INTERNATIONAL COMPARISON OF ENVELOPE AIRTIGHTNESS MEASUREMENTS

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Abstract
Good envelope airtightness is a prerequisite for energy efficiency and effective ventilation of buildings. Through the implementation of specific national requirements, airtightness has evolved positively in many countries, while the European Directive on Energy Performance of Buildings and its associated CEN standards are expected to bring further improvements. However, Member States address the issue very differently in their national regulation.

This paper aims to collect recent measurement results of whole building airtightness from different European Member States, to present a comparable analysis among them and to identify specific trends. For this purpose, a total of 1,094 n_{50} values from field airtightness measurements from 7 European countries were brought together.

Differences that vary from 1.09 for Norway to 6.38 for Greece were found between the mean n_{50} values for the category of "houses". Mode n_{50} values are found to be again the highest for Greece (4.5), while being 2.5 for France and Finland and 1.5 for all other countries. Airtightness data for houses fits into a theoretical Weibull distribution while a considerable asymmetry in distribution was found for all countries expect for Greece and Norway.

From the statistical study of airtightness for buildings with different uses but located in the same country, French "houses" prove to differ statistically significant from almost all other categories of French buildings.

Introduction
Airtightness of buildings has been proven to constitute an important factor from a variety of perspectives: it affects the infiltration rate of the building, therefore influencing both the quality of indoor air and the need for ventilation, as well as the energy used for heating and/or cooling. Airtightness is one of the fundamental factors used for predicting the ventilation rates in buildings. Its main characteristic is that it is not dependent on the pressure differences across the buildings envelope, so that it can be used as a parameter for comparing and characterising the building stock and its construction quality.

As awareness of its impact on energy use and indoor air quality spreads further, building airtightness is increasingly becoming an issue across European countries. Field measurements and good practice examples over the world highlight the importance of good control over the permeability of buildings; however, the results of such studies are not yet synthesised in a way that they can provide a coherent overall picture.

Airtightness measurements are normally performed in order to characterise the permeability of the buildings envelope in the absence of any climatic or other external influences. The building is therefore either pressurised or depressurised to create such pressure difference that climatic influences are minimised. The pressure difference is created by means of a fan, while the created airflow can either be observed visually, or quantitative measured. To date, the most common method to determine the airtightness of a building is the so-called blower-door method described in EN 13829. Recently, another technique started being applied in dwellings with mechanical ventilation systems, namely the IMPEC technique described by Litvak et al (2002). This technique replaces the blower door frame by using the mechanical ventilation extract air duct system. However, most of the existing measurements have been performed through the predescribed blower door method.

In this paper, whole building airtightness measurement results from 7 European Countries have been collected and analysed. The objective is to make a comparison between the measured values to try to identify specific trends. The study is carried out within the framework of WP5 “Stimulation of good building and ductwork airtightness through the European Energy Performance of Buildings Directive”, of the IEE ASIEPI project for the Assessment and Improvement of the EPBD Impact (for new buildings and building renovation) Contract N°: EIE/07/169/SI2.466278.

Expressing the airtightness of buildings

The airtightness of a building is calculated either in terms of airflow rate through the buildings envelope at a given conventional pressure, or in terms of equivalent leakage area.

The airflow rate can be calculated through equation 1.

$$Q= C\Delta P^n \qquad (1)$$

where Q is the volume airflow rate through the leakage site (m^3/s)
ΔP is the pressure difference across the leakage site (Pa)
n is the flow exponent ($0.5<n<1$) and
C is the airflow coefficient ($m^3 s^{-1} Pa^{-n}$)

The airtightness can then be quantified using equation 2

$$n=Q/V \qquad (2)$$

where n (1/h) is the ratio of air leakage flowrate (m^3/s) at a given pressure, weighted by the heated volume of the building (m^3).

