ***28.12 cent per kWh*** and a standing charge of €272 including vat (June 2020). This equates to an approximate annual household bill of ***€1,453.04.*** This unit rate will see an increase by ***11.35%*** from August 2022 whereby the standard unit rate will increase to ***31.3 cent*** including VAT. (Note: VAT on electricity is temporarily reduced from 13.5% to 9% until October 2022.)

This rise in cost of electricity to the consumer will see household bills increase to an average cost of ***€1,674 / year*** or €279 for each 2 monthly bill from August 2022. *(Ref: Money guide Ireland: July 2022).* From a EU perspective, the weighted average price of electricity to the Irish household

consumer has since 2016, fluctuated above and below the Euro Area average and has grown by 18% in S2 of 2021, some 13% higher compared with S2 0f 2020.

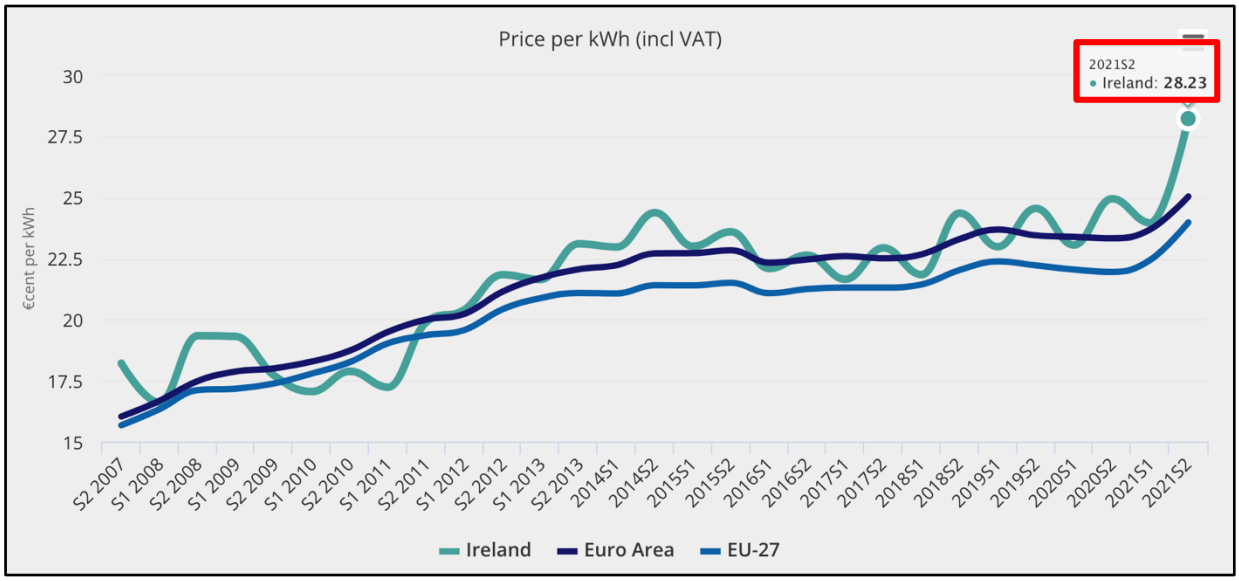


Figure 15: Average household electricity prices per kWh incl. of Vat. Ref: Sustainable Energy Authority of Ireland (SEAI): 2021.

Figures for the cost of running Irish household appliances prepared by An Board Gais Energy, highlighted that the tumble dryer is place second only to electric showers in terms of the most energy intensive appliance in the home reporting a cost of €1.70/hr (8500W shower) and €1.00/hr (5000W tumble dryer) respectively. With an average energy usage of 4.5kWh per cycle (Ref UK Energy Savings trust).

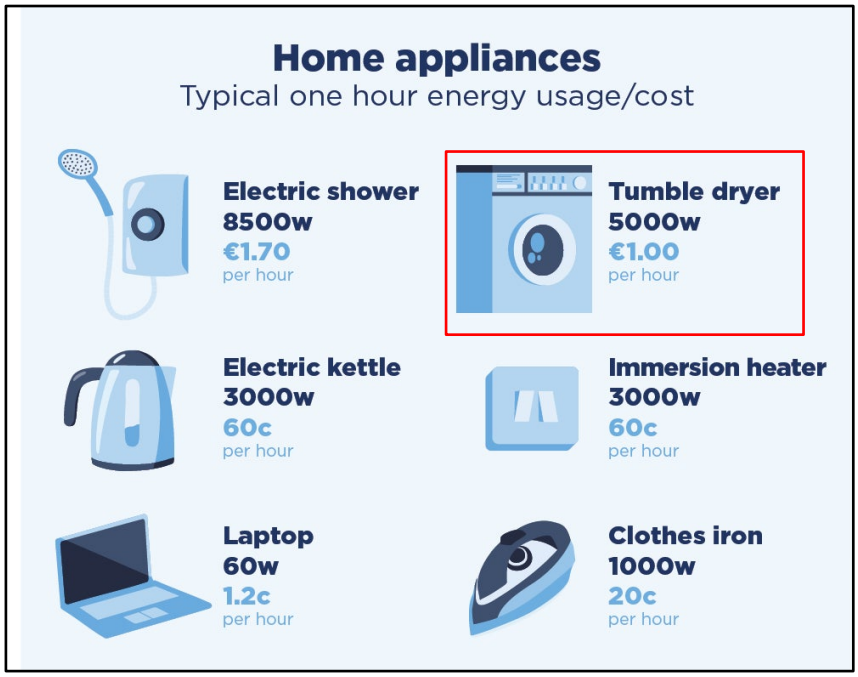


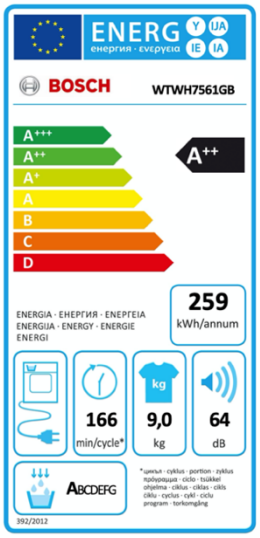
Figure 16:Ref An Board Gais Home Energy solar energy guide.

As outlined above, the actual kWh usage for a tumble dryer per full load cycle is an estimate that is based on multiple variables ranging from energy label rating - to - age of dryer model. To understand to what extent tumble dryers are energy inefficient compared to natural outdoor passive drying systems similar to that made by Lennon lines necessitates a comparative model exercise to be demonstrated on a 'case-by-case' basis.

