Residential buildings airtightness frameworks: A review on the main databases and setups in Europe and North America

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1. Introduction

- growing interest for airtightness
- fast spread of regulatory frameworks
- stricter requirements, schemes for testing and quality control
- creation of airtightness databases

2. Objectives

- Explore the main airtightness databases
  - Data available
  - Input scheme
  - Purpose
  - Analysis
  - Structure
  - Requirements
- Compare databases
  - Differences
  - Gaps
  - Strengths and weaknesses
  - Problems and opportunities

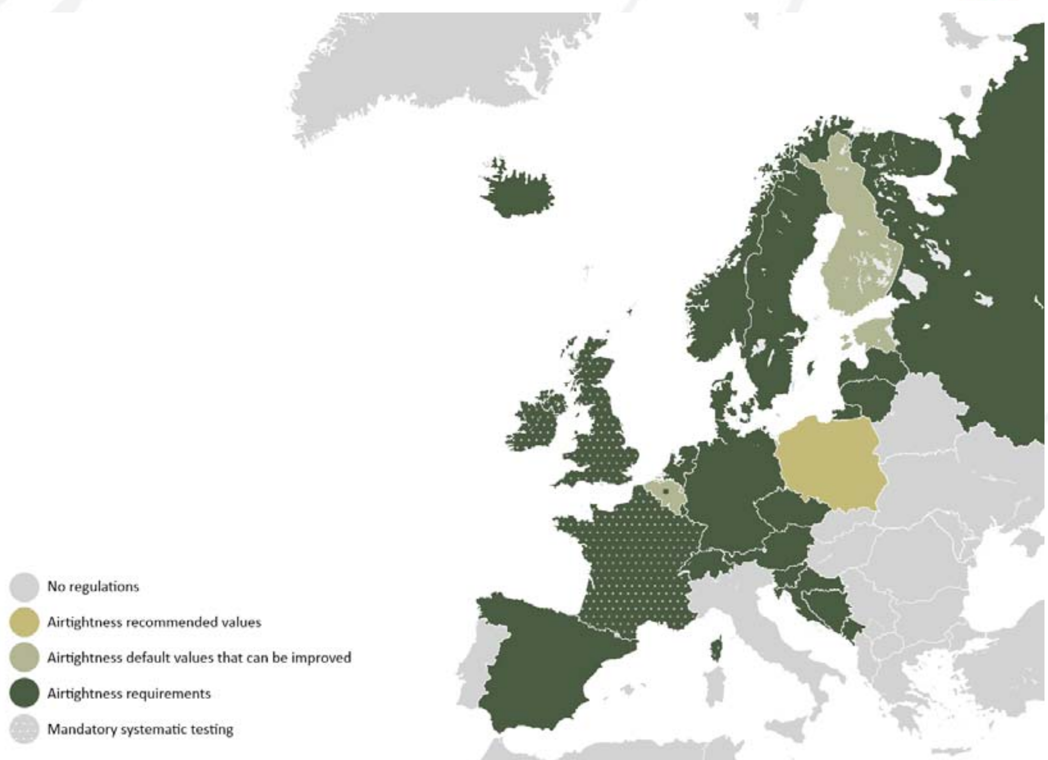
3. Why are airtightness databases useful?

- demonstrate compliance with regulations
- input data for buildings energy and ventilation estimations
- information for modelling and designing
- factors are the most important
- evaluate building design, construction practices and quality
- develop guidelines
- evaluate the effectiveness of individual measures
- visualise time trends
- evaluate the progress of the built stock
- compare the building performance with other countries

4. Normative airtightness frameworks

- Europe: EPBD (nZEB)
  - Air infiltration control
  - No specific requirements
  - Different approach in each country
- North America: national energy codes
  - Air infiltration control
  - Different energy policies in each state or region

