Protocol and Management Information System for Indoor Air Quality Assurance in the Refurbishment of Office Buildings

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ABSTRACT

Refurbishment activities currently account for more than one-third of the total construction output in the EC and is projected to grow stronger with the ageing of buildings and the positive views on the economic viability and environmental advantages of retaining buildings. There is concurrent concern expressed over the health effects and loss in productivity resulting from the sick building syndrome; indoor air quality (IAQ) being acknowledged as a main cause of this syndrome.

Refurbishment work is uniquely different from new build work. Substantial demolition and removal of existing materials is involved often without the guidance of "as built" information. Buildings are often occupied during construction work; building operatives and occupants are immediately exposed to high episodic doses of pollutants from demolition and from newly installed materials. The extent of refurbishment work and it's potential for causing IAQ problems needs to be addressed as the health and productivity of building operatives and occupants can be adversely affected by such work.

The research project developed a Protocol and supporting Information System to pre-empt, prevent, mitigate, monitor and control IAQ problems at every stage of a refurbishment project life-cycle.

INTRODUCTION

The combined effects of an ageing building stock in the EC, rapid developments in building technology and office automation and, rising occupiers requirements have provided strong impetus for building refurbishment activities. This trend is expected to continue unabated as refurbishment continues to be viewed positively as a means of conserving resources and a cost-effective way of providing a new economic life to structurally sound but functionally and technologically obsolescent buildings.

Building refurbishment work differs significantly from new build work. There is substantial renewal of parts of the existing fabric and furnishings often without the guidance of "as built" information. Buildings are often occupied during refurbishment work, necessitating the continuous operation of services in the building.

Occupants and building operatives will be immediately exposed to high episodic doses of pollutants from the construction process and materials either from the work front or through the HVAC systems. Refurbishment work potentially create indoor air quality (IAQ) problems, which is acknowledged as a main contributory cause of the sick building syndrome.

Very little documented research has to date been carried out on the vagaries of refurbishment work; even less is done on the management of such works for IAQ assurance. The research project brought together a multi-disciplinary and multi-professional team to address and contain the IAQ problems resulting from refurbishment work by establishing a Refurbishment Protocol and an Information System to support implementation of the Protocol.

TECHNICAL DESCRIPTION

The research addresses the strong refurbishment-IAQ link and seeks to establish a protocol and supporting management information system to ensure the quality of the indoor air during the execution of refurbishment work and in the subsequent use and occupation of the refurbished building.

The main causes of indoor air problems which act in combination in refurbished buildings was identified in an IAQ cause and effect diagram shown in figure 1.