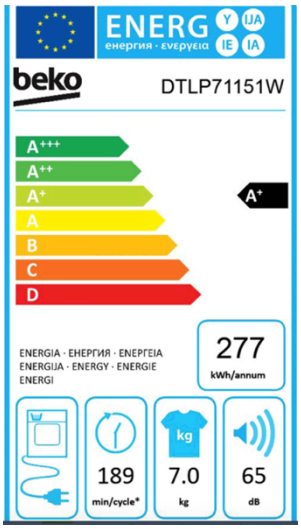
14.0 Overview of chosen energy rated dryers

To do this, we will evaluate the energy efficiency of 4 energy rated dryers commonly found in the consumer market. Details of the chosen dryers are as follows:

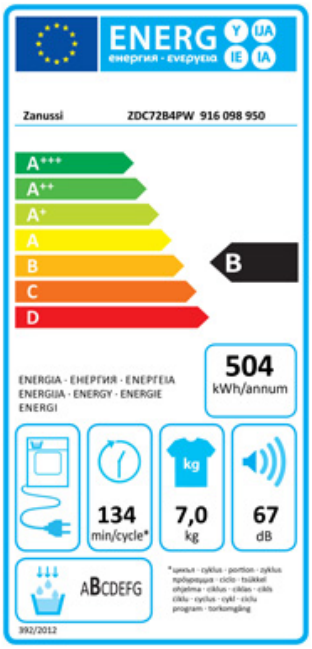
14.1 Bosch WTWH7561GB:



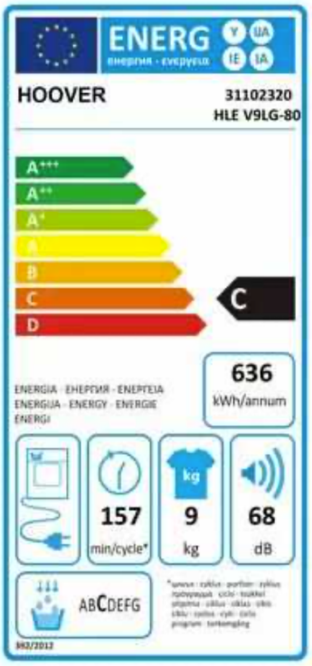
14.2 Beko DTLP71151W



14.3 Zanussi ZDC72B4PW 916098950



14.4 Hoover HLEV9LG-80



15.0 Overview of dryer energy cost (incl. initial outlay) over lifetime (13yrs).

Model	Price (€)	Energy label rating	Capacity (kg)	Condensation efficiency	Annual Energy usage (kWh)	Annual Energy cost (€)	Lifetime energy cost incl. initial outlay (€)
Bosch WTWH7561GB	499	A++	9 kg	Class A (91%)	259	72.83	**€1,445.80**
Beko DTLP71151W	409	A+	7kg	Class B (81%)	277	77.89	**€1,421.57**
Zanussi ZDC72B4PW	489	B	7kg	Class B (81%)	504	141	**€2,331.42**
Hoover HLEV9LG-80	299	C	9kg	---	636	178.84	**€2,623.96**

Figure 17:Dryer Initial outlay & energy consumption cost over appliance lifetime (13 years).

Note:

- Standard unit rate electricity applied ***28.12 cent per kWh*** (Electric Ireland) : July 2020
- Lifetime / *Mean Time Till Failure (MTTF)* : **13 years.**
- Annual estimated energy consumption **(kWh)** is based on 160 cycles of a combination of full and partial loads on a standard cotton programme in accordance with the EU 2017/1369 framework for energy labelling (as outlined on the dryer products energy label statement)

16.0 Lennon Lines range of outdoor drying products

The Lennon line range of outdoor drying products ranges from uncovered mobile clothesline concepts to enclosed ***'all weather'*** outdoor drying solutions of various sizes and are summarised as follows.

Product name	Cost (€)
Lennon uncovered mobile clothesline	**€360.00**
Urban deluxe premier	**€1,190.00**
7.5ft x 6.5ft All-weather enclosed	**€1,390.00**
10ft x 6.5ft All-weather enclosed	**€1,490.00**
12.5 ft x 6.5ft All-weather enclosed	**€1,590.00**
15 ft x 6.5ft All-weather enclosed	**€1,690.00**
17.5 ft x 6.5ft All-weather enclosed	**€1,890.00**
20 ft x 6.5ft All-weather enclosed	**€2,090.00**

16.1 Lennon Lines outdoor drying line lifetime expectancy.

The Lennon outdoor clothes drying products are promoted as :

- Manufactured from rust-resistant, galvanised box iron frames that accommodate internal bracketing in order to avoid outside face welding that may interrupt with the galvanising protection of the steel.
- Use a unique louvre panel system comprising of variable sized unobstructed openings
- Use heavy duty corrugated 'clear' sheeting
- Being easily transported / moved via use of its wheeled feet attachments.

A lifetime or 'Mean Time Till Failure (MTTF)' declaration for their products are not mentioned in the advertising material. In terms of the nature of manufacture associated with galvanised dipped ,welded box frame structural components it can be reasonably understood that the expected lifetime of these products would equal and quite easily surpass that of a tumble dryers lifetime expectancy of 13 years. An argument could be made that the relative lifetime expectancy of a Lennon line product could indeed exceed that of a tumble dryer x 2 as the number of moving components are minimal and can be easily maintained and replaced if deemed necessary. In terms of cost differences, it is clearly evident that no energy costs are associated with their product and any outgoing costs comprise the initial purchase price and over the lifetime of the product any associated maintenance and/or replacement component costs that may arise. Assuming all things being equal in terms of anticipated costs for maintenance, the following table is a representation of the savings (monetary) that can be realised between an A+, B & C rated tumble dryer and a typical Lennon lines outdoor (passive)drying clothes dryer product.

1. **Lennon line** All weather Enclosure (15 ft x 6.5 ft)
2. **A+** rated Beko DTLP71151W tumble dryer
3. **B** rated Zanussi ZDC72B4PW
4. **C** rated Hoover HLEV9LG-80

Drying product Type	Initial outlay (€)	Annual Energy consumption (kWh)	Annual Energy cost (€)	Lifetime energy cost (€)	**Lifetime Initial outlay & energy cost (€)**
Lennon enclosure	€1,690.00	nil	nil	nil	€1,690.00
A+ rated dryer	€409	277	€77.89	€1,012.00	€1,421.00
B rated dryer	€489	504	€141	€1,833.00	€2,322.00
C rated dryer	€299	636	€178.84	€2,324.92	€2,623.92

Note: Calculated on a **13 year** lifetime / MTTF projection and a current electricity unit rate of ***28.12 cent per kWh.***

17.0 Carbon CO2 emissions offset

With households accounting for an estimated 60% of global carbon footprint, a significant potential to reduce CO2 emissions exists when it comes to laundering. A variety of studies have revealed that approximately one third of the greenhouse gases associated with clothing, occur during the 'use phase'…i.e. washing of textiles. When comparing the energy uses of different household appliances over the course of a year, it becomes evident how energy-hungry even the most efficient tumble dryers can be. According to Carbon Footprint, an A+ fridge-freezer used 24 hours a day will produce 116kg CO2; an A-rated washing machine used 187 times will generate 51kg CO2; and a dishwasher used 135 times at 65°C will create 84kg CO2. The **A-rated** tumble dryer reviewed by the Energy Saving Trust, used 3 times a week, highlighted that it would approximately ***160kg CO2 per year.*** Over three times that of a washing machine, and double that associated with boiling a kettle.

