A guide to

HVAC Building Services Calculations

Second edition

BSRIA Guide 30/2007
Supported by the DTI

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PREFACE

This publication provides practical, easy to follow methodologies for a range of calculations used in the design of heating ventilating and air conditioning building services systems.

The calculation sheets are presented in five sections covering:

- Heating loads and plant
- Cooling loads and plant
- Water flow distribution systems
- Air flow distribution systems
- Acoustics for building services

The calculation sheets provide practical guidance including design watchpoints, design tips and rules of thumb, and are intended to aid the design process and reduce errors. The guidance is based primarily on data and procedures contained within the *CIBSE Guides*, together with other sources such as *Building Regulations*, with clear cross-referencing provided to data sources.

This publication is intended primarily to help junior design engineers, working within a structured and supervised training framework, by providing assistance in completing the basic calculations needed to define operating conditions for systems, size distribution systems and to specify required duties for plant and equipment. It is not the purpose of this guide to identify the most appropriate system for a particular application. Such decisions require knowledge, experience and analysis of the application.

This guidance is also not intended to be exhaustive or definitive. It will be necessary for users to exercise their own professional judgement, or obtain further advice from senior engineers within their organisation when deciding whether to abide by or depart from the guide. The calculation sheets are relevant to many design applications, but cannot be fully comprehensive or cover every possible design scenario. Every design project is different and has differing needs, and it is the professional duty of the responsible design engineer to consider fully all design requirements. Designers should exercise professional judgement to decide relevant factors and establish the most appropriate data sources and methodologies to use for a particular application.

Designers must be aware of their contractual obligations and ensure that these are met. Following this guidance - or any other guidance - does not preclude or imply compliance with those obligations. Similarly, it is the duty of the designer to ensure compliance with all relevant legislation and regulations.

It is hoped that design practices and individual designers will be encouraged to share knowledge and experience by extending and adding to the design watchpoints and design tips, and disseminating this work within their organisations. BSRIA would be pleased to receive any such contributions for incorporation into any future revisions of this publication to provide wider industry sharing of such knowledge.

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INTRODUCTION

BSRIA has been researching into the design process and design methodology in the building services industry since the mid 1990's. This has produced guidance on the use of engineering design margins[1], feedback to design[2] and quality control systems for detailed technical design[3]. The overall aim has been to develop systematic guidance for the industry that would contribute to greater consistency in design and to an overall raising of design standards.

The studies have involved considerable discussions with industrial partners on their current and future needs, and several visits to the design offices of a number of industrial contributors to the projects. A majority of those organisations consulted said that a lack of formal design guidance and inadequate recording of calculations was a major barrier to quality improvement in design. Many also felt that standardised formal procedures would help improve the quality of design outputs.

BSRIA's research also revealed that there is a lack of standardisation in design procedures, both between companies and between individuals. Many companies have developed their own design guidance and approaches to calculation procedures, leading to considerable diversity within the industry. This can make it difficult to cross-check work done by others, which could lead to differences in system design parameters and sizes, and even calculation and design errors. There are many specific examples of design errors and issues that should have been considered during design calculations and have led, (or could have led) to operational problems or subsequent litigation[4], including:

- Omission of HEPA filter resistance from fan-pressure calculations, requiring subsequent fan motor replacement which then required additional silencing
- Omission of duct sizes and flows from drawings, leading to incorrect sizes being installed
- Incorrect pipe and pump sizing for a constant temperature heating circuit, necessitating replacement of system distribution network
- No allowance for pipework expansion on a heating mains.

Although there is considerable design guidance and data available to inform the design process much of it is intended for use by experienced engineers, who have fulfilled a programme of education and training and have design experience. For example, while the design guides published by the Chartered Institution of Building Services Engineers (CIBSE)[5] provide essential design data for building services engineers, they are intended for use by experienced engineers, and therefore do not always show how to design in detail by giving every necessary calculation step. They also do not show how different calculation routines link together to build up the design process.

Research has also shown that many employers are currently finding it difficult to recruit design engineers with appropriate building services skills and experience, which necessitates recruiting and retraining engineers from other disciplines.[6] Output from building services courses is currently falling,[7] which implies there will be no short term improvement in this situation.

These recruits, with no building services training or experience, will require close supervision and considerable training which can place a heavy burden on company resources.

While there is no substitute for an appropriate quality control framework and adequate supervision by qualified senior staff, good training resources and technical support can provide an invaluable adjunct to company training provision.

Aim

As a result of all these factors many of the leading organisations involved in education and training in the building services industry, including BSRIA, CIBSE, ESTTL and HVCA and a number of industrial contributors embarked on this project to develop simple and clear guidance on building services calculation procedures that would be applicable across the industry.

Objectives

The resulting guidance is intended to be suitable as an in-company learning resource, in order to improve quality and communication within the design process. This should reduce the risk of design calculation errors and omissions, simplify the task of calculation checks and improve the overall efficiency of the design process.

A comprehensive review of current building services design practice and calculation procedures was carried out in consultation with the industry. This was closely linked to current industry design guides and reference material in order to develop this good practice guidance for building services calculation procedures, including:

- An overview of the building services design process;
- Flowcharts of key calculation sequences;
- Practical procedures and calculation sheets covering 30 key building services calculation design topics;
- Clear cross-referencing to the CIBSE Guide and other appropriate reference sources.

The calculation sheets provide an overview of each procedure, with guidance on design information, inputs and outputs, design tips and watchpoints and worked examples, to aid the design process and reduce errors. They are supplemented with illustrations and guidance on how to use appropriate tables, figures and design information correctly.

Intended users

This guidance is intended for practising building services design engineers, and will be particularly relevant to junior engineers and students on building services courses. Junior engineers would be expected to use it under supervision, (for example within a formal company training scheme) as part of their practical design work. Students can use it within the taught framework or industrial training component of their course, guided by course tutors as appropriate. The guidance should also encourage clear recording and referencing of calculation procedures which will aid quality assurance requirements and allow simpler and easier in-house checking of design work.

The guidance complements the CIBSE Guides, in particular Guide A covering design data, Guide B covering heating, ventilation and air conditioning, and Guide C covering reference data. It especially complements the CIBSE Concise Handbook[8] a companion volume showing the use and practical application of commonly used design data from other CIBSE Guides.

The Practical Guide to Building Services calculations also closely complements the BSRIA Guide: BG 4/2007 *Design Checks for HVAC – a quality control framework (Second edition)*[3]. This provides good practice guidance for building services technical procedures and design management, including design guidance sheets for 60 key design topics and check sheets that can be used in project quality assurance procedures.

