THE INFLUENCE OF ACTIVITY ON INDOOR FUNGAL LEVELS – A NOVEL TECHNIQUE FOR SIMULATING DISTURBED CONDITIONS

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ABSTRACT
Obtaining accurate representations of airborne viable fungal levels indoors is complicated by different sampling methodologies and internal and external variables and conditions. The concentrations and composition of airborne fungal spora indoors can vary widely both temporally and spatially. Various studies have shown that human activity has a significant effect on the concentrations of microorganisms isolated during sampling. These studies often require the occupant to be present within the sampling environment, or to be in the process of an activity, or involve complex ways of simulating human activity (dancing, walking, shuffling papers) or disturbed conditions (utilising specialised vibration equipment), most of which are difficult to reproduce. The methodology described in this study, to simulate activity/disturbed conditions, had to be easy to replicate, and equipment utilised readily accessible and affordable. Results showed strong and significant correlations with consistently higher concentrations of airborne viable fungal spores resuspended from carpets in the study homes. Indoor activity ratios (I:A) developed in this study, can serve a similar function as indoor outdoor ratios (I:O), in providing a better indication of fungal change and possible indoor sources.

INDEX TERMS
Simulated activity, disturbed conditions, indoor fungi, residential homes, carpets, cleaning

INTRODUCTION
Contamination from indoor sources and the ensuing dispersal of airborne particulates and fungi either in the workplace or home environment, can often lead to a loss of productivity and minor or severe health effects and symptoms (Sivasubramani et al. 2004, Ferro et al. 2004, Toivola et al. 2004, Peters et al. 2001). Fungi, bacteria and dust are typically ubiquitous in carpets and soft fabric flooring, but complications arise with poor soft floor hygiene and/or water damage incidents providing moisture and nutritional substrates (dust, carpet material, padding/underlay, glue) for microbial organisms to proliferate to problematic levels (ACGIH 1999).

Numerous scientific and epidemiological studies suggest that a significant risk factor for both upper respiratory and pulmonary symptoms may be attributed to prolonged exposure to airborne fungi (Dales et al. 1997, Godhish et al. 1996, Brunekreef et al. 1994). Fungal spores and fine particulates can remain airborne for long periods and are subject to drift throughout the home or workplace. They can adhere to vertical surfaces (walls) and settle on horizontal surfaces (finished furniture, carpeting and/or smooth floors). In addition, these spores and particulates can be transferred on clothing to other places within and between homes and to schools or workplaces where they can be inhaled, thereby contributing to respiratory symptoms (Ferro et al. 2004, Lioy et al. 1999).

The aerosolisation (airborne release) of fungal spores and particulates from their source is driven by external energy sources and additionally by environmental factors (Sivasubramani et al. 2004). Settled spores and particulates present on hard and soft surfaces in the indoor environment may become resuspended by air movement caused by various activities including human disturbance (walking, cleaning, foot traffic, etc.), or by environmental changes such as changes in air humidity and wind gusts (Lehtonen et al. 1993, Ferro et al. 2002 & 2004, Long et al. 2000, Flannigan and Hunter 1998, Thatcher and Layton 1995, Pasanen et al. 1991).

Many studies have investigated the influence of carpeting on indoor fungi in domestic environments (Berry 2004, Bishop et al. 2004, Nilsson et al. 2004, Franke et al. 1997). Several studies have since shown that human activity and disturbed conditions has a significant effect on the concentrations of microorganisms isolated during sampling (Buttner et al. 1993, Greene et al. 1962). These studies often require the occupant to be present within the sampling

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environment, or to be in the process of an activity, or involve complex ways of simulating human activity or disturbed conditions eg dancing, walking, shuffling papers, or the use of specialised vibration equipment, most of which are difficult to reproduce. The methodology described in this paper, to simulate disturbed conditions had to be easy to replicate, and equipment utilised readily accessible and affordable. The results presented in this paper come from carpeted residential and office environments, whereby the method for simulating disturbed conditions was replicated.

RESEARCH METHODS

The developed methodology for simulating disturbed conditions, was trialled in 25 residential and 9 office environments. All homes were single storey, of brick construction, ranging between 2 to 30 years old and were within a 15km distance from Murdoch University. The nine offices were located in the second storey of a building at Murdoch University. All offices were roughly of the same size and occupancy rate (1 person). Specific specification required no tobacco smoking within the home and office and for all homes and offices to be carpeted (tufted wool or synthetic).

Monitoring protocol

Fungal monitoring was conducted in the bedroom of each participant in the home environment and in the middle of the office environment, with N-6 Andersen multi-hole impactor samplers (Andersen Instruments Inc. Atlanta GA) co-located at a height of 1-1.5m above the ground, for two minutes at a flow rate of 28.3 L/min (Cheong et al. 2004, Foarde and Berry 2004, Hyvarinen et al. 1993). External variables were more controllable in the office environments and as such were kept to a minimum (windows and doors kept closed during sampling, rubbish bins emptied the night before), whereas in the home environments, external variables were not controlled, to reflect real-time realistic domestic conditions.