Depending on the country, the standard used and the local uses, the conventional pressure difference used may be either 1, 4, 10 or 50 Pa and the respective infiltration air change rate being n_1, n_4, n_{10} or n_{50}. In this study we consider all measurement results at the pressure difference of 50Pa, which is commonly used for measurements.

Analysing the sample

For the purposes of this study, a total of 1094 n_{50} values from field measurements were collected from 7 countries: Belgium (excerpt from BBRI measurement database, 2007), Greece (Sfakianaki et al, 2008), The Netherlands (Cornelissen et al, 1994 and 1996), France (excerpt from CETE de Lyon measurement dataset, 2007), Norway (excerpt from Norwegian low energy dwelling project - SINTEF), Finland (Korpi et al, 2007) and Germany (excerpt from BlowerDoor GmbH dataset, Dorschky et al, n.d.).

Some of the n_{50} values have been provided as such while others have been calculated through the equations mentioned earlier in this paper.

In order to be able to use the available data, the building categories have been summarised as given in Table 1.

Table 1. Summary of building categories across the 7 countries

	Belgium	Greece	The Netherlands	France	Norway	Finland	Germany
Houses [(1)]	“detached single family house” “semi detached single family house”	“detached single family houses”	“eengezinswoning”	“maison individuelle”	“detached” “detached in row” “row”	“houses” “single family houses”	“familie house”
Apartments [(2)]			“flat” “flatwoning(en)” “gestapelde laagB” “hatwoning” “kamerwoning” “maisonette” “portiekwoning”	“appartement” “immeuble logement collectif (partie de batiment)”		“apartments”	
Industrial buildings	“industrial buildings”			“industrie”			“industrial hall”
Offices	“office buildings”			“bureaux”			“office building”
Hotels [(3)]				“hôtel”			
Information desks [(3)]				“enseignement”			
Multiple use halls [(3)]				“sale polyvalente”			
Sport halls [(3)]				“locaux sportifs”			
Whole apartment buildings [(3)]				“immeuble logement collectif (batiment entiere)”			
Home for elderly people [(3)]							“home for old people”
Hospitals [(3)]							“hospital kosowo”
Libraries [(3)]							“library”
Schools [(3)]							“highschool”
Shops [(3)]							“shop”
Service houses [(3)]							“service house (toilets +shower)”
Highselfstores [(3)]							“highselfstore”
Others [(3)]				“autre”			

(1) All individual and completely independent buildings that are being used as residences for a single family.
(2) Residences for a single family, which form part of a building.
(3) Later on in the study, all buildings of this category have been added up in the category “others” as the sample size was too small

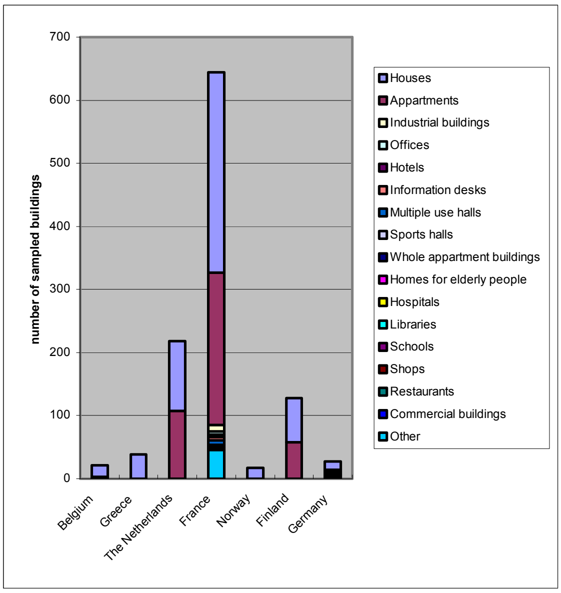
Table 2 presents the examined samples together with an initial rough statistical analysis.