New entrants to building services may find it helpful to read the overview information given in the BSRIA illustrated guides volumes 1 and 2.[9]

THE BUILDING SERVICES DESIGN PROCESS

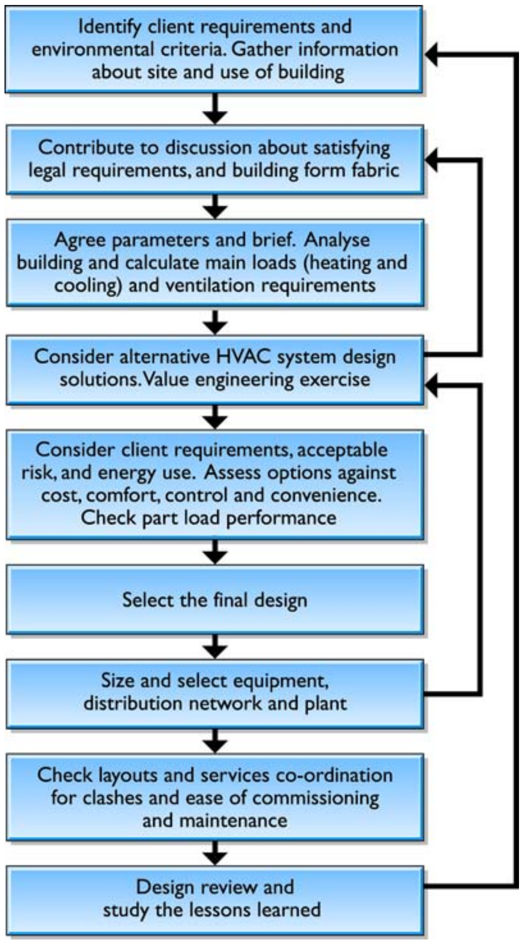
Calculation procedures are a necessary component of design but it is important to see them in the context of the whole design process. Decisions made as part of initial design and during the calculation procedures will affect system design, installation, operation and control.

The BSRIA publication *Design Checks for HVAC – a quality control framework (Second edition)*[3], provides a useful and relevant discussion of the building services design process. As part of this work, a detailed analysis of design procedures and tasks was carried out for building services design and a simple linear model of the building services design process derived was derived as shown. This gives a single design sequence, from statement of need, through problem analysis, synthesis and evaluation to final solution and enables design tasks to be clearly linked to both preceding and succeeding actions. Some primary feedback loops are shown, but in practice there are often feedback loops between all tasks and even within specific tasks.

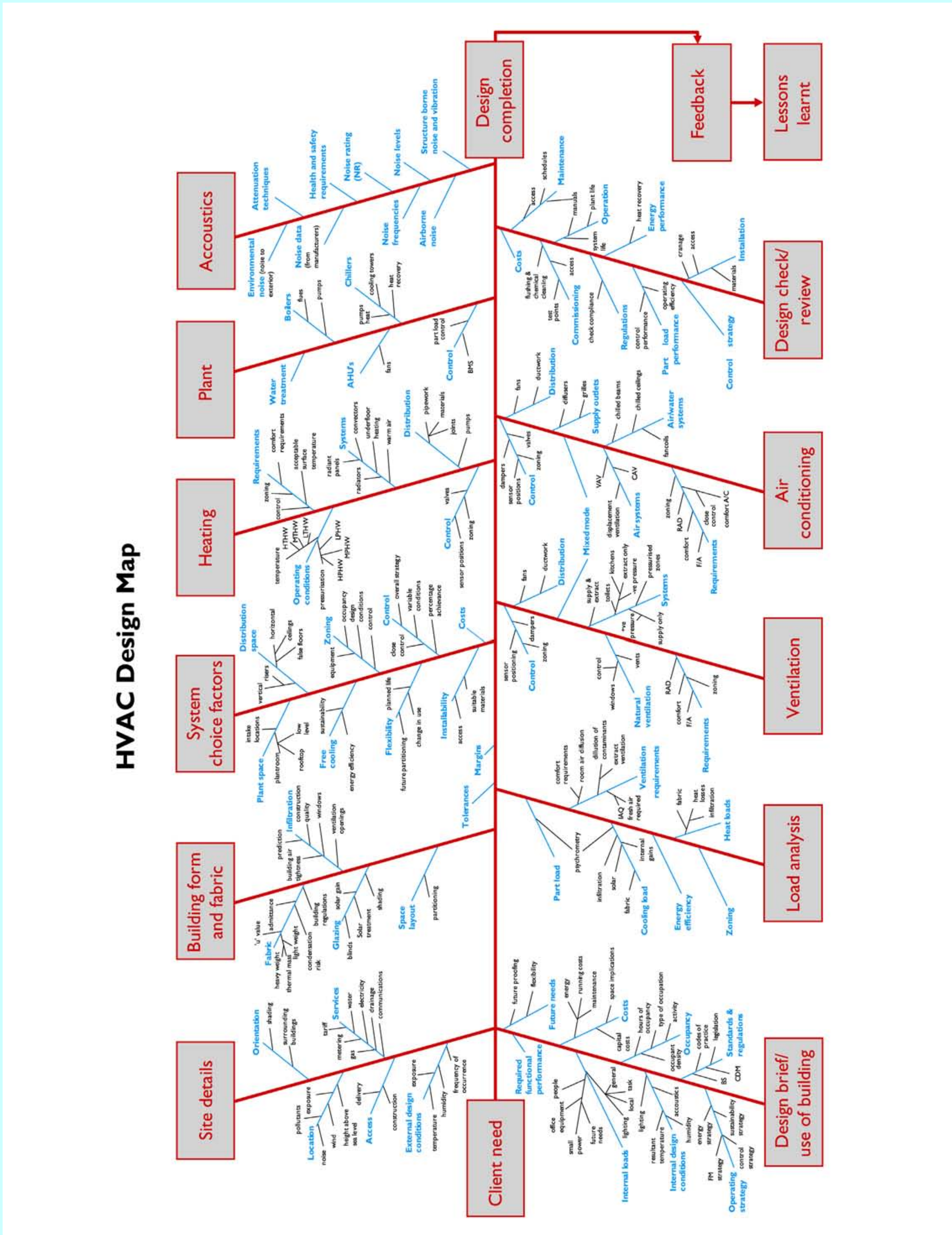
This work also mapped the building services design process, both as a sequence of design tasks and as a series of topics that make up the design process. This detailed map of the process is shown opposite. The map is shown as a linear view of design, (with iteration and intermediate feedback omitted) in the form of an Ishikawa or fishbone diagram. The process originates from the client's need on the left with various branches feeding into the main design line to eventually reach design completion and design feedback. The map may be of particular benefit to junior engineers as it will enable them to put their contribution to the whole design process in context. When engineers carry out load calculations or pipe sizing, it is easy to forget that this is part of a larger process with consequences for impact on future system installation, operation and control.

Note that CIBSE Guides B1 to B5 have been combined to form *Guide B – Heating, Ventilation, Air Conditioning and Refrigeration*. This publication provides references to both individual B guides and the combined B Guide where appropriate.

Figure 1: Simple example of a building services design process.



THE BUILDING SERVICES DESIGN PROCESS



OVERVIEW OF CALCULATION SHEETS

The calculation sheets are organised into five sections covering over 30 topics relevant to building services design:

Heating loads and plant

This section covers the key topics and calculations relevant to establishing heat loads for a space or building and sizing heating plant, covering infiltration, U values, heat loss, heating load, radiator sizing and boiler sizing. It explains how to use design data from different sources to establish heat losses and heating loads and explains the different components that make up plant loads.

Cooling loads and plant

This section covers the key topics and calculations relevant to establishing cooling loads for a space or building and sizing cooling plant, covering internal gains, external gains, cooling load, supply air temperature, cooler battery sizing and humidifier duty selection. It provides an overview of heat gains, explains maximum simultaneous loads and explains how to determine acceptable supply air temperatures and size plant components.

Water flow distribution systems

This section covers the key topics and calculations relevant to the sizing of water flow distribution systems, covering pipe sizing, system resistance, pump sizing and water system pressurisation. It explains how to read information from pipe sizing tables, how to work out pressure loss through pipe fittings, and how to determine the index run.