Simulated activity/disturbed conditions

Two sets of indoor measurements were taken for comparative analysis. The first measurement was taken prior to a simulated activity/impaction test and another immediately after the disturbed conditions. The impaction test involved a standard fully inflated (30 psi) basketball dropped from a height of 1.5m in a grid-like pattern over the entire exposed carpeted area for a period of 60 seconds. Outdoor samples were collected 2m away from the homes and offices to represent outdoor air that may enter the buildings from windows or doors for further comparison.

Malt extract agar (MEA-DIFCO) and Dichloran 18% Glycerol agar (DG18-Oxoid) were utilised in side by side sampling in order to enumerate a broad spectrum of fungi. Both media were amended with Chloramphenicol (Sigma) to limit bacterial growth (Cheong et al. 2004). Cultures were then incubated (5 days, 22^{o}C ±1^{o}C, 30%RH ±5%), counted and reported as the number of colony forming units per cubic meter of air (CFU/m^{3}). A subset of samples was differentiated to determine the fungal profile.

RESULTS

Strong correlations were found in all groups (Control: r = 0.933, Vacuum: r = 0.948, Steam Clean: r = 0.946, Air Filter: r = 0.945) with no significant differences between the indoor air levels collected before the simulated activity and after the simulated activity ($P > 0.05$ in all cases).

Indoor fungal levels following the simulated activity were on average 15.6% higher than pre impaction levels prior to the cleaning interventions (pre) and 9% higher than pre impaction levels, after the cleaning interventions (post) (Figs. 1 to 4).

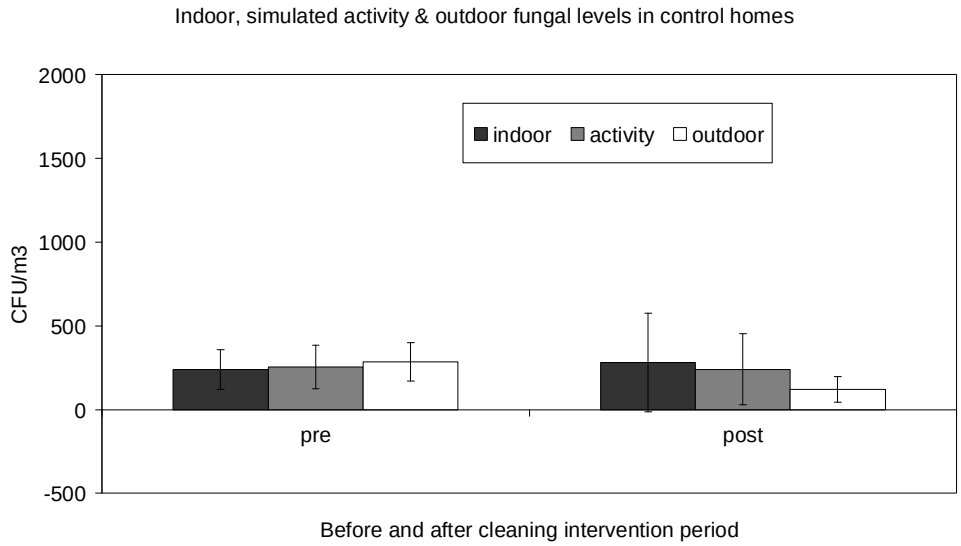

Figure 1. *Airborne viable fungal levels in control homes. Includes fungal levels indoors, levels subsequent to a simulated activity, and concurrent outdoor levels. Error bars indicate standard deviation.*

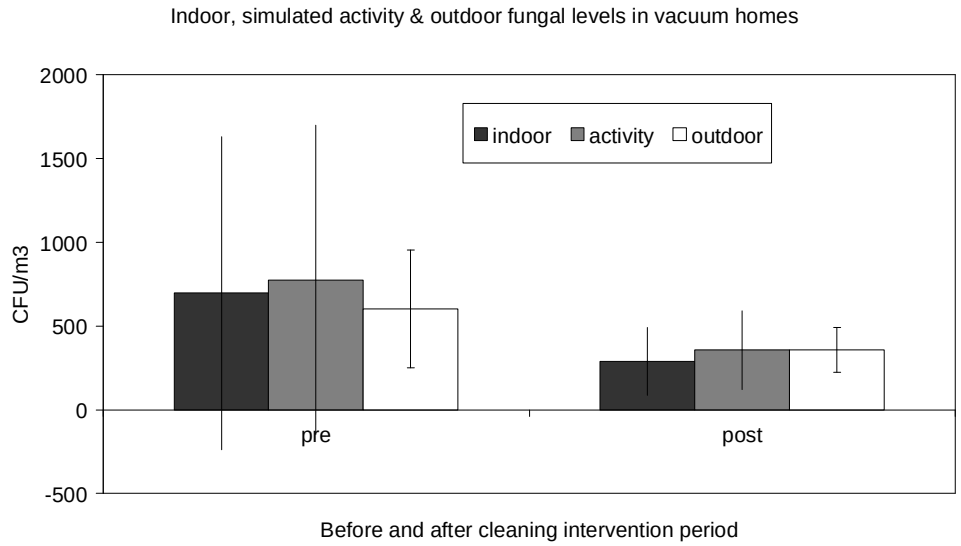

Figure 2. *Airborne viable fungal levels before and after vacuum cleaning intervention. Includes fungal levels indoors, levels subsequent to a simulated activity, and concurrent outdoor levels. Error bars indicate standard deviation.*

