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Evaluation of the airtightness of energy efficient buildings in the UK and the Czech Republic

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1 Introduction

The current legislative standards require as much as possible energy efficient construction. One of the basic principles of energy efficient buildings is perfectly airtight envelope of buildings. Perfectly airtight envelope is characterized by the absence of "ventilation" cracks and leaks of the building envelope.

The members of European Union are committed to reduce CO_2 emissions from energy consumption by 20% by the year 2010, relative to 1990 levels. This is a long term commitment outlined in the Energy White Paper for a 60% reduction in UK CO_2 emissions by the year 2050. The energy use within buildings accounts for approximately half of all UK CO_2 emissions.

Untightness leads to uncontrolled air exchange and increased heat loss. Especially in areas with lots of wind and in exposed situations, this results in ventilation heat loss that could constitute up to 10% of total heat consumption. (Bauer, Mösle & Schwarz, 2010)

2 Airtightness of buildings

Airtightness is essential to improving the energy performance of buildings. In the United Kingdom, the temperature of the outside air is nearly always lower than the temperature of the inside the buildings. Air leakage from the inside to the outside of the building is results in:

- significant reduction in thermal resistance of thermal insulation due to air leakage through the insulation, leading to increased realized fabric U values,
- an increase fabric heat losses, resulting in an increase in space heating requirement,
- increased energy costs. (Johnston)

A much greater problem happens in case of untight component joints. Humid air comes in through the cracks and condenses inside the construction. This can lead to humidity damage and favours mould growth. (Bauer, Mösle & Schwarz, 2010)

2.1 Air leakage

Air leakage is the uncontrolled flow of air through gaps and cracks in the fabric of a building. Air leakage is sometimes referred to as infiltration or draughts. Air leakage should not to be confused with ventilation. Ventilation is the controlled flow of air into and out the building through purpose built ventilators that is requires for he comfort and safety of the occupants. Too much air leakage leads heat loss and discomfort to the occupants from cold draughts. (ATTMA, 2010)

2.2 Airtightness and air permeability

Airtightness is a term used to describe the air leakage of a building. The airtightness of a building determines the uncontrolled background ventilation or leakage rate of a building which, together with purpose-provided ventilation, makes up the total ventilation rate for the building. (Johnston)

Airtightness is frequently expressed in terms of a whole building leakage rate at an artificially induced pressure, in the UK 50 Pa is used (n_{50}), or in terms of an equivalent leakage area. Traditionally, airtightness was expressed in air changes per hour (with units ach or h^{-1}). However, nowadays air permeability is more commonly used (with units m3/(h.m2) representing m^3 of air flow per hour, per m^2 of envelope area) as it takes into consideration the effects of shape and size. The lower air permeability of a building, the greater the airtightness. (Johnston)

Air permeability is the physical property used to measure airtightness of the building fabric. It is defined as air leakage rate per hour per square metre of envelope area at a test reference pressure differential across the building envelope of 50 Pascal. The envelope area of the building, or measured part of the building, is the total area of all floors, walls and ceilings bordering the internal volume subject to the test. This includes walls and floors below external ground level. Overall internal dimensions are used to calculate this area and no subtractions are made for the area of the junctions of internal walls, floors and ceilings with exterior walls, floors and ceilings. The limiting air permeability is the worst allowable air permeability. (ADL1A, 2010)

3 Airtightness of UK energy efficient houses

3.1 Airtightness and UK regulations

Approved document L1A of building regulations 2010 (ADL1A, 2010) requires that the building fabric should be constructed to a reasonable quality of construction so that the air permeability is within reasonable limits. Guidance on a reasonable limit for the design air permeability is given as 10 $m^3/(h.m^2)$ at 50Pa. Design air permeability is defined in ADL1A 2010 as the value of air permeability that is selected by the designer for use in the calculation of the Dwelling Carbon Dioxide Emission Rate (DER). In the majority of cases, checking compliance with the regulation will require some degree of compulsory pressure testing. The exception to this concerns small developments of no more than two dwellings.

Compliance with the requirement of ADL1A 2010 should be demonstrated if the measured air permeability is not worse than the limit value of 10 $m^3/(h.m^2)$ at 50Pa. The assessed air permeability shall be determined as follows:

a) where the dwelling has been pressure tested, the assessed air permeability is the measured air permeability,
b) where the dwelling has not been tested, the assessed air permeability is the average test results obtained from other dwellings of the same dwelling type on the development increased by a margin of + 2.0 $m^3/(h.m^2)$ at 50 Pa,
c) on small developments, where the builder has opted to avoid testing, the assessed air permeability is the value of 15.0 $m^3/(h.m^2)$ at 50 Pa. (ADL1A, 2010)

Table 1: Limiting Fabric Parameters (ADL1A, 2010)

Fabric Parameters	**Limit**
Roof	0.20 $W/(m^2.K)$
Wall	0.30 $W/(m^2.K)$
Floor	0.25 $W/(m^2.K)$
Party wall	0.20 $W/(m^2.K)$
Windows, roof windows, curtain walling and pedestrian doors	2.00 $W/(m^2.K)$
Air permeability	10 $m^3/(h.m^2)$ at 50 Pa

3.2 The AECB energy standards

The AECB Energy Standards is one from a series of documents published as part of the AECB's CarbonLite Programme. These standards can be applied to buildings in both the domestic and non-domestic sectors. They are expressed in terms of a combination of limits on space heating energy consumption, primary energy consumption and CO_2 emissions.

