# COMBINE: HVAC-DESIGN PROTOTYPE SPECIFICATION

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ABSTRACT

In recent years, there has been much discussion about the need for improvement in the quality of building design software. One area of design software improvement which has received much attention is that of information integration. Such integration is recognised as both desirable in its own right and necessary for advances in other areas of building design research. Advanced functions such as project management, intelligent design interfaces and complex building thermal performance simulation all depend to some extent on the free interchange of information.

An approach to this problem of information, interchange which has gained much support is the concept of "product modelling" promoted by the CIM research community.

The COMBINE project has a twofold objective in this regard: (a) to develop a building product model and (b) to demonstrate, by means of prototypes, how such a model may be applied to the building design process. In the context of the COMBINE project, the DTP-2 HVAC-Design prototype demonstrates the product modelling approach to the process of HVAC design.

At this stage of the project, the DTP-2 team have produced a functional specification of the prototype detailing how the prototype will support the process of HVAC design and the interaction between the building product model and the design tools incorporated in the prototype.

## 1. OUTLINE OF THE COMBINE PROJECT

The COMBINE project involves 15 partners from eight European countries and is funded by the EC JOULE research program. The project officially commenced in August 1990 and is scheduled to run until 1992.

The project seeks to develop the conceptual framework necessary for integrating the software tools used by different actor's (i.e architects, consulting engineers, quantity surveyor's, contractors etc.) in the building design process.

This integration effort depends greatly on the free flow of information from one design professional's software to that of other designers. The information to be transferred is a description of some aspect of the building, in the terms employed by the designer from whom the description originates. For example, a structural engineer will describe the building in terms of the steel members making up its frame and their associated characteristics of strength and rigidity. A Heating, Ventilating and Air-Conditioning (HVAC) engineer, on the other hand, will be interested in the heat transfer properties of these materials.

In order to achieve integration it is necessary to construct a data model of the building which will be comprehensive enough to hold the information required to fully describe the building to all the professionals, involved in its design. Such a model is called a "product model" by the Computer Integrated Manufacturing (CIM) community. In the COMBINE project this product model is called the Integrated Data Model (IDM) and its specification and implementation is the major task in the project.

The model itself is to be based on previous work in this area, most notably the ISO-STEP initiative (Heinrichs and Helpenstein, 1991). In order that this model be more than just a paper draft a prototype implementation is to be produced. This prototype IDM is to be used for transferring information between a series of prototype design tools addressing different areas of building design [see fig. 1]. These design tools, called Design Task Prototypes (DTP's) are being developed within the COMBINE project, to test the concepts evolved and to demonstrate them to design professionals. The DTP software developers have an obligation to involve practising designers and engineers in the specification and on-going development of the prototypes. (Augenbroe, 1989)

The COMBINE project has been organised into several task groups, namely, the integrated data model (IDM) task, who bear overall responsibility for the product model. This work is being carried out by the Delft University of technology, Netherlands and the Centre Scientifique et Technique des Batiments, France aided by other teams.

The Building Performance Evaluation (BPE) task group are responsible for supervising the uniform description, analysis and documentation of the simulation tools used by the DTP's.

Seven design task prototype (DTP) groups;

DTP-1: Construction design of external building elements.
(University of Newcastle upon Tyne, UK
Building Research Establishment, UK)

DTP-2: HVAC-design
(University College Galway, Ireland
Comite Scientifique et Technique des Industries Climatiques, France)

DTP-3: Dimensioning and Functional organisation of inner spaces.
(Lab. d'Etudes Meth. Architect, Belgium)

DTP-4: Input generation for Thermal Simulation tool in the later design stage.
(Danish Building Research Institute)

DTP-5: "L-T method" in the early design stage.
(University of Ulster at Jordanstown, UK
University of Edinburgh, UK)

DTP-6: Energy-Economic Design.
(VTT, Finland
PI-Consulting, Finland)

DTP-7: Visualisation tool for graphical representation of a building.
(this DTP is being developed by the IDM team)