Appliance	Usage	Assumptions	Cost per year	kg CO_2 per year
Microwave Oven	96 times per year	0.945 kWh per use (based on 1.39 kWh for full power and 0.5 kWh for defrosting)	£9.07	39
Washing Machine	187 washes per year	EU energy label A-rated gives an average consumption at 40°C using a 2kg load to be 0.63 kWh	£11.78	51
Electric Tumble Dryer	148 uses per year	2.50 kWh per cycle Based on an average load capacity of 4.76 kg of dry laundry	£37.00	159
Kettle	1542 uses per year	0.11 kWh per use based on heating 1 Litre of water	£16.90	73
Gas Oven	135.1 uses per year	1.52 kWh per use	£7.60	38
Gas Hob	424 uses per year	0.9 kWh per use	£14.12	71
Electric Oven	135.1 uses per year	1.56 kWh per use	£21.08	91
Electric Hob	424 uses per year	0.71 kWh per use	£30.10	129

Figure 18:Carbon Footprint study: https://www.carbonfootprint.com/energyconsumption.html

This simple table shows that a tumble dryer that operates 148 yearly cycles at 2.5kWh per cycle equates to 370kWh / year. Equivalent to the creation of 159kg CO2 per year (0.429kg per kWh). Assuming this approximate figure of **0.429kg per kWh**, the following anticipated kgCO2 projections can be determined.

Drying product Type	Annual Energy consumption (kWh)	CO2/kg produced
Lennon enclosure	nil	nil
A+ rated dryer	277	118.83
B rated dryer	504	216.21
C rated dryer	636	272.84

18.0 Impacts of tumble dryers on secondary energy systems

During the use phase, tumble dryer use can affect the ambient room temperature and condition for the room in which it is located , but that effect happens to different extents depending on the tumble dryer type used. As the drying process is done at elevated temperatures, heat transfer through convection to the room is to be assumed for all types, depending on the amount of insulation present in the drier. For non-air-vented driers, leakage of humid air is also to be expected at varying degrees. The net energy contribution to the ***secondary system (inhouse climate)*** depends on whether the drier is located in a heated room or not. Studies have shown that 59% of existing tumble driers in 2018 were located in a heated room. (1)

As already stated in this report, moisture can be leaked to the room due to non-perfect condensation processes but air-vented driers do not have this problem, as all moisture is vented to the outside environment. This leaking moisture can in severe cases lead to structural damage and/or mould especially if the drier is situated in small non-heated rooms where the moisture can condensate to droplets on cold walls. If placed in a heated room, the requirements for increased ventilation would naturally add to the energy consumption of the local space heating systems. Dryers that have heating elements have generally lower condensation efficiency compared to driers with heat pumps (91% of heat pump dryers sold in 2016 had condensation efficiency labels B or better, while only 47.2% of dryers with heating elements achieved this level of condensation efficiency). For air-vented tumble dryers, if the dryer is located in a heated room, then it uses the temperate indoor air as air supply, which after being heated in the machine, is vented to the ambient. This means that cold ambient air (especially in northern Europe) needs to replace the vented air. This air needs to be heated through the space heating system, giving rise to an additional energy consumption related to the use of the tumble drier, if the drier is located in a heated room.

Using an air vented dryer also necessitates drilling a hole through the building envelope which results in a passive leakage of energy throughout the year. In this instance, if a mechanical ventilation heat recovery system (MVHR) is installed in the building (i.e as is the case for Passive House construction), this hole can bypass a potential heat exchanger thereby increasing the household heat consumption for the dwelling.

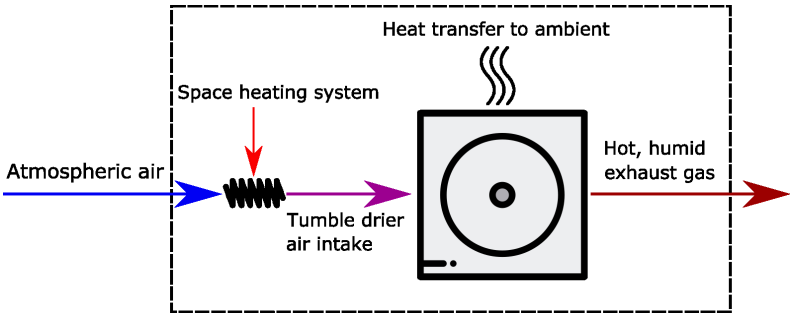


Figure 19: Secondary system impact associated with air-vented tumble dryers.

19.0 Indoor Air Quality

In recent years, a growing body of scientific evidence has indicated that the air contained within residential homes and other buildings can be more seriously polluted than outdoor air and is not restricted to just urban locations. Other research indicates that a significant percentage of people are spending approximately 90% of their time indoors, thus making them more susceptible to the effects of potential indoor air pollutants. Such groups include the young, the elderly and those impacted by illness including sufferers from respiratory or cardiovascular disease.

While pollutant levels from individual sources may not pose a significant health risk by themselves, most homes have more than one source that contributes to indoor air pollution. There can be a serious risk from the cumulative effects of these sources.

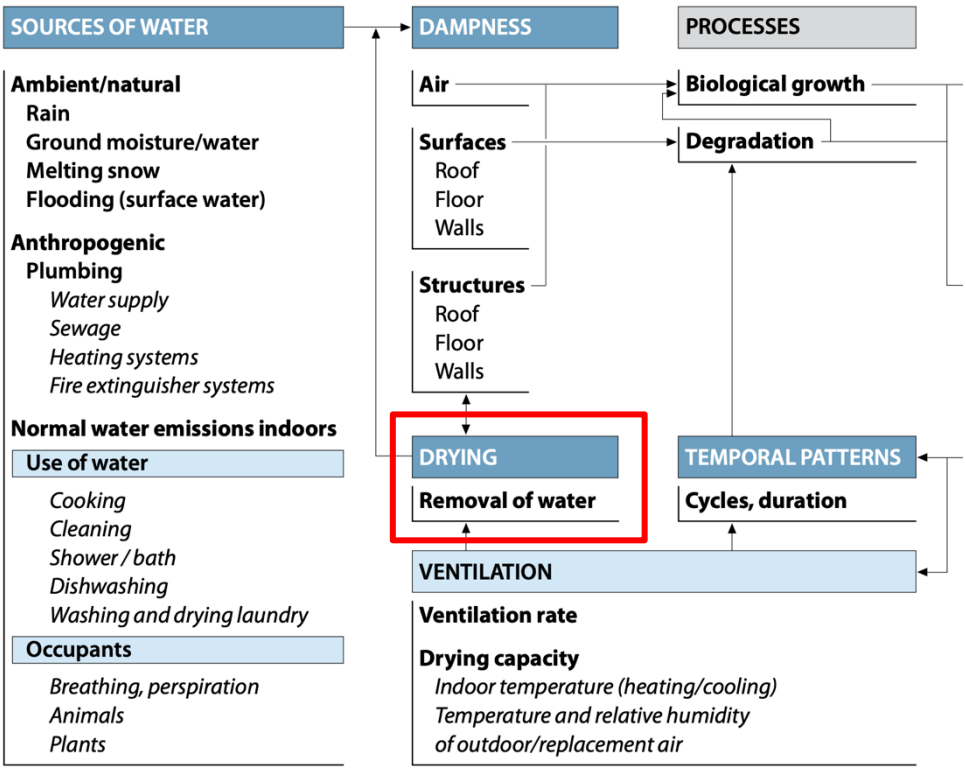


Figure 20: Pathways linking sources of dampness with health implications for occupants within the built environment. Indoor laundering and drying regimes are recognised as a key contributor in this regard: Ref: ***Indoor Air Quality and Mould Issues*** *: World Health Origization (WHO) report 2009.*

As the Irish government continues to work with the house building industry to build new dwellings to meet escalating demand, there has been a number of significant policy changes made in recent years to increase the availability of nearly zero energy building (nZEB) dwellings in the housing market. Rather than homes being zero carbon, there has been a primary focus on energy efficient fabric and services rather than integrated renewable generation in setting the standards. This

approach has led to houses being built with high levels of insulation, minimum air loss and technologies incorporated to minimize energy and water usage.

