The relationship between airtightness and ventilation in new UK dwellings

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Abstract

The ATTMA airtightness testing competent persons scheme collects pressure test data and metadata from the majority of new build dwellings in the UK. This article uses the dataset to investigate the importance of the ventilation strategy in airtightness design and construction. Design and measured airtightness were tested for association with declared ventilation strategy.

It was found that ventilation strategy makes a statistically significant difference to airtightness, however this difference is too small to be practically relevant. Properties with mechanical ventilation and heat recovery (MVHR) were shown to have a mean designed air permeability only 0.46 m^3/m^2h lower than naturally ventilated dwellings. 73% of homes with MVHR have design airtightness greater than or equal to 5 m^3/m^2h and 17% of naturally ventilated dwellings have design airtightness less than 5 m^3/m^2h. We discuss how current design is not maximising the CO_2, cost and air quality benefit of each ventilation strategy.

A new approach to regulatory compliance is proposed which explicitly links the designed airtightness and chosen ventilation system. It is suggested that compliance could then be achieved using a set of airtightness ranges linked to appropriate ventilation strategies. This could be expected to result in reduced energy consumption and carbon emissions for new build homes compared to the current approach, and would also potentially lead to better outcomes for occupants in terms of indoor air quality.

Keywords ATTMA, airtightness, testing, building regulations, data

Practical Summary

Analysis of a large database of the airtightness of new UK dwellings found that ventilation strategy makes very little difference to airtightness design. For dwellings with MVHR the results suggest that infiltration levels are too high to maximise the energy savings; for naturally ventilated homes there may be air quality issues. Coupling airtightness design and ventilation strategy can reduce a dwelling's energy demand and can support achieving the required energy performance rating.

Introduction

Minimal unwanted air leakage combined with provision of adequate fresh air are two fundamental priorities in new UK dwellings.[1, 2] The four UK devolved administrations have different building regulations; this paper focuses on the English case. The English regulations treat the two priorities in two separate sections, Part L (energy) and Part F (ventilation). The mechanism for accounting for air leakage through the building fabric has for many years consisted of specifying an infiltration rate as part of the design energy calculation [1]. However, evidence collected in the early 2000s showed that actual air permeabilities could be much higher than these design assumptions.[3-5] A system has therefore been in place since 2006 in which a design air permeability target is set, then evidence must be provided that this target is met in the real building. This is demonstrated using a blower door test carried out on the newly built dwelling, reporting air permeability in units of cubic metres (volume) per square metre (external envelope area) per hour at 50 Pascals.[6] The English regulations only require testing on a sample basis although data indicates that around three quarters of new buildings are tested[7].

The ventilation strategy for any new dwelling would normally be chosen at the design stage and would incorporate technical guidance on compliance with the ventilation requirements of the Building Regulations by Approved Document Part F in England.[2] This is a separate document to the energy regulations covering airtightness, since ventilation is a purposeful means of providing fresh air whereas air infiltration is not relied on for this.[1] The English ventilation guidance does not give detailed recommendations on airtightness levels but instead uses an air permeability of 5 m^3/m^2h at 50 Pa as a threshold. If a dwelling is designed with a lower air permeability than this level, a fixed amount of purpose provided ventilation is required. If the design air permeability is greater, a lower amount of purpose provided ventilation is required. This applies to all ventilation strategies, and may influence the decision on whether to specify mechanical or natural ventilation.

Until recently, little data has been available in which airtightness and ventilation could be examined together. However, the introduction of a mandatory lodgement scheme by the UK's Air Tightness Testing and Measurement Association (ATTMA) in 2015 has led to a large dataset of pressure test results of new build dwellings in the UK. ATTMA released 192,731 test records collected from August 2015 to December 2016 for the authors to analyse. These records comprised of pressure test results in m^3/m^2h at 50 Pascals, with accompanying metadata for each test. The metadata includes the inputs to the air permeability calculation,[8] the air permeability design target and the ventilation strategy for each dwelling.

This paper addresses the relationship between airtightness (both design and measured) and ventilation strategy, in regulation and practice. We begin by giving an overview of the air permeability data and its target driven distribution, based on previous work. We then introduce the ventilation data and examine its association with the air permeability data.

Airtightness dataset and its previous analysis

Previous work[7] analysed the ATTMA dataset and found the following:

Recorded air permeability is bunched around design targets.

Design and measured air permeability are shown on the left and right subplots of Figure 1 respectively.

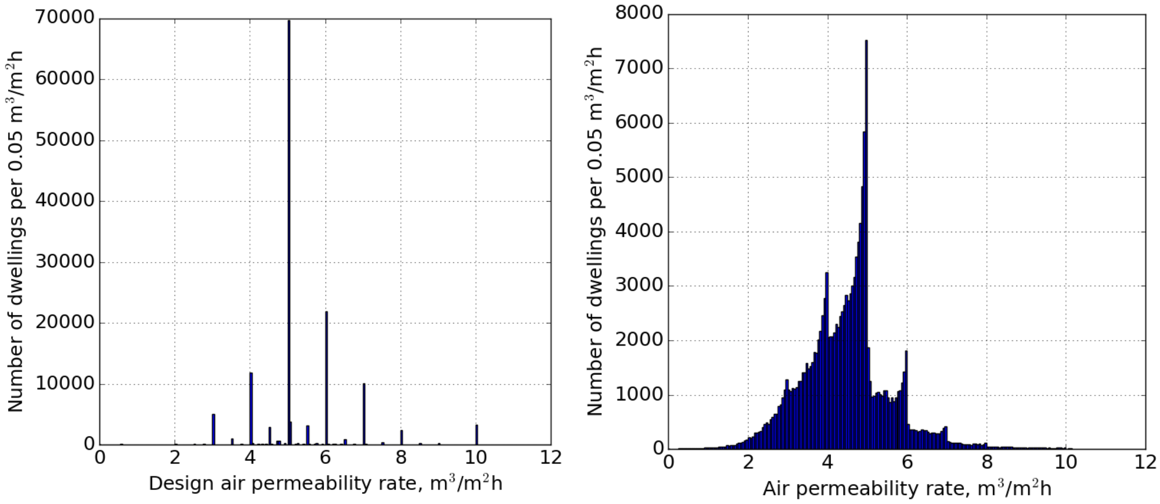

Figure 1. Design (left) and measured (right) air permeability for dwellings in the ATTMA dataset.

