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An alternative method for evaluating the air tightness of building components

Osama A.B. Hassan

Department of Applied Physics and Electronics, Umeå University, SE-90187 Umeå, Sweden

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ABSTRACT

In this study, an alternative and general approach is advanced to evaluate the air leakage area and air infiltration rate in building envelope components such as exterior/internal walls and floors. In this method, the leakage area is determined with the help of acoustical and physical methods by measuring the sound reduction index of the building. The air flow rate through air leaks is determined with the help of leakage area and pressure difference over the floor/wall. The heat losses and convective moisture rate through leaks in the building are subsequently evaluated with the help of the calculated air infiltration rate.

1. Introduction

Air tightness is a fundamental building property that impact air movement in and through the building envelope. This air movement through cracks, openings, leaks in the building envelope affect heat and moisture flow in building. This in turn affects the indoor climate and energy use in different ways. A poor airtightness can lead to decreased insulation due to higher heat losses, cold inner surfaces and subsequently reduced thermal comfort, and increased ventilation and infiltration rate. Other negative impacts can be poor air quality due to transport of contaminants between indoor air and outdoor air, the emissions from materials (e.g., radon, CO_2 emissions), and poor acoustic insulation.

In countries that are characterized of being cold most of the year, the optimization of energy use is increasingly becoming essential from the economic and environmental point of view. The concepts of passive house, low energy buildings and nearly zero-energy buildings are some creative steps towards achieving energy efficiency and better energy performance in cold climate. Technically, a high degree of air tightness is one of important criteria that must be satisfied in such buildings.

Air tightness testing is aimed at tracing any undesirable drafts and uncontrolled air flow through the building. In this context, a number of studies on airtightness issues in building process have been written with different focus. Sherman and Chan [1] reviewed the techniques to measure the airtightness of building envelope in a number of countries with different climate conditions. Other studies relate airtightness measuring techniques, especially fan pressurisation, to modelling infiltration and designing ventilation systems; see e.g., Limb [2], Sherman [3], Palmiter and Francisco [4], McWilliams [5] and Jeong et al. [6]. In general, the fan pressurization including blower door system [7] and tracer gas method [8] are two common methods for measuring airtightness of the building envelope.

Component leakage procedures are used in the diagnostic application to evaluate how the leaks are distributed in the building. In this context, transient methods are used to measure the air tightness of building envelope components such as floors and exterior walls, see e.g., Carrey and Etheridge [9] and Lee et al. [10]. For measuring component leakage area, a balanced fan approach has been used; see e.g. [5].

Iodache and Catalina [11] used an acoustic approach to estimate the air permeability of a building façade with double pane wooden windows. Measurement of the transmission loss of the façade was carried out while the air permeability was measured using standardised pressurization technique with blower door system. The measurement results were correlated by a developed regression model. The results reflect that the air infiltration rate and out-door/indoor airborne transmission loss can be related for real buildings and so a mathematical model can be developed,

E-mail address: osama.hassan@tfe.umu.se.

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which in turn replace the expensive leakage techniques used to measure airtightness of buildings. It can be noticed here that such a developed model is a semi-empirical one and as such it cannot be generalised to comprise other building components such as floors and internal walls with various structural configurations, etc. Moreover, building designs are often different, which implies that one need to predict different regression models. This implies additional costs to develop semi-empirical models as well as time consuming process. This necessitates a general model to evaluate the leakage area and air flow rate of building components.

This article advances a new and general model to evaluate the leakage area and air infiltration rate using mainly simple acoustical methods. The leakage area and sound reduction index (or transmission loss) are related by analytical expressions. In this context, an internal wall in a building is used as an example application to demonstrate the developed model. The method can be used in the diagnostic part to evaluate the airtightness of the building. In the same context, the method is neither expensive nor weather dependent. With the help of this method, the heat losses and convective moisture rate through leaks in the building envelope can also be determined. Moreover, the article discuses briefly some practical measures to improve the airtightness of building components.