Table 2. Summary of n_{50} field measurements for the 7 countries of the study

Country	Source	Number of available n50 values	Types of buildings tested	mean n50	min n50	max n50	stdev	stdev/ mean	median
Belgium	Belgium Building Research Institute (BBRI)	21	18 houses, 1 industrial, 2 offices	4,99	0,50	22,50	5,10	1,02	3,70
Greece	National and Kapodistiran University of Athens, Group Building Environmental Research (NKUA)	39	39 houses	6,38	1,87	13,10	3,15	0,49	2,64
The Netherlands	Netherlands Organisation for Applied Scientific Research (TNO)	218	110 houses, 108 appartments	1,48	0,06	6,20	1,03	0,70	1,26
France	Centre d' Etudes Techniques de l' Equipement de Lyon (CETE de Lyon)	644	317 houses, 242 appartments, 10 industrial, 5 offices, 4 hotels, 5 information, 7 multiple use halls, 4 sports, 4 whole appartment buildings, 46 others	3,38	0,04	60,96	4,42	1,31	2,55
Norway	Stiftelsen SINTEF (SINTEF)	17	17 houses	1,09	0,17	2,79	0,86	0,79	0,74
Finland	Tampere University of Technology, Department of Civil Engineering Helsinki University of Technology, HVAC laboratory	128	70 houses, 58 appartments	2,54	0,30	16,20	2,33	0,92	2,05
Germany	BlowerDoor GmbH, Energie- und Umweltzentrum (EUZ)	27	13 houses, 3 industrial, 2 offices, 2 homes for eldrly people, 2 shops, 1 hospital, 1 school, 1 library, 2 other	1,21	0,01	4,70	1,07	0,88	1,00

As can be seen from the table, the measured samples differ significantly from country to country, both qualitatively and quantitatively. Some countries have performed airtightness measurements in representative samples of buildings, while others were just starting up. Also, in some countries measurements have been performed on just one specific category of buildings, while in others various categories and building types have been examined. Figure 1 graphically depicts the differences in the sample size and type between the countries.

Figure 1. Graphical view of the samples of examined buildings



At first sight, the values presented in the table are not sufficient to draw conclusions about how building stocks among the countries compare. As the distribution of values is too broad, further characteristics of the sampled buildings need to be considered. The airtightness of a building may be influenced by a series of factors, the most important ones being the type and year of construction. The type of construction is influenced by the planned use, the climatic conditions, the materials available and the standards used in the specific country. Figure 2 shows a breakdown of the building sample per country and year of construction.

Figure 2. Breakdown of the building sample per country and year of construction.

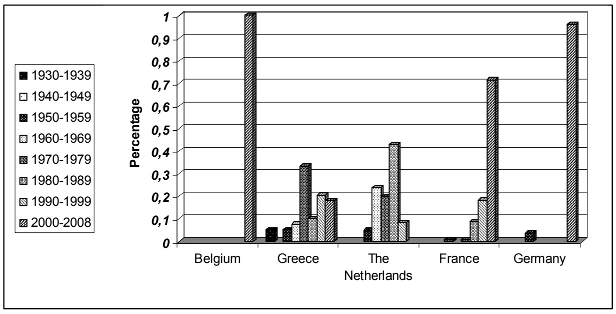
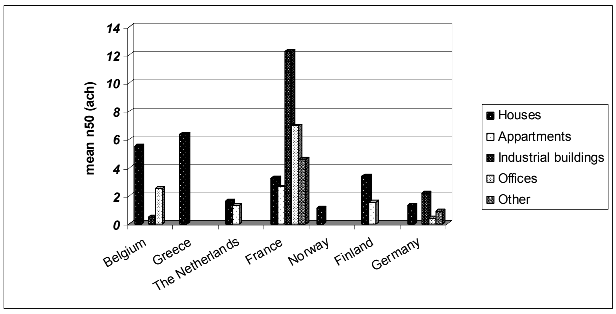


Figure 3 presents the mean n_{50} value per country and building type. All building categories with only a few values available have been summed up as being in the 'others' category. The figure shows dramatic differences between the mean n50 values for specific categories of buildings among the different countries, however, with the exception of houses and apartments, sample size is too small to draw conclusions for the country stocks.

