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# Influence of the building envelope permeability upon the annual heating load

Influența permeabilității la aer a anvelopei clădirii asupra sarcinii anuale de încălzire

Vlad Iordache[1)], Andrei Damian[1)]

[1)] Research Center CAMBI, Technical University of Civil Engineering of Bucharest
Bd. Pache Protopopescu nr.66, sector 2, București, Romania
*Email: vlad.iordache@cambi.ro, adamian7@yahoo.com*

**Rezumat.** *Prezentul articol urmăreşte evidențierea permeabilității anvelopei unei clădiri individuale asupra necesarului de energie pentru încălzire, utilizând metodologia de calcul Mc-001/1,2,3-2006. Clădirea este de tip "casă individuală" din mediul rural, ne-adăpostită de vânt, şi având o permeabilitate medie a anvelopei exterioare. Acest grad de etanşeitate la aer a fost verificat prin efectuarea unor teste de permeabilitate cu un echipament dedicat acestui scop. Rezultatul obținut experimental, în termen de număr de schimburi de aer prin infiltrații,* $n_a$, *a confirmat cu succes ipoteza de permeabilitate medie, iar eroarea ce apare între necesarul anual de energie pentru încălzire între* $n_a$ *calculat şi* $n_a$ *măsurat a fost de 3,2%.*

**Cuvinte cheie:** rata de infiltrații, măsurări experimentale, consumuri de energie

**Abstract.** *In this paper is outlined the influence of the building envelope permeability on the energy heating load, by using the Romanian Methodology for Building Performance, Mc001/1,2,3-2006. The analyzed building is an individual house, located in a rural area, classed within the "no sheltered to wind" category and supposed to have a medium permeability to outside air infiltrations. This air-tightness class was confirmed by performing a building permeability test under different air pressure differences. It resulted from these experiments a global airchange rate of 0,72* $h^{-1}$, *very close to the estimated value of 0,8* $h^{-1}$. *The calculated annual heating load was found to be also very close for the cases: "*$n_a$ *measured" and "*$n_a$ *estimated for medium air permeability", the relative error being as small as 3,2%.*

**Key words:** infiltration rate, experimental measurements, energy consumption calculation

## 1. Introduction

The energy efficiency is one of the most significant research field due to its implications upon $CO_2$ emissions and to the augmenting energy price. Residential and office buildings represent one of the most high energy consumer sectors [1] and therefore the research is carried out in the building energy consumption field. Different calculation national [2], [3] and international [4] norms were elaborated for the energy consumption calculation for the building heating and warm water preparation. The heating energy consumption is calculated as an integrated heating loss over the entire heating season; the heat loss is composed of transmision and infiltration losses. For an existing building the heat consumption calculation is based on the estimation the thermal characteristics of the building. This estimation is not always an accurate one, and therefore it may lead to significant errors in heating consumption estimation.

The influence of the air change rate upon the building energy consumption may overpass 50% [5]. The national and european norm do not present a methodology in order to estimate the air change rate, and leave the energy auditor to visually estimate its value based on his own experience. Thus, considering the high influence of the air change rate, the lack of accuracy of this air change rate estimation will propagate and result into wrong estimation of the energy consumption and to misleading building clasification.

In the literature we find that the air infiltration rate can be estimates much faster, with inexpansive devices and with exceptional accuracy [6] compared with classic experimental measurement protocol [7]. The experimental measurement protocol for air infiltration rate was also refined for large appartment buildings [8], overcoming a difficulty that limited for many years this type of measurement.