Country	Parameter	Units	Requirements	On-site testing
Airtightness mandatory values				
Austria	n_{50}	h^{-1}	Natural ventilation < 3 Mechanical ventilation < 1.5	Not mandatory
Belgium – Brussels region	n_{50}	h^{-1}	< 0.6	Not mandatory
Bosnia	n_{50}	h^{-1}	Natural ventilation < 3 Mechanical ventilation < 1.5	Not mandatory
Croatia	n_{50}	h^{-1}	Natural ventilation < 3 Mechanical ventilation < 1.5	Not mandatory
Czech Republic	n_{50}	h^{-1}	Natural ventilation < 4.5 Mechanical ventilation < 1.5 Heat recovery system <1	Not mandatory
Denmark	w_{50}	$l/(s \cdot m^2)$	$A_{env}/A_{floor} \leq 3$: < 1 $A_{env}/A_{floor} > 3$: < 0.3	Not mandatory
France	q_4	$m^3/(h \cdot m^2)$	Single-family < 0.6 Multi-family < 1	Mandatory
Germany	n_{50}	h^{-1}	Natural ventilation < 3 (exceptions with active components < 1.5) Mechanical ventilation < 1.5	Not mandatory
Iceland	q_{50}	$m^3/(h \cdot m^2)$	< 3	Not mandatory
Ireland	q_{50}	$m^3/(h \cdot m^2)$	< 5	Mandatory
Latvia	q_{50}	$m^3/(h \cdot m^2)$	Natural ventilation < 3 Mechanical ventilation < 2 Heat recovery system < 1.5	Not mandatory
Liechtenstein	q_{50}	$m^3/(h \cdot m^2)$	New buildings: Natural ventilation < 2.4 Mechanical ventilation < 1.6 Renovations: Natural ventilation < 3.6 Mechanical ventilation < 2.4	Not mandatory
Lithuania	n_{50}	h^{-1}	Class C: < 2 Class B: < 1.5 Class A: < 1.0 Class A+ and A++: <0.6	Not mandatory
Luxembourg	n_{50}	h^{-1}	Natural ventilation < 3 Mechanical ventilation < 1.5 Heat recovery system < 1	Not mandatory
Monaco	q_4	$m^3/(h \cdot m^2)$	Single-family < 0.6 Multi-family < 1	Mandatory
Montenegro	n_{50}	h^{-1}	Natural ventilation < 3 Mechanical ventilation < 1.5	Not mandatory
Netherlands	w_{10}	$dm^3/(s \cdot m^2)$	<1	Not mandatory
Norway	n_{50}	h^{-1}	< 1.5	Not mandatory
Russia	n_{50}	h^{-1}	Natural ventilation < 4 Mechanical ventilation < 2	Not mandatory
Slovenia	n_{50}	h^{-1}	Natural ventilation < 3 Mechanical ventilation < 2	Not mandatory
Spain	n_{50}	h^{-1}	Compacity $V/A_E \leq 2$: < 6 $V/A_E \geq 4$: < 3	Not mandatory
Sweden	q_{50}	$m^3/(h \cdot m^2)$	< 0.6	Not mandatory
Switzerland	q_{50}	$m^3/(h \cdot m^2)$	New buildings: Natural ventilation < 2.4 Mechanical ventilation < 1.6 Renovations: Natural ventilation < 3.6 Mechanical ventilation < 2.4	Not mandatory
United Kingdom	q_{50}	$m^3/(h \cdot m^2)$	< 10	Mandatory
USA	n_{50}	h^{-1}	< 3 climate zone 3 to 8 < 5 climate zone 1 and 2	Mandatory (depending on state level speed of national energy code adoption)
Airtightness recommended values				
Poland	n_{50}	h^{-1}	Natural ventilation < 3 Mechanical ventilation < 1.5	Not mandatory
Airtightness default values that can be improved				
Belgium (Flanders and Wallonia)	q_{50}	$m^3/(h \cdot m^2)$	12	Mandatory, to improve from default values
Canada	n_{50}	h^{-1}	3.2 with basic air barrier specifications 2.5 with extra prescriptive details	Mandatory, to improve from default values
Estonia	q_{50}	$m^3/(h \cdot m^2)$	Single-family: 6 Other buildings: 3	Mandatory, to improve default values
Finland	q_{50}	$m^3/(h \cdot m^2)$	4	Mandatory, to improve from default values
No whole building values suggested or no consideration at all				
Albania **Andorra** **Belarus** **Bulgaria**	**Cyprus** **Greece** **Hungary** **Italy (except Trento and Bolzano regions)**	**Malta** **Moldova** **North Macedonia** **San Marino**	**Serbia** **Ukraine** **Portugal** **Slovakia**	