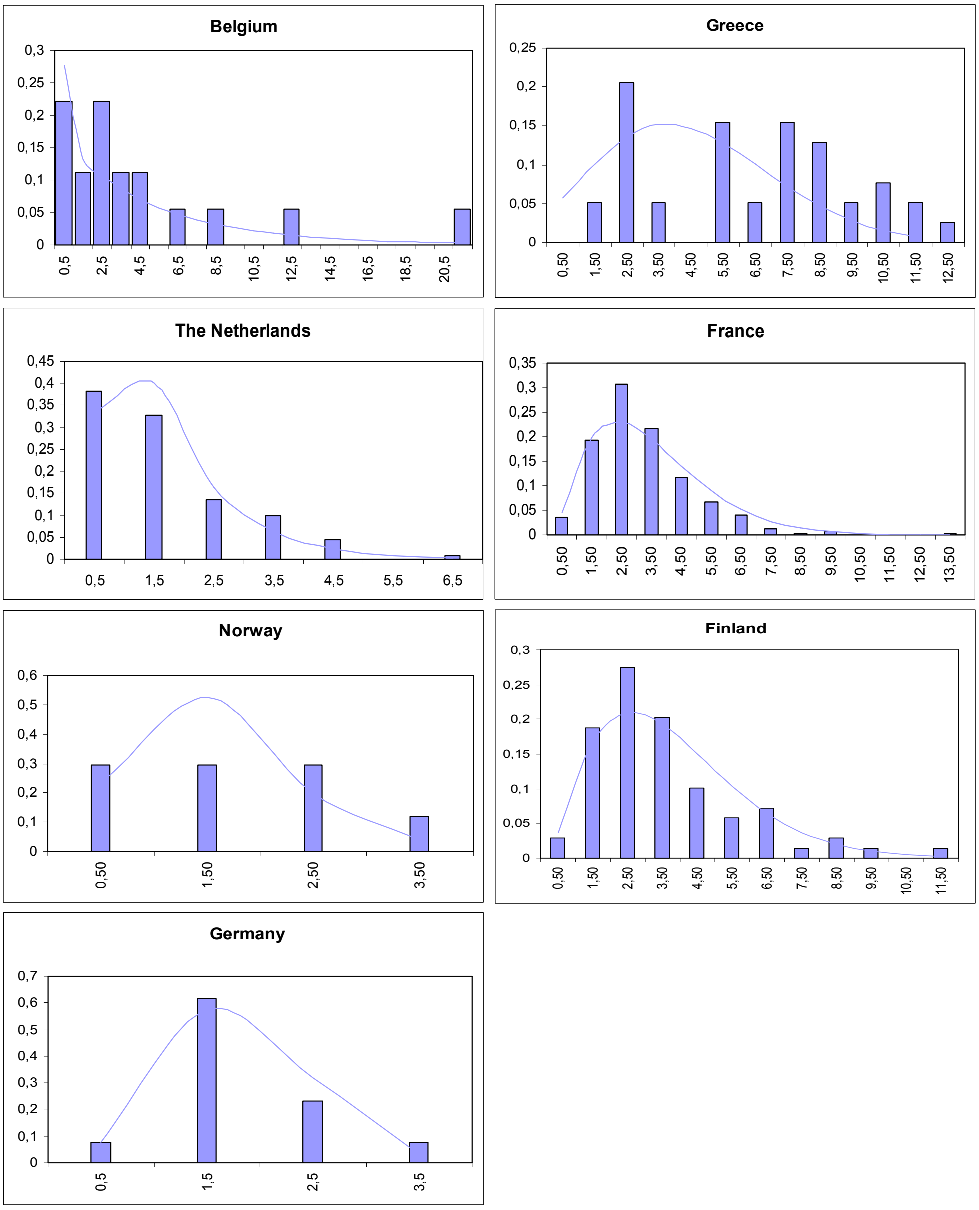
Figure 3. Mean n50 value per country and building type.