The distribution of design targets is dominated by a peak at 5 $m^3/h.m^2$ potentially as a result of this value's use in the notional building recipe to set the carbon emission target under current new dwelling energy legislation in England.[1] This peak, as well as the others visible at 3, 4, 6, 7 m^3/m^2h, are reflected in the data as sharp spikes with steep drops immediately after them.

Figure 2 further illustrates the relationship between measured air permeability and the set of design targets. For each target, the modal recorded airtightness is in bin whose upper band is the target and whose lower bound is the target minus 0.05 m^3/m^2 h. This appears to be very precise achievement of the targets for a high number of dwellings.

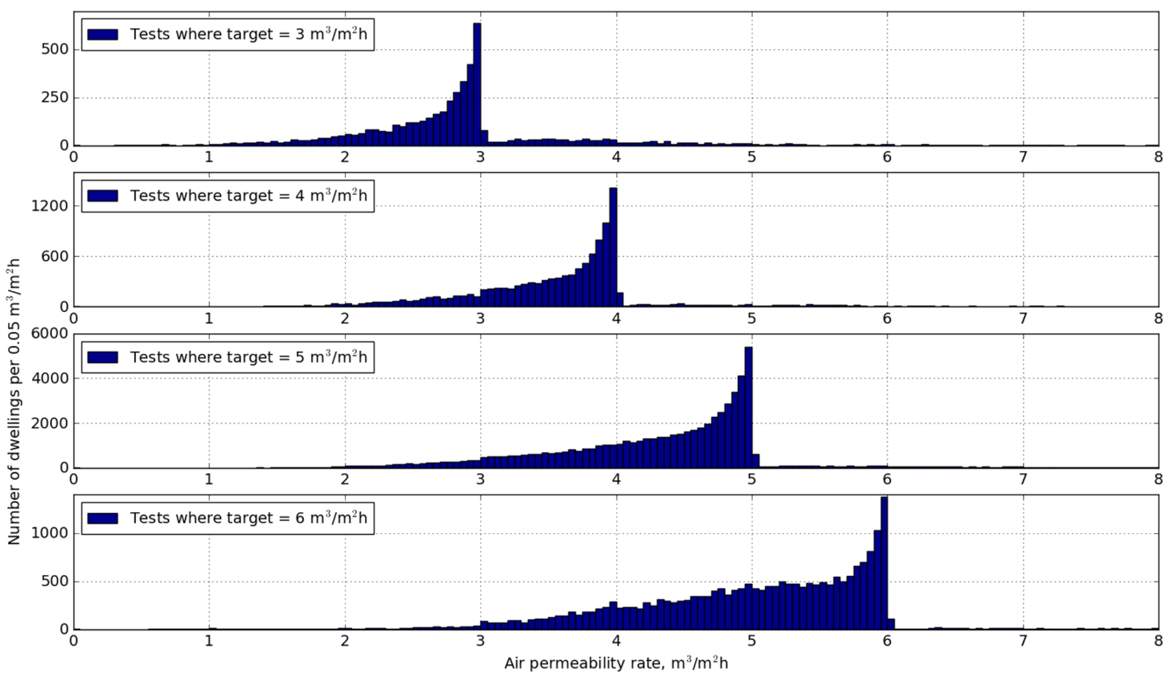

Figure 2. Air permeability distributions grouped by design target for the four most common targets.

The sharp peaks exhibited in Figure 1 and Figure 2 represent the outcome of a process in which design targets can be met very precisely. This in turn suggests the existence of a combined process of sealing and measurement, where sealing can stop as soon as the design target is reached. 92% of sites only have one test lodged, indicating that any remedial sealing had already taken place by the time of the regulatory test. The previous work[7] discussed the likely prevalence of post-construction sealing to achieve the design target, including during the test itself. The ATTMA test standard places strict limitations on the amount of sealing that can take place during the test.

Unconventional design targets may indicate attempts to maximise benefit from multiple regulations

The fifth most common design target recorded in the ATTMA metadata is 5.01 m^3/m^2h, representing 4% of dwellings. One explanation may be the threshold in the English ventilation regulations (mentioned in the Introduction) that designing to an air permeability leakier than 5 m^3/m^2h allows provision of less purpose-provided ventilation, accounting for a higher infiltration level. Developers may minimise the cost of ventilation systems whilst also satisfying energy requirements, by setting a design target just above the 5 m^3/m^2h threshold.

The above is an example of how different regulations are used together in practice to minimise cost, but without necessarily specifying the most suitable airtightness level given the ventilation strategy. In this paper we argue that in order to achieve this the relationship between airtightness and ventilation requires strengthening at a regulatory level. We make this argument by undertaking further analysis of the ATTMA dataset, below.

Relationship between airtightness and ventilation strategy

The declared ventilation systems in the ATTMA data and their relative frequencies are given in Table 1. Naturally ventilated dwellings dominate the sample, followed by those using mechanical ventilation and heat recovery (MVHR) and mechanical extract ventilation (MEV). Other ventilation types represent around 1% of the sample. The prevalence of natural ventilation over mechanical ventilation in the data indicates that developers are currently choosing simplicity and reduced cost over the likely increased complexity and cost of mechanical systems.

Ventilation type (Acronym)	Ventilation type (Full)	Sample size	Proportion of sample with this ventilation strategy
Natural	Natural Ventilation	86687	62%
PSV	Passive Stack Ventilation	811	< 1%
MEV	Mechanical Extract Ventilation	15543	11%
MVHR	Mechanical Ventilation with Heat Recovery	36906	26%
Other	Other Ventilation System covered by a European Technical Approval. May include for example Positive	665	< 1%

	Input Ventilation (PIV) or hybrid systems		

Table 1. Ventilation types and their prevalence in the ATTMA dataset.