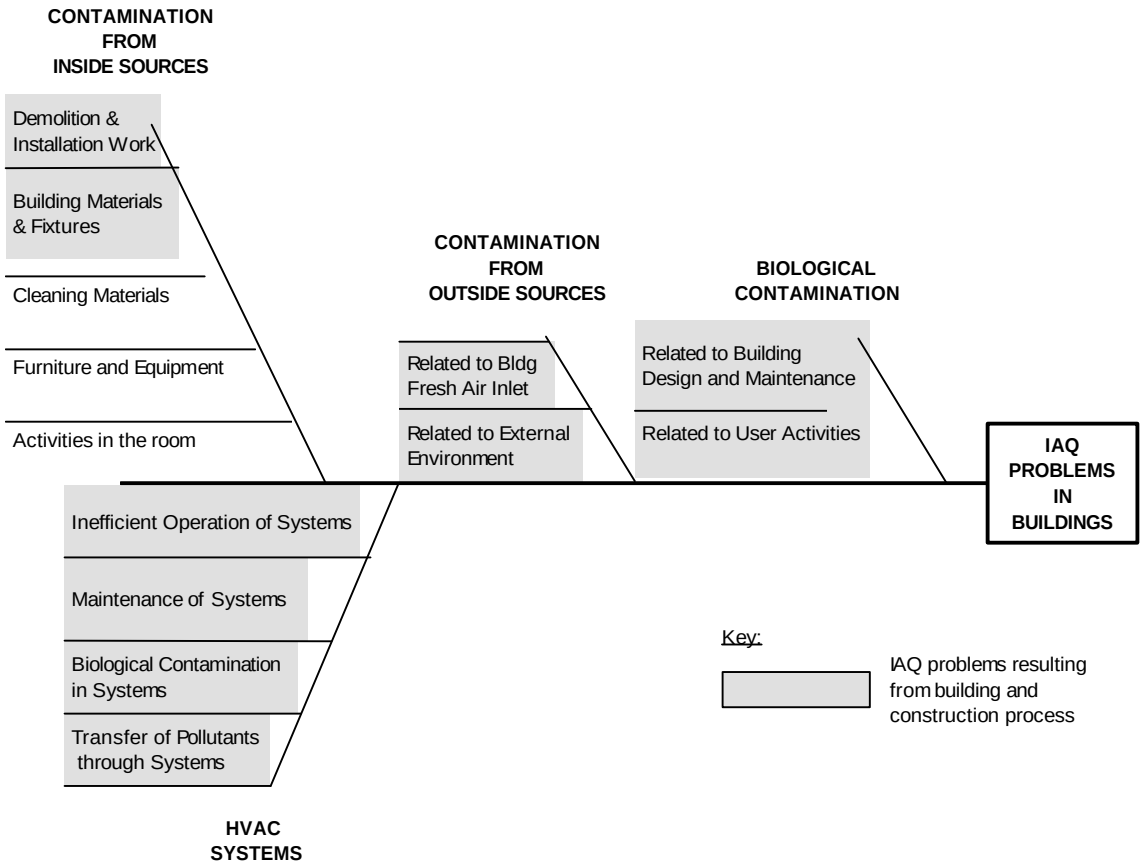

Figure 1: IAQ Cause and Effect Diagram

The scope of investigation in this research project centred primarily on IAQ problems resulting from the building and construction process. The other IAQ problems are caused mainly by occupiers/users and can be mitigated in a complementary educational programme on the proper use and occupation of buildings for IAQ assurance.

The research methodology recognises that process control in construction is the core of quality assurance. This concept was applied to a refurbishment project life cycle to achieve indoor air quality assurance. The several acknowledged phases involved in a building life cycle was used as a framework to define problems, provide structured information, set procedures and audits for IAQ assurance throughout each phase of the building refurbishment process; see figure 2.

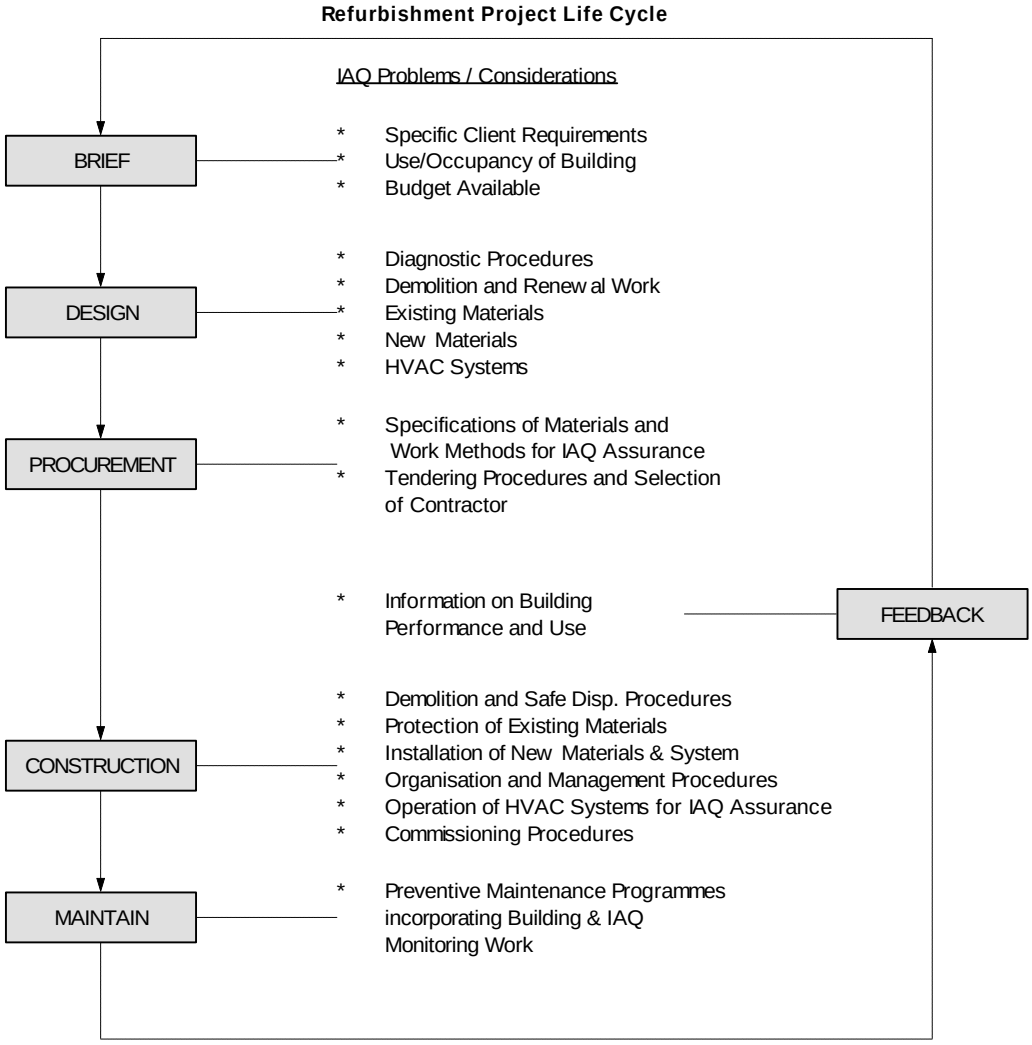

Figure 2: Refurbishment Project Life Cycle

Three main research tasks collectively sought to control IAQ problems resulting from refurbishment through the:

1. Development of methods to determine the "as is" building and indoor air quality condition in order to plan control measures for pollutants arising from the demolition and disposal of existing materials.
2. Development of methods to control pollutant levels of materials by treatment at source, organising and sequencing of the work and design and operation of HVAC systems together with a system for monitoring and evaluating the IAQ during refurbishment work.
3. Establishment and testing of a refurbishment protocol for IAQ assurance and accompanying instruction manuals and development of an information system to support implementation of the protocol.