2. Method

The method may be summarised through the following steps:

1. Measurement and calculation of the sound reduction index of the wall/floor both at building and at laboratory. Alternative to the measurement at laboratory, the sound reduction index of the building component can, instead, be calculated using the theory of sound insulation of building elements.
2. The leakage area (e.g., holes, openings and cracks of different sizes) is calculated with the help of step 1.
3. The air infiltration rate through the leakage area can be calculated with the help of pressure difference on each side of the building component and the leakage area. Other quantities such as heat losses and convective moisture flow may also be determined using air infiltration rate though a single building component or through the whole building envelope.

In the following, an overview of these steps is presented.

2.1. Formulation of the acoustical terms

A signal is generated in order to measure sound transmission through a wall/floor. A transmitter (or noise source), a receiver in form of a microphone and a frequency analyser to display the impulse response in Hz is needed. From the measurement results, the weighted sound reduction index can be calculated by using the standard ISO 717-1 [12]. The calculation is carried out within the frequency range 100 Hz–3150 Hz. The general expression for sound reduction index of a partition wall/floor can be written as

$$R = L_1 - L_2 - 10\log\left(\frac{A_2}{S}\right) \quad (1)$$

where L_1 is the average sound pressure level in the sender room (dB), L_2 the average sound pressure level in the receiving-room, A_2 the absorption area of the receiver-room (m^2S) and S the partition are a(m^2). The average sound pressure level in the sender-room and receiving room can be written as

$$L_p = 10\log\left(\frac{1}{n}\left[10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + \ldots.. + 10^{\frac{L_{pn}}{10}}\right]\right) \quad (2)$$

where L_{p1}, L_{p2} are sound pressure levels measured at a position 1, 2, n in the room.

For the measurement, the sound level must be corrected against the background noise. This correction may be calculated for each frequency band as follows,

$$L = 10\log\left(10^{\frac{L_{S+N}}{10}} - 10^{\frac{L_N}{10}}\right) \quad (3)$$

where L_{S+N} is the total measured sound level in the room, and L_N is the background noise level. No correction is needed if the difference between the measured noise and background noise is greater than 10 dB. If, on the other hand, the difference is less than 3 dB the background noise is too high for accurate measurement.

The absorption area of the receiving room may be measured or calculated as

$$A_2 = \sum_i^n \alpha_i S_i = \frac{0.161\ V}{T} \quad (4)$$

where α and S are the absorption coefficient and the area of the actual surface, respectively, V the room volume (m^3), and T the reverberation time (s).

The above calculation procedure is based on the ISO 140-3 [14] for measuring airborne sound insulation at laboratory and on ISO 140-4 [15] for measuring the airborne sound insulation between rooms at field.

From an instructive point of view, Eq. (4) takes into consideration the influence of typical building spaces (e.g., multiple walls, windows, furniture items and finishing materials) on the sound absorption and the sound reduction index of the wall. Typically, by measuring the reverberation time and volume of the receiving room, the absorption area will be calculated with the help of Eq. (4). Alternatively, the absorption area can also be calculated theoretically by knowing the absorption coefficient (α) of each room components.

Note that Eq. (4) assumes that the sound energy is equally diffused throughout the room. If this condition is not fulfilled (e.g., due to the large surface areas with differentiated absorption), then one can use other formulae describing the reverberation time [13]. In the same context, it is assumed here that cracks and other infiltration sources on the surrounding surfaces of the receiving room will not influence the validity of Eq. (4) to calculate the total absorption area of the receiving room; see also [15].

For the case of a façade, the ISO 140-5 [16] gives the following equation for the sound reduction of a façade, R_{tr}:

$$R_{tr} = L_{eq,1} - L_{eq,2} + 10\log\left(\frac{S}{A_2}\right) \quad (5)$$

where $L_{eq,1}$ is the equivalent continuous sound pressure level in front of the façade and $L_{eq,2}$ is the corresponding term in the receiving room. Further details on the methods to measure the sound insulation of complete facades can be found in the ISO 140-5 standard [16].

Note that for the method, Eq. (5) and Eq. (1) will be applied to evaluate the airtightness of the building façades and partition walls/floors in the building, respectively.

If different components have sound reduction indexes R_1, R_2, R_n and areas S_1, S_2, S_n, the total sound reduction index of the composite wall can be obtained as