The government has set a target of Zero Carbon Homes by 2016, and is proposing a similar target for the non-domestic sector by around 2020. All three standards - Step One/Silver, Step Two/Passivhaus and Step Three/Gold - lead to such large CO_2 savings that future atmospheric CO_2 concentrations would be markedly reduced if they were applied widely enough and quickly enough. (AECB)

Step 1 or the Silver Standard is on a par with the German Low Energy Standard. Silver Standard can be summed up as best widely-available technology. It does not push the technological boundaries radically forward but it represents a big advance on normal UK building practice. The very good energy and CO_2 performance is achieved without the addition of renewables equipment. It is achievable using products and materials which are readily available on the UK market and can be delivered at or very close to current building costs, given care at the design stage. If it were applied in full to housing, the AECB estimates that it would lead to a 70% reduction in CO_2 emissions versus an average existing dwelling in the stock. (AECB)

Step 2 or the German Passivhaus Standard is probably the best known standard in Europe. It has not been widely-applied in the UK but a number of projects are underway. Passivhaus maximises the use of energy efficiency technologies. If it were applied in full to housing, we estimate that it would lead to over an 80% reduction in CO_2 emissions, versus the average for the existing dwelling stock. Overall, Passivhaus corresponds to best international practice in the design of building envelopes, their services and equipment. Using Passivhaus in the UK should eventually encourage the manufacture of similar technologies in the UK. (AECB)

Thermally the Gold Standard is almost identical to the Passivhaus Standard or the Swiss MINERGIE P standard. The lower primary energy use reflects savings in space and water heating, cooking, lights and appliances. The lower CO_2 emissions reflect the stronger requirements in particular for energy efficient electrical appliances and equipment and a requirement for more electricity-producing renewables. As a ballpark figure, the CO_2 emissions would be 5% of those of a normal UK building. This reflects the significance in buildings, which meet high thermal standards, of the CO_2 emissions due to the electricity consumed for lights and appliances. If a Step 3 Gold Standard building, such as a dwelling or other residential-type building, has gas heating and uses electricity for lights and appliances, approximately one-third of its primary energy is used for space and water heating and two-thirds of it is used for electricity-specific tasks. Overall, Step 3 Gold Standard corresponds to best international practice in the design of building envelopes, their services and equipment. (AECB)

The standards are applicable to new detached, semi-detached and row houses; blocks of flats; student residences; care homes; hotels; prisons and small non-residential premises such as village halls, other community buildings, visitor centres, small shops, churches and doctors' and dentists' surgeries. The principles are very similar for all these building types. The standards may be applied with care to larger non-domestic buildings such as offices and schools. (AECB)

The Table below illustrates the requirement of airtightness of buildings in the UK, for all AECB energy standards.

Table 2: The AECB Airtightness Energy Standards

Feature	**Air leakage per unit of thermal envelope area under pressure**
Step 1 **Silver Standard**	≤ 3.0 $m^3/(h.m^2)$ at 50 Pa for whole-building MEV ≤ 1.5 $m^3/(h.m^2)$ at 50 Pa for balanced MVHR
Step 2 **Passivhaus Standard**	0.75 $m^3/(h.m^2)$ at 50 Pa
Step 3 **Gold Standard**	As step 2 / 0.75 $m^3/(h.m^2)$ at 50 Pa

3.3 Input data

The source of sample data set on the airtightness of UK energy efficient buildings is Low Energy Building Database (LEB). This site contains information about energy efficient building projects in the United Kingdom. The site provides information about techniques, strategies and materials involved in building and refurbishing houses in a sustainable and energy efficient manner.

The sample of data set contains information on 29 energy efficient buildings of different occupation date, location, construction type and values of airtightness. The size of sample is not the result of random sampling and cannot claim to be unequivocally representative of the UK energy efficient houses. Data from the last 8 houses in Table 3 comes from the BRE Innovation Park in Watford.

