BREATHING FEATURES ASSESSMENT OF POROUS WALL UNUITS IN RELATION TO INDOOR AIR QUALITY

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ABSTRACT

Traditional building technologies establishing highly-breathing multi-layered wall systems provide healthy indoor environment and energy efficiency in buildings due to the use of lightweight, porous, water vapour permeable and thermal resistive building materials. The breathing performance of traditional buildings and materials that contribute to the healthy indoor conditions and air quality are needed to be investigated in detail. That knowledge on breathing performance has also vital importance for the improvement of the contemporary building and materials technologies.
The study was conducted on three kinds of porous masonry units: mud brick, collected from the sound parts of the traditional houses of Hamzalı Village, Kırıkkale (Turkey) and autoclaved aerated concrete (AAC) type G2 and type G4, the commonly used lightweight concrete material which are also produced in Kırıkkale. These three groups of materials were examined in terms of their air exchange properties by means of laboratory analyses. Some supportive laboratory analyses were also done on material characterization of the samples. The experimental setup is developed for the analyses of the samples, particularly for the assessment of air flow through the material by using CO_2 as tracer gas.
The interpretation of the results were done in order to compare the porous building materials in terms of their effects on indoor air quality. The double-zone experimental setup based on concentration decay procedure was found to be useful to better-understand the air exchange features of a material in terms of rates of concentration decrease and increase in neighbouring zones by monitoring the concentration of outgoing air. The data achieved is expected to improve the contemporary building walls by benefitting from the self-ventilation capability of building materials and to provide healthier indoor conditions for the occupants. The results are also useful to discuss the airtightness aspect of passive house technology and to minimize the mechanical ventilation needs for fresh air intake by benefitting from the self-ventilation performance of air permeable skin.

KEYWORDS

Indoor air quality, breathing walls, mud brick, autoclaved aerated concrete, air exchange properties.

1 INTRODUCTION

Traditional building technology provides energy efficiency and good indoor air quality in houses by using porous, water vapour permeable building materials establishing highly-breathing multi-layered wall systems (Meriç *et al.*, 2013; in press). Each layer of a mud brick traditional wall section has particular performances, such as water impermeable exterior finishing layers and thermal resistive intermediate layers while each layer allows continuous passage of water vapour along the overall wall section. The breathing performance of traditional buildings that contribute to the healthy indoor conditions and air quality needs to be investigated in detail. That knowledge is essential for the improvement of the contemporary building materials and construction technologies. Due to the high porous and breathing characteristics of autoclaved aerated concrete (AAC), it appears to be an alternative material to establish contemporary breathing walls. The potentials and restrictions of

AAC, therefore, need to be examined in terms of its breathing properties. In this regard, the experimental study was shaped to discover the air exchange characteristics of traditional mud brick and AAC unit samples. Supportive laboratory analyses were done to define the raw material characteristics of traditional mud brick.

The concept of airtightness is mostly defined as absence of air leakage and excluded from the issues of ventilation in buildings (Fennell and Haehnel, 2005). Some others focus on minimum airtightness levels required for energy saving and support that the higher airtightness levels the lower energy costs (Katunsky *et al*,.2013). The studies that support maximum airtightness propose controlled mechanical ventilation systems. The operating and maintenance expenses of mechanical ventilation systems as well as the risk of health problems associated with the mechanical ventilation systems, such as Legionnaire’s disease, are some of main reasons of why natural self-ventilation properties of building materials have vital importance on the healthy indoor conditions and air quality (US EPA, 1991; Hodgson, 1992). On the other hand, most studies point out that indoor air quality would suffer in case of over-airtightness (Sherman and Chan, 2004; Kirch, 2008a; Kirch, 2008b). The inherent breathing features of building components can provide self-ventilation at a certain level while minimizing the energy cost for mechanical heating, ventilation, and air conditioning (HVAC) systems. The breathing features of porous building materials and their contribution to the indoor air quality, therefore, are the key concerns of this study.