5. Whole building airtightness databases

- Databases structure

Country	United Kingdom	France	USA	Canada	Czech Republic	Germany	Belgium (Flemish region)	Spain
Initiative	Government	Government	Government	Government	Independent association	Independent association and individuals	Government	Academic
Responsible	Competent Tester Persons: ATTMA and iATS	Cerema (private body)	Lawrence Berkeley National Laboratory – LBNL	Natural Resources Canada	ABD.CZ project (Association Blower Door CZ)	FLiB (independent association)	BCCA, BCQS and the Federal Insurance Company	University of Valladolid
Size	ATTMA - over 500.000 iATS - over 55,000	Over 220,000	Over 150,000	Over 846,000	419	Around 1000	Over 22,000	401
Creation	ATTMA - 2002iATS - 2015	2007	Mid 1990s	2003	2001	2003	2015	2017
Current state	Ongoing	Ongoing	Ongoing	Ongoing	On hold	On hold	Ongoing	On hold
Update	Continuously	Yearly	Occasionally	Continuously	Occasionally	Yearly	Continuously	Occasionally
Platform	Online (https://www.attmalodgement.org, https://iats-lodgement.org.uk)	Offline	Online (http://resdb.lbl.gov/)	Online (https://www.nrcan.gc.ca/)	Offline	Offline	Online (http://dossier.bcca.be)	Offline
Data format	Purpose provided software	Formatted excel spreadsheet	Open-source data management system (PostgreSQL)	Oracle database with an OMNIS 7.8 interface	Formatted excel spreadsheet	Formatted excel spreadsheet	Pdf test report	Formatted excel spreadsheet
Data communication	Online platform upload for test certificate emission	Formatted excel spreadsheet sent yearly to qualification body	Datasets of energy programs get added occasionally	Data files upload to an automated web-based file processor	No clear information	Questionnaire	Online platform where testers upload the test report	Online server upload
Quality control	Auditing both on and off-site by sampling	Auditing both on and off-site by sampling	Dependent on the data source	File processor performs validation and data integrity tests and random file reviews	No	Validation of 5 test reports for recertification every 3 years	Onsite and desktop inspection	Full off-site compliance checks
Tester scheme	Mandatory training program approved by a Competent Tester Person	Qualibat certification	Certified experts for the Energy Star and the Guaranteed Performance programs	Independent certified energy advisors	No	FLiB certification. Training by certified organisations	Quality framework with optional training or mandatory theoretical and practical exam	Mandatory training program
Sampling scheme	Yes	Yes	No	No	No	Yes	No	Yes (quota sampling scheme)
Type of building	Residential and non-residential buildings	Residential and non-residential buildings	Residential	Residential. Pre- and post-energy retrofit	Residential and non-residential buildings	No clear information	Residential and non-residential building	Residential
Predominance	Residential	Single-family	Single-family (92%)	Low-rise dwellings	Single-family	Single-family	Single-family dwellings (78%)	Multi-family

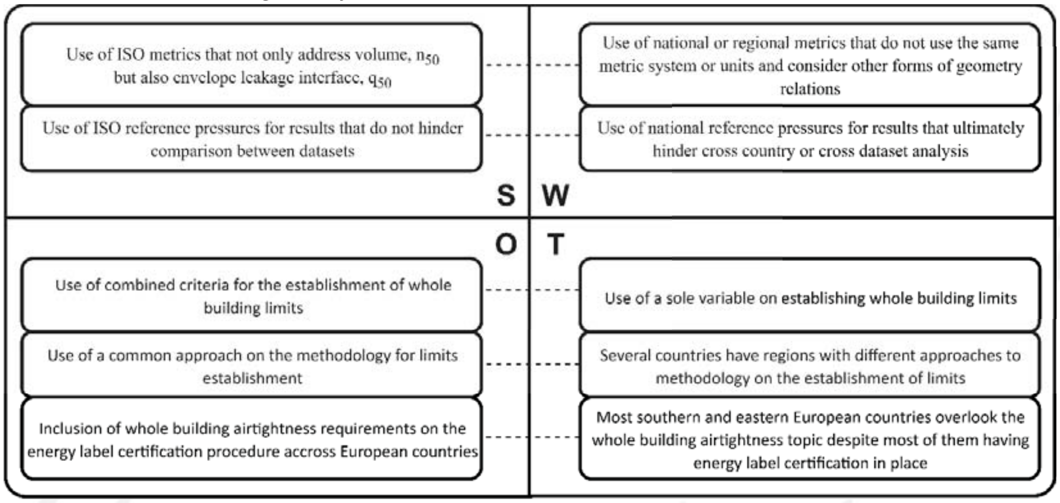
- Measurement data acquisition

Compilation of test standards, guidelines, and methodologies on measurement data acquisition by analysed countries with an established database.