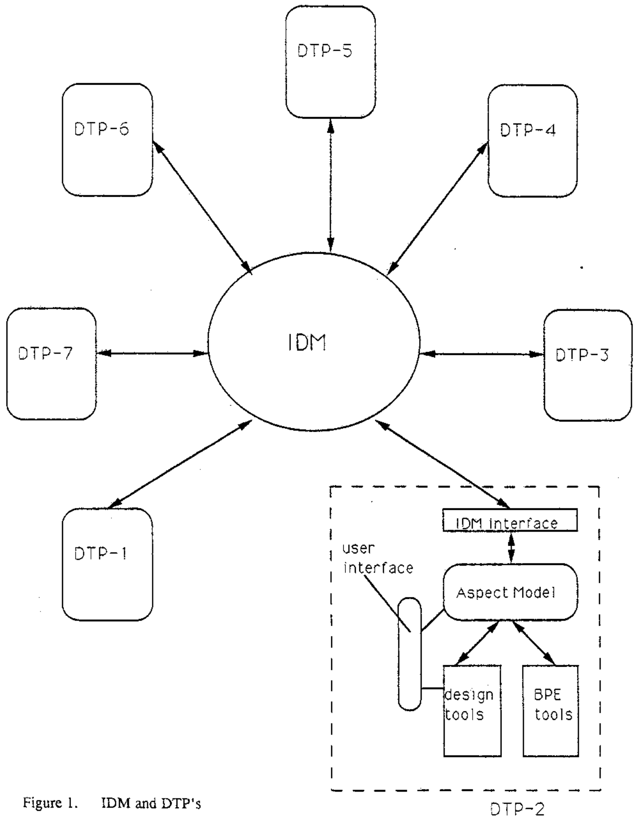


Figure 1. IDM and DTP's

The ultimate aim of the COMBINE project is to provide some of the groundwork necessary for the construction of integrated intelligent building design systems (IIBDS's) (Augenbroe, 1989). IIBDS's will be design aids which cover all stages of building design, offering an intelligent user interface which will help the designer with decision making. Underlying this user interface will be a set of design tools for modelling and simulation which will be able to exchange data and information freely. These tools will cater for all of the design disciplines involved in a building project and will address the problem of managing the interaction of these professionals. The construction of such systems is a substantial task and will involve research in the area of Intelligent Front Ends (IFE's), Object-Oriented simulation tools and Knowledge engineering, in addition to the application of product modelling techniques to buildings.

This paper sets forth a specification of the HVAC Design prototype, DTP-2 which is being produced by CATERU, UCG, Ireland and CoSTIC, France.

The general objectives of DTP-2 are to (a) integrate the HVAC design task into the overall building design task addressed by COMBINE and (b) produce a prototype which offers the HVAC designer support in the conceptual design of heating and ventilating systems for medium sized commercial and residential buildings.

## 2. COMPUTER SUPPORT OF HVAC SYSTEM DESIGN - BACKGROUND

Doheny and Monaghan (Doheny and Monaghan, 1987) breaks the process of HVAC design into the following stages.

1. Data Gathering and discussions with building owner/architect.
2. Concept design i.e configuring subsystems and components into an overall system.
3. Overall system layouts, sizing of major components and energy simulations.
4. Detailed design i.e, design of lighting, heating and other components.
5. Specifications and contract documents.
6. Drafting.

Software tools which support designers in the later design stages (3 through to 6) are presently available. These tools however have some limitations (Monaghan and Doheny, 1986; Augenbroe and Winkelmann, 1990; Selkowitz, Papamichael and Wilde, 1986). By and large, they address specific tasks in the design process and are not integrated. The implication of this lack of integration is that if more than one tool is to be used on a project much time and effort is spent in converting the output of one tool to input for the next. As most of these programs are hard to learn and require large amounts of input data, this constitutes a severe disincentive to their use.

A further limitation is the lack of software support at the predesign and concept design stages where the most important decisions regarding the future form and equipment of the building are made.

Where existing commercial integrated design tools exist, i.e mainly in the building services sector (Cymap, 1990; Facet, 1990; Hevacomp, 1990), these tools are primarily concerned with the detailed level of design and place little or no emphasis on the early, conceptual stage of system configuration. They are complex requiring a skilled operator and their internal data representations are proprietary.

These difficulties have hindered the widespread acceptance of computer simulation tools for evaluating future cost and performance of HVAC systems. An American study in 1987 carried out by the American Institute of Architects (American Institute of Architects, 1987) showed that only 10% of architectural firms in the U.S use simulation software in practice. Augenbroe (Augenbroe and Winkelmann, 1990) maintains that a similar situation exists in Europe.

Much work is being done in the field of Intelligent Front Ends (IFE's) (Sharratt, 1991; Clarke and MacRandal, 1991) in an attempt to make the task of using such powerful and complex tools easier. These IFE's seek to incorporate a significant level of knowledge in relation to the process of building design, the applications being used and the user's objectives and style of interaction with the machine. The primary motivation for these IFE's is to make the task of learning and using a complex simulation tool easier.

A related field of research which directly addresses the need for conceptual design support is the use of expert systems in the process of HVAC system selection. Several prototype expert systems in the HVAC field have been produced (Doheny and Monaghan, 1987; Fazio, Zmeureanu and Kowalski, 1989; Peuportier and Sommereux, 1990). These systems illicit information from the designer on the type of building being serviced, patterns of usage etc. and, based on these constraints, propose various systems suitable for the application.

A further field of research which has a bearing on the integration problem is that of object-oriented simulation environments. Most present day simulation tools are of a monolithic, non-modular nature. This makes them difficult to adapt for the simulation of new HVAC components and systems. It also hinders them from using newer techniques emerging in user interfaces. These difficulties have prompted the idea of object-oriented simulation environments in which models of arbitrary complexity can be built by linking together calculation objects. This "building-block" approach facilitates the integration of building design software by allowing calculation objects to be shared among different simulation environments and by the object's reuse in building other models. Efforts in this field include the American Simulation Problem Analysis Kernel (SPANK), the British Energy Kernel System (EKS), the Swedish Ida and the French ZOOM projects (Augenbroe and Winkelmann, 1990; Clarke, 1985).