Figure 3 shows the distribution of design targets for each ventilation strategy, including only the most common air permeability design targets from Figure 1 (3,4,5, 5.01, 6 and 7 $m^3/h.m^2$)Note that the y-axis of Figure 3 is normalised in order to compare the shape of the distributions as opposed to focussing on the prevalence of each type of system. Note also that the targets 5 and 5.01 are combined into one category, 5, to simplify Figure 3.

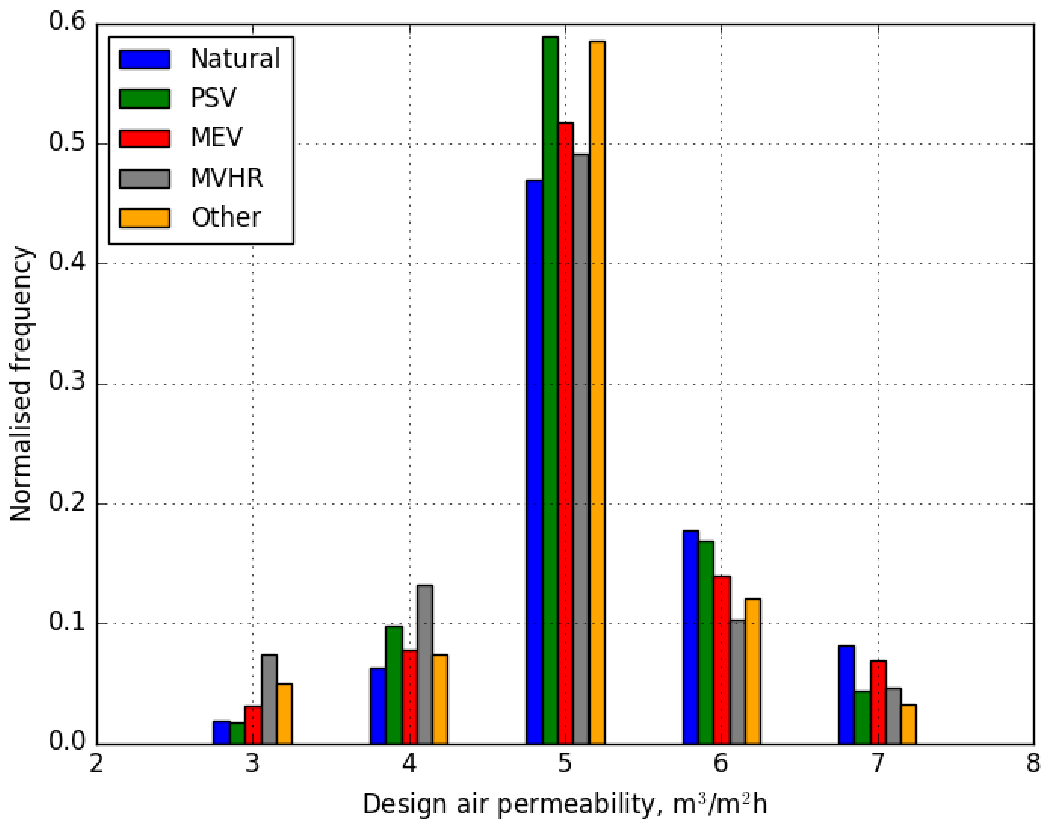

Figure 3. Normalised histogram of design air permeability grouped by design ventilation strategy for 5 common targets.

The distribution of measured air permeability for each type of ventilation system is summarised by the box plot in Figure 4.

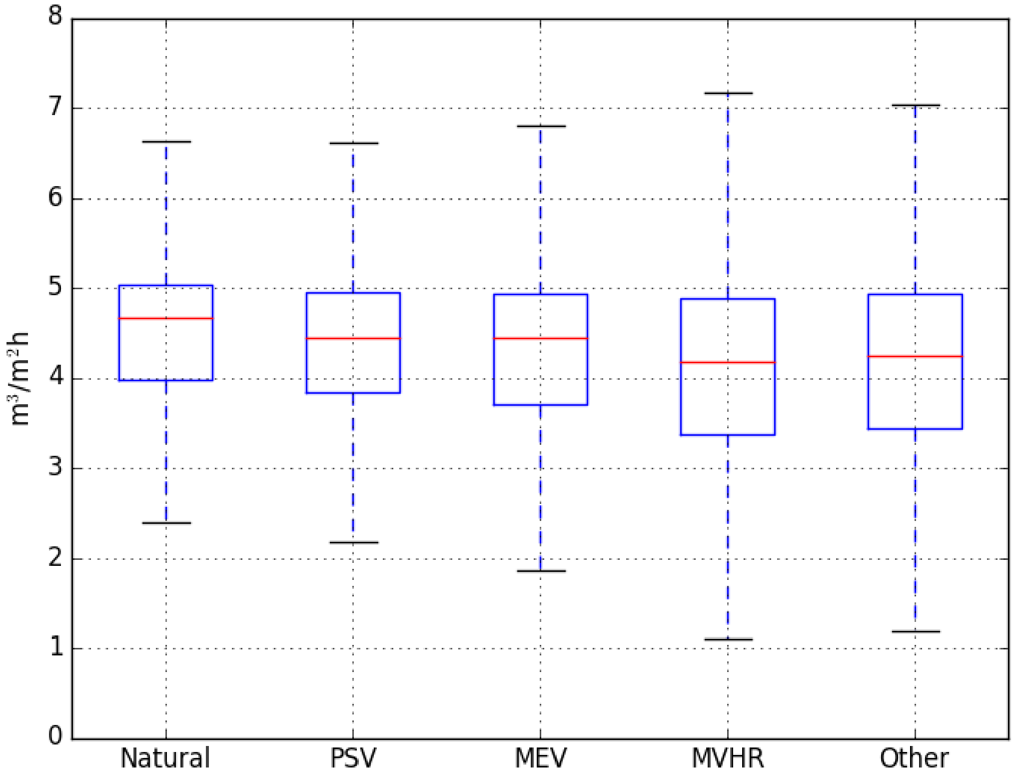

Figure 4. Measured air permeability by ventilation strategy. Medians shown in red.