The main tasks, sub-tasks and interdependencies between tasks is illustrated in figure 3.

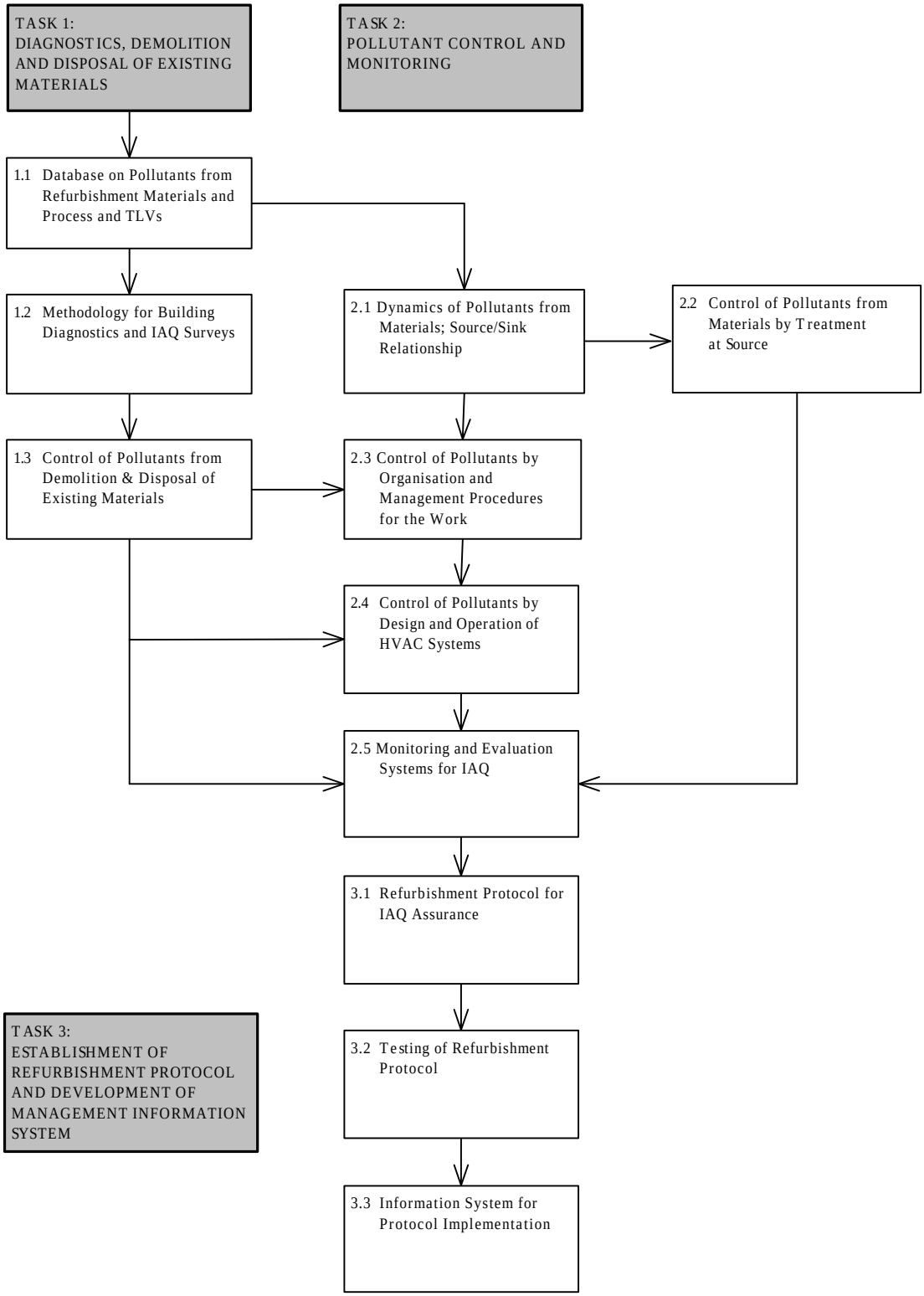

Figure 3: Main Tasks, Sub-tasks and Interdependencies between Tasks

Task 1: Diagnostics, Demolition and Disposal of Existing Materials

The main objective of Task 1 was to assess and develop control strategies to limit the IAQ problems resulting from the existing building, its materials and associated demolition and removal work. Task 1 was structured into three sub-tasks.

Sub-task 1.1: Data Base on Pollutants from Refurbishment Materials and Process

The objective of this sub-task was to create a data base on pollutant characteristics of refurbishment materials and the refurbishment process with provisions for updating the data as an on-going activity after the project.

Literature Review

19 main material groups as listed in table I were investigated in a literature review. Pollutants arising from demolition and disposal of existing materials and plant during refurbishment as listed in table 2 were investigated for their pollutant characteristics. In addition, pollutants arising from HVAC-systems were investigated; these included components such as heating and cooling coils and heat recovery exchanges.

