Indoor Aerosol Pollution Measurement in Energy Efficient Homes

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Abstract

This essay outlines the plan to assess the concentrations of particulate matter in energy efficient homes and investigate how they are influenced by ventilation systems. Using real-time optical particle counters, particulate matter will be sampled in two rooms of each of the 50 dwellings that are designated energy efficient for periods of 24 hours. The air exchange rate of the ventilation system as well as the type of ventilation system will be taken into account. A variety of research questions will be addressed, including exploring the effects of factors such as building occupancy patterns, and retrofit status, on particulate matter concentrations. This is the first time that a full study of particulate matter in energy efficient homes will be completed in Ireland, and represents one of very few such studies conducted internationally.

Introduction:

In Europe, over the last number of years there has been considerable encouragement and emphasis placed on improving the energy performance of buildings through design and construction, and retrofitting homes to bring them up to the energy efficient standard. Most of this encouragement comes from the requirements to reduce CO_2 emissions internationally and from an awareness of ever decreasing fossil fuel reserves and increasing costs of using energy. The European commission has estimated that buildings account for 40% of the energy used in Europe and 36% of the CO_2 emitted from Europe (EC, 2012).

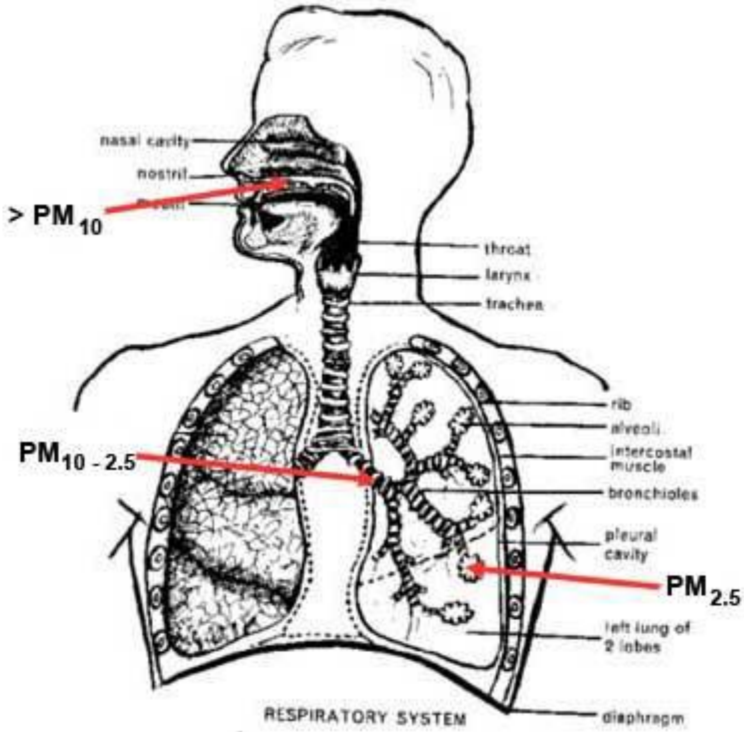
Although it is recognised that indoor airborne particulate concentrations are dependent on factors such as the air exchange rate, building materials and occupation patterns, (Hanninen et al., 2004) the precise relationships between particulate concentrations and ventilation characteristics have been sparsely researcher and are not understood, and the filling of this knowledge gap, with special emphasis on the energy efficient building sector, provides the motivation for the current study.

Particulate Matter (PM)

An aerosol is a suspension of liquid or solid particles in a gas. PM is made up of small particles and liquid droplets which are formed from a number of components such as dust or soil particles, organic chemicals, and acids (Environmental Protection Agency, 2013). PM is measured in microns (10^{-6} meters) and the diameter of PM can range from 100 microns to 0.001 microns in size. PM is categorised by size according to the diameter.

In the context of human health, the size of particles is significant, as this has an influence on their interaction with the respiratory tract. Inhalable dust is the fraction of dust that can be inhaled into the mouth and nose. Thoracic dust is the particulate fraction of dust that enters the airways of the lungs and have a diameter of between 10 µm and 2.5 µm. Respirable dust is made up of particulates that can be deposited anywhere in the gas exchange region and have a diameter of 2.5 µm or less. The figure below (figure 1 – particulate deposition) shows where the different sizes of PM can be deposited in the respiratory tract (Center for Environment, Commerce and Energy, 2010).

Figure 1 – Particulate deposition in the human respiratory tract



Inhalable coarse particles are larger than 2.5 µm but smaller than 10 µm in diameter where as fine particles are 2. 5µm or smaller in diameter. Fine particles can travel longer distances, can penetrate deep into the lungs and can be enriched with toxicants (Manoli et al., 2002).

