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Proposal for a Procedure for the Characterization of Air Systems Based on an Extended Model

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ABSTRACT

Duct Air Leakage Tests (DALT) are carried out on air distribution systems according to the procedures prescribed by specific International Standards. All these Standards, without exception, refer to an equation that estimates leakage as the product of a leakage coefficient (f) multiplied by a leakage area value (A), multiplied by the static pressure differential raised to an exponent (n), The exponent is assumed to be constant and equal to 0,6 or 0,65 which are average values based upon databases of actual measurements. Within certain limits, this simplified assumed-exponent model fulfils the classification requirements but does not prove reliable for the analysis of leaks under operating conditions and, thus, for verifying the increase in energy consumption associated with air distribution system leakage. For such purposes, as already discussed in previous works by some co-authors, the application of variable -exponent model appears to be necessary; this requires a test procedure capable of obtaining the n-value. This paper proposes a procedure for obtaining the f and n parameters. It stems from the procedure currently used for leakage characterization of building envelopes, including some operational strategies for improving the quality of measurements and reducing test times. The methodology was applied on a real system and the values were identified. Finally, this paper proposes a method to translate this leakage characterization into the classifications used in existing standards.

INTRODUCTION

In recent years, growing attention from institutions and international regulatory bodies towards energy efficiency has driven the development of advanced methods for quantifying and measuring inefficiencies in building systems. The 2024 revision of the Energy Performance of Buildings Directive (EPBD) highlights the importance of identifying and quantifying air leakage in duct systems as a critical factor in assessing overall energy inefficiencies.

Quantifying air leakage under operational conditions presents significant challenges due to metrological issues. The need for highly precise measurement methods and instruments with very low combined uncertainty often makes these procedures

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economically unfeasible for most operators. The ASHRAE 215-18 Standard [1] emphasizes the importance of reliable and precise procedures by addressing uncertainty calculation in detail. Since direct measurements are difficult to perform in the field, an alternative approach is to analytically estimate leakage through models. The power law is widely accepted to be the model that best describes air leakage behavior.

$$m_{exf} = (f \times A) \times \Delta P^n \quad (1)$$

where: m_{exf} is air flow rate, f is leakage coefficient, A is the surface area of the ductwork, ΔP is the static pressure difference across the leaking surface, and n is the leakage exponent. Experimental studies have demonstrated [2,3]that this model accurately represents leakage behavior, with fit-determination coefficient R^2 values very close to unity, confirming the model's validity.

Evolution of Standards and Leakage Classification

The power law model was initially used for classifying leakage performance. Key documents defining classification Standards in the United States and Europe include SMACNA Air Leakage Test Manual (1985)[4], DW/143 (1983)[5], Eurovent 2/2 (1996)[6]. The leakage exponent, which in common air systems is expected to be within the range from 0,5 to 0,8, was assumed to be constant and equal to the average value of 0,65 as a form of simplification to facilitate testing. This happens in all the current Standards in both Europe and the US as well as in other countries such as South Korea. In some countries like Spain and Estonia, the classification of ducts based on fixed 0,65 exponent is mandatory by national laws [7]. However, recent in-depth studies carried out among others by one of the co-authors of this paper in 2024 [8–10] have shown that this simplification implies criticalities, including the possibility for the same system to belong to different classes depending on the test pressure.

The most recent technical normative references include ASHRAE and EN Standards [11] [12]. EN 16798-3, currently under revision extend the original classification, redefining and renaming the leakage classes but still maintaining the fixed 0,65-exponent model as a reference. Additionally, Standards such as EN12599 [13] introduce testing procedures at operational pressures, highlighting the limitations of the current approach.

At the same time, organizations like ASTM in Standards E779-19 [14] and E3158-18 [15], or ISO in Standard 9972 [16] focused on the characterization of air tightness of buildings' envelope, utilize a model with a variable exponent that is better suited for representing real-world conditions. The move away from the simplified model towards the adoption of the extended model for air systems as well is desirable in many respects, however the only way to characterize it is by on-site measurement.

The measurement procedures currently applied are based on the simplified model and are therefore unsuitable for characterization using the extended model.

This research paper aims to: i) analyze current procedures and instrumentation for leakage classification; ii) identify their potential and limitations; iii) propose a procedure for using the extended model executable with instruments and time frames already used by DALT operators.