A national (UK) study of the effects of feedback on domestic energy use (4) discovered that there were considerable differences in energy use between similarly constructed homes. It was expected that energy use would be affected by occupancy levels, age, income level and the energy Standard Assessment Procedure (SAP) score of the building but the study revealed there was no appreciable link between any of these. This report concluded that although there has been much progress made in energy efficiency in the last few years by building homes that are more sustainable, the way people '***behave***' and '***use***' energy needs to however, be fully researched if there is to be further progress made against targets.

Central to occupants behaviour in these new energy efficient and airtight homes is their behaviour with regards to laundry. In particular clothes drying; a seemingly ubiquitous task which can lead to potential health consequence to the dwelling occupants.

20.0 User behaviour

The main parameters affected by user behaviour that are important to the energy and condensation efficiency of household tumble dryers are:

- The average number of cycles per week
- The loading of the dryer per cycle, i.e. how much is the machine filled in average with respect to its rated capacity
- The time the machine is left on '***left-on'*** mode by the user before it is switched off .
- The cleaning frequency of lint filter and heat exchanger is important to ensure consistent performance of the machine, as failing to regularly do so will increase the energy consumption per cycle.

21.0 Overview of indoor clothes drying specific building standards & regulations:

In the context of what is permissible to ensure adequate ventilation standards are achieved in new builds in Ireland, Part F of the Second Schedule to the Building Regulations 1997 is amended to read as follows:

Means of ventilation.	F 1	Adequate means of ventilation shall be provided for people in buildings. This shall be achieved by a) limiting the moisture content of the air within the building so that it does not contribute to condensation and mould growth, and b) limiting the concentration of harmful pollutants in the air within the building.
Condensation in roofs.	F2	Adequate provision shall be made to prevent excessive condensation in a roof or in a roof void above an insulated ceiling.

Figure 20: Part F Technical Guidance Document: Ventilation

Part F section 1.1.3 stipulates that…..***"The means of ventilation should be capable of providing a satisfactory indoor air quality for human respiration in occupied areas of a building by"*** :

- rapidly diluting pollutants, including odours, and water vapour to levels which do not pose direct or indirect health risk;
- removing excess water vapour from areas where it is produced in significant quantities, such as kitchens, utility rooms, bathrooms and shower rooms so as to reduce the likelihood of creating conditions that support the growth of mould, harmful bacteria, pathogens and allergens;
- removing harmful pollutants from areas where they are produced in significant quantities;
- providing an adequate supply of fresh air for persons using an area in a building;
- dispersing residual pollutants and water vapour.

Building regulations provide very little guidance specifically on clothes drying internally. Changes to **Part L** (Conservation related to fuel & energy) have been made with an aim to achieve cost effective abatement in the construction of new buildings and to stimulate more on fabric focused learning and use in order to achieve energy savings.

Part F 'Ventilation' has a primary focus on ensuring dwellings are built sufficiently to achieve health and well-being, control odour, airborne pollutants and excess humidity. It sets out various strategies

that should, if applied correctly ensure good ventilation regardless of the level of air tightness in new homes, yet it does little to address the issues caused by passive clothes drying internally and neither part F or L specifically addresses the ongoing issue of drying clothes within dwellings.

In Northern Ireland and the UK, the ***Code for Sustainable Homes*** (CSH) went a step further by outlining specific recommendations and advisory guidelines centred on the provision of a desired provision for clothes drying in new homes. It did this by attributing 'credits' for the inclusion of a designated drying space / drying area that is secure and either designed for external or internal use. It also stipulated that internal rooms such as bedrooms, kitchens and living rooms are not allowed to incorporate drying spaces and that drying spaces must comply with part F of the building regulations in order to prevent mould and condensation from occurring. In 2010, the code was amended to re-define the 'drying space' to require an intermittent extract rate of 30 litres per second (30 l/s). Alternatively an outbuilding or an external secured space was considered to be acceptable. The CSH had not been mandatory for homes built privately, with emphasis being placed only on 'affordable' housing needing to meet level three of the code (although the CSH was withdrawn in 2015).

22.0 Air tightness impacts in domestic settings.

Building regulations in Ireland, England, Wales and Northern Ireland have required since 2006, mandatory air leakage testing of new homes to prove that they meet target air permeability standards. Within the regulation framework for building energy efficiency, poor air tightness can be responsible for up to 40% of heat loss from buildings (5). If air permeability is reduced from 10 cu m per hour, this gives 90kg of carbon savings per year per dwelling, which equates to 12,000 tons of savings per year in the domestic sector.(6)

With this tightening of building envelopes, reduction of ventilation rates, use of new building technologies and techniques, air tightness can be considered to be a contributing factor to the diminishing quality of indoor air. Since the introduction of Part F standards, there has been little time to assess the long term impact on building fabric and occupant health when living in such air tight environments with condensation now considered as a 'modern' building disease that has contributed to the escalation of the 'Sick Building Syndrome' phenomena.

23.0 Sick Building Syndrome (SBS)

Sick Building Syndrome (SBS) is an imprecise term that is used to describe those buildings in which there is a prevalence of a range of symptoms that can cause discomfort and a sense of being unwell

to its occupants. There is a high incidence of SBS evident in certain types of buildings, particularly those that are sealed and mechanically ventilated or air-conditioned. It must be noted for clarity in the context of this study's primary topic (that of indoor laundering), that SBS is a complex phenomenon, with much of the evidence of SBS being circumstantial, with no single underlying cause being more specific or challenging than another. Rather, the causes are multi-factorial and inter-related.

Contributing factors to the prevalence to SBS include high temperatures, low relative humidity's, inadequate ventilation, insufficient fresh air supply, poor lighting and a lack of negatively charged ions. Airborne pollutants such as chemicals, dusts, fibres and microbiological contaminants may have toxic, pathogenic, irritative or allergenic effects with pollutants originating from building occupants (e.g. respiratory carbon or tobacco smoke), from building fabric and/or furnishings through "off-gassing", involving the gradual releasing of gases and vapours such as formaldehyde from building materials, furniture, resins and house hold cleaning products.

Figure 21: Contributing factors to Sick Building Syndrome (SBS).

23.1 Sick Building Syndrome and indoor laundering

In terms of the contributing factors to SBS incidences in buildings that can be attributed to an 'indoor clothes drying regime', the most circumstantial impacts are those that derive from moisture and mould build up in a dwelling as a result of moisture release when drying clothes.

Most new homes in Ireland use automatic washing machines which when used sees much of the water being spun out at a high speed and drained away. Never-the-less, even the most efficient machines leave water in the fabrics to the extent that a typical 4kg load of 'spun' washing can emerge up to 2.2 kg heavier from the machine, the equivalence of approximately 2 litres of water.