It is becoming clear that these diverse efforts are to some extent complementary, Bjork identifies areas of common interest between the Product model research community and those researching Intelligent Front ends (Bjork, 1991). Augenbroe and Winkelmann (Augenbroe and Winkelmann, 1990) clearly demonstrate the link between product models and the integration of simulation into the building design process. They also show how the newer "object-oriented" simulation tools facilitate this integration, because of their modularity and flexibility.

The COMBINE project specifically addresses itself to the early stages of building design, because of the lack of emphasis presently placed on support for this phase of design and also because of the impact which decisions made at this stage have on the final form and performance of the building.

The main emphasis in the COMBINE project is on facilitating the flow of information between design disciplines. By increasing the ease and quality of communication between the design professions in order that consultants may be involved in the design process at an earlier stage and contribute more to the conceptual design of the building. A higher quality of design is expected as a result.

Attention is focused on data exchange rather than matters of design methodology and project management, because a reliable means of data exchange between design domains is necessary before these other aspects of design integration can become a reality. As discussed above, solutions to this problem of data exchange can aid efforts in other areas of building design research. All of which fits well with the COMBINE project's stated aim of developing a conceptual framework for future building design systems.

In accordance with the aims of the COMBINE project the HVAC-Design prototype is to address the early stages of building design.

The prototype is intended to pursue the goal of data integration by incorporating existing simulation tools in a framework which allows them to take their input from a shared data model of the building (IDM). This data model is based, as far as possible, on existing standards in order that the model be as open and extensible as possible.

A central goal of the HVAC-Design prototype is to appeal to design professionals. The functional specification of the prototype is dictated by the standards, practice and perceived requirements of the design profession. This emphasis on "design-led" software environments is motivated by the wish to see the results of this research applied by practising design professionals.

## 3. SCOPE OF HVAC-DESIGN PROTOTYPE.

As stated in the introduction, the process of design may be broken into stages ranging from data gathering through concept design, detailed design, etc. to final specification and drafting. Also, it is widely acknowledged that the area of HVAC design entails the examination of a broad range of systems and components. The number of heating methods and systems is almost unlimited when one considers fuel type, method of conversion of fuel into heat, transmission medium if applicable, and the choice of heat emitter.

Within the time and budget constraints of the present COMBINE project, it is not possible to deal with every aspect of HVAC design. The purpose of this section is (a) to define the scope of the HVAC-Design prototype in terms of the prototype's "depth" and "breadth" and (b) to briefly explain the reasons for the decisions taken in defining the scope. "Depth" refers to the design stages which are supported in the prototype, while "Breadth" refers to the type and range of HVAC systems which are considered in the prototype (see figure 2).

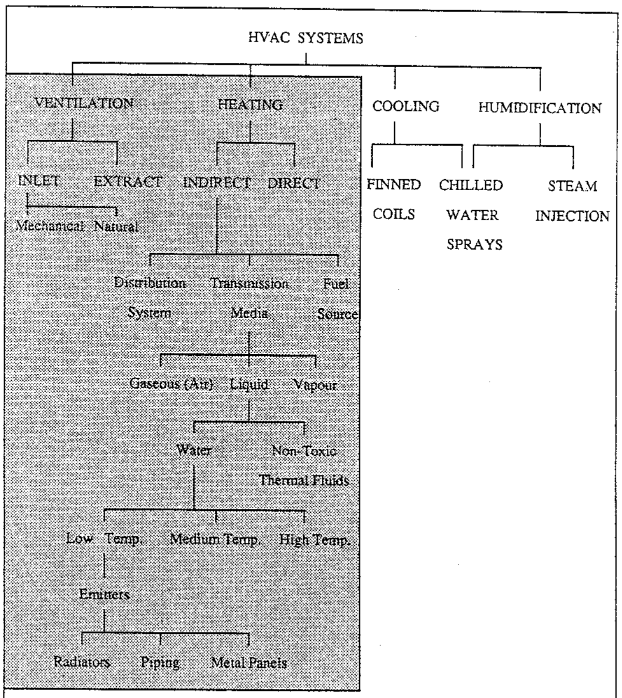


Figure 2. Classification of HVAC systems - Domain Knowledge (part only shown)
"Shaded Area" denotes present emphasis of the HVAC-Design Prototype

The limitations imposed by the scope does not substanially hinder the overall objectives of the COMBINE imitative i.e. data integration between different design disciplines and incorporation of design and simulation tools to assist in building design remain the primary aims of the HVAC-Design prototype. Although the HVAC-Design prototype is limited in scope, it is envisaged that the prototype will be developed in a framework that will allow further enhancement to take place easily. The main factors affecting choice in breadth and depth are the need to be innovative (i.e. software assistance in areas which are not well supported) and, because of time constraints, the desire to utilise the design expertise which is more readily accessible to this team (i.e. knowledge available from the industry in the U.K. and Ireland.). A logical progression from this prototype would be a more thorough examination of the HVAC industry in other parts of Europe and the US.

