Environment International 51 (2013) 182–195

Contents lists available at SciVerse ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Predicting the microbial exposure risks in urban floods using GIS, building simulation, and microbial models

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ARTICLE INFO

Article history:
Received 22 August 2012
Accepted 24 October 2012
Available online 23 December 2012

Keywords:
Flood
Mould
GIS
Hygrothermal
Urban
Building simulation

ABSTRACT

London is expected to experience more frequent periods of intense rainfall and tidal surges, leading to an increase in the risk of flooding. Damp and flooded dwellings can support microbial growth, including mould, bacteria, and protozoa, as well as persistence of flood-borne microorganisms. The amount of time flooded dwellings remain damp will depend on the duration and height of the flood, the contents of the flood water, the drying conditions, and the building construction, leading to particular properties and property types being prone to lingering damp and human pathogen growth or persistence. The impact of flooding on buildings can be simulated using Heat Air and Moisture (HAM) models of varying complexity in order to understand how water can be absorbed and dry out of the building structure. This paper describes the simulation of the drying of building archetypes representative of the English building stock using the EnergyPlus based tool 'UCL-HAMT' in order to determine the drying rates of different abandoned structures flooded to different heights and during different seasons. The results are mapped out using GIS in order to estimate the spatial risk across London in terms of comparative flood vulnerability, as well as for specific flood events. Areas of South and East London were found to be particularly vulnerable to long-term microbial exposure following major flood events.

1. Introduction

London is one of the most flood-vulnerable major cities in Europe, with risks of tidal flooding from the Thames and fluvial and surface water floods from heavy precipitation. Major tidal floods in 1928 and 1953 caused significant damage to the city, whilst more recently the summer floods of 2007 saw 1000 London households flooded following heavy rainfall. It has been estimated that a 1-in-50 year rainfall event would lead to the flooding of 1 in 7 London buildings and damages of tens of billions of pounds (GLA, 2009). In addition, small, localised floods caused by broken water mains are also a regular occurrence. Climate change is projected to result in rising sea levels and an increased frequency of rain storms, which may lead to a greater frequency of flood events in London.

Flooding can lead to a number of health issues for building occupants. Mould, bacteria, and protozoa can grow or persist on flooded building surfaces, some of which can release harmful bioaerosols into the indoor air (Taylor et al., 2011), leading to potential respiratory problems. Building dampness is one of the key factors associated with the exposure to various microbial hazards. Microbial contaminants on indoor surfaces following flooding may also pose a health risk to occupants through direct contact, should they touch a surface that is contaminated with a flood borne pathogen. Occupants who choose to leave their flooded properties because of the risks present in damp properties may also experience increased health problems such as mental illnesses (Tapsell and Tunstall, 2008) related to their displacement. The duration of displacement may be prolonged following a flood; the 2007 floods in Hull resulted in over 10% of households remaining in temporary accommodation two years after the event (Hull City Council, 2009). The reasons for extended displacement can be complex, and include delays in remediation due to insurance issues, busy remediation companies, and the extent of the work required to return the dwelling to a habitable state. However, the amount of time taken to dry different buildings is one of the key issues effecting displacement. Therefore, understanding the duration of damp within buildings under different drying scenarios can help to predict the potential risk to occupants following a flood.

Heat, Air, and Moisture (HAM) models are tools used in building simulation to predict moisture performance, from individual materials, to building envelopes and whole-buildings. HAM models have been used in the past for simulating the impact of flooding on buildings (Blades et al., 2004; EU, 2007; Nicolai and Grunewald, 2006). In our previous study, simulations of the drying behaviour of a number of typical London dwellings indicated that there are differences in the drying rates of different dwelling types following a flood due to

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http://dx.doi.org/10.1016/j.envint.2012.10.006

the built form and building fabric construction and drying type (Taylor et al., in press). One of the key findings of this research was that modern purpose-built flats were more difficult to dry than detached or semi-detached properties, and that buildings with cavity walls insulated with glass fibre, or with an Autoclaved Aerated Concrete (AAC) inner leaf were more difficult to dry than those with solid brick or uninsulated cavity walls with a brick inner leaf.

The types of dwellings and their building fabrics vary throughout London, meaning that the results from our previous research can be applied spatially to determine the drying difficulty of different locations within the research area. Similarly, the depth of flood water during flood events will also vary spatially, meaning that simulations that take into account the depth of a flood event may be applied to models of specific floods in order to predict areas of vulnerability within London. Finally, the city population varies spatially in terms of its socio-demographic profile and population density, and therefore its vulnerability to health problems following a flood event.

The objective of this paper is to integrate the results of HAM building simulations with GIS-based building stock models and flood models in order to predict the locations within London that are particularly vulnerable to long-term damp following a flood event. Building on previous research, the drying behaviour of different London archetypical buildings will be simulated drying under different conditions and after floods of different heights. The mould model of Clarke et al. (1998) is used to predict the risk of mould growth on different surfaces within the flooded buildings and determine the total internal surface area presenting a microbial risk. The simulation results will be used to map both the comparative drying ability of the buildings in different locations by examining the drying time under the same flooding and drying conditions, and the actual drying behaviour after a specific flood event by taking the flood depth into account for individual buildings. Finally, areas which may be at high risk due to a high risk of floods, an abundance of slow drying buildings, social vulnerability, and population density are identified. The results of this analysis can be used to identify areas where the city may be particularly vulnerable to the effects of flooding due to the combination of built form, demographics, and flood risk.

