DEVELOPMENT OF A WEB-BASED SOFTWARE TOOL FOR PREDICTING THE OCCURRENCE AND EFFECT OF AIR POLLUTANTS INSIDE MUSEUM BUILDINGS

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Abstract

This paper describes the ongoing development of a software tool to assist museums, galleries, archives and libraries in dealing with air pollution damage to collections caused by pollutants from the external environment such as sulphur dioxide, nitrogen dioxide and ozone. The tool will provide information, advice and case studies on pollution damage and will have at its core a computer model to predict the performance of buildings in controlling external pollutants. It will estimate indoor/outdoor pollution concentration ratios from a range of building parameters, such as ventilation strategy and rate, interior layout and surface finishes. The software tool is being developed in close co-operation with museum partners and other potential end-users such as architects and engineers. On completion, the software tool will be available as a freely accessible website.

Keywords

preventive conservation museum buildings pollution ventilation

modelling internet java applet

INTRODUCTION

Air pollution is one of many complex preventive conservation problems facing those charged with the care of cultural heritage. Air pollutants have many different effects on a wide range of cultural heritage materials. Whilst the nature of these reactions are generally well-understood, less is known about the concentration and dose levels at which pollutants cause significant damage, and consequently what concentration standards should be specified for museum environments. Appropriate monitoring techniques have been developed to measure pollutants in the museum environment, however most are still costly and difficult for non-technical staff to set up and interpret results, particularly in the majority of organisations that do not employ conservation scientists.

This paper describes a research project ‘Innovative Modelling of Museum Pollutants and Conservation Thresholds’ (IMPACT) that is addressing these problems through the development of a novel internet-based software tool that will provide background information on pollution, to enable museums and other organisations with indoor cultural heritage, such as galleries, libraries and archives to (i) assess the potential threat to their particular collections from air pollution; (ii) determine what action may be needed and (iii) determine how well (or badly) their building performs in protecting their collection from pollutants either from outside or generated by sources inside the building itself. This latter task will be addressed not just by web pages of advice and information, but by an interactive pollutant model that will enable end-users to predict the indoor/outdoor ratio of various externally sourced pollutants in their building, and given the availability of external pollution data from national monitoring networks, to predict the indoor concentration of pollutants such as sulphur dioxide, nitrogen dioxide and ozone.

It is not intended that this model should replace the need to take pollution measurements, but that it should be used as a complementary tool having a role in situations where resources are not available to carry out measurements, or at the design stage of a new building or refurbishment, where the effect of different ventilation strategies, room layout, and indoor materials on indoor pollution concentration can be predicted. Use of the model could therefore lead to improved and more sustainable designs for museum buildings.

In order to ensure the practical usefulness of this tool the project is being undertaken jointly with museum and architectural partners who give an end-user perspective on the work of the universities and research institutions that are developing the software.

On completion the software tool will be available freely through the internet.

OUTLINE OF THE SOFTWARE TOOL: DESIGNING FOR END-USER NEEDS

The views and requirements of museum, architect and engineer end-users were sought through two project workshops. These took the form of a series of introductory presentations on the problems that the software tool could address, followed by extensive small-group discussions with the end-users on issues such as current knowledge of damaging pollutants, pollution control strategies, software features and the nature of the software/user interface.