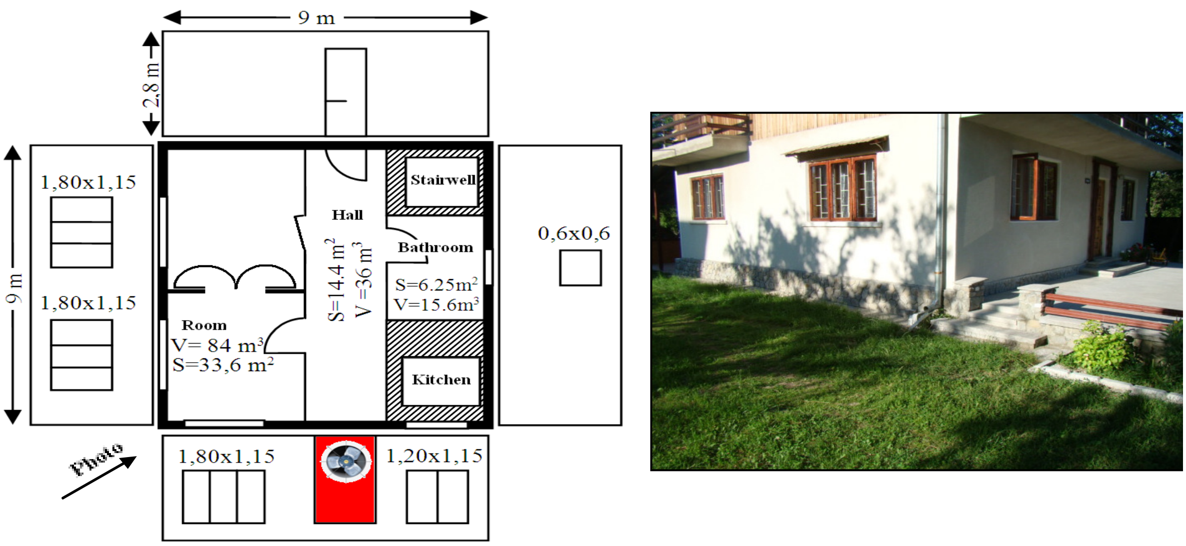
Thus, due to todays research advancement, the experimental estimation of the building facade permeability may become a competitive alternative for the precarious method proposed by the curent national and european methodologies for building energy consumprion estimation. In this research we want to evaluate the impact of the accurate experimental estimation of air change rate upon the building energy consumption.

The methodology for energy certification proposes the energy commissioner a table to chose the air infiltration rate accordint to different characteristics of the building, among which the building permeability which is estimated visualy from three types (high permeability, medium permeability and low permeability). In this study we will compare the energy consumption for a real building for the three different values of the infiltration rate proposed by the calculation methodology. Further, we will compare all these results with the energy consumption calculated based on experimental estimation of building air permebility for the same building.

The paper presents the analised building and the experimental measurements of the air infiltration rate, the energy calculation model and the results and comparaision between the different simulations.

## 2. Experimental measurements of the infiltration rate

We chose for this experiment an individual dwelling (Figure 1) that presents the benefit of a large applicability and also is adapted for a permeability measurement system due to its small size. This house (basement, ground level, first level and attic) has a ground surface of approximately 80m², common dimensions for a Romanian individual dwelling. The ground level is made of masonry while the first level is made of wood. Our study was limited just on the ground floor because of the similarities of a common appartment energy certification. We carried out experimental measurements of the airtightness for the ground floor appartment and also all each individual room from the ground floor.




a. Plan of the house b. Picture of the house

Figure 1: Plans of the studied house, ground floor and façades [7]

The air tightness experimental device [9] which is a “Blower Door” consists in the following equipment and measurement devices: false door, radial fan with variable speed, variable voltage device, dual differential micro manometer, computer and „Tectite” software (Figure 2). The pressurization method was used in order to determine the two parameters *C* and *n* of the permeability law [10].

Figure 2: Picture illustrating the measurement device during the tests [7]

The permeability laws for each indoor space (Figure 3) were learned under the form of power law regression models for two cases (the unsealed facade– USF and sealed facade–SF). Further on, the permeability law of the façades (total airflow, $Q_{Facade}$, in m$^3$/h) were obtained by subtracting the permeability law for the analyzed space with the sealed façade $Q_{SF}$ from the permeability law corresponding to the same space with unsealed façade $Q_{USF}$, for all of the three spaces : room (R), bathroom (B) and hall (H):