Air flow distribution systems

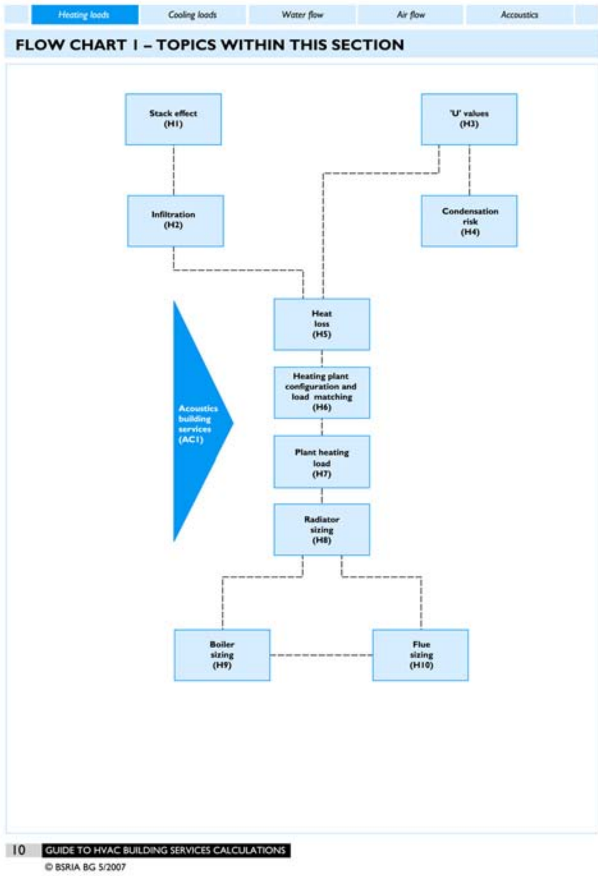
This section covers the key topics and calculations relevant to the sizing of air flow distribution systems, covering duct sizing, system resistance, fan sizing, grille and diffuser sizing, and space pressurisation. It explains how to read information from the CIBSE duct sizing chart, how to convert from circular to rectangular duct sizes, discusses practical selection of duct sizes to enable economic system installation, explains how to work out pressure loss through duct fittings, and how to apply corrections for air density changes.

Acoustics

This section shows how acoustics must be considered in building services design as most items of mechanical plant or equipment generate noise. This noise can be transmitted through the building to its occupants and outside the building to the external environment.

Calculation flowcharts are provided at the beginning of each section as shown opposite. These show the calculation procedures in that section and help to explain how different calculation routines link in sequence to build up the design process. This enables any one calculation sequence to be viewed in the context of the broader design process. Some other relevant design inputs and related processes are also shown for completeness, although they are not included in this current guidance as detailed calculation procedures.

Although the calculation procedures provided in this guide are grouped into four sections with calculation sequence flowcharts given for each section, during a real design process all the sections will inter-link. For example, emitter and boiler sizing will require consideration of pipe sizing, boiler sizing needs, details of heater batteries, duct sizing requires consideration of heating and cooling loads and ventilation requirements.



For each calculation topic the guidance provides the following information, as appropriate:

Overview

An overview of the calculation topic and procedure explaining what it is and where and when it is used to put it in context.

Design information required

This explains literally what you need to know to carry out a particular calculation, such as the design information necessary for a procedure, for related design decisions, system layouts or selection of equipment. This could include design data such as an internal design temperature or a mass flow rate, fluid type and temperature, and other design information such as duct material, insulation details and floor to ceiling heights.

Key design inputs

Key technical data (with units) essential for that particular calculation procedure such as mass flow rate, heating load, and limiting pressure drops.

Design outputs

The required design output from a particular calculation procedure which will be used to either inform future design, or to form part of the specification or design production, such as schedules of loads, schematic diagrams, system layout drawings with sizes and design data included, and schedules of equipment sizes and duties.

OVERVIEW OF CALCULATION SHEETS

Design approach
This provides guidance on the design approach to be considered during a calculation procedure and points to be aware of such as designing to minimise noise, the need to check that all of a system is under positive static pressure and the need to reduce corrosion risk.

Calculation procedure
This provides step-by-step procedural guidance, explaining the use of any charts or tables that are likely to be used.

Note: While the calculation procedures are as comprehensive as possible, no design guidance manual can be fully comprehensive for all design applications. It is the responsibility of the designer to add additional information as required by a particular project. Every design project is different and has differing needs and it is the responsibility of the design engineer to fully consider all design requirements

Example
One or more worked examples to illustrate the calculation procedure in detail.

Rule of thumb design data/ cross-check data
Relevant rule-of-thumb data which could be used (with caution) to provide reasonable data for use in design, such as selection of an acceptable pressure drop for use in pipe or duct sizing, or could be used to provide an approximate order of magnitude, a cross-check on a design output such as a watts per square metre, or watts per cubic metre check on a heating load.

References
Reference to relevant design information sources, such as *CIBSE Guides*, BSRIA publications, and *Building Regulations*.

See also:
Reference to other relevant calculation sheets in this guide.

Design tips
These provide practical design tips at the point where they are relevant during the explanation of the calculation procedure.

- **Design tip:** For example, the tips could include checking ceiling space available for ductwork distribution, checking both velocity and pressure drops are acceptable.

Design watchpoints
These provide guidance on things to watch out for or be aware of during the design process. An example is shown below.

DESIGN WATCHPOINTS

1. For example, the design watchpoints could include checking that the minimum fresh air requirement is always met, to cross-check computer outputs, to check noise levels are acceptable from selected grilles and diffusers, to ensure that duct dimensions selected are standard or readily available sizes.

Use of the guidance
Design calculations are part of the design process and therefore will form part of the project design file and records and be subject to standard in-company quality assurance (QA) and quality control (QC) procedures. As such they should always be properly recorded and checked. By clearly identifying required design inputs and design outputs in this guidance, and providing a clear methodology, users are encouraged to follow a good practice approach to design. Junior engineers would be expected to use this guidance within a framework of adequate supervision within their organisations, however the following notes highlight some good practice approaches to the use of design calculations.

Identify data sources
It is good practice to clearly record/cross-reference to data sources to enable input information to be adequately verified and to allow track-back of data if necessary. This is particularly important if changes occur in the design which necessitate reworking certain design calculations. Data used should be clearly identified as eg from a client brief (with date and design file reference), or from good practice sources such as the CIBSE Guides, BSRIA publications, British Standards etc. (again with precise details of the publication, date and exact source reference eg page number, table etc),

State assumptions
Where any assumptions are made in the calculation process because data is currently unknown these should be made overt, ie clearly noted as assumptions, and if necessary approved by a senior engineer. Assumptions made should always be reviewed at the end of any calculation process to check again that they were reasonable. If a calculation will need to be redone when more detailed information is provided (eg from a client, manufacturer etc) then this should be clearly noted.

Record calculations clearly
Design calculations should always be properly recorded and checked. Always ensure that all calculations are recorded in sufficient detail that they can be clearly followed by others. Be aware that if a problem arises on a project this could mean revisiting calculations several years after they were originally done.

Avoid margins without justification
Margins should never be added during a calculation process without an adequate reason for doing so and with the approval of a senior engineer. Excessive margins can result in system oversizing and poor operational performance and control. If any margins are used they should be clearly identified and a justification given for their use, which should be recorded in the design file. The use of margins should be reviewed at several stages during the design process to check their appropriateness and avoid any duplication or excess eg at the end of a calculation procedure, at design review stage etc.
(For more information on the use of margins in engineering design refer to *Design Checks for HVAC – A Quality Control Framework for Building Services Engineers*[3], topic sheet number 1 – Design Margins and CIBSE Research Report RR04, *Engineering Design Margins*[1].)