Statistical analysis of airtightness for houses

Given the available sample size and other characteristics, special attention has been paid to examining statistically the stock of houses. Figure 4 shows the distribution of n50 values for houses in each country.

Figure 4. Distribution of n50 values for houses in each country.



By fitting the frequency distribution to a theoretical statistical law, we succeed in extracting statistical conclusions about the whole population, at a selected significant level. The provided n_{50} values for the category "houses" which is covered by all 7 examined countries prove to fit well into the theoretical Weibull distribution with two parameters. Parameter "a" is proportionally equal to the mean value of data, while "b" is inversely equal to the variance of the values. Table 3 summarises the statistical results for n_{50} values for houses.

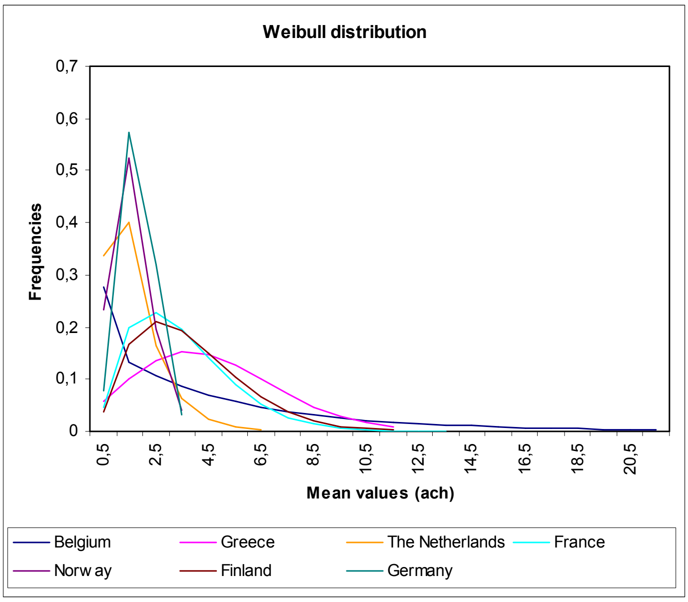
Table 3. Statistical results for n_{50} values for houses

	a	b	mode	mean	S	cv	skew	median
Belgium	4.89	0.952	1.5	5.51	5.30	96%	2.3	3.75
Greece	5.782	2.095	4.5	6.38	3.15	49%	0.1	6.39
The Netherlands	1.144	1.077	1.5	1.63	1.16	71%	1.3	1.35
France	3.302	1.614	2.5	3.22	1.68	52%	1.6	2.85
Norway	1.191	1.527	1.5	1.09	0.86	79%	0.8	0.74
Finland	3.648	1.657	2.5	3.38	2.65	78%	2.3	2.60
Germany	1.469	2.344	1.5	1.34	0.97	72%	1.07	1.0

As can be seen from the table, the values representing the mean air changes per hour for houses vary from 1.09 for Norway (followed by Germany and The Netherlands) to 6.38 for Greece (with Belgium being close at 5.51). The difference between the mean n_{50} values for houses in Finland and Norway, where the climatic conditions over the year are quite similar, is worthy of further examination.

The values of the coefficient of skewness (*skew)* show a considerable significant asymmetry distribution in all cases, expect for Greece (0.1) and Norway (0.8). For this reason, a better suitable parameter to be considered is the *mode* value. The *mode* arises from the curve of the theoretical fitting (Weibull distribution) shown in Figure 5. The mode values are found to be 4.5 for Greece -the data of which are close to a normal distribution- 2.5 for France and Finland, and 1.5 for all other countries.

Figure 5. Theoretical Weibull distribution for n_{50} values for the 7 countries



Airtightness of buildings with different uses
Of specific interest is also the study of airtightness for buildings located in the same country, but with different uses. This study, carried out through t-test of the difference of the means, was feasible only for France and Germany, as only those two countries provided measurements for various building types.