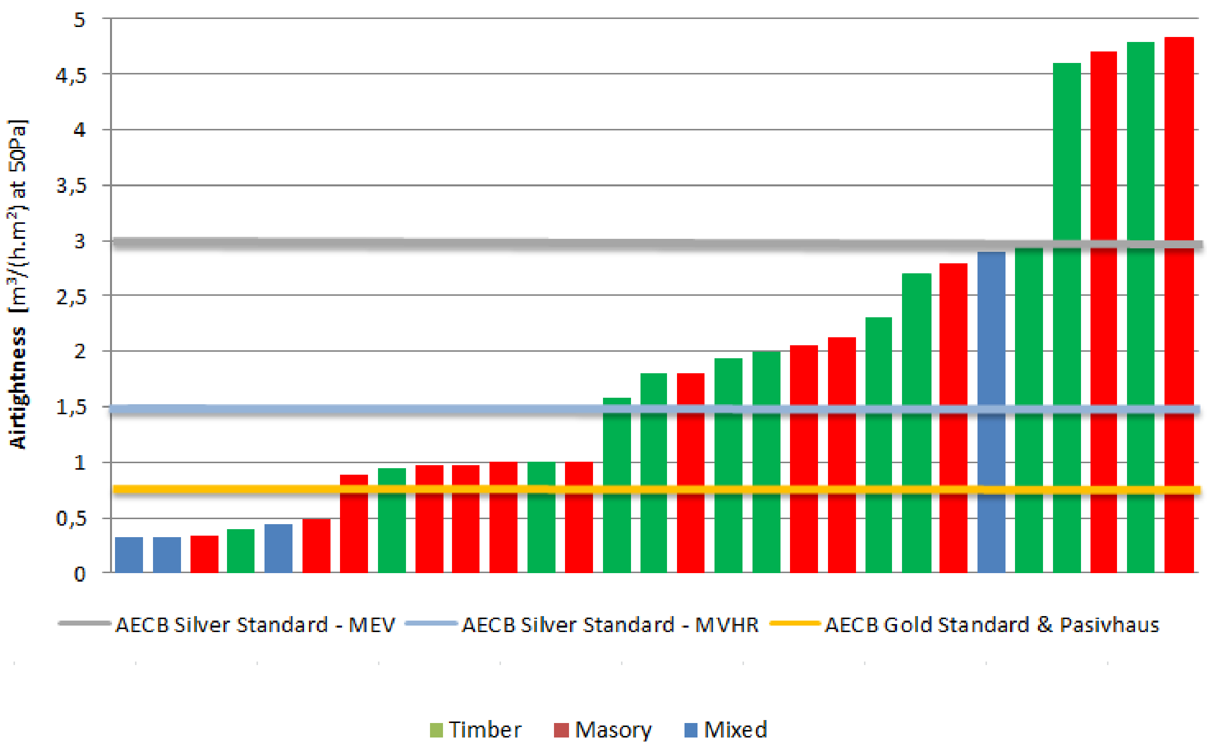

Figure 1: Data sample of airtightness energy efficient houses grouped by construction type

Table 3: Data sample of air leakage UK energy efficient houses.

Ref.	**Location**	**Year**	**Construction**	**Air permeability test** [$m^3/(h.m^2)$ at 50Pa]
UK01	Rochford Essex	2010	Mixed	0.33
UK02	Rochford Essex	2010	Mixed	0.33
UK03	Denby Dale	2010	Masonry	0.34
UK04	London	2011	Timber	0.40
UK05	St Helens	2011	Mixed	0.44
UK06	London	2010	Masonry	0.49
UK07	Hereford	2009	Masonry	0.88
UK08	Congerstone	2009	Timber	0.95
UK09	Birmingham	2009	Masonry	0.97
UK10	Sonning	2009	Masonry	0.98
UK11	York	2008	Timber	1.58
UK12	York	2008	Timber	1.94
UK13	Shrewsbury	2010	Masonry	2.05
UK14	Polzeath	2009	Masonry	2.13
UK15	Guildford	2005	Timber	2.31
UK16	Storrington	2009	Timber	2.70
UK17	Leicester	2010	Masonry	2.80
UK18	Woking	2005	Timber	3.00
UK19	London	2007	Timber	4.60
UK20	Queenborough	2010	Masonry	4.70
UK21	Gartocharn	2008	Timber	4.80
UK22	Watford, Willmott Dixon	2007	Timber	1.80
UK23	Watford, Hanson EcoHouse	2007	Masonry	4.83
UK24	Watford, Barratt Green House	2008	Masonry	1.00
UK25	Watford, Sigma Home	2007	Timber	1.00
UK26	Watford, Cub House	2010	Mixed	2.90
UK27	Watford, Renewable House	2009	Timber	2.00
UK28	Watford, Princes ´s House	2011	Masonry	1.00
UK29	Waftord, Affordable House	2006	Masonry	1.80

4 BRE Innovation Park

As part of my study abroad, I visited BRE Innovation Park with supervisor Stephen Neal. Visit the BRE Innovation Park was held together with other students of the University of Portsmouth on March 21, 2012. The Building Research Establishment Innovation Park features the world's most sustainable buildings, landscape design and innovative low carbon products, materials and technologies.

The BRE Innovation Park features eight of the world's most sustainable houses (built to the Code for sustainable homes), a health centre of the future, a refurbished Victorian Terrace and over 400 different construction innovations and emerging technologies as well as a state of the art community landscape design.