$$Q_{Facade} = Q_{USF} - Q_{SF} \qquad (m^3/h) \qquad (1)$$

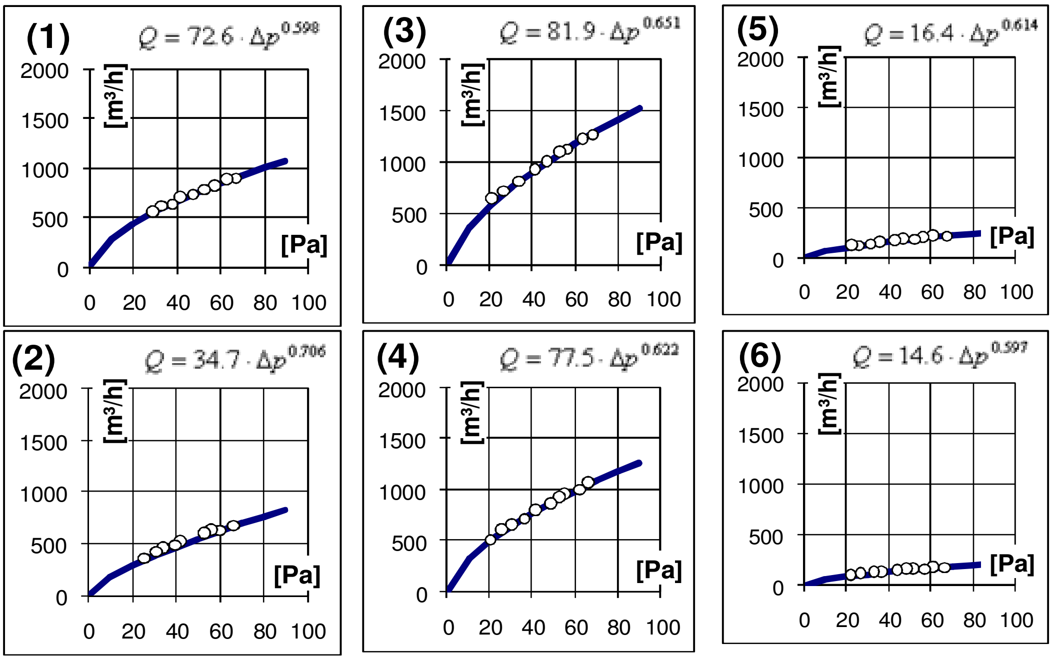



Figure 3. Permeability laws experimentally evaluated - (1) Room USF (2) Room SF (3) Hall USF (4) Hall SF (5) Bathroom USF (6) Bathroom SF [7]

The infiltration air change rate, $n_a$, was estimated as the ratio between the total infiltration air flow and the volume V (equation 1). The „$n_a$" was further determined by replacing each infiltration air flow $Q_{USF,SF}$ of the room, bathroom and hall with the corresponding formulas (Figure 3) for a pressure difference of 4 Pa. The final value of the infiltration air rate measured was 0,72 ($h^{-1}$).

$$n_a = \frac{Q^R + Q^B + Q^H}{V} \qquad (m^3/h) \qquad (2)$$

and, taking into account the previous assumptions, it could be written as:

$$n_a = \frac{\left(Q^R{}_{USF} - Q^R{}_{SF}\right) + \left(Q^B{}_{USF} - Q^B{}_{SF}\right) + \left(Q^H{}_{USF} - Q^H{}_{SF}\right)}{V} \quad (m^3/h) \qquad (3)$$

The error of this estimation of parameter „$n_a$" is about 5%, corresponding mainly to the error of the measurement device [11], [7], thus one can conclude that this Blower Door experimental stand is a high accuracy measurement device for such permeability measurements.

In this study we wish to determine the impact of visual estimation of this parameter "$n_a$" upon the heating energy consumption. Thus we will further analyse how this parameter estination will influence the heating energy consumption by comparing the three possible values proposed by the Romanian Methodology of Energy Certification and Audit [3] with the measured value, presented above.

## 3. Prediction model for heat consumption

In order to evaluate the energy performance of buildings and their installations, Romania has developed since 2007 a methodology based on the National law 372/2005. This document is called ”The methodology for the calculation of buildings performance” [3] and contains at present five parts:

- Part One, called”The building envelope”,
- Part Two, called ”Energy performance of building installations”,
- Part Three, called ”Energy Audit and Energy Performance Certificate of the building”
- Part Four, called ”Calculation breviary of the energy performance for buildings and apartments”, and,
- Part Five, called”Model of Energy Performance Certification for an apartment”

This methodology is designed to achieve three possible targets:

- Energy certification for new buildings, in order to obtain their Commissioning Agreement from the Local Authority,
- Energy certification for existing (built) apartments when they are part of a commercial transaction (buying-selling contract), and,
- Energy Performance Certification and then Energy Audit for an existing (built) building, in order to implement energy saving measures for this building, as could be thermal rehabilitation.