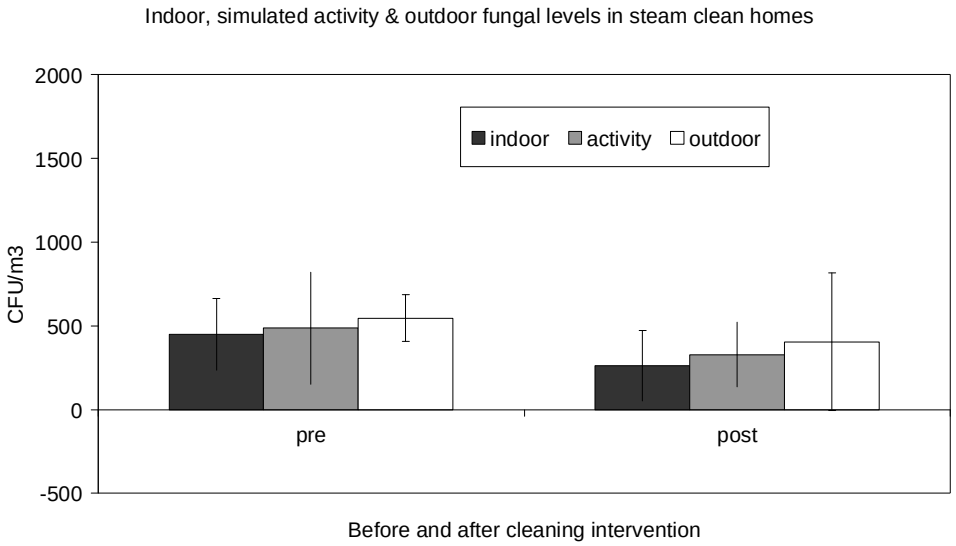

Figure 3. *Airborne viable fungal levels before and after steam cleaning intervention. Includes fungal levels indoors, levels subsequent to a simulated activity, and concurrent outdoor levels. Error bars indicate standard deviation.*

DISCUSSION

The most important findings of the paper should be put into perspective with prior knowledge. Possible sources of error that may affect the interpretation of the results should also be discussed.

CONCLUSION AND IMPLICATIONS

Do not simply repeat results or discussion, but provide some overall comments on the findings and their applicability in other settings or applications. The discussion of implications should tell the reader what the importance of the work is for others including researchers, building designers, owners and operators, or occupants.

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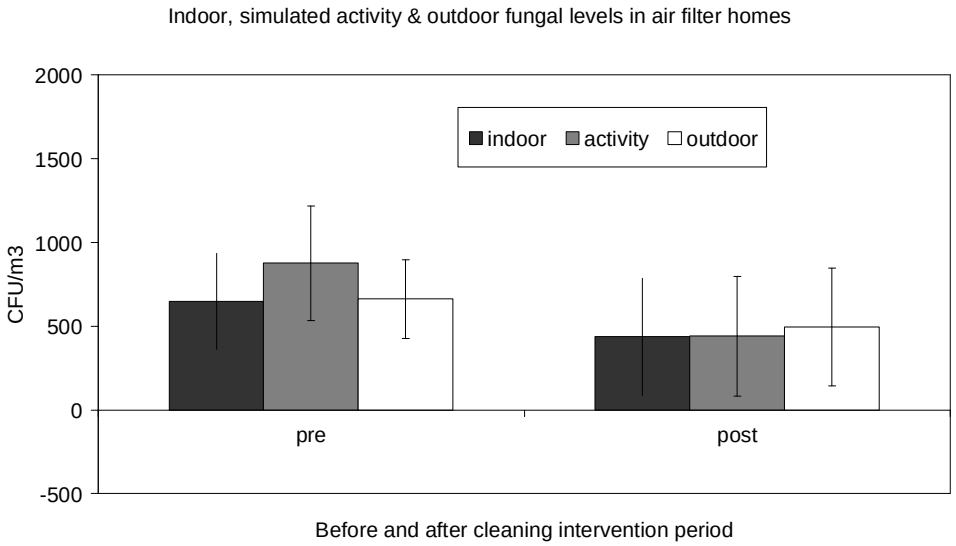

Figure 4. *Airborne viable fungal levels before and after air filter intervention. Includes fungal levels indoors, levels subsequent to a simulated activity, and concurrent outdoor levels. Error bars indicate standard deviation.*

Figure 5. *Difference in indoor fungal levels following simulated activity test .*

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