Airtightness of Nepalese Residential Buildings

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Abstract

Experimental field measurements regarding airtightness following the fan pressurisation method were done on 25 typical residential buildings at different locations in Nepal. The field measurement data were classified according to building type and building age. The mean air permeability (Q_{50}) for the studied buildings was 6.9 l/s·m² and the mean air change rate was 55.5 air changes per hour at 50 Pa. The maximum air leakage rate (Q_{50}) was 28.4 l/s·m² for brick masonry in mud mortar type and the minimum recorded was 1.7 l/s·m² for brick masonry in cement mortar type building. Brick masonry in mud mortar-type buildings was found to be leakier regardless of the building age, and brick masonry in cement mortar-type buildings was comparatively more airtight. Leakage locations identified through visual inspection included the spacing between the door frame and operable door area, horizontal window slider, joint areas of window frame and wall, wood plank-based wall structure, roof joint areas and holes in the wall. This research is the first of its kind in Nepal to assess the airtightness of buildings, and the outcome of this research is one of the key parameters to evaluate the thermal performance of Nepalese buildings scientifically.

Keywords

infiltration, building airtightness, blower door test, residential buildings, Nepal

1 Introduction

Airtightness is the property of a building that inhibits air leakage and is determined by measuring the airflow required to maintain a specific pressure difference between indoors and outdoors (ASTM International, 2010)

Numerous studies have been performed to identify the airtightness of buildings and their contribution to building energy savings (Kalamees, 2007; Sherman and Dickerhoff, 2015; Vinha et al., 2015). This has resulted in strict regulations for the maximum air leakage through a building envelope in most European and other developed countries. Strict regulations for maximum air permeability of 3 m³/hr·m² in Estonia (Kalamees, 2007) 1.5 l/s·m² floor area in Denmark (Erhorn-Kluttig et al., 2009) 7.0 1/h ACH_{50} as per IECC standard in the United States (Erhorn-Kluttig et al., 2009) and 0.6 1/h ACH_{50} (Passive House Institute, online) defined by Passive House Institute are some examples of this formulation. Building Airtightness and its effect on energy efficiency is a new and emerging concept in the Nepalese mindset. This has led academics and researchers to understand the importance and necessity of building airtightness to improve indoor air quality and indoor thermal comfort. This study is the first of its kind to identify the present scenario of the level of airtightness in Nepalese residential buildings.

Nepal has wide variations in altitude that influence the climate and consequently the building technology and lifestyle in general. The most common building practice in the upper hilly region (above 2000 meters) is the Stone Masonry in Mud Mortar (SMM) type building. Similarly, Brick Masonry in Mud Mortar (BMM) and Brick Masonry in Cement Mortar (BMC) type buildings are found in the Mid-hills (610 meters – 2000 meters) and Terai (below 610 meters). Bamboo and wood-based structures are primarily found in the Terai belt of Nepal. Building technology prevalence in Nepal by building type is shown in Fig. 1 (Central Bureau of Statistics Nepal, 2019). Fig. 1 shows that mud bonded brick/stone-based and cement-bonded brick/stones-based buildings are found predominantly in Nepal. In other words, these buildings are means of shelter for approximately 13 million people in Nepal (CBS, 2019).

Previous studies have shown that buildings in the Terai belt get uncomfortably hot in summer, and those
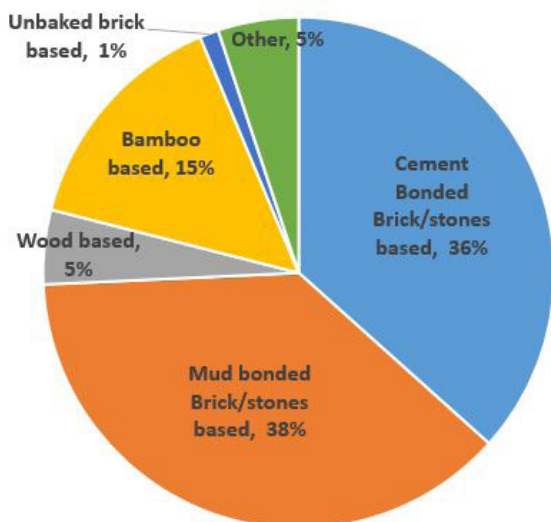
Fig. 1 Household distribution by building type in Nepal (Annual Household Survey 2019)