The knowledge gained from these workshops was used to draw up a specification for the software tool and a plan for the website and pages (figure 1). One of the main outcomes of the workshops was that for most end-users the information pages would be as important as the model itself. Therefore the decision was made that the model should be embedded into these pages, so that an inexperienced user, with concerns about pollution issues could be guided through a series of steps, first to understand which parts of their collection are vulnerable to pollutant damage and with what likely effects, with examples; what pollutant concentrations cause these effects and what are considered 'safe' levels. Users would then be introduced to the pollution model, which would guide them in estimating the indoor/outdoor ratio of damaging pollutants such as ozone, sulphur dioxide and nitrogen dioxide in their building. At this point they would be able to access further information allowing them to compare the estimated levels with known thresholds and standards, and offering remedial and preventive strategies with case studies of actual museum buildings. The IMPACT software tool is being designed to address specifically the questions that arise for museum-type buildings. It can be used as a design tool for new building and refurbishment projects. Different ventilation strategies and building designs can be modelled to see their effect on internal air pollution. It can be used to identify locations within a building where the lowest and highest pollutant concentrations are likely to be found. Researchers interested in the long-term effects of pollutants may even be able to use it to model historic pollutant concentrations inside museum buildings, useful in determining overall pollutant dose for objects.

An important part of the development of the website is analysis of potential users so that its usefulness to them can be optimised. Potential users had been identified as architects, engineers, conservators and conservation scientists. From the end-user workshops it was evident that of these groups, the most frequent and numerous users are likely to be conservators and conservation scientists with responsibility for collections care, but lacking easy access to pollution monitoring equipment or techniques. Most museums monitor temperature, humidity and light levels quite carefully but it will only be in the larger institutions that monitoring of indoor pollution levels is additionally carried out.

A typical user is one who does not have much experience in modelling pollution levels through the use of equations and computer simulation. It was therefore decided that the computer model should be simple to use, invite exploration and be educational so that users would gain a greater understanding of the relative importance of the different parameters which determine pollution levels in a building and be helped to make informed decisions on how to control the museum environment.

The web-based tool is being consciously designed not to reproduce simply the functionality of other existing computer models. Comprehensive air pollution dispersion models for buildings are already available and can be downloaded from the world wide web, for example CONTAMW, developed by the American National Institute of Standards and Technology and COMIS, developed by the Lawrence Berkeley National Laboratory (Haghighat and Ahmed 1996). A model such as CONTAMW requires a fair degree of proficiency in the use and interpretation of computer simulation models. The IMPACT model, on the other hand, is being designed partly for people who would find such computer models daunting or too time consuming to use but who still need answers to questions on pollution levels inside their buildings. A web-based model has the advantage of running on any computer platform via a web browser and does not require support by any other installed software. The programme is being written as a Java applet using version 1.1 which is compatible with modern web browsers without the need to download extra plug-ins.

In setting out to make the programme simple and intuitive to use, the perceived payoff will be a greater number of new and repeat users. It should be possible to use the programme without having to read extensive help pages. Default inputs will be provided so that the program will always produce an output even while the user is learning how to use it.

SCIENTIFIC BASIS OF THE IMPACT POLLUTION MODEL

It has long been known that the concentrations of reactive pollutants such as ozone, sulphur dioxide and nitrogen dioxide, even in buildings without any pollutant filtration, are generally lower than in the outside air (Spedding, 1969). This is because indoor surface materials act as pollutant sinks, adsorbing and reacting with gases and so removing them from the air. A building with a low air change rate and a high internal surface area of appropriate materials protects objects in a collection from the damaging effects of reactive gas pollutants.

The extent to which a solid surface reacts with a gas is quantified by the *deposition velocity* v_{dep}. This can be thought of as the flux to a surface of reactive gas in terms of volume of gas (m^3) to area of surface (m^2) per unit time (s). As such it has units of $m^3\ m^{-2}\ s^{-1}$, which upon dimensional analysis reduce to $m\ s^{-1}$, i.e. units of velocity. Deposition velocities are specific to particular gas-surface interactions. For instance, a very reactive gas such as ozone on activated carbon has a high deposition velocity whereas a less reactive gas such as nitrogen dioxide on a relatively inert material such as glass has a much lower deposition velocity. Deposition velocities both indoors and outdoors have been measured in laboratory studies for many gas-surface interactions, (see for example Sehmel 1980, Coburn et al 1993). It is a major undertaking of the IMPACT project to measure the deposition velocities of typical museum interior surface materials to construct a database of reference data for use in the IMPACT model. Measurements are being made for sulphur dioxide, nitrogen dioxide and ozone and at a range of relative humidity (RH) values: 30, 50, 70 and 90% RH, because of the RH-dependence of v_{dep} (Judeikis and Stewart 1976). Work is in progress to model mathematically the relationship between v_{dep} and RH. This will enable the use of existing literature data in the database of v_{dep} values and reduce the number of measurements required to characterise the deposition behaviour of museum materials. These aspects will be described in subsequent publications.