2 MATERIAL AND METHOD

The study was conducted on mainly mud brick and AAC samples, both of which were porous masonry units and well-known with their good breathing capability (Andolsun, 2006; Andolsun *et al*., 2006; Jacobs *et al*., 1992; Kömürcüoğlu, 1962; Meric *et al*. 2013; Meric *et al*. in press; Naranyan *et al*., 2000, Torraca, 2009): The mud brick units were collected from the sound parts of the traditional houses of Hamzalı Village, Kırıkkale (Turkey), together with mud mortar and mud plaster samples complementing the mud brick wall section. Those houses are about 70 year old. The AAC units are manufactured in Kırıkkale (Turkey). The commonly-used types of AAC blocks, type G2 (infill unit) and type G4 (load-bearing unit), were selected for the study. The breathing features of these materials were examined with an emphasis on their air exchange rate. Supportive analyses were also done on some basic physical and physicomechanical characteristics of mud brick and AAC samples, such as density (ρ, g.cm^{-3}), effective porosity (ϕ, % by volume), ultrasonic pulse velocity (UPV, m.s^{-1}) and modulus of elasticity (MoE, GPa) as well as on some raw materials characteristics of original mud brick samples, such as silt & clay ratio, binder-aggregate ratio and fibre ratio.

The air exchange properties of each sample were determined by measuring the air flow through the material by using CO_2 as tracer gas and an experimental setup was developed for this purpose by adapting the concentration decay method defined in the international standard ASTM E 741-11 (2011). This method was assumed to represent the case for an indoor having a very high carbon dioxide concentration level (after it has been occupied) and ventilating itself only by the porous wall section. The experimental setup developed for the determination of air change rate was composed of mud brick or AAC block samples positioned in between two chambers/zones (Figure 1). Each block sample with the sizes of 180mm x 125mm x 310mm (thickness x height x length) sealed two plexiglass chambers positioned at its both sides. The volume of each chamber was 0.016m^3 with the dimensions of 130mm x 390mm x 310mm. The concentration of CO_2 (in ppm) in each chamber was measured by using a CO_2 analyser “Testo 480” with two indoor air quality measuring probes. One probe was placed in each chamber. During the experiment, the ambient temperature, relative humidity and absolute pressure in the chambers were also recorded for the analyses. The solution composed of 2g sodium hydrogen carbonate powder in 50ml pure acetic acid which was put in a glass beaker acted as the source of CO_2 in the Chamber 1(Ch-1) and provided a CO_2 concentration about 15000 ppm. This high concentration level was assumed to simulate over-occupied indoor environment. The CO_2 concentration in the Chamber 2 (Ch-2) was filled with fresh air which has a CO_2 concentration level around 400 ppm. The change in the CO_2 levels in the chambers in time was recorded at 5s intervals by the CO_2 analyser for a period of 24 hours. The concentration decay curves were produced showing the CO_2 concentration in the chamber, C, as a function of square root of time. The slope of the linear regression presented the rate of decrease in CO_2 concentration in Ch-1, R_D and the rate of increase CO_2 concentration in Ch-2, R_I, for each sample block.