in the upper hilly region get uncomfortably cold in the winter (Rijal et al., 2010). The indoor air quality is poor (Shakya and Shakya, 2007; Pandey et al., 1989; Pokharel and Rijal, 2020), and the energy demand required to meet the thermal loads is increasing every year (MoF, 2018). Various building energy modelling (Rijal and Yoshida, 2005; Fuller et al., 2009) based studies have been conducted to find the thermal performance of Nepalese buildings, but all studies are found to have used assumed air infiltration rates for the analysis. The studies have put forward many reasons alongside poor airtightness of buildings and infiltration being one of the contributing factors for poor indoor thermal performance of buildings. The Government of Nepal has not defined any rules for building airtightness and indoor thermal comfort, and thus no field studies have been performed to test the airtightness of Nepalese buildings to date.

The authors realised it was time that studies to identify the airtightness of Nepalese residential buildings be conducted such that the building thermal performance and indoor thermal comfort be assessed and analysed. This study is the first of its kind that presents the blower door test results of 25 typical residential buildings to quantify the building's airtightness. This study paves the way for academics and researchers to study the effect of building airtightness on the energy demand, indoor thermal comfort and consequently human health, which is a subject of utmost importance. The authors have also presented the air permeability results based on building type and building age.

2 Method
2.1 Building description
Twenty-five residential buildings were measured for building airtightness. The selected buildings vary in construction year, building technology used, and geographical location; however, all buildings were naturally ventilated, and no mechanical devices were installed to condition indoor air. Eight blower door tests were performed on the whole building, three of which had pitched roof constructions with attic spaces and five had flat roof constructions. Nineteen measurements were done on apartments in multistory buildings.

Fig. 2 shows a recently built typical multistory BMC type building with flat roof construction from Pokhara. An SMM type building from Chame, Manang, is shown in Fig. 3. These buildings are characterised by massive 200 mm to 300 mm walls with wooden plank windows. Most SMM-type buildings have attic spaces with pitched roofs with a galvanised iron sheet.

Fig. 4 shows a multistory BMM type building in Dhulikhel, Kavre, with pitched roof construction. Fig. 5 shows the blower door test setup mounted on the exterior door of a study building during an actual airtightness test.

2.2 Test description
The airtightness measurements have been done with a Blower door test system, which can pressurise or depressurise a building (Sherman and Chan, 2004). The envelope airtightness test was performed using the blower door fan pressurisation method according to ISO 9972:2015 (ISO, 2015).

Fig. 2 Typical BMC type building at Pokhara

Fig. 3 Typical SMM type building at Chame, Manang

Fig. 4 Typical BMM type building at Dhulikhel

Fig. 5 Blower door test setup in an actual airtightness test

The airtightness test was performed using a calibrated standard Model 4 Minneapolis blower door test setup with DG-1000 pressure and flow gauge with an accuracy of ±0.4% (TEC, 2017) produced and distributed by The Energy Conservatory (TEC).

The dimensions of the buildings were measured. The blower door test system was mounted on one of the exterior doors. All enclosed intentional openings such as exterior doors, windows and ventilation holes were closed. The blower door fan was connected to the DG-1000 manometer and was wirelessly controlled via the TEC AUTO TEST application. To further comply with the technical standard ISO 9972:2015 (ISO, 2015), indoor and outdoor temperature measurement was read through a calibrated temperature sensor and was duly input in test readings. The test setup included 10 points with flow measurements at pressure differences of 70 Pa to 10 Pa with intervals of 7 Pa. A regression line was used to average the measurements for the ten pressure difference points.