The pollution model is based on a simple steady-state deposition model that can predict the indoor behaviour of important reactive pollutants that have only external sources. It is assumed that gas-surface (heterogeneous) reactions are the most significant for these reactive pollutants. However, gas-gas (homogeneous) reactions that can take place indoors are also being investigated and where they prove to be significant, they will be included in the model.

A steady state rather than dynamic model has been adopted because the nature of air pollution damage to materials is thought to proceed by an integrated dose law (Brimblecombe 1996). Thus, the overall dose is given by concentration x time and so the same dose can be arrived at by exposing an object to 1ppb for 100 years or 10 ppb for 10 years. It is well known that the rate of pollutant damage is affected by factors such as temperature and relative humidity, but in the museum environment, where efforts are made to stabilise these conditions, it can be reasonably assumed that under given RH and temperature conditions, damage from pollutants will be proportional to the dose a material or object receives. Museum personnel must therefore consider long-term trends in pollutant behaviour if they wish to protect objects from pollution damage for subsequent generations. Short-term variations that as occurs in minutes or hours can be useful in identifying pollutant sources, but are not necessarily a good guide to long-term effects on objects, and are not provided for in the IMPACT model. The supporting website associated with the IMPACT model includes information on accepted limits for pollutants in the museum environment above which the objects in a collection are put at risk. For some gases, e.g. ozone, the levels must be very low if objects are to be preserved for periods as long as hundreds of years. (Cass et al, 1991). Limits have often been set at what was thought to be achievable given existing technologies and ambient conditions and are not necessarily based on evidence from the deterioration of materials (Blades et al, 2000).

The initial stage of the IMPACT model has been developed as a single zone model, where the unit being modelled is a single room inside a building, or a building that consists of a single zone, such as the Sainsbury Centre for Visual Arts, Norwich, UK. Museum buildings of this type are rare but this relatively unrealistic representation of a building can be useful for reaching a qualitative understanding of the relative importance of various building parameters in determining the pollution concentration.

The construction of a simple model in the first phase of the project facilitates the design of the computer interface that the model operates under. This was an important aspect of the project: the functionality and user-friendliness of the model was to be refined and improved through the participation of the user group of conservators, scientists, engineers and architects. Therefore it was necessary to have a simple working model and interface in existence for the user group to try out and comment on. The user group was brought together initially through two workshops where the aims of the project were described and an early version of the model demonstrated. Their comments and input were drawn up into a specification for the software tool and used in the design of a working version of the model which was made available for their testing through a password-protected website.

The intention is to go on to design a more complex model that can better deal with many roomed and multi-zoned buildings. This will involve further development of the ventilation modelling in particular, but will be able to draw extensively on what has been learnt about the computer interface and its user-friendliness from the single zone model.

Single zone model – theoretical basis and interface design

The concentration of a pollutant in the air of a room can be calculated from a mass balance equation that takes into account the amount of contaminant in the air entering and leaving the room and any reduction due to deposition on the internal surfaces of the room. For the IMPACT model we have neglected the possibility of internal sources of pollutant and only consider the equilibrium condition, in this case the equations for a single zone reduce to (Weschler et al, 1989)

$$I/O = ach/(v_{dep}(S/V) + ach) \qquad (1)$$

where I/O is the concentration indoor/outdoor ratio of a particular pollutant gas, v_{dep} is the deposition velocity of the surface materials in the building, S is the area of the internal surfaces of the building, V is the buildings volume and ach is the air change rate of the building.