METHODS

Measurement procedures and methods were developed essentially to verify whether or not a system or a partial section of the system belongs to a certain class. In Europe and the U.S.classes use different unit system (SI vs. IP) but the way they are defined is the same and is essentially based on the determination through measurements of the value of the leakage coefficient f intended as the specific leakage rate per unit surface area (in the case of the American Standards, per a quantity defined in $100ft^2$) and referenced to the test pressure. Each class is defined on the basis of a maximum value of f. According to this approach, the EN Standards [17] list 7 air leakage classes (ATC) from ATC1 to ATC7, similar to the SMACNA-defined C_L32, C_L16, C_L8, C_L4 and C_L2 tightness classes [18].

Test Pressures

Along with the definition of Classes, the Standards provide detailed instructions on how to experimentally verify whether an air system belongs to an expected-by-design class. These instructions specify the type of instrumentation to be used, the

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method of selecting and setting up the section of the system to be tested, and the pressures at which the test must be conducted.

The main issues with the simplified model lies in the fact that if the actual system behavior does not correspond to an exponent 0,65, the measured leakage factor is not pressure independent. For this reason, the tests are prescribed to be performed at a predefined pressure depending on the expected class. Component-specific Standards define these pressure levels in tables that are different depending on the component or manufacturing technologies [19,20]. EN12599 Standard released in 2012 [13] specifies the testing of entire installed systems, allows testing at different pressures "as close as possible to the average operating pressure of the system", indicating some specific values in a quite wide range (200 to1000Pa).

The DALT Test Procedure

The DALT procedure utilizes an instrument consisting of a fan driven at variable speed, a flow meter and a precise manometer. The process involves measuring the flow rate required to maintain a pre-determined static pressure value; a simple flow rate balance indicates that the inlet flow rate corresponds to the sum of the flows exfiltrated by overpressure through the leakage points. The consistency of the measurement carried out in this way is closely related to the assumption that the internal static pressure remains almost constant at all points of the system [23]. The operating procedure for a duct air leakage test - DALT test is basically the same for all Standards and involves the following steps:

1) The system or part of the system to be tested is identified. Different references indicate how much of the system is to be tested depending on the type of application; some Standards also indicate a minimum surface area that is to be considered for the validity of the test. The calculation of the surface area (A) value is performed according to a specific Standard EN14239 [24].
2) The ductwork to be tested is isolated from the rest of the system (or from the air handling unit) by placing a temporary plate in a flange and all the diffusers as well are temporary sealed with airtight plugs.
3) A flexible duct is placed to connect the fan of the DALT instrument with the system to be tested and a pressure tap is placed to measure the static pressure inside.
4) The rotational speed of the fan is manually increased until the pressure reaches the value required for the test.
5) After a minimum test stabilization time, the required flow rate is measured.

Having adopted a fixed exponent model, only a single measurement is needed to determine the value of f. The value of the leakage coefficient f obtained through this test and referred to the simplified model is indicated in this document by using the subscript 0,65 ($f_{0,65}$), while the parameters referred to the extended model will be referred to as f_{ext} and n_{ext}, so:

$$f_{0,65} = \frac{m_{exf}}{A \times \Delta P^{0,65}} \quad (2)$$

The $f_{0,65}$ value thus obtained is compared with the expected Class limit and the test result is thus set to passed or failed.

From the point of view of classification according to the Standards, in addition to the issue of the dependence of the $f_{0,65}$ coefficient on testing pressure, a second potential issue is the calculation of the leakage area A, and that can be critical as the Standard related to air ducts' area calculation [24] adopts a series of simplifications that make the estimate repeatable but at the same time quite inaccurate.

As seen, the procedure presented does not provide sufficient data for the characterization of the extended model; the need to identify both model parameters f_{ext} and n_{ext} can only be satisfied by introducing a multi-point measurement to be performed at different pressures. The adoption of a new procedure can also constitute an opportunity to improve some aspects of the current standardized procedure.

PROPOSED ALTERNATIVE MEASUREMENT PROCEDURE

The proposed multi-point testing procedure takes into account the following criteria:

a) The procedure must be based on the use of existing DALT instruments without imposing their replacement.
b) Each measurement must be able to be conducted in the manner already used by current DALT tests.
c) The procedure must be applicable to the entire duct system, thus eliminating the need to calculate the value of the surface area A except for the additional purpose of estimating the value of the parameter $f_{0,65}$ for classification.
d) The selection of the measurement instrumentation must be easily identifiable starting from the expected leakage

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percentage and the nominal flow rate of the system to be tested.

e) The procedure using the extended model must be able to effectively characterize the system over the entire range of operating pressures and not at predetermined pressures.