Collectively these houses demonstrate diverse and innovative approaches to sustainable design and construction. They each share the common goal of having a low impact on the environment but a high impact on the quality of life of building and community occupants and CO_2 emissions reduction. The BRE Innovation Park is a world leading and ground breaking demonstration development designed to give a glimpse of how the future delivery of sustainable buildings and communities can be achieved not only in the UK but around the world. (BRE Innovation Park, 2012)

The Chapter 4 presents 8 sustainable houses in which airtightness were measured. The following houses are included in the statistical survey of data set:

- Willmont Dixon Community Healthcare Campus
- Hanson EcoHouse
- Baratt Green House
- Sigma House
- Cub House
- Renewable House
- The Prince´s House
- Osborne Affordable House

4.1 Willmont Dixon Community Healtcare Campus

The Willmont Dixon Community Healthcare Campus was originally constructed as a sustainable school in 2007, using a laminated solid timber building system. Converted to a healthcare campus in 2009, the building provides an evolving showcase for the latest innovations in construction. Its main objective is to demonstrate the importance of retrofit in improving the sustainability and energy efficiency of hospitals and health centres. (BRE Innovation Park, 2012)

Figure 2: BRE Innovation Park, Watford, Willmont Dixon building

Table 4: Technical specification (BRE Innovation Park, 2012)

Year of	**Fabric U values** [W/(m^2.K)]				**Air permeability test**
construction	**Walls**	**Glazing**	**Floor**	**Roof**	[m^3/(h.m^2) at 50Pa]
2007	0.25	1.80	0.20	0.18	1.80

Design standards		BREAM Excellent rating
Construction type		Solid timber panel system
Windows type		Double glazed, Argon filled
Building services strategies	**Heating**	ASHP
	Ventilation	Predominantly natural with some MVHR
Renewable energy	**PV**	Yes
	Solar Thermal	Yes
Rainwater harvesting		Yes
Greywater recycling		Yes

4.2 Hanson EcoHouse

The Hanson EcoHouse was the first masonry house designed to Level 4 of the Code for Sustainable Homes. The building is shaped like a kiln. It draws hot air up through a roof-light which opens automatically according to the indoor temperature, while simultaneously drawing in cool fresh air at a low level from vents in the ground floor bedrooms. This system helps to enhance natural air currents, minimising the reliance on energy intensive cooling systems. (BRE Innovation Park, 2012)

Figure 3: BRE Innovation Park, Watford, Hanson Ecohouse

Table 5: Technical specification (BRE Innovation Park, 2012)

Year of construction	**Fabric U values** [W/(m^2.K)] **Walls**	**Glazing**	**Floor**	**Roof**	**Air permeability test** [m^3/(h.m^2) at 50Pa]
2007	0.18	0.78	0.16	0.14	4.83

Design standards		Code for Sustainable Homes Level 4
Construction type		Pre-fab cavity wall construction
Windows type		Triple glazed, Krypton filled
Building services strategies	**Heating**	GSHP
	Ventilation	Natural
Renewable energy	**PV**	No
	Solar Thermal	Yes
Rainwater harvesting		Yes
Greywater recycling		No

4.3 Barrat Green House

The Barratt Green House was the winner of the 2007 Home for the Future design competition run by the Mail on Sunday and the British Homes Awards. Created with urban living in mind, it was the first home by a mainstream house builder designed to Level 6 of the Code for Sustainable Homes. (BRE Innovation Park, 2012)

Figure 4: BRE Innovation Park, Watford, Barrat Green House

Table 6: Technical specification (BRE Innovation Park, 2012)

Year of construction	**Fabric U values** [W/(m^2.K)] **Walls**	**Glazing**	**Floor**	**Roof**	**Air permeability test** [m^3/(h.m^2) at 50Pa]
2008	0.11	0.68	0.11	0.11	1.00

Design standards		Code for Sustainable Homes Level 6
Construction type		180mm external wall insulation
Windows type		Triple glazed, Krypton filled
Building services strategies	**Heating**	GSHP
	Ventilation	Natural
Renewable energy	**PV**	No
	Solar Thermal	Yes
Rainwater harvesting		Yes
Greywater recycling		No

4.4 Sigma House

The Sigma Home was the first home in the UK designed to Level 5 of the Code for Sustainable Homes. Comprising two units, one complete and one left unfinished to demonstrate the innovations, the Sigma Home benefits from modern methods of construction with closed-panel timber frame construction at its heart. (BRE Innovation Park, 2012)

Figure 5: BRE Innovation Park, Watford, Sigma House

Table 7: Technical specification (BRE Innovation Park, 2012)

Year of construction	**Fabric U values** [W/(m^2.K)] **Walls**	**Glazing**	**Floor**	**Roof**	**Air permeability test** [m^3/(h.m^2) at 50Pa]
2007	0.15	0.68	0.18	0.15	1.00

Design standards		Code for Sustainable Homes Level 5
Construction type		Closed panel timber frame system
Windows type		Triple glazed, Argon filled
Building services strategies	**Heating**	Underfloor solar thermal, ASHP
	Ventilation	MVHR
Renewable energy	**PV**	Yes
	Solar Thermal	Yes
Rainwater harvesting		Rainwater butts
Greywater recycling		Yes

4.5 Cub House

The Cub House was launched at the Ideal Home Show in 2010. It is designed to meet Level 5 of the Code for Sustainable Homes. The modular home is made in England by Future Form and requires 16 days offsite manufacture, with seven days on site construction and installation. It is commercially available as a one, three or five bedroom home. Construction is from modular 65-90% recycled steel frame with high levels of insulation and glass fibre rainscreen cladding. (BRE Innovation Park, 2012)