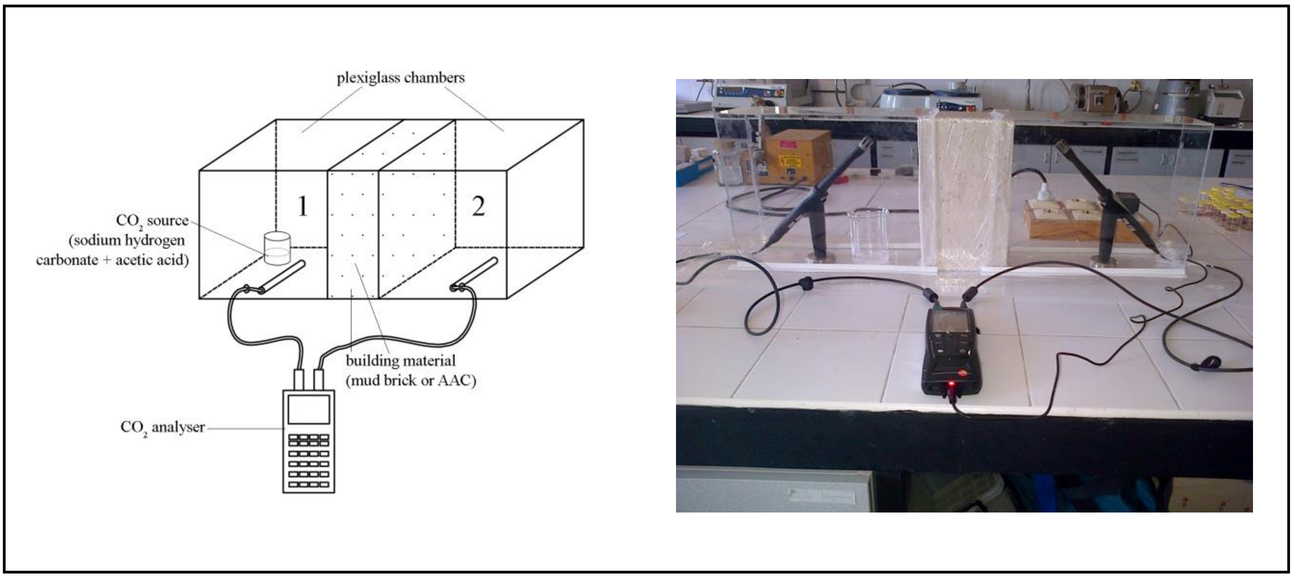

Figure 1: Experimental setup for the analyses of air exchange in double zone by using CO_2 as tracer gas.

Density and porosity of the material samples were examined by the standard analyses described in RILEM (1980). The modulus of elasticity of the samples were determined indirectly by means of equations described in ASTM D 2845-08 (2008) and RILEM (1980), using their ultrasonic pulse velocity (UPV) and density values. The UPV values were measured in the direct transmission mode (cross direction) by using a portable PUNDIT Plus CNS Farnell Instrument with 220 kHz transducers.

For the determination of binder-aggregate ratio, fibre ratio and clay-silt content of mud brick, mud plaster and mud mortar samples were examined by sieve analysis (Teutonico, 1986). The samples were kept in water. First, fibre ingredients suspended in water were separated. Following the drying out of the samples, they were sieved by using a set of sieves with specific sizes of 4mm, 2mm, 1mm, 0.500mm, 0.250mm, 0.125mm and 0.063mm.

3 RESULTS AND DISCUSSION

The results were evaluated to compare the air exchange characteristics of mud brick and AAC block samples. The relevant material characteristics of the samples were also determined for the joint interpretation of the results.

The mud brick samples were found to have considerable high ratio of silt & clay (the grain size below 0.063mm) with the value of 48.9% by weight (Table 1). The largest portion of the aggregate was determined to be within the grain sizes of 0.25mm and 0.063mm with 41.8% by weight while 10% of belonging to the particles between 4mm and 0.25mm. The ratios of the aggregates and fibres were determined to be 52.8% and 0.2%, respectively, by weight (Table 1). The mud plaster and mud mortar samples complementing the mud brick masonry wall section seemed to have similar binder-aggregate ratios which may signal the use of same local and natural raw material sources.

Table 1: The results of some raw materials characteristics for the mud brick, mud plaster and mud mortar samples.

Sample Type	Silt&Clay Ratio (%)	Aggregate Ratio (%)	Fibre Ratio (%)
Mud brick	48.86 ± 4.40	52.75 ± 5.53	0.15 ± 0.12
Mud plaster	43.03 + 6.14	56.97 ± 6.14	0.89 ± 0.06
Mud mortar	43.27 ± 0.87	56.73 ± 0.87	1.57 ± 0.21

The data on air exchange characteristics of mud brick and AAC block samples are presented in Table 1 together with their density, porosity, modulus of elasticity and water vapour diffusion resistance index properties. All samples were less dense and highly porous materials while the mud brick had higher density and lower effective porosity values G2 and G4 types of AAC. The mud brick seemed to have higher MoE than the AAC samples while having the lowest UPV value. The G2 type of AAC used as infill block presented very low MoE among all samples. All samples were highly-breathable materials due to their very low resistance to water vapour permeation while the mud brick presented noticeable higher breathing capability than the AC samples. The physical and physicomechanical properties of the samples signalled the differences in the pore structure of the mud brick and AAC samples.