Ultrafine particles are the smallest class of particulates, and are generated from combustion emissions. These particles are usually 0.1 - 1 µm in diameter and make up more than half of the particle mass in the surrounding air (Brunekreef and Forsberg, 2005).

The European Directive on Ambient Air Quality and Cleaner Air for Europe (2008) defines PM_{10} and $PM_{2.5}$ as the following:

"PM_{10} shall mean particulate matter which passes through a size-selective inlet as defined in the reference method for the sampling and measurement of PM10, EN 12341, with a 50 % efficiency cut-off at 10 µm aerodynamic diameter."

"$PM_{2.5}$ shall mean particulate matter which passes through a size-selective inlet as defined in the reference method for the sampling and measurement of PM2,5, EN 14907, with a 50 % efficiency cut-off at 2,5 μm aerodynamic diameter."

The air quality limit value for PM_{10} in a 24 hour period is 50 μg/m^3 and 40 μg/m^3 averaged over one calendar year (Air Quality Directive (2008)). The air quality target value for $PM_{2.5}$ in Europe is currently 25 μg/m^3 per year; with the limit value set for 2015 for $PM_{2.5}$ at 25 μg/m^3 and the limit value set for 2020 for $PM_{2.5}$ at 20 μg/m^3. Under EU law a target value must be attained in so far as is possible, the current target value becomes the limit value in 2015 and a new limit value will be introduced in 2020. The limit value is a legally binding value; that is based on the average exposure indicator value and the percentage reduction required by the Air Quality Directive.

The World Health Organisation (WHO) has set the mean values for exposure to $PM_{2.5}$ to 25 μg/m^3 in 24 hours and 10 μg/m^3 averaged in a year. The mean values for PM_{10} are 50 μg/m^3 in 24 hours and 20 μg/m^3 in a year. The WHO values are stricter than the EU air quality standards, and the WHO have explained their reasoning behind the values as the following:

"*As no threshold for PM has been indentified below which no damage to health is observed, the recommended value should represent an acceptable and achievable objective to minimise health effects in the context of local constraints, capabilities and public health priorities.*" (WHO, 2008).

Health Effects of Particulate Matter

PM is believed to contribute to cardiovascular and respiratory disease and it has been found that people subjected to long term exposures to PM have a significantly increased chance of having a cardiovascular incident and therefore can have a higher mortality rate; even in populations where there has been only a short term but acute exposure to PM, a slight increase in the risk of cardiovascular incident has been demonstrated. Studies have shown that PM causes deterioration in respiratory function, increased use of medication and in particular a decrease in lung functionality. Studies such as Brunekreef and Forsberg (2005) have shown that the potencies of PM_{10} and $PM_{2.5}$ are size related in the context of respiratory disorders, in addition, there are further studies completed by Castillejos et al., (2000), Host et al., (2008), and de Hartog et al., (2003) on mortality, morbidity, and cardio-respiratory symptoms respectively. Nawrot et al., (2007) found evidence that seasonal variation can have an impact on the potential detrimental effects of PM. Experiments have shown that this is because the potency of PM depends on the chemical composition of the PM which fluctuates depending on the season i.e. winter or summer (Happo et al., 2010, Jalava et al., 2007). Apart from inhaling PM in outdoor air, exposure to bio-aerosols indoors is a pertinent health subject, which is believed to be accountable for respiratory symptoms, asthma and infections (Jones, 1999). Exposure to bioaerosols and indoor aerosols arising from other sources is of particular concern as it has been estimated that people spend the vast majority of their time indoors between work and home (Myers and Maynard, 2005).

Ventilation and Energy Efficient Homes

It is clear that the role of ventilation is important in determining indoor aerosol exposure. However, since the 1970's, energy costs have risen steadily and in response to this houses have been modified to become more air tight in order to reduce heating costs; the greatest cost for ventilation/heating is when there is a large temperature difference between outdoors and indoors, this has led to the development of energy efficient homes in Europe. The energy efficiency methodology increases the air tightness of the house which in turn reduces the amount of heating and ventilation needed. While the cost of running the house is decreased by the energy efficiency of the house there have been suggestions that the air tightness of the house can lead to increased likelihood of mould and condensation where there is high humidity in the house. Rousseau (2003) concluded that in order to reduce operating costs of the house, increase comfort and prevent condensation from forming, levels of insulation needed to be increased. This can be over come by keeping the heating on during the night, increasing ventilation rates, or increasing insulation at the thermal bridge, all of which are expensive to implement. An alternative solution is to use a dehumidifier, which has additional costs to the home owner. In order to reduce heat losses by air leakage a continuous air barrier is built-in to the insulated walls and although this can benefit in the reducing entry of particulate matter, it can have the opposite effect on particulate matter generated indoors, which is more likely to remain in the house for a longer period unless removed by appropriate ventilation. If the ventilation of the house is poor or incorrectly maintained then the ventilation system may actually be continuously re-circulating particulate matter and therefore concentrating (bio-accumulating) particulate matter in the home. This has been recognised as a potentially detrimental step in the context of human health. A review of literature by Sundell et al., (2011) showed that negative health effects increased when ventilation rates were lower.