Figure 6: BRE Innovation Park, Watford, Cub House

Table 8: Technical specification (BRE Innovation Park, 2012)

Year of construction	**Fabric U values** [W/(m^2.K)] **Walls**	**Glazing**	**Floor**	**Roof**	**Air permeability test** [m^3/(h.m^2) at 50Pa]
2010	0.21	1.25	0.22	0.16	2.90

Design standards		Code for Sustainable Homes Level 5
Construction type		Modular steel frame, 65-90% recycled
Windows type		Double glazing, with e-coating
Building services strategies	**Heating**	Combination ASHP, MVHR and DHW
	Ventilation	MVHR
Renewable energy	**PV**	Yes
	Solar Thermal	No
Rainwater harvesting		Yes
Greywater recycling		No

4.6 Renewable House

The Renewable House uses renewable materials to deliver an affordable everyday home with extraordinary environmental credentials. The Renewable House demonstrates the exceptional sustainability of renewable materials, but without compromising on style or affordability. By choosing renewable materials, The Renewable House meets Level 4 of the Code for Sustainable Homes. (BRE Innovation Park, 2012)

Figure 7: BRE Innovation Park, Watford, Renewable House

Table 9: Technical specification (BRE Innovation Park, 2012)

Year of construction	**Fabric U values** [W/(m^2.K)] **Walls**	**Glazing**	**Floor**	**Roof**	**Air permeability test** [m^3/(h.m^2) at 50Pa]
2009	0.19	1.30	0.10	0.16	2.00

Design standards		Code for Sustainable Homes Level 4
Construction type		Timber frame and Hemcrete
Windows type		Triple glazed, Argon filled
Building services strategies	**Heating**	Electric underfloor heating
	Ventilation	MVHR
Renewable energy	**PV**	No
	Solar Thermal	Yes
Rainwater harvesting		No
Greywater recycling		No

4.7 The Prince‘s House

The Prince’s House demonstrates a simple, low-tech and easy to build alternative for volume housebuilders seeking to meet increasingly stringent low carbon targets for new homes. It comprises two separate units: one complete and one left unfinished to demonstrate how traditional design principles need not be compromised to make low carbon homes. (BRE Innovation Park, 2012)

Figure 8: BRE Innovation Park, Watford, The Prince‘s House

Table 10: Technical specification (BRE Innovation Park, 2012)

Year of construction	**Fabric U values** [W/(m^2.K)]				**Air permeability test** [m^3/(h.m^2) at 50Pa]
	Walls	**Glazing**	**Floor**	**Roof**	
2011	0.20	0.75	0.11	0.11	1.00

Design standards		Code for Sustainable Homes Level 4
Construction type		Single skin walls of aerated clay block
Windows type		Triple glazed, Argon filled
Building services strategies	**Heating**	Wood burning stove with gas boiler
	Ventilation	Natural
Renewable energy	**PV**	No
	Solar Thermal	No
Rainwater harvesting		Rainwater butts
Greywater recycling		No

4.8 Osborne Affordable House

The Osborne Affordable House was designed as a low cost, quick build system for the social housing market. Built in 2006 using the i-SIP structural insulated panel system by Innovaré, it is designed to consume a third of the energy required for heating a house constructed to 2006 Building Regulation standards. The Osborne Affordable House was built before the Code for Sustainable Homes was established. (BRE Innovation Park, 2012)

Figure 9: BRE Innovation Park, Watford, Osborne Affordable House

Table 11: Technical specification (BRE Innovation Park, 2012)

Year of construction	Fabric U values [W/(m^2.K)] Walls	Glazing	Floor	Roof	Air permeability test [m^3/(h.m^2) at 50Pa]
2006	0.14	0.80	0.16	0.10	1.80

Design standards		Ecohomes Excellent
Construction type		SIP system
Windows type		Triple glazed, Argon filled
Building services strategies	**Heating**	ASHP, Electric skirting board heating
	Ventilation	MVHR
Renewable energy	**PV**	No
	Solar Thermal	Yes
Rainwater harvesting		No
Greywater recycling		No

5 Exploratory Data Analysis

Exploratory Data Analysis (EDA) is an approach to analysing data sets to summarize their main characteristics in easy to understand form, often with visual graphs, without using a statistical model or having formulated a hypothesis. (Sullivan, 2007)

There are a number of tools and determinants that are useful do exploratory data analysis, such as frequency distributions, mean, median, mode, histograms, range, skewness, kurtosis, and percentiles.

Table 12: Descriptive of characteristic Source: Output of IBM SPSS Statistics

AirPermeabilityTest		**Statistic**	**Std. Error**
Mean		1.8983	.26257
95% Confidence Interval for Mean	Lower Bound	1.3604	
	Upper Bound	2.4361	
5% Trimmed Mean		1.8230	
Median		1.8000	
Variance		1.9999	
Std. Deviation		1.4140	
Minimum		.33	
Maximum		4.8300	
Range		4.5000	
Interquartile Range		1.8400	
Skewness		.931	.434
Kurtosis		-.028	.845

The mean is the average value of sample and it is represented by value 1.90 $m^3/(h.m^2)$ at 50 Pa. The mean is not always being the best measure of central tendency, especially if data are skewed. For example, few energy efficient houses with extremely good airtightness may decrease the overall average.