Figure 3 and Figure 4 indicate that airtightness levels appear to be similar for different ventilation strategies. In Figure 3, each ventilation strategy is associated with a distribution of design targets with a strong mode at 5, and with a minority of dwellings at each integer target above and below this. In Figure 4, median measured air permeabilities are similar across ventilation categories, with an interquartile range of 1-1.5 m^3/m^2h.

The quantitative difference in airtightness levels across ventilation types was investigated using statistical testing. Firstly, the test method was selected by further investigation of the dataset. Both design and measured air permeability grouped by ventilation strategy exhibit unusual distribution shapes due to being bunched around or falling exactly at certain targets. The Kolgorov-Smirnov test for normality was carried out for each group, each time indicating non-normal distributions. For small datasets this would mean that parametric tests (such as comparing means) and parametric descriptions (such as error on means) are not appropriate. However, the dataset used here is very large (sample sizes 665-86687 per group) and parametric descriptions and tests may therefore be applied. One-way ANOVA was therefore used to compare group means.

Summary statistics for each group are given for design air permeability in Table 2 and measured permeability in Table 3. Table 2 shows that the mean design air permeability is similar for each ventilation strategy. The median design air permeability is identical for each ventilation strategy. The error on the mean is very small for the natural ventilation, MEV and MVHR groups. This is due to the very large sample sizes of tens of thousands. The consequence is that to detect a statistically significant difference between groups, the actual differences between group means only need to be very small.

Table 2. Summary statistics for design air permeability by ventilation type.

Ventilation type (Acronym)	Mean design air permeability (m^3/m^2.h)	Error on the mean (m^3/m^2.h)	Median design air permeability (m^3/m^2.h)
Natural	5.48	0.00	5
PSV	5.19	0.04	5
MEV	5.29	0.01	5
MVHR	5.02	0.01	5
Other	5.10	0.04	5

Table 3. Summary statistics for measured air permeability by ventilation type.

Ventilation type (Acronym)	Mean measured air permeability (m^3/m^2.h)	Error on the mean (m^3/m^2.h)	Median measured air permeability (m^3/m^2.h)
Natural	4.66	0.00	4.67
PSV	4.45	0.03	4.44
MEV	4.39	0.01	4.44
MVHR	4.22	0.01	4.18
Other	4.34	0.06	4.24

The same pattern is observed in Table 3, describing measured air permeability. Again, the group means are all similar to each other, errors on the means are very small for the larger groups, and the group medians are similar to each other.

Having provided some interpretive context in Table 2 and Table 3, the groups are compared against each other in Table 4 and Table 5. The null hypothesis is that the group means are all equal, and the significance level used when testing the hypothesis was $p = 0.05$. One-way ANOVA followed by multiple comparison tests were carried out. Table 4 and Table 5 show each group in the first column compared to each other group in the first row. An ‘X’ is shown where no significant difference was found between two groups. Where a significant difference between airtightness design and measurements for different ventilation systems was found, the difference between means is given with its lower and upper 95% confidence intervals. A positive difference indicates that the group in the column has a larger mean than the group in the row. For example, the first row and second column of Table 4 shows that natural ventilation has a mean 0.28 m^3/m^2h higher than PSV.

Table 4. Differences between means of design air permeability by ventilation strategy. All units m^3/m^2h

	Natural	PSV	MEV	MVHR	Other
Natural		0.28 (0.16,0.40)	0.18 (0.15, 0.22)	0.46 (0.43, 0.47)	0.38 (0.25, 0.51)
PSV			X	0.17 (0.05, 0.29)	X
MEV				0.24 (0.27, 0.30)	0.20 (0.07, 0.33)
MVHR					X
Other					

Table 5. Differences between means of measured air permeability by ventilation strategy. All units m3/m2h

	Natural	PSV	MEV	MVHR	Other
Natural		0.20 (0.09, 0.32)	0.27 (0.24, 0.30)	0.44 (0.42, 0.46)	0.32 (0.19, 0.45)
PSV			X	0.24 (0.12, 0.35)	X
MEV				0.17 (0.14, 0.20)	X
MVHR					-0.12 (-0.25, -0.01)
Other					

The results in Table 4 and Table 5 show that, for both design and measured air permeability, ventilation strategy makes a statistically significant difference in some cases. These cases are those in which two very large groups are compared: namely, natural ventilation, MEV and MVHR. The large sample sizes mean that differences between group means only have to be of the order 0.02 m^3/m^2h to be found as significant.

However, taking this information in combination with the means and medians for each group in Table 2 and Table 3, the *practical* difference between group means is very small. Mean design air permeabilities all fall between 5.02 and 5.48 m^3/m^2h, a total difference of 0.46 m^3/m^2h. Median design permeabilities are identical, due to 5 m^3/m^2h being the most common target in every group. Mean measured air permeabilities differ by only 0.44 m^3/m^2h across the three groups, which is unsurprising given the similarity of the design targets across groups.

These airtightness results are in contrast to the differences in air permeability for different ventilation strategies given in technical guidance. For example, ATTMA documentation suggests a difference of 2-3 m^3/m^2h between a good practice MVHR and naturally ventilated dwelling.[8] Natural ventilation strategies would normally be expected to be associated with higher design air permeabilities so that infiltration through the building fabric can be combined with simple intermittent fans and trickle ventilators to provide adequate fresh air. By comparison, MVHR systems would be expected to be used in more airtight buildings, with the ventilation system providing the majority of fresh air supply to the dwelling so that energy is not wasted heating more incoming air than necessary.[9] However, the data indicate that in practice there is little difference in building fabric airtightness design and implementation between naturally and mechanically ventilated dwellings.

The results also provide a large scale confirmation of findings in previous work focussing on MVHR installations in new homes.[10] The authors obtained design and measured air permeability data in 54 such dwellings and highlighted the large spread of design airtightness targets (0.5-7 m^3/m^2h), with 26% of these dwellings having measured air permeability exceeding 5 m^3/m^2h. The ATTMA dataset gives similar values of 17% of measured test results and 25% of design targets exceeding 5 m^3/m^2h for homes with MVHR.

The weak relationship between design airtightness and ventilation strategy suggests that matching ventilation design to energy targets is not prioritised. This is discussed in the following sections.