Instrument Selection

Existing DALT instruments are characterized by a variable-speed fan that is able to reach high pressure levels (i.e. up to 2000Pa - 8 in.W.G according to EN1507 or EN 12327) and flow rates comparable to the leakages expected by the leakage class of that duct section. In order to increase the measuring range, some manufacturers provide an interchangeable double flow-meter section in order to guarantee a suitable accuracy over a double range, high-flow/low-flow. The proposed procedure allows these existing DALT instruments to be used at lower pressures, because measuring the flow exponent makes extrapolation to pressures other that the measurement point(s) more accurate. These lower pressures also allow larger duct sections (including sometimes the entire system) to be tested with the same equipment.

The suitability of the instrument to be used depends on a double check: *i)* the fan must allow the system to be tested at the maximum operating pressure *ii)* the expected value of the exfiltrated air flow rate must be consistent with the measurement range of the flow-meter.

In the case of systems with higher expected leakage flow rate, it is still possible to split the system into two or more sections. As far as the required accuracy and measurement uncertainty are concerned, there is no reason to demand different requirements from the current DALT tests.

Setting Up the System to be Tested

When testing the entire system, the need for sealing with caps extends to all terminals, in addition, fan-side shut-off can be obtained out directly on the connection between the air handling unit and the ducting, following the same methodology used for the usual DALT tests with a possible advantage in terms of accessibility. If there is a need to test more than one section, a main branch can be chosen which extends to the connection with the air handling unit and one or more secondary branches can be sectioned off at the point of derivation from the main branch.

Measurements Analysis

The aforementioned experimental tests conducted since 1985 as well as Standards and bibliographical references [22] show that there is a general agreement in considering the power-law in the form of the extended model as capable of characterizing the behaviour of air leakage. The technique used to determine the values of the model parameters from a series of measured pressure/flow rate pairs is called unweighted log-linearized linear regression. The technique is an established process and is present and illustrated in numerous references related to the application of the extended model with respect to the tightness of building envelopes. The description of the mathematical procedure can be derived from Annex C of the ISO 9972 Standard [16]. The same procedure can be found in annex A1 of ASTM E779:2019 [14]. In contrary to measurements on buildings, measurements on air systems show even better the consistency of the extended model due to the substantial absence of external disturbances and internal density and pressure variations, this makes it reasonable to investigate methods that require fewer measurements.

The choice of the number of measurements has a significant impact on the time and cost of the test, so the definition of a suitable procedure requires careful consideration of what is a meaningful number of pressure values at which to test the system.

The minimum number of measurements for the regression procedure be applied is two (i.e. two pairs of pressure/flow rate values), however, with a greater number of measurements it is possible to introduce the evaluation of the R^2 parameter and thus a quantitative information regarding the consistency of the measurements with the identified model; for this reason it was assumed that the minimum number of measurements to be considered is three.

Tests were carried out on an existing system to assess this point. The system is a primary air system serving a two storey office building and is built with circular ducts. The ductwork was set up according to the Standard DALT procedure and 10 measurements were carried out between 50Pa and 500Pa, with steps of 50Pa. The instrument is a TSI model PAN341 whose maximum measurable flow rate is 720 m^3h^{-1} (200Ls^{-1} - 424cfm) and maximum pressure +2500Pa (10 in.W.G.), with accuracy of 2,5% for flow measurement and 1% for pressure measurement. In table 1 the pressures/flow rates pairs are shown.

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Table 1. Pressure / Flow Rate Measurements from 50Pa to 500Pa

measure	Pressure	Measured flow rate m_{exf}			A x	Compare to (A x f_{ext})
n	ΔP[Pa]	[m^3/h]	[L/s]	[cfm]	[L/s $Pa^{-0,65}$]	%
1	50	133	36,9	78,2	2,91	-42%
2	100	192	53,3	113,0	2,67	-47%
3	150	239	66,4	140,6	2,65	-49%
4	200	270	75,0	158,9	2,40	-52%
5	250	302	83,9	177,7	2,32	-54%
6	300	333	92,5	195,9	2,27	-55%
7	350	361	100,3	212,4	2,23	-55%
8	400	388	107,8	228,3	2,29	-56%
9	450	415	115,3	244,2	2,27	-57%
10	500	438	121,7	257,7	2,24	-57%

From the full set of measurements, the parameters value and the coefficient of determination R^2 were calculated by regression, resulting in the following: $(f_{ext} \times A) = 4{,}997$, $n_{ext} = 0{,}513$; $R^2 = 0{,}999$. These values were used as reference values for subsequent analysis. Table 1 also shows the values of $f_{0.65}$ calculated according to 2) for each individual measure, as well as the percentage deviation from the value of f_{ext}; as will be shown in the following, the difference is due to the presence of a multiplying ΔP-dependent term whose value turns to one if $n_{ext} = 0{,}65\ only$.