Standard deviation is expressed as the positive square root of the variance. It is the average difference between observed values and the mean. The standard deviation is used when expressing dispersion in the same units as the original measurements. It is used more commonly than the variance in expressing the degree to which data are spread out. The standard deviation is 0.26 for whole sample of data set.

Variance is expressed as the sum of squares of difference between each measuring and mean, which quantity is then divided by the sample size. Variance is used as a measure of dispersion. In general, the higher the variance, the more spread out the data. Finally, the variance is 1.99. The value of variance is practically interpretable and thus cannot be determined if the value of variance represents valid data. It is necessary the value of variance to compare with the variances of various class groups.

Skewness describes how to concentrated data points are at the high or low end of the scale of measurement. The value of skewness confirmed higher frequency values smaller than their mean value. Also, the standard deviation was set and its equals to 0.434.

Kurtosis describes how concentrated data are around the mean. The kurtosis assesses how peaked or flat is the distribution of data. The ideal value rendered by the equation for kurtosis is 0 for the normal distribution. The table above (Table 12Table 12: Descriptive of characteristic Source: Output of IBM SPSS Statistics) indicates Kurtosis is - 0.028, which is almost equal to zero. There is a presumption of normal distribution of the data set. This presumption must be verified by Test Kolmogorov - Smirnov or Shapiro - Wilkov Test for the normal distribution.

Table 13: Percentiles Source: Output of IBM SPSS Statistics

AirPermeabilityTest	**Percentiles**						
	5	**10**	**25**	**50**	**75**	**90**	**95**
Weighted Average(Definition 1)	.3300	.3400	.9150	1.8000	2.7500	4.7000	4.8150
Tukey's Hinges			.9500	1.8000	2.7000		

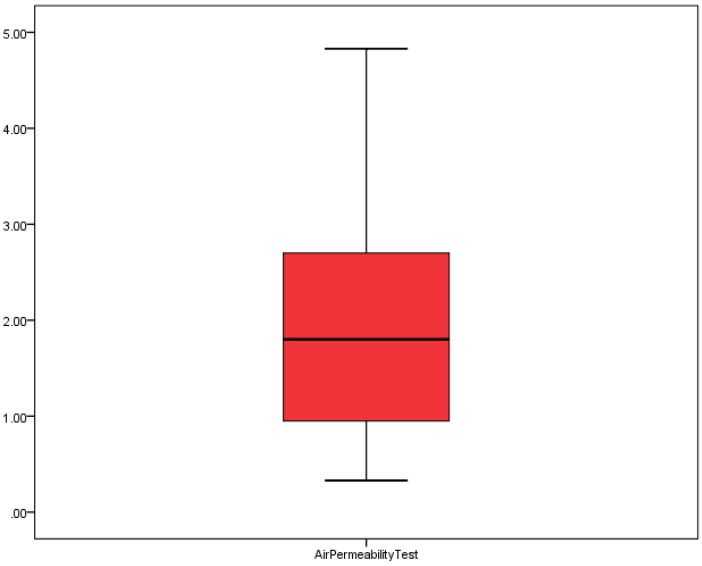

Figure 10: Box Plot of airtightness Source: Output of IBM SPSS Statistics

A boxplot (figure 10) displays at least five important pieces of information about a set of data represented airtightness of energy efficient houses in the UK. The median of the data is represented by the line in the centre of the rectangular red box. In this set of data this is the bar representing a value of 1.80 $m^3/(h.m^2)$, which essentially divides the data into two equal halves. The median of dataset is almost equal to the mean. This fact is confirmed by the low value of kurtosis. In the sample is situated more frequency of values lower than the mean value (55 %). The two ends of the rectangles represent the Third Quartile, located at about 2.75 $m^3/(h.m^2)$, and the First Quartile at 0,92 $m^3/(h.m^2)$. The other two values always shown are the maximum and minimum value of the data set. The minimum value is 0.33 $m^3/(h.m^2)$ and the maximum value is 4.83 $m^3/(h.m^2)$ for this set of data.

The boxplot splits the dataset into quartiles. The First and Third quartiles are the edges of the brown box is represented by values 0.92 $m^3/(h.m^2)$ and 2.75 $m^3/(h.m^2)$. We can state, 25 per cents of the airtightness are lower than 0.92 $m^3/(h.m^2)$, or 75 % of values airtightness of energy passive house is greater than 0,92 $m^3/(h.m^2)$. In addition, the box plot indicates that 75% of values lower than 2.75 $m^3/(h.m^2)$.

The point at a greater distance from the median than 1.5 times the interquartile range is plotted individually as circle. This point represents potential outlier. In our case there are no potential outliers.