CO_2 consequences of weak relationship

The lower than expected differentiation in air permeability target (and implementation) between different ventilation strategies is likely to lead to higher CO_2 emissions than necessary for dwellings with mechanical ventilation. This issue was illustrated by modelling the impact of air permeability on CO_2 emissions, with different ventilation systems, using the UCL parametric domestic energy calculator[11] which is based mainly on the UK's national calculation methodology, the Standard Assessment Procedure.[12] Note that this model is a predictive tool, not incorporating real energy data. CO_2 emissions were estimated according to the requirements of the 2013 English building regulations[1] for three standardised dwelling types: detached, mid-terrace and mid-floor end flat. For each dwelling type, a range of values for air permeability were used as inputs, under two different ventilation system scenarios (natural ventilation and MVHR), but keeping all other input values as per the regulatory target notional building recipe[13]. The performance parameters for the MVHR system were set at typical values for thermal efficiency (85%) and specific fan power (1.5 W/l.s).

An example result from this analysis is presented in Figure 5, showing calculated CO_2 emissions for a mid-terraced house with either MVHR or natural ventilation. These results illustrate the consequences of different air permeabilities, with rising carbon emissions for both ventilation systems as air permeability increases.

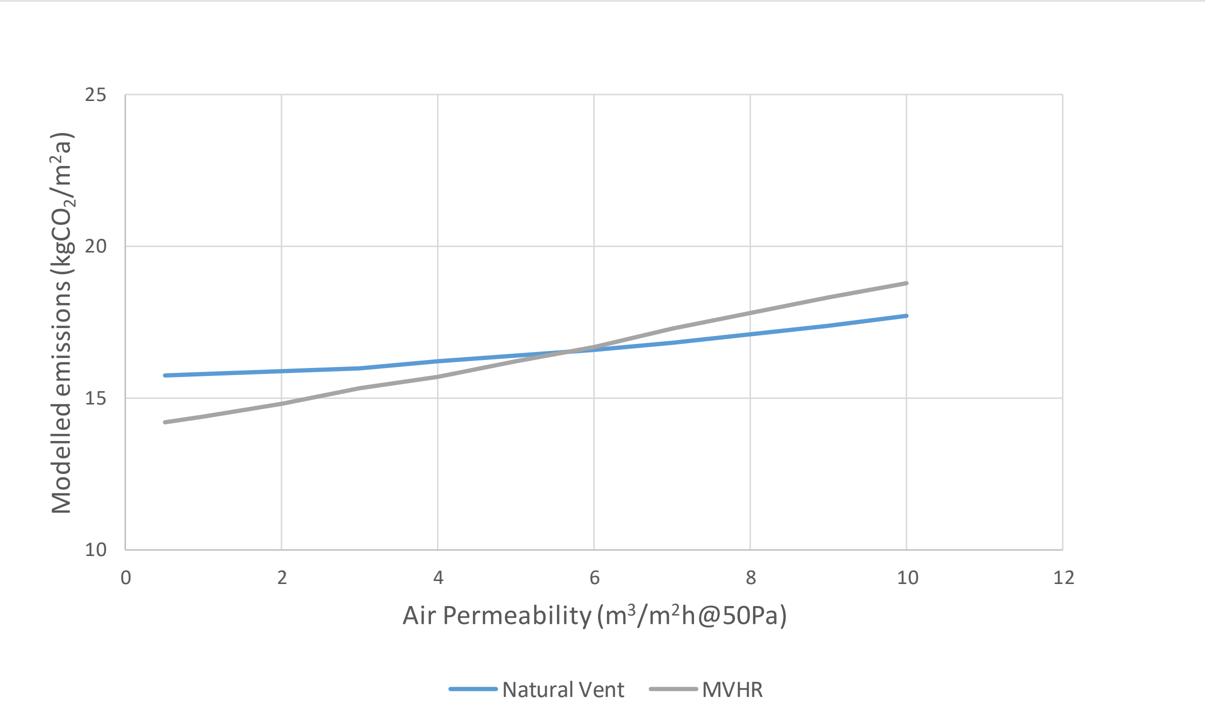

Figure 5. Carbon emissions for an example dwelling at different air permeabilities and with different ventilation types.

The first point to note from Figure 5 is that the CO_2 emissions rise more steeply with air permeability for the MVHR case than the natural ventilation case. Most of the difference in gradient arises because, in the UK, the majority of homes are heated using gas boilers, while mechanical ventilation systems are fuelled using electricity generated predominantly from fossil fuels. This leads to the CO_2 intensity of electricity being higher than that of natural gas, although the ratio of the two is constantly changing as the UK's electricity decarbonises. The second, smaller component of the difference in gradient is due to the extra energy required to run the MVHR system. Appendix 1 gives a version of Figure 5 with delivered energy as the dependent variable to evidence the above point.

Figure 5 is now used to illustrate the following points. Using the most common design air permeability in the ATTMA dataset for dwellings with MVHR, 5 m^3/m^2h (see Figure 3), the predicted annual CO_2 emissions are 16.2 $kgCO_2/m^2a$. If instead a design target of 3 m^3/m^2h is set and achieved, an annual CO_2 saving of 6% is predicted. Furthermore, a target of 1 m^3/m^2h would save 11% of annual CO_2 compared to the original target of 5 m^3/m^2h. Finally, Figure 5 extends down to a target of 0.5 m^3/m^2h to represent the air permeability of a Passivhaus[1], giving a CO_2 saving of 12%.

For the same dwelling model, but with natural ventilation instead of MVHR, an air permeability target of 5 m^3/m^2h gives modelled annual CO_2 emissions of 16.4 $kgCO_2/m^2a$: very similar to the MVHR value. However, achieving a lower air permeability brings little CO_2 benefit compared to the MVHR case; Figure 5 shows a flattening of the relevant line at low air permeability values due to a non-linear relationship between air leakage and energy demand. Thus, the regulations do not incentivise designing naturally ventilated dwellings under 5 m^3/m^2h; this is positive. However, we show later using the dataset that a substantial proportion of naturally ventilated dwellings are designed with a lower air permeability than this.