With regard to depth, the HVAC-Design prototype relates only to the preliminary design stages of HVAC design, i.e. Concept design. The concept design stage entails the designer determining the outline form of the final HVAC system. Historically, the time and resources allotted to this stage were minimal because of the difficulty of data interchange between the design professionals (i.e. architects and HVAC engineers ), "Lack of integration inhibits their [HVAC consultants] involvement in early stages" (Augenbroe, 1989). Many HVAC designers have regarded quality concept design as being paramount to the whole process of HVAC design (Monaghan & Doheny, 1987; Clarke & MacRandal, 1991). Substantial changes made to the building and thermal system design becomes difficult after the preliminary stage. Furthermore, the latter stages of design are well supported by others. (HEVACOMP, 1990; CYMAP, 1990 etc.). As the COMBINE initiative seeks to investigate and aid the information exchange between design professionals, and because concept design is dependant on this exchange of information, a prototype incorporating concept design is deemed to be a rational progression.

The breadth of the prototype is limited to supporting the design of heating and ventilating systems i.e. issues relating to air cooling and humidification are not included. Air conditioning is not as prevalent in the U.K. and Ireland as it is in continental Europe and the US because of the temperate climate. Also, due to the following factors, air conditioning is not being installed in new buildings unless absolutely essential: (Alexander & Jones, 1989)

* Energy conservation
* Desire to reduce high capital costs and maintenance
* Desire to avoid the problem of Sick Building Syndrome
* Environmental issues (greenhouse effect, CFCs, etc. )

The breadth is also limited by virtue of the fact that COMBINE concentrates predominantly on residential, small to medium-sized commercial and institutional buildings (e.g. hotels schools etc.).

The specific objectives of the HVAC-Design prototype are to assist the engineer from the first meeting with the architect and building owner to the stage when a preliminary design configuration of an HVAC system is available i.e. an outline system is specified to provide the desired indoor environmental conditions at minimum life cycle cost. The HVAC systems are limited to the principal heating and ventilating systems i.e.:

* Constant Volume Warm Air Heating systems;
* Mechanical Ventilation systems;
* Water-based Heating systems;
* Natural Ventilation systems.

In conclusion, it should be stated that the function of the prototype is to assist the engineer in the process of design rather than to act as an expert system which tries to replace the engineer. Given the current state of the art in AI technology, a prototype could not try to emulate all the heuristics and subjective knowledge involved in designing a HVAC system for a building.

## 4. APPROACH

As stated previously, the primary aim of COMBINE is to develop a conceptual framework for the future integration of software tools used by the different disciplines in building design. COMBINE also proposes the use of prototypes, limited in application, to establish, test and demonstrate the concepts required for this framework. The area of data integration is regarded as being the initial step in achieving this aim. With regard to prototypes, the main emphasis is on interface-issues between the design and simulation tools. Enhancement of these tools is left to a later stage. It is also important that the concept of future IIBDSs reflects the views of all building design professionals. In summary, the purpose of a software prototype that facilitates the HVAC designers' activities is to (a) test information exchange with the Integrated Data Model (IDM) and (b) demonstrate the value of such a proposed integrated environment to HVAC design professionals.

In order to develop the HVAC-Design prototype within the project time and budget constraints, it is beneficial to identify specific areas of interest that serve to achieve these goals. Hence the objectives of the prototype are to:

* Allow the transfer of HVAC domain specific information to and from the IDM. Information emanating from one design discipline and required by another discipline must flow through the IDM;
* Coordinate all HVAC-Design activities within a suitable user interface;
* Allow the use of current state of the art design and simulation tools within the prototype. An important facet of this objective is the desire to minimise the work of the designer in terms of input and tuition;
* Support the designer's decision-making by supplying summaries of numerical data, and appropriate presentation of relevant non-numerical information;
* Support the efficient and reliable flow of information within the prototype itself;
* Present and store the HVAC designer's point of view of the project;

The general approach to achieving these aims is to:

1. Clarify functional links via IDM with software environments of other design professionals;
2. Establish the technical content of the prototype;
3. Ensure the prototype allows for addition of further technical content in future;
4. Identify the target hardware/software environment;
5. Formalise the general structure of information in the prototype.

These areas are discussed in greater detail in the following paragraphs.