OVERVIEW OF CALCULATION TOPICS

Heating loads and plant

H1 Stack effect
H2 Infiltration
H3 U values
H4 Condensation risk
H5 Heat loss
H6 Plant heating load
H7 Heating plant configuration and load matching
H8 Radiator sizing
H9 Boiler sizing
H10 Flue sizing

Cooling loads and plant

C1 Internal heat gains
C2 External gains
C3 Cooling plant loads
C4 Ventilation – Outdoor air requirements
C5 Supply air quantity and condition
C6 Heating/cooling coil sizing
C7 Return air temperature effects on coil duty
C8 Humidifier duty
C9 Dehumidification

Water flow distribution systems

W1 Pipe sizing – General
W2 Pipe sizing – Straight lengths
W3 Pipe sizing – Pressure drop across fittings
W4 System resistance for pipework – Index run
W5 Pump sizing
W6 Control valve selection/sizing
W7 Water system pressurisation

Air flow distribution systems

A1 Duct sizing – General
A2 Duct sizing – Selecting a circular duct size
A3 Duct sizing – Circular to rectangular ducts
A4 Duct sizing – Pressure loss through fittings
A5 Duct system – Index run
A6 Fan sizing
A7 Grille and diffuser sizing
A8 Air density correction
A9 Pressurisation of spaces

Acoustics

AC1 Acoustics for building services

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ALPHABETICAL LIST

Applying HVAC building services calculations

Model Demonstration Project

By David Churcher, John Sands and Chris Parsloe

BSRIA Guide BG 1/2006
Supported by dti

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APPENDICES

1 INTRODUCTION TO THE BUILDING PROCESS

Overview of the building process

The building process covers the complete project from inception to successful handover, either to the developer for later fit-out or to the end-user for occupation. This encompasses a number of stages and can vary with the type of project. There are many models of the building process, and it is outside the scope of this project to review all of them. The *Royal Institute of British Architects Plan of Work* stages (RIBA, 1999), shown in Table 1, are used as the model for this report. The *Plan of Work* breaks projects down into a series of work stages (A to M).

The 2002 edition of the Association of Consulting Engineers *Agreement B2 (2002 Conditions of Engagement for Mechanical and Electrical Services Engineering* uses the same work stages to define a project. These are also shown in Table 1.

Table 1: RIBA Plan of Work stages.

RIBA Plan of Work		ACE Conditions (2002)	
Work stage	**Title**	**Stage**	
A	Appraisal stage	C1	Pre–design
B	Strategic brief	C2	
C	Outline proposals	C3	Design
D	Detailed proposals	C4	
E	Final proposals	C5	
F	Production information	C6	
G	Tender documentation	C7	Construction
H	Tender action		
J	Mobilisation/project planning	C8	
K	Construction		
L	After practical completion		

Note that the RIBA *Plan of Work* is being revised and is likely to be issued in 2007.

Mechanical and electrical designers may be appointed, either to provide a full design and calculation service, or to produce a performance specification for development by an m&e contractor. This is covered in more detail on page 3. In all cases there should be clear lines of accountability within the project team. In a building project this is traditionally determined by the architect.

Project management is a core requirement to make sure that:

- The completed building provides the functional requirements stipulated in the brief
- the cost budget is met
- the programme is met
- quality levels are achieved
- the building can be safely maintained, operated and decommissioned.

There are three critical success factors for projects to remain under good control and to increase the likelihood of providing excellent value for money. These are:

- Cost estimates are calculated from a properly defined specification of what the completed building must provide – this is usually called a functional specification or a performance specification
- contracts for design work, building work and supply of materials and components are awarded according to the best value rather than lowest price
- decisions regarding variations to the project are made according to whether they provide functions necessary for the building to perform in the way the client requires.

Project management techniques particular to building services are explained in the BSRIA's *Project Management Handbook for Building Services*, AG 11/98.

Project inception

The need for a project is determined by business or policy requirements that are identified and justified well in advance of design or construction work. This is done through the business case. One option always open to the client is to do nothing.

The purpose of the project is to satisfy the requirements defined by the client according to the business (or policy) needs. This covers both commercial clients, such as developers and public sector clients, such as National Health Service trusts or local authorities. These needs will define:

- What the completed project is for
- the deadline by which it must be delivered
- the maximum amount it can cost
- the quality threshold it must reach.

If the business or policy needs are achieved then the client will receive value for money and the project will be considered a success. Business or policy needs must not be confused with achievement of technical specifications (for example, providing a specified internal temperature in an office space) which are a means to achieving business needs, not ends in themselves.

Analysis of claims and litigation in respect of building services has shown that 45% of successful claims are due to errors in design concepts and parameters (Griffiths & Armour, 1999). The importance of fully and correctly understanding a client's business needs cannot be overstated.

Initial understanding of client needs can be changed by interpretations made by others (for example the architect or the surveyor), particularly if the building services engineer becomes isolated from the client and end-user. It is therefore important that a client can express its needs directly to the full design team, including the building services engineer.

1 INTRODUCTION TO THE BUILDING PROCESS

Assembling the project team

The selection of the project team is based on many factors beyond the scope of this publication. Project team selection has been adequately covered in many other publications (for example in Chapter 17 of the *Handbook of Project Management*, Gower, 2000).

The selection and internal and external management of the project team (and the contractual conditions under which that management must operate) is vital to the success of a project. Specifically, the early appointment of the building services engineer can add real value to a project, particularly the orientation of the building on its site, the layout of the building and the space planning, and their effects on the operating efficiency and energy use of the building.

In very general terms, conditions of engagement attempt to limit exposure to litigation by imposing boundaries of responsibility rather than fostering a spirit of co-operation that is essential for a successful project. Great care must be taken by the client and the client's advisors to ensure that the responsibilities defined for different members of the team do not leave areas unaddressed or create areas of overlapping responsibilities.

Before accepting any terms of engagement it is essential that the client and the specialist and professional team members fully understand and agree the contents, limitations and respective responsibilities of all participants. The latest BSRIA publication, BG 6/2006: *A Design Framework for Building Services – Design Activities and Drawing Definitions*, provides project teams with a set of comprehensive pro-formas, completion of which will determine which member of the project team is taking the lead on particular aspects of design.

More detail of the appointment of the building services engineer is discussed on page 3.

Briefing

Briefing can be defined as:

- The process by which a client informs others of needs, aspirations and desires, either formally or informally
- the process by which a client's requirements are investigated, developed and communicated to the construction industry.

Briefing is an essential and important part of the project process. It sets the cost and value parameters for the project and defines a client's requirements and needs. Good briefing is essential for good design. It will ensure the project team delivers a product that meets the needs of the client and end user, and delivers a building that will benefit the client's business interests.

In many projects, the client (who appoints the building team) will not be the same as the end-user of the completed building. For example, a university that is building a new teaching block may delegate the role of client to its internal facility managers, although the end-users will be the lecturers and students.

In situations like this, the building's success will be determined by the degree to which it meets the needs of the end-users.

The project team, including the services engineer, should find out as much as they can about the end-users' needs. As users can change, so can the requirements. It is better to have a consolidated brief from the main client that states the end users' requirements.

Buildings are a major financial expenditure for most clients. Some poorly performing buildings have been reported in the post-occupancy evaluation project, PROBE (Post-occupancy Review Of Buildings and their Engineering). These studies showed that buildings with poorly performing architecture and engineering services could create unsatisfactory working environments. This can have serious consequences for a client's business.