Country	United Kingdom	France	USA	Canada	Czech Republic	Germany	Belgium	Spain
Current test standard	BS EN ISO 9972:2015 [73]	NF EN ISO 9972:2015 [89]	ASTM E779-19 [76] ASTM E1827-11 [75] sp: single point tp: two points	CAN/CGSB-149.10 [78]	ČSN EN ISO 9972:2017 [90]	DIN EN ISO 9972:2018 [70]	NBN EN ISO 9972:2015 [91]	UNE EN ISO 9972:2019 [92]
National guidelines	TSL1:2016 [93]	FD P50-784:2016 [84]	2018 IECC [40]	NBC 2015 [44]	ČSN 73 0540-2:2011 [19]	EnEV 2014 [22] DIN 4108-7:2011 [94]	STS-P 71-3:2014 [95]	None
Test conditions	Wind Temperature Height	Wind Temperature Height	E779: Height Temperature E1827: Wind Temperature	Wind	Wind Temperature Height	Wind Temperature Height	Wind Temperature Height	Wind Temperature Height
Method/ Building preparation	Method 2 on temporary sealing according to method 2 are present in the national guidelines	Method 3 Additional instructions on temporary sealing and guidelines on air leakage location	Permanent and temporary sealing actions in national guideline Additional instructions on the airtightness measurement standard	Permanent and temporary sealing actions in national guidelines Additional instructions on the airtightness test standard	Method 1 or 2 (preferred)No additional instructions on national guidelines	Method 2Instructions on temporary sealing according to method 2 are present in the national guidelines	Method 1 or 2Instructions on temporary sealing according with method 1 or 2 and air leakage location identification are present in the national guidelines	Methods A and B[a]
Minimum initial and final baseline (duration)	10 points (30s)	10 points (30s)	E779: 5 points (10s) E1827:1 point	1 point	10 points (30s)	10 points (30s)	10 points (30s)	10 points (30s)
Minimum test extent (duration)	7 points (-), equal steps < 10 Pa between steps Lowest $\Delta P > 10$ Pa or $5\times \Delta p_0$ 50 Pa $<$ Highest $\Delta P < 90$ Pa	10 points (10s), equal steps < 10 Pa between steps Lowest $\Delta P > 10$ Pa or $5\times \Delta p_0$ 50 Pa $<$ Highest $\Delta P < 100$ Pa	E779: Over 5 points (10s) 10 Pa $< \Delta P < 60$ Pa 5–10 Pa between steps E1827: Repeated sp (5×): 50 Pa Repeated tp (5× each): 12.5 Pa and 50 Pa	8 points (-) 15 Pa $< \Delta P < 50$ Pa 5 Pa between steps	At least 5 points (-), equal steps <10 Pa between steps Lowest $\Delta P > 10$ Pa or $5\times \Delta p_0$ 50 Pa $<$ Highest $\Delta P < 100$ Pa	At least 5 points (-), equal steps <10 Pa between steps Lowest $\Delta P > 10$ Pa or $5\times \Delta p_0$ 50 Pa $<$ Highest $\Delta P <$ 100 Pa	At least 5 points (-), equal steps <10 Pa between steps Lowest $\Delta P > 10$ Pa or $5\times \Delta p_0$ 50 Pa $<$ Highest $\Delta P < 100$ Pa	10 points (-), equal steps[a] $11< \Delta P < 65$ Pa
Regression method	Ordinary least squares	Ordinary least squares	Ordinary least squares	Weighted least squares	Ordinary least squares	Ordinary least squares	Ordinary least squares	Ordinary least squares
Pressure direction	Either or both	Either or both	E779: Both E1827: Either or both	Depress.	Either or both	Either or both	Either or both	Both
Metrics	q_{50} ($m^3.h^{-1}m^{-2}$)	q_4-surf ($m^3.h^{-1}m^{-2}$); n_{50} (h^{-1})	E779: EfLA @ 4Pa (cm^2); N_{50} (h^{-1}) E1827: q_{50} ($m^3.h^{-1}m^{-2}$)	EqLA @10Pa(m^2); NLA ($cm^2.m^{-2}$)	n_{50} (h^{-1})	q_{50} ($m^3.h^{-1}m^{-2}$)	n_{50} (h^{-1}) q_{50} ($m^3.h^{-1}m^{-2}$)	n_{50} (h^{-1}) q_{50} ($m^3.h^{-1}m^{-2}$)