The results of air exchange properties of the samples were summarized below (Figures 2-4):

- The concentration decay of CO_2 in Ch-1 was observed to be the fastest at G4 type of AAC block with the R_D of 98.4 ppm.$s^{-1/2}$ while a very slight passage of CO_2 to the other side (Ch-2) was observed with the R_I value of 2.3 ppm.$s^{-1/2}$ (Figure 4). This signalled that G4-AAC sample have tendency to absorb CO_2 while not permitting its passage to the other side. The G4-AAC material may filter CO_2 particles in its pore structure.
- The reduction in CO_2 concentration seemed to be fast in G2 type of AAC block with the R_D value of 70.9 ppm.$s^{-1/2}$, however, that rate is slower when compared with the R_D of G4-AAC sample (Figure 3 and Figure 4). G2-AAC sample presented faster increase in CO_2 concentration in Ch-2 with the R_I value of 37.6 ppm.$s^{-1/2}$. That designated the air permeability G2-AAC sample from one side to the other is more than G4-AAC sample while both AAC samples have tendency to absorb CO_2 at certain extents.
- The highest transmission of CO_2 from Ch-1 to Ch-2 was observed in mud brick sample with the R_I value of 61.6 ppm.$s^{-1/2}$. The reduction in CO_2 concentration in Ch-1, on the other hand, was lower than expected with the R_D value of 31.5 ppm.$s^{-1/2}$. The very fast increase in CO_2 concentration in Ch-2 may decrease the difference in the CO_2 concentration between two chambers. This phenomenon may be one of the reasons for the slowing down the R_D in Ch-1.

It is known that the main mineral in the composition of AAC is tobermorite-11Å (Narayanan and Ramamurthy, 2000), which may react with atmospheric carbon dioxide (CO2) gas in the presence of moisture and be converted to silica and calcium carbonate (Matsushita, *et al.*, 2000; 2004). AAC blocks was observed to be attractive for CO_2 gas by keeping it in its porous fabric and acting like an indoor air cleaning material, that could be attributed to its inherent material characteristics.

Table 2: The data on density (ρ), effective porosity (ϕ), ultrasonic pulse velocity (UPV), modulus of elasticity (MoE), water vapour diffusion resistance index (μ) and the rates of CO_2 concentration decrease (R_D) and increase (R_I) of the mud brick and AAC samples

Sample Type	ρ (g.cm^{-3})	ϕ (%)	UPV (m.s^{-1})	MoE (GPa)	μ (unitless)*	R_D in Ch-1 (ppm.s$^{-1/2}$)	R_I in Ch-2 (ppm.s$^{-1/2}$)
Mud brick	1.60±0.03	42.37±0.34	1321±65	2.569±0.242	1.4 – 1.6	-31.539	61.595
G2-AAC	0.42±0.00	74.10±1.23	1703±20	1.109±0.017	3.8 - 5.7	-70.908	37.635
G4-AAC	0.62±0.02	67.67±2.49	1955±30	2.168±0.119	3.2 - 6.4	-98.370	2.265
* The µ values of mudbrick and AAC samples was obtained from the literature, Meric et al. (2013) and Andolsun (2006), respectively.							