Briefing, in the context of the building process, is thought of as solely referring to a client brief. In practice, the briefing process extends throughout the design stages of a building project. It is an iterative process involving regular feedback from clients, advisers, the design team and end users. The brief ideally should provide everything the design team need to know about the building the client requires, the site being used and its links to the local environment.

Good briefing is essential to ensure that the client's needs are met and that best value for money is obtained. The brief usually starts as a statement of needs from the client and then evolves into a consolidated brief for the project.

The statement of needs will usually contain the following data:

- The client's business function
- the client's business objectives
- the structure of the client organisation
- the client's perceived need for the project
- any relevant historical background
- the triggers that have necessitated change
- the perceived consequences of failure/risk analysis
- the nature of advice needed to progress the project.

The statement of needs is entirely in the hands of the client and has a profound effect throughout the project. It is important that all consultants and contractors involved in the project have seen the statement of needs and understand it.

The consolidated brief would include all of the basic information contained in the client brief and strategic brief, as listed above. It would also include specific details of the project team and proposed building design solutions (in so far as these have been decided), client requirements regarding issues such as the attitude to be adopted towards health and safety, the procurement method to be adopted, and the quality criteria to be applied throughout the project.

1 INTRODUCTION TO THE BUILDING PROCESS

Typical contents include:

- Details of the project team
- project description
- description of the proposed building functions
- site location and access details
- details of constraints arising from legislation or other factors
- total floor areas of proposed buildings
- building layouts
- proposed number of occupants
- details of any special equipment or processes to be housed in buildings
- space requirements for people and equipment
- internal and external environmental design conditions
- design solutions to be adopted
- the required life span of the proposed building and of individual components
- the agreed construction procurement strategy
- cost budgets
- design and construction programmes.

The consolidated brief develops alongside the proposals from the project team, including contractors and specialists.

Appointment and duties of the building services engineer

Appointment

An enquiry for design services might come to the building services engineer from the client, the architect, the main contractor or the m&e subcontractor, depending on the nature of the project and the procurement route. However, the approach to selection is likely to be based on one of the following methods.

Appointment on merit, whereby appointment is based purely on the client's previous experience of working with the building services engineer. Fees may be calculated according to a partnering arrangement between the client and the engineer, or by negotiation.

Competitive interview, whereby some form of specified presentation must be given. This might be appropriate where the client has an outline project description and wishes to hear the designer's views before making an appointment. The scope of services and fee would be negotiated afterwards with the preferred firm.

Design ideas competition, whereby a designer is chosen based on design ideas. The design fee is stated in the competition conditions.

Design submission, whereby a designer is chosen based on a design submission and the quoted fee. The client would usually pay for the design submission.

Fee tender, whereby a designer is selected based solely on the fee quoted for a given project brief and description of service required.

Fee tender and qualifications, whereby a designer is selected based on an assessment of proven technical qualifications and ability, as well as the quoted fee.

One to one negotiation, whereby appointment is based on one or more interviews. This is a useful method for getting a designer on board at a very early stage in order to help the client consider, develop and define requirements.

Qualifications-based selection, whereby a designer is selected on quality, such as technical qualifications, previous relevant experience, and general suitability. Having short-listed, typically, three companies on this basis, the finalists are interviewed and a selection made. The scope of services and fee is negotiated afterwards.

Design duties

Most m&e designers are appointed using *Agreement B2*, published by the Association of Consulting Engineers. The duties within *Agreement B2* can be aligned with the RIBA work stages, as shown in the example in Table 2.

The duties of the building services engineer also reflect the fact that building services are dynamic systems. The selection of components, their installation and their commissioning all influence the system performance. More so than other design disciplines, building services design is an iterative process, where initial assumptions about materials and construction methods may be shown to be incapable of achieving the functional specification. In these cases, changes to the materials or components may mean a re-design.

One of the major causes of conflict between building services engineers and other members of the project team is a lack of clear understanding regarding the division of responsibilities, particularly at the interfaces of work done by designer and installer. One example of this is responsibility for preparation of the co-ordination drawings. Other areas of conflict include the degree of detail provided on drawings.

This can cover:

- Precise services routes
- responsibility for design re-evaluation due to alternative plant selection and the implication of changes
- responsibility for the specification of requirements for systems commissioning
- the preparation of handover material.

1 INTRODUCTION TO THE BUILDING PROCESS

Table 2: RIBA work stages and detailed design duties from ACE agreement B2, Normal Services.

RIBA work stage	ACE Agreement B2 Detailed design service*	ACE	
A - Appraisal stage	Obtain and inform the client's brief Discuss roles and responsibilities of the project team Discuss the likely requirement for site staff, such as Clerk of Works, Facilities manager	C1	Pre-design
B - Strategic brief	Obtain information regarding utility services to the site Comment on any physical site restrictions Make initial recommendations regarding technical viability of the works	C2	
C - Outline proposals	Visit the site as necessary and gather relevant data and information Advise the client of the need for any surveys or special investigations, such as occupancy survey or drainage survey Consult with utilities and the relevant authorities Consider alternative outline solutions Prepare outline reports and sketches in order to develop the brief Provide an approximate cost plan and advice based on unit area rates	C3	Design
D - Detailed proposals	Develop the design of the detailed proposals in collaboration with other consultants Prepare sketch drawings showing spatial/structural requirements for plant rooms, major items of plant, major ducts and service routes Assess preliminary loads for power, heating and cooling Assess the thermal performance of the building envelope and examine details of solar control. Prepare initial sizing of heating/cooling plant Negotiate with utility authorities regarding incoming services	C4	
E - Final proposals	Develop the design and prepare sufficient schematic drawings, schedules and specifications to allow consultants to finalise their proposals Assist the lead consultant in co-ordinating the m&e services into the overall design Prepare a revised cost plan based on unit area rates	C5	
F - Production information	Prepare detailed design drawings Prepare specifications	C6	
G & H - Tender documentation and tender action	Assemble documents for tender Comment on tender returns	C7	Construction
J, K & L - Mobilisation/ project planning, construction, practical completion	Advise the client on the need for the appointment of site staff Comment on installation drawings and builders' work drawings submitted by the contractor Attend relevant site meetings and make other periodic visits to site Provide technical advice regarding payment to contractors Examine testing and commissioning procedures Examine records of commissioning results Comment on record drawings and operation and maintenance manuals prepared by the contractor Inspect the works on completion and record any defects	C8	
Part M - Feedback	Activities not defined by ACE, but important to performance Fine tuning User education		Handover

* Summarised by Fulcrum Consulting

The new BSRIA guide BG 6/2006: *A Design Framework for Building Services* provides detailed proformas for clients, design teams and contractors to agree an allocation of design activities and deliverables among themselves. In this way the potential for conflict arising from duplication or omission of design activities can be minimised.

There are potential areas of conflict between members of a project team that are particularly relevant to building services engineers.

Conflicts can arise when building services designs are based on superseded versions of the architect's layout drawings. This can occur when the architect continues a design right up to issue of tender information. If significant changes are made to the architectural drawings, the building services engineer will have to modify design during or after the tender process. This gives the potential for delays and additional cost.

Tender returns from building services contractors may exceed the client's budget. This usually requires some re-design by the building services engineers. Responsibility for paying for this re-design will need to be established.

1 INTRODUCTION TO THE BUILDING PROCESS

The design process

Overview

Design is a complex process which involves the activity of translating ideas, proposals and statements of needs and requirements into precise descriptions of a specific product. Design problems are often ill-defined, and their solutions are often not obvious. There is also rarely one correct answer to a design problem. Different designers will arrive at different but possibly equally satisfactory solutions.