The area of information flow entails close coordination with other prototype developers and the IDM task teams to clarify all aspects of data integration. Communication with other design professionals such as architects, civil engineers and quantity surveyors serve to determine common areas of functionality between the different building design domains

Establishing the technical content of the prototype requires extensive research, which may be classified as follows:

- Review of HVAC design textbooks (Faber & Kell, 1989; Pita, 1981; Haines, 1988). This serves to examine the processes of HVAC design, to document current simulation techniques and to acquire knowledge of subsystems and components;
- Review of Code books, Guides and manuals (ASHRAE, 1987; ASHRAE, 1986; ASHRAE, 1985; ASHRAE, 1983), (CIBSE, 1988a; CIBSE, 1988b; CIBSE, 1988c). As well as augmenting the information available in textbooks, these provide guidance on constraints imposed on design. Guides also provide reference data for input to software tools such as weather data and costing indices;
- Consultations with design professionals in the form of meetings and questionnaires provide an insight into the vast amount of subjective knowledge required in HVAC design. Professionals also assess design and simulation tools currently available;
- Review of work by professional bodies and research organisations is carried out in order to establish potential areas for future enhancement of tools;
- Review of current software to establish current state of the art by reviewing publications and literature. To this end, BSRIA (BSRIA, 1989) have compiled a directory of technical software in the building services area;

It is imperative that the prototype not only reflects the state of the art in the HVAC design industry today but also allows new techniques to be added in future. These new techniques are made possible as a result of the enhanced information exchange between the various design disciplines. It is the view of the authors that the process of HVAC design should be less dependent of simulation tools and be more contingent on the design tasks involved. Hence, the prototype is controlled by the designer at all times, with the ability to activate any tool, provided there is sufficient information available.

The implementation of the HVAC-Design prototype will be carried out on 386 micro computers supporting the UNIX environment, because of the potential for wider availability of this hardware/software combination to design professionals

In general, the knowledge required for the purpose of designing an HVAC system may be defined as being heuristic design knowledge (i.e. rule of thumb, subjective experience etc) augmented by numerical information. In order to facilitate the acquisition of this knowledge and to ensure modular and efficient programming it is necessary to formalise this knowledge in some manner. It is envisaged that the design knowledge required for this prototype may be classified according to it's function in the HVAC design process as follows:(Doheny & Monaghan, 1987)

(1) Domain knowledge - knowledge of HVAC systems and components (see figure 2);
(2) Constraint knowledge - constraints imposed by building owners goals, legislation, economic limits etc.. An example of a constraint is that an occupied room with heavy smoking requires a minimum ventilation rate;
(3) Procedural knowledge - knowledge of the HVAC design procedure. This includes all the objective (cost, capacity etc) historic and subjective knowledge involved in designing a system;
(4) Analysis algorithms - knowledge of how to quantitatively evaluate and analyse developing and final solutions i.e. simulation and design calculations as documented in code books and design texts.;
(5) Solution knowledge - knowledge of the developing solution. As the processes of design are carried out, the results of design decisions and simulation runs are stored for referral by the designer, and future presentation to other design disciplines.

The approach adopted by the HVAC-Design prototype reflects this formalisation of the design knowledge.

## 5. FEATURES AND FUNCTIONAL SPECIFICATION OF THE PROTOTYPE

The functional specification of the DTP-2 HVAC-Design prototype cannot be viewed in isolation from the design methodology which it is intended to support. The approach taken in explaining the specification is therefore to describe how it is thought that a designer might use the prototype from the time he meets the building owner/architect to the time he arrives at an overall system layout. That is to say stages one to three in Doheny and Monaghan's classification (Doheny and Monaghan 1987).

This design methodology has been arrived at by studying the literature of the professional bodies (CIBSE, 1988a; CIBSE, 1988b; CIBSE, 1988c; ASHRAE, 1987; ASHRAE, 1986; ASHRAE, 1985; ASHRAE, 1983) and texts commonly used in building services degree-level university courses (Haines, 1988; Martin and Oughton, 1989; McQuiston and Parker, 1988; Pita, 1981), followed by consultations with consulting engineers presently working in design practice.

The architecture of the prototype has been prompted by these investigations [see fig. 3]. Computer support is offered by the HVAC-Design prototype only at those points in current design practice where such support appears appropriate.

### 5.1 Features

In the interests of clarity it would be useful, before fully detailing the functional specification, to discuss some less common features of the prototype. These concern the support offered by the prototype in the area of

(a) Estimating capital costs of an installed system.
(b) Legal compliance checking.