From the study for France (Figure 6) statistically significant differences in means were observed between the category "houses" and almost all other categories (Table 4). For all other cases, except for the comparison between the categories "apartments" and "industrial buildings", no significant differences were observed. The category "others" was not taken into account as it summarises several different types of buildings.

Figure 6. Mean n50 values for the French building sample.

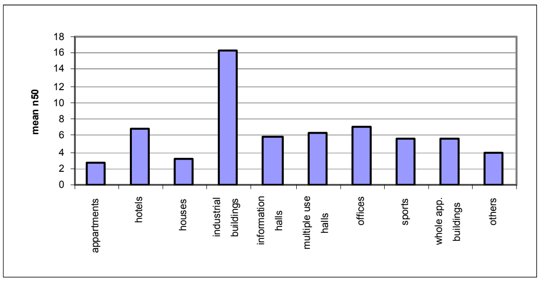
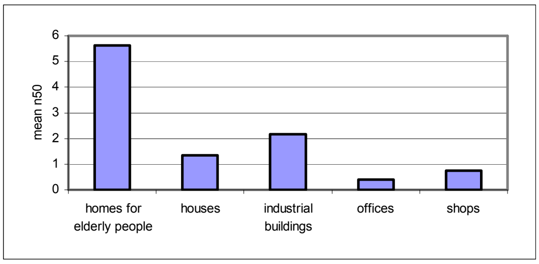


Table 4. Absolute values of t-test of the difference of the means for France

	Apartments	Hotels	Houses	Industrial buildings	Information halls	Multiple use halls	Offices	Sports	Whole apartment buildings	Others
Apartments	0	1,79	**2,01**	**7,52**	1,48	2,01	2,02	1,25	1,26	1,72
Hotels		0	**4,35**	1,10	0,32	0,11	0,02	0,66	0,83	1,28
Houses			0	**12,62**	**3,20**	**4,08**	**4,08**	**4,84**	**2,84**	2,06
Industrial buildings				0	1,34	1,43	1,22	1,24	1,25	4,45
Information halls					0	0,13	0,35	0,06	0,06	0,85
Multiple use halls						0	0,13	0,17	0,17	1,16
Offices							0	0,62	0,70	1,43
Sports								0	0	0,73
Whole apartment buildings									0	0,73
Others										0

A similar analysis is carried out for 5 building categories for Germany (Figure 7).

Figure 7. Mean n50 values for the German building sample.



Significant differences in means were observed between the category “homes for elderly people” and all other categories (Table 5). Between any other possible combinations of building categories, no significant differences were observed.

Table 5. Absolute values of t-test of the difference of the means for Germany

	Homes for elderly people	Houses	Industrial buildings	Offices	Shops
Homes for elderly people	0	**6,07**	**2,01**	**18,51**	**9,76**
Houses		0	1,04	1,32	0,83
Industrial buildings			0	1,03	0,82
Offices				0	0,68
Shops					0

However, the previous discussed results for Germany concerning the category “homes for elderly people” should be considered with great care since only two such buildings were measured. In order to arrive at more precise conclusions, more details on other parameters such as type and quality of construction, year of construction, specific habits, etc. should be studied.

Conclusions
The existing 1094 n_{50} values collected from field airtightness measurements of the 7 European countries prove to differ - both qualitatively and quantitatively - in such a way that no reliable conclusions can be drawn for the overall building stocks as such. Conclusions are limited to comparison data for specific building categories or for specific countries.

Dramatic differences exist between the mean n_{50} values among the different countries for the category of "houses", which vary from 1.09 for Norway (followed by Germany and The Netherlands) to 6.38 for Greece (with Belgium being close at 5.51), while differences in mean n_{50} values for houses are also found between countries with similar climatic conditions.