Table 14: Frequency Table of airtightness of UK energy efficient housing

Data Range	Frequency	Relative Frequency	Cumulative Relative Frequency
0.00 – 0.50	6.0	0,207	0,207
0.50 – 1.00	4.0	0,138	0,345
1.00 – 1.50	3.0	0,103	0,448
1.50 – 2.00	4.0	0,138	0,586
2.00 – 2.50	4.0	0,138	0,724
2.50 – 3.00	3.0	0,103	0,828
3.00 – 3.50	1.0	0,034	0,862
3.50 – 4.00	0.0	0,000	0,862
4.00 – 4.50	0.0	0,000	0,862
4.50 – 5.00	4.0	0,138	1,000

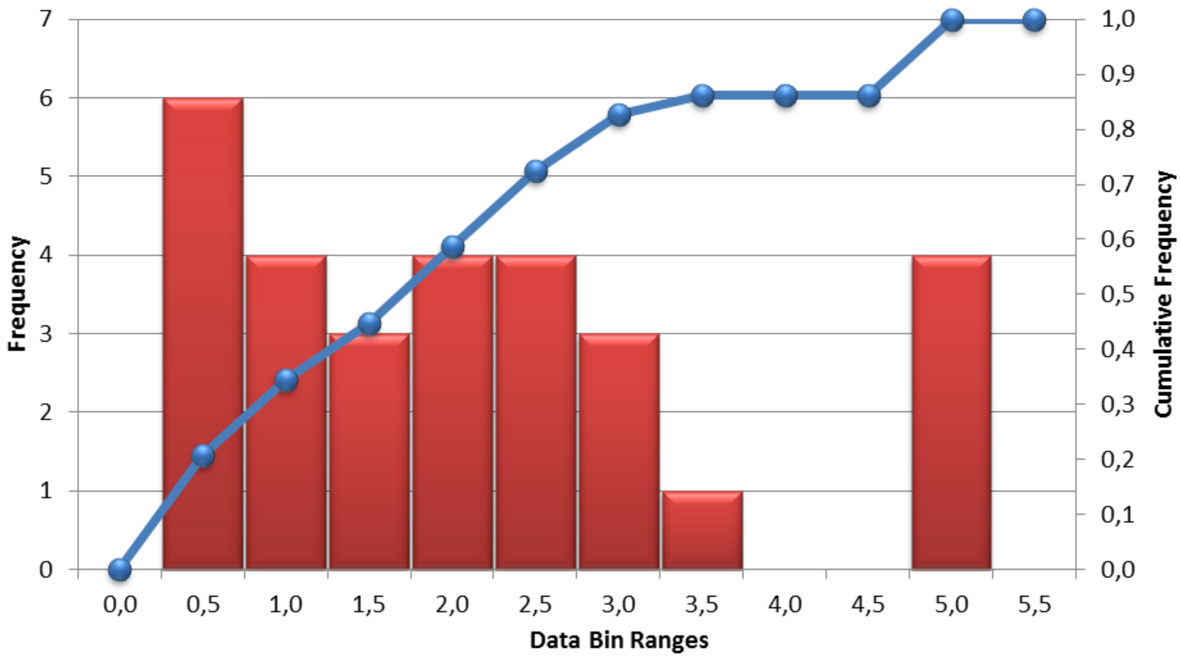

Figure 11: Distribution of airtightness of UK energy efficient houses

6 Comparison requirements with other countries

The United Kingdom is not the only country to have whole building airtightness requirement. Currently, Belgium, France, the Netherlands, Norway, Sweden, Switzerland, and the USA have criteria to limit whole building air leakage from dwellings. (Limb, 2001)

However, different countries express the air leakage criterion in different ways, making cross-country comparisons difficult. For instance: Belgium, the Netherlands, Norway and the USA express the criterion in terms of ach at a specific reference pressure (4, 10 or 50 Pa); France, Switzerland and the UK express the criterion in terms of $m^3/(h.m^2)$ at a given pressure difference (4 or 50 Pa); whilst Sweden uses $l/(s.m^2)$. Nevertheless, a simple and relatively crude comparison can be undertaken if assumptions are made about the volume and surface area of a typical building, and by normalising the air leakage criteria to a standard pressure differential. The Table below illustrates the results of such a comparison, for all of the countries that have air leakage criteria for dwellings. (Johnston)

Table 15: Maximum whole building airtightness requirements for dwellings (Limb, 2001)

Country	**Building requirement**	**Normalised** ach at 50 Pa
Belgium	< 3 ach at 50 Pa when balanced mechanical ventilation is used < 1 ach at 50 Pa when heat recovery devices are used	3.00
France	0.8 to 2.5 $m^3/(h.m^2)$ at 4 Pa	11.0
Netherlands	Class 1 – Max of 1.4 to 2.24 ach at 10 Pa. Class 2 – Max 0.72 to 1.15 ach at 10 Pa.	6.50
Norway	Detached and undetached houses – 4 ach at 50 Pa. Other buildings two storeys high or less – 3 ach at 50 Pa. Other buildings more than two storeys high – 1.5 ach at 50 Pa.	4.00
Sweden	The average air leakage rate at 50 Pa does not exceed 0.8 $l/(s.m^2)$.	2.88
Switzerland	New buildings – 0.75 $m^3/(h.m^2)$ at 4Pa upper limit. Refurbished buildings – 1.5 $m^3/(h.m^2)$ at 4 Pa upper limit.	3.30
UK	Does not exceed 10m3/h/m2 at 50 Pa	8.30
USA	Max 1.6 ach at 4 Pa.	8.50