The test conducted at ten equidistant pressure levels is highly time-consuming due not only to the number but also to the need to reach by control the set pressure for each measurement and wait for the system to stabilize. Therefore, the possibility of reducing the number of measurements has been analyzed. In order to do that a further analysis was then conducted by considering different triplets of values extracted from the ten measurements taken. Using each of these triplets, regression was applied and the parameters f_{ext} and n_{ext} calculated, and the comparison between these and the reference ones showed that the triplet leading to values closer to the reference ones are the ones which includes the most widely spaced measurements. This is consistent with the fact that, in a classical linear regression, the extreme have the biggest influence on the result and the slope of the trendline obtained is more affected by measurement error if the points are closer to each other. In the next sections of the paper the use of more than three testing points will be assessed.

The proposed procedure is based on this consideration and on the observation that, in general, the effectiveness by which measurements can accurately characterize the leakage model depends on the following testing conditions: *i)* the validity of the assumption of invariance of the static pressure within the tested ducting; *ii)* measurements must be conducted at pressures that cover the entire range of working values; *iii)* flow measurements are conducted within the range in which the flowmeter guarantees the required accuracy; *iv)* each new measurement is acquired after the settlement time of the system. These conditions can be considered separately and the analysis of each of them can provide useful operating recommendations for the optimization of measurements.

Pressure Invariance

The pressure invariance hypothesis is based on the consideration of the disproportion between the flow rates required by the leakage compensation and the sizing flow rates of the ductwork. Normally the air leakage under operating conditions is required to be less than 10% of the nominal flow rate. Considering a DALT test carried out at operating pressure, the compensation flow rate delivered by the external fan is expected to be comparable to that value. If the connection is located close to the AHU (with largest cross-section sized for nominal flow value) then also the velocities reached in that section during the test will be 10% of the design velocity and therefore the pressure losses will be 1% of those expected due to quadraticity with velocity: this favors substantial invariance of the internal pressure.

In addition to this, another potentially critical aspect must be considered: if the compensating flow rate is introduced at a non-negligible speed due to a small cross-section of the connecting duct, the presence of a dynamic component can alter the static pressure value precisely at the point of supply. Since many instruments place the pressure tap directly on the connection flange, the test pressure is detected at the potentially worst point and there is a real possibility that the measured static pressure will be altered. These considerations lead to the proposal of two improvements over traditional DALT procedures:

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The first is that the point of insertion of the external fan should be at the largest section of the system tested, i.e. just after the connection to the air handling unit. Imagining that the minimum pressure at which the measurement can be made may be of the order of 50Pa, considering a variation of 2% as the maximum acceptable with respect to this value corresponds to 1Pa, which can be translated into a dynamic pressure referred to an air velocity of 1,29 ms^{-1}. The initial sections of a distribution system are generally designed considering a velocity around 7$m.s^{-1}$, with the consequence that if the connection to the instrument takes place in proximity to the AHU, the dynamic pressure due to the compensation flow rate can only cause disturbance if the leakage rate is greater than (1,29/7) x100=18%.

The second improvement provides for the pressure tap to be positioned not in correspondence with the injection point but at a reasonable distance from it, i.e. a distance considered to be safe beyond which local turbulence phenomena due to the injection can be considered exhausted. Going back to the concepts currently adopted in terms of the minimum distance for flow equalization in aeraulic systems, this minimum distance can be considered to be 5 equivalent diameters from the point of connection to the external fan [25].

If adequate spacing is not available, it is possible to increase the cross-section of the connection pipe or, if necessary, to set up a multiple connection. The proposed rule is that, in the absence of the 5-diameter spacing, the compensating flow rate must be injected taking care that the velocity is not such as to make relevant contributions to the reference pressure value, i.e. containing the inlet velocity below 2,5 ms^{-1}(corresponding to a velocity pressure of P_V=3,75Pa). For example, in the case of the above-mentioned instrument whose maximum measurable flow rate is 720 m^3h^{-1} (200 Ls^{-1} or 424 cfm), the connection should be made by means of a duct with a diameter of not less than 350 mm, which corresponds to an inlet velocity of 2,08 ms^{-1} (P_V=2,6 Pa).