Table 1: Material Groups Investigated

Material Groups
Additives and Solvents
Asbestos cement
Bitumen
Brickwork
Cloth
Concrete
Fibre boards
Glass
Insulation material
Jointing & Caulking Materials
Metals
Natural stone
Paints & Coatings
Paper
Plaster & Screeds
Plastics
Rubber
Wood
Wood Preservatives

Table 2: Pollutants from the Refurbishment Process Investigated

Pollutants
1. Concrete dust. 2. Natural stone dust. 3. Gypsum plaster dust. 4. Mortar dust. 5. Ceramic tile dust. 6. Hard / soft wood dust. 7. Wall paper dust. 8. Composite board dusts. 9. Fibreglass particles. 10. Asbestos. 11. Soot and carbon dusts. 12. Ferrous metals (including rusts). 13. Non-ferrous metals (including rusts). 14. Fumes resulting from welding / cutting ferrous & non-ferrous metals. 15. Plastics. 16. Tars and bitumen's. 17. Fibres from soft furnishings, carpets, curtains, blinds etc. 18. Microbiological hazards, spores, moulds. 19. Paints, 20. Fume / splashes from fuels, petrol, diesel, paraffin, 21. Exhaust fume gasses from petrol and diesel engines.

The Database

The database consists of datasheets on pollutants from building materials and processes with separate sheets for each pollutant from each material. Materials and construction processes were classified according to the SfB-system; their chemical composition; classifications of pollutants emanating and their health effects and, permitted Threshold Limit Values (TLV's) if known. Non-existent information on pollutant behaviour was built up by expert extrapolation and field and, laboratory sampling and analysis. The information is organised in a computerised standardised format which enables retrieval by key-words.

In all, a total of 170 materials, 21 construction processes and, pollutions arising from 13 component parts of HVAC systems were investigated. The database covers 370 datasheets, consisting of over 1,300 pages. All datasheets are available on hardcopies and in WP 6.0 disks.

Sub-task 1.2: Methodology for Building Diagnostics and IAQ Surveys

Sub-task 1.2 sought to develop a combined methodology and procedure for building diagnostic and IAQ surveys to be executed prior to commencement of refurbishment

work to determine the 'as is' technical and IAQ condition of the existing building. This information is required to facilitate refurbishment design and planning and to enable pre-emptive actions to control existing IAQ problems and to mitigate any problems which could result from the refurbishment.

Inspection Proforma for Determining 'As Is' Building and IAQ Condition

An inspection proforma for assessing the Building and IAQ condition of the building to be refurbished was developed. The Building Survey was based on the methodology developed for the Dutch Housing Condition Survey, whilst the IAQ Survey was based upon current practice adopted for such investigations.

The proforma consists of three parts:

1. A General part, in which global information on the building is determined;
2. A Building Diagnostics Survey, where the technical "as is" condition of the building components is ascertained;
3. An IAQ questionnaire survey on occupiers.

Sub-task 1.3: Control of Pollutants from Demolition and Disposal of Existing Materials

Sub-task 1.3 sought to identify, and investigate the pollutants most commonly encountered during the demolition stage of refurbishment work and to establish guidelines for the assessment, monitoring and control of these pollutants during demolition and subsequent disposal from site.

Pollutants in Demolition Work

A 'pollutant think-tank' was held on-site at a major refurbishment project in London; the participants were construction staff who had gained many years direct experience of working on a wide range of complex refurbishment projects. Pollutants in the form of solids, liquids and gases were considered and those pollutants / irritants that are commonly encountered during the demolition stage of refurbishment work were identified. (Refer Table 2 of subtask 1.1 for pollutant list.)

Specifications for Controlling Pollution from Demolition and Disposal of Existing Materials

Two key stages were identified in the sequencing and scheduling of demolition work to control pollution arising viz:

- Sequencing and scheduling before the commencement of any demolition work;
- Sequencing and scheduling during the demolition operations.

The specifications for Sequencing and Scheduling Demolition operations covered aspects ranging from ‘ Competent Person’; plant and machinery operation, disposal of demolition waste and communication procedures.

Task 2: Pollutant Control and Monitoring

The overall objectives of task 2 were to assess and develop control strategies to limit IAQ problems resulting from newly installed materials and from the interactions between existing and new materials, and to develop methodology for monitoring and evaluating IAQ during and after execution of the refurbishment work. This task was structured into 5 sub-tasks.

Sub-Task 2.1: Dynamics of Pollutants from Materials; Source/Sink Relationships

The objectives of sub-task 2.1 were to determine and identify the pollutants from newly installed materials, their source/sink relationships with existing materials in buildings, and to set limit values for these pollutants.

Materials Investigated

A selection of 20 materials was made to determine and identify the pollutants from these materials, and their source/sink relationships with existing materials in buildings. The criteria for selection was the known intensity and health effects of pollutants from the materials and the frequency of use of the material in building refurbishment work. Volatile Organic Compounds (VOCs) were the main consideration, but other types of pollutants were also taken into account. As Total VOCs (TVOC) had no scientific validation as an indicator of indoor air problems, and was rather a technical device than explanation for adverse health effects, single VOCs were used as the main consideration to determine health hazards.