Table 1 shows flow coefficient (n) values for all the blower door tests performed. The flow coefficient (n) values are such that 0.45<n<1.05 (ABAA, 2016) is true and all values are greater than 0.5 and less than 0.9, which further confirms the tests to be valid as per the technical standard. Pressurisation and depressurisation tests were conducted on all test buildings, the average of which was taken to define the building airtightness.

3 Result and discussions
3.1 Test results
The building airtightness test results for 25 buildings are summarised in Table 1. Of the 25 measurements, eight measurements were performed on a whole building, and the remaining 17 measurements were conducted on apartments (a single flat of a multistory building). Table 1 shows the average pressurisation and depressurisation test result

Table 1 Summary of blower door test result of experiment buildings

Building	Age of building	Enclosure test space description	Floor area (m²)	Enclosure area (m²)	Volume (m³)	ACH at 50 Pa	Air leakage per floor area (l/s·m²)	Air leakage per enclosure area (l/s·m²)	Flow exponent
BMC type building									
1	22	Building	102	464	764	19.3	40.2	8.9	0.610
2	22	Apartment	102	246	312	18.1	15.3	6.4	0.650
3	3	Apartment	62	649	189	24.9	21.1	2.0	0.584
4	27	Building	72	792	221	21.4	18.1	1.7	0.653
5	7	Apartment	19	114	60	22.1	18.7	3.2	0.520
6	5	Apartment	22	102	67	23.1	19.5	4.2	0.540
7	21	Building	88	1088	268	120.7	102.2	8.2	0.650
8	3	Apartment	12	63	32	23.6	18.0	3.4	0.588
9	2	Apartment	58	209	176	29	24.5	6.8	0.590
10	4	Apartment	14	77	44	34.6	29.3	5.5	0.573
11	21	Building	29	150	259	29.6	72.5	14.2	0.560
12	21	Apartment	22	139	66	34.1	28.9	4.5	0.507
13	23	Apartment	55	202	167	23.4	19.8	5.4	0.571
14	23	Apartment	32	169	99	37.4	30.9	5.9	0.556
15	20	Apartment	63	137	193	10.4	8.8	4.1	0.529
16	2	Apartment	67	259	203	23	19.4	5.0	0.510
17	2	Apartment	59	219	180	19.8	16.7	4.5	0.508
18	4	Apartment	16	80	48	20.6	17.5	3.4	0.599
19	4	Apartment	17	86	53	26.4	22.4	4.6	0.582
20	8	Apartment	22	344	67	29.7	14.2	1.6	0.507
BMM type building									
21	8	Building	14	107	79	139.4	212.1	28.4	0.528
22	30	Apartment	8	53	25	82.7	70.0	11.0	0.556
23	20	Building	12	641	64	433.6	623.9	12.1	0.650
SMM type building									
24	4	Building	53	208	144	42.4	32.2	8.2	0.608
25	4	Building	53	208	144	48.5	17.9	9.3	0.608

values for air infiltration (in ACH) and air leakage (l/s·m²) at 50 Pa pressure difference. The maximum recorded air leakage was 28.4 l/s·m² and the minimum recorded was 1.7 l/s·m². The average ACH_{50} and Q_{50} recorded were 55.5 ACH and 6.9 l/s·m², respectively.

Table 2 shows the airtightness results based on building age groups. All 25 measurements were grouped into three age groups, as shown in Table 2. There were 10 observations for buildings aged less than 5 years, 4 observations for buildings aged 5 to 10 years and 11 observations for buildings older than 10 years. The readings show that 5 to 10-year-old buildings had a maximum average air leakage of 28.4 l/s·m2. The minimum air leakage rates observed for those mentioned above three distinct building age groups were 2.1, 1.7 and 1.6 l/s·m2, respectively, which correspond to the air leakage rate for BMC type building.

