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Moisture Production and Extraction in New Zealand Homes

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Abstract: The effect of moisture in New Zealand homes is a topic which has been studied intensely, yet problems still arise from excess moisture. The effects that moisture can have in homes is well documented; however very few studies exists on sources of moisture created by occupants. Typically, studies have focused on removing moisture after its production, rather than focusing on its source. This paper examines both the moisture produced in bathrooms in New Zealand homes and the effectiveness of extraction fans found in these bathrooms. A literature review was conducted on the amount of moisture produced in bathrooms and the common factors that make extraction fans ineffective. From this, a survey was conducted and experiments performed to measure the amount of moisture produced in a typical New Zealand home and the effectiveness of commercially available fan and duct systems. The main findings from this study were that commercially available ventilation systems for removing moisture from homes are performing well below the requirements of the New Zealand building code.

Keywords: Ventilation; moisture; bathroom; extraction fans.

1. Introduction

Despite advances in building technology and material performance, problems relating to excess moisture in the home are still occurring. A 2010 house condition survey conducted by the Building Research Association of New Zealand (BRANZ) found that at the time of the study, 53% of owner-occupied houses and 73% of rental properties had problems relating to mould (Buckett, et al., 2010). The reasons behind this included poor ventilation, excessive subfloor moisture, use of unflued gas heaters and inadequate levels of insulation. Typically, with poor ventilation and lack of infiltration, a cycle occurs where moisture condenses on the windows and surfaces overnight. When the air temperature increases during the day this moisture evaporates into the air and the cycle repeats (Cox-Smith, 2015). Numerous studies have been undertaken by BRANZ focusing on the effects of moisture and removing moisture from the home (McNeil, et al., 2015). However, little data exists on moisture created by occupants and how their behaviour around moisture-generating activities impacts the total moisture load in the home. To design ventilation systems that mitigate issues relating to mould, an understanding of the total moisture load in the building is needed.

This study aims to understand how much moisture is produced in a typical New Zealand bathroom and whether typical ventilation systems are capable of removing this moisture. With new construction methods resulting in houses becoming more airtight, it is important to install effective ventilation systems to remove moisture (Larson, 2004). The most effective way to remove moisture is through the use of an extraction fan that vents directly to the exterior (Elkink, 2012). Extraction fans installed in New Zealand homes are typically noisy and inefficient and vent into the roof cavity (Rosemaier, 2014). Knowledge gaps relating to duct installation also exist with little guidance from manufacturers on factors that could affect the extraction fan performance.

2. Literature Review

A wide range of moisture-generating activities have been documented in literature, covering activities such as cooking, showering and cleaning. However, the data generated for each of these activities tends to vary between studies with very wide gaps in the data. Reasons for this include different methodologies, measuring conditions and occupant behaviour. Apart from construction moisture and subfloor moisture, moisture generation relates strongly to occupant behaviour. For this, it is crucial to understand how occupants behave in their environment. The most comprehensive data set was published by the International Energy Agency in the IEA Annex XIV and has been widely used throughout the literature quoted by several different studies including TenWolde (2001). Another popular, although older study, was Hite and Bray's study, Research in Home Humidity Control (1949).

The range of literature reviewed consisted of documentation of experiments and methods relating to a 'typical' family of four comprised of two adults and two children. On average across the literature, 12,400g of moisture is predicted to be released into the typical home per day. Clothes washing and drying was determined to have a significant impact in the home, with one source stating potential extreme days could generate up to 40,000g (40kg) of moisture (Straube & Burnett, 2005; Hanssen, 1984). Moisture released from bathing and showering varied between studies ranging from 200 – 2,400g per day from a combination of the events (Trechsel, 2001; Hanssen, 1984). From this literature, there is no consistency between studies and no studies relating to a New Zealand context. This shows that these activities could be performed again with the moisture release measured in a New Zealand context. To do this an understanding of the activities duration and occurrence was needed. This, like the literature reviewed, was performed through a survey.