The 20 materials selected for investigation were as follows:

1. Silicone caulking (dry conditions and waterproofing)
2. Polyurethane caulking
3. PVC-containing wallpaper)
4. Chip board
5. Flooring adhesive
6. Wall covering adhesive, plastic material (PVC)
7. Parquet glue (parquet adhesive)
8. Glues for (glazed) tiles
9. Man-made fibers (mineral wool and glass wool)
10. Asbestos (fibres)
11. Plastic paint (water soluble, solvent-dilutable)
12. Paint with mineral spirit solvent (aliphatic, terpentine)
13. Gypsum board
14. Alkyd paint with mineral spirit solvent
15. Urea formaldehyde lacquer (2-component)
16. Cementitious floor leveling compound
17. (Cellulose) Lacquer with aromatic thinner
18. Cement based filler (putty with additives)
19. PVC floor covering
20. Carpeting (with glues)

The Source/Sink Dynamics of each material was fully investigated and described. As materials emit a large variety of chemical compounds, most of which are only of theoretical significance, the most important pollutants were selected to achieve feasibility of measurements and analysis. The criteria for the selection of the pollutants were:
- abundance of the chemical compound;
- health hazards;
- high toxicity (e.g. isocyanate), or carcinogenity (e.g. benzene);
- experimental knowledge from field and laboratory measurements;
- decay time of chemical compound.

Information concerning emission rates was found to be very limited and sink phenomena lacking. Major testing in laboratory settings was hence instituted to determine the dynamics of pollutants especially concerning sink phenomena.

Emission Testing

A three step technical approach was used in the testing:
1. Measurements of actual emissions from single materials, yielding source behavior, method: FLEC; (Field and Laboratory Emission Cell)
2. Measurements of whole material systems, yielding source/sink relationships, method: Chamber tests and FLEC;
3. Measurements of experimental sites, for verification of results of simulations, methods: FLEC and other field sampling.

Emission Model for Pollutions from Building Materials

A mathematical model was developed from the empirical studies on source/sink dynamics of materials. The aim of this model is to calculate the concentrations of emissions into the indoor air by building materials. The knowledge of concentrations is needed for example to estimate the time when it is safe to occupy the premise.

The calculation procedure requires the following input information:
- the surface area of the emitting material;
- volume and air exchange rate ;
- refurbishment program including materials;
- schedule of work;
- knowledge of the pollutants from materials;
- the limit values of pollutants.

The testing of the mathematical modelling was done with experimental refurbishment construction site measurements and, measurements in chamber test. Within the limits of accuracy in practice, the prediction of concentrations of VOC components was possible with the model developed. Chamber and FLEC-tests would however, have to be carried out for every new material or combinations of materials to determine the parameters of Ef_0:

emission factor, when t = 0 (μg/m^{2}h); k: slope of concentration-time-graph at the beginning and, s: slope of concentration-time-graph in 'steady state' used in the model.

Sub-Task 2.2: Control of Pollutants from Materials by Treatment at Source

The objective of sub-task 2.2 was to establish the conditions and specify the methodologies and guidelines for pro-actively controlling pollutants from newly installed and existing materials to within TLVs by treatment of the materials before installation work.

Emission Classifications of Material Groups

Based upon existing literature review, material groups were classified into three categories of high, medium and low pollutive behavior based on the following criteria:

- Low emission material: maximum TVOC emission factor = 40 μg/m^{2}h
- Medium emission material: maximum TVOC emission factor = 100 μg/m^{2}h
- High emission material: emission factor is hundreds of μg/m^{2}h

Conditioning of Materials

Each of the 20 materials investigated in the project (see task 2.1 for list of materials) was reviewed in terms of the emission characteristics of the material and its use factors in the building to develop IAQ control and, operatives protection measures. IAQ Control Data Sheets were produced for each of the 20 materials, these covered a description of Potential IAQ Problems and IAQ Control Measures including:

- Material Handling Requirements
- Material Storage Requirements
- Working Procedures
- Personal Protective Equipment Required

Recommendations for Control of Pollutants from Materials

Recommendations formulated include material selection with regard to source/sink dynamics; ten 'commandments' in respect of material selection and, guidelines for material substitution.

Sub-Task 2.3: Control of Pollutants by Organisation and Management Procedures for the Work

The objective of sub-task 2.3 was to establish the conditions and specify the methodologies and guidelines for control of pollutants resulting from refurbishment work to within TLVs through organization and management procedures for the work.

Organisation (O&M) Procedures

A generic description of office buildings, by construction elements and age was produced to provide an overview of the existing materials which could be encountered during refurbishment.

Flow charts for the O&M procedures which are to be instituted before and during the construction work were developed in addition to Specifications for the following:
- Conditions for Working with Pollutant Operations
- Waste Disposal and Material and Equipment Transportation
- Housekeeping Procedures on the Work
- Housekeeping Procedures outside Work Area
- Procedures of Communication in Refurbishment Work

Sub-task 3.4: Control of Pollutants by Design and Operation of HVAC Systems

The objective of task 2.4 was to specify the methodologies and guidelines for design and operating the HVAC systems to control and limit the spread of pollutants from refurbishment work.