Table 2 Building airtightness analysis based on building age

Building age (in years)		Less than 5	5 to 10	Above 10
Numbers of observations		10	4	11
ACH_{50}	Average	29.3	53.6	75.5
	Maximum	48.5	139.4	433.6
	Minimum	19.8	22.1	10.4
Air leakage per enclosure surface area (l/s·m²)	Average	5.3	9.4	7.5
	Maximum	9.3	28.4	14.2
	Minimum	2.1	1.7	1.6

Table 3 shows the airtightness of buildings based on building technology used in Nepal. The observed average maximum air leakage for the BMM building was 28.4 l/s·m², and the minimum air leakage for the BMC type of building was 1.6 l/s·m². BMC type of building, with air leakage as high as 14.2 l/s·m², was also observed, which depicts poor airtightness of BMC type buildings.

Table 3 Building airtightness analysis based on construction technology used

Building type		BMC	BMM	SMM
Numbers of observations		20	3	2
ACH_{50}	Average	29.6	218.6	45.4
	Maximum	120.7	433.6	48.5
	Minimum	10.4	82.7	42.4
Air leakage per enclosure surface area (l/s·m2)	Average	5.2	17.2	8.7
	Maximum	14.2	28.4	9.3
	Minimum	1.6	11.0	8.1

3.2 Discussions

Numerous experimental studies (Ji and Duanmu, 2017; Kalamees, 2007; Sinnott and Dyer, 2012) have been conducted around the globe to identify the airtightness of buildings using the fan pressurisation method as mentioned in this article. Studies conducted on 226 residential buildings in Finland (Vinha et al., 2015), of which 10 were brick masonry buildings, showed an average air change rate (ACH_{50}) of 2.8 for brick masonry buildings. Similarly, infiltration tests on residential buildings in Athens (Sfakianaki et al., 2008) showed an average ACH_{50} of 7. The Nepalese counterpart had an average ACH_{50} of 29.6, which gives a comparative picture of how leaky the Nepalese buildings are. Field observations indicate poor construction practice as the main reason for the high air leakage rate in Nepalese buildings.

Lowering the air leakage from the building is crucial as it leads to higher thermal comfort (Shahi et al., 2021). In addition to improving the airtightness, the U-value of building materials and the overall heat loss rate also define indoor comfort in buildings. The studied buildings were not investigated for their U-value; however, studies (Shahi et al., 2021) conducted on similar building typologies in Nepal indicate high thermal loss from the building envelope.

Typical leakage locations that were visually identified during blower door tests were spacing between the door frame and wall, door and floor level, gaps in the window frame and wall, spacing in horizontal window sliders, joint areas of peaked/gable roof and holes in walls. The identified leakage paths through different fixed and operable building structures are shown in Figs. 6 to 9:

1. As seen in Fig. 6, there was space between the window frame and the wall structure. The operable windows are made of wooden plank and within them had huge holes, which provided a free path for air to flow in and out of the building. Fig. 6 was for the BMM type building. In old and recently built BMC

Fig. 6 Spacing between window frame, wall and operable window area
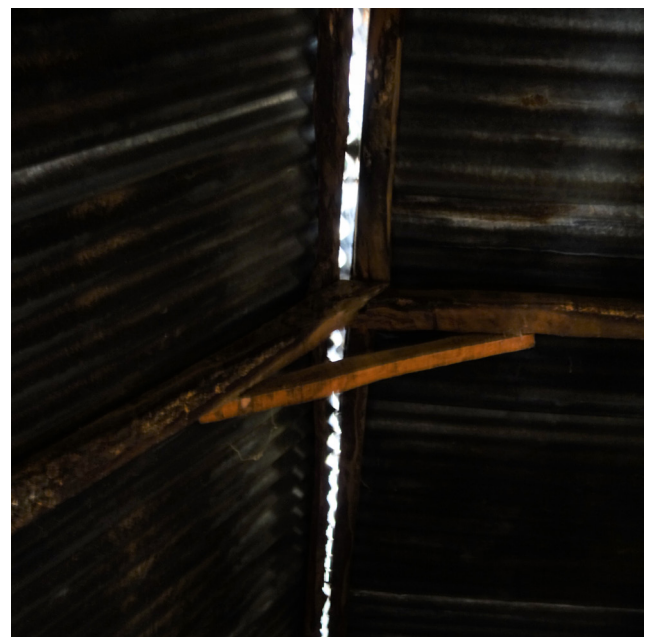
Fig. 7 Spacing in the pitched roof