Two major features characterise the design process. First, design tends to evolve through a series of stages at which the solution is increasingly refined to greater levels of detail, moving from broad outline through to fine detail. Second, design tends to contain iterative cycles of activities during which designs and design components are tested, evaluated and refined. Feedback loops are therefore an essential component of design. Most models of the design process involve many feedback and iteration loops.

There are many instances where the expertise of the building services engineer can influence the form of a building, including:

- Suggesting thermal mass for use in passive heating and cooling systems
- optimising fenestration and roof lights to maximise daylight without compromising thermal performance
- suggesting a narrow footprint to allow natural ventilation
- modification to floor heights to accommodate sufficient underfloor or ceiling voids for services distribution
- suggested orientation of the building to optimise solar gain – either to minimise to prevent overheating in summer or to maximise to encourage thermal gain in winter
- suggested orientation to use prevailing winds to enhance natural ventilation
- suggested layout of spaces within the building to simplify services distribution
- contributing to structural design options to accommodate services distribution.

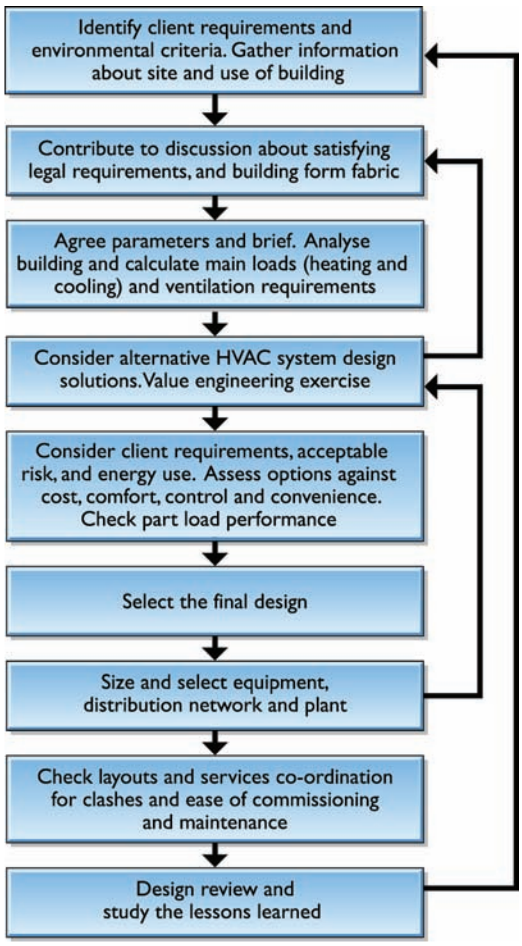
The building services design process

Figure 1 shows an example of the building services design process, based on the model developed by BSRIA and published in AG 1/2002: *Design Checks for HVAC*. This gives a simple design sequence from a statement of need, through problem analysis, synthesis, and evaluation to a final solution. Only some of the feedback loops are shown, but in practice there are often feedback loops between all tasks and even within specific tasks.

This sequence of design tasks has been developed into a design map showing the breadth of design choices and considerations for building services design, (Figure 2). This provides an overview of the design process to both inform the designer and to enable design elements to be seen in context. However, the real design process usually involves a number of iterations with overlap from one design stage to another. It may be necessary to revise calculations or modify assumptions at almost any stage.

In turn, this may lead to a series of subsequent revisions. Such revisions will have cost implications, which should also be considered as the overall process is managed and controlled. The calculations used in this document are taken from the BSRIA guide BG 30/2003: *Practical Guide to HVAC Building Services Calculations*. The use of standard calculations helps designers to document their design process, which then makes it easier to make revisions at a later date.

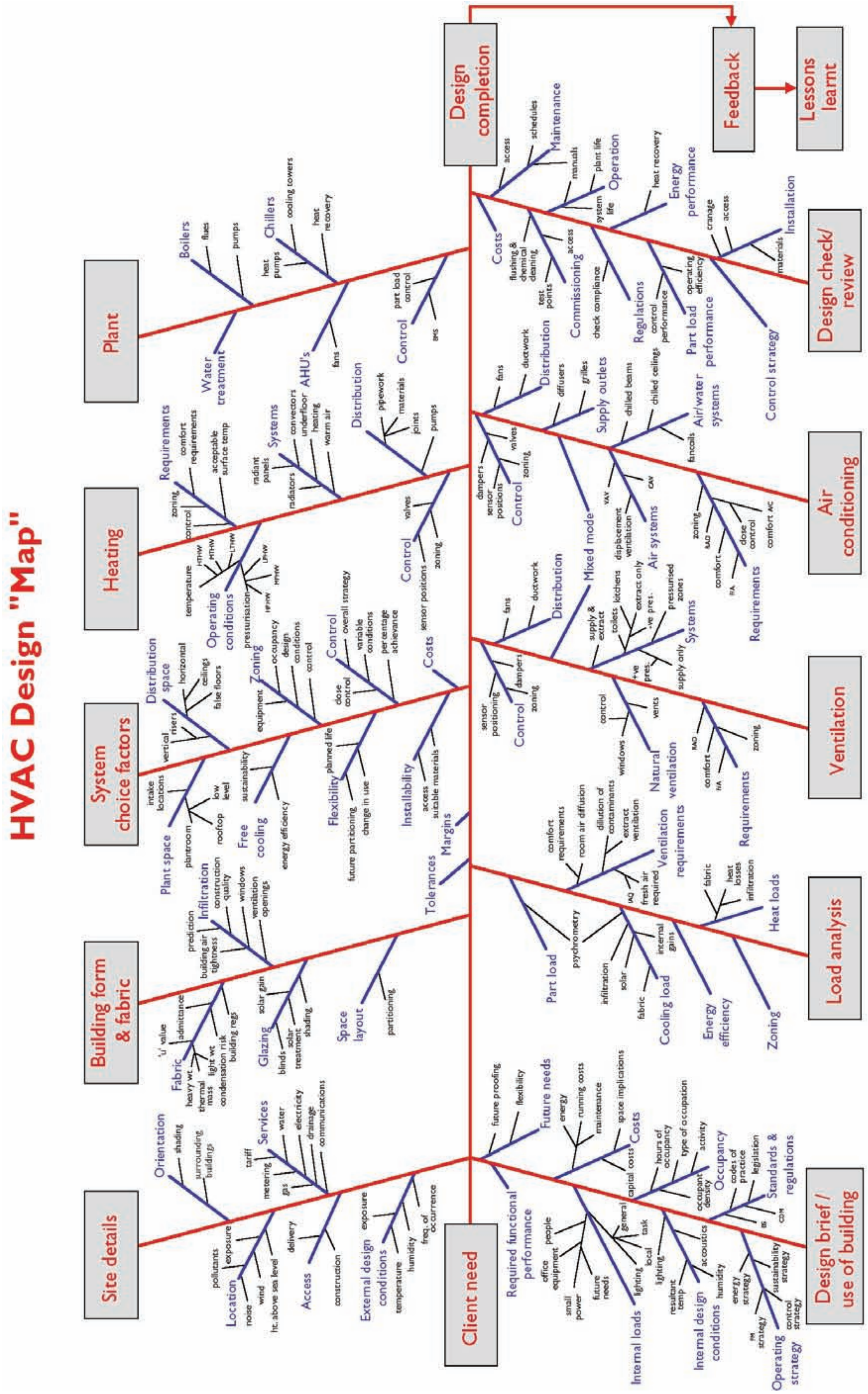
Figure 1: Simple example of a building services design process.