Design and Operation Specifications for HVAC Systems

From a combination of practical experience, literature review, case studies and engineering calculations made, full design and operation specifications for HVAC Systems were developed. These covered the following aspects:
1. Diagnostic and Determination of the Existing HVAC System
2. Design of the HVAC System
3. Use of the HVAC during the refurbishment work
4. Procurement and construction
5. Maintenance
6. Documentation

Guidelines for design and operation of HVAC Systems to control pollutants spread covered the following:
1. Negative pressurization
2. Positive pressurization
3. Dilution
4. Local air cleaners
5. Local exhaust
6. Air Distribution; Displacement Ventilation
7. Temporary HVAC (Supply and Return)
8. Temporary HVAC (Supply Only)
9. Temporary HVAC and Local Exhaust

Commissioning Procedures for HVAC Systems

The commissioning procedures developed includes functional performance testing and documentation in connection.

Sub-task 2.5: Monitoring and Evaluation System for IAQ

The objective of sub-task 2.5 was to develop and specify a system for monitoring and evaluating IAQ before, during and after refurbishment operations to assess the effectiveness of pollution control strategies and initiate corrective action where necessary.

The system for monitoring and evaluating IAQ during refurbishment was developed along the following lines of actions.
1. Preventive Measures;
2. Monitoring and Control during demolition and refurbishment;
3. Monitoring and Control after refurbishment;

Manuals have been provided on the implementation of the measures and interpretation of the results of the measures, some of which included questionnaire surveys.

4. Supporting Documentation for IAQ control and Monitoring.

To augment the IAQ Control and Monitoring System developed, a list of supporting documents were developed or identified as required, the latter documents being build up from external information sources such as equipment suppliers and material manufacturers.

Task 3: Refurbishment Protocol and Information System

The main objectives of Task 3 were the development of a Refurbishment Protocol and a Management Information System for Indoor Air Quality (IAQ) Assurance. This task has received input from all preceding tasks. The research work was divided into three sub-tasks.

Sub-task 3.1: Refurbishment Protocol for IAQ Assurance

The objective of sub-task 3.1 was to develop the Refurbishment Protocol for IAQ Assurance in the framework of the building life cycle. A secondary objective of the sub-task was preparing a training manual to guide implementation of the protocol.

Refurbishment Protocol / Protocol Design

The protocol has been developed on the following basis:

- Any party in the construction and development process can use the protocol at any phase in the construction and development process; the decisions in each phase are hence to a certain extent, stand-alone decisions;
- The protocol visualises decision hierarchy;
- Decisions are allocated to parties, whose roles in the organisational forms depend on the procurement method.

If the building is not occupied during refurbishment, the protocol will focus on safeguarding IAQ for construction workers and for subsequent building occupants after hand-over of the refurbished building. If the building is occupied during refurbishment, the protocol additionally aims at safeguarding IAQ for the building occupants during refurbishment work.

The protocol consists of a series of flow charts indicating the decisions to be taken at the various phases of the construction and development process including related documents. Decisions are supported by underlying flow charts which visualises the different elements of a decision. An explanation has been given of the contents of each decision and document.

In the automated version of the protocol in the information system, the flowcharts, the table and explanations have been integrated. Documents referred to are, if available, retrievable. Decisions are presented on screen including necessary explanations and available information. If decisions consist of sub-decisions, the user is guided through all required decisions.

Training Manual for Implementing Protocol

The training manual is designed to be a supporting document in a training programme, and intended for end users (owners, contractors, architects, consultants). It provides an overview of the protocol, its purpose, its features and limitations, in order that they can decide on its on a project or 'sell' the concept to a potential client.

Sub-task 3.2: Testing of the Refurbishment Protocol

The objective of sub-task 3.2 was to test the Refurbishment Protocol established in sub-task 3.1 and to modify the protocol where necessary. Testing involved an evaluation of the framework of the protocol by parties likely to use it, thereafter some practical testing on real life projects was undertaken. It was originally envisaged that an evaluation on six refurbishment projects will be made. However, refurbishment projects proceeding in tandem with the research were hard to come by. The testing was hence done on four projects in two different countries, on different building types, in various stages of the refurbishment work. The tests generally revealed the following:

- The cost of implementing the protocol will be similar to the costs incurred in assuring air quality through present legislated safety procedures. The advantages of employing the protocol would be the added ability to focus on the issues it raises.
- Owners were reluctant to apply the Protocol in their refurbishment projects as they objected to the IAQ Surveys on building occupiers.
- Architects working on limited project budgets were reluctant to consider IAQ control measures on their own accord; this reluctance could ultimately mean that regulations may have to be imposed to ensure/control Indoor Air Quality.
- Most of the IAQ control strategies developed in the Protocol were pragmatic and were successful in protecting the occupiers in the building.
- The tight schedule imposed by the owner compelled the contractor to undertake demolition and new construction at the same time in different places, and to cut out intermediate phases of cleaning and drying.

Sub-task 3.3: Management Information System for Protocol Implementation

The objective of sub-task 3.3 was to design and develop an information retrieval system to support decision making in each phase of the Refubishment Protocol for IAQ assurance.