A firm legal framework for reducing ventilation rates to meet energy conservation targets has been established over recent decades. As an example, the legislative structure for the Irish context is now summarised, and this is mimicked across Europe and beyond. In 2002, the Energy Performance Buildings Directive was introduced, and transposed into Irish law in 2006. The Energy Performance Buildings Directive introduced an array of provisions for the improvement of energy efficiency of new and existing buildings. In 2010, it was recast and then superseded by the European Union (Energy Performance of buildings) regulations 2012. These regulations also require that any building that is being sold, rented or built must have an energy performance certificate.

In Ireland, the Building Control Act which was introduced in 2007, together with The Building Regulations are aimed at increasing thermal and energy efficiency of homes, by specifying the level of air tightness for new homes. Air permeability according to the Technical Guidance Document L conservation of fuel and energy (2011) dwellings should be 10 $m^3/hr/m^2$ at 50 Pa with best practice at 5 $m^3/hr/m^2$. Part F of the technical guidance document gives guidance on the different types of ventilation systems that can be used and the minimum values for extraction rates.

There are a number of types of ventilation system that can be used in energy efficient homes such as Heat, Ventilation and Air Conditioning (HVAC) system or Mechanical Heat Recovery Ventilation (MHRV) system.

A HVAC system is one type of combined ventilation system that serves as the heart of an energy efficient house. A well designed and correctly maintained HVAC system can help to prevent outdoor air contaminants from entering the house. The system must have the capability of filtering, diluting and exhausting the outdoor air pollutants. Studies have shown that up to 60% of indoor air quality problems have been related to poorly maintained HVAC systems (Burroughs and Hansen, (2004)).

A MHRV system is a type of ventilation system that uses the heat from the air leaving the system to heat air that is being pumped into the rooms. They system uses a transfer box usually located in the attic where warm stale air is taken from the house; its heat is then exchanged to fresh air from outside, and pumped through the house. The stale air and fresh air never mix during the heat exchange process.

Present State of Knowledge and Objectives of the Current Work

While there have been several studies of the effect of ventilation on moisture prevalence and mould growth in homes, investigations regarding the effect of ventilation on gaseous and particulate pollutants are extremely rare. One recent study, by Derbez et al., (2014) surveyed seven newly built homes classed as energy efficient in France. Researchers examined many different indoor air quality parameters before and during the first year of occupancy such as total volatile organic compounds, carbon monoxide, PM 2.5, and several other indoor environmental parameters. Air exhaust and air exchange per hour was simultaneously measured with the pollutants and an evaluation of the perception of the occupants was carried out. It was found that $PM_{2.5}$ was higher during occupancy than before occupancy and that the levels of $PM_{2.5}$ showed seasonal variation. Overall, $PM_{2.5}$ levels were low compared to standard French homes. It was found that the mechanical ventilation with heat-recovery system allowed an air exchange per hour that was $0.5h^{-1}$ or higher.

Based on a review of current literature, a number of important knowledge gaps currently exist regarding the relationship between low ventilation levels and indoor particulate pollution, specifically:

1. To date, the seasonality of indoor PM variations in energy efficient homes has only been described for a very small sample size
2. Existing studies that have investigated the relationships between indoor PM variations and ventilation rates have not examined a comprehensive range of PM emission scenarios, i.e. different types of heating and cooking sources
3. Existing studies have focused on measuring indoor air pollution concentrations before and after occupancy of new dwellings, but to the author's knowledge, there have been no similar studies in dwellings that have undergone retrofitting and refurbishment to reduce ventilation rates.

In the present work, it is envisaged that TSI SidePak AM510 Personal Aerosol Monitors fitted with $PM_{2.5}$ impactors will be used to collect and log real-time data on airborne $PM_{2.5}$ in the kitchen and main bedroom of a target sample of fifty dwellings that are designated energy efficient. Both newly built dwellings and retrofitted dwellings will be included, and the sample dwellings with both gas and electrical heating and cooking appliances, and dwellings containing smokes. Indoor PM concentrations will be collected over a 24 hour period with the monitor set to log at 1 minute intervals; assessment of peaks and daily variability in exposure will to be determined. A daily log will be kept by the participant that may help in identifying peaks in the data. Data will be collected during the summer and winter to allow for seasonal variation. The expected results from the project will be that PM will vary depending on the season, the type of building ventilation system, air exchange rates, and occupancy rate of the dwelling. The results may then be compared to those of standard non energy efficient dwellings to investigate the differences in levels of PM between the two types of dwellings.

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