The energy performance certification of a building or apartment follows to assign it to an ”energy class”, which could be form A (best energy class), to G (worst energy class), passing through the intermediary classes: B, C, D and E. This assignment is a result of the total annual specific energy consumption of the building/apartment, $q_{tot}$, for five possible building services: heating (index ”heat”), domestic hot water production (index ”DHW”), lighting (index ”light”), mechanical ventilation (index ”MV”) and air-conditioning (index ”AC”). The term ”specific” means that the total annual energy consumption, $Q_{tot}$ (in kWh) is divided by the total heated surface of the building or apartment, $S_{heated}$ ($m^2$):

$$q_{tot} = \frac{Q_{tot}}{S_{heated}} \text{ (kWh/m}^2\text{*year)} \quad (4)$$

where $Q_{tot}$ is equal to the sum of the five possible total annual energy consumptions mentioned above:

$$Q_{tot} = Q_{heat} + Q_{DHW} + Q_{light} + Q_{MV} + Q_{AC} \text{ (kWh)} \quad (5)$$

It should be pointed out that an important number of buildings are not provided simultaneously with all five building services appearing as energy consumers within (5). In this case, the missing consumptions will vanish from this relastionship.

Following that idea, we approach the case of one-family or multi-family individual houses, which are the subject of this paper. For these buildings, the building services always available are: the heating, the DHW production and the lighting, while the mechanical ventilation and the air-conditioning are rarely implemented. Sometimes, the unique mechanical ventilation is made by extraction of the stale air from bathrooms and kitchens, by means of small extractions fans.

Even that some houses owners install individual AC devices, such as mono-SPLIT or multi-SPLIT systems, these equipments could not be considered as a proper AC system, with a known period of commissioning. Therefore, the term $Q_{AC}$ from the relation (5) could not be evaluated and it will be suppressed from this calculation. According to these observations, the relation (5) could be simplified when applying it to individual houses case, obtaining:

$$Q_{tot} = Q_{heat} + Q_{DHW} + Q_{light} \qquad \text{(kWh)} \qquad (6)$$

The annual primary energy consumption for heating, $Q_{heat}$ (kWh), depends on the building annual heating load, $Q_L$ (kWh) and also on the global energy efficiency of the heating system, $\eta_{global\text{-}heat}$ (-), which includes: energy losses at the final consumers level, energy losses along the thermal distribution network and energy losses at the thermal production source:

$$Q_{heat} = \frac{Q_L}{\eta_{global-heat}} \qquad \text{(kWh)} \qquad (7)$$

According to its physical meaning, the term $\eta_{global\text{-}heat}$ will be expressed by:

$$\eta_{global-heat} = \eta_{emiss-heat} * \eta_{distrib-heat} * \eta_{source-heat} \quad (-) \qquad (8)$$

where:

$\eta_{emiss\text{-}heat}$ energy efficiency of heat emission at the final consumers level (-),

$\eta_{distrib\text{-}heat}$ energy efficiency of thermal distribution, from the heat production source to the final consumers (-), şi

$\eta_{source\text{-}heat}$ energy efficiency of the heat generation source (-)

The three efficiencies mentioned above depend uniquely on the heating system design, on its commissioning and on the heat generation source, while the term $Q_L$ depends only on the building thermal insulation degree and on the building envelope permeability to outside air infiltrations, also known as ”building airtightness”.

According to the monthly method of the Romanian methodology of buildings performance, the annual building heating load, $Q_L$, could be determined as follows:

$$Q_L = H * \left( \sum_{k=1}^{n} \left( \theta_i - \theta_{e,k} \right) \right) * T \quad \text{(kWh)} \qquad (9)$$

where:

$\theta_i$ building indoor air temperature, as mean value for the heating period (ºC);

$\theta_{e,k}$ outside air temperature, equal to the mean value for the month ”k” (ºC);

H building global heat loss coefficient (W/K), and

T duration of the heating period (hours).

This relationship should be applied for building with continuous heating regime, as residential buildings, hospitals, kindergartens or hotels during winter season. The values for the monthly outside temperatures, $\theta_{e,k}$, could be picked up from the Romanian standard SR 4839/2007 [12].