The above discussion explored the implications of moving from the most common design value – 5 m^3/m^2h – to lower values. Figure 5 also illustrates the consequences of designing to higher air permeabilities. As an extreme case, increasing the design air permeability from 5 to the regulatory maximum of 10 m^3/m^2h leads to an increase of 16% and 8% for MVHR and natural ventilation respectively. This highlights the contribution of air leakage to overall dwelling emissions, and provides further evidence that using MVHR with building fabric with leaky building fabric has fairly serious consequences in terms of CO_2 emissions.
Similar trends are observed in other building types, as shown in Table 6.

Table 6. Predicted annual CO2 emissions for a range of house types, airtightness levels and ventilation strategies.

Standardised Dwelling Type (gross floor area)	**Part L 2013 Target Carbon Emission Rate ($kgCO_2/m^2.a$)**	**Air Permeability ($m^3/h.m^2$ @ 50Pa)**	**Natural Ventilation Dwelling Carbon Emission Rate ($kgCO_2/m^2.a$)**	**MVHR Dwelling Carbon Emission Rate ($kgCO_2$/m2.a)**
Mid Terrace House ($79\ m^2$)	16.4	3	16.0	15.3
		5	16.4	16.2
		10	17.7	18.8

[1] Airtightness in a passivhaus is measured in air changes per hour, and the required level is 0.6 ach^{-1}. This equates to an air permeability of approximately 0.5 m^3/m^2h in the case of the example mid-terrace in Figure 5. Note that the airtightness is the only feature of the Passivhaus concept which is modelled here; otherwise the building is modelled according to the 2013 Building Regulations.

Detached House ($104\ m^2$)	17.4	3	17.0	15.8
		5	17.4	16.9
		10	18.8	19.7
Mid Floor End Flat ($61\ m^2$)	16.1	3	15.8	15.5
		5	16.1	16.3
		10	17.4	18.5

The analysis in this section is illustrative, using a simple model which does not include many of the real-world features of airtightness construction and ventilation installation such as underperformance of ventilation systems[14] and the airtightness testing process itself[7]. However, the result in Table 6 demonstrate that designing different airtightness levels for different ventilation strategies can reduce the carbon emissions associated with dwelling energy use by reducing wasted heat. This is especially the case in dwellings with MVHR, where using the same design target as for non-mechanically ventilated dwellings (i.e. 5 m^3/m^2h) represented an increase in carbon emissions of 11% compared to using a more suitable target of 1 m^3/m^2h. In the ATTMA data, 73% of dwellings with MVHR have a design target of 5 m^3/m^2h or above, indicating a substantial missed opportunity for CO_2 savings.

This conclusion is supported by previous studies using a range of methods. Lowe et al showed using a theoretical argument that airtightness in dwellings with MVHR should not exceed 3 ach^{-1} (approximately 3 m^3/m^2h) to provide CO_2 savings over extract-only ventilation;[15] an empirical study by Banfill et al found that to obtain any CO_2 benefit at all over natural ventilation, airtightness of MVHR dwellings should be under 3 m^3/m^2h – or ideally approaching Passivhaus standards.[9]

Relating this analysis to the actual airtightness of the new build stock is difficult since, as indicated in Section 2, in an unknown proportion of cases the target air permeability may have been achieved by secondary or temporary sealing measures which may deteriorate relatively quickly or even immediately. Combined with other factors that change airtightness over a building's lifetime,[16] the long term distribution of airt permeability remains unknown. However, from Table 6 it is possible to calculate indicative figures for the impact of a decline from 5 m^3/m^2h at the point of construction to 10 m^3/m^2h: estimated CO_2 penalties are 8% for each dwelling type with natural ventilation and 13-17% across different dwelling types with mechanical ventilation. Such issues would contribute to the well-documented performance gap between expected and real energy use.

In summary, the regulatory processes driving airtightness and ventilation do not appear to be working in tandem. Building design is therefore not being optimised, leading to the potential for energy savings for MVHR systems being under-realised. The next section reflects on why this might be occurring and what could be done to better match airtightness strategy with ventilation type.

Discussion

The UK's largest dataset of airtightness test data shows a set of recorded results driven by energy targets, which is the intention of the energy regulations. It is likely that the presence of these targets encourages some good practice - airtight design and construction – along with some sub-optimal ways of meeting the targets.[7] However the targets are being achieved, they appear to heavily influence airtightness at least at the point of the test.

Analysis of the dataset suggests only small air permeability differences (both design and measured) for dwellings with different ventilation types. This means that a subset of MVHR dwellings have more infiltration - and in turn significantly higher carbon emissions - than necessary.

Conversely, a subset of naturally ventilated dwellings may have inadequate provision of fresh air. In the ATTMA data, 17% of naturally ventilated dwellings have a target air permeability under 5 m^3/m^2h, meaning that they require additional trickle ventilation. To the authors' knowledge there is no empirical study of whether this requirement results in adequate fresh air, however a study was carried out by Sharpe et al in Scotland which has similar regulation.[17] The authors found that for a sample of 40 new-build naturally ventilated dwellings with a mean measured air permeability of 4 m^3/m^2h at 50 Pa, indoor CO_2 levels exceeded 1000 ppm for a high proportion of the time. It is therefore possible that airtight naturally ventilated English dwellings also exhibit higher than advised CO_2 levels, although more research is required to test this.

The findings in this paper raise the question of why ventilation and airtightness are not being designed to work together. A superficial answer could be that there is little requirement to align airtightness and ventilation in the Building Regulations, where a basic threshold is set dictating that design permeabilities less than 5 m^3/m^2h require a set amount of additional ventilation but do not further pursue the link.

The insufficient link between airtightness and ventilation in the Building Regulations may be caused by a variety of factors. It is possible that this issue has not been addressed simply due to priorities being placed elsewhere in the regulations e.g. structure and fire, as previous work has concluded.[18] Alternatively, natural variability in construction may have led to concerns that it would be difficult to build to different airtightness standards for different ventilation types (with the possible exception of exceptionally airtight construction methods such as Passivhaus).