Design of the Management Information System

The Management Information System has been developed as a computerised search and retrieval system in which all information produced in preceding tasks is linked to the Refurbishment Protocol for IAQ Assurance. (Figure 4). Its design is based on the browser technology used in Internet applications. This affords quick browse and retrieval options and excellent linking to the flowcharts of the Refurbishment Protocol. Another advantage is that all documents produced in the preceding research tasks could be easily introduced in the information system with a minimum of new software development.

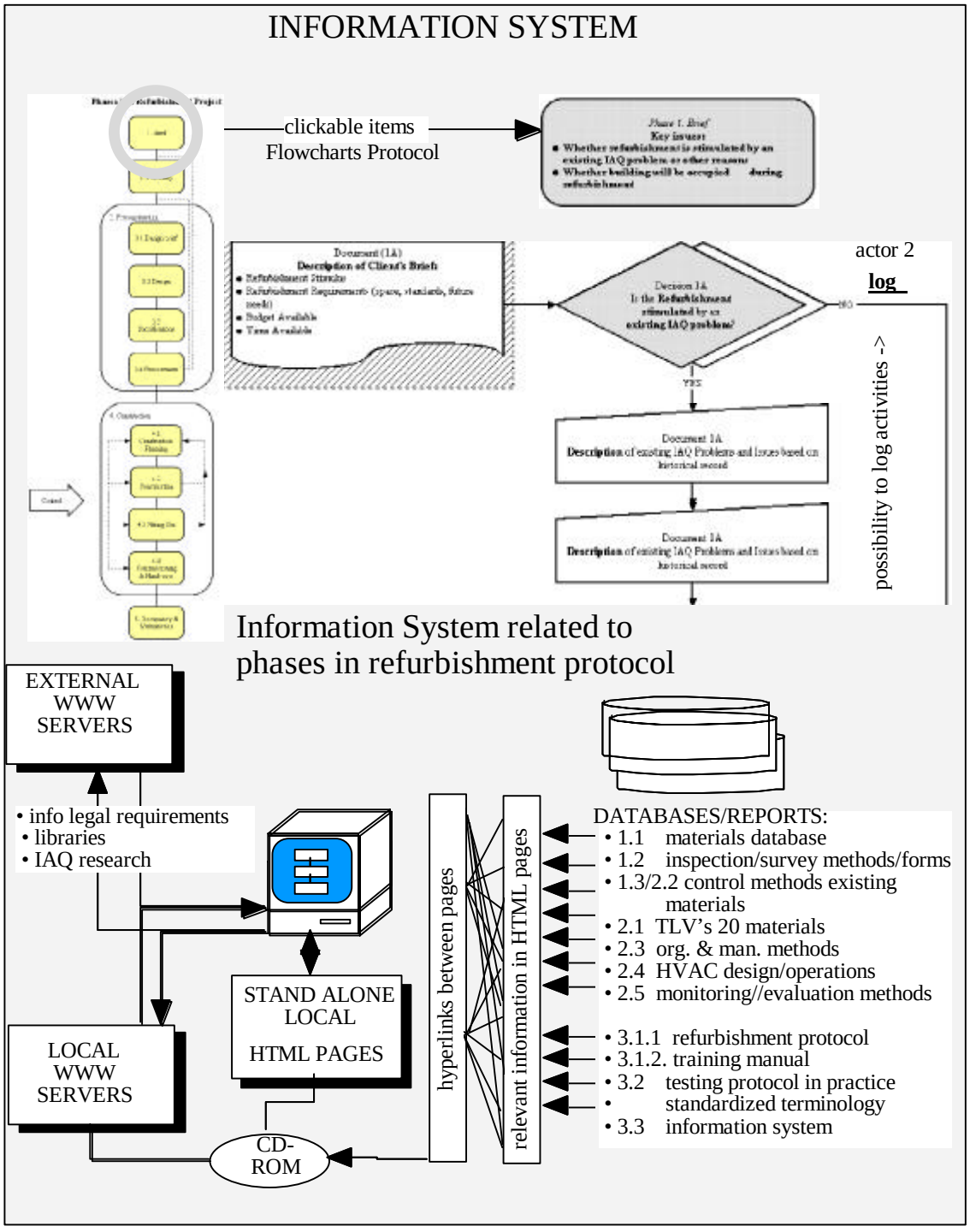

Figure 4: Design of the Management Information System

Lay-out of the Management Information System

To access the Management Information System in an easy way, three entries are defined. The most important entry is the entry through the "Refurbishment Protocol" along the different stages of the refurbishment process. The second entry is through a table of contents by which the full documents can be accessed directly. The third entry is focused on materials/pollutants and their properties.

The following modules were defined.
1. Module to consult the Information System through the Refurbishment Protocol;
2. Module to document all actions taken into a project database (log-book);
3. Module to consult the supporting documents through a table of contents;
4. Module to query the information system on materials/pollutants and properties;
5. Calculation module to estimate the pollution load and decay rate during and after the application of building materials.

An overview is presented in figure 5.