The model calculates the indoor/outdoor ratios rather then the absolute value of a pollution contaminant in a building. The IMPACT website will provide links to national monitoring network sites giving outdoor pollution levels for cities so that the ratios can be converted into absolute values. It is also possible to make rough estimates of pollution levels of some gases from models that categorise the environment surrounding a building in terms of human population, traffic density etc.

Equation (1) assumes that a pollutant gas once absorbed by a surface material does not desorb at a later date. This is a reasonable assumption for reactive gases, though in the case of nitrogen dioxide it is known that surface reactions can lead to the re-emission of the relatively inert gas nitrous acid (Spicer et al, 1993). The programme will adjust the v_{dep} value of the gas-surface interaction, based on the relative humidity input, as described in the previous section.

In order to calculate the value of I/O using Equation (1) the model needs the user to input the dimensions of the building, the average internal temperature, average relative humidity, the indoor surface materials and the buildings ach. In order to keep the program as flexible as possible the program will offer different ways of specifying certain parameters, so for example air change rate can be input directly if known, but if not the building fabric has to be characterised on some scale to give a rough estimate of its value. The user specifies the materials which cover the internal surfaces from a menu for the walls, floor and ceiling separately. The programme calculates an average v_{dep} for the building from the deposition velocity of the materials and the proportion of the internal surfaces they cover. Figure 2 shows a prototype interface for the single zone model. The user selects or types in values in the input side of the programme under the headings Environmental and Room properties. The model's calculated outputs are in the form of numerical values under the heading Output and a graph. The graph shows the indoor/outdoor ratio of NO_2 for a range of air change rates centred on the value that the user has input. The user can easily experiment with altering the input values and recalculating the outputs. Alternative methods of showing the results, such as colour shading according to concentration are also being explored. These will be particularly useful in the multi-zone model, where they can show variation in concentration among rooms.

Multi-zone model

A typical room will exchange air with other rooms in a building as well as the outside air and in such a situation a multi-zone model is required. The model needs to calculate the air flow pattern in the building which determines how contaminants are dispersed amongst the rooms. Parameters such as the air change rate between rooms or zones are not likely to be known by the average targeted user and could be expensive and time consuming to measure. Although a conservator may have more knowledge on the airflow patterns in their building when they have a well-documented mechanical ventilation system installed.

The multi-zone model is being designed to estimate air change rates from data that conservators will know or can easily collect. For example, the average temperature of rooms, the number of windows, doors and other openings between rooms, their dimensions and their physical condition (whether tight fitting modern construction or more loose fitting). Another important parameter, the outdoor wind speed can be estimated from factors such as the urban setting of the building. As in the single zone model the user selects the type of surface materials found in each room so that the model can calculate an average deposition velocity for the room and the air contaminant levels relative to the outside air. The aim is to develop a model simple enough to use that the user is encouraged to experiment with the input parameters and so decide on their relative importance in determining the levels of indoor air contamination. Beyond a certain point an increased level of complexity in the computer model could not be justified or be regarded beneficial when the aim is to direct the user to the correct strategy for improving the museum environment.

CONCLUSIONS

This paper has presented work that is not yet complete, but it has discussed the aims and methodology by which the IMPACT software tool is being developed. It is intended that this approach, with the close co-operation of research organisations and universities with end-users will result in a scientifically valid and practical model and software tool. As work progresses further information on the development of the tool will be posted at the UCL Centre for Sustainable Heritage's website www.ucl.ac.uk/sustainableheritage, which will eventually host the final, freely available software.