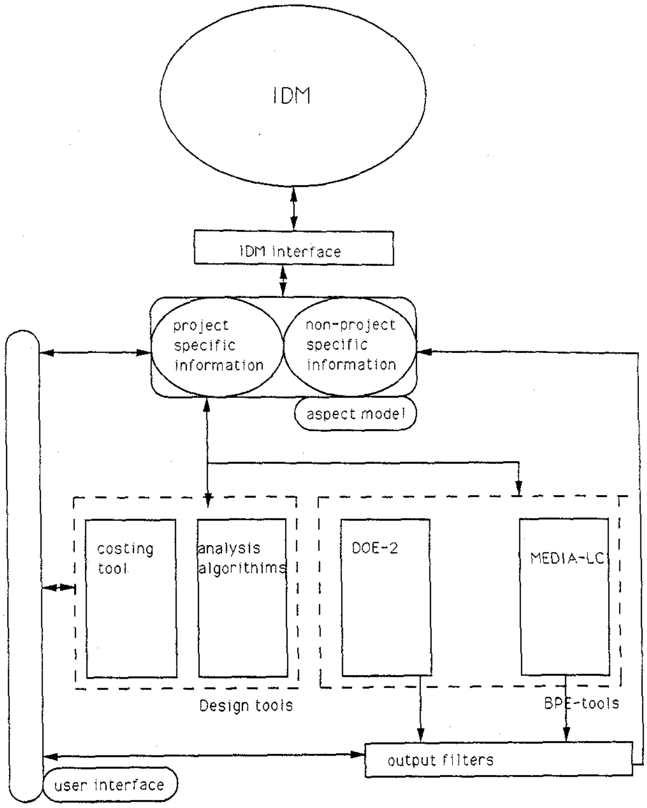


Figure 3. DTP-2 Prototype

#### 5.1.1 Estimating Capital Costs of an Installed System

When talking to Quantity Surveyors and Consulting Engineers in practice in Ireland, it was discovered that the Quantity Surveyors Association maintain a national database of building cost breakdowns submitted by their members. These building cost breakdowns are indexed according to building type, location and the year in which the cost breakdown was made. The cost breakdowns follow a national classification scheme (An Foras Forbartha, 1986). This information, in conjunction with the Quantity Surveyor's own records of previously costed jobs, allow him to arrive at a good estimated cost per square metre for a particular building type. The quantity surveyor will compare this figure with the cost of his current project to determine if it falls within the norm.

Consulting engineers are often told by a building owner what type of system they would like. Alternatively, they may be asked to propose a system for the building. In both cases they are then requested to estimate a typical cost per square metre for the system. The owner then makes his decision whether to go ahead with the proposed system on the basis of this estimate.

When determining this estimated cost, the consulting engineer at present typically finds himself pricing individual plant items from previous quotes or manufacturer's price lists (Davis, Belfield and Everest, 1982). He then totals these pricings to arrive at the overall estimate for the system.

The drawback with this approach is that it involves the engineer in a detailed system breakdown far too early in the design process. The effort involved in arriving at a cost estimate discourages the consultant from looking at more than one or two systems.

What would be useful here would be a costing tool, built on a database akin to the one possessed by the quantity surveyors. This would allow the engineer to take a global view of the building and the system to be installed. For a particular building type equipped with a certain type of system the engineer would be able to get information on previous, similar projects and base his estimated costs on this. Given a sufficiently large and representative sample of previous projects the figures thus produced should be accurate enough for the building owner to decide whether to proceed or not. Such a tool, by making the process of arriving at an estimated installed cost easier, would benefit the designer by allowing him to consider a wider range of systems at this stage.

As a first step a costing tool is to be coded based on a database holding details of a consultancy firm's past projects. If at some later stage a national information pooling scheme, similar to the quantity surveyors one, becomes viable it should be possible to incorporate the extra data made available with little difficulty.

It is to be noted that this costing mechanism will give a typical installed cost for a system, the issue of running costs for that system is a separate one. Both the capital and running costs for a system will considered when deciding between options.

### 5.1.2 Legal Compliance Checking

Legislation has, in the last two decades, become an area of increased concern for HVAC consultants. Simulation of legislation is regarded as a substantial task. According to Faber & Kell " No precis of current Acts of Parliament or the Regulations and Guidance Notes published under these Acts can be either complete or up to date; nor can a digest of local authority bye-laws or regulations purport to be comprehensive."

As well as conforming to guides such as CIBSE and ASHRAE, the area of building design is constrained by national standards, codes, building regulations and local planning regulations. The HVAC design prototype provides a tool which ensures that the building complies with regulations regarding natural ventilation. The main objective of the tool is to demonstrate the value of a legal compliance checker and also to highlight the potential difficulties entailed in developing a comprehensive tool in this area.

## 5.2 Functional Specification

The research team has identified twenty-two groupings of functions that support the HVAC design professional's work. These are listed below in an "approximately sequential" order, i.e the consultant may choose to carry out some functions in a different order or may iterate through certain sequences of functions.

For example, groups 1 and 2 relate to information gathering, while item 22 deals with the report of the consultant's decisions. The intervening groups deal with assistance to the creative aspects of preliminary design.

The twenty-two groupings may be summarised as follows:

| | |
|---|---|
| 1-4: | Information Gathering and Zoning |
| 5-7: | Heat Loss Calculations |
| 8: | Ventilation Requirements |
| 9: | Design Decisions on HVAC system |
| 10: | Natural Ventilation Calculations |
| 11: | Estimation of Approximate Capital Costs |
| 12: | Legal Compliance Check (Ventilation) |
| 13: | Mechanical Ventilation Calculations |
| 14: | Air-Conditioning Calculations (not to be implemented) |
| 15: | Prompting of Systems supported by HVAC-Design prototype |
| 16-21: | Repeated Simulation Runs |
| 22: | Semi-Automatic generation of reports on designed system |

1. Retrieval of the Building Information in the IDM

The designer accesses the IDM to retrieve all information relative to the HVAC domain. The assumption is that a full set of building shell information will be available from one of the architectural prototypes. The information retrieved is to be stored in a local database called the Aspect Model (AM). This Aspect Model contains both project specific data and data which may apply to more than one project (e.g weather files).