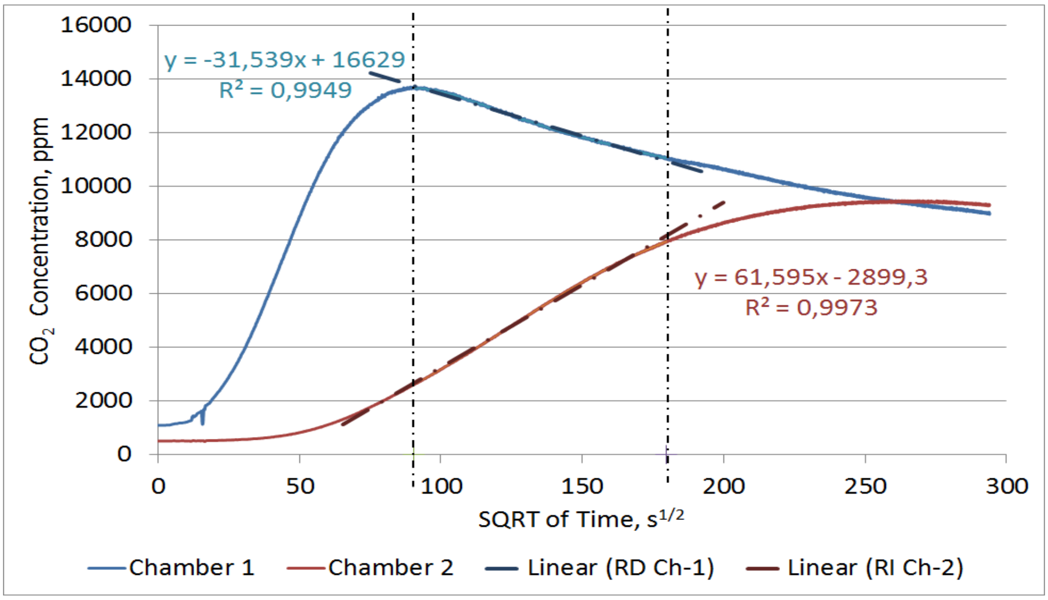

Figure 2: The CO_2 concentration curves in Ch-1 and Ch-2 during the 24 hours examination period of mud brick block sample: The linear fitting of CO_2 concentration versus square root of time showing the rates of concentration decrease in Ch-1 (RD Ch-1) and concentration increase in Ch-2 (RI Ch-2) as the slope of the regression line.

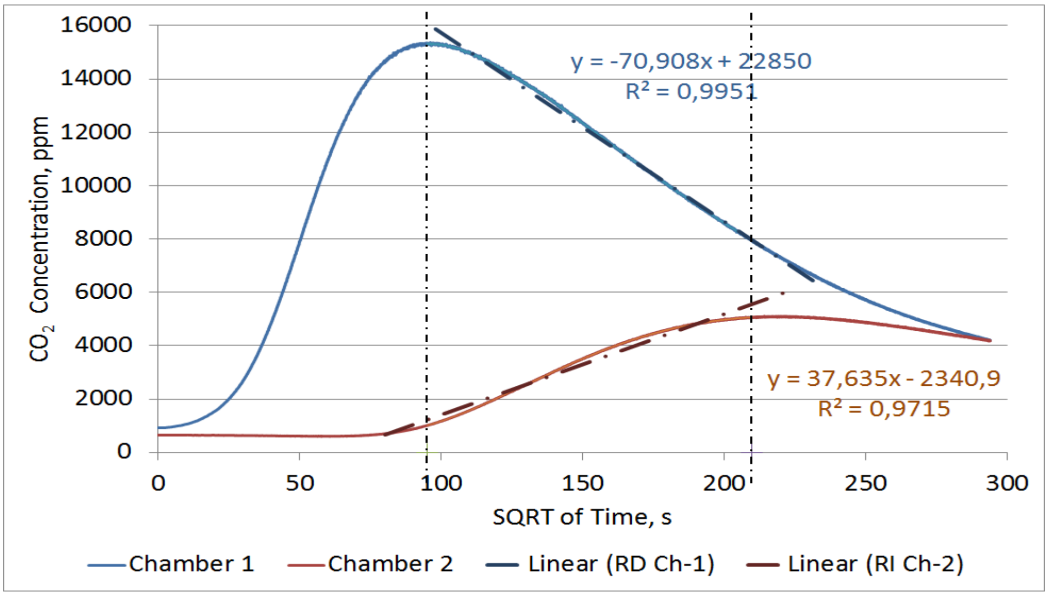

Figure 3: The CO_2 concentration curves in Ch-1 and Ch-2 during the 24 hours examination period of G2 type of AAC block sample (G2-AAC): The linear fitting of CO_2 concentration versus square root of time showing the rates of concentration decrease in Ch-1 (RD Ch-1) and concentration increase in Ch-2 (RI Ch-2) as the slope of the regression line.