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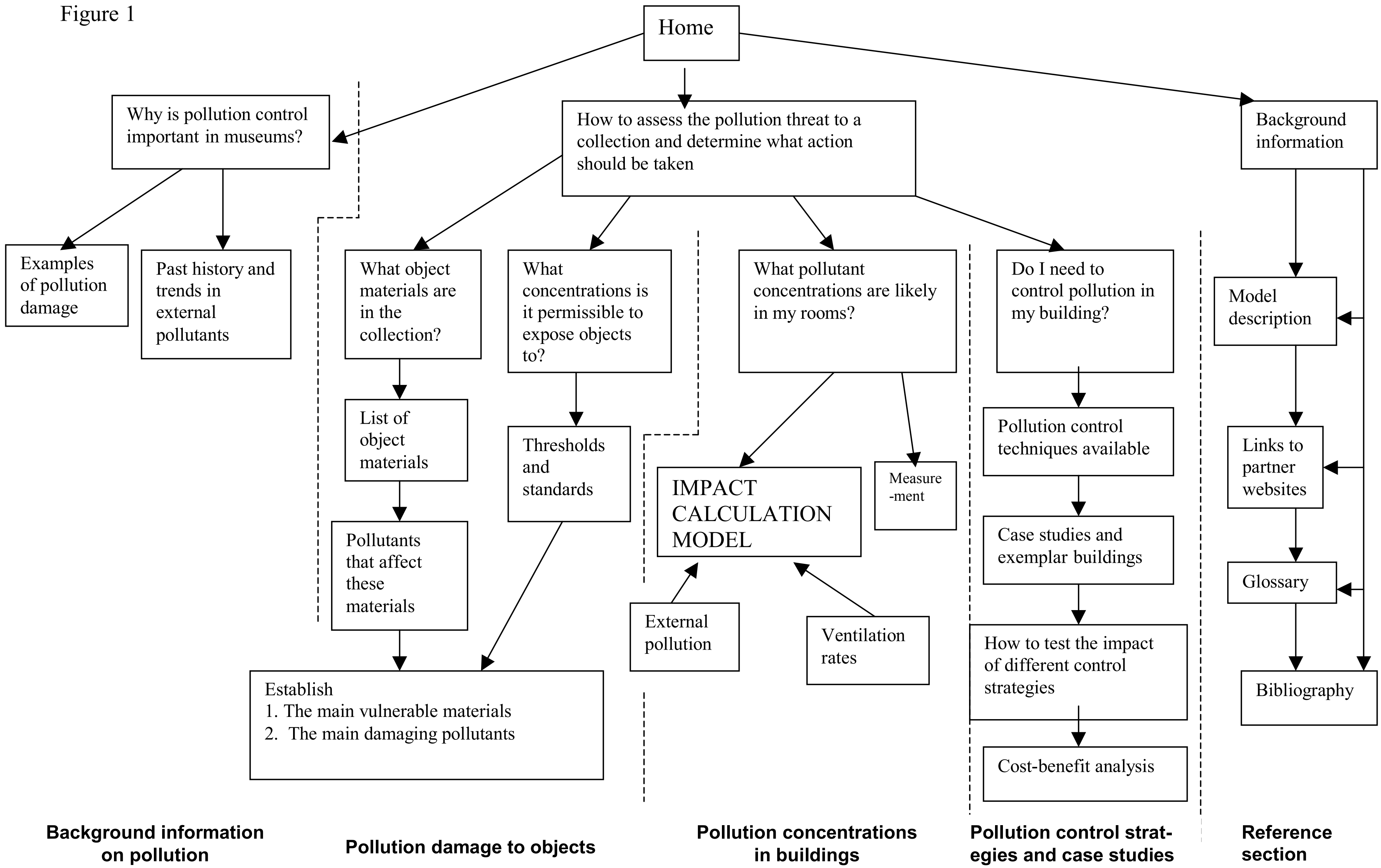
[3431 Words]

Figures Captions

Figure 1. Schematic diagram of the planned layout of the IMPACT website.

Figure 2. Screen image of the prototype single zone model, with graphical output.

Figure 1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