The statistical analysis of the airtightness of houses for all 7 countries prove to fit well into the theoretical Weibull distribution, which means that similar conclusions can be drawn for the whole existing stock of houses in each country. Furthermore, the examined values of skewness show a considerable asymmetry in distribution in all cases expect for Greece (0.1) and Norway (0.8). While considering the mode n_{50} values, those are found to be again the highest for Greece with 4.5, while being 2.5 for France and Finland and 1.5 for all other countries. Such differences between f.e. Greece and Norway can be explained on the basis of the climatic differences and thus the specific needs and points of attention while constructing buildings in each country.

From the statistical study of airtightness for buildings with different uses but located in the same country, French "houses" prove to differ statistically significant from almost all other categories of French buildings. The question is if this finding can be explained or supported in terms of f.e. specific French building construction regulation for houses.

Finally, an important conclusion of this study is the fact that, in order to arrive at more precise level of details of intercomparison of airtightness, an expansion of the available sample is strictly necessary both horizontally (level of available details per measurement; type and quality of construction, year of construction, specific habits, etc.) and vertically (number of measurements per building category).

Scope and limitations of the research
The scope of this study was to examine and compare existing airtightness measurement data from 7 specific European countries with specific background information. The data collected through the current study will be made available for the purposes of updating the existing AIVC database of airtightness measurements in the near future.

As there is no standard approach for airtightness available across Europe, each Member State has adopted each own terminology and calculation method and airtightness issues are tackled very differently in the EPBD implementations of each Member State. For instance, some MS have chosen to set a minimum envelope airtightness requirement, where others are using default values for airtightness in their EP calculation. Each country has also its own specific way of measuring and presenting the airtightness data, some using default n_{50} values, other using I_4 or q values, etc. Finally, specific details and characteristics per country may be of special interest for comparative studies, such as specific construction details, types of buildings etc.

However, in order to be able to make any comparison at all between the available data, some kind of standardisation/aggregation of categories was necessary. During the implementation of this standardisation procedure, some of the detail level of the available data may have been lost. The use of a common terminology and taxonomy of buildings would help overcome this problem when comparing and aggregating national data.

The scope of a further study could be to broaden the sample size for different building categories across the countries, to add measurement data from countries of different climatic regions, to investigate specific trends after implementation of the EPBD requirements, to relate different types of construction to year of construction etc.

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References

Cornelissen H.J.M., Gids de W.F., (1994) *Gegevensbestand luchtdoorlatendheid van woningen, TNO rapport 94-BBI-R1760*, 21 december 1994.

Cornelissen H.J.M., Gids de W.F. (1994) *Opbouw van het gegevensbestand luchtdoorlatendheid van woningen, februari 1993, in relatie tot de opbouw van het Nederlandse woningbestand, TNO rapport 94-BBI-R1762*, 21 december 1994.

Cornelissen H.J.M., Gids de W.F. (1996), *Lichtdoorlatendheid van woningen. Merendeel van de nieuwbouw blijkt behoorlijk luchtdicht*, J. BouwWereld, nr 18, 27 September 1996.

Dorschky S., Simons P., Rolfsmeier S. (n.d.) *Blowerdoor Messung großer Gebäude – mit einem und mit mehreren Gebläsen.*

Korpi M., Vinha J., Kurnitski J., (2007) *Pientalojen ja kerrostaloasuntojen ilmanpitävyys*, In: Vinha, J. & Korpi, M. (edit.) Rakennusfysiikka 2007: Uusimmat tutkimustulokset ja hyvät käytännön ratkaisu, 18 – 19 October 2007 Tampere, Finland, pp. 253-260.

Litvak A., Fournier M., Carrié F.R., (2006) *Envelope and ductwork airtightness data in France : Field practice, regulatory approach, energy implications and progress needed,* 1st Blowerdoor European Symposium - e.u.[z.], Fulda (D). 23 - 24 June 2006.

Sfakianaki A., Pavlou K., Santamouris M., Livada I., Assimakopoulos M.N., Mantas P., Christakopoulos A., (2008) *Airtightness measurements of residential houses in Athens, Greece,* J. Building and Environment 43 (2008), pp. 398–405.