The options that exist for domestic clothes drying currently comprise the following three options:

1. **Drying clothes outdoors:** The most traditional and conventional method for drying clothes involving pegging to an outside line either in a garden or communal space. Main advantages include the removal of water from the clothes in an outdoor setting outside of the buildings internal space and a reliance on solar energy to complete the drying process. Weather however, is notoriously an unpredictable factor alongside the variance in daylight (drying) hours that make outdoor drying difficult.
2. **Indoor clothes drying:** In order to dry clothes indoors there is a dependency on the use of energy to facilitate the evaporation of water. Clothes drying on radiators means that energy comes from the boiler and can detract from the energy used to heat the home. For clothes dried on a clothes rack indoors, the energy needed to evaporate the water comes from the ambient air in the room and the internal temperature will drop slightly to facilitate the effective drying of the clothes. In addition, the water which evaporates will fill the home and may appear as condensation on the windows or walls thus contributing to the establishment of mould, dampness and microbe growth.
3. **Tumble drying:** Involving the conversion of the clothes water content into vapour. By far the most energy inefficient method as they use considerable amounts of electricity to run. For example, clothes containing 2kg of water at 15°C would necessitate approximately 700kj of energy to heat it to 100°C and further energy usage due to steam conversion.

Despite an upsurge of public awareness about building energy efficiency and sustainable building practices, there still remains little evidence of any notable measures being introduced to current building regulations to 'specifically' counteract the impacts that indoor domestic clothes drying regimes can have on energy usage and moisture level build-up in the home. As a result, further discussion needs to be undertaken at a national level to investigate :

1. What regulatory measures can be best reviewed and further implemented to incorporate changes in designs of new builds to adequately provide for effective clothes drying regimes.
2. To what extent does indoor drying impact air quality & relative humidity leading to the incidence of Sick building syndrome (SBS) within the Irish domestic building stock.

The presence of many biological agents in indoor environments is due to dampness and inadequate ventilation. Excess moisture on almost all indoor materials leads to growth of microbes, such as mould, fungi and bacteria, which subsequently emit spores, cells, fragments and volatile organic compounds into indoor air. Moreover, dampness initiates chemical or biological degradation of materials, which also pollutes indoor air. Dampness has therefore been suggested to be a strong, consistent indicator of risk of asthma and respiratory symptoms. The health risks of biological contaminants of indoor air could thus be addressed by considering dampness as a risk indicator.

In this context it has been proven that clothes draped on drying frames or warm radiators can significantly raise moisture levels in the home by up to 30%, creating ideal breeding conditions for mould spores. Health impacts consequent to moisture release from clothes drying indoors have been proven to lead to the following conditions.

23.2 Aspergillus fumigatus spores

Aspergillosis is a condition caused from a fungal mould called aspergillus that is present in the air we breathe. Found outdoors and indoors, Aspergillus Fumigatus is caused through breathing in small spores of mould found in humid environments including damp buildings and dust.

Professor David Denning and his team from the National Aspergillosis Centre in Manchester in the UK, have in recent years issued a warning about the health impacts associated with drying clothes indoors. He and his team have concluded that there has been a significant rise in the number of patients who had inhaled Aspergillus fungal spores attributed to the increase in moisture levels in homes that help to create an ideal breeding condition for mould spores.

"One load of wet washing contains almost two litres of water, which is released into a room."

Prof David Denning National Aspergillosis Centre in Manchester

An underlying hypothesis supporting research findings has shown that damp textiles drying slowly over a period of several hours (up to a day or more in moist, cool climates such as Ireland), tend to be more potent in terms of fostering fungal spores compared to other producers of moisture that are more concentrated but prevail in shorter durations (also more convectively driven and often exhausted rapidly such as cooking). The prevalence of washing cycles at or below 40°C may also result in spores present in dirty laundry remaining active once clean. (7)

The below chart (Fig:3) outlines the results carried out using 22 No. case studies to identify mould spore concentration levels using the Colony Forming Unit (CFU) count measured in CFU/m3. It involved taking air samples from dwellings that performed a passive indoor drying regime over a sustained two week period.

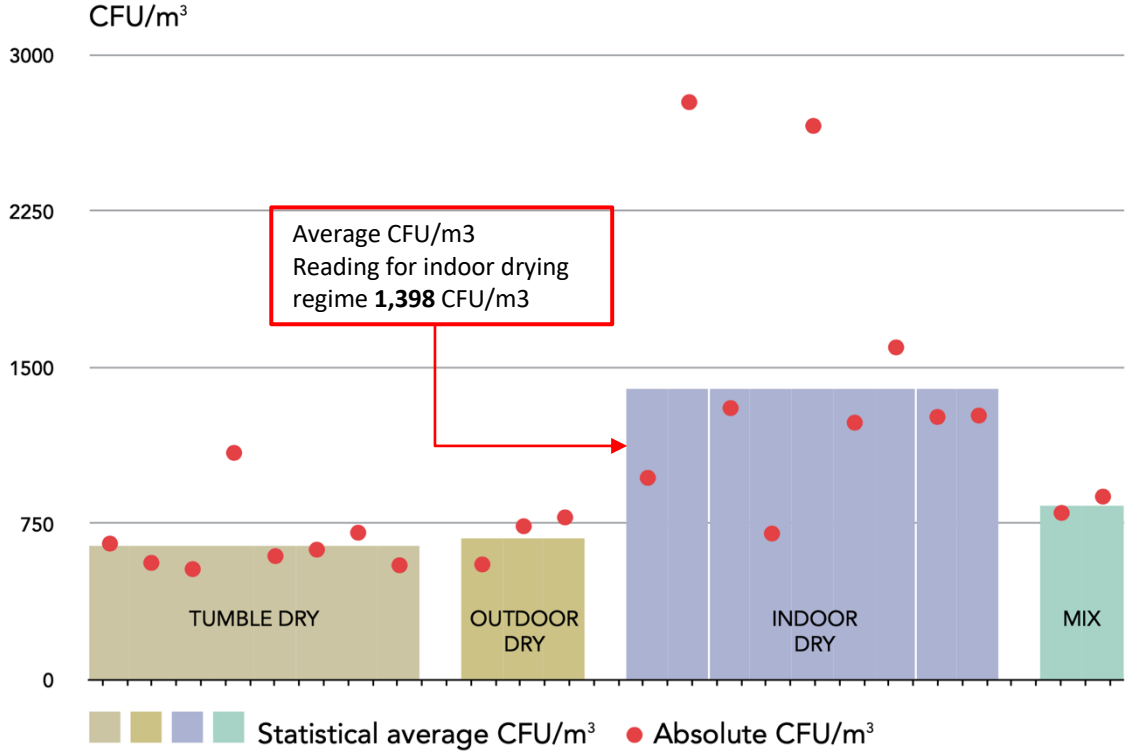


Figure 22: Mould spore concentration readings (CFU/m3) for predominant drying periods measured over a two week period in 22 no. dwellings.

Note: Colony-Forming Unit (CFU): *means that cfu/g is colony-forming unit per gram and cfu/ml is colony-forming unit per millilitre. A colony-forming unit is where a colony of microbes grow on a petri dish, from one single microbe. A value reading of* ***1,000 CFU/m3*** *(i.e colony forming units) or fungal spores would be considered to be excessive and a risk to human health* ***700-1,000*** *is 'moderately high',* ***500-700*** *'moderately low' and less than* ***500*** *is considered a low reading.*

The above chart highlights a distinct difference between indoor drying associated CFU count levels compared to drying regimes that utilised tumble dryers & outdoor drying methods. A reading of **1,398 CFU/m3** for washing that was dried passively indoors places this drying option in the 'excessively high' scoring rank.