Based on the model developed in the *Design Checks HVAC – A Quality Control Framework for Building Services Engineers*, AG 1/2002.

1 INTRODUCTION TO THE BUILDING PROCESS

Figure 2: HVAC design map.



2 THE DEMONSTRATION PROJECT

Introduction

The remainder of this report demonstrates the application of the calculations published in BSRIA's Guide BG 30/2003: *A Practical Guide to HVAC Building Services Calculations*, as a construction project progresses through the two principal stages of HVAC design: outline and detailed proposals, followed by final proposals and production information.

The demonstration project has been based on a real building to make the calculation process as realistic as possible.

The project starts with a building specification, which is summarised in the rest of this section. Section 3 then presents the calculations made during outline and detailed proposals stages (ACE Stages C3 and C4). Section 4 presents the calculations made during final proposals stage (ACE Stages C5).

The specification details given below are of the type usually provided by an experienced client. In many cases, the initial brief may contain much less detail. In these situations the building services engineer should meet with the client and other members of the design team to understand the client's needs for the building and to discuss how the different design disciplines can work together to produce the optimum design.

It is assumed that the appointment of the consulting engineer is as detailed in ACE *Agreement B2 Schedule I – Detailed Design Normal Duties*.

The building

The development is on an existing estate, purpose-built for business use, and is located in a previously undeveloped part of the estate. The original estate was developed in the 1940s and has changed ownership three times with various tenants on short term and long-term leases. The estate is five miles from the M3 in southern England, and is surrounded by controlled forestry land.

The development consists of three main areas, shown in drawing 70206/01 in Appendix A:

- Two blocks of offices (each including an internal atrium): 10 220 m^2 (110 000 ft^2)
- laboratories and workshops at the rear of the building: 3345 m^2 (36 000 ft^2)
- reception area and internal two-storey circulation space that links the office blocks and the laboratories.

The client will occupy one of the two office blocks, plus the laboratory and workshops. The remaining office block will be let to a local business. The client has provided the following details of what it wants and what it needs according to its business requirements. Where appropriate, comments and references explain the criteria.

Client's functional requirements

Office layout

The office space of the building should generally be open-plan with the facility to incorporate 3 m-wide by 6 m-deep cellular offices around the perimeter, as and when required. The planning grid is 1500 mm, within a 7·5 m structural grid. The planning grid will affect how building services components can be modularised for easiest fit and the spacings to be used between components. Both structural and planning grids are shown on the arrangement drawings in Appendix A.

Lighting

The client is keen to optimise the amount of natural daylight in the office space, but appreciates that the size of the office and the likelihood of partitions being installed for separate perimeter offices will reduce daylight effectiveness.

Design occupancy

The client requires an occupancy density of 1 person per 15 m^2 of offices. This is within the current guidance of 12 m^2 to 17 m^2 per person published by the British Council for Offices (BCO). This allows for approximately 255 occupants for the client and the same for the tenant.

Source of equipment

Systems and components are to be obtained from reliable sources able to provide matching spares and replacements.

Duty and standby provision

The term duty/standby describes a plant arrangement whereby duplicate or standby plant is provided to maintain continuity of service in the event of failure of the main plant or duty plant items.

This should not be confused with spare capacity, which is an additional plant capacity over and above the design value. Spare capacity is typically used to provide a boost in power at start-up of the system, or to lessen the effects of losing an item of duty plant.

There are no business-critical activities planned for the office building (such as data centres, or dealing rooms), so standby plant is not required. However, as office work would be compromised by failure of cooling in summer or heating in winter, the systems should be easily accessible for maintenance and repair.

Security systems

The building is to incorporate a closed-circuit television system around the perimeter of the building and at entrances and exits of the building. A door access system is required for all entrances and exists to the building.

2 THE DEMONSTRATION PROJECT

Design criteria for building services

Specific design criteria are generated in two ways.

First the client may specify the criteria based on previous experience of construction. This requires the client to have a detailed knowledge of the design and construction processes and will typically arise if the client is a property developer or frequently involved in procuring buildings.

Second the design team, usually led by an architect or a design and build contractor, will meet with the client to ascertain the building's requirements and translate these into technical design criteria. Depending on the timing of design team appointments, these meetings may not always include building services engineers.

However the criteria are generated, the building services engineer will need to check that these comply with the appropriate regulations.

Using the information provided, the architect can design a suitable building and the building services engineer can start the preliminary calculations to design the services.

For the demonstration project, many of the criteria specified by or agreed with the client are based on recommendations from CIBSE or the British Council for Offices (BCO). For brevity, the criteria included here focus on the office building that is the subject of the design process in later sections of this guide.

Occupancy heat load (office)

At 22°C (Winter)

- Sensible: 90 W/person.
- Latent: 50 W/person.

Based on *CIBSE Guide A –1999 table 6.1*

At 24°C (Summer)

- Sensible: 80 W/person.
- Latent: 60 W/person.

Based on *CIBSE Guide A –1999 table 6.1*

Small power loads (office)

20 W/m² of net office area. The BCO 's recommended range is 15 to 25 W/m² which allows for future expansion. A higher figure may be appropriate if the client's business requires lots of office equipment.

Lighting loads (office)

12 W/m² of net office area. This is at the lower end of the BCO's recommended range of 10 to 25 W/m².

Fresh air allowance (office)

12 l/s per person based on 1 person/15 m². This is in line with the BCO's recommended range of 8 l/s to 12 l/s.

Infiltration rate

The specification is for the building to achieve the good practice guidelines for air tightness, with an air permeability index of 5 m³/(h.m²)

Indoor design conditions

Winter

Offices: 22°C±2°C (This is the BCO's recommendation).

Summer

Offices: 24°C±2°C (This is the BCO's recommendation).

Indoor design conditions should reflect the average condition in the space and not the temperature at the thermostat. The figures for this demonstration project were selected by the client in the knowledge that these will require mechanical refrigeration. A different client who wishes to use natural ventilation or thermal mass to regulate summer temperatures will need to agree different criteria.

Outdoor design conditions

Winter design

-4°C db; saturated.

Summer design

29°C db; 20°C wb.

The chillers must operate in conditions up to 40°C in order to provide cooling capacity in the event of ambient conditions above design.

Humidity

The client has not provided any specific criteria for humidity control in this case, but 50% has been used for the purposes of these calculations as a typical figure for office environments.

Acoustics

The standard for the open plan office spaces is NR38, as recommended by *BCO Guide* (2000). In the perimeter zone where cellular offices may be installed at a later date, cross-talk must be limited to maintain privacy between adjacent offices. The BCO recommended noise level standard for these cellular offices is NR35.

Relevant building construction details

Building grid and floor capacity

- Primary grid (generally): 7·5 m²
- floor slab loading capacity: 3·50 kN/m²
- additional capacity for light partitions 1·0 kN/m².

(Allowance of 10% of floor area to withstand 7·5 kN/m² in a location defined by the developer.)

Roof drainage

The roofs of the offices, and the circulation space are to incorporate uPVC rainwater outlets, connecting to rainwater drainage collection system, to down pipes within service risers. Roof drainage design to incorporate overflow system to provide a safety warning.

2 THE DEMONSTRATION PROJECT

External wall elevations

External solid wall

- Outer brick skin: 105 mm
- insulation: 75 mm
- air gap: 50 mm
- lightweight block: 100 mm
- plaster: 13 mm.