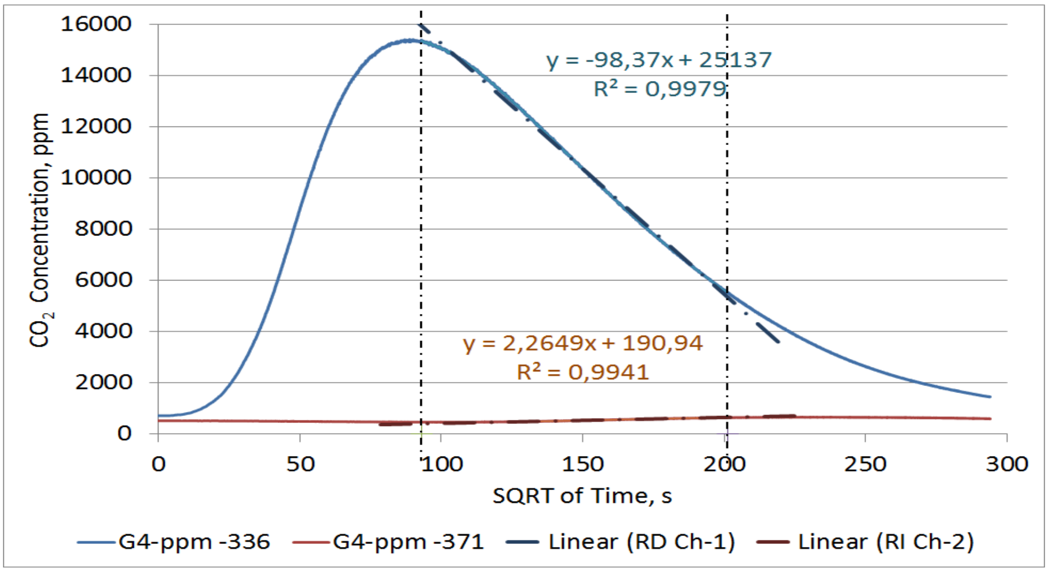

Figure 4: The CO_2 concentration curves in Ch-1 and Ch-2 during the 24 hours examination period of G4 typeof AAC block sample (G4-AAC): The linear fitting of CO_2 concentration versus square root of time showing the rates of concentration decrease in Ch-1 (RD Ch-1) and concentration increase in Ch-2 (RI Ch-2) as the slope of the regression line.

4 CONCLUSIONS

Breathing features of building envelopes should be taken into consideration for the improvement of contemporary building walls by benefitting from air exchange ventilation through building materials and to provide healthier and sustainable indoor conditions for the occupants. The preliminary results of the study are also expected to discuss the airtightness aspect of passive house technology and to minimize the mechanical ventilation needs for fresh air intake by benefitting from the self-ventilation performance of air permeable skin. Comprehensive studies are required to benefit more from the inherent breathing features of porous building materials.

The preliminary examination on the air exchange properties of traditional mud brick and autoclaved concrete masonry blocks have shown that those highly-breathable materials have different air exchange properties depending on their physical, physicomechanical and compositional properties, all of which shape their particular porosity characteristics. The air exchange capability of highly breathing materials may contribute to the indoor air quality by considering their self-ventilating capacities during the design stage of buildings and by improving the consciousness on materials selection for constructions.

The double-zone experimental setup based on concentration decay procedure was found to be useful to better-understand the air exchange features of a material in terms of rates of concentration decrease and increase in neighbouring zones by monitoring the concentration of outgoing air. That method allowed differentiating particular performances of porous materials. For instance, the relatively rapid reduction of CO_2 level in a room may signal the higher air exchange characteristics of a material or may be due to the reacting capability of the material composition with CO_2 particles.

Further studies on measuring self-ventilation capacity of building materials are required, especially on measurable parameters that can be used to assess and estimate their self-ventilation characteristics.

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