Measurements Optimization

Considering a three measurements case for semplicity, a suitable way of conducting effective measurements can be to proceed by starting with the measurement at the highest pressure to be tested and then identifying subsequent values in such a way as to make maximum use of the flowmeter's range, e.g. by exploiting the proportionality between rotation speed and flow rate if the fan control allows this, or by reducing the pressure until the minimum measurable flow rate value is reached. The pressure of a third measurement can be found at the intermediate flow rate value. Since the parameters of the extended model are not pressure-dependent, the flow/pressure value pairs measured in this way will fulfil the criteria stated above of covering the widest possible range from the maximum operating pressure value downwards with three equally spaced measurements and consistent with the flowmeter. In this way, pressure control on predetermined set values does not have to be implemented, and this can reduce the detection time to only transient exhaustion time. This measurement procedure allows to be effective even in the case there is the need to detect more than the three measurements defined as the minimum necessary.

In case of velocity control of the fan is available, the operational procedure can therefore be summarized as follows: after connecting the fan to the system, the supply frequency of the fan is increased until the design operating pressure is reached. If the extension of the ductwork section under test has been correctly selected for the DALT instrument used (or vice versa), under these conditions the measured flow value will fall within the higher part of the measuring range of the flowmeter.

At this point, the frequency is reduced to 2/3 of the previously determined frequency (e.g., if the original frequency is 60 Hz, the new frequency will be 40 Hz). After allowing time for stabilization, a second pressure/flow rate pair is recorded.

Finally, the process can be repeated to acquire a third pair of measurements at a flow velocity corresponding to 1/3 of the original frequency, ensuring beforehand that the flow measurement does not fall below the lower limit of the manometer's range. If this is the case, it will be acceptable to acquire the third measurement at the declared lower limit of the flow meter and the second measurement at an intermediate level.

This approach yields three measurements evenly distributed across the flow meter's range, avoiding the time inefficiencies associated with performing measurements at predefined pressure points.

The use of the minimum number of measurements (three) was taken in consideration of the fact that it is more important to have measurements far apart rather than a large number of measurements close together. However, the incidence of the number of measurements considered was analyzed with respect to the consistency by which f_{ext} and n_{ext} can be determined, with the condition that the measurements considered are equidistant and span the full measurement range of the flow-meter. Table 2 shows the values of the parameters determined considering groups of 3,4 and 5 measurements and the respective percentage changes compared to the 10-measurement case.

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Table 2. Impact on Number of Measurements in Determining Extended Model Parameters

Considered Points		A x f_{ext}	n	Compare (A x f_{ext})%	*Compare (n)* %	R^2
10 points	1 to 10	4,997	0,5128	0% (reference)	0% (reference)	> 0,999
5 points	(1,3,5,7,9)	4,980	0,5135	-0,3%	0,0%	> 0,999
	(2,4,6,8,10)	5,019	0,5119	0,4%	0,0%	> 0,999
4 points	(1,4,7,10)	4,892	0,5162	-2,1%	0,1%	> 0,999
3points	(1,5,10)	4,892	0,5162	-2,1%	0,1%	> 0,999
	(1,6,10)	4,897	0,5162	-2,0%	0,1%	> 0,999

In Figure 1 the measurement plots and trendlines between 10-measurement acquisition and optimized three-measurement acquisition are shown and compared to the trendline related to the simplified model based on single measurement at 500Pa.

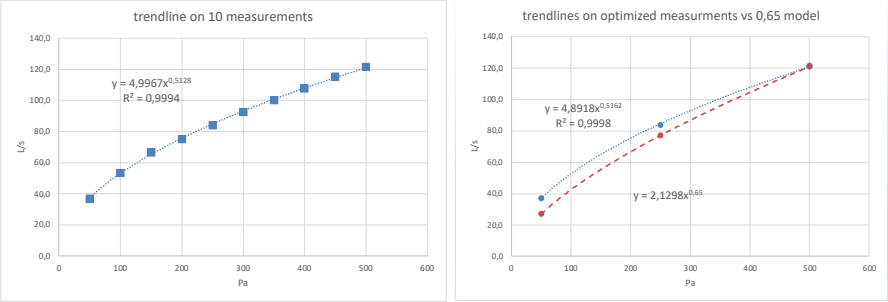

Figure 1. comparison between trendline obtained on 10 measurements (left), trendline obtained on three optimized measurements and trendline according to simplified 0,65 model (right).