2. Addition of Extra Project Information

To the Aspect Model, the designer adds any extra information not provided by the IDM. For example, budget for HVAC system, name and address of the consultant designing the system.

3. Zoning of the Building

The designer imposes one or more zoning schemata on the building shell information in the Aspect Model. This zoning schemata is linked to the spaces described in the Aspect Model but is independent of them, allowing one zoning scheme to be replaced by another without difficulty.

4. Editing of Building Information

At any stage the designer can edit the Aspect Model to enter more building shell information if required. Such editing might be required, for example, if the Designer wished to add an extra layer of insulation to an exterior wall before calculating heat losses.

This function is not receiving a high priority in DTP-2 as other DTP teams have responsibilities in the area of building envelope design and the assumption is that a complete description of the building shell will be available from the IDM. It is necessary however to provide some form of editing facility here, because HVAC designers in practice have occasional need to investigate the impact on building thermal performance of changes in items such as glazing type, and insulation.

Allied to this editing facility and as an aid to the designer, lists of mandatory inputs (inputs which must be specified if the tool is to run, as opposed to optional inputs) for each of the simulation tools' functional modules and the entities in the Aspect Model associated with these inputs are maintained. This helps the designer by (a) allowing him to determine, on request, how much extra mandatory information is required to run a particular simulation tool module and (b) allows the interface to automatically inform the designer when the mandatory information set for a simulation tool module is completely specified, i.e when there is enough information entered in the Aspect Model for a simulation tool module to run.

5. Generation of Heat loss/gain Calculation Input

The first BPE function which is envisaged as being activated, is a heat loss/gain calculation.

The designer chooses which tool or tools he wishes to use for the heat loss/gain calculations. Once his/her choice is made, then the input data are generated for the BPE tools from the information held in the Aspect Model.

6. Direct Use of BPE tools Heat loss/gain Simulation

The designer may, if (s)he wishes, edit the BPE input file generated from the Aspect Model and add extra, BPE tool specific, inputs (i.e inputs which are not modelled in the Aspect Model). He does this using the BPE tool's own user interface.

This feature is provided to allow the Designer to use the BPE tools directly in a stand alone mode. This is allowed because it is not intended to rewrite any BPE tool. The function of the prototype is to provide a communication link between the BPE tool and the model of the building being designed. It is not intended to force the BPE tool to use only those inputs which are provided for by this communication link. If the Designer wishes (s)he can make use of inputs which are not provided in the building model. The drawback with using such inputs is that inconsistencies may arise between the description of the building generated from the Aspect Model and that submitted to the BPE tool.

If any lines in the file generated from the Aspect Model are altered during this editing the designer will receive a warning that this has occurred before he submits the input file to the tool. Though obviously desirable, no further consistency checking beyond this simple syntax check is to be under undertaken in the present project, because of time constraints.

7. Heat loss/gain Calculations

The modified input files are then submitted to the designer's choice of BPE tools, where the heat losses and heat gains of winter and summer are evaluated. The HVAC-Design prototype provides BPE tools that do heat loss/gain calculations. It is left to the designer to choose his particular view of the results generated by the simulation. The prototype provides a detailed report of the simulation run or a 'filtered' set of outputs that may be examined conveniently by the designer. The results of the heat loss and gain calculations are stored in the Aspect Model for further use in the design process.

8. Determination of Ventilation Requirements

Subsequent to the calculation of thermal load, the designer is advised to examine the ventilation requirements in the building. The DTP-2 team provides a suite of simple design tools that evaluate this rate based on methods documented in CIBSE (CIBSE, 1988a; CIBSE, 1988b; CIBSE, 1988c), ASHRAE (ASHRAE, 1987; ASHRAE, 1986; ASHRAE, 1985; ASHRAE, 1983), Faber & Kell (Faber & Kell, 1989), research institutes (BS 5925, 1980; BRE, 1982) and other textbooks. The result of this stage is a minimum volumetric flow rate per unit time which is presented to the designer and is stored in the Aspect Model as developing solution knowledge.

9. Design Decisions on HVAC system

HVAC systems may be organised, according to their functionality, into three basic types:(Doheny & Monaghan 1987)

Heating only with natural ventilation;
Heating only with mechanical ventilation;
Heating, ventilation and air conditioning.

The designer, using subjective experience and all the solution knowledge that exists in the Aspect Model must choose the optimum basic type of HVAC system for the building. The HVAC-Design prototype does not aim to emulate this type of expert knowledge, however, the prototype provides assistance by offering the design and simulation tools that are described below.

10. Natural Ventilation Calculations

In the area of natural ventilation, the prototype provides a design tool to assist the designer in the sizing of openings to achieve the required ventilation rates. The simulation of natural ventilation is very complex due to the natural forces of wind and stack effects. With this in mind, the authors do not intend to provide any simulation tool unless it is validated, and accepted by the building services industry.

11. Estimation of Approximate Capital Costs

The designer can at any stage call on the costing tool (described in the previous section 5.1.1) to determine an average installed cost per square metre for the building type and its associated system type.