Fig. 8 Gap in the pitched roof and wall joint area

type buildings, a leakage path was identified as the spacing between the window frame and window. Horizontal window sliders in aluminium framed

Fig. 9 Holes in the wall surface

windows also aid the airflow in and out of the BMC type building.

2. Pitched roof joint area in the BMM type building was not properly sealed, as shown in Fig. 7, which promoted in/exfiltration of air.

3. Huge spacing between the pitched roof and wall joint area was observed, as seen in Fig. 8. The roof sheets were poorly managed and had holes.

4. As seen in Fig. 9, numerous holes were seen in the wall structures. Bricks/clothes were found pushed into some of the holes, causing some to be partially closed and others were left open.

5. Huge spacing between the door and the floor level was observed in the BMC type building and is prone to air infiltration/exfiltration.

Table 2 and Table 3 show the mean air leakage indicators values. Huge variability within the same building type and age group was observed. This variation in the measurement result makes it difficult to set a standard leakage rate for buildings or take a reference leakage rate for further research on building energy modelling. However, the test results analysis based on building age and building types showed BMC type building comparatively more airtight than BMM and SMM type building irrespective of the building age.

The identification of individual leakage locations is not possible through visual inspection alone. Blower door tests are performed to quantify the leakage rate in the enclosed test space but cannot help locate the leakage location. Smoke tests are one standard method of identifying the leakage path and locations. However, smoke tests were not within the scope of this work.

Despite this, as mentioned earlier, the authors were able to visually identify some of the leakage locations in the building structure, images of which are shown in Figs. 6 to 9.

Most Nepalese buildings in the Terai belt were found to have fixed openings in the wall surface near the ceiling level. Such openings served as ventilation for the indoor space. The same was true for buildings in the hilly belt with huge cracks/holes in the wall surface. Thus, closing such openings to make the building airtight would require additional consideration of the indoor ventilation and air quality.

During the field study, it was observed that the occupants were aware of the air leakage into the building, but no effort to seal the leakage areas were even considered. Upon discussion with the residents of the study buildings, it was found that most residents did not bother to seal the leakage areas due to economic reasons. Some residents were not bothered with those leakages as they mainly depended on changing food and clothing habits to adapt to the changing weather.

4 Conclusion

The paper summarises the building airtightness-related field data considering the air permeability and air leakage in ACH_{50} of the enclosed test space.

The recorded mean air leakage rate of the 25-building study was 6.9 l/s·m²@50 Pa with 55.5 ACH_{50}. The recorded maximum leakage rate was 28.4 l/s·m²@50 Pa, and the minimum was 1.6 l/s·m²@50 Pa. The study indicates poor airtightness of Nepalese buildings and, in several cases, resembles an open building as per the technical standard.

The field study shows the BMC-type building to be more airtight than BMM and SMM type buildings. The results also depict newer buildings to be more airtight than older ones. Meanwhile, regardless of the building age, the BMC type buildings were found to have the lowest air leakage rates.

The primary reason behind the high air leakage rate in Nepalese residential buildings irrespective of the building techniques used and building age is the poor construction practice and lack of regular building maintenance. The author believes that professional and scientific construction practice and timely building envelope maintenance can solve this problem.

Considering the huge differences in the housing style, comfort standards and particularly the weather, it is not

appropriate to compare the air leakage rate of Nepalese buildings with the European and ASHRAE standard buildings which have rather strict building airtightness requirements.

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