The images show that even the optimized three-point measurement (1,5,10) yields a in good agreement on that obtained from a 10-measurement acquisition at ten predetermined pressure levels. The percentage differences between the parameter $(f_{ext} \times A)$ and the exponent n_{ext} obtained in the two methods are -2,1% and 0,1% respectively, In any case, it can be considered that, operating as proposed, a higher number of measurements (four or five) may only require a limited increase in time.

Reliability of Results to Classification Standards.

Characterization by means of the extended model provides an efficient tool for estimating leakage over the entire validity range of the model.

Indeed, the main characteristic of the extended model is the invariance of the proportionality coefficient $(f_{ext} \times A)$ with respect to pressure. This can allow a virtual test to be carried out at the pressures required for the verification of the expected class and, by applying this method, certain limitations inherent in the DALT tests in classification can be overcome.

Firstly, the characterization performed at low pressure can be more easily performed on the whole system with an existing DALT instrument which, used at high pressure, may only be suitable for characterizing sections of the system.

In addition, the verification of the leakage class involves tests carried out at pressures that are higher or much higher than those required for characterization using the proposed procedure; this may imply, for some specific types of construction, a mechanical stress on the system that may lead to temporary deformations or, in the worst cases, the compromise of sealants or of the joints of some components.

The relationship linking the coefficient f of the extended model (previously referred to as f_{ext}) with the coefficient $f_{0,65}$ can be obtained by taking a virtual measurement (using the model) of the exfiltration rate m_{exf} at the test pressure defined by the expected class and calculating $f_{0,65}$ as follows

$$f_{0,65} = \frac{m_{exf}}{A \times \Delta P^{0,65}} = \frac{1}{A \times \Delta P^{0,65}} \left(A \times f_{true} \times \Delta P^{n_{ext}}\right) = \Delta P^{(n_{ext} - 0.65)} \times f_{ext} \qquad 3)$$

For classification purposes the exact value of $f_{0,65}$ must be calculated by applying the formula and it will be necessary to extract the value of f_{ext} from the parameter $(f_{ext} \times A)$ obtained experimentally. This will require the calculation of area A in accordance with EN14239. The value of A, although not precise, will only influence classification operations, while all

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analytical leakage calculation operations necessary for energy evaluations will benefit from the direct experimental knowledge of the combined parameter ($f_{ext} \times A$).

CONCLUSIONS

The subject of duct leakage has gained renewed interest following the increase in energy efficiency Standards required by national and international regulatory bodies, which have expressed the need to be able to quantify leakages under operating conditions. The use of direct measurement-based methodologies for operating leakage has not received much market penetration due to implementation issues, and the alternative, which uses analytical calculations, requires reliable models. The model currently embedded into standards utilizes a power law with fixed exponent and equal to 0,65. The choice of this simplified model was made in the 1980s with the aim of simplifying testing procedures and making it easier to classify air systems by means of single point measurements. This paper has attempted to show that, from the point of view of energy loss assessment, the use of an extended model with measured flow exponents could provide better accuracy.

The proposed procedure is based on the need to be able to carry out the characterization tests with the same tools used for single-point DALT classification tests, with the advantage that since the parameters of the extended model are invariant with the test pressure, the tests can be carried out at lower pressures with lower flow rates and thus make it easier to apply the test to the entire duct system.

The proposed procedure also indicates that a minimum of three measurements at different pressures are required to obtain adequate uncertainty in the measured parameters. The procedure, verified on a real system, showed that it was possible to switch from a 10 measurement multi-point test at defined pressures to a 3,4 or 5 measurement multi-point test, showing maximum percentage differences between the resulting model parameters of -2,1% for the value of ($f_{ext} \times A$) and 0,1% for the value of n_{ext}.

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NOMENCLATURE

m	=	volumic air flow rate [$m^3\ h^{-1}$, $L\ s^{-1}$, cfm]
ΔP	=	Static Pressure difference [Pa, in.w.g]
f	=	Leakage coefficient [$L\ s^{-1}\ m^{-2}\ Pa^{-n}$]
C_L	=	Leakage coefficient [$cfm\ ft^{-2}\ (in.w.g)^{-n}$]
A	=	Leaking surface [m^2, ft^{-2}]
n	=	Leakage exponent

Subscripts

$\square_{exf}$	=	exfiltration
$\square_{0,65}$	=	referred to the simplified model with n=0,65
$\square_{ext}$	=	referred to the extended model

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