The findings in the data, and the questions they generate, present an opportunity to step back and review the purpose and formulation of airtightness design targets in England and their link to ventilation regulations.[19] This topic has been recognised and tackled to some extent by existing industry bodies. The trade-off between energy and ventilation is discussed in CIBSE Guide A[20] but specific guidance is not given; more quantitative guidelines are given by the Building Control Alliance (BCA),[21] and benchmarks of airtightness for naturally and mechanically ventilated dwellings are given by BSRIA.[22] The Scottish regulations on domestic ventilation have perhaps the most explicit link to airtightness:[23] a simplified version of the design process reproduced from the Scottish government's guidance is given in Figure 6. This flowchart, used at building design stage, requires builders to commit to a design airtightness range then directs them to an appropriate ventilation strategy for the given of airtightness.

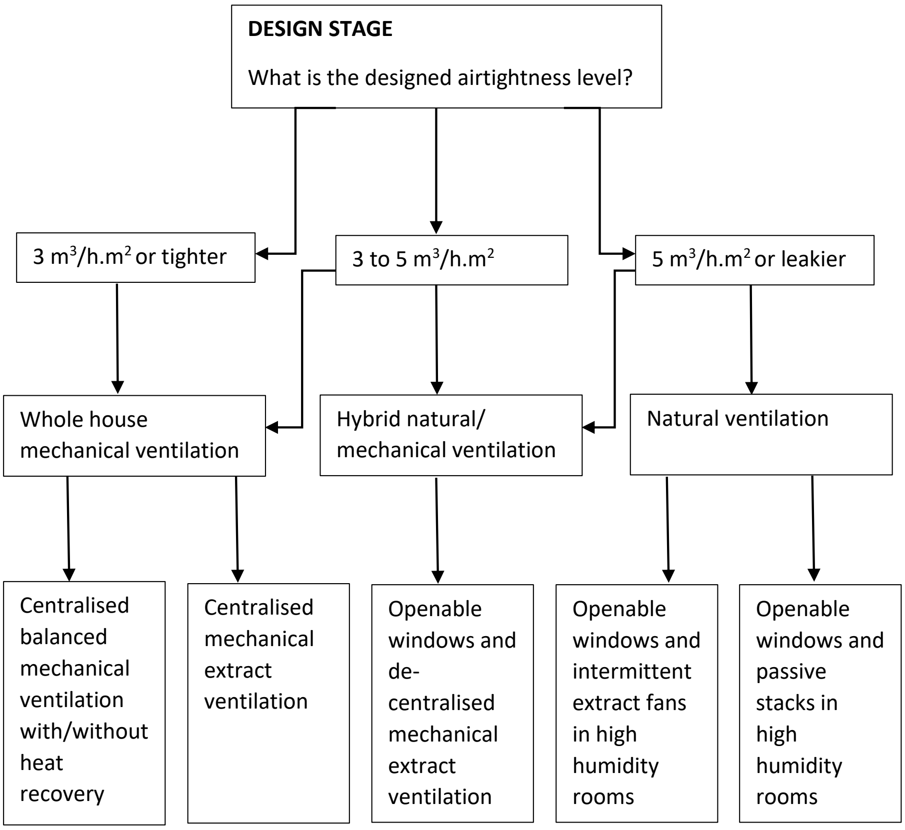

Figure 6. Simplified illustration of ventilation strategy and airtightness design process in the Scottish building regulations.

There may be many different approaches to linking airtightness and ventilation which improve on current practice. Below we suggest one possible approach, based on the Scottish example. In this implementation, categories for design air permeability are explicitly linked to categories of ventilation strategy, along with different requirements for background ventilation. This is shown in Table 7.

Table 7. Suggested ranges of design air permeability and associated ventilation strategy.

Ventilation System Category	Ventilation Strategy	Fabric Airtightness Strategy	Design Air Permeability Range ($m^3/h.m^2$ @ 50 Pa)	Background Ventilators
System 1a	Natural Ventilation	Airtight Fabric	3 to 5	Yes - High Equivalent Area
System 1b	Natural Ventilation	Leaky Fabric	5 to 7	Yes - Standard Equivalent Area
System 1c	Natural Ventilation	Very Leaky Fabric	7 to 10	Yes - Standard

				Equivalent Area
System 3a	Mechanical Extract Ventilation	Very Airtight Fabric	<3	Yes - Standard Equivalent Area
System 3b	Mechanical Extract Ventilation	Airtight Fabric	3 to 5	Yes - Standard Equivalent Area
System 3c	Mechanical Extract Ventilation	Leaky Fabric	5 to 7	None
System 4a	Mechanical Ventilation with Heat Recovery	Very Airtight Fabric	<3	None
System 4b	Mechanical Ventilation with Heat Recovery	Airtight Fabric	3 to 5	None

For each design air permeability category, a set of options for ventilation is allowed - although not all options are available to all levels of airtightness. Table 8 summarises the allowed options in Table 7.

Table 8. Suggested permitted ranges of airtightness for different ventilation strategies.

	<3 m^3/m^2h	3-5 m^3/m^2h	5-7 m^3/m^2h	7-10 m^3/m^2h
Natural		Allowed	Allowed	Allowed
MEV	Allowed	Allowed	Allowed	
MVHR	Allowed	Allowed		

Given the permitted air permeability categories, developers would be required to demonstrate that completed properties have a measured air permeability within the range specified in the design.

The approach of specifying airtightness ranges is used because it is a suitable compromise between the two extremes of specifying a fixed target for each ventilation strategy and not requiring any link between airtightness and ventilation. The former extreme, fixed targets, is unlikely to be practically feasible due to the difficulty of constructing a building to an exact level of leakiness. It is also not necessary since a ventilation strategy does not require a precise level of airtightness to function optimally. The latter extreme, no link, is close to the current situation and has been argued in this paper to lead to sub-optimal building performance. The suggested compromise of ranges of air permeability allows airtightness to be matched with ventilation strategy whilst also leaving some flexibility in the design and construction process. This flexibility may also help alleviate the problem of post-construction sealing; this is discussed elsewhere.[24]

Further regulation around the airtightness of dwellings requires additional research. Firstly, in order to maximise the benefit of MVHR installations, it must be shown that permeabilities under 3 m^3/m^2h are consistently achievable in practice, which was not the case in the MVHR research undertaken recently in the UK.[10] Conversely, it is imperative that MVHR functions properly if it is to be specified only in buildings with low air permeability, else air quality is at risk. Research suggests that achieving the benefits of MVHR is currently challenging due to issues spanning installation, commissioning and performance.[10, 14, 25-27] Secondly, it would be instructive to evaluate the effectiveness of existing building regulations that attempt to link airtightness to ventilation type - such as the Scottish approach in Figure 6 – to assess whether matching airtightness category and ventilation type works in practice. The range approach used in Scotland and built upon in the suggestion in this paper is only one possible approach to strengthening the link.