The building global heat loss coefficient, H, is expressed by:

$$H = H_T + H_V \qquad \text{(W/K)} \qquad (10)$$

where :

$H_T$ is the heat loss coefficient for transmission across the building envelope, which can be calculated according to the Part One of the methodology [3], and,

$H_V$ is the heat loss coefficient for ventilation losses, which could be written as follows:

$$H_V = \rho_a * c_a * n_a * V \qquad \text{(W/K)} \qquad (11)$$

where:

$\rho_a$ air density of the outside air entering the building by natural ventilation, in $kg/m^3$,

$c_a$ thermal mass capacity of the ventilation air, in kJ/kg*K,

V inside air volume of the whole building, in $m^3$, and

$n_a$ ventilation rate of the building with outside air, in $h^{-1}$.

The term $n_a$ is calculated as the ratio between the ventilation airflow passing through the building, $D_{vent}$ ($m^3/h$) and the inside building volume, V: $n_a = D_{vent}/V$.

Therefore, this ventilation rate depends directly on the ventilation airflow supplied to the building by a natural or a mechanical ventilation system. This airflow should be determined either by setting up an hygienic value according to the national regulation [13], or by calculating the infiltration airflow through the building envelope, as a result of building airtightness-for natural ventilation systems.

According to the Part One of the methodology for buildings performance [3], for residential buildings provided with only natural ventilation, such as individual houses, the ventilation airflow is dependent on the building sheltering class related to wind and on the building envelope airtightness, as presented in table 1.

*Table 1*

**Definition of sheltering classes and air permeability rates for individual houses**

| Building category | Sheltering class | Building airtightness | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| | | Airflow rate by infiltration through building envelope (in $h^{-1}$) | | |
| Individual houses (multi-family buildings) | No sheltered (very tall buildings, buildings situated in open spaces with no neigbourhoods) | 1,5 | 0,8 | 0,5 |
| | Moderately sheltered (buildings situated inside the towns, buildings protected by trees) | 1,1 | 0,6 | 0,5 |
| | Sheltered (buildings situated within the towns center, buildings within the woods) | 0,7 | 0,5 | 0,5 |

The building permeability to air infiltrations is merely due to the quality of the sealing for windows joinery, which represents the more exposed airway path from the building envelope. Therefore, in the same methodology-Part One, are defined three permeabilities classes according to the windows sealing system, more precisely:

- High air permeability (i.e. low airtightness), for buildings having old joinery without sealing gaskets;
- Medium air permeability (i.e. medium airtightness), for buildings with new joinery with usual sealing gaskets, and

- Low air permeability (i.e. high airtightness), for buildings with new joinery and tight sealing gaskets

The terms $Q_{DHW}$ and $Q_{light}$ the equation (6), meaning the primary annual energy consumption for DHW production, and the primary annual energy consumption for lighting purposes, could be calculated by the formulas presented within the Part Two of the Romanian calculation methodology for buildings energy performance [3]. These formulas will not be presented here because they are beyond the scope of this paper.

## 4. Comparison between experimental and estimated infiltration rates

As a result of our permeability tests performed on the house studied, described within the Chapter 2 of this paper, it appeared that the airflow rate obtained for the whole house was equal to 0,72 $h^{-1}$. According to the house location, we decided to assign it in the ”No sheltered” class, as described within table 1.

The major problem for the building energy analysis is to evaluate the building airtightness. In our case, it was determined from experimental measures with the Blower Door, but, in most of practical cases, the energy auditor doesn’t dispose of this equipment. Therefore, he would arbitrary choose a value of the airflow rate by infiltrations, $n_a$, deciding in what category should be classified the analysed building, according to table 1. The figure 4 illustrates the comparison between the annual specific heating loads, $Q_{L,spec}$ (in kWh/m$^2$year), calculated for the following case study:”No sheltered building”, three possible airflow rates by infiltration according to the possible airtightness classes (High, Medium and Low), and a supplementary airflow rate, corresponding to the measured value: $n_{a,measured}$=0,72 $h^{-1}$. The similar results could be seen also in table 2.