Glazed elevations

- Polyester powder coated aluminium thermally broken curtain wall system.
- full height (slab to soffit) glazing–outer pane: 6 mm clear
- air gap:12 mm
- toughened inner pane: 6 mm.

(Clear high performance thermal coating to the outside surface of the inner pane.)

Internal partitions

General internal solid partitions comprise: plasterboard, an air gap and plasterboard.

A glazed wall to the atrium at the centre of each office block comprises floor to ceiling double-glazed units.

A glazed wall between the offices and the two-storey circulation space comprises floor to ceiling double-glazed units as per the external façade.

Ground floor and roof construction

- Carpet tiles
- raised flooring system (150 mm void)
- concrete slab 100 mm.
- Insulation: 25 mm
- oversite/blinding: 250 mm
- felt/bitumen: 5 mm
- insulation: 100 mm
- cast concrete: 210 mm.

Ceilings (offices)

The perimeter margin is formed with a British Gypsum mineral-fibre ceiling, to a 1500 mm planning grid, incorporating 500 × 500 mm white perforated Tegular-metal tiles in an exposed fineline grid. The ceiling provides a minimum of 25 dB(A) sound reduction.

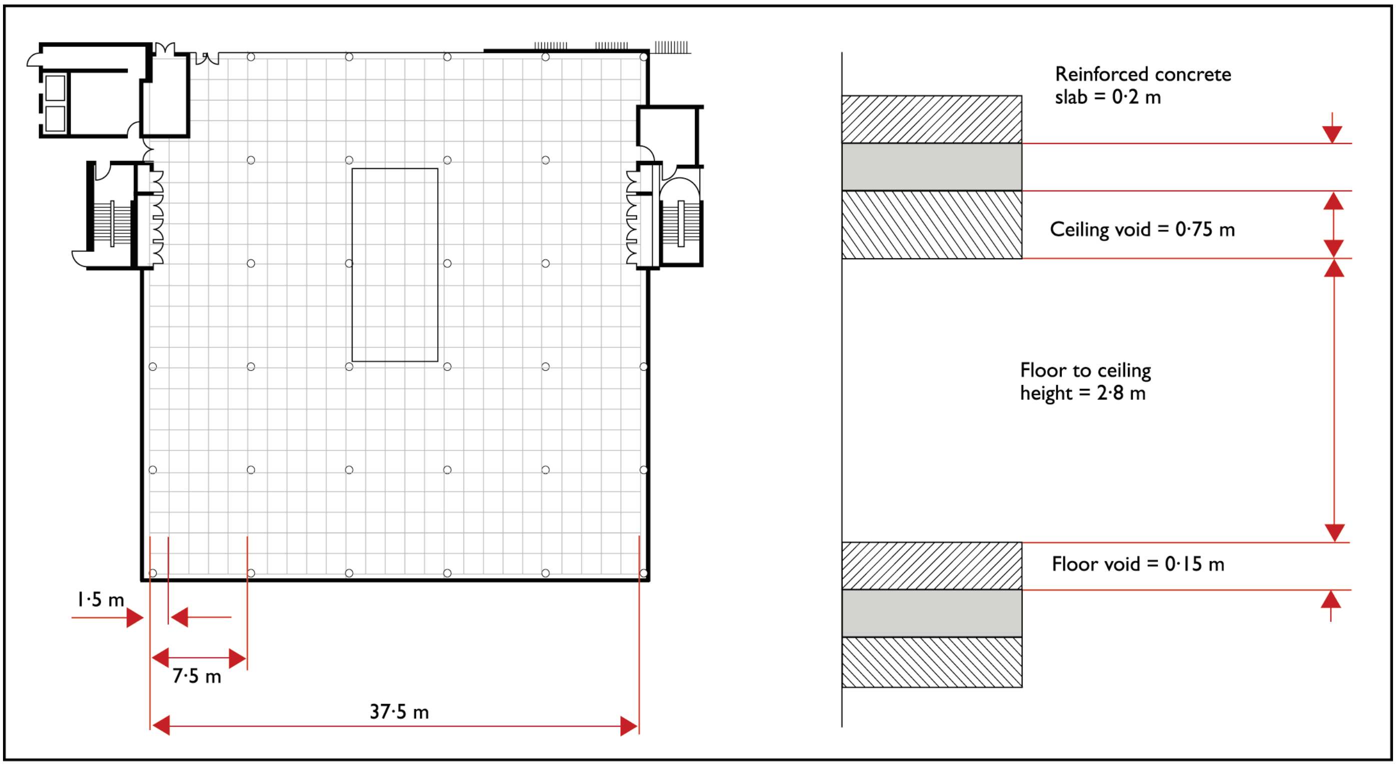
Building dimensions

The dimensions for a building are normally taken from the approved drawings by the architect. The main dimensions concerning the office space in this hypothetical project are given below and shown in Figure 3.

- Internal office height: 2·8 m
- raised floor zone (depth): 0·15 m
- ceiling void (height): 0·75 m nominal height, but allow 0·2 m beam depth below slab soffit on grid lines, therefore 0·55
- distance between columns: 7·5 m
- maximum internal distance between walls: 37·5 m
- reinforced concrete floor thickness: 0·2 m
- planning grid: 1·5 m.

For calculating heat gain and loss through the external walls, designers should use the slab to soffit dimension not the internal office height, as heat will also be transmitted to and from the floor and ceiling voids.

Figure 3: General office layout and vertical section.



2 THE DEMONSTRATION PROJECT

Calculation topics

The calculation topics covered by in BSRIA Guide BG 30/2003: *Practical Guide to HVAC Building Services Calculations* and this model demonstration project are listed in Table 3, below. The references (for example H1) are to the calculation sheets in BG 30/2003. Table 3 also indicates which topics are covered in which of the two stages of the design process that are demonstrated in this report.

Table 3: Schedule of calculation topics.

Calculation topic	Outline and detailed proposals (section 3)	Final proposals and production information (section 4)
Stack effect (H1)		
Infiltration (H2)	✓	
U values (H3)	✓	
Condensation risk (H4)	✓	
Heat loss (H5)	✓	
Plant heating load (H6)	✓	
Radiator sizing (H7)		
Boiler sizing (H8)	✓	
Flue sizing (H9)	✓	
Pipe sizing – general (W1)	✓	
Pipe sizing – straight lengths (W2)		✓
Pipe sizing – pressure drop across fittings (W3)		✓
System resistance for pipework – index run (W4)		✓
Pump sizing (W5)		✓
Water system pressurisation (W6)		
Internal heat gains (C1)	✓	
External gains (C2)	✓	
Cooling plant loads (C3)	✓	
Ventilation – fresh air requirements (C4)	✓	
Supply air quantity and condition (C5)		✓
Heating/cooling coil sizing (C6)		✓
Humidifier sizing (C7)		
Duct sizing – general (A1)	✓	
Duct sizing – selecting a circular duct size (A2)	✓	✓
Duct sizing – circular to rectangular ducts (A3)	✓	
Ductwork - pressure loss through fittings (A4)		✓
Duct sizing – index run (A5)		✓
Fan sizing (A6)		✓
Grille and diffuser sizing (A7)		✓
Air density correction (A8)		
Pressurisation of spaces (A9)		
Acoustics for building services (new)		
Dehumidification (new)		
Control valve selection/sizing (new)		✓
Effect of return air temperature on coil duty (new)		
Heating plant configuration and load matching (new)		

The calculations marked new will be included in a revision of the *Practical Guide to calculations*.