12. Legal Compliance Check (Ventilation)

This prototype includes a stand alone tool which verifies that the building conforms to the requirements laid down by the proposed Irish Building Regulations (Dept. of the Environment, 1988) and local Irish regional by-laws (Galway Urban District Council 1928) regarding natural ventilation (e.g window sizing, space around building). This tool, although limited in application, serves as a demonstration of the potential problems entailed in incorporating such constraints in a design tool.

13. Mechanical Ventilation Calculations

The designer using his subjective experience, the solution knowledge and the natural ventilation tools at his disposal may decide that natural ventilation is inadequate and hence, would prefer to assess mechanical ventilation. The HVAC-Design prototype simulates the overheating that would occur in summer in a forced ventilation system. As in the case of the natural ventilation results, the output from this simulation is, in whole or part pending the designer's approval, stored in the Aspect Model as part of the developing solution.

14. Air Conditioning Calculations (not to be implemented)

Due to the fore-mentioned limitations in budget and time, cited in the introduction and scope sections, the prototype shall not provide any assistance in the field of air conditioning. It is envisaged that any further development of this prototype would have to include this region of the domain knowledge classification. Hence, the HVAC-Design prototype is developed with this future enhancement in mind.

15. Prompting of Systems Supported by HVAC-Design Prototype

At this stage the designer will be told, by the prototype, what systems the Aspect Model and BPE tools combined can handle (cases exist where the BPE tools can simulate a system which cannot at present be described in the Aspect Model, i.e full air conditioning systems).

16. Modelling of System Configuration

The designer will then model the system or systems he wants to simulate, detailing the distribution system, the plant items and any relevant economic data costs. This modelling function will have to be carried out in the Aspect Model because if the system is modelled directly in the BPE tools using their native interfaces three problems arise;

(a) if you wish to simulate the same system using two different tools you will have to describe the system twice, once in each tool.

(b) there can be no cross checking to ensure that the system as described in one tool conforms to the system as described in another.

(c) when details of the system finally chosen are to be returned to the IDM the details will have to be extracted from the internal description of the system in the relevant BPE tools, a separate interface reading each BPE tool for this information would have to be developed.

Choosing to model the system directly in the BPE tool also prevents you from incorporating any assistance (i.e help screens) you might wish to give the designer in configuring his system.

17. Generation of System Simulation Inputs

Having chosen and modelled his system(s) and chosen the BPE tool(s) he wishes to use to simulate the operation of the system. The designer can then request that the system simulation input file(s) be generated for the BPE tools(s).

18. Direct Use of BPE tools System Simulation

The designer has the option the edit the input file(s) so produced, to include BPE tool specific options (i.e system configurations not modelled in the Aspect Model). The same type of simple consistency checking as in the case of the heat loss/gain calculations will be done (see step 6.)

19. System Performance Simulation

The simulation is run by the chosen BPE(s).

20. Output of System Simulation Results

The results generated are filtered, by the prototype, to a simpler general set. The designer can look both at this filtered set and at the raw output of the BPE tools. The reduced set of results is automatically stored in the Aspect Model and can be accessed by the designer at any time.

21. Tuning of Simulated System

If the performance of the system(s) falls outside the required limits the designer can return to the system modelling interface described in step 16. Here he can adjust the parameters of the system(s) and simulate the operation of the adjusted system(s). He may also if he wishes discard the original system and choose a different one for simulation. He will repeat this process iteratively until he is satisfied with one of the system configurations.

22. Semi-Automatic Generation of Report on Designed System

When the designer has decided on a system configuration he can then generate a report on the chosen system configuration with details of its technical performance, capital and running costs. This report is compiled automatically from the data held in the Aspect Model. This report will then be transferred to the IDM as the output of the DTP-2 HVAC-Design prototype.

## 6. DATA TRANSFER WITH THE IDM

As presently specified the HVAC-Design prototype accesses the IDM at two stages. The first transfer of data occurs at the commencement of the HVAC engineer's involvement. This data transfer involves, at a minimum, a description of the building envelope and the intended use to be made of the building.

The form in which the data is introduced allows it to be transferred directly to the simulation and other design tools residing in the prototype. This is intended to overcome the problem of repeated manual input of data to BPE tools described in section 2 of this paper.

The second transfer occurs when the designer has completed his system configuration. The chosen configuration with accompanying details of simulated performance and costings is detailed in the IDM.

## 7. DISCUSSION AND CONCLUSION

This paper seeks to describe the DTP-2 HVAC-Design prototype in the context of the COMBINE project and the wider building design research community. The need for better software tools for building design has been clearly identified by many researchers and designers. That a standard for data exchange between these tools is a prerequisite for improvement in design software, is an idea that has achieved wide acceptance, as evidenced by the on-going international efforts of the AEC (Architecture, Engineering and Construction) committees of the ISO/STEP organisation.

The COMBINE project's aim is to address this need for data exchange and design integration. Within the COMBINE demonstrate how the HVAC consultant engineer may benefit from these efforts. To this end the prototype is designed to support existing design practice and demonstrate where the benefits of integration research may be creatively applied in practice.

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