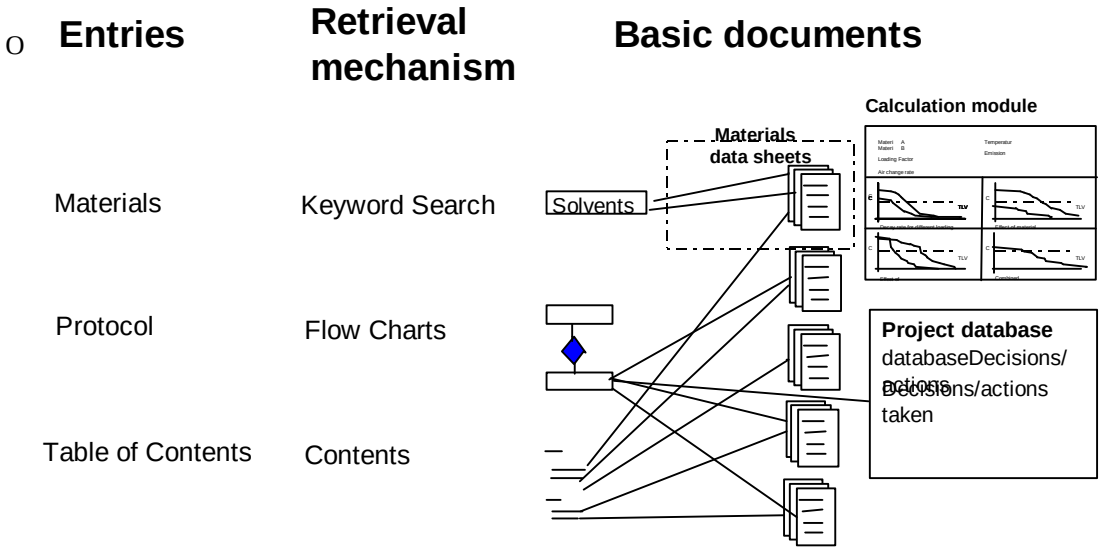

Figure 5: Overview of Modules incorporated in the Management Information System

The computerised Refurbishment Protocol has a 'layered' structure. Layer 1 contains the flowcharts of the Refurbishment Protocol which are accessed by clicking on a relevant process stage. The organisation of the flow charts has an hierarchical structure. From the top level more deeper levels can be accessed, until the level of the actual decisions is reached (layer 2). From this point, information to support decision making (layer 3) can be accessed by clicking on the symbol that is linked to that

decision or action. This layer contains all relevant information supporting decision making (e.g. documents, checklists, enquiry forms, databases, calculation modules).

System Requirements

The Management Information System runs on hardware currently available on the market. Hardware and software allows the system to run in several configurations:
- Stand alone configuration
- Internal web-server for in-company use on more than one building site (Intranet configuration)
- Internet configuration (accessible to more companies at the same time.)

User Manual

A user manual has been prepared for instructing the users on the technical details for implementing the Management Information System in the various configurations (CD-ROM, Intranet and Internet)

RESEARCH RESULTS

The research results comprises a Refurbishment Protocol and supporting Information system for IAQ assurance in refurbishment work, on a CD ROM. Components of the Protocol include:
- A Data Base on Pollutants from Refurbishment Materials and Process and their TLVs;
- A Methodology for Building Diagnostics and IAQ Surveys of existing buildings;
- Specifications of Measures to control Pollutants through Treatment of Materials at Source, Organisation and Management Procedures for the Work and Design and Operation of HVAC Systems; including a model for estimating the pollution load and rate of decay of the pollution, during and after the application of some selected building materials.
- Specification of a System for Monitoring and Evaluating IAQ in refurbishment work;
- Refurbishment Protocol for IAQ Assurance and Instruction Manuals for use of the protocol;
- An Information System to support implementation of the Protocol which logs all control measures taken into a project database.

CONCLUSION

The research project had been motivated by the strong potential for refurbishment work to cause IAQ problems which could affect the health and well-being of building

operatives and occupiers who remain within the building whilst work is carried out around them.

The aim of the research work was to develop management procedures to enable the pre-empting, prevention, mitigation and monitoring of the IAQ problems in refurbishment work. These procedures were structured into a protocol developed around the accepted five stages in a building project (viz. Brief, Feasibility, Design, Construction and Operation and Maintenance) with a Management Information System to support implementation of the protocol.

The research brought together a multi-disciplinary multi-professional team who were predominantly practitioners/end users of the results. The research results are hence pragmatic and is in the process of being selectively adapted for use within the individual organisations concerned. However, industry-wide implementation of the research results is likely to be thwarted by the current climate under which the building industry operates. Building owners are reluctant to recognise the need to address the IAQ problems caused by refurbishment for reasons of cost and the fear of creating a negative impression on occupiers; building professionals and contractors are unwilling/unable to invest in implementing the IAQ controls within the constraints of fixed fees and prices for the work.

Regulations for ensuring the Health and Safety of operatives appear to vary in standards between countries and do not specifically refer to IAQ assurance on the workfront, particularly for refurbishment work which is undertaken in confined site conditions. There is even less reference to IAQ assurance for occupiers who are likely to be affected by the emissions from the work.

If and when regulations for control of IAQ problems resulting from refurbishment work are instituted, the research results can be used as a basis of formulating a code of practice for the refurbishment/construction of 'healthy' buildings and ultimately integrated into a total quality management certification system for construction work.

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