The above readings indicate that the presence of damp material drying slowly indoors over a period of several hours tends to be more potent in terms of fostering fungal spores by comparison to alternative drying techniques such as using tumble driers or an external drying solution
Added to this, water soluble volatile organic compounds (VOC's) can also increase in concentration levels in parallel with increased humidity levels occurring in the home as a result of indoor clothes drying. One of the most common VOC's experienced in dwellings is that associated with emissions from formaldehyde residues that reside in multiple sources such as resins, cleaning products, timber particleboards and other common building and/or furnishing materials. In the US considerable research has been carried out to evaluate the association of passive indoor drying (PID) with fabric softeners and in particular acetaldehyde (classified as carcinogenic) associated irritations to scented laundry products emanating from tumble dryers. (8)

It is estimated that approximately 10% of the population can be adversely affected by laundry products, with particular impacts among asthmatics. Surfactants, phenol, bleach, dioxane, phosphates, ethylenediaminetetraacetic (EDTA) and nonylphenol ethoxylates (NPE) are examples of VOC's present in laundry detergents.

23.3 Textile Fragrances

A "***fragrance***" is a scent and is a formulation of chemicals intended to provide an aroma or mask an odour. Many fragrances are made up of volatile organic compounds (VOC's), with approximately 4000 ingredients having been documented for use in the composition of a fragrance. (9)

A "***fragranced consumer product***" is a product that contains an added fragrance or that is largely comprised of a fragrance. Fragranced products cover hundreds of everyday items, such as air fresheners, deodorizers, cleaning supplies, essential oils, candles, soaps, personal care products, colognes, hand sanitizers and more importantly in the context of this study's subject matter, ***laundry detergents and fabric softeners***.

"***Fragrance sensitivity***" is a health condition characterized by one or more types of adverse health effects from exposure to one or more types of fragranced consumer products.

Fragranced laundry products are reported to emit numerous volatile organic compounds (VOCs), including terpenes such as limonene with fragrance emissions known to be associated with health effects such as asthma attacks and breathing difficulties. Furthermore, fragrance terpenes are

primary indoor air pollutants that can react with other compounds and contribute to both indoor and outdoor air pollution.

Fragranced product emissions coming from an indoor drying regime is essentially unregulated and are not required to be fully and specifically disclosed on labels and/or safety data sheets. Therefore, in the context of this study it is worth highlighting that passive indoor drying can give way to exposure to such reported emissions over the long-term.

Literature reviews reported a number of findings concerning emissions derived from fragranced laundry products. (10) Among the general population from four countries researched, 32.2% of adults on average report fragrance sensitivity resulting in adverse health effects from exposure to a fragranced consumer product. Among vulnerable sub-populations, the prevalence of fragrance sensitivity is even higher with a reported 57.8% of asthmatic individuals and 75.8% of autistic individuals reporting adverse effects. Specific population exposure (weekly) is reported to come from laundry products (87.1%).

The Goodman study (11) investigated the concentrations of D-limonene emitted from residential dryer vents using fragranced laundry products and changes in concentrations after switching to fragrance-free products over a sustained 4 week period. After the 1 month period of trials using fragrance free laundry products was completed, D-limonene concentrations were reduced by up to 99.7% in dryer vent emissions and by up to 72.7% in laundry room air. This demonstrated the improvements to air quality that could be achieved if emissions from fragranced laundry could be avoided. It also indicated that formation and concentrations of secondary pollutants such as formaldehyde, acetaldehyde, and ultrafine particles occur when drying fragranced laundry indoors which can be best avoided by introducing one of two measures comprising:

1. A complete switch to fragrance free products (not possible due to consumer demand)

2. Offsetting a dependency and use of inadequately vented laundering activity entirely.

24.0 Environmental Assessment of domestic laundering

The Centre for Research on Indoor Climate and Health at Glasgow's Caledonian University and the Energy Systems Research Unit at the university of Strathclyde back up these finding having conducted a research study entitled "*Environmental Assessment of domestic Laundering*" (12). In this study they found that the main health risks associated with indoor clothes drying centred around moisture build-up in the home giving rise to high mould spore counts (leading to asthma, eczema etc), increased presence of dust mites and potential health impacts associated with hazardous carcinogenic chemicals being released via the use of fragranced fabric softeners. In particular, the study highlighted that the prevalence of an indoor clothes drying regime in Scottish domestic dwellings was attributed to high level of fuel poverty in populated urban environments compounded by inadequate or lack of proper outdoor drying amenities being available. In Glasgow alone, it was estimated that 87% of dwelling occupants dried clothes indoors during the heating season and that as much as 30% of the moisture build up in homes was as a result of clothes drying.

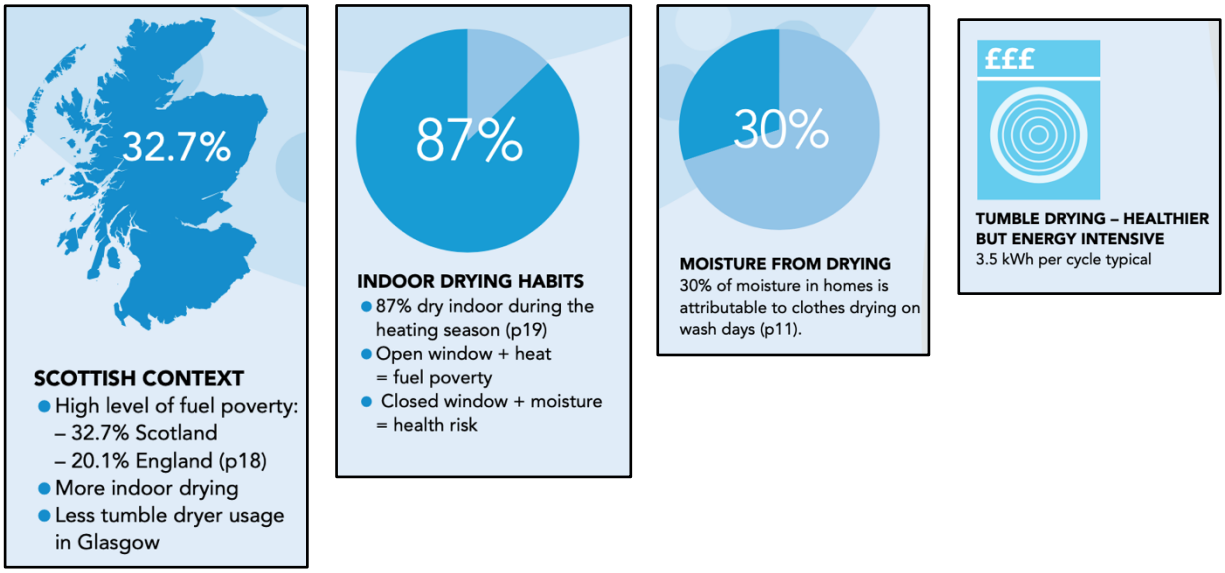


Figure 23: Overview of insights from the Scottish study "Environmental Assessment of domestic laundering"

In the context of the client company (Lennon lines) need to gain an insightful understanding of the impacts associated with passive indoor drying (PID) regimes, the Mackintosh report carried out by this research centre delved into the laundry drying habits across a large demographic mix of domestic households.