2. Methodology

This research required combining a number of different data sources and models including building stock models, HAM simulations, GIS data, and flood models. For more information on the building stock development, HAM models used, and modelling methodology, readers are advised to refer to Taylor et al. (in press).

2.1. Building simulation

The building stock archetypes used in this study were originally developed by Oikonomou et al. (2011) and represent 15 of the most commonly occurring built form and dwelling age combinations within their research area (29% of the Greater London Authority household spaces). Some dwellings were not relevant, for example flats above ground level and those with shops underneath, as they would not be directly impacted by flood waters. The English Housing Survey (DCLG, 2008) was used to identify the most common building fabric types in each building archetype; in cases of cavity walls, both insulated and uninsulated walls were considered. Hygrothermal material data for the construction materials in the building envelopes were taken from the WUFI database (IBP, 2007), whilst information on glass fibre was taken from Hokoi and Kumaran (1993). A summary of the built forms, age brackets, and most common wall types can be seen in Table 1; for further information, readers are referred to Taylor et al. (in press).

The methodology for simulating the flooding and drying of the archetypes using HAM models has been previously described in Taylor et al. (in press); this paper expands on this initial work by simulating floods at a number of different flood depths. No simulation package was known to be available that would allow both the simulation of water movement into a structure using a pressure head of water, and the whole-building simulation of the internal and external drying of the building. Therefore, two separate HAM models were used to simulate the flooding and drying of the buildings: Delphin 5.6 (Nicolai and Grunewald, 2006) and the EnergyPlus-integrated UCL-HAMT (University College London Heat and Moisture Transfer) (EnergyPlus, 2008). Delphin was used to simulate the flooding of the wall and floor assemblies, whilst UCL-HAMT was used to simulate the drying of whole buildings. Two drying scenarios were considered:

- Comparative drying performance: the drying performance of building archetypes under the same drying conditions and flood depth was used to illustrate the difficulty of drying property types. In this case, buildings were modelled as being naturally ventilated buildings with their windows and internal doors open and no central heating following a flood of 0.5 m on January 1st. Abandoned buildings were modelled with all windows and internal doors closed and the heating turned off. A flood depth of 0.5 m was selected based on the modelled maximum height of a 1-in-20 year tidal flood risk for Hackney, East London
- Actual drying performance: buildings were simulated as being abandoned, with the windows and external doors closed following a flood on January 1st and July 1st. Buildings were modelled flooded to four different heights (0.1 m, 0.5 m, 0.7–1.0 m, and 2.0 m) to examine the relationship between flood depth and drying time. The range of flood depths (0.7–1.0 m) for the second highest flood was due to the presence of internal doors within the building; as the ceiling height varied in the different dwellings, the flood depth had to be shifted to accommodate the 2 m high door on internal surfaces, and ensuring that the airflow network remained consistent throughout all the flood depths. Buildings were modelled as being abandoned as it was assumed that the flooded homes would be evacuated or sealed following a major flood.

To simplify the model, cavities in the external wall and subfloor were modelled in certain assembly types by including a layer of air or insulation in the HAMT assembly. As a consequence, ventilation

Table 1
Simulated building archetypes, with age, built form, and modal wall types.

Building code	Age bracket	Built form	Modal wall types
H01	1902–1913	Terrace with large T	Solid brick wall and suspended wooden floor
H02	1914–1945	Simple terrace	Uninsulated brick/brick cavity Insulated brick/brick cavity
H03	1914–1945	Large semidetached	Uninsulated brick/brick cavity Insulated brick/brick cavity
H04	1960–1979	Purpose built	Uninsulated brick/AAC cavity Insulated brick/AAC cavity
H05	1902–1913	Simple terrace	Solid brick wall and suspended wooden floor
H06	1946–1959	Purpose built	Uninsulated brick/brick cavity Insulated brick/brick cavity
H07	1980–2008	Purpose built	Uninsulated brick/AAC cavity Insulated brick/AAC cavity
H08	1902–1913	Terrace with attic	Solid brick wall and suspended wooden floor
H09	1914–1945	Bungalow	Uninsulated brick/brick cavity Insulated brick/brick cavity
H10	1960–1979	Simple terrace	Uninsulated brick/AAC cavity Insulated brick/AAC cavity
H11	1960–1979	Purpose built	Uninsulated brick/AAC cavity Insulated brick/AAC cavity
H12	1914–1945	Purpose built	Solid brick wall
H14	1946–1959	Step linked terrace	Uninsulated brick/brick cavity Insulated brick/brick cavity
H15	1946–1959	Purpose built	Uninsulated brick/brick cavity Insulated brick/brick cavity