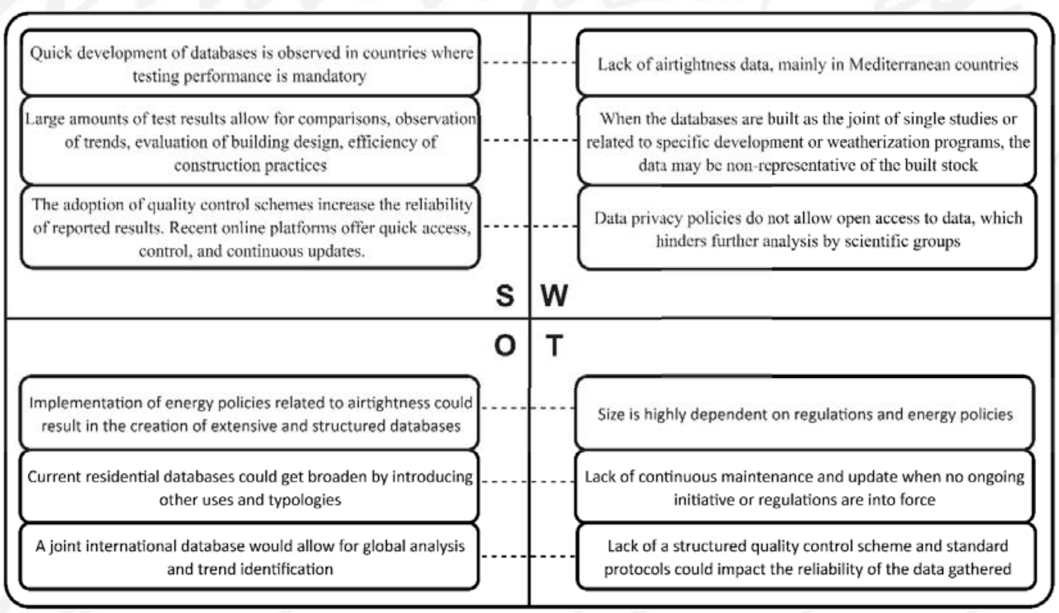
6. Strengths, weaknesses, opportunities and threats

SWOT scheme on regulatory context



6. Strengths, weaknesses, opportunities and threats

SWOT scheme on the structure of databases



6. Strengths, weaknesses, opportunities and threats

SWOT scheme on measurement data acquisition

S	W
Use the combined effect of wind, temperature, and height when assessing test conditions, such as the most recent version of ISO	Use of a unique variable or a non-complete combination of them when assessing test conditions
Use of the ISO methodology on baseline data acquisition or longer time average periods	Use of baseline data that is insufficient in quantity – number of points – and quality – time average of each point
Use of over five pressure stations	Use of too few pressure stations on measurement, which significantly enhances precision errors
Use of a weighted least square regression method on the model application	Use of ordinary least square regression method proved inferior that its weighted version
Use the average of both pressure directions	Possibility of use of only one pressure direction for the acquisition of final test results

O	T
Convergence would bring positive results and more cooperation between parties	Significant differences in the American and European approaches to the topic
Uniform adoption of ISO measurement protocol although some changes should be considered, on data treatment, e.g., regression method, on detailing, e.g., test preparation, and on restrictions of decision, e.g., pressure directions and method application for the energy certification label	Broad adoption at European national level of several national complementary documents with further instructions on geometry quantification, additional test preparation actions, and clarification on the Interpretation of the test method to use
Convergence on metrics for results presentation and geometry quantification procedure would allow cross-study comparisons and knowledge discovery	The use of different metrics associated with uncertainties on geometry quantification makes the results from datasets not comparable
Adoption of an international level scheme regarding leakage location detection, as France and Belgium already implement	Frequent disregard to a systematic detection of leakage location

Conclusions

- Trends: stricter requirements and mandatory testing
- Main issues to address in the near future:
  - lack of uniformization in method between countries
  - need for minimum data
  - implemented setups
- Common framework proposal:
  - User friendly, accessible web-based platform
  - Unambiguous quantitative measurement procedure
  - Dwelling information on visual inspection.
  - Qualitative tests to locate leakages
  - Quality Management Schemes, including procedures for tester training, and results control

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ABSTRACT

The airtightness of buildings has gained relevance in the last decade. The spread of the regulatory frameworks, the demand of stricter requirements, schemes for testing and quality control, the creation of airtightness databases and its analysis, is proof of this reality. The present review encompasses schemes developed in Europe and North America with regard to these aspects for national residential sectors. A normative framework on requirements and recommendations at the national level is compiled. Whole building airtightness databases are compared based on their structures and measurement data acquisition protocols. Gathered complementary information not directly related to testing is analysed and airtightness influencing factors importance and relationships are discussed. Weaknesses and strengths in the different aspects of the existing database setups are identified. Also, neglected or not entirely undertaken topics are pinpointed together with the suggestion of possible opportunities for future works and changes. Amongst other relevant remarks and discussions, it is concluded that the lack of uniformization in method between countries, the need for a minimum data setup, the lack of data analysis on relating the energy impact with the advancement in requirements of airtightness performance and the implemented setups are some of the main issues to address in the near future.

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