Figure 24: BBC Report of the Mackintosh Environmental Architecture Research unit study findings that 87% of Glasgow homes were found to adopt indoor clothes drying regimes during cold weather periods. https://www.bbc.com/news/uk-scotland-20176376

24.1 Mackintosh Environmental Architecture Research Unit (MEARU)

The Mackintosh report was conducted to investigate the issues associated with indoor domestic clothes drying across both private and social housing sectors in Glasgow, Scotland. This report and its findings can be considered as a good benchmark for typical Irish clothes drying habits (Urban setting) as both countries are exposed to similar daylight calendar's, weather related environments and urban population demographics. The report focused on the laundry habits across a wide demographic mix of residents and undertook a detailed analysis of air quality and energy consumption resulting from these habits. The report was carried out as a result of needing to highlight and address the following typical issues and scenarios that domestic laundering activity was experiencing:

1. Precipitation levels in Northern hemisphere are such that the opportunity for exterior drying and outside drying regimes are severely impacted by excessive moisture laden air levels.
2. Current ventilation provisions within housing do not address the problem of lengthy moisture spikes resulting from indoor drying, often relying on occupants to open windows and consequently facilitating the escape of indoor heat in cold weather.
3. The current trends towards nZeb airtight construction and spatially restrictive homes potentially intensifies the moisture build-up from all sources. Compounded with the lack of any current requirement in statutory building standards for a designated drying space to be enclosed, this issue leads to further moisture circulating within the dwelling.

4. Levels of fuel poverty in the northern hemisphere are already excessive and are currently facing unprecedented fuel and energy shortage impacts as a result of the impending energy crisis. Domestic heat loads experienced during drying cycles are making a bad situation worse with tumble drying being more energy intensive than the 'open window' approach to passive drying.
5. The study highlights a strong case for introducing an appropriate funding initiative in tandem with retrofit projects to address the problem associated with air & health quality impacts resulting from indoor passive drying regimes.

The study and its findings led to the preparation of a design guide to provide technical guidance an design upgrades to existing building stock so that energy consumption levels and any undesirable side effects with respect to air quality that may have health consequences to dwelling occupants could be addressed. The study involved the surveying, monitoring and analysis of the drying practices of 100 households between the months of March 2009 to January 2010. Backdrop to the findings included face-to-face interviews, questionnaires centred on laundry habits, analysis of heating bills, review of heating and ventilation provision within the designated households, measurements of temperature, CO2, and humidity levels. This was augmented with a keeping of diary accounts by a quarter of the residents that undertook the study, air sampling and the logging of washing machine & tumble dryer energy expenditures experienced.

Hygrothermal properties of flooring & furnishings materials were reviewed ,tested and measured for heat and mass transfer modelling as well as testing to determine moisture buffering potential for passive drying tasks. They were also able to dynamically model moisture transition and quantify energy consumption and humidity levels resultant from the dominant effect of ventilation and other influencers such as levels of insulation in the home, buffering ability of household materials and climate impacts.

In general terms, the survey outlined that housing provision (comprising all ages, forms and construction types) directly influence the diversity of the drying methods applied within them. Passive indoor drying (PID) was the dominant approach to drying clothes and highlighted overwhelming evidence that improper means for isolating and exhausting moisture, mould spore, odours and VOC's existed.

Interestingly, only half of the respondents in the surveys conducted had access to outdoor or covered semi-indoor drying options with issues such as lack of security and adequate washing line space being the primary setbacks to avail of an outdoor drying capability.

Key findings from the report are outlined under the following subheadings, but in general terms the attitudes to drying clothes indoors was presented as follows.

1. 87% of those surveyed (out of a 100 no. participants in the study), conformed that they employed passive indoor drying, 64% of which stipulated that they dried clothes on or near to heat sources.
2. On average 23% had reported that they boosted their heat to 'speed up' or facilitate a quicker drying time broken down as follows, 19% in autumn, 21% in winter & 32% in spring.

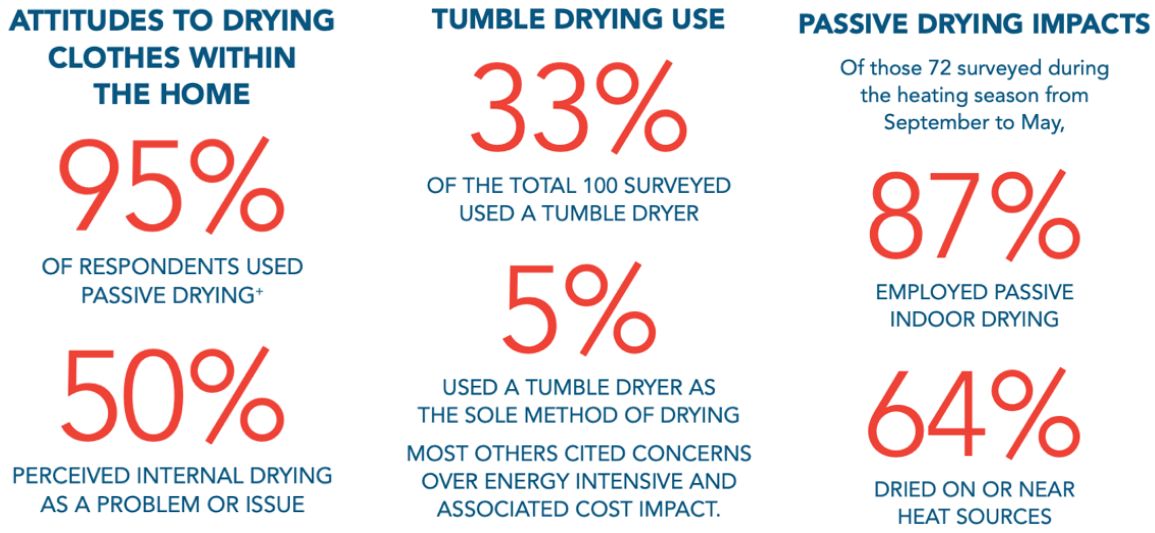


Figure 25: Overview of Passive Indoor Drying (PID) findings from the survey of 100no. households.

3. Room temperatures needed to be raised by approximately 3°C in the presence of damp laundry in order to keep relative humidity (rh) levels constant within dwellings.
4. 64% had access to mechanical extraction in their bathrooms but 34% did not know if the extract was manual or automatic. 42% had this extraction in their kitchen. The use of window trickle vents by themselves is not enough to mitigate the presence of damp laundry leading to people opening windows thus impacting heating routines and increasing energy consumption.
5. Some 2.0 – 2.5 litres of moisture are released into the home for a full 15-17 item wash load when washes were carried out at a mean temperature of 21°C and RH of 47.5% under specific conditions.

Spot data measurements carried out in the homes to determine temperature and relative humidity levels enabled the vapour pressure (VP) levels to be determined in kPa to denote absolute moisture level.