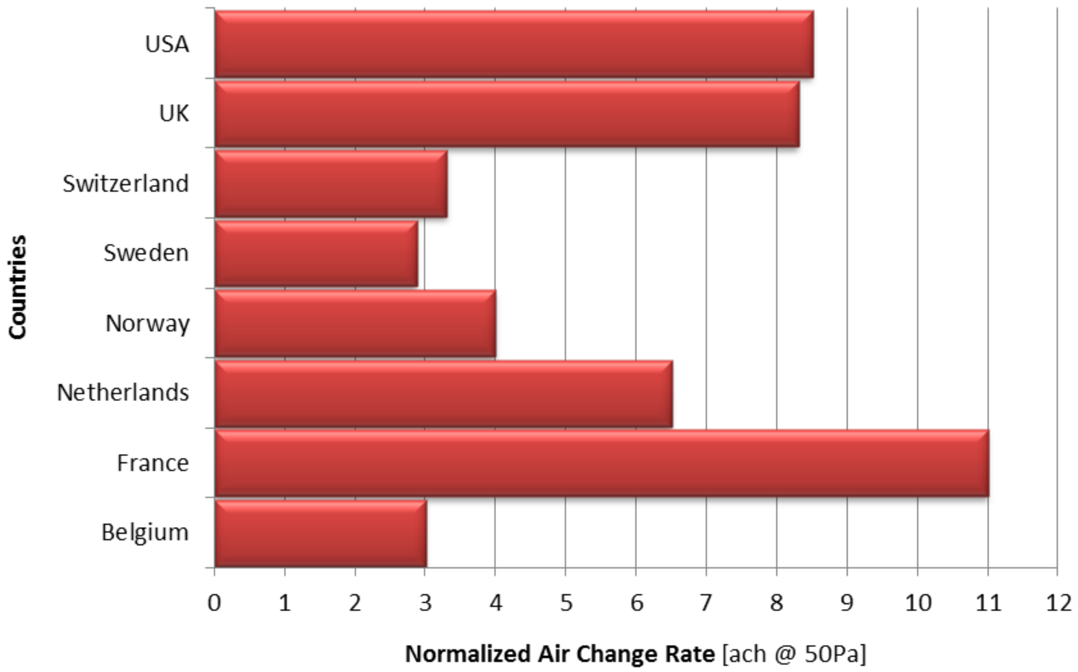

Figure 12: Maximum whole building airtightness requirements for dwellings

Nevertheless, a simple and relevant comparison can be undertaken if assumptions are made about the volume and surface area of a typical building, and by normalising the air leakage criteria to a standard pressure differential. Such an approach was adopted by Limb (2001), who assumed an internal building volume of 300 m^3, a surface area of 250 m^2 and normalised the figures to a pressure differential of 50 Pa. (Limb, 2001)

The comparison highlights the wide range of normalised air leakage criteria that exists. The most stringent criteria tend to be found in countries with severe climatic conditions, such as Sweden (2.88 ach at 50Pa), whilst countries with more temperate climates tend to have less stringent criteria, for instance France (11 ach at 50Pa). Part of the reason for this is likely to be the fact that in countries that experience severe climatic conditions, leaky buildings can result in extreme user discomfort. (Limb, 2001)

6.1 Comparison requirements with the Czech Republic

Czech Republic has no requirements for airtightness of buildings, but only the recommended values. Airtightness of buildings is in the Czech Republic referred to as n_{50}. The value n_{50} is characterized with leakage flow rate at 50 Pa divided by the building's volume:

$$n_{50} = \frac{Airflow\ rate\ at\ 50\ Pa}{Heated\ Volume}\ [h^{-1}\ or\ ach\ at\ 50\ Pa]. \qquad (1)$$

The value of n_{50} expresses airtightness in numbers, and indicates how often the air volume of the building concerned is exchanged per hour at a pressure difference of 50 Pa. The value of n_{50} equals to 0.60 means that a maximum of 60% of the complete building air volume can escape per hour.

Recommended values of airtightness of buildings are presented in the following standards: ČSN 73 0540-2 and TNI 73 0329. The Table 14 illustrates the recommended values of air tightness in the Czech Republic.

Table 16: Recommended values of airtightness of buildings (CSN 73 0540, 2011)

Ventilation of buildings	**Recommended values of n_{50}** [h^{-1}]	
	Level I	**Level II**
Natural and combined ventilation	4.50	3.00
Mechanical ventilation	1.50	1.20
Mechanical ventilation with heat recovery	1.00	0.80
Mechanical ventilation with heat recovery in energy efficient buildings (Energy passive houses)	0.60	0.40

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