*Table 2*

**Annual specific heating load, $Q_{L,spec}$ calculated for estimated and measured air infiltration rates**

| | Possible airtightness classes ($n_a$ estimated) | | | Real case ($n_a$ measured at 4 Pa pressure difference outside-inside) |
|---|---|---|---|---|
| | Low | Medium | High | |
| | Airflow rates by infiltration through building envelope (in $h^{-1}$) | | | |
| | 1,5 | 0,8 | 0,5 | 0,72 |
| $Q_{L,spec}$ (kWh/m$^2$ year) | 317 | 248 | 219 | 240 |
| Relative difference related to the ”Medium” case (%) | 27,8 | 0 | -11,7 | -3,2 |

Influence of the building envelope permeability upon the annual heating load

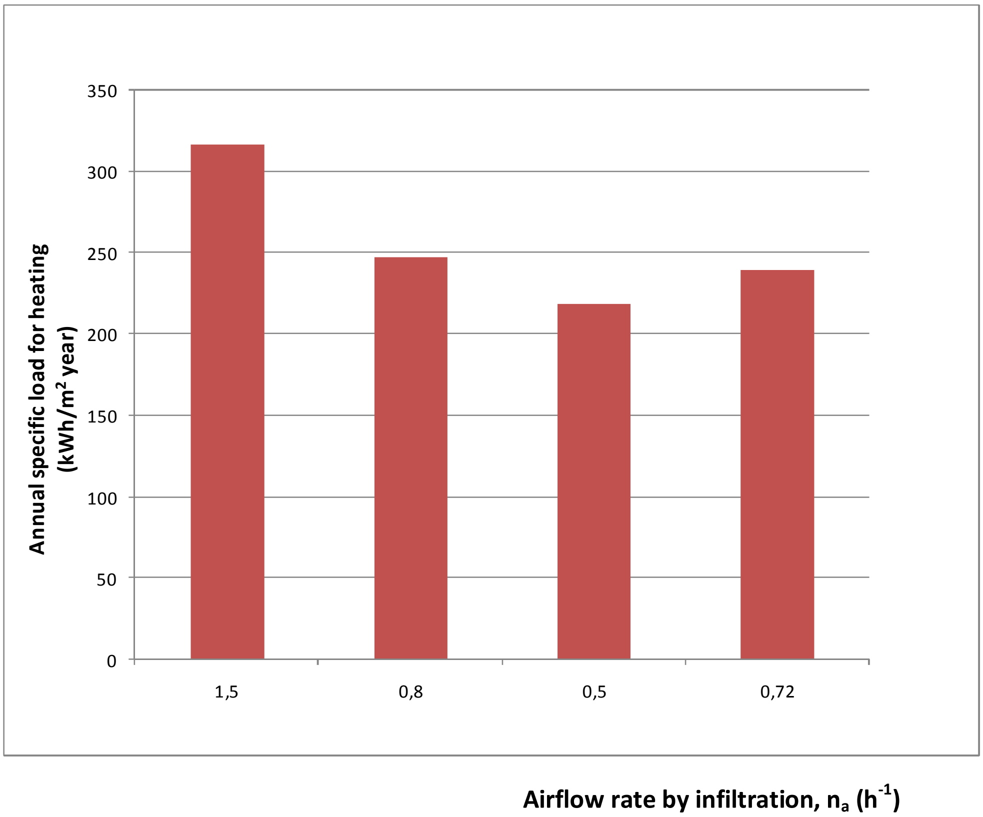



Figure 4: Comparison between annual specific loads for heating ($Q_{L,spec}$) for three possible airflow rates and the real airflow rate, determined by permeability tests

It can be noticed that, the measured ”$n_a$” is very close to the ”Medium airtightness” case, which suggests that the analysed building belongs to this airtightness class. This classification would be a difficult task for another building when lacking the possibility to perform permeability tests. According to this observation, the resulting annual specific load for heating, $Q_{L,spec}$, is very similar for the cases: ”$n_a$ measured” and ”$n_a$ estimated for medium air permeability” (e.g. 240 kWh/m$^2$year vs. 248 kWh/m$^2$year).

## 5. Conclusions

The main conclusions resulting from this study are the following:

1) The experimental tests for building permeability are always the best way to determine the global airchange rate ”$n_a$” ;
2) The estimation of the ”$n_a$” for people not trained in building systems would be a very difficult task;
3) The relative error between the annual specific energy needs for heating, calculated for the cases: ”$n_a$ measured” and ”$n_a$ estimated for medium air permeability” appeared to be smaller than 4%;

More work is required to evaluate the influence of the airchange rate, ”$n_a$” , upon the annual building cooling load, as well as upon the global annual energy consumptions for heating and cooling purposes.

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