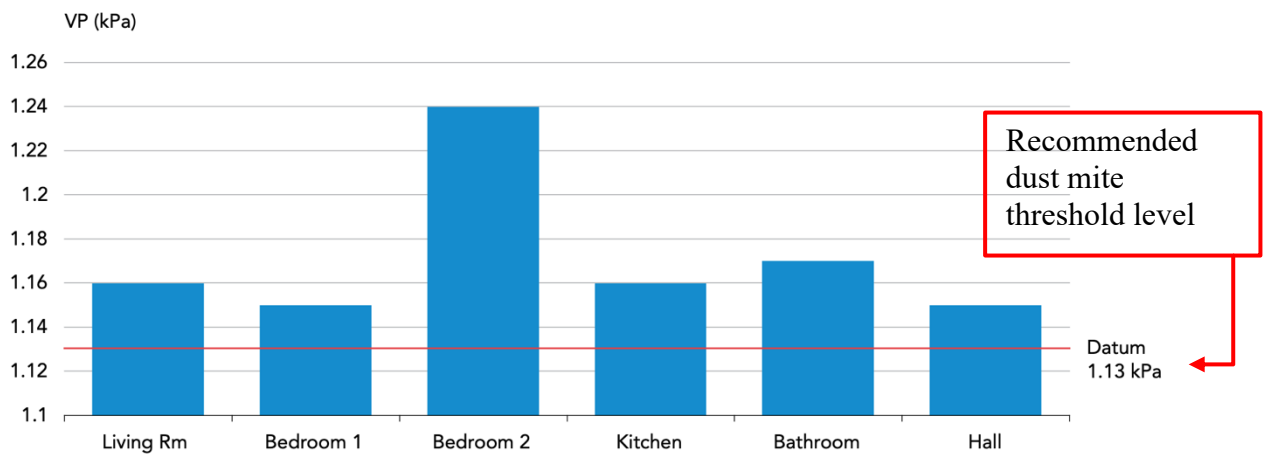


Figure 26: Spot data readings taken from 100no. dwellings – average vapour pressure per room

The results above indicate where vapour pressure is above desirable maxima in terms of dust mite growth. All of the rooms indicated humidity levels to be above (2-10%) the recommended dust mite threshold of 1.13kPa. (13)

Vapour pressure levels rise correspondingly with the release of water vapour while drying particularly just after the end of a wash cycle (from 1.4 kPa, eventually peaking at 1.78 kPa). The vapour pressure level is highest during overnight drying periods as evident from the below chart.

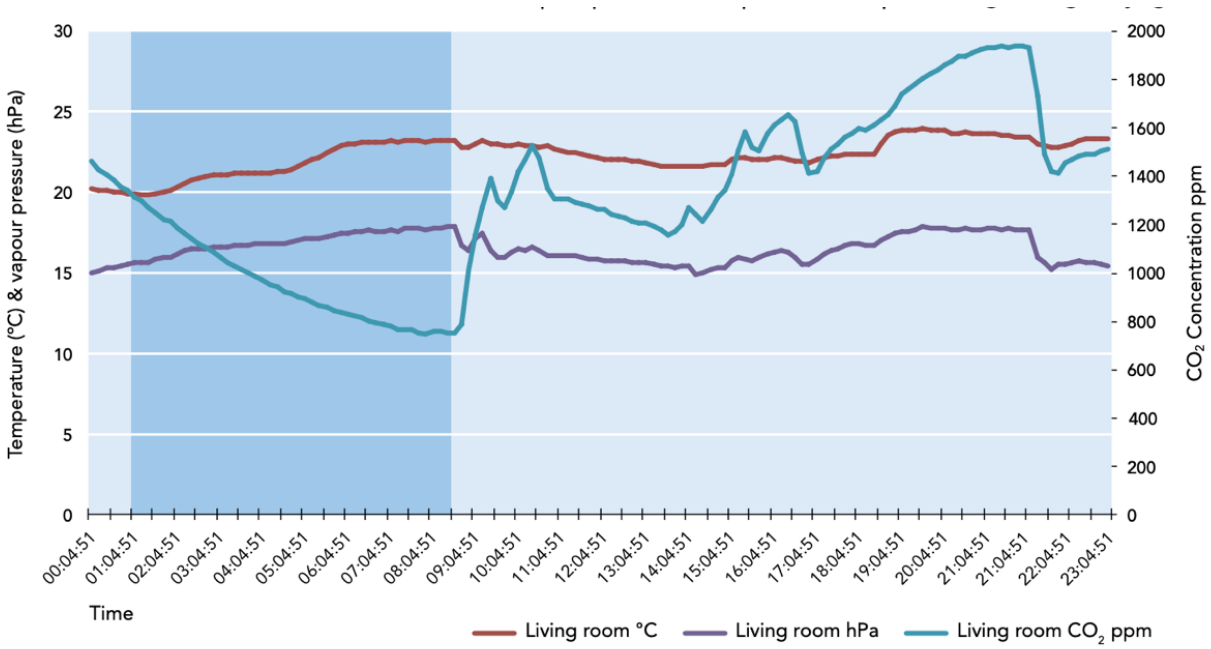


Figure 27: Vapour pressure (hectopascals – hPa) show signs of spiking during night-time passive indoor drying regimes.

25.0 Dust mite growth from passive indoor drying (PID)

In terms of dust mite growth, passive indoor drying adds to the problem in already over-moist and poorly ventilated homes. Over 75% of households surveyed in the Glasgow study had average absolute moisture levels above the recognised upper threshold for dust mite growth linked to asthma risk in vulnerable groups. Rooms that are subject to poor ventilation control such as bedrooms which are subjected to passive drying and steam ironing tend to exacerbate the problem of moisture and thus dust mite growth. The presence of mites in a building is associated with the relative humidity (RH) of the indoor air and they require a RH reading in excess of 60% to become a problem.

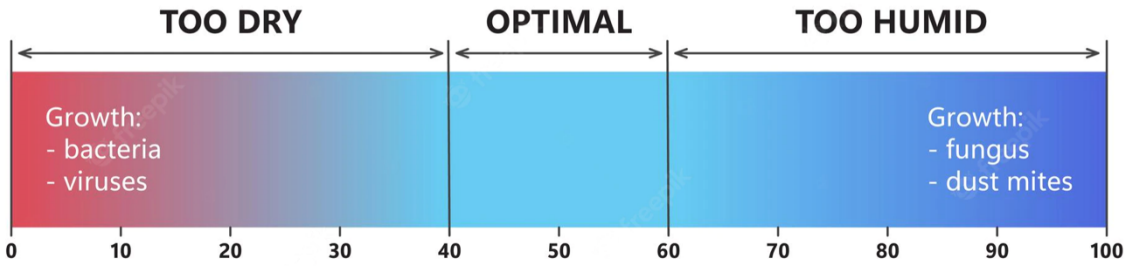


Figure 28: Optimal RH indoor levels represented on a gradient scale.

In a research report to investigate the corelation between dust mites and domestic laundering regimes (14), concluded that domestic washing and drying systems applied should involve wash temperatures benchmarks of at least 55 degree C but that higher temperatures >55 degrees C for a sustained period of at least 12 minutes is sufficient to eliminate >80% of mites.

The Immunology Department at Beaumont hospital Dublin emphasise that dust mite prevention is best managed by adopting their 7 step recommendation for eradicating dampness in the home by aiming for a humidity level of between 35 – 50% and specifically:

"***Avoiding drying clothes indoors, especially in bedrooms and living rooms, unless using dryers which are vented outdoors***"

Immunology Dept, Beaumont Hospital Patient information : '*House dust mite allergies*'

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