The second part of the literature review conducted was to analyse the existing literature on the performance of extraction fans. NZS4303:1990 Ventilation for acceptable indoor air quality, states for extraction of air that bathrooms and toilets need 25l/s intermittent or 10l/s continuous air exchange. A number of common practices in residential households leading to poor performance of extraction fans, are due to a lack of knowledge regarding extraction fans and ducts. For example, installing an oversized fan will remove moisture effectively, but could also have negative impact on the house causing depressurisation. This can also lead to other issues such as an increase in the noise produced, as well as high energy consumption (Fuoss, 2004). By installing undersized fans, moisture will not be adequately removed due to limited power efficiency (Kim & Yang, 2016). Therefore, it is vital that correct extraction fan and ducts are assembled and installed in order to effectively deal with the moisture caused by the occupants.

Another crucial element in the performance of extraction fan systems is the connected duct. A study conducted by Abushakra, Walker and Sherman (2004) evaluated the pressure drop in flexible ducts caused by compression of flexible ducts in residential and light commercial applications (Abushakra, et al., 2004).

It was observed that the pressure drops in flexible duct systems were higher than expected based on design calculations. The flexible ducts are often found to be compressed to varying degrees which leads to excessive pressure drop, increase in fan power, flow restriction and increase in noise (Abushakra, et al., 2004). The results in the study showed that moderate compression in flexible ducts could increase the pressure drop by a factor of four (often seen in field installations), while further compression could increase the pressure drop by factors close to ten (Abushakra, et al., 2004). Another study by Weaver (2011), resulted in similar findings in relation to residential flexible ductwork. The study suggested that the configuration of flexible ducts has a significant impact on the performance of extraction fans. The set of experiments that were conducted demonstrated the static pressure drop for various percentages of compression. Unnecessary compression causing bends in the flexible duct can raise the static pressure loss by as much as a factor of ten (Weaver, 2011). Weaver (2011) stated that installation of the ductwork plays a very crucial role in the performance of extraction fans. Therefore, it is important that designers and contractors are aware about how important it is to install flexible ducts properly and avoid any static pressure losses. Other effects that increase the pressure drop in the duct are caused by changes in the geometry of the airflow path, bending of the duct, and significant sagging of the duct between supports.

A study done in Korea on bathroom extraction fans by Kim and Yang (2016) showed that performance of the extraction fans failed to meet manufacture regulations. Suggesting that changes in construction and design methods can effectively improve the extraction fan performance. This study also raised an interesting point about the technical proficiency of the installer of the fan connecting components. Skills of the installer had a significant influence on the performance of the extraction fan (Kim & Yang, 2016). It is therefore necessary to have a skilled installer who has an understanding of the impact that poor installation of the ducting has on the performance of the extract fans.

Another notable factor that plays a role in the performance of the extraction fans is the location of the extraction fan. It is important to carefully locate the extraction fan to allow it to remove the moisture effectively and ensure maximum air-flow through the bathroom. The fan should not be located beside a window where fresh air comes in (Simx, 2013). Poor installation of the extract fans will lead to performance well below the anticipated level of operation. Currently, numerous commercially available extraction fans do not include a moisture sensor. It is vital to pair an extraction fan system with a sensor to ensure the system is turned on and kept on at appropriate times to help remove moisture.

2.1. Performance of commercially available extraction fans

A primary aim of this study is to investigate the effectiveness of current commercially available extraction fans and to test if they meet the building code requirements. As part of this literature review, the manufacturing company Simx Limited was contacted regarding their commercially available Manrose extraction fans. Simx tests their fans on a double chamber Static Pressure Rig and then calculate free air performance and airflows along six different Pascal resistances. The manufacturing company does not consider the duct a factor and how it could affect the airflow rate of the extraction fan and whether it will still meet minimum building code requirements.

The free air flow performance of extraction fans studied the claim that the fans meet and exceed the minimum Building Code requirements. It is also assumed by the manufacturer that once the duct is connected to the fan the completed installation will meet also meet Building Code requirements. There was no information available on the relationship between the extraction fan and duct, or how it will affect the performance in terms of air flow rate and pressure drop. The manufacturing company test the airflow rate without a connected duct, which means that they are assuming that after installing the duct and fan, it will have the same airflow.