Finally, more research is needed into the deterioration of building fabric airtightness from the value at the point of the test, and how this influences the long-term performance of the ventilation system.[16] In this article it was recommended that the ventilation strategy and building fabric are designed together – they must also work together in practice over the lifetime of the ventilation system.

Conclusions

This research used the UK's largest airtightness test dataset to quantify the relationship between air permeability (both designed and measured) and ventilation strategy. This relationship was found to be statistically significant for the main ventilation types but practically insufficient, with mean design airtightness of dwellings with MVHR being only 0.46 m^3/m^2h lower than that of naturally ventilated dwellings. This compares to a recommended 2-3 m^3/m^2h difference in current guidance in order to maximise the benefit of mechanical systems. The similar distributions in design airtightness across ventilation strategies led to 17% of naturally ventilated dwellings aiming for under 5 m^3/m^2h and 73% of dwellings with MVHR with a target greater than or equal to 5 m^3/m^2h. These results are also reflected in the measured test data.

The implications for carbon emissions of building to similar airtightness levels across ventilation types was explored using a simple model. In one illustrative example, for a mid-terraced house, predicted extra CO_2 emissions as a result of setting and meeting a design target of 5 instead of 1-3 m^3/m^2h for MVHR was 6-11%. The possible air quality implications were also mentioned as recent evidence points to difficulties in maintaining low enough CO_2 concentrations in new build airtight dwellings with natural ventilation.

These results highlight that ventilation and airtightness are insufficiently linked in the English building regulations. In practice this leads to the achievement of fixed airtightness design targets without making the best use of the ventilation. We argue that the design process should consider the impact of both ventilation system selection and airtightness strategy in tandem in order to maximise energy performance and minimise the risk of low air quality.

Revisions to the Building Regulations could be used to better link airtightness and ventilation strategy, for example by matching ranges of air permeability with categories of ventilation at design stage. This could be used to move away from meeting exact targets, instead promoting design within certain ranges of air permeability, each suited to optimising the potential of the ventilation type. Joining up these two design priorities could lead to lower CO_2 emissions and higher air quality of the new build stock.

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Declaration of Conflicting Interests

The authors declare that there is no conflict of interest.

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Figure references

Figure 7. Design (left) and measured (right) air permeability for dwellings in the ATTMA dataset.
Figure 8. Air permeability distributions grouped by design target for the four most common targets.
Figure 9. Normalised histogram of design air permeability grouped by design ventilation strategy for 5 common targets.
Figure 10. Measured airtightness by ventilation strategy. Medians shown in red.Figure 11. Example CO2 emissions calculation for one house type (mid-terrace).
Figure 12. Simplified illustration of ventilation strategy and airtightness design process in the Scottish building regulations.

Appendix 1

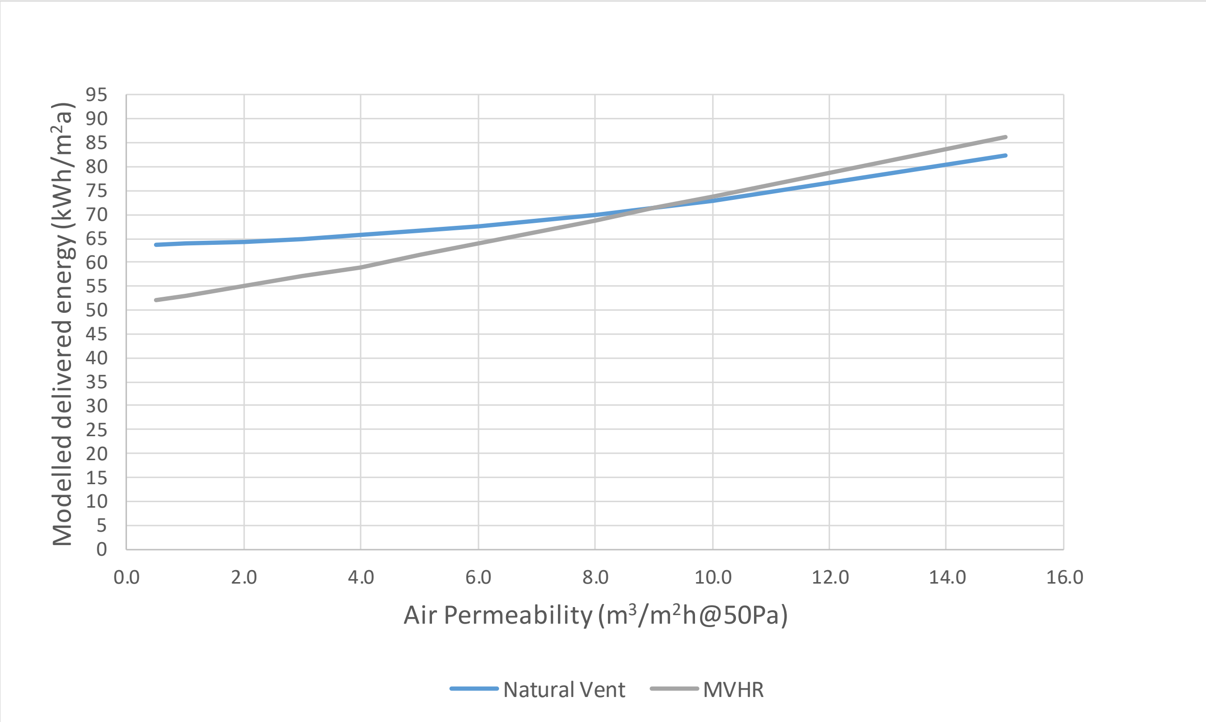

Figure 13. Version of Figure 5 using delivered energy as the dependent variable.