2. Survey

To determine how occupants behave in their own homes a survey was created and sent to the Faculty of Architecture at Victoria University of Wellington and BRANZ employees, receiving 99 responses. From the survey responses, it was found that occupants favoured showers over bathing in a bathtub with 100% of respondents having showers and only 13% taking both. The duration of these were 8.7 and 20.5 minutes respectively. Hand washing at home was around seven times per day per person. Use of a towel after showering and bathing is assumed to be 2.7 times per day per household based off the daily number of showers and baths taken by the respondents. 64% of respondents had a clothes dryer that was used in the home. 30% of these respondents had dryers that were vented to the outside and 10% had a condenser dryer. The remaining respondents stated either their dryer was vented to the outside or the respondent did not know if it had a vent. Typically, dryers were used more frequently in the winter at 2.9 times per household per week and in summer 1.4 times.

3. Experiments

3.1 Moisture generating experiments

The following experiments were either conducted in the home or in a controlled workshop. Each experiment was carried out using a similar method; the process of measuring the weight before and after an event. This would determine the amount of moisture that has or will eventually be released into the air via evaporation. Experiments were conducted several times to determine an average amount of moisture released. Methods from Yik, et al. (2004) for a majority of experiments were followed closely where possible.

After a person washes their hands and after showering/bathing, towels are used to dry themselves. For this experiment the moisture released into the air is assumed to be the water that is absorbed by the towel. The towel was placed on the scale before use and then weighed again after. It was found that from hand washing 3.9g of moisture is absorbed per wash or 27.5g/person.day. From showering 89.3g is absorbed per shower. However, this will vary depending on the person.

Mopping floors contributes to moisture in homes via evaporation from water that remains on the floor area. Mopping floors in New Zealand is typically completed using a mop but can also be done by hand using a sponge, rag or similar. Both methods were tested for this experiment where an area of vinyl floor was marked out and mopped five times for each method. This resulted in an average moisture release of 13.7g/m^2. Assuming a kitchen of 3m x 4m and a bathroom of 2.4m x 3.5m gives a total area of 20.4m^2. This is an estimate which will not relate directly to every household, therefore a m^2 rate is presented. A household that mops 20.4m^2 will release 289.8g of moisture on days where floors are mopped.

Leaving washing to dry indoors or using an unvented clothes dryer is assumed to release large amounts of moisture into the air. Data from the survey and Yik, et al. (2004) were used to create a typical washing load and the quantities of the items being washed. The dry clothes were weighed individually on the scale before being placed in a top loader washing machine. These clothes were then weighed again after being washed to determine the amount of moisture that would be released from drying the item. For a typical household of 2.7 occupants, a rate of 2,478g/load is estimated with a total of 4.5 loads of washing washed per week. It is assumed that an unvented clothes dryer releases all the clothes moisture into the air and none remains in the machine.

Evaporation of water from showering is assumed to add significant amounts of moisture to the air because of the high temperature of the shower water and the warm poorly ventilated environment. This moisture evaporates into the air and once the air is saturated will begin to condense on surfaces within the bathroom. To calculate an estimate for moisture release from showering a model derived by Shair, et al., 1979 was used taking into account ventilation, infiltration, vaporisation from the shower and water vapour condensation onto the bathroom surfaces (Yik, et al., 2004).

$$w(t) = (b/a) + (w_o(b/a)\exp(-at) \quad (1)$$

$$a = (S + Q + kA)/V \quad (2)$$

$$b = (Sw_s + Qw_o + kAw_w)/V \quad (3)$$

Where: $w(t)$ = Moisture content in the bathroom air at time in $kg.kg^{-1}$; (t); w_o = moisture content in the air entering the bathrrom due to ventilation in $kg.kg^{-1}$; w_s = saturated moisture content of the air in equilibrium with the water droplets in $kg.kg^{-1}$; S = coefficient of moisture transfer from the shower water to bathroom air in $m^3.s^{-1}$; k = Coefficient of moisture transfer between the bathroom air and surfaces enclosing the bathroom in $m.s^{-1}$; Q = ventilation flow rate due to mechanical ventilation in $m^3.s^{-1}$; A = total area of surfaces enclosing the bathroom in m^2; t = time in s; p = air density in $kg.m^3$.

Using this model (1), for a shower lasting 8.7 minutes, a total moisture release of 401.4g per person is estimated, equating to 46.1g/minute. Moisture released from bathing in a bathtub was also calculated resulting in 174.2g/event, but from the survey results very few people bathed in a bathtub compared with showering.

From the experiments it is found that many of the events that contribute to moisture in bathrooms release moisture over a long period depending on the indoor climate. Towel use and floor mopping have a slow release rate compared to activities like showering and unvented clothes drying where moisture is released quickly over a short period. For a typical shower and clothes drying event based on the survey findings and experiments these activities release 401.4g/person and 2,478g/event respectively. Measures to reduce the amount of moisture released into the air from the two largest contributors would include reducing the length of showers and the total amount of clothes left to dry indoors. However, this may not always be achievable. With the amount of moisture released into the air known, this raises the question of whether this moisture will contribute to problems like mold and mildew in the home. Ventilation is key to prevention of these types of issues, so typical bathroom ventilation systems that are able to cope with this much moisture are vital.

3.2 Extraction fan performance

To establish whether current bathroom extraction fans can cope with the moisture released in bathroom, methods from Abushakra, et al., 2004 study and Weaver, 2011 were adapted to determine the extraction fan performance. Since the study was conducted overseas, alterations were made in the equipment used for measuring the airflow and size of duct in the experiment due to the availability.

All experiments concerning extraction fans were conducted in a laboratory. Two different testing procedures were conducted with each setup consisting of different equipment and interpretation software for measuring the 100mm and 150mm extraction fans' airflow performance. First the airflow performance of the fan is measured using the hot wire method to find out if it met the performance that is quoted by the manufacturer. The second method uses Laminar Flow Element (LFE), LFE Pressure gauge (measured pressure difference) and MKS Transducer (Airflow rate) all used in the experiment to ensure the reliability and accuracy of the result.

Both methods demonstrated that the 150mm fan did not meet the company specifications giving a different rate of air flow. However, the last test with the laminar flow element provided a more reliable result because the variables could be more easily controlled.

Hot Wire Anemometer

The Hot wire anemometer experiments resulted in the extraction fans performing well below their quoted performance shown in Table 4. The 100mm fan does not met the building code requirement of 25l/s intermittent or 10l/s continuous air exchange, because it was only able to achieve 8.6l/s airflow rate, whereas the 150mm extraction fan met the building code requirement on its own, but failed after adding 1m of duct.

Table 4: Comparison of manufacturer and tested airflow performance

Axial fan	NZBC requirement (l/s)	Quoted performance (l/s)	Airflow – no duct (l/s)	Airflow – 1m duct (l/s)
100mm extraction fan	25 intermittent or 10 continuous	23	8.6	6.7
150mm extraction fan	25 intermittent or 10 continuous	94	73.6	60.1

Laminar Flow Element (LFE) and Extraction Fan

The airflow performance of the extraction fan was measured by the LFE shown in Figure 10. The LFE measures the airflow and the MKS measures the pressure on the other side of the extract fan.

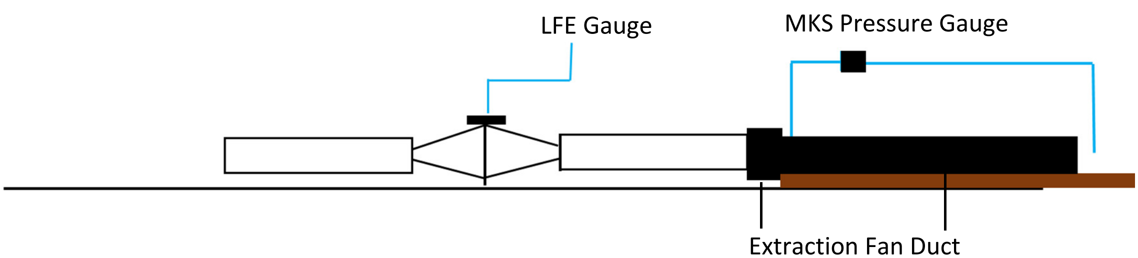

Figure 10: Laminar Flow Element (FLE) experiment set up (Authors image)

Testing of the extraction fan using the LFE method resulted in the fan not meeting the minimum Building Code requirements of 25/s nor its quoted performance of 23/s shown in Table 5. The 150mm fan meets the Building Code requirement, however when 1m of duct is added the airflow rate drops from 26.3 to 22.8l/sec and thus fails to meet the Building Code requirements.

Table 5: Comparison of extraction fans and New Zealand Building Code

Axial fan	NZBC requirement (l/s)	Quoted performance (l/s)	Airflow – no duct (l/s)	Airflow – 1m duct (l/s)
100mm extraction fan	25 intermittent or 10 continuous	23	6.8	3.6
150mm extraction fan	25 intermittent or 10 continuous	94	26.3	22.8

Laminar Flow Element (LFE), 150mm Extraction Fan and PVC Duct

This aim of the experiment was to measure the airflow of different lengths of ducts. Table 6 shows the difference in airflow between PVC and a rigid duct at different lengths with the 150mm extraction fan connected. In both types of ducts airflow reduces as the length of duct increases. By increasing the length of the duct, the pressure drop will increase and the airflow will decrease. Both the experiment and literature review show that flexible (PVC) ducts are less effective and play a significant effect on the extraction fan performance. Flexible ducts are popular to install in residential dwellings because of their low cost, easy installation and ability to navigate around tight corners.

Table 6: PVC and rigid airflow ducts

150mm axial fan	Length (m)	PVC airflow (l/sec)	Rigid airflow (l/sec)
	1	22.8	n/a
	2	22.6	25
	3	22.5	23

This third experiment involved a 3m flexible duct which was compressed down into 0.15, 1 and 2m lengths. The findings in Table 7 show that a slight compression can result in a large pressure drop and result in lower airflow rate. When the duct has no compression (fully stretched) this results in a higher airflow compared to compressed. This is because the flexible duct tested had a spiral helix construction, therefore it has the highest friction loss. The inner surface of the flexible duct changes shape with compression which increases turbulence and friction loss. The flexible duct is soft and flexible therefore it is easy to squeeze through tight places and compress excessive lengths to fit between connections.

Table 7: Compression of 3m PVC flexible duct

150mm axial fan	Compression scenario (m)	PVC airflow (l/sec)	Pressure drop (Pa/m)	Compression (%)
(Compression)	0.15	20.8	95.3	98
	1	20.8	18.4	80
	2	20.6	8.8	60
(Fully stretched)	3	22.5	4.8	40

The final experiment performed involved adding a number of bends ranging from 60 – 90° to a 3m PVC flexible duct with the 150mm fan. This resulted in the airflow reducing dramatically to 1.23l/s with one bend compared to no bends which had an airflow of 22.5l/s shown in Table 8. The reasoning behind this dramatic increase may be attributed to the degree of the bend. Further testing is required with bends of smaller angles to understand whether this data can be fully trusted.

Table 8: Number of bends on the flexible duct

150mm axial fan	No of bends on 3m	PVC airflow (l/sec)
	0	22.5
	1	1.23
	2	1.24
	3	1.21

4. Conclusion

The aim of this study was to investigate how much moisture is produced from day to day activities and what effect extraction fans have in New Zealand households. With 53% of owner-occupied houses and 73% of rental properties having mould, an understanding of the sources of moisture caused by occupants within the home is needed (Buckett, et al., 2010). Typically, literature tends to focus on removing moisture from the home rather than managing it at its source (McNeil, et al., 2015). By undertaking experiments relating to a typical New Zealand household, it was found that an estimate of 3,831g of moisture could be released into the air on a day where high moisture generating activities are performed like showering and use of an unvented clothes dryer. To minimise the amount of moisture released into homes, duration of moisture generating events like showering and the quantity of clothes left to dry indoors could be reduced. These measures alone are not able to prevent moisture being released into the air, which is where extraction fans should be used to remove moisture.

Overall, the research conducted indicated that the size of the fan, location of the fan, excessive length, number of bends and various compression on the duct all contribute to the failure of residential fan systems and duct systems. The manufacturer's claims for the performance of their 100mm fans may meet the minimum requirements on paper, but the research demonstrates that as typically installed in practice, the completed fan installation does not meet the ventilation requirements of the NZBC Clause G4.

Both designers and contractors need to be made aware that the following recommendations will help to meet Clause G4.

- Use rigid duct wherever possible.
- If using flexible duct, ensure it is stretched out which will avoid bends and slight compression.
- Specify timers and sensors of the extractions fans.
- Use 150mm fans instead of 100mm.
- Avoid angled corners in ducts
- Have a maximum of 2m of duct connected to the exterior
- Allow fresh air into the room, to supplement the air being extracted

To reduce the impact of moisture in homes, testing of different types of fans and a wider range of duct sizes is needed to determine the most efficient fan and duct system for residential dwellings. Testing of manufacturers claimed performance and actual performance is also key to ensure consumers